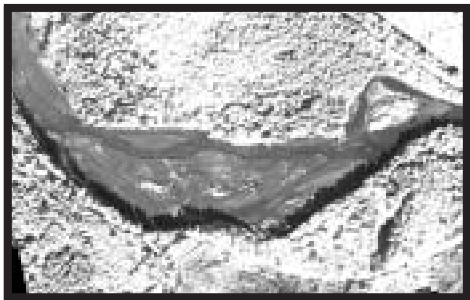
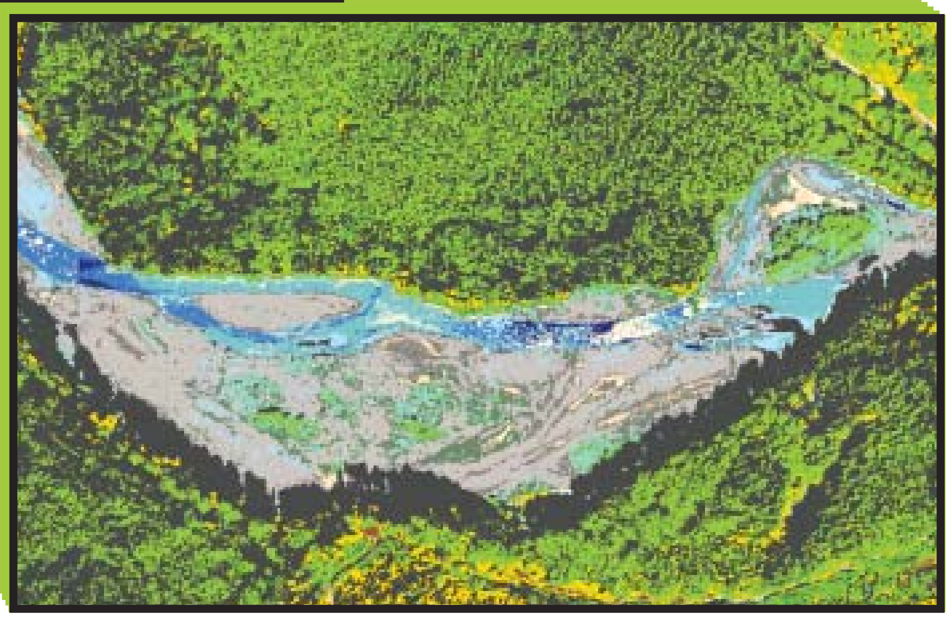
Characterization of Instream Hydraulic and Riparian Habitat Conditions and Stream Temperatures of the Upper White River Basin, Washington, Using Multispectral Imaging Systems

Water-Resources Investigations Report 03-4022





Prepared in cooperation with the
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By Robert W. Black and Alan Haggland, U.S. Geological Survey; and Greg Crosby, Utah State University

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 03-4022

Prepared in cooperation with

WASHINGTON STATE DEPARTMENT OF ECOLOGY and the
PUYALLUP TRIBE

Tacoma, Washington
2003

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND DATUM

CONVERSION FACTORS

Multiply	By	To obtain
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
square kilometer (km^2)	247.1	acre
kilometer per hour (km/h)	0.6214	mile per hour (mi/hr)
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=1.8\ °C+32.$$

DATUM

Vertical datum: Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NAVD 29).

Horizontal datum: Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Characterization of Instream Hydraulic and Riparian Habitat Conditions and Stream Temperatures of the Upper White River Basin, Washington, Using Multispectral Imaging Systems

By Robert W. Black *and* Alan Haggland, U.S. Geological Survey; *and* Greg Crosby, Utah State University

ABSTRACT

Instream hydraulic and riparian habitat conditions and stream temperatures were characterized for selected stream segments in the Upper White River Basin, Washington. An aerial multispectral imaging system used digital cameras to photograph the stream segments across multiple wavelengths to characterize fish habitat and temperature conditions. All imageries were georeferenced. Fish habitat features were photographed at a resolution of 0.5 meter and temperature imageries were photographed at a 1.0-meter resolution. The digital multispectral imageries were classified using commercially available software. Aerial photographs were taken on September 21, 1999. Field habitat data were collected from August 23 to October 12, 1999, to evaluate the measurement accuracy and effectiveness of the multispectral imaging in determining the extent of the instream habitat variables.

Fish habitat types assessed by this method were the abundance of instream hydraulic features such as pool and riffle habitats, turbulent and non-turbulent habitats, riparian composition, the abundance of large woody debris in the stream and riparian zone, and stream temperatures. Factors such as the abundance of instream woody debris, the location and frequency of pools, and stream temperatures generally are known to have a significant impact on salmon. Instream woody debris creates the habitat complexity necessary to maintain a diverse and healthy salmon population. The abundance of pools is indicative of a stream's ability to support fish and other aquatic organisms. Changes in water temperature can affect aquatic organisms by altering metabolic rates and oxygen requirements, altering their sensitivity to toxic materials and affecting their ability to avoid predators.

The specific objectives of this project were to evaluate the use of an aerial multispectral imaging system to accurately identify instream hydraulic features and surface-water temperatures in the Upper White River Basin, to use the multispectral system to help establish baseline instream/riparian habitat conditions in the study area, and to qualitatively assess the imaging system for possible use in other Puget Sound rivers.

For the most part, all multispectral imagery-based estimates of total instream riffle and pool area were less than field measurements. The imagery-based estimates for riffle habitat area ranged from 35.5 to 83.3 percent less than field measurements. Pool habitat estimates ranged from 139.3 percent greater than field measurements to 94.0 percent less than field measurements. Multispectral imagery-based estimates of turbulent habitat conditions ranged from 9.3 percent greater than field measurements to 81.6 percent less than field measurements.

Multispectral imagery-based estimates of non-turbulent habitat conditions ranged from 27.7 to 74.1 percent less than field measurements. The absolute average percentage of difference between field and imagery-based habitat type areas was less for the turbulent and non-turbulent habitat type categories than for pools and riffles. The estimate of woody debris by multispectral imaging was substantially different than field measurements; percentage of differences ranged from +373.1 to -100 percent. Although the total area of riffles, pools, and turbulent and non-turbulent habitat types measured in the field were all substantially higher than those estimated from the multispectral imagery, the percentage of composition of each habitat type was not substantially different between the imagery-based estimates and field measurements.

INTRODUCTION

An aerial multispectral imaging system was used to identify instream hydraulic and riparian habitat conditions and stream temperatures in the Upper White River Basin, Washington, September 1999 (fig. 1). The study was done by the U.S. Geological Survey (USGS) in cooperation with the Washington State Department of Ecology (Ecology) and the Puyallup Tribe. The primary purpose of this assessment was to characterize habitat and temperature conditions in specific reaches of the Upper White River Basin as specified in the report "White River Spring Chinook Habitat Guidance: A Water Quality Management Approach for the Upper White River" (Upper White River Chinook TMDL Framework Team, 1998) and the draft monitoring plan for the baseline conditions in the drainage basin (Adams and Schuett-Hames, 1997). Habitat indicators to be assessed by this method were key pieces of large woody debris in the stream and riparian zone and the abundance of pools and riffles. The information is being used to establish baseline conditions in the White River drainage basin to help interpret long-term monitoring information. Stream temperature imagery were taken to improve the understanding of the temperature dynamics in the surveyed streams to assist drainage basin restoration.

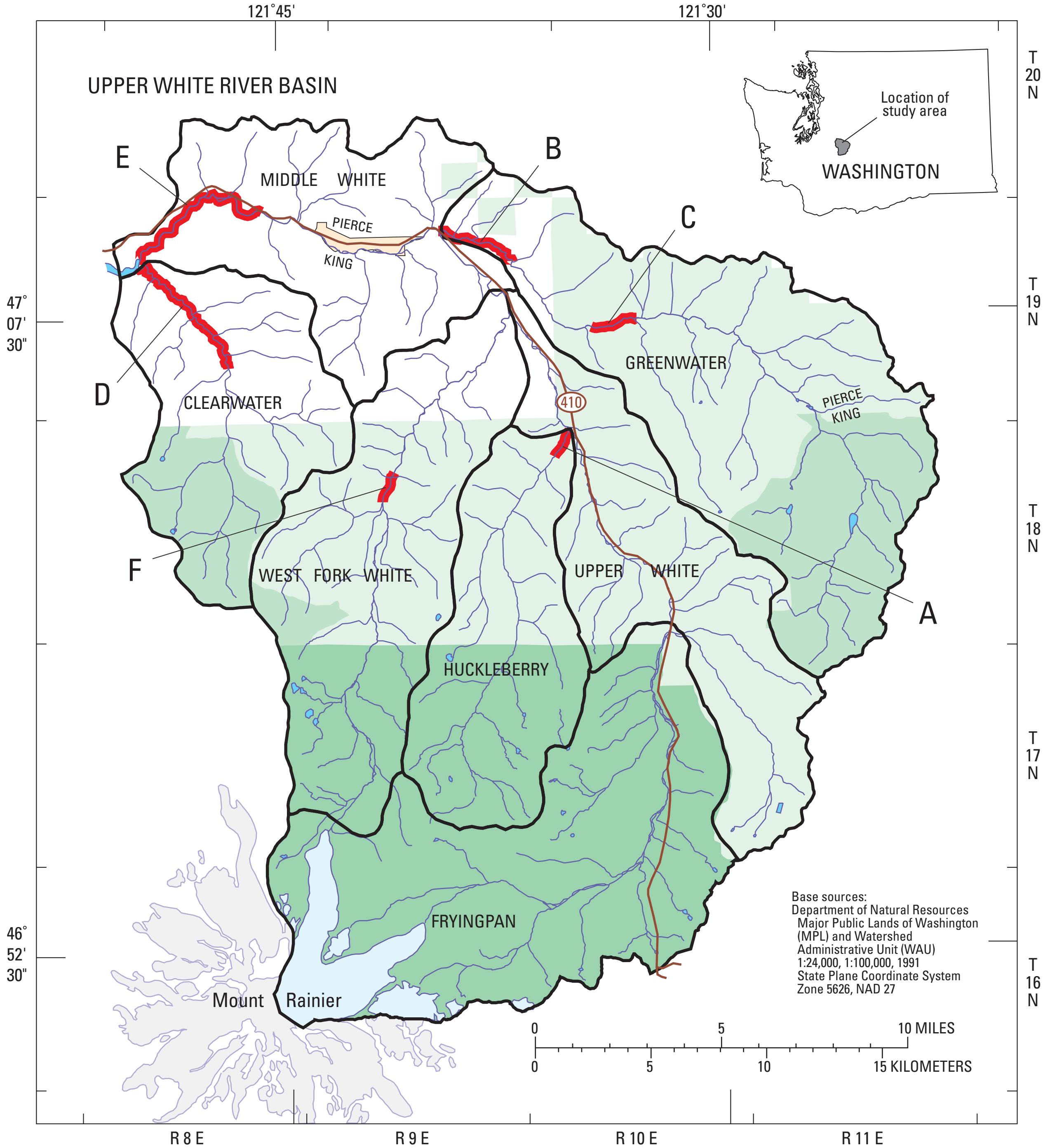
The specific objectives of this project were:

(1.) Evaluate the use of an aerial multispectral imaging system to accurately identify instream hydraulic features in the Upper White River Basin.
(2.) Use an aerial multispectral imaging system to help establish baseline instream/riparian habitat conditions in the Upper White River Basin.
(3.) Use an aerial infrared sensing procedure to determine stream temperatures of selected reaches of the Upper White River.
(4.) Evaluate the imaging system for possible use in other Puget Sound rivers.

Traditional Measurement of Fish Habitat

The quality of a stream is critical to the reproduction and survival of aquatic organisms such as the chinook salmon (*Oncorhynchus tshawytscha*). The chinook salmon was listed as threatened in the Puget Sound Basin by the National Marine Fisheries Service and U.S. Fish and Wildlife Service in March 1999. Repeated measurement of habitat variables over time can characterize a measure of current habitat conditions as well as temporal changes in habitat conditions. Without long-term habitat measures, interpreting habitat in terms of historical conditions often can be difficult. Long-term habitat monitoring has been lacking in most of the Pacific Northwest river systems (Bisson and others, 1992). By the time many streams are surveyed, their habitats have already been altered by anthropogenic factors.

Traditionally, most habitat surveys have relied on field work in which trained biologists and geomorphologists walk a stream of interest measuring various physical features. On-the-ground habitat monitoring is extremely important for specific variables and specific levels of detail, but it is often a time-consuming and costly process. The quality of the habitat data also can vary depending on sampling methods and experience level of personnel.



EXPLANATION

LAND USE

- National Forest
- National Park
- National Wilderness
- Privately owned land
- State park
- Glacier

RIVER REACH SEGMENT

A. Huckleberry Creek segment - Washington State Department of Ecology (ECOLOGY) stream segment 1.
B. Lower Greenwater River segment - ECOLOGY stream segments 1 through 3.
C. Upper Greenwater River segment - ECOLOGY stream segments 8 through 9.
D. Clearwater River segment - Washington Department of Ecology stream segments 1 through 4.
E. White River segment.
F. West Fork White River segment.

Reaches flown

Boundary of Drainage Basin Administrative Unit.

Figure 1. Locations of reaches flown using aerial multispectral and thermal imaging systems and land use in the Upper White River Basin, Washington, September 1999.

Aerial photographs have been used to evaluate habitat conditions over many miles of stream channels. However, determining the quantity and quality of available habitat from photographs requires an individual to digitize or measure habitat conditions, which is time-consuming and costly. In addition, if new questions arise after the aerial photographs are analyzed, the photographs may have to be re-measured or re-digitized to address the new questions or objectives.

The benefits of using multispectral imaging to characterize instream habitat and riparian conditions are numerous (Bartz and others, 1994; Redd and others, 1994). The instruments can collect large amounts of unbiased georeferenced imagery data in a few days. After a few days of processing, the data can be used to quantitatively assess the abundance and location of habitat features such as pools and riffles. The quantitative habitat information as well as the multispectral imagery could be incorporated into such fisheries management information systems such as the Northwest Indian Fish Commission's Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) database. The processed multispectral imagery is digitally stored so it can be re-evaluated in the future as new imaging processing tools become available. Furthermore, comparison of the digital multispectral imagery with future imagery facilitate evaluating changes in habitat conditions in the Upper White River system.

This methodology is relatively new and has not been tested widely in river systems of disparate physiographic regions. The information generated from this process depends upon many of the same factors that traditional aerial photography does, such as atmospheric humidity, platform stability, and air clarity. The multispectral imaging system has been used on rivers with very high sediment load, but has not been used extensively in glacially fed streams (Anderson and others, 1994; and Panja and others, 1994).

Importance of Physical Habitat Water and Temperature to Fish

The numerous cold water rivers found throughout western Washington are home to assemblages of migratory and resident fish typical of the Pacific Northwest, USA. Within the rivers and streams of the Puget Sound Basin of western Washington, there are at least 14 families of fish represented by over 40 species and subspecies of freshwater riverine fish including the salmon and anadromous trout (Washington Dept. of Wildlife and Bonneville Power Administration, 1992; and Olympic National Park Service, 1995). Although the diversity of fish species is limited in the Puget Sound Basin (Moyle and Herbold, 1987), many unique stocks of migratory (anadromous) salmon and trout are found throughout the basin. A fish stock refers to "the fish spawning in a particular lake or stream(s) at a particular season, which to a substantial degree do not interbreed with any group spawning in a different place, or in the same place during a different season" (Washington State Department of Fish and Wildlife and Western Washington Treaty Indian Tribes, 1994).

Historically, the Upper White River Basin had a healthy population of spring chinook salmon. In the 1980s, the number of adults returning to spawn in the Upper White River Basin decreased to as low as six individuals. The construction of two impassable dams in the lower drainage basin, in addition to other natural and anthropogenic factors, have impacted the number of returning salmon. The Upper White River spring chinook are unique in that they return to the river from May to mid-September and spawn from mid-August through September in the upper part of the drainage basin. This differs from fall chinook which generally spawn in the lower reaches of mainstem rivers (Busack and Shaklee, 1995). Recent hatchery operations utilizing returning Upper White River spring chinook have helped increase the number of spring chinook in this drainage basin (Upper White River Chinook TMDL Framework Team, 1998). In March 1999, the chinook (*Oncorhynchus tshawytscha*), and chum (*O. keta*) salmon, and bull trout (*Salvelinus confluentus*) were listed as threatened in the Puget Sound Basin by the National Marine Fisheries Service and U.S. Fish and Wildlife Service.

Habitat damage resulting from hydropower development, logging, mining, agriculture, and urbanization, and potentially over-fishing and competitive interactions with hatchery fish represent the greatest threats to the chinook salmon as well as other species in the Pacific Northwest (Nehlsen and others, 1991; and Riddell and Swain, 1991). Changes in aquatic habitat can have a direct influence on all aquatic communities, including salmon, and the evaluation of habitat conditions is required for assessing biological integrity. As early as the 1900s, scientists recognized the role that stream and river habitats played in affecting the health and number of fish and other aquatic biota (Steinmann, 1907; Shelford, 1911; and Theinemann, 1912). The health of salmon in the Pacific Northwest has been directly linked to habitat quality (Bisson and others, 1992). Aquatic habitats in the Puget Sound Basin have been considerably altered by natural and, more recently, human activities.

In the nineteenth century, the Federal government claimed jurisdiction over navigation and proceeded to straighten river and stream channels and clear them of large organic debris to allow steamboats, log rafts, barges, and other vessels unimpeded passage. In addition, many non-navigable streams were cleared and straightened to facilitate the transport of timber from the headwaters to the lumber mills downstream. The clearing and straightening of streams was particularly common in the Pacific Northwest. By the early 1880s, most timber within 3.2 km (2 mi) of Puget Sound had been logged (Buchman, 1936). Loggers and engineers cleared streams to improve the movement of floated logs and enhance the effectiveness of splash dams used to create holding lakes to transport logs downstream (Sedell and Duval, 1985). Before a stream could be used to transport logs, it had to be "improved" (Brown, 1936). Improvements included blasting or removing boulders, large rocks, leaning trees, sunken logs, or obstructions of any kind. By the 1880s, a part of most streams in the Puget Lowlands had been "improved" for log transport (Cox, 1974) and by 1900, more than 130 companies were involved in river and stream improvement operations in the State of Washington (Sedell and Duval, 1985). More than 150 log transporting or splash dams were in existence in western Washington by the early 1900s (Sedell and Duval, 1985). Splash dams had the potential to significantly alter the physical and biological conditions of many streams by creating debris-laden floods that scoured out channels, thereby reducing habitat complexity (Harmon and others, 1986).

Urbanization also has resulted in habitat degradation in western Washington (King County Surface Water Management Division, 1993). For example, fish habitat in the mainstem of the Cedar River (King County, Washington) has been reduced by about 56 percent because of water-supply dams, land development, levees, bank alterations, and removal of large woody debris (King County Surface Water Management Division, 1993). Water diversions and flood-control activities in the last 80 years changed the once-braided channels of the lower mainstem of the Cedar River to a single-thread channel (King County Surface Water Management Division, 1993). Similar effects of urbanization have been observed in many of the large lowland rivers, particularly near the mouths of rivers (Bortleson and others, 1980). The physical changes in these streams correspond to changes in the aquatic biota such as fish and aquatic invertebrates (Black and Silkey, 1998).

Although habitat plays a critical role in the overall quality of streams in the Puget Sound Basin, only a limited number of reports have summarized existing habitat conditions and data (Ralph and others, 1991; 1994; and Black and Silkey, 1998) in spite of the abundance of habitat data collected by timber companies, Federal agencies (U.S. Forest Service, U.S. Fish and Wildlife Service, and National Park Service), State agencies, Indian tribes, county and municipal agencies, and universities. A number of efforts are underway to organize existing habitat data into drainage basin and regional scale summaries and evaluations (Schuett-Hames and others, 1994; and SSHIAP, 1995).

Even though an extensive summary of existing salmon habitat data in western Washington has not been completed, factors such as the abundance of instream woody debris, the location and frequency of pools, and stream temperatures generally are known to have a significant impact on salmon. Instream woody debris creates the habitat complexity necessary to maintain a diverse and healthy salmon population. Woody debris provides cover from predacious fish and wildlife as well as velocity refuges for numerous aquatic animals. In addition, woody debris can create a variety of physical habitat, such as large pools, through the deflection of streamflow.

The abundance of pools is indicative of a stream's ability to support fish and other aquatic organisms. For many species of fish, pools provide a safe and energetically favorable habitat (Fausch, 1984; and Wilzbach, 1985). The removal of wood from streams, changes in discharge, sedimentation, channelization, and other anthropogenic factors can decrease the number of pools in a stream. The number of pools in many of the forested streams of the Puget Sound Basin are well below historic levels (U.S. Forest Service, 1993; Black and Silkey, 1998).

Habitat conditions affect water temperature in a stream or river. The quantity and type of instream structure, as well as the abundance of shade-producing features and vegetation adjacent to a stream, also can affect temperature conditions. Changes in water temperature can affect aquatic organisms by altering metabolic rates and oxygen requirements, altering their sensitivity to toxic materials and affecting their ability to avoid predators (Reiser and Bjornn, 1979). All aquatic organisms have optimal temperature ranges for maintaining a healthy existence. For example, the optimal temperature range for spring chinook migration is between 3.3 and 13.3 ^{o}C (Reiser and Bjornn, 1979).

Urbanization, logging, and agricultural activities affect water temperatures. For example, increases in water temperatures in streams after logging was well documented for small drainage basins (less than 1,000 acres) (Anderson, 1973). Stream temperatures are significantly affected if logging extends into the riparian zone. The cumulative effects of physical disturbances on larger streams (greater than 100 mi^2 drainage area) are less clear because the drainage basins are disturbed incrementally over a long period of time. Riley (1996) reports that the variability in climate and hydrology over a 5- to 10- year period may mask water temperature trends caused by physical disturbances in these larger drainage basins. However, the influence of natural environmental factors, such as ground-water inflow, also can affect stream temperatures.

Acknowledgments

This study could not have been completed without the assistance of many individuals and organizations. This study was funded by the Washington State Department of Ecology, the Puyallup Tribe, and the U.S. Geological Survey. We are especially grateful for the field and technical help provided by the U.S. Forest Service, Weyerhaeuser Corporation, Tahoma Audubon Society, Washington Department of Fish and Wildlife, Muckleshoot Tribe, and the Northwest Indian Fisheries Commission. We are particularly grateful to Dr. Christopher Neale in the Department of Biological and Irrigation Engineering at Utah State University, Logan, Utah, who helped pioneer the methods used for this study. Without his input and help, this study would not have been possible.

DESCRIPTION OF STUDY AREA

The area evaluated by the multispectral imaging system in this study has been identified as the Upper White River Basin by the Washington State Department of Ecology (Ecology) (Upper White River Chinook TMDL Framework Team, 1998). The drainage basin extends from the confluence of the White and Clearwater Rivers to the headwaters of the White River in western Washington State (fig. 1). Six unique stream segments throughout the drainage basin totaling 24.6 kilometers were selected for this study (fig. 1, table 1).

The location of these stream segments was based on the methods outlined in the Timber Fish and Wildlife's Ambient Monitoring Program Manual (Pleus and others, 1999) and current information on important chinook use areas. Ecology located and identified specific stream segments for this study. Each study segment had a unique name and identification number (see tables 10-14, at back of report). The major land use in the basin is forestry. The U.S. Forest Service, National Park Service, and Weyerhaeuser Company are the principal landowners.

Table 1. River segments evaluated using the multispectral imaging system in the Upper White River Basin, Washington, September 1999

[**Nominal river elevation**: The elevation above sea level used to develop the flight plans for each river reach segment. m, meter]

	River reach segment (fig. 1)	Nominal river elevation (m)	Quadrangle maps
A	Huckleberry Creek (segment 1)	671	Sun Top
B	Lower Greenwater River (segments 1–3)	549	Greenwater, Nagrom
C	Upper Greenwater River (segments 8–9)	610	Sun Top
D	Clearwater River (segments 1–4)	427	Bearhead Mountain, Cyclone Creek
E	White River (segment 1)	427	Cyclone Creek
F	West Fork White River (segment 1)	702	Clear West Peak

METHODS

Field Measurements

Field habitat data were collected from August 23 to October 12, 1999, by field teams of two to four scientists from the U.S. Geological Survey, U.S. Forest Service, Weyerhaeuser Company, Ecology, and the Northwest Indian Fish Commission. One measurement error reach (study reach) was located in each of the six study river segments flown except the West Fork White River segment. The beginning and ending coordinates for each study reach are shown in tables 10-14. All field teams used Level 2 or 3 habitat sampling protocol (Pleus and Schuett-Hames 1998; Pleus and others, 1999; and Schuett-Hames and others, 1999).

Flow conditions in the White River study reach prevented the measurement of pool and riffle conditions as described in Pleus and Schuett-Hames (1998), Pleus and others (1999), and Schuett-Hames and others (1999). Instead of characterizing the location and abundance of pools and riffles in the White River, surface turbulence was measured. These measurements included documenting the area of habitat types with and without surface turbulence. Habitat types with smooth surface flow and no surface turbulence were characterized as non-turbulent habitat. All other habitat types were characterized as turbulent.

Habitats with non-turbulent surface waters are not necessarily pools as defined in Pleus and others (1999). According to Pleus and others (1999), riffles represent a broad range of wetted channel conditions. Riffles include the classic shallow and low gradient area with surface turbulence associated with increased flow velocity over gravel and cobble beds. They also include deeper areas without surface turbulence such as "glides" or "runs." Pools are sections of a stream channel where water is impounded within a closed topographical depression. These depressions create a basin within the stream channel that would hold residual water even if there were no streamflow. Pleus and others (1999) present a detailed discussion of specific criteria that must be satisfied in order to classify a geomorphic unit as a pool. All pools were identified using these criteria.

Field measurements of habitat conditions collected for comparison with the imagery-derived estimates were (1) study reach lengths, (2) percentage of and total area of instream habitat types (pools, riffles, turbulent, non-turbulent), (3) lengths and widths of large woody debris area, (4) composition of riparian vegetation, and (5) stream temperature. The area of instream woody debris identified in the field was calculated from mean diameter, mean length, and total number of pieces of wood (tables 10-14).

Habitat types of interest at all measurement error study reaches, except the White River, were pools and riffles. Surface turbulence also was measured for some study reaches. Conditions in the White River study reach were not safe enough to perform some instream measurements. Therefore, only visible woody debris in the active channel, surface turbulence, and study reach length were measured.

The field data were collected only to evaluate the measurement accuracy and effectiveness of the multispectral imaging in determining the extent of the instream habitat variables identified above. All field data are summarized in tables 10-14.

Vegetation in the riparian zone was field characterized at selected points in each of the five study reaches. Vegetation and other characteristics in the riparian zone were broadly classified as bare soil, boulder, conifer trees, deciduous vegetation, grass and gravel, roads, shadows, shrub, and large woody debris. A paired *t*-test was used to statistically compare the differences between field and multispectral imagery data for the instream habitat types and woody debris. A limited budget prevented the implementation of a more traditional remote sensing accuracy assessment (Jensen, 1996).

Multispectral Imaging Systems

Aerial multispectral imaging of instream and riparian habitats and stream temperature of the Upper White River was done by the Remote Sensing Services Laboratory of Utah State University under contract to the U.S. Geological Survey. Aerial multispectral photographs were taken on September 21, 1999. Each river segment was flown twice, once before and once after solar noon to optimize sun penetration in the river corridor. The low sun angle at the time of year and large trees along the river corridor in all stream segments did not permit flights to be ideally matched to general segment compass orientation (for example, southeast to northwest orientations flown early in the day, and northwest to southeast orientations flown late in the day).

Imageries were photographed using three Kodak model 4.2i digital cameras with a 2024 × 2048 pixel frame size along with an Inframetrics Model 760 thermal scanner with a 640 × 480 pixel frame size. The three digital cameras had filters in the green (0.545-0.555 µm), red (0.665-0.675 µm), and near infrared (NIR) (0.790-0.810 µm) wavelengths in order to create multispectral imagery that could be used to characterize instream hydraulic and riparian habitats. The digital cameras had 20 mm lens and were set at 7 milliseconds exposure with a 60 percent overlap. The instrument package also contained a Global Positioning System (GPS) for georeferencing the multispectral imagery (Neale, 1997). The thermal imagery was photographed using a 50-degree Celsius water temperature range setting (3 to 53 degrees Celsius). The accuracy of the water temperature determination was not established and was viewed as experimental.

The plane was flown at 3,500 feet above ground level at a speed of 110 miles per hour to attain a 0.5-meter resolution for the multispectral imagery. Thermal imagery was taken simultaneously at 1.0-meter resolution and recorded on videotape. The digital camera imageries were recorded electronically by software on the onboard computer. The aerial-based multispectral imaging system took under 3 hours to photograph the entire study area.

Imagery Processing

The digital imageries were imported into and processed with ERDAS Imagine software (ERDAS Imagine V8.4, ERDAS, Inc. Atlanta, Georgia). The imageries were geometrically corrected for distortion due to the curvature of the lens. The three bands were then overlayed on one another using a second order polynomial that was uniquely created for this flight. The multispectral imagery was then corrected for vignetting effects (Neale and Crowther, 1994). Digital orthophoto imaging was used to rectify the multispectral imagery to a base map. The multispectral imagery was rectified using a second order polynomial rectification technique in ERDAS Imagine software.

Imagery mosaics were created for each of the six segments flown (fig. 2*A*). The five study reaches where field data were collected were clipped out of the entire mosaicked imageries as part of the classification training and measurement error work. The classification training data consisted of vegetation and instream hydraulic characteristics positively identified in the imagery by USGS scientists for each of the study reaches examined in the field. The spectral qualities of these positively identified hydraulic features (i.e. pools, riffles, large woody debris, etc.) were used as training data to collect statistics from each of the three spectral bands. These statistics create a "signature" for a given vegetation or instream hydraulic category or class that is used by the supervised classification routine in ERDAS. Once all the training statistics had been collected, the statistics for all the classes were tested for separability. This determined if classes were actually unique or if they overlapped with other classes. Classes that were poorly distinguished were continually refined using the classification routines in ERDAS until a supervised classification of instream and riparian habitat was created for all five study reaches (fig. 2*B*). The supervised habitat classification "signature" created for the five study reaches was then used to classify the remaining instream and riparian conditions throughout the six stream segments (fig. 2*C*).

Thermal imageries corresponding to the multispectral imageries were "grabbed" from the videotape by first simulating a 60 percent overlap from the tape of continuous thermal scanning. The thermal imagery was then registered to the multispectral imagery. Rectified thermal imageries were then mosaicked onto the six stream segments. A temperature bar at the bottom of the strip was used to provide the relative temperature values. The brightness values in the imagery and the temperature code (2.8 to 52.8 degrees Celsius in one case) have a linear relation. This relation was used to assign brightness values to relative water temperature values (fig. 3).

Measurement Error Approach

After the classified imageries were received from the Remote Sensing Services Laboratory and the field data compiled, the imagery data were checked for measurement error. All classified imageries were first checked for correct georeferencing, projection, format, and cell size. Some of the thermal index grids in the thermal imageries were initially in a floating point format and were converted to integer prior to inclusion in the value attribute table (VAT). The VAT summarized area statistics for relative water temperature and instream hydraulic conditions (for example, pools and riffles) and riparian vegetation conditions (for example, shrub, conifer, roads, etc.) for each of the imageries (fig. 2). The information contained in the VAT were imported to spreadsheets.

Next, all classified hydraulic, riparian, and relative water temperature conditions representative of submerged conditions in all imageries were extracted based on the area classified as wet (for example, run, riffles, submerged gravel, etc.), gravel, and those areas in the lowest 10 percent of the thermal imaging range. This procedure identified the extent of the bankfull channel in all imageries. Relative water temperature imageries were used to help identify the channel because extensive tree shadows in the multispectral imageries obscured the view of the stream channel.

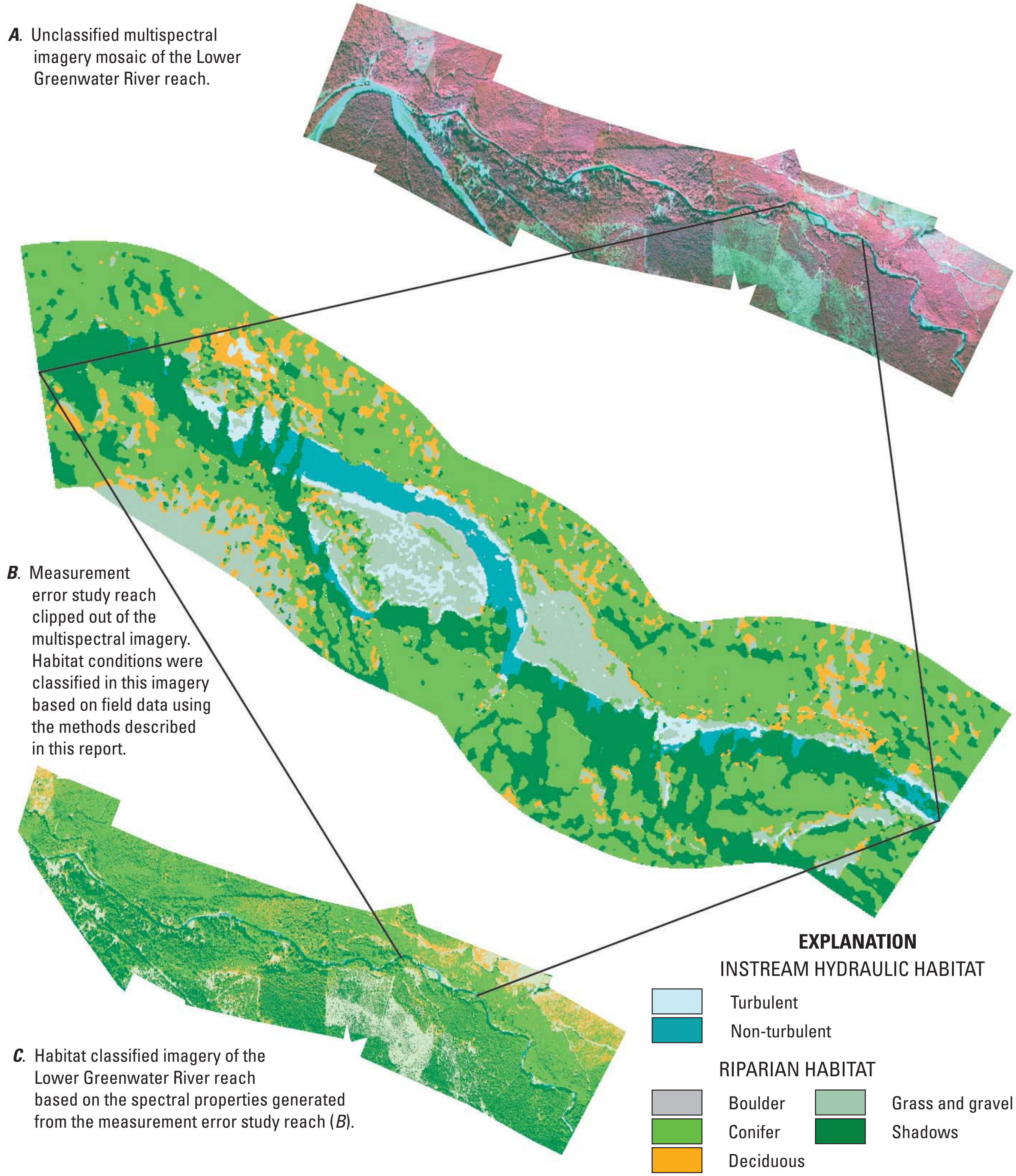


Figure 2. Instream hydraulic and riparian habitat classification methods using multispectral imaging in the Upper White River Basin, Washington, September 1999.

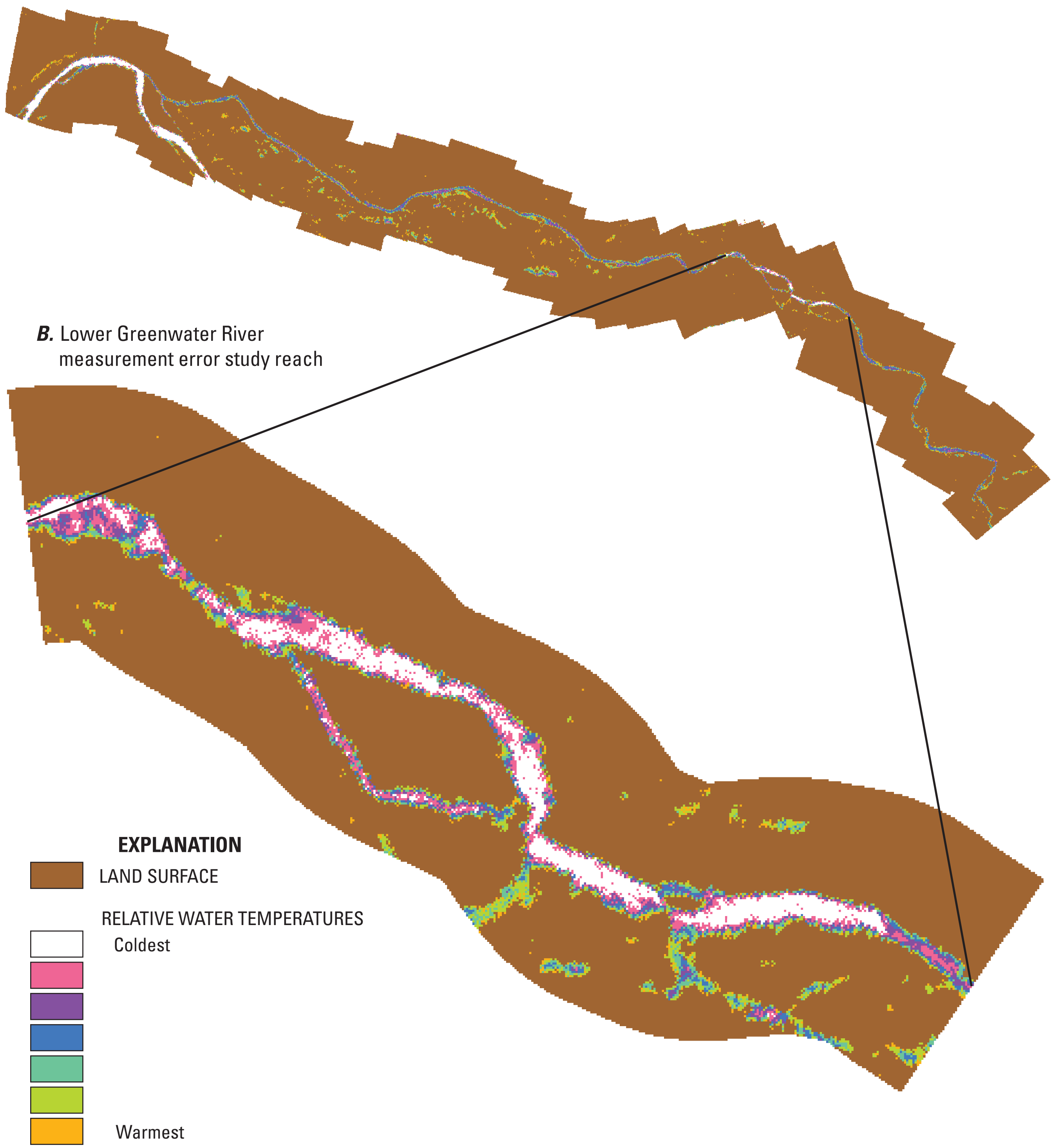


Figure 3. Thermal characterization of the Lower Greenwater River reach in the Upper White River Basin, Washington, September 1999.

Because the thermal imageries captured information in the infrared wavelengths, shadows did not obscure the location of the stream channel. Using the wet-plus-gravel imagery subset and the low-temperature imagery subset for each site as an on-screen backdrop, a bankfull channel center-line was digitized.

For each of the measurement error study reaches, GPS data collected in the field were used to generate a vector GIS data set to identify the downstream and upstream boundaries. This data set was overlayed on the channel center line described above. A 61- to 122-meter (200- to 400-foot) buffer on either side of the channel center line was then created and used to 'clip' the hydraulic, riparian, and relative thermal imageries for each of the study reaches (fig. 4). These new riparian buffer subsets of the hydraulic and relative water temperature imageries were used to tabulate aerial-based habitat data for comparison to field-based data.

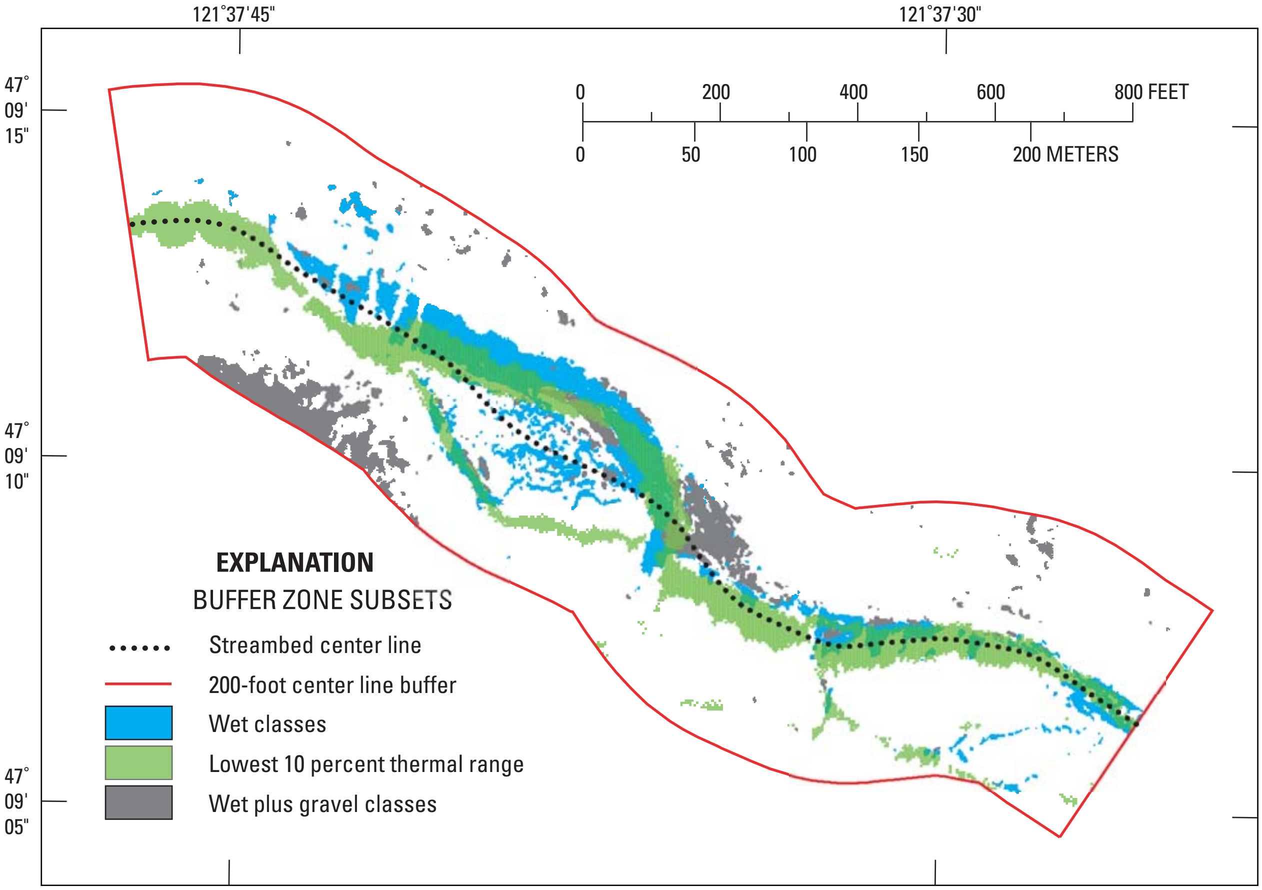


Figure 4. Approach used to generate buffers on either side of the stream channel in the Upper White River Basin, Washington, September 1999.

By combining the multispectral and thermal imaging data, a center line for the active channel for each of the six flow study reaches could be generated and a buffer zone on either side of the imagery could be clipped out of the original multispectral and thermal imageries.

CHARACTERIZATION OF INSTREAM HYDRAULIC AND RIPARIAN HABITAT CONDITIONS AND STREAM TEMPERATURES

Huckleberry Creek

Measurement Error Study Reach

The Huckleberry Creek measurement error study reach is 300 meters long and is a small, forest stream with a well-developed riparian canopy (fig. 1, river reach segment A). Discharge at the time of field sampling was 1.25 cubic meters per second.

Instream hydraulic habitat measured in the field as either pool or riffle and turbulent or non-turbulent was similar to habitat conditions characterized by the multispectral imagery. Field data and multispectral imagery indicate that the 300-meter long study reach is dominated by riffle and turbulent habitat (table 2). Riffle habitat measured in the field was 89.8 percent of the instream area, and 75.5 percent using the multispectral imagery. Turbulent habitat measured in the field was 81.2 percent of the instream area, and 75.5 percent using the multispectral imagery. However, the overall areas of pools and riffles and turbulent and non-turbulent habitat conditions characterized by multispectral imagery were several times less than habitat conditions measured in the field. This difference in total instream habitat area between the field measurements and multispectral imagery was due to the extensive canopy cover in the study reach (figs. 5*A* and 5*B*). The extensive shadows in the imagery also compromised the characterization of instream habitat (table 2).

After combining the visually characterized instream habitat imagery with the stream imagery as defined by the thermal characteristics, the total instream area characterized by the multispectral imagery (3,449.0 square meters) was much more similar to the area measured in the field (3,807.1 square meters) (table 2). Field measurement of total reach length was within 5.6 meters of total reach length estimated using GPS point measures with the multispectral imagery (table 2).

Total area of woody debris measured in the field was 378.4 square meters (table 2). Instream wood could not be identified using the multispectral imagery. Other than shadows, conifers dominated the riparian zone (table 2).

Thermal imaging accurately characterized more of the wetted stream channel than multispectral imaging because the thermal imagery was less affected by the forest canopy shadows adjacent to the stream (fig. 6). The relative water temperature scale used in figure 6 is a linear scale. The number of temperature probes was insufficient to permit calibration of the relative water temperatures. However, some patterns of water temperature variation can be seen in the thermal imagery.

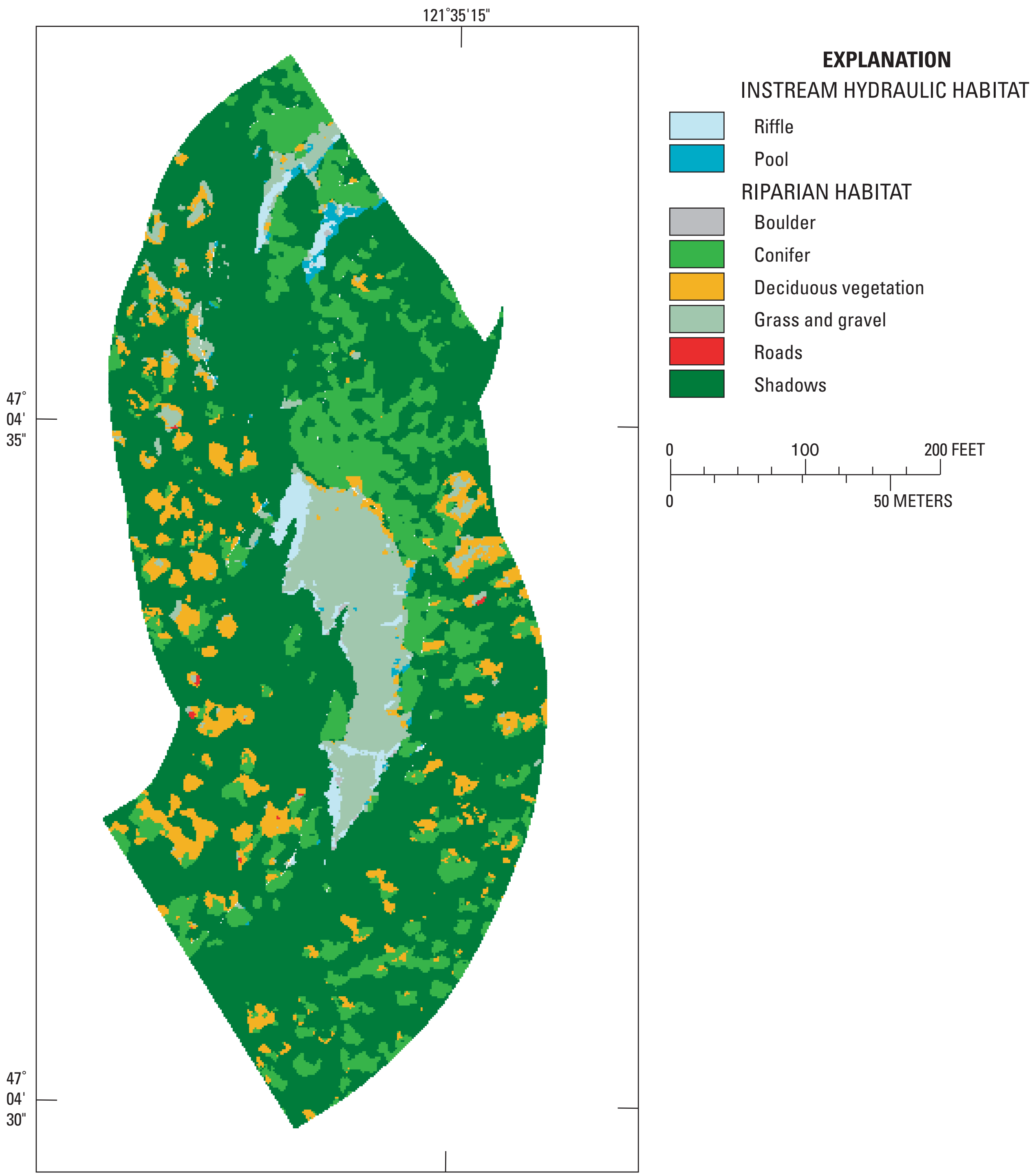
The thermal imageries were photographed at a 1-meter resolution. For each square meter of water observed during the aerial flight, a relative water temperature was recorded. A proportional distribution of relative water temperatures for each of the 1-square-meter blocks in the Huckleberry Creek measurement error study reach is shown in figure 7. Most of the Huckleberry Creek measurement error study reach was composed of colder water. Cool to warmer water was more uniformly distributed throughout the remainder of the reach. The actual water temperature range could not be characterized due to the limited number of temperature probes installed during the aerial flight, but the water temperature range in the Huckleberry Creek measurement error study reach does exhibit a pattern typical of a well-shaded cold water mountain stream (fig. 7).

Table 2. Instream hydraulic and riparian habitat conditions in the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, September and October 1999

[**Beginning and end of reach**: Latitude and longitude for measurement error study reaches were derived from handheld GPS units while in the field. Latitude and longitude for the entire creek study segment were estimated from 1:24,000 scale topographic maps provided by Ecology. **Measurement error study reach**: Habitat field work was conducted by the U.S. Geological Survey. **Entire Creek study segment 1:** Field work was conducted by the U.S. Forest Service. **Field and flight dates**: Field dates were spread out over a number of days. **Instream habitat**: The total area of instream habitat is the sum of either riffles and pools or turbulent and non-turbulent conditions. **Total instream area**: Total instream area is based on multispectral habitat data and aerial based temperature data. Total instream area based on field data can be compared to either total instream area from the multispectral data or to the corrected total instream area based on instream habitat and water temperature. For further clarification of this calculation, see the "Methods" section. **Abbreviations**: m^2, square meter; m, meter, ft, feet. —, no data]

	Segment 1 Reference points 4 through 7 Buffer size =61 m (200) ft				Segment 1 Reference points 0 through 10 Buffer size = 61 m (200 ft)			
	Latitude	Longitude			Latitude		Longitude	
Beginning of reach	47°04'36"	121°35'19"			47°04'46"		121°35'07"	
End of reach	47°04'27"	121°35'22"			47°04'09"		121°35'36"	
	Measurement Error Study Reach				**Entire Creek study segment 1**			
	Field data		**Multispectral data**		**Field data**		**Multispectral data**	
Habitat conditions	**Oct. 1999 (early)**		**Sept. 21, 1999**		**Oct. 1999 (early)**		**Sept. 21, 1999**	
	Square meters	**Percent**	**Square meters**	**Percent**	**Square meters**	**Percent**	**Square meters**	**Percent**
Instream								
Riffle	3,420.1	89.8	570.0	75.5	11,420.1	93.8	2,964.6	61.9
Pool	387.0	10.2	185.4	24.5	761.2	6.3	1,821.2	38.1
Turbulent	3,092.1	81.2	570.0	75.5	—	—	—	—
Non-turbulent	714.9	18.8	185.4	24.5	—	—	—	—
Riparian								
Bare soil	—	—	0.0	0.0	—	—	0.0	0.0
Boulder	—	—	30.5	0.1	—	—	293.9	0.2
Conifer	—	—	5,940.8	17.0	—	—	46,514.3	27.3
Deciduous vegetation	—	—	2,620.5	7.5	—	—	7,013.6	4.1
Grass and gravel	—	—	3,029.7	8.7	—	—	6,140.3	3.6
Roads	—	—	21.2	0.1	—	—	280.6	0.2
Shadows	—	—	23,354.7	66.7	—	—	110,374.5	64.7
Shrub	—	—	0.0	0.0	—	—	0.0	0.0
Wood	378.4	—	0.0	0.0	280.2	—	0.0	0.0
Total instream area (m^2)	3,807.1	—	755.5	—	12,181.3	—	4,785.8	—
Total instream area based on instream habitat and water temperature (m^2)	—	—	3,449.0	—	—	—	—	—
Total reach length (m)	300	—	294.4	—	989.0	—	1,464.0	—

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

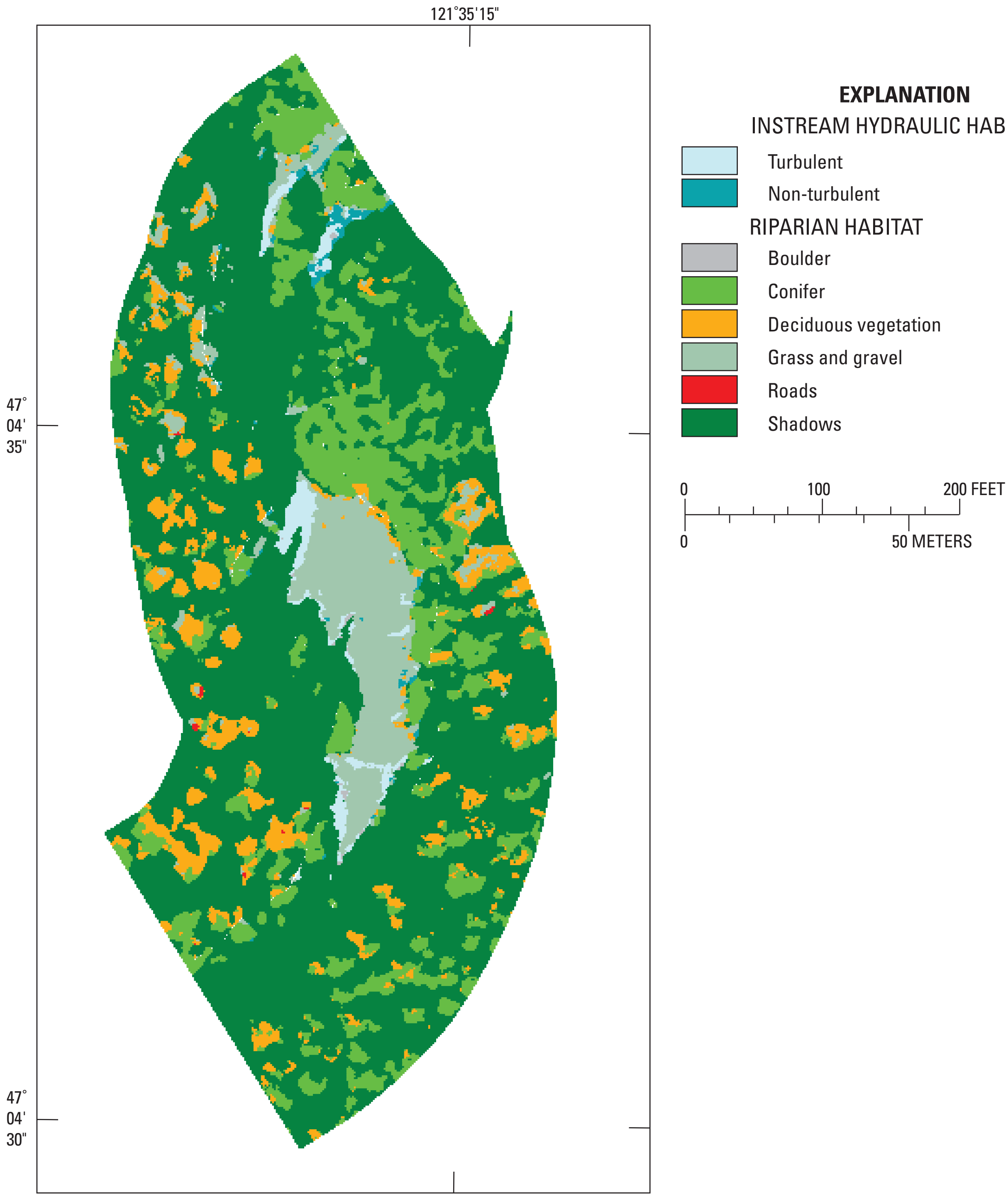


A. Instream habitat conditions characterized as either riffle or pool.

Figure 5. Classifications of instream hydraulic and riparian habitat conditions in the Huckleberry Creek measurement error study reach in the Upper White River Basin, Washington, September 1999.

Classifications were based on field data collected by the U.S. Geological Survey.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



B. Instream habitat conditions characterized as turbulent or non-turbulent.

Figure 5.—*Continued.*

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

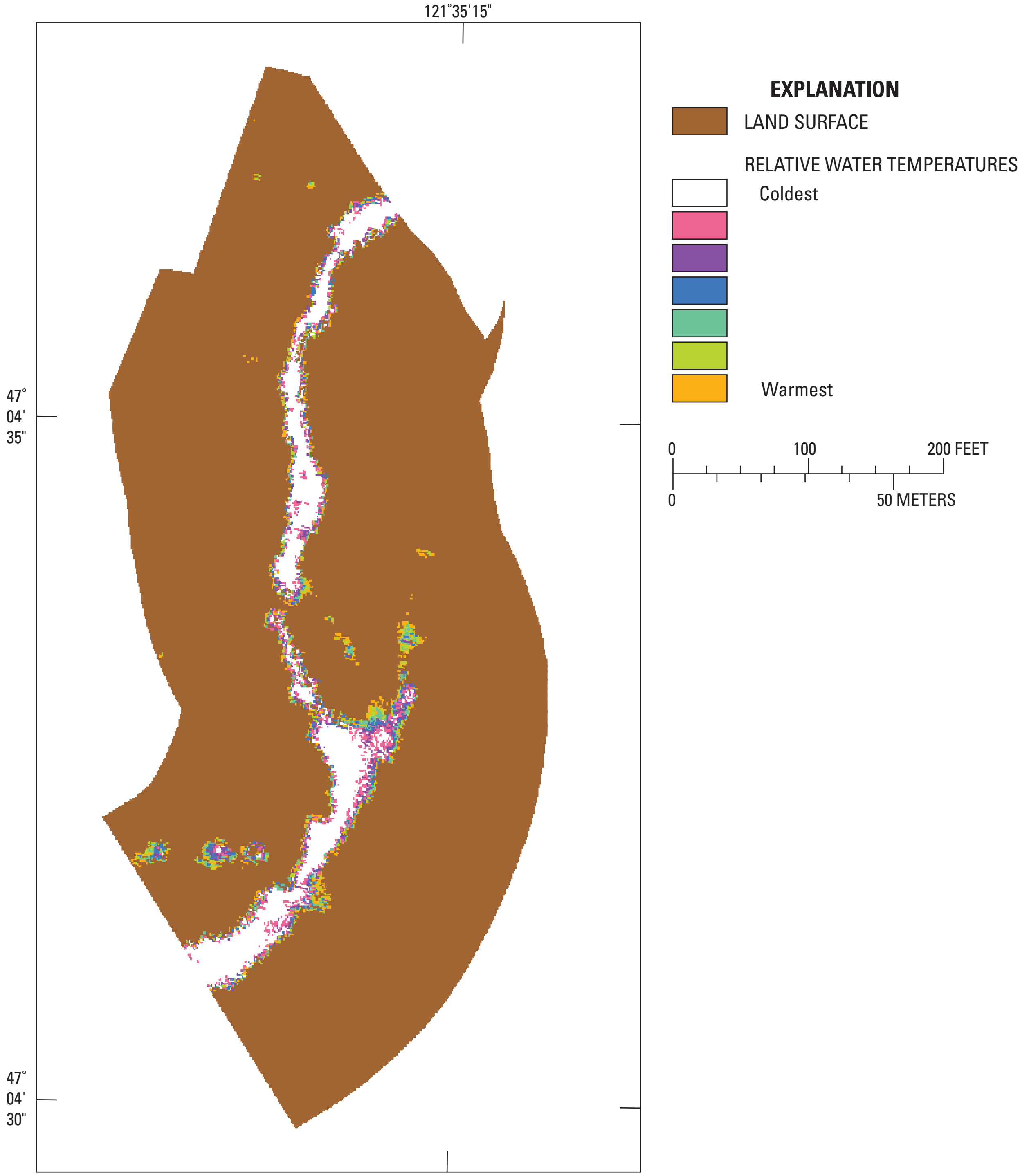


Figure 6. Characterization of thermal conditions in the Huckleberry Creek measurement error study reach in the Upper White River Basin, Washington, September 1999.

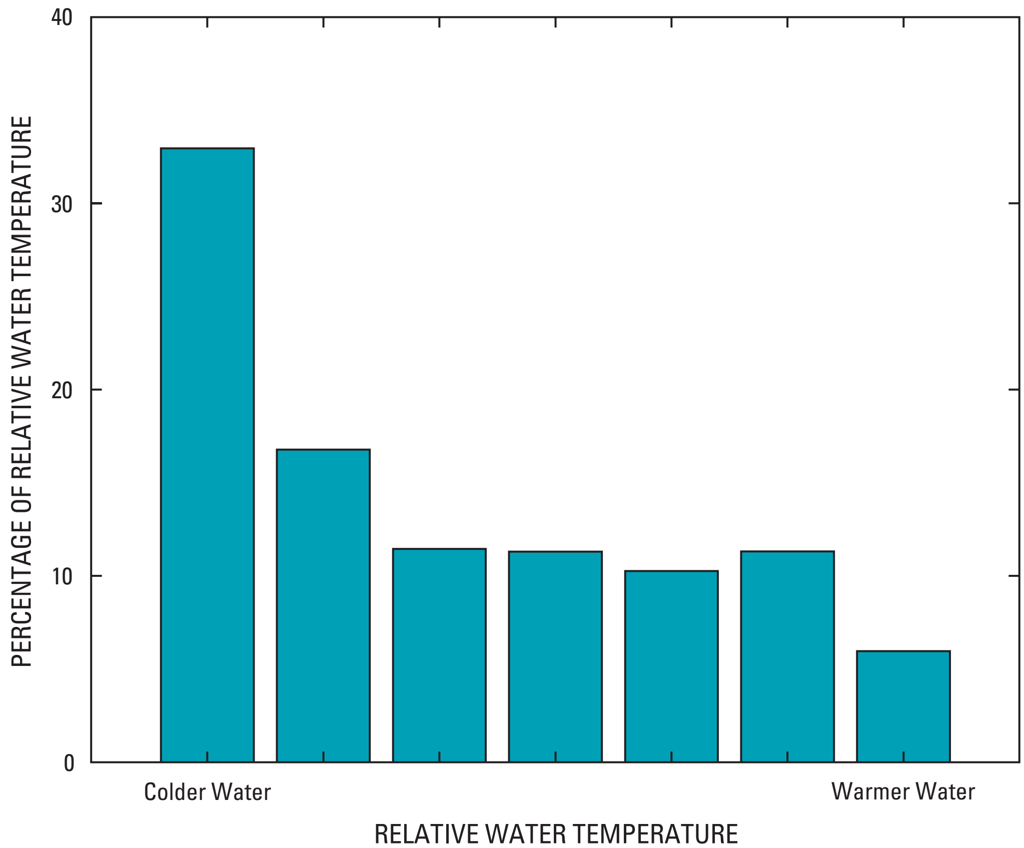


Figure 7. A proportional distribution of relative water temperatures in the Huckleberry Creek measurement error study reach in the Upper White River Basin, Washington, September 1999.

Entire Segment

The entire Huckleberry Creek study segment 1 was characterized using the same multispectral imaging approach used for the measurement error study reach. Unlike the other study reaches (fig. 1), the entire study segment 1 of Huckleberry Creek was field sampled by the U.S. Forest Service (see table 10, at back of report). Therefore, the field data collected for the entire segment were compared with the data from the multispectral imaging.

Riffle habitat dominated the entire length of segment 1 of Huckleberry Creek (93.8 percent). The multispectral data identified a smaller percentage of riffle habitat as well as a much smaller total instream area (table 2). This difference can be attributed to the extensive canopy cover for this segment (fig. 8).

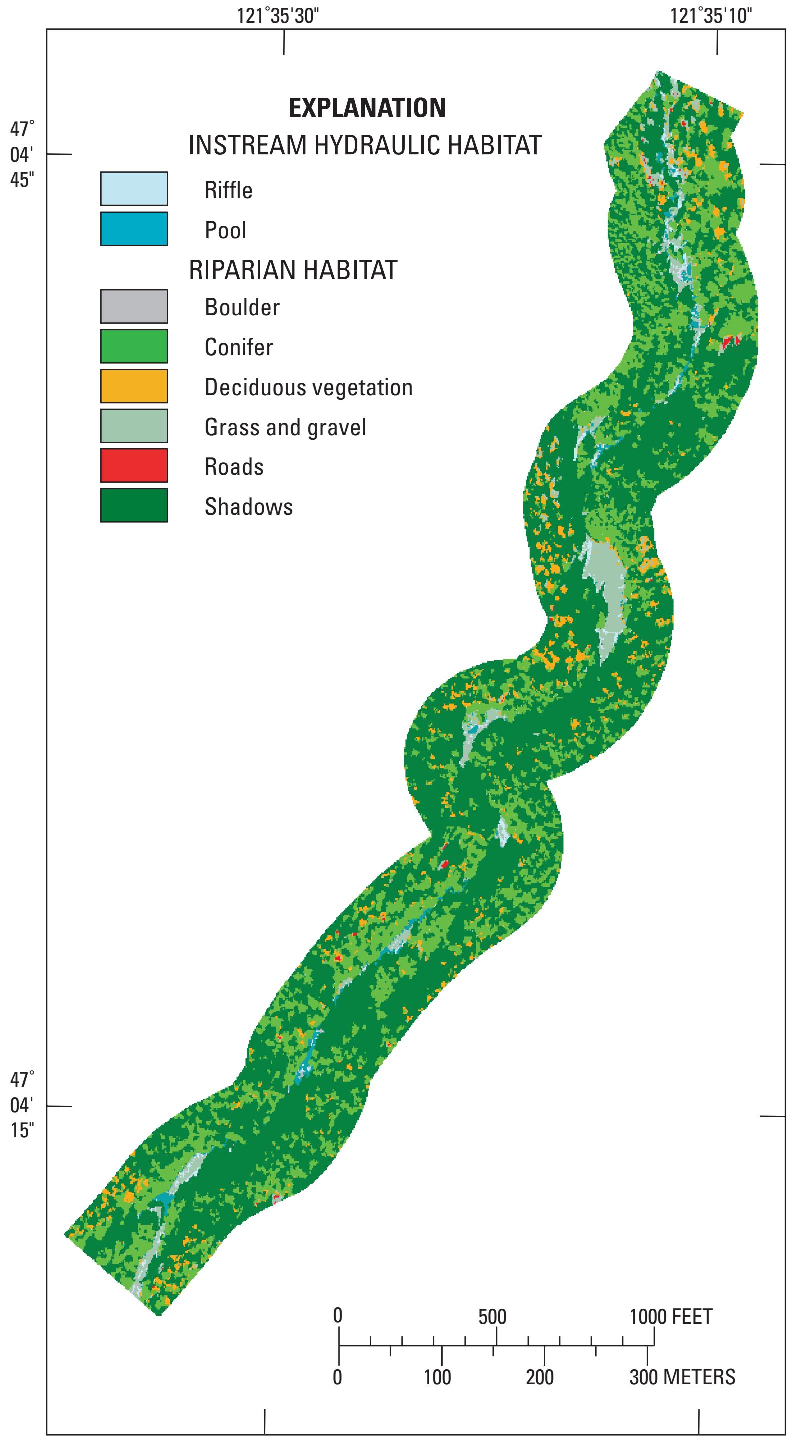
Field measurement of total segment length was markedly different than total segment length characterized by multispectral imagery (table 2). This difference is most likely because precise latitude and longitude measurements were not available for the beginning and end of this segment and were estimated from 1:24,000-scale topographic maps provided by Ecology.

Turbulent and non-turbulent habitat conditions were not measured by the U.S. Forest Service for the entire Huckleberry Creek segment, but the spectral properties derived from the USGS measurement error study reach were used to characterize turbulent and non-turbulent hydraulic habitats in the entire segment (fig. 8*B*).

Total area of woody debris measured in the field for the entire segment was 280.2 square meters (table 2). The multispectral imaging approach did not identify any instream wood. The difference between the amount of wood measured in this segment and the smaller Huckleberry Creek measurement error study reach within this segment highlight the measurement inconsistencies that can occur when two different teams measure the same variables (table 2). The U.S. Geological Survey conducted the habitat field work for the Huckleberry Creek measurement error study reach and the U.S. Forest Service conducted the habitat field work for the entire Huckleberry Creek study segment 1. The cause of these differences is unclear. Conifers were the dominant riparian vegetation type in the entire Huckleberry Creek segment (table 2). However, extensive shadows in the imagery also compromised the characterization of instream habitat.

As shown by the relative thermal imagery and a proportional distribution of relative water temperatures, the entire Huckleberry Creek segment was dominated by colder water (figs. 9 and 10). The entire segment had a slightly broader distribution of colder water than the measurement error study reach. This could be the result of more numerous openings in the canopy cover over the length of the entire Huckleberry Creek segment.

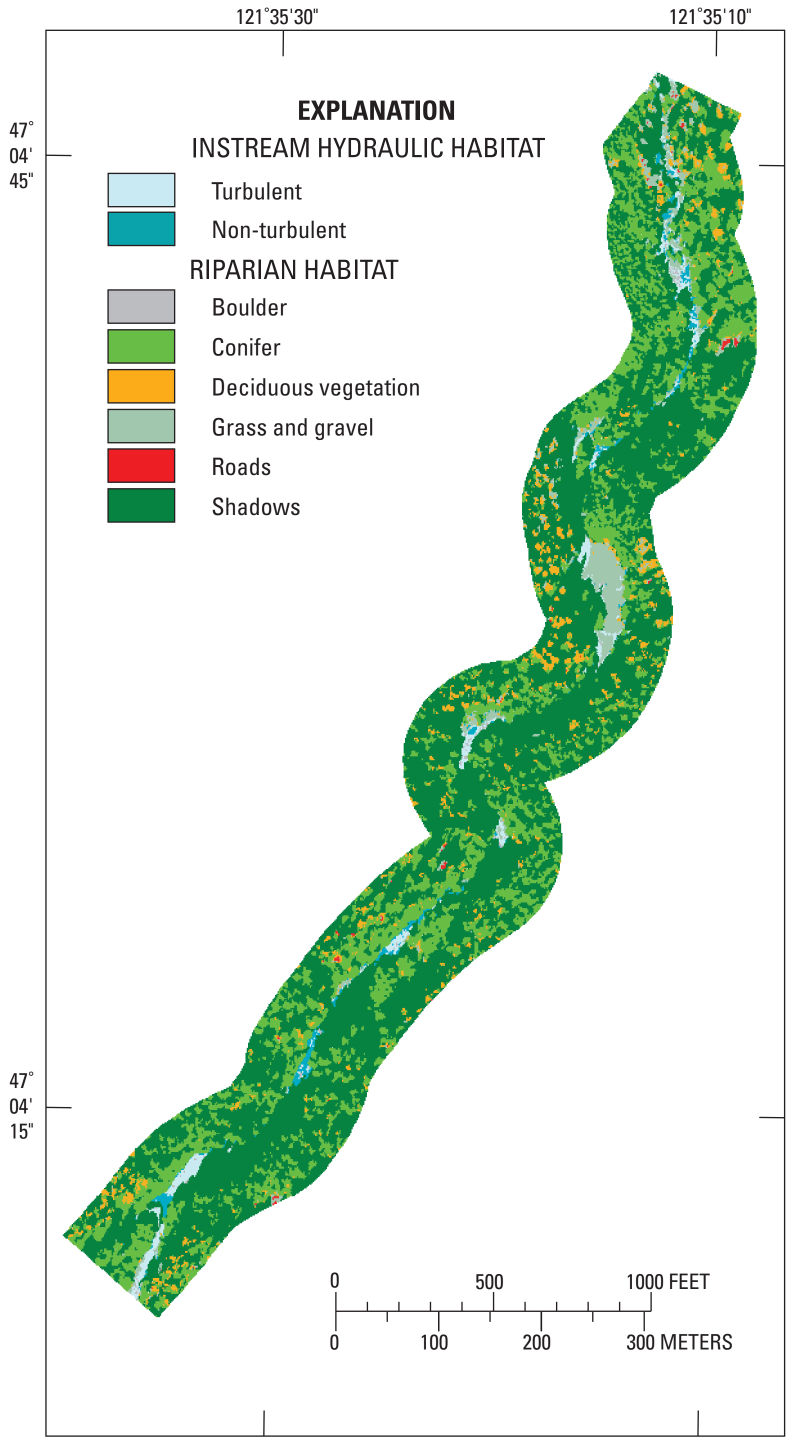
To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



A. Instream habitat conditions characterized as either riffle or pool.

Figure 8. Characterization of instream hydraulic and riparian habitat conditions in the entire Huckleberry Creek segment 1 in the Upper White River Basin, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



B. Instream habitat conditions characterized as either turbulent or non-turbulent.

Figure 8.—*Continued*.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

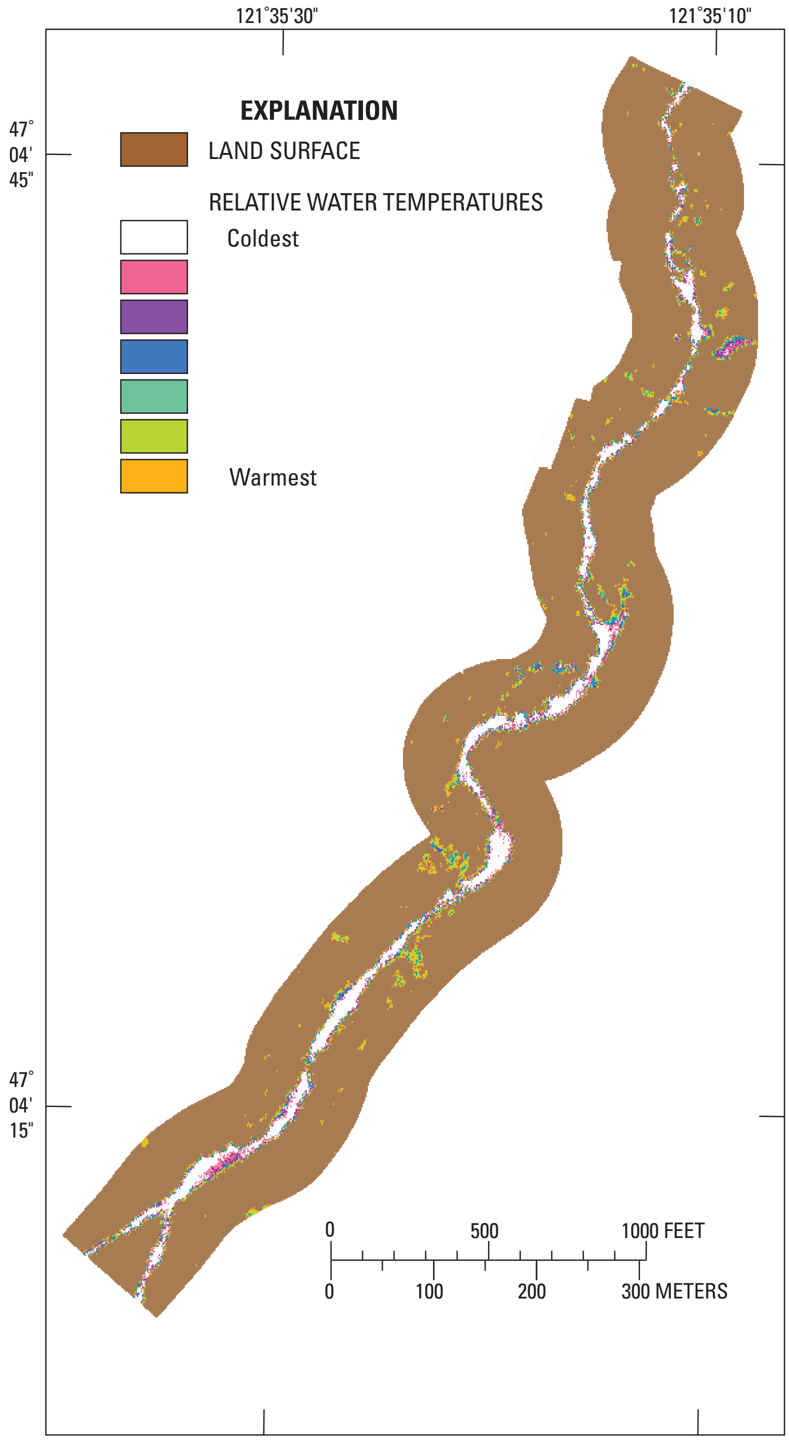


Figure 9. Characterization of thermal conditions in the entire Huckleberry Creek segment 1 in the Upper White River Basin, Washington, September 1999.

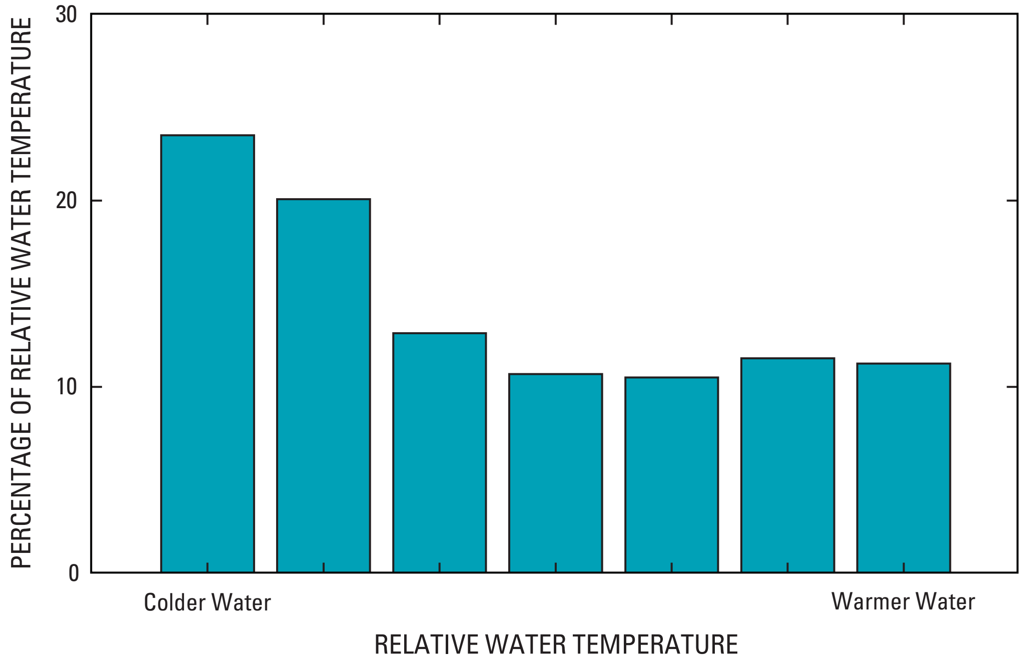


Figure 10. A proportional distribution of relative water temperatures in the entire Huckleberry Creek segment 1 in the Upper White River Basin, Washington, September 1999.

Lower Greenwater River

Measurement Error Study Reach

The Greenwater River measurement error study reach was 500 meters long and its upstream end coincides with the beginning of Ecology's segment 3. Segment 3 of the Greenwater River is at the upstream end of the lower Greenwater River reach highlighted in figure 1 (river reach segment B). Discharge in the Greenwater River at the time of field sampling was estimated to be 1.3 cubic meters per second and the mean bankfull width was 18.5 meters (table 11, at back of report).

Field data and multispectral imagery indicate that the 500-meter long study reach is dominated by riffle habitat (table 3). Field data indicate that the reach is dominated by non-turbulent habitat conditions. However, the multispectral imagery indicate that the reach is characterized by proportionally similar amounts of turbulent and non-turbulent habitat; however, the abundance of non-turbulent habitat is under-estimated (table 3). Comparing the abundance of pools and riffles to non-turbulent and turbulent habitat types highlights the specific identification criteria used to characterize pools. The results presented in table 3 suggest that a proportion of the area within the riffle habitat type might have been classified as "runs" or "glides" by other investigators.

The overall areas of habitat types characterized by the multispectral imaging approach was substantially less than habitat conditions measured in the field. Total instream habitat measured in the field was 10,298.2 square meters and 5,235.3 square meters using the multispectral imagery. Some of this difference is due to canopy cover, but more is caused by shadows (figs. 11*A* and 11*B*). Extensive shadows in the imagery also compromised the characterization of instream habitat (table 3). After combining the visually characterized instream habitat imagery with the stream imagery as defined by the thermal characteristics, the total instream area characterized by the multispectral imaging approach (11,764.8 square meters) was much more similar to the area measured in the field (10,298.2 square meters) (table 3). Field measurements of total reach length were within 23 meters of total reach length estimated using GPS point measures with the multispectral imagery (table 3).

Total area of woody debris measured in the field was 393.7 square meters (table 3). The multispectral imaging approach did not identify any woody debris (table 3). Conifers dominated the riparian zone, but grasses and gravels also made up a substantial portion of the riparian zone (figs. 11*A* and 11*B*, table 3).

Areas of warm water throughout the reach were characterized by thermal imaging (fig. 12). These areas of warm water correspond with areas that lack canopy cover and have shallow water. One area of warmer water temperature was associated with a recent landslide. Although some areas of warmer water temperature were observed, these thermal imageries are based on water-surface temperatures and may not represent conditions throughout the water column. A frequency distribution of water temperatures for this study reach indicates the predominance of cold surface water with a relatively uniform distribution of warmer water (fig. 13).

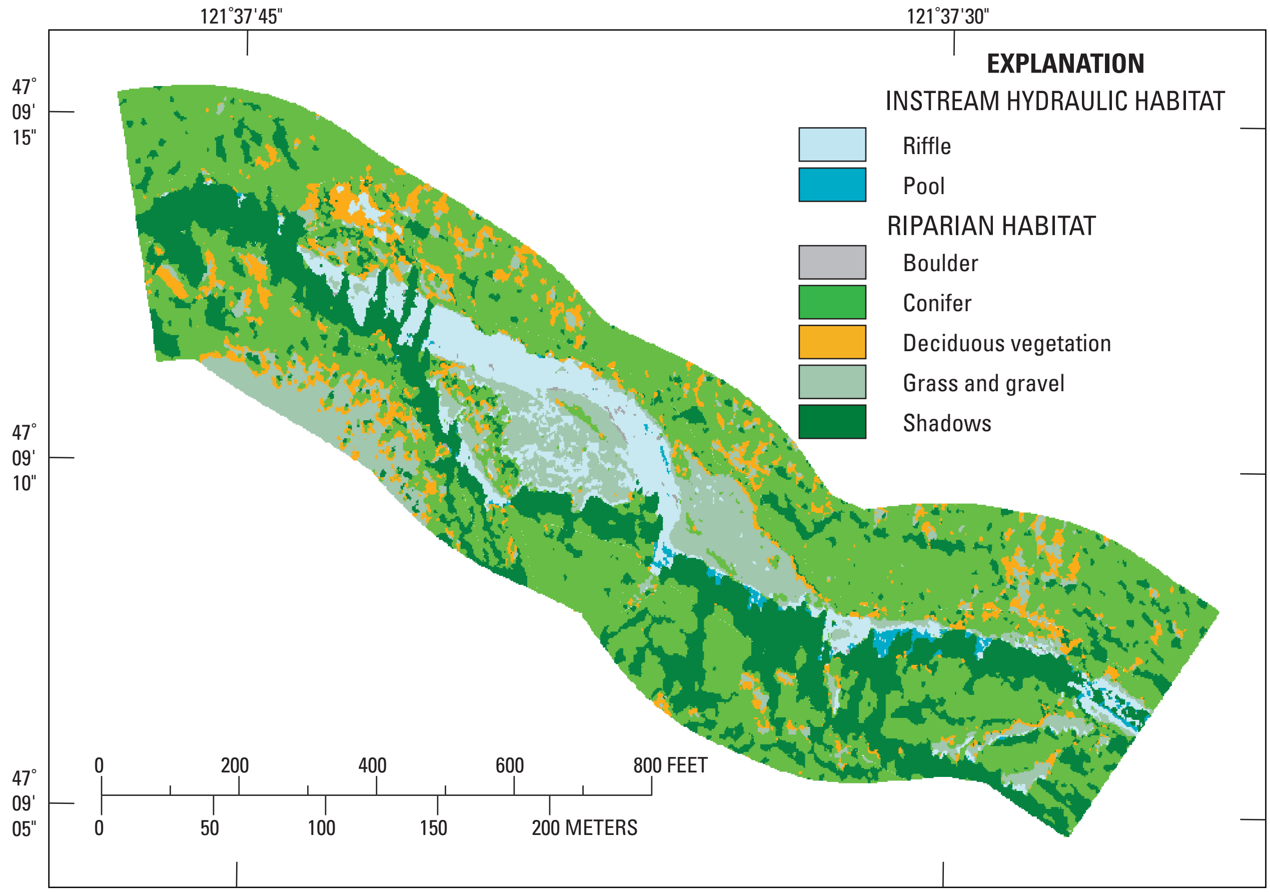
Table 3. Instream hydraulic and riparian habitat conditions in the Lower Greenwater River measurement error study reach and river segments 1, 2, and 3 in the Upper White River Basin, Washington, September 1999

[**Measurement error study reach**: Habitat field work was conducted by the U.S. Geological Survey. **Field data**: Field dates were spread out over a number of days. **Instream habitat**: The total area of instream habitat is the sum of either riffles and pools or turbulent and non-turbulent conditions. **Total instream area**: Total instream area is based on multispectral habitat data and aerial based temperature data. Total instream area based on field data can be compared to either total instream area from the multi-spectral data or to the corrected total instream area based on instream habitat and water temperature. For further clarification of this calculation, see the “Methods” section. **Abbreviations**: ft, feet; m^2, square meter; m, meter. —, no data]

	Ecology Segment 3 Reference points 0 - 5 Riparian buffer size = 61 m (200 ft)		Ecology Segments 1 - 3 Riparian buffer size = 61 m (200 ft)	
	Latitude	Longitude	Latitude	Longitude
Beginning of reach	47°09'12.4"	121°37'51.6"	47°09'31"	121°39'34"
End of reach	47°09'05.7"	121°37'30.2"	47°08'46"	121°37'03"

Habitat conditions	Measurement Error Study Reach				River segments 1 - 3	
	Field data		Multispectral data		Multispectral data	
	Sept. 1999 (late)		Sept. 21, 1999		Sept. 21, 1999	
	Square meters	Percent	Square meters	Percent	Square meters	Percent
Instream						
Riffle	7,567.8	73.5	4,881.3	91.7	18,993.3	83.4
Pool	2,730.4	26.5	444.0	8.3	3,789.6	16.6
Turbulent	2,267.1	22.0	2,478.4	46.5	8,511.2	37.4
Non-turbulent	8,031.1	78.0	2,846.9	53.5	14,271.6	62.6
Riparian						
Bare soil	—	—	0.0	0.0	0.0	0.0
Boulder	—	—	76.6	0.1	232.7	0.1
Conifer	—	—	31,531.0	54.1	245,619.3	52.9
Deciduous vegetation	—	—	4,250.1	7.3	17,579.1	3.8
Grass and gravel	—	—	7,975.1	13.7	33,705.5	7.3
Roads	—	—	0.0	0.0	0.0	0.0
Shadows	—	—	14,496.3	24.9	167,235.5	36.0
Shrub	—	—	0.0	0.0	0.0	0.0
Wood	393.7	—	0.0	0.0	0.0	0.0
		—	—	—	—	—
Total instream area (m^2)	10,298.2	—	5,325.3	—	22,782.9	—
Total instream area based on instream habitat and water temperature (m^2)	—	—	11,764.8	—	—	—
Total reach length (m)	500.0	—	523.0	—	4,029.1	—

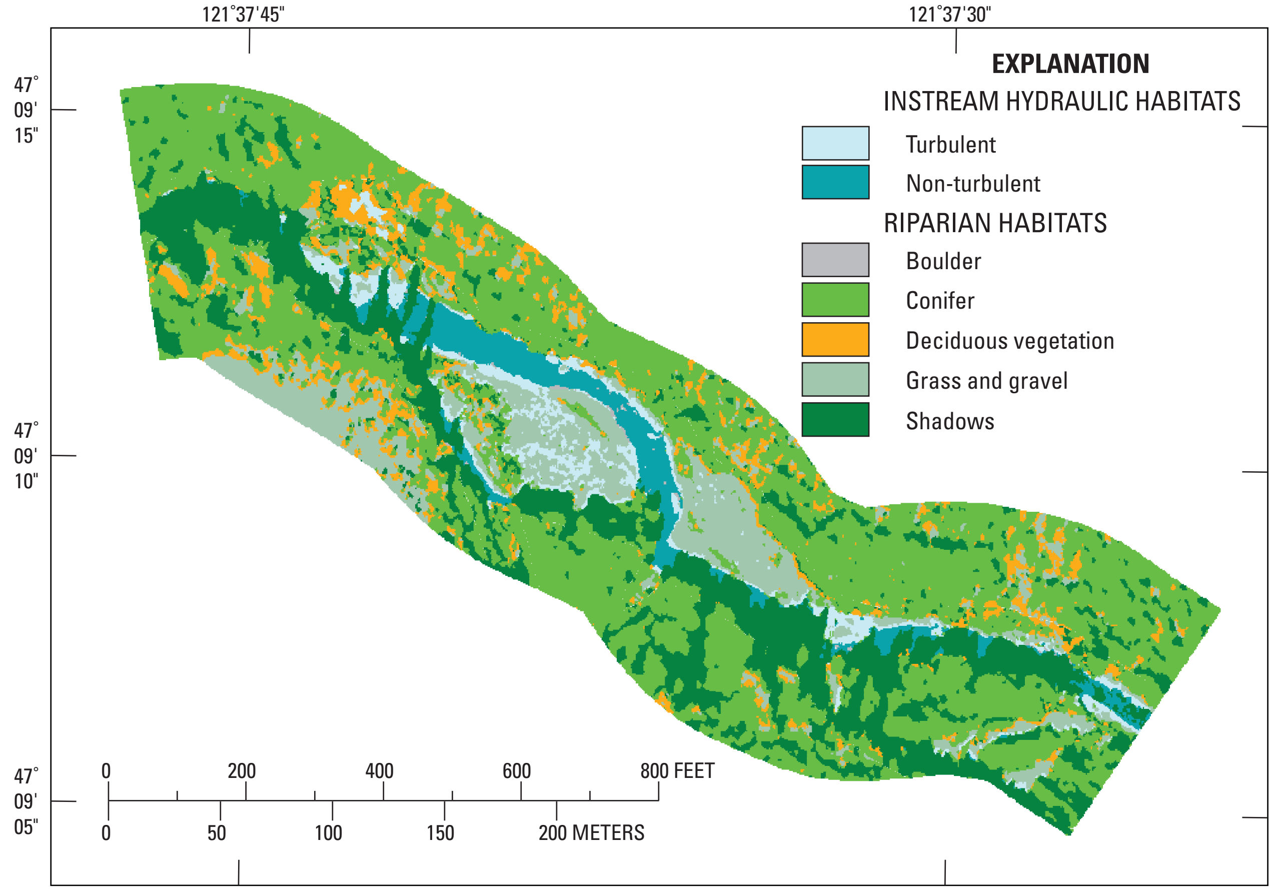
To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



A. Instream habitat conditions characterized as either riffle or pool.

Figure 11. Characterization of instream hydraulic and riparian habitat conditions in the Lower Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



B. Instream habitat conditions characterized as either turbulent or non-turbulent.

Figure 11.—*Continued*.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

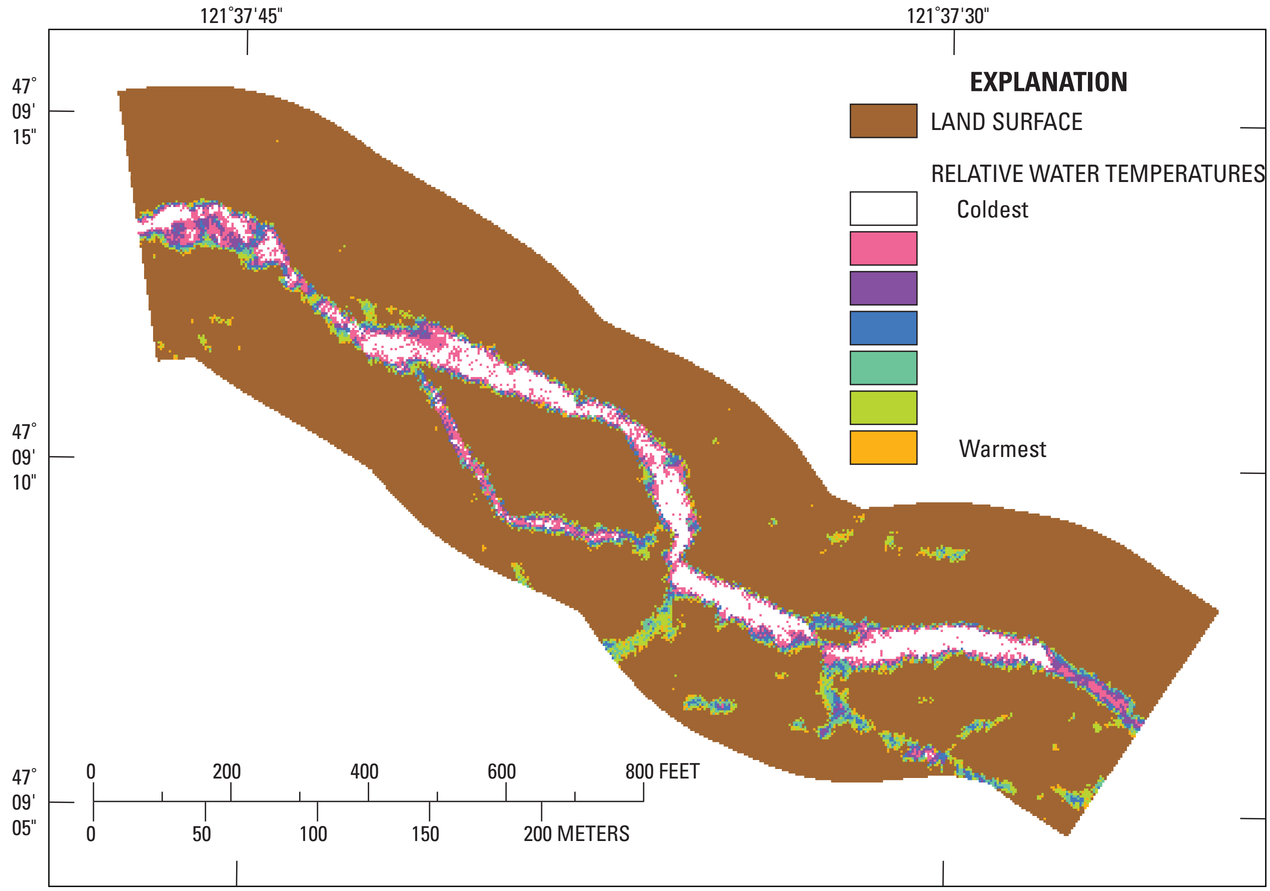


Figure 12. Characterization of thermal conditions in the Lower Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

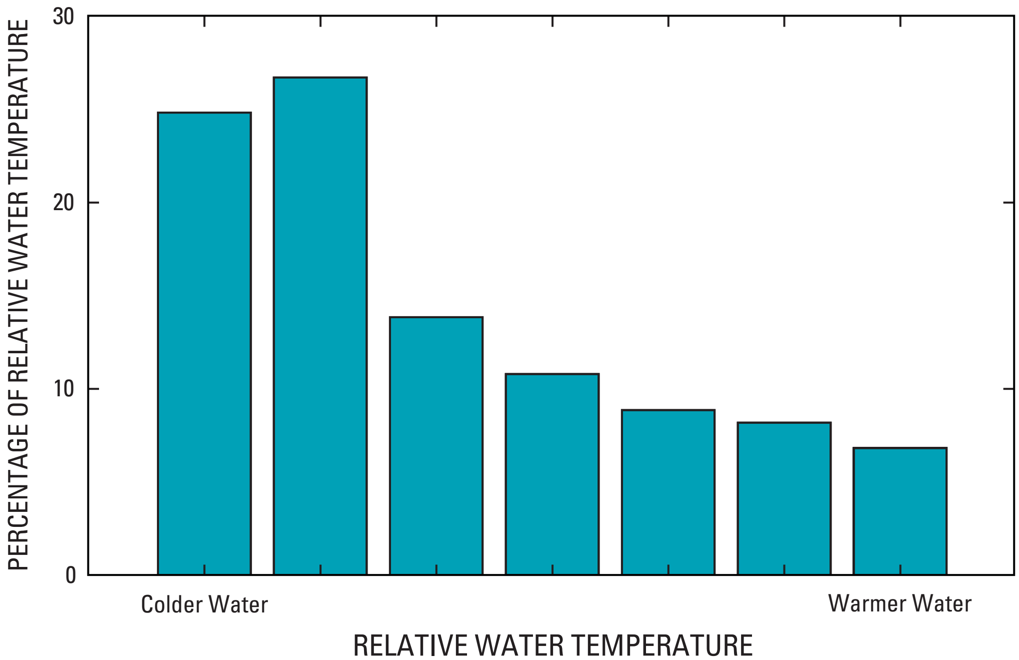


Figure 13. A proportional distribution of relative water temperatures in the Lower Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

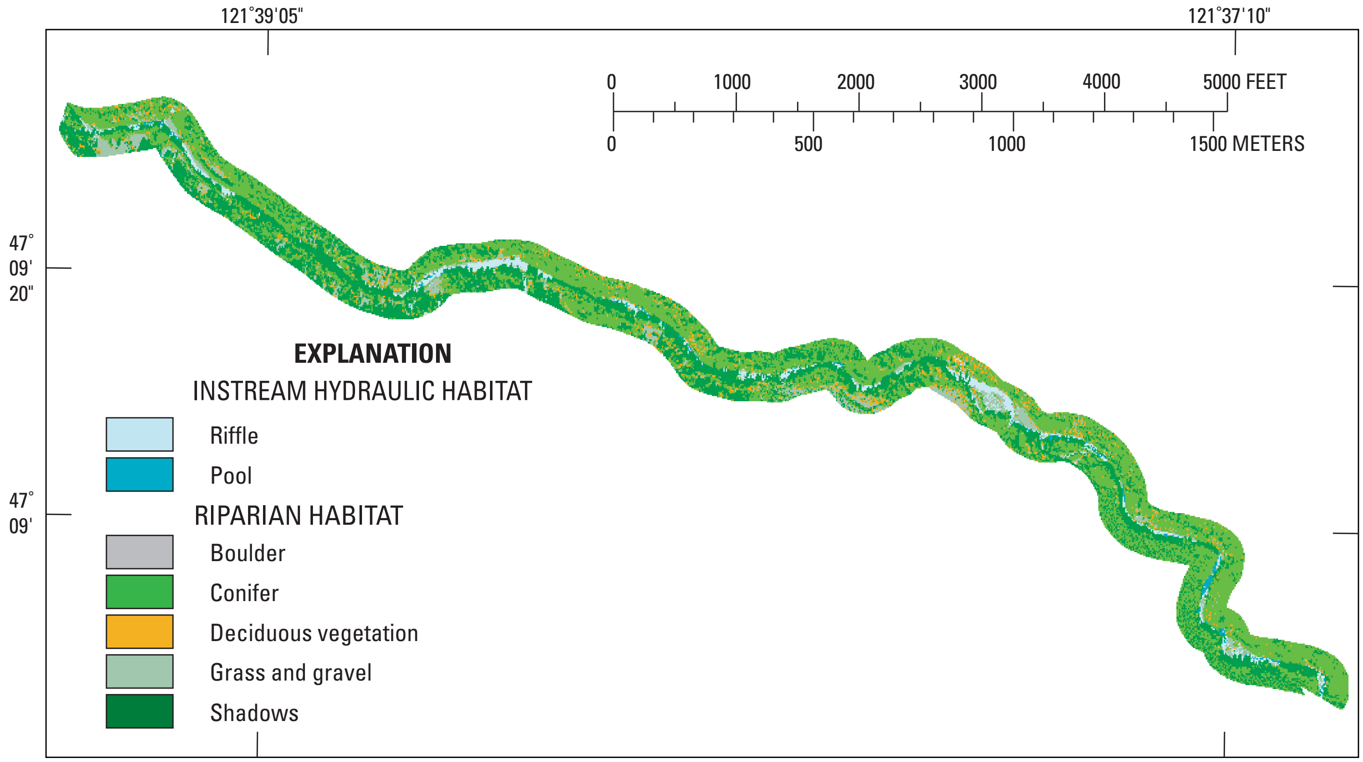
Entire Segment

The entire Lower Greenwater River segments 1, 2, and 3 was characterized using the same multispectral imaging approach used for the measurement error study reach (fig. 1, table 3).

As for the study reach, riffle habitat dominated the entire length of river segments 1, 2, and 3 (fig. 14*A*). The entire Lower Greenwater River segments also was dominated by non-turbulent habitat types, as observed in the study reach (fig. 14*B*, table 3). Conifers dominated the riparian zone, but shadows were extensive (table 3).

The relative thermal imagery and a proportional distribution of relative water temperatures for the entire segments 1, 2, and 3 showed a distinctive shift in the distribution of water temperature from predominantly cold water to warmer water (figs. 15 and 16). Although the cause of this shift is not known, it appears as though the measurement error study reach may be an area of groundwater upwelling while the remainder of segments 1, 2, and 3 may not be receiving such groundwater inputs.

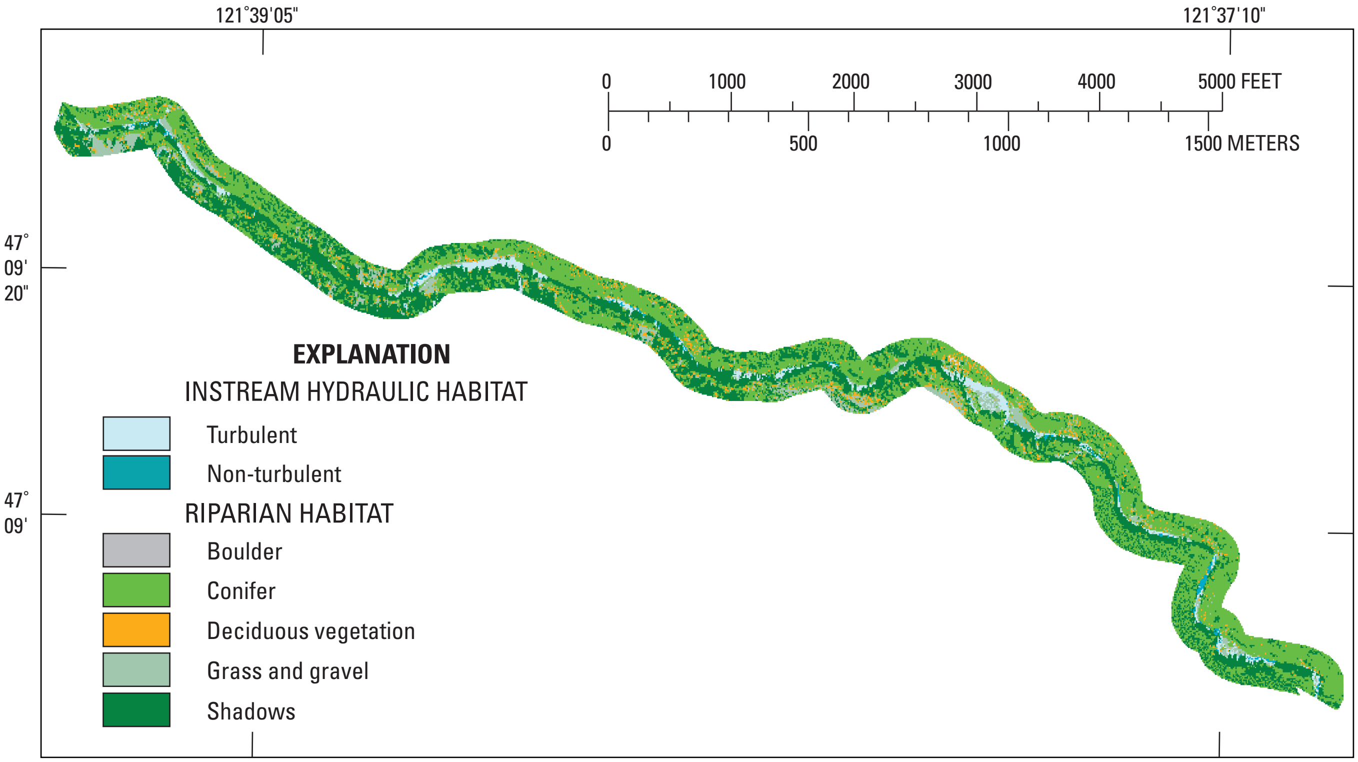
To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



A. Instream habitat conditions characterized as either riffle or pool.

Figure 14. Characterization of instream hydraulic and riparian habitat conditions in the entire Lower Greenwater River segments 1 through 3 in the Upper White River, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



B. Instream habitat conditions characterized as either turbulent or non-turbulent.

Figure 14.—*Continued.*

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

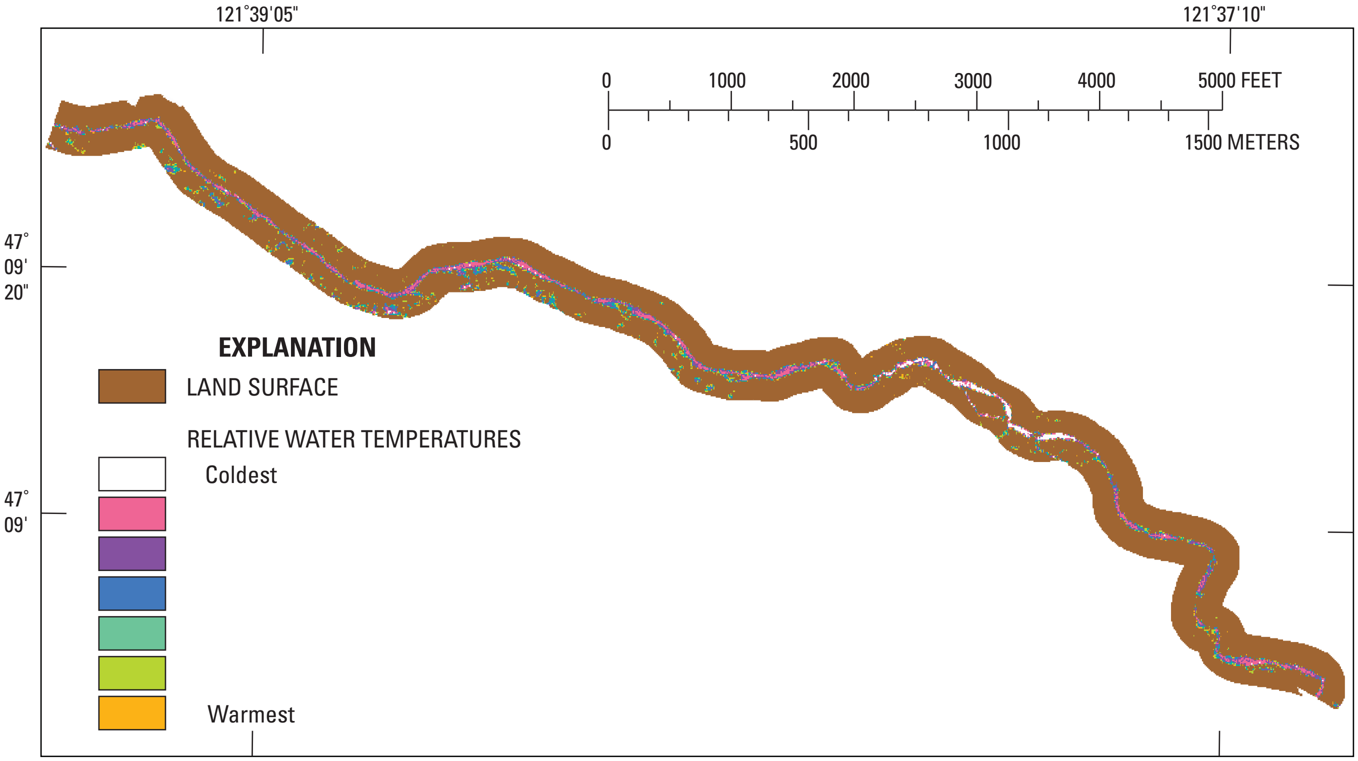


Figure 15. Characterization of thermal conditions in the entire Lower Greenwater River segments 1 through 3 in the Upper White River, Washington, September 1999.

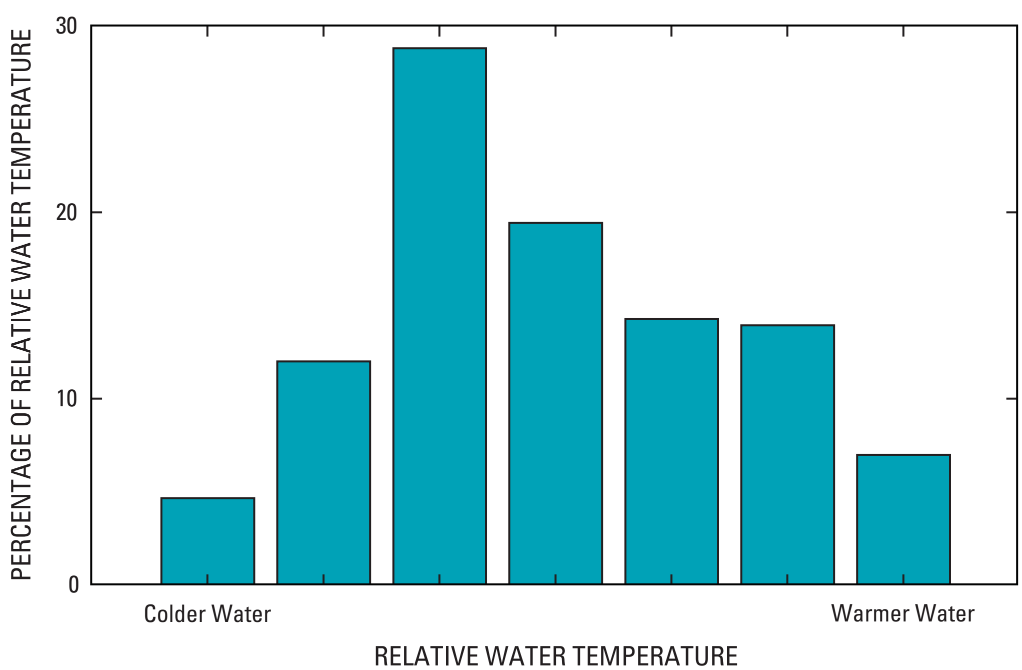


Figure 16. A proportional distribution of relative water temperatures in the entire Lower Greenwater River segments 1 through 3 in the Upper White River Basin, Washington, September 1999.

Upper Greenwater River

Measurement Error Study Reach

The Upper Greenwater River measurement error study reach is 2,100 meters long and extends from the upper end of the Ecology's segment 8 to the end of the Ecology's segment 9 in the upstream one-half of the Upper Greenwater River study segment (fig. 1, river reach segment C). Discharge in the upper Green River at the time of field sampling was 1.5 cubic meters per second and the mean bankfull width was 21.1 meters (table 12, at back of report).

Field data and multispectral imagery indicate that the 2,100-meter long study reach is dominated by riffle habitat (table 4). Riffle habitat measured in the field was 88.6 percent of the instream area and 84.8 percent using the multispectral imagery. The abundance of pool and riffle habitat conditions were substantially under-estimated using the multispectral imagery (table 4).

Total instream habitat measured in the field was 27,907.6 square meters and 8,391.1 square meters using the multispectral imagery. Some of this difference is due to canopy cover, but most is likely caused by shadows (fig. 17). A portion of the thermal imagery for this study reach was unusable, which prevented calculation of a total instream area from the multispectral and temperature imageries. Conifer vegetation cover dominated the riparian habitat, but shrubs/small trees also made up a significant portion of the riparian habitat (fig. 17, table 4).

Total area of woody debris measured in the field based on instream woody debris was 1,266.2 square meters and 5,990.9 square meters using multispectral imagery (table 4). The overestimation of woody debris generated by the multispectral analysis is most likely because of (1) a misclassification of the imagery or (2) a classification of large areas of woody debris outside of the area examined during the field. Identification of woody debris in the field was limited to wood located, at least partially, within the active bankfull channel (Schuett-Hames and others, 1999). Further GIS analysis could be restricted to the active channel, which might provide a better estimate of instream wood for this study reach.

Areas of warmer water temperatures throughout the reach were characterized by thermal imagery (fig. 18). These areas of warmer water correspond with areas that lack canopy cover and have shallow water. A frequency distribution of water temperatures indicates that both cold and warm water were present in this reach (fig. 19).

Table 4. Instream hydraulic and riparian habitat conditions in the Upper Greenwater River measurement error study reach and river segments 8 and 9 in the Upper White River Basin, Washington, August and September 1999

[**Field data**: Field dates were spread out over a number of days. **Instream habitat**: The total area of instream habitat is the sum of either riffles and pools or turbulent and non-turbulent conditions. **Abbreviations**: ft, feet; m^2, square meter; m, meter. —, no data]

Ecology Segments 8 and 9						
Riparian buffer size = 122 m (400 ft)						
	Latitude	Longitude			Latitude	Longitude
Beginning of reach	47°07'23"	121°32'58"			47°07'12"	121°34'21"
End of reach	47°07'30"	121°31'48"			47°07'29"	121°31'54"
	Measurement Error Study Reach				River segments 8 and 9	
Habitat conditions	Field data Aug. 1999 (late)		Multispectral data Sept. 21, 1999		Multispectral data Sept. 21, 1999	
	Square meters	Percent	Square meters	Percent	Square meters	Percent
Instream						
Riffle	24,731.9	88.6	7,117.3	84.8	13,620.6	78.0
Pool	3,175.7	11.4	1,273.8	15.2	3,773.9	22.0
Riparian						
Bare soil	—	—	0.0	0.0	0.0	0.0
Boulder	—	—	949.8	0.3	1,138.2	0.1
Conifer	—	—	96,905.8	27.6	204,209.4	24.8
Deciduous vegetation	—	—	0.0	0.0	0.0	0.0
Grass and gravel	—	—	16,546.9	4.3	34,722.7	4.2
Roads	—	—	568.2	0.2	630.6	0.1
Shadows	—	—	156,987.6	44.7	407,229.8	49.6
Shrub	—	—	74,476.1	21.2	163,231.2	19.9
Wood	1,266.2	—	5,990.9	1.7	10,691.3	1.3
Total instream area (m^2)	27,907.6	—	8,391.1	—	17,394.5	—
Total reach length (m)	2,100	—	1,554.6	—	3,533.7	—

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

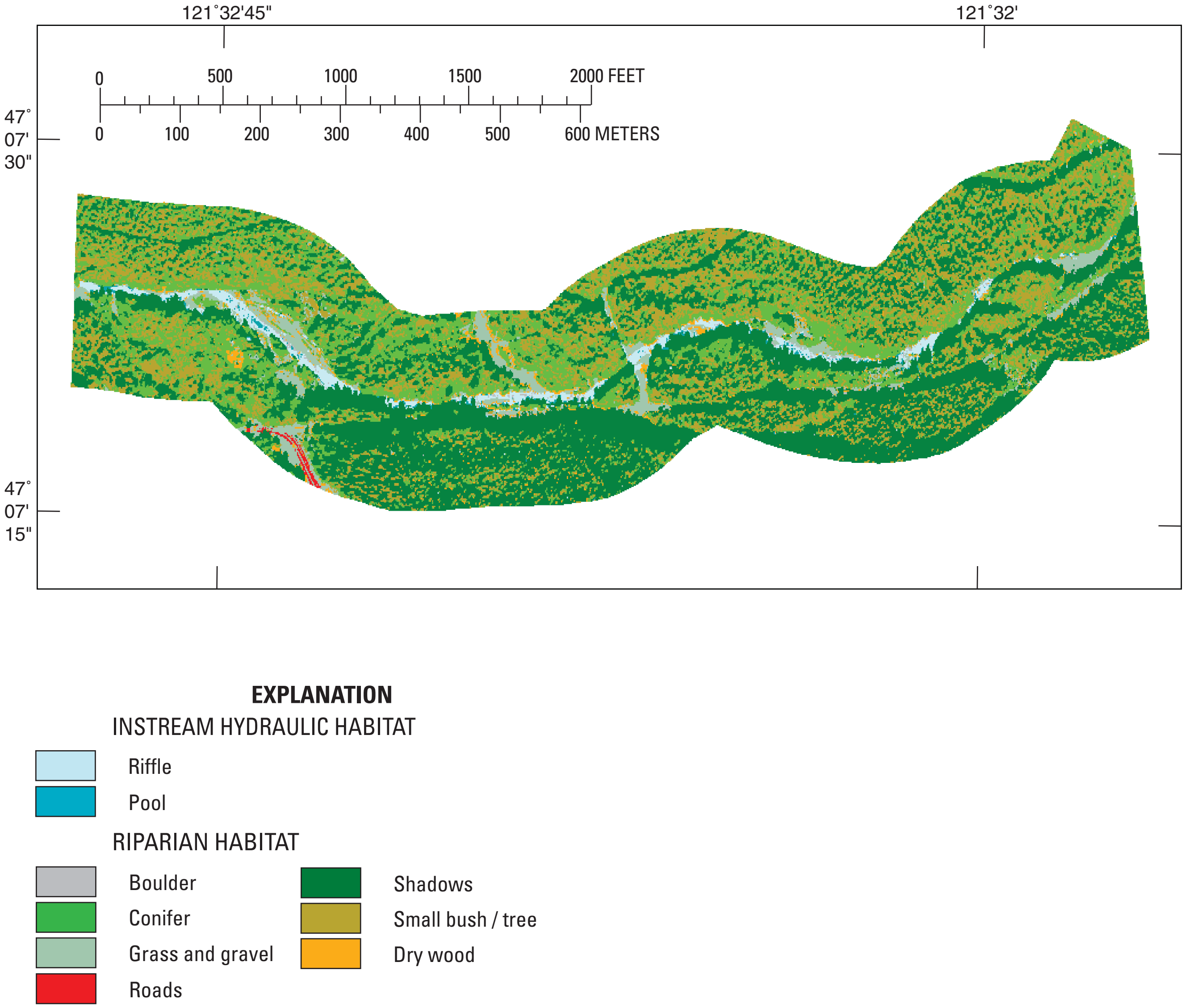


Figure 17. Characterization of instream hydraulic and riparian habitat conditions in the Upper Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

Characterization based on field data collected by the U.S. Forest Service.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

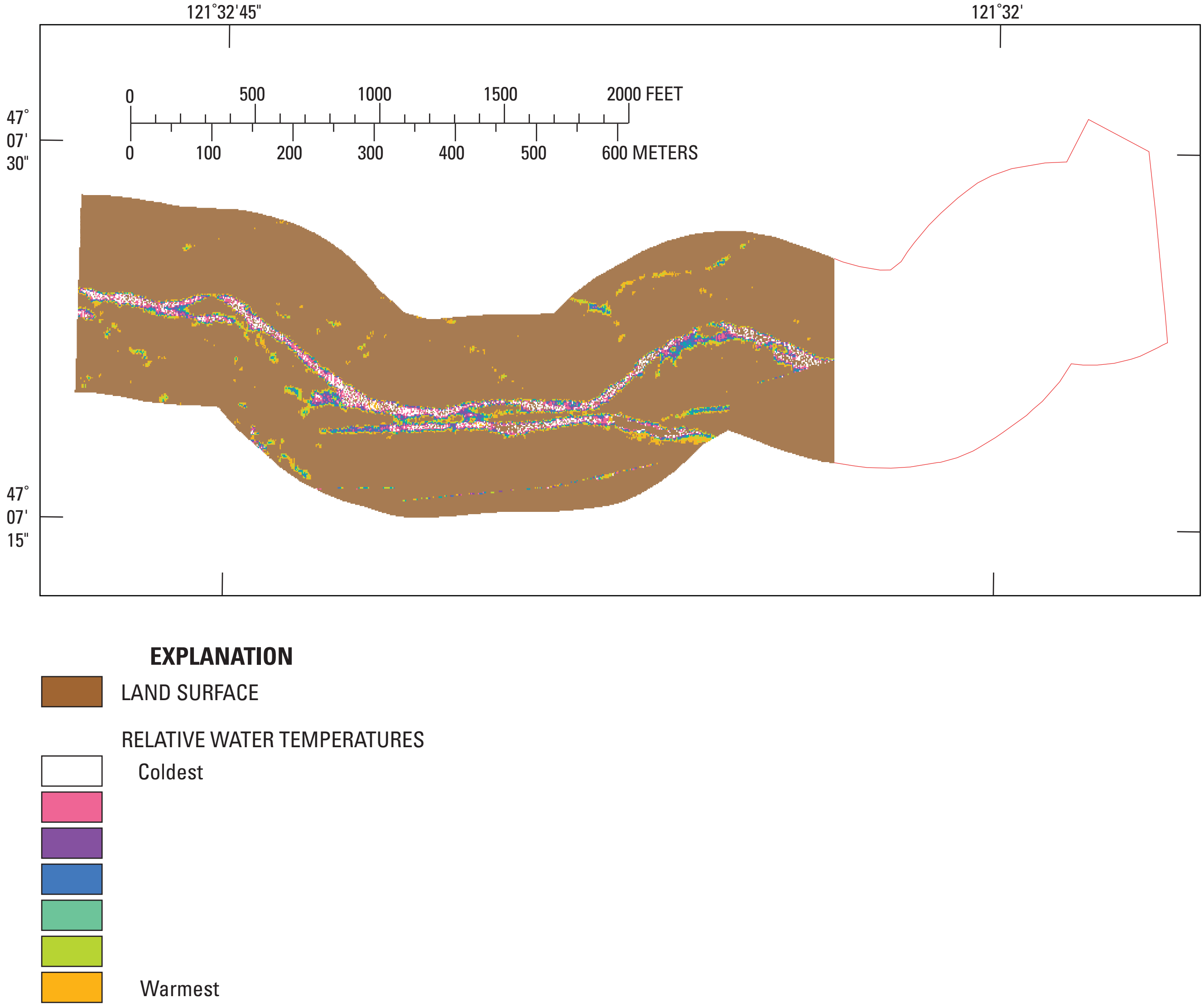


Figure 18. Characterization of thermal conditions in the Upper Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

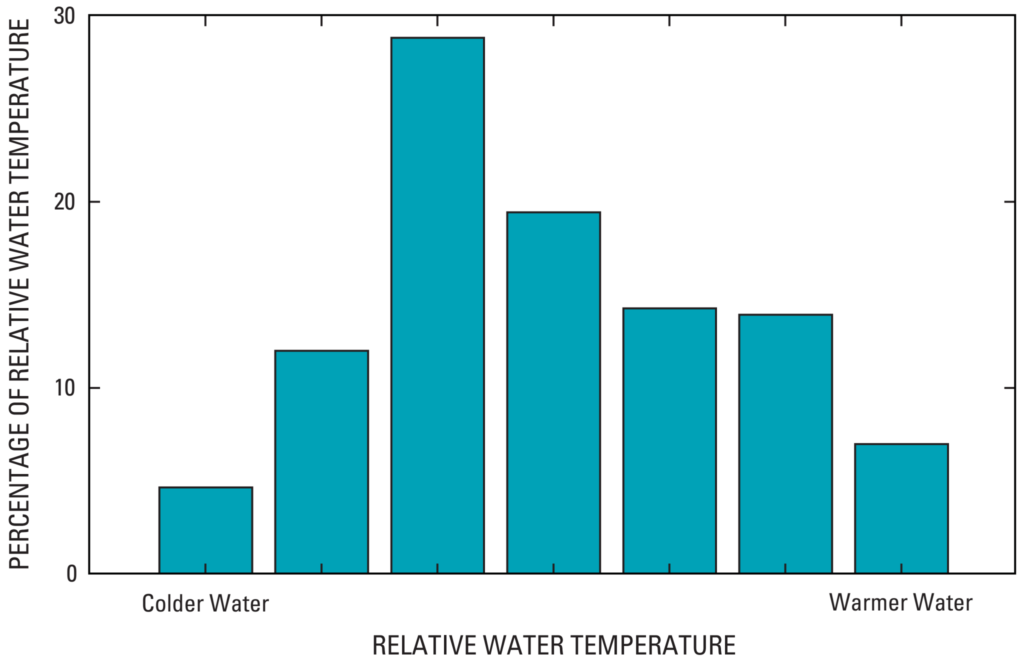


Figure 19. A proportional distribution of relative water temperatures in the Upper Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

Entire Segment

The entire Upper Greenwater River segments 8 and 9 were characterized using the same multispectral imaging approach used for the measurement error study reach (fig. 1, river reach segment C, and table 4). As for the study reach, riffle habitat dominated the entire length of river segments 8 and 9 (fig. 20). Conifers dominated the riparian zone, but shrubs also were a substantial component (table 4). Shadows dominated the imagery and impacted the classification results for this imagery.

As shown by the relative thermal imagery and a proportional distribution of relative water temperatures, the entire Upper Greenwater segment showed a subtle shift from cold to warmer water (figs. 21 and 22).

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

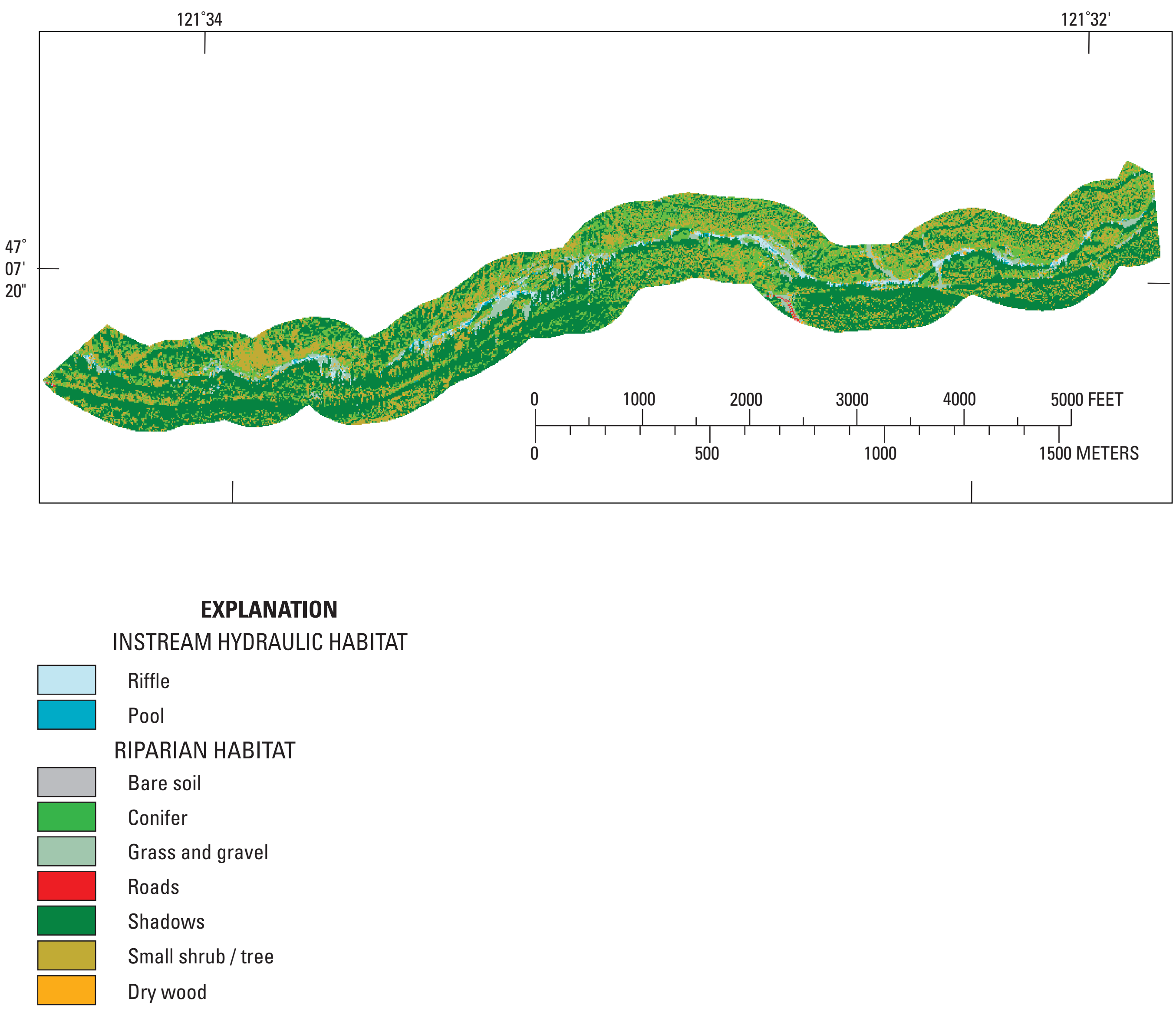


Figure 20. Characterization of hydraulic and riparian habitat conditions in the entire Upper Greenwater River segments 8 and 9 in the Upper White River Basin, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

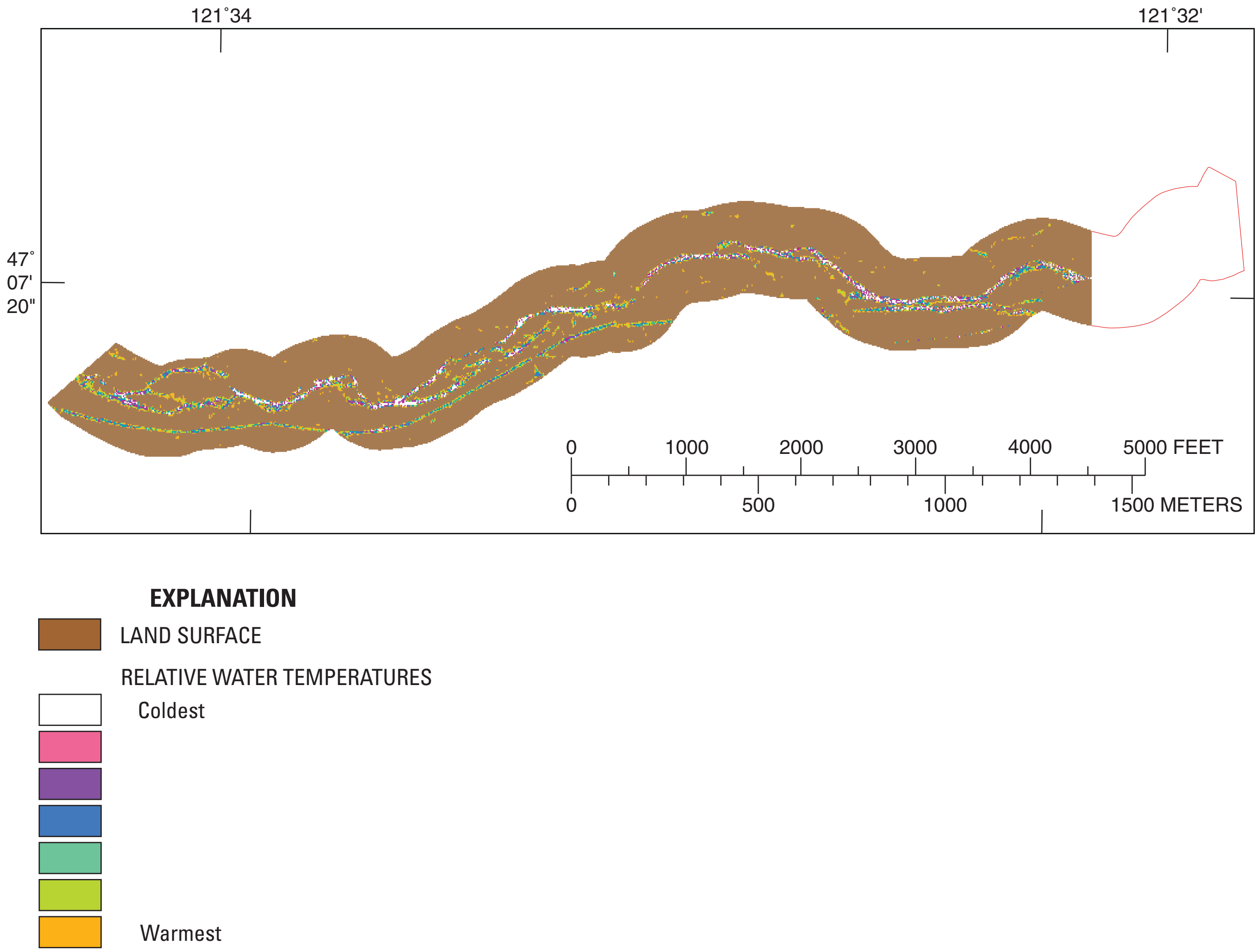


Figure 21. Characterization of thermal conditions in the entire Upper Greenwater River segments 8 and 9 in the Upper White River, Washington, September 1999.

A part of the thermal image for this segment could not be generated due to corrupted data.

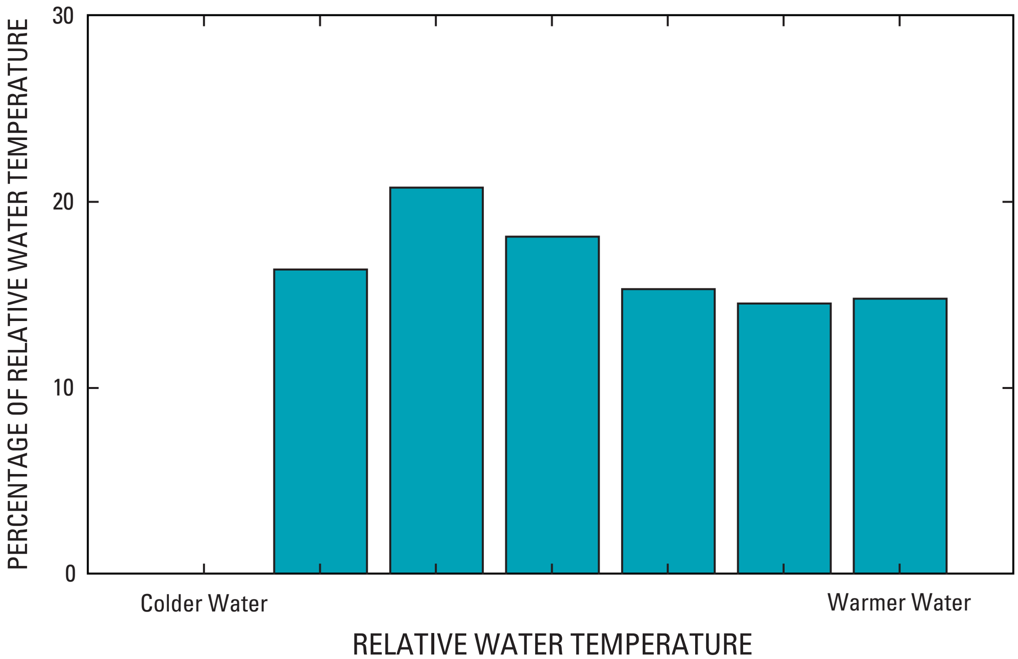


Figure 22. A proportional distribution of relative water temperatures in the entire Upper Greenwater River segments 8 and 9 in the Upper White River Basin, Washington, September 1999.

Clearwater River

Measurement Error Study Reach

The Clearwater River study reach was 900 meters long and started at the beginning of Ecology's river reach segment 2. Four Ecology river reach segments are contained within the Clearwater River reach identified in figure 1; river reach segment 2 is the second reach from the downstream end of this reach. Discharge in the Clearwater River study reach at the time of field sampling was estimated to be 0.4 cubic meter per second (table 13, at back of report).

Field data and multispectral imagery indicate that the 900-meter long study reach is dominated by riffle and turbulent habitat (figs. 23*A* and 23*B*; table 5). Although the proportions of habitat conditions identified by the field and imaging methods showed the same rank-order patterns, the total instream area of pools and riffles and turbulent and non-turbulent habitat types identified by the multispectral imaging approach were substantially less than habitat conditions measured in the field. For the study reach, the multispectral imaging approach characterized less than one-half of the instream habitat area (table 5). Most of this difference is due to canopy cover and shadows (figs. 23*A* and 23*B*). Total instream habitat measured in the field was 14,784.0 square meters and 11,325.8 square meters using the combination of multispectral and thermal imagery.

For this study reach, the addition of the thermal data did not improve the imagery-based estimate of total instream habitat as well as for some of the other study reaches. This is likely because the remaining instream habitat not observed in either the multispectral or thermal imagery was obscured by canopy cover.

Field measurements of total reach length were within 73 meters of total reach length estimated using GPS point measures with the multispectral imagery (table 5). The increase in linear measurement error as compared with other study reaches could have resulted from the extensive canopy cover and shadows in this reach. The shadows could have affected the proper identification of the channel center line from the aerial imageries.

Total area of woody debris measured in the field was 349.4 square meters, however, only 163.9 square meters of wood was characterized by multispectral imagery (table 5; table 13).

Areas of warmer water temperatures throughout the reach were characterized by thermal imaging (fig. 24). These areas of warmer water correspond with areas that lack canopy cover and have shallow water. Warmer water accounted for the highest proportion of surface waters imaged in the Clearwater study reach (fig. 25).

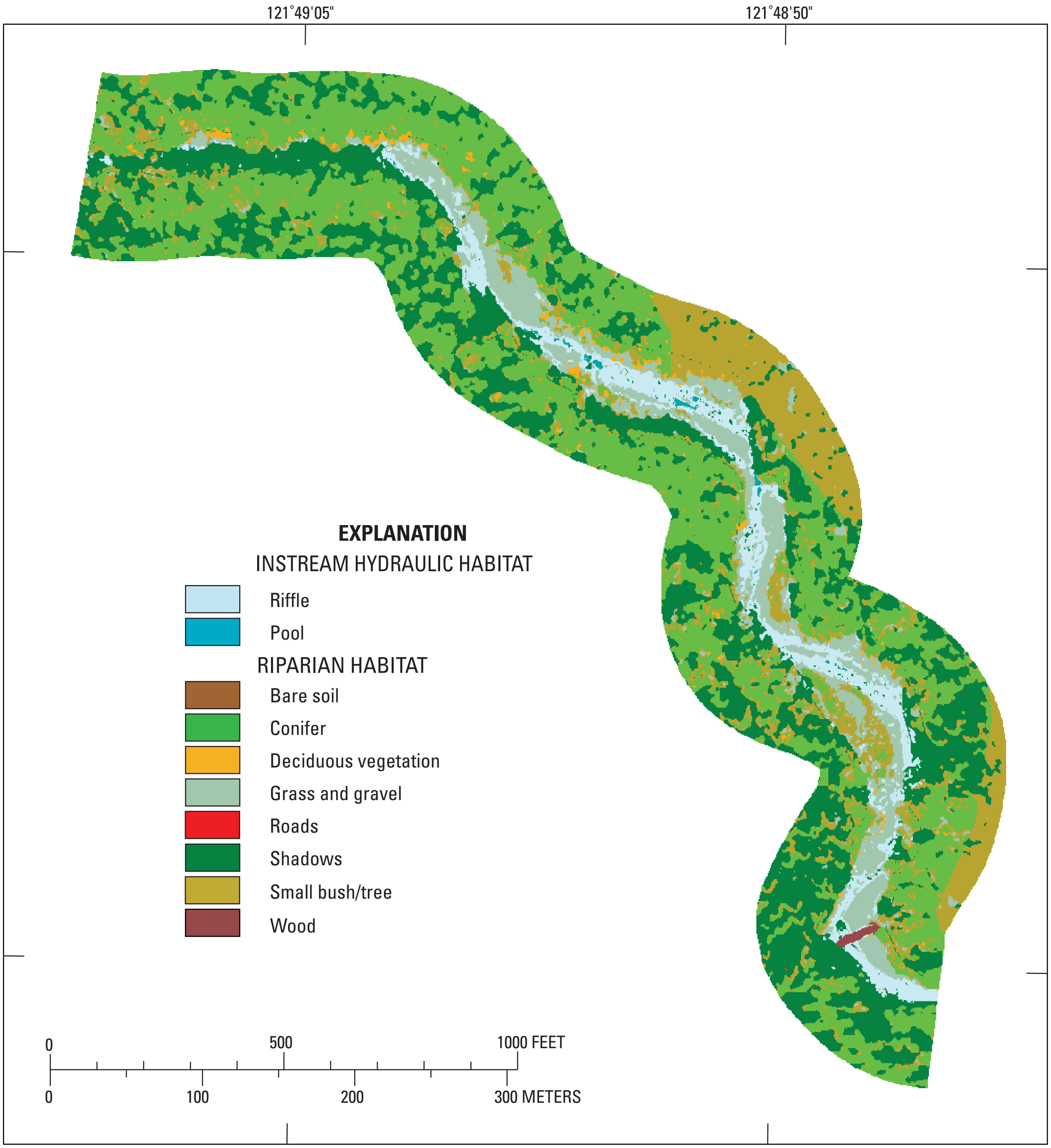
Table 5. Instream hydraulic and riparian habitat conditions in the Clearwater River measurement error study reach and river segments 1 through 4 in the Upper White River Basin, Washington, September 1999

[**Field data**: Field dates were spread out over a number of days. **Instream habitat**: The total area of instream habitat is the sum of either riffles and pools or turbulent and non-turbulent conditions. **Total instream area**: Total instream area is based on multispectral habitat data and aerial based temperature data. Total instream area based on field data can be compared to either total instream area from the multi-spectral data or to the corrected total instream area based on instream habitat and water temperature. For further clarification of this calculation, see the "Methods" section. **Abbreviations**: ft, feet; m^2, square meter; m, meter. —, no data]

	Ecology Segment 2 Riparian buffer size = 61 m (200 ft)		Ecology Segments 1 - 4 Riparian buffer size = 61 m (200 ft)	
	Latitude	Longitude	Latitude	Longitude
Beginning of reach	47°08'22"	121°49'16"	47°08'47"	121°50'06"
End of reach	47°08'05"	121°48'49"	47°06'23"	121°46'55"

Habitat conditions	Measurement Error Study Reach				River segments 1 - 4	
	Field data		Multispectral data		Multispectral data	
	Sept,. 1999 (early)		Sept. 21, 1999		Sept. 21, 1999	
	Square meters	Percent	Square meters	Percent	Square meters	Percent
Instream						
Riffle	11,522.4	77.9	6,892.4	78.0	65,943.8	98.9
Pool	3,261.6	22.1	195.1	22.0	719.8	1.1
Turbulent	11,062.9	74.8	4,395.7	62.0	33,561.8	50.3
Non-Turbulent	3,721.2	25.2	2,691.9	38.0	33,101.8	49.7
Riparian						
Bare soil	—	—	4.1	0.0	948.7	0.1
Boulder	—	—	0.0	0.0	0.0	0.0
Conifer	—	—	45,222.2	40.6	341,812.5	40.4
Deciduous vegetation	—	—	970.6	0.9	8,322.4	1.0
Grass and gravel	—	—	11,467.6	10.3	64,943.8	11.2
Roads	—	—	280.6	0.3	3,839.7	0.5
Shadows	—	—	35,480.4	31.8	321,619.4	38.1
Shrub	—	—	17,849.4	16.0	73,208.5	8.7
Wood	394.4	—	163.9	0.1	406.2	0.0
Total instream area (m^2)	14,784.0	—	7,087.5	—	66,663.6	—
Total instream area based on instream habitat and water temperature (m^2)		—	11,325.8	—	—	—
Total reach length (m)	900	—	973	—	7,505.7	—

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

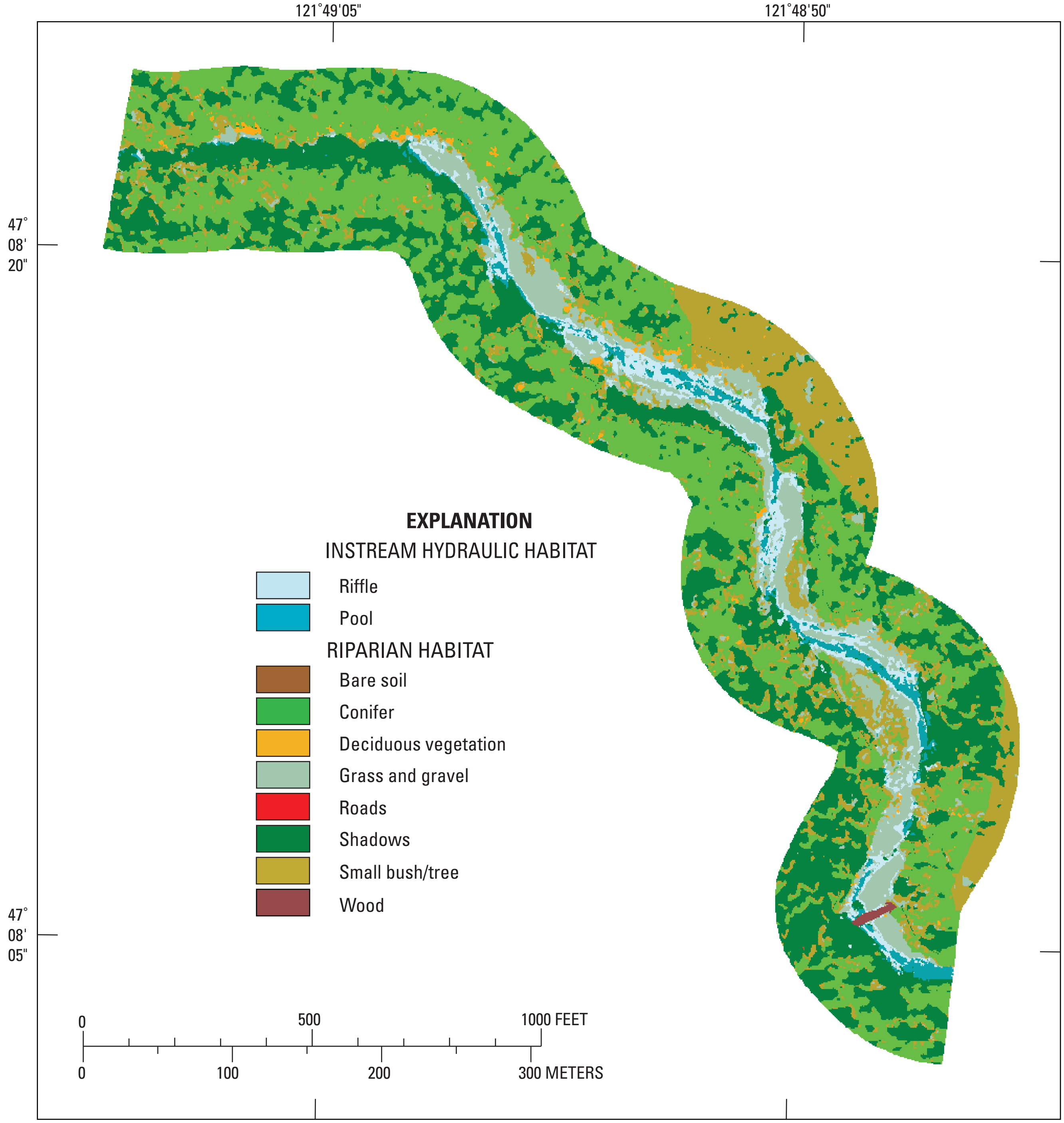


A. Instream habitat conditions characterized as either riffle or pool.

Figure 23. Characterization of hydraulic and riparian habitat conditions in the Clearwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

Field data were collected by Weyerhaeuser Company.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



B. Instream habitat conditions characterized as either turbulent or non-turbulent.

Figure 23.—*Continued.*

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

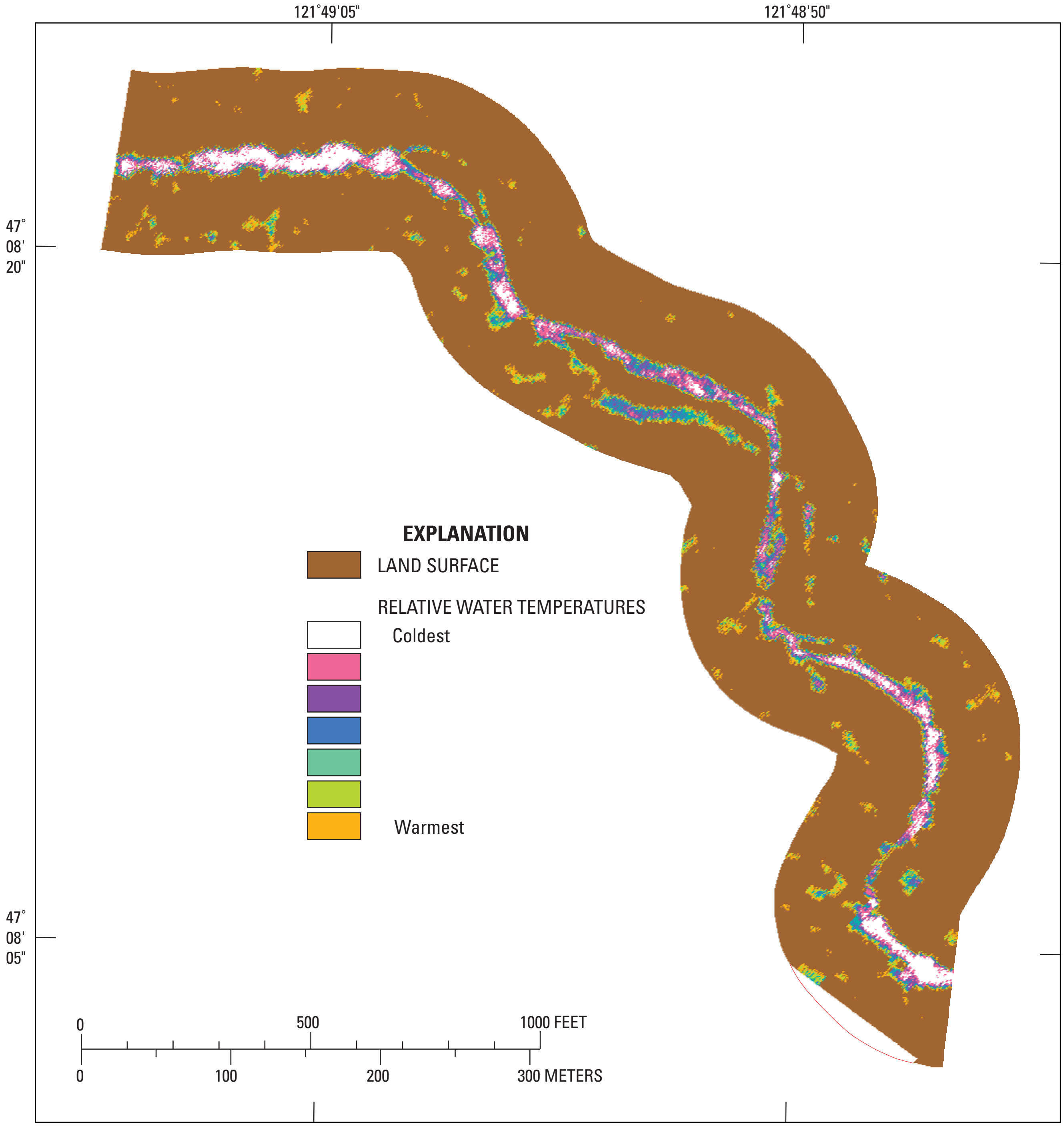


Figure 24. Characterization of thermal conditions in the Clearwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

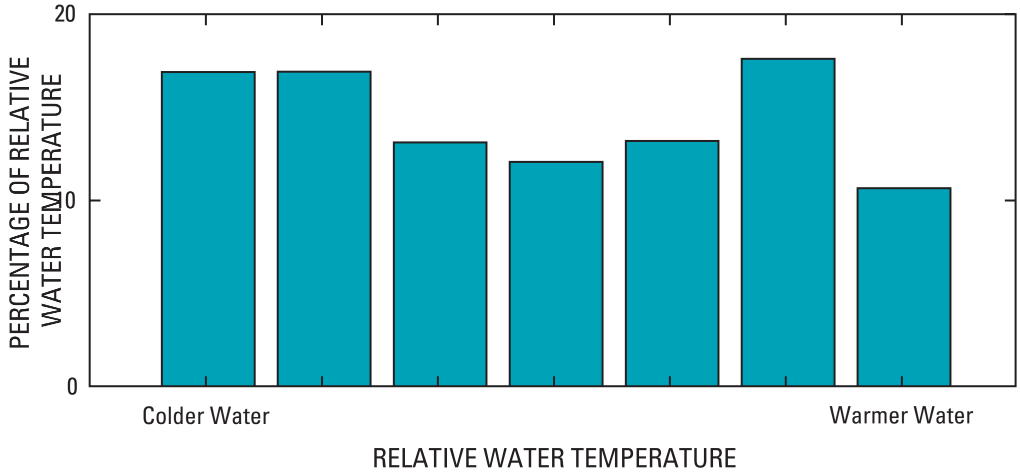


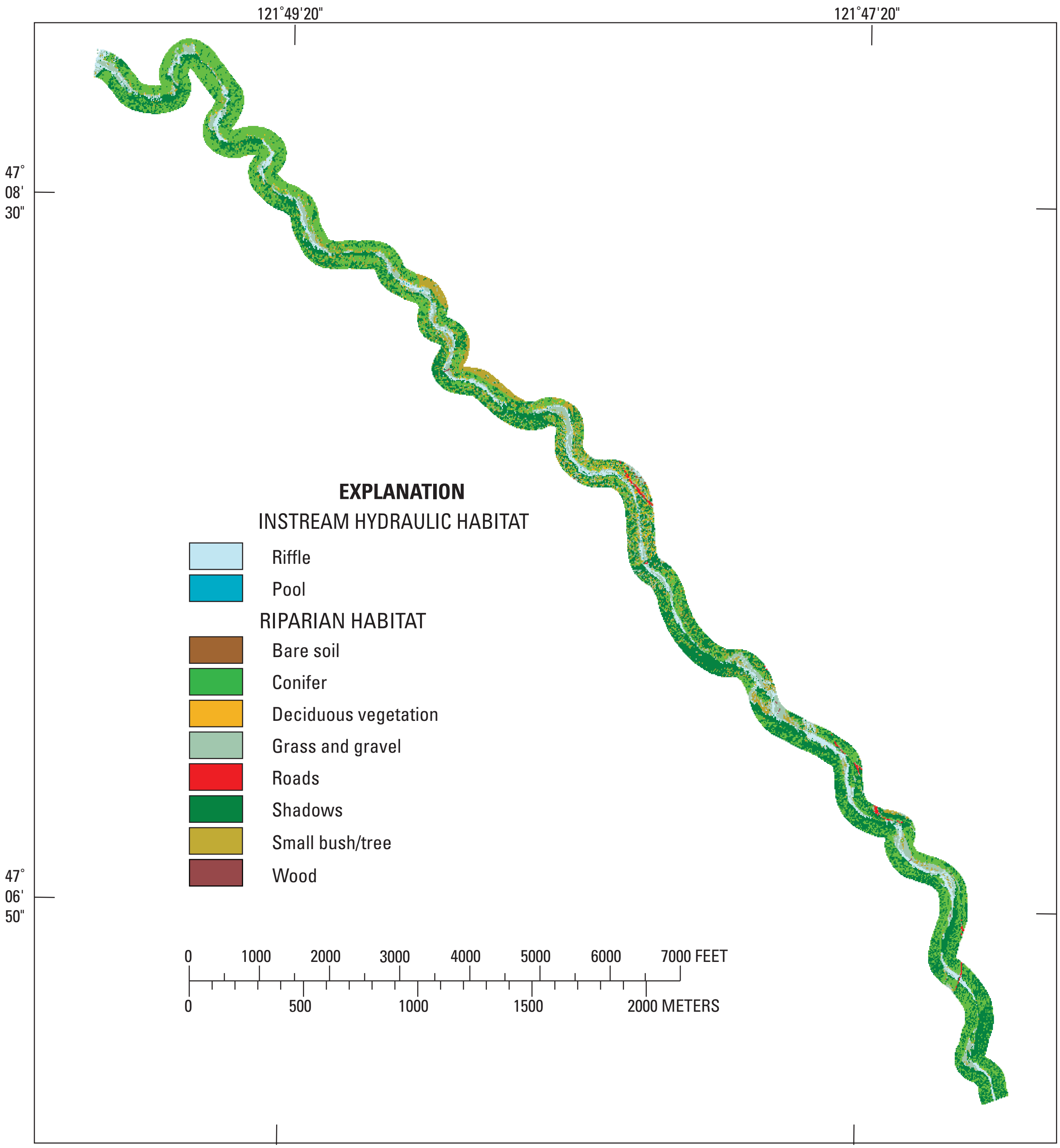
Figure 25. A proportional distribution of relative water temperatures in the Clearwater River measurement error study reach in the Upper White River Basin, Washington, September 1999.

Entire Segment

The entire Clearwater River segments 1-4 were characterized using the same multispectral imaging approach used for the measurement error study reach (fig. 1, river reach segment D, and table 5). As for the study reach, riffle habitat dominated the entire length of river segments 1-4 (fig. 26*A*). Turbulent and non-turbulent habitat conditions for the entire Clearwater River segment were about equal. Turbulent habitat was 50.3 percent of the instream area and non-turbulent was 49.7 percent (fig. 26*B*). This contrasts with what was observed within the Clearwater River measurement error study reach (table 5), where turbulent habitat was greater. These differences may be real or maybe the result of extensive shadows and canopy cover over the stream. For the total Clearwater River segment, 38.1 percent of the riparian zone was obscured by shadows. Conifer vegetation made up the largest component of the riparian zone (table 5).

As shown by the relative thermal imagery and a proportional distribution of relative water temperatures, areas of colder and warmer water are indicated in this reach of the Clearwater River (figs. 27 and 28). The proportional distribution indicates that water temperatures vary greatly in this stream reach. The locations of warmer water in this segment might indicate areas in which further temperature monitoring might be appropriate with additional work designed to identify the causes for any elevated water temperatures.

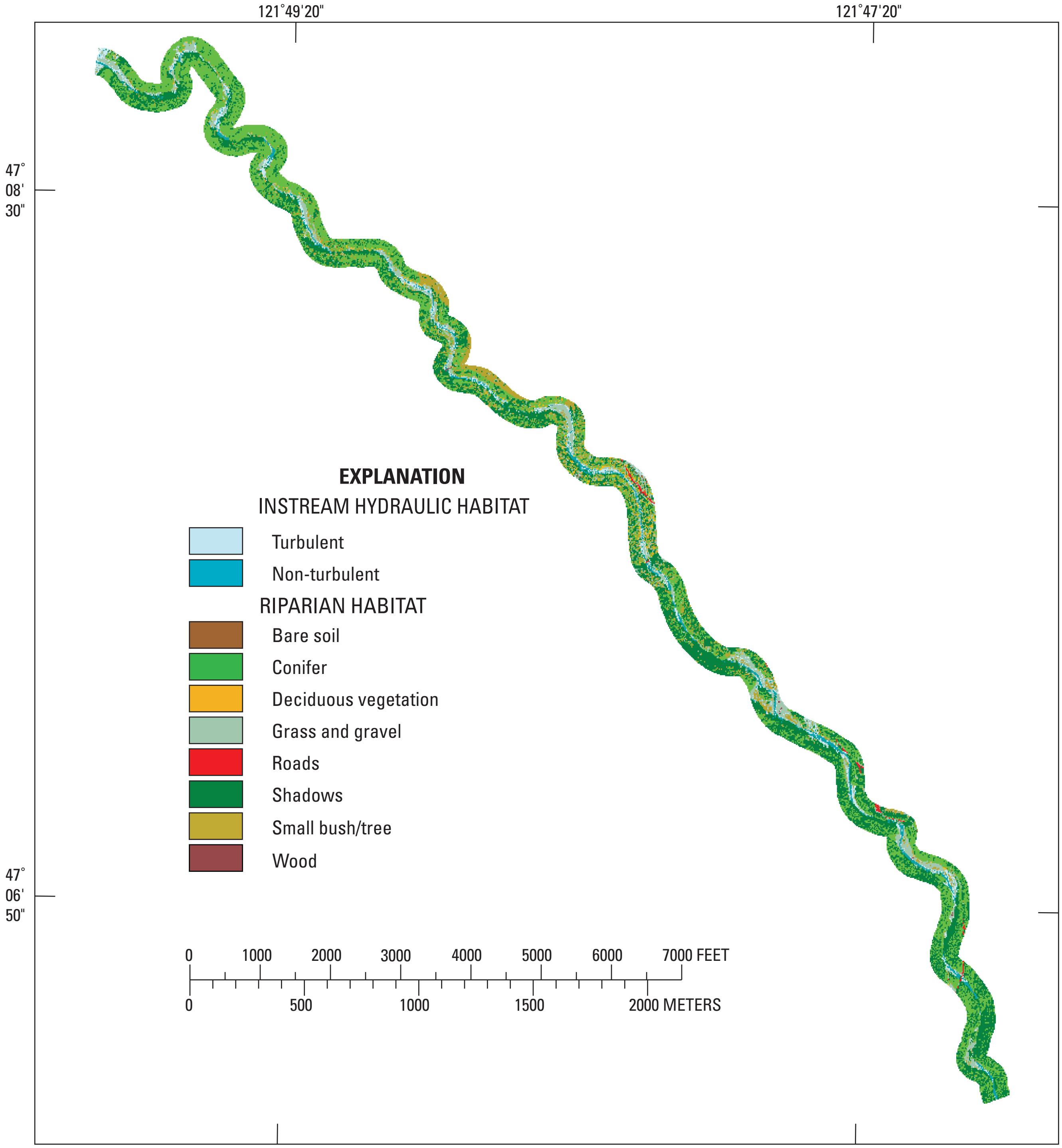
To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



A. Instream habitat conditions characterized as either riffle or pool.

Figure 26. Characterization of hydraulic and riparian habitat conditions in the entire Clearwater River reach segments 1 through 4 in the Upper White River Basin, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



B. Instream habitat conditions characterized as either turbulent or non-turbulent.

Figure 26.—*Continued.*

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

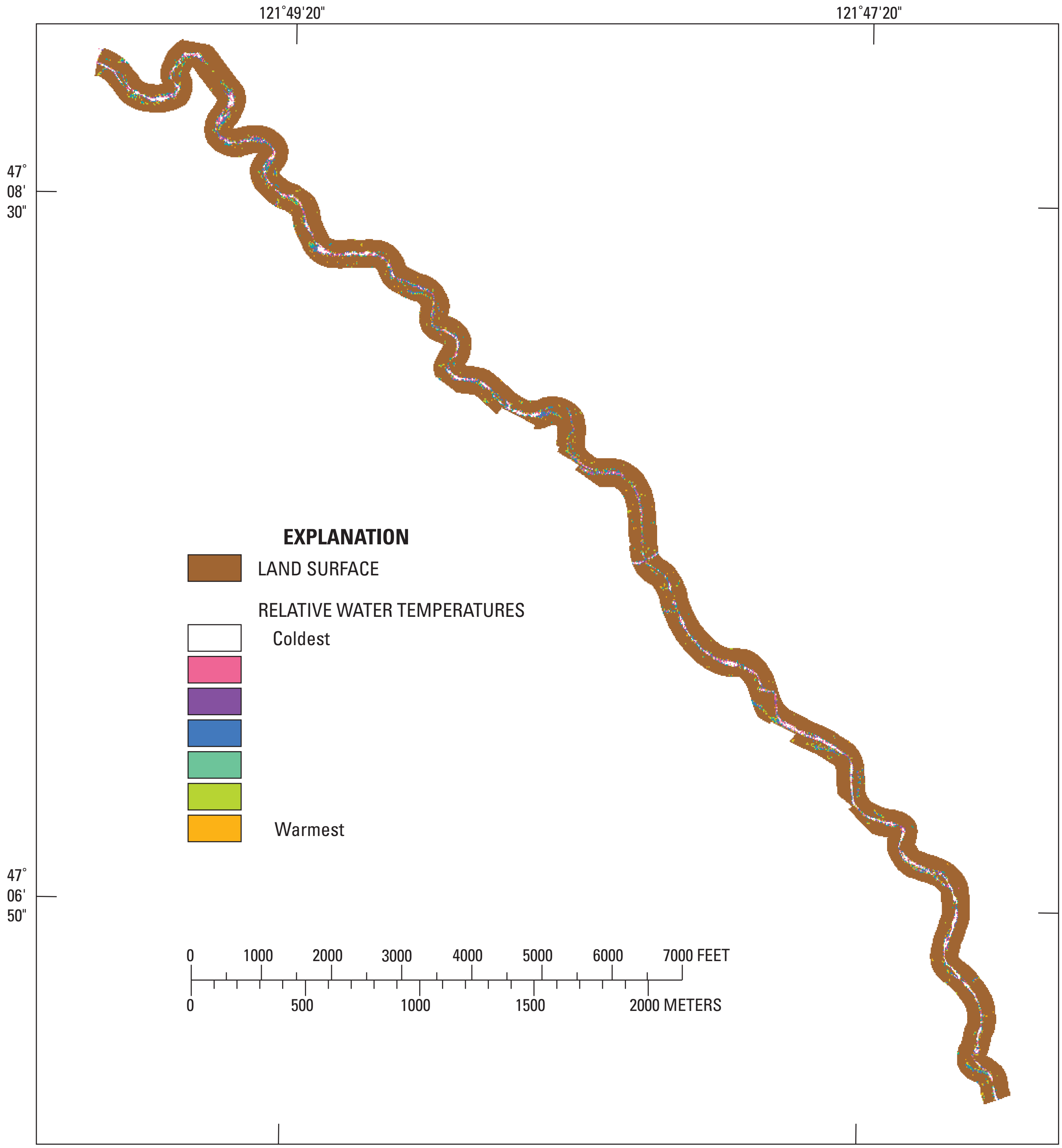


Figure 27. Characterization of thermal conditions in the entire Clearwater River reach segments 1 through 4 in the Upper White River Basin, Washington, September 1999.

Field data were collected by the Weyerhaeuser Company.

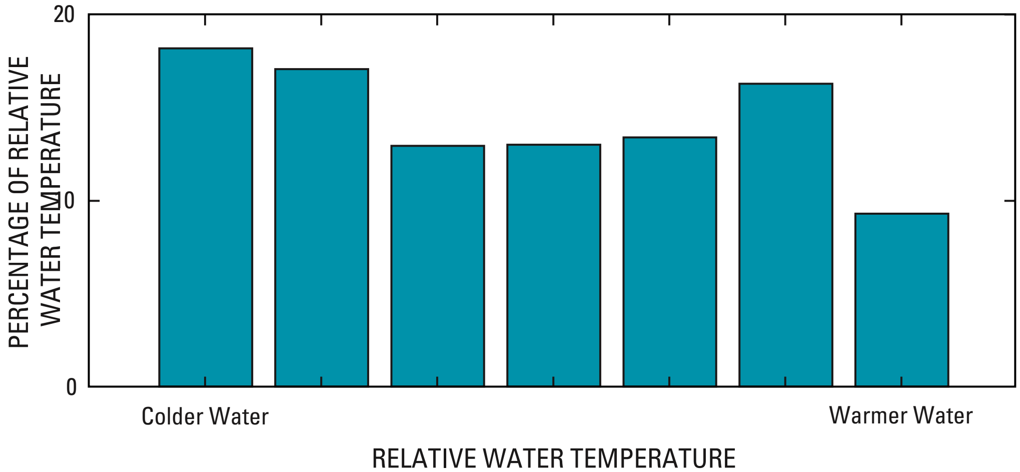


Figure 28. A proportional distribution of relative water temperatures in the entire Clearwater River reach segments 1 through 4 in the Upper White River Basin, Washington, September 1999.

White River

Measurement Error Study Reach

The White River measurement error study reach is 700 meters long and was located at the upstream end of the White River segment (fig. 1, river reach segment E). Unlike the other study reaches, the White River is a large non-wadeable river. Therefore, the field methods used to describe habitat conditions in the other study reaches were not appropriate. Modified methods were used to measure the area of turbulent and non-turbulent habitat conditions in the study reach, but not the area of pools and riffles. Discharge was not measured in the study reach due to the inability to wade the stream and associated safety issues.

The study reach is a stream system with a slight majority of non-turbulent habitat (fig. 29, table 6). The multispectral imagery for the same study reach also showed a system with a similar majority of non-turbulent habitat (table 6). As was observed for most of the other study reaches, the field survey measured a greater total area of instream habitat.

Total instream area characterized using the combination of multispectral and thermal imagery was 12,369.8 square meters (table 6). For this study reach, the addition of the thermal data did not much improve the estimate of total instream habitat compared to some of the other study reaches. The remaining instream habitat not observed by either the multispectral or thermal imagery was likely obscured by canopy cover. Field measurements of total reach length were within 10.4 meters of total reach length estimated using GPS point measures with the multispectral imagery (table 6).

The multispectral imaging approach did not identify any instream woody debris even though 223.5 square meters (table 6) of woody debris was observed and recorded during the field evaluation (table 14, at back of report).

The relative thermal imagery and a proportional distribution of relative water temperatures, shows a very few patches of warm water along the margins of the river (figs. 30 and 31). Unlike many of the smaller and shallower study reaches, the proportional distribution of water temperatures in the White River did not exhibit a warm water peak (fig. 31).

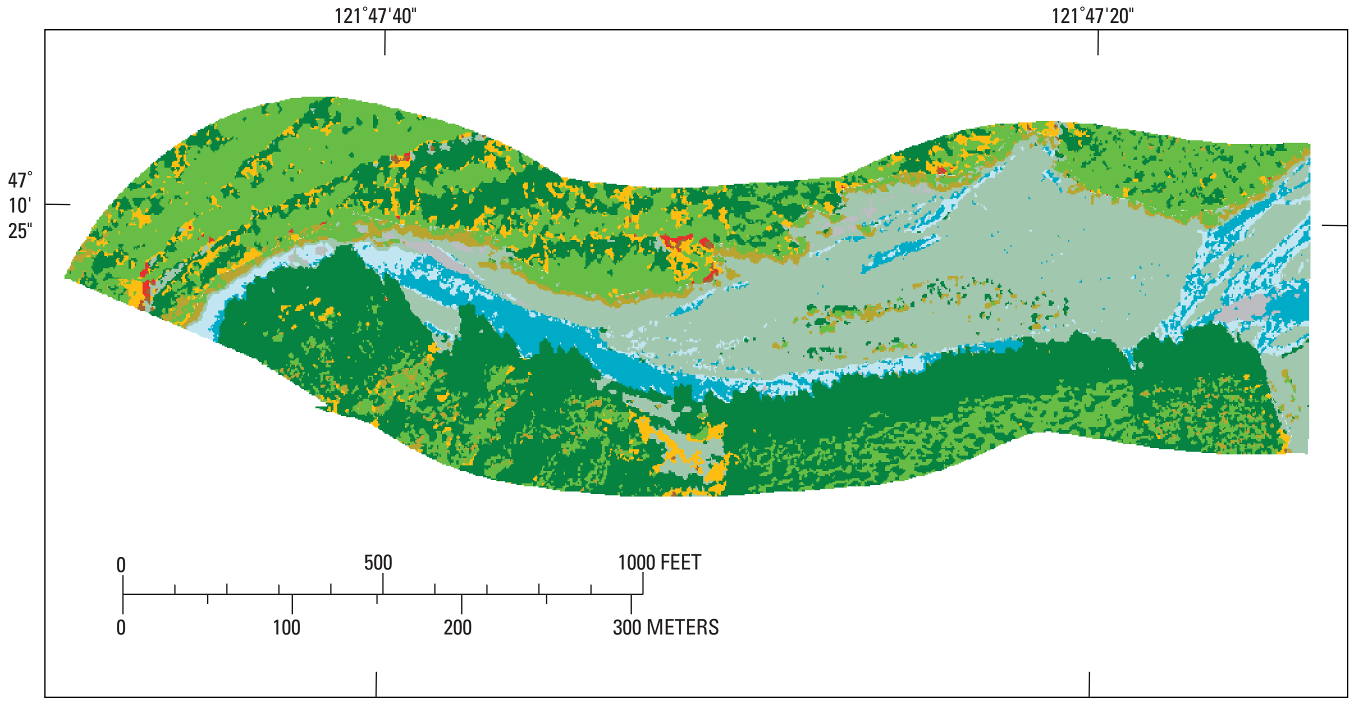
Table 6. Instream hydraulic and riparian habitat conditions in the White River measurement error study reach and the entire river segment in the Upper White River Basin, Washington, September 1999

[**Field data**: Field dates were spread out over a number of days. **Instream habitat**: The total area of instream habitat is the sum of either riffles and pools or turbulent and non-turbulent conditions. **Total instream area**: Total instream area is based on multispectral habitat data and aerial based temperature data. Total instream area based on field data can be compared to either total instream area from the multi-spectral data or to the corrected total instream area based on instream habitat and water temperature. For further clarification of this calculation, see the "Methods" section. **Abbreviations**: ft, feet; m^2, square meter; m, meter. —, no data]

	Riparian buffer size = 91.5 m (300 ft)		Riparian buffer size = 91.5 m (300 ft	
	Latitude	Longitude	Latitude	Longitude
Beginning of reach	47°10'22"	121°47'49"	47°08'47"	121°50'06"
End of reach	47°10'24"	121°47'18"	47°10'02"	121°45'40"

Habitat conditions	Measurement Error Study Reach				Entire river segment	
	Field data		Multispectral data		Multispectral data	
	Sept. 1999 (late)		Sept. 21, 1999		Sept. 21, 1999	
	Square meters	Percent	Square meters	Percent	Square meters	Percent
Instream						
Turbulent	9,058.0	45.4	4,901.7	43.8	63,661.4	30.4
Non-Turbulent	10,869.4	54.6	6,298.9	56.2	146,044.4	69.6
Riparian						
Bare soil	—	—	200.3	0.2	7,148.8	0.8
Boulder	—	—	1,022.3	0.9	12,903.1	1.4
Conifer	—	—	30,276.8	26.4	222,896.8	24.4
Deciduous vegetation	—	—	5,104.3	4.4	54,704.3	6.0
Grass and gravel	—	—	32,077.2	27.9	169,541.4	18.6
Roads	—	—	207.0	0.2	3,256.7	0.4
Shadows	—	—	41,985.2	36.6	400,898.4	44.0
Shrub	—	—	3,954.9	3.4	40,722.5	4.5
Wood	223.5	—	0.0	0.0	0.0	0.0
Total instream area (m^2)	19,927.4	—	11,200.8	—	209,705.8	—
Total instream area based on instream habitat and water temperature (m^2)	—	—	12,369.8	—	279,702.6	—
Total reach length (m)	700	—	689.6	—	8,490	—

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



EXPLANATION

INSTREAM HYDRAULIC HABITAT

- Riffle
- Pool

RIPARIAN HABITAT

- Bare soil
- Boulder
- Conifer
- Deciduous vegetation
- Grass and gravel
- Roads
- Shadows
- Shrub
- Wood

Figure 29. Characterization of hydraulic and riparian habitat conditions in the White River measurement error study reach in the Upper White River Basin, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

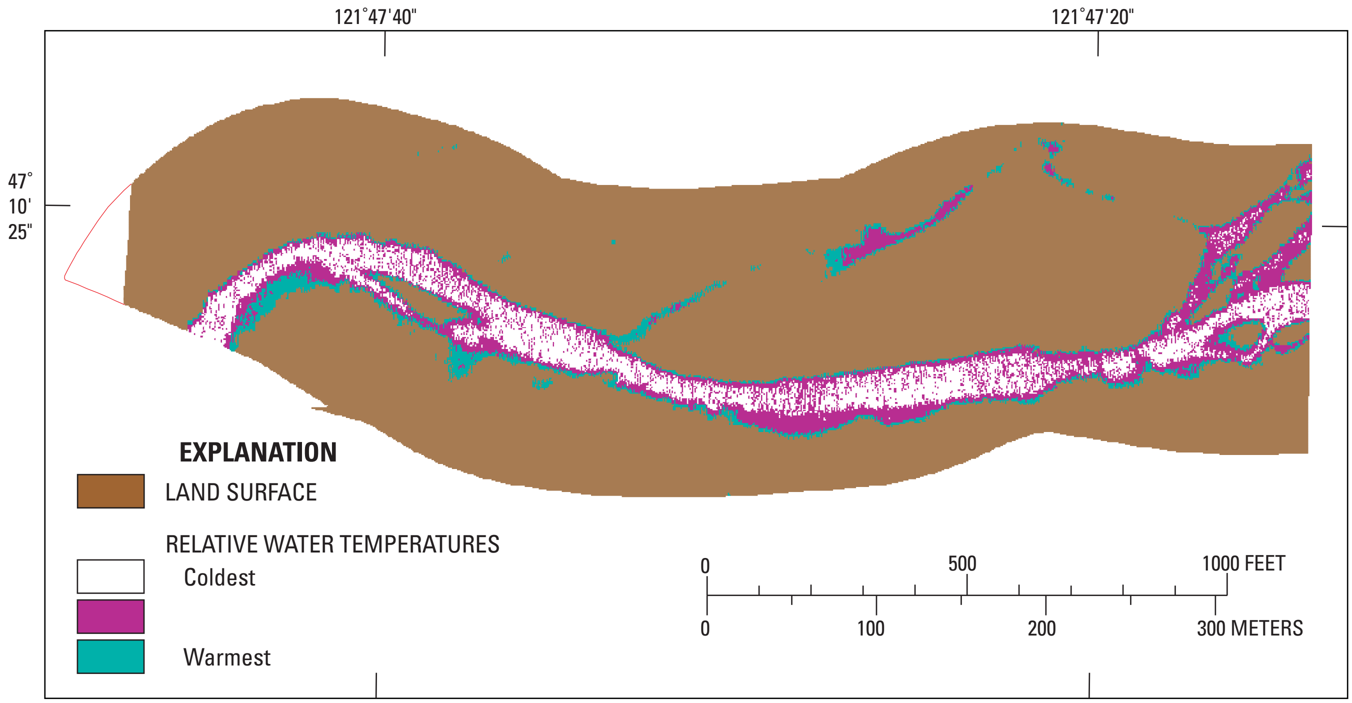


Figure 30. Characterization of thermal conditions in the White River measurement error study reach in the Upper White River Basin, Washington, September 1999.

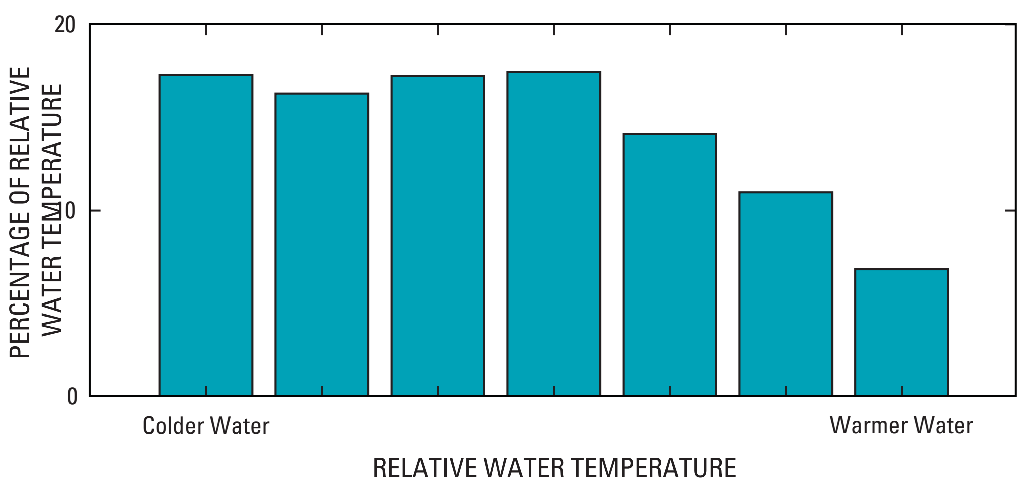


Figure 31. A proportional distribution of relative water temperatures in the White River measurement error study reach in the Upper White River Basin, Washington, September 1999.

Entire Segment

The entire White River segment was characterized using the same multispectral imaging approach used for the measurement error study reach (fig. 1, river reach segment E, and table 6). Turbulent habitat was 30.4 percent of the instream area and non-turbulent was 69.6 percent (fig. 32). For the total White River segment, shadows dominated the riparian zone followed by conifers, grasses, and gravel (table 6).

As shown by the relative thermal imagery and a proportional distribution of relative water temperatures, the distribution for the entire segment did not exhibit any warm water peak (figs. 33 and 34). However, the entire White River segment did exhibit a shift in relative water temperature from colder to intermediate temperatures. The reason for this shift is unknown.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

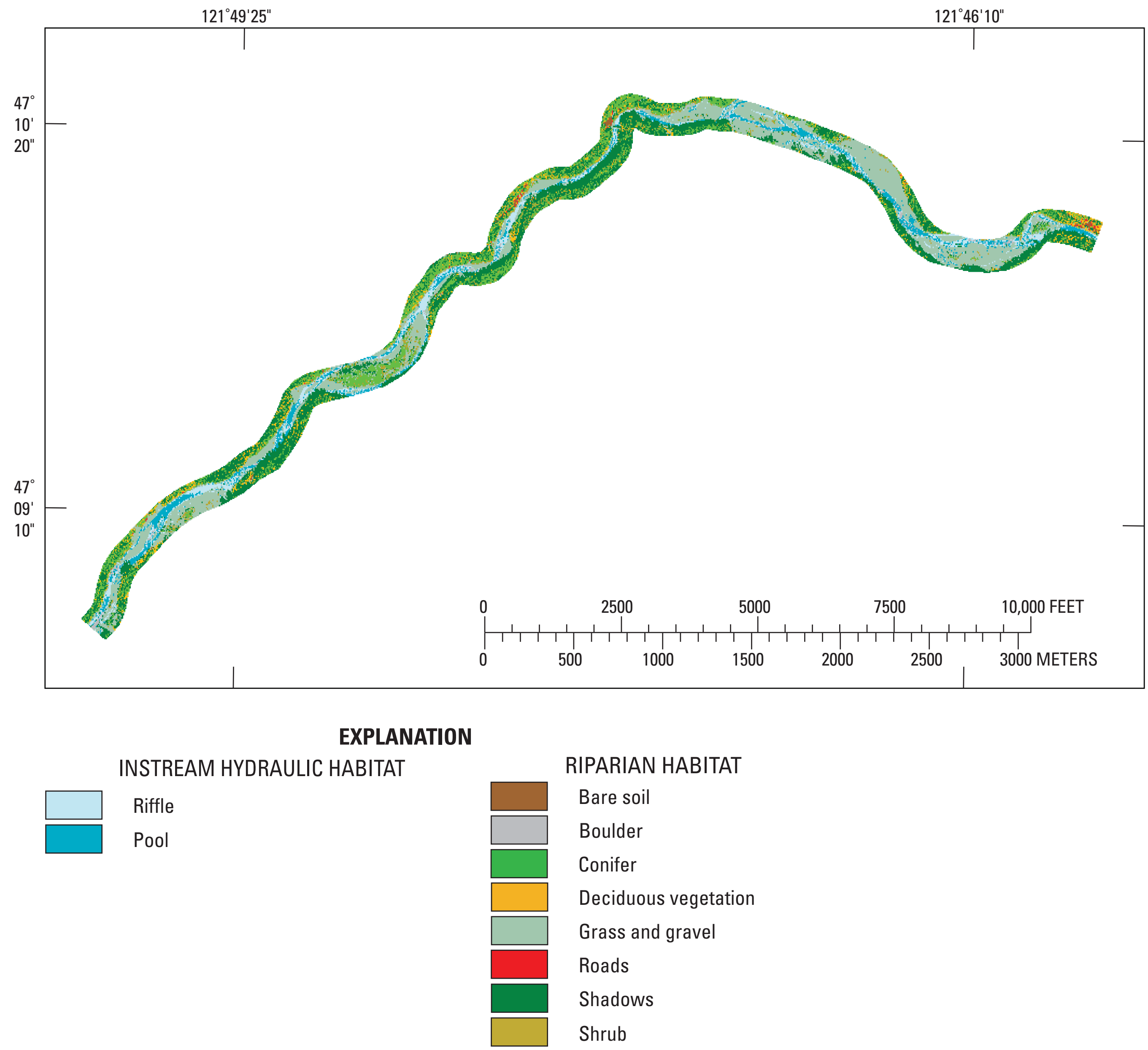


Figure 32. Characterization of hydraulic and riparian habitat conditions in the entire White River reach segment in the Upper White River Basin, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

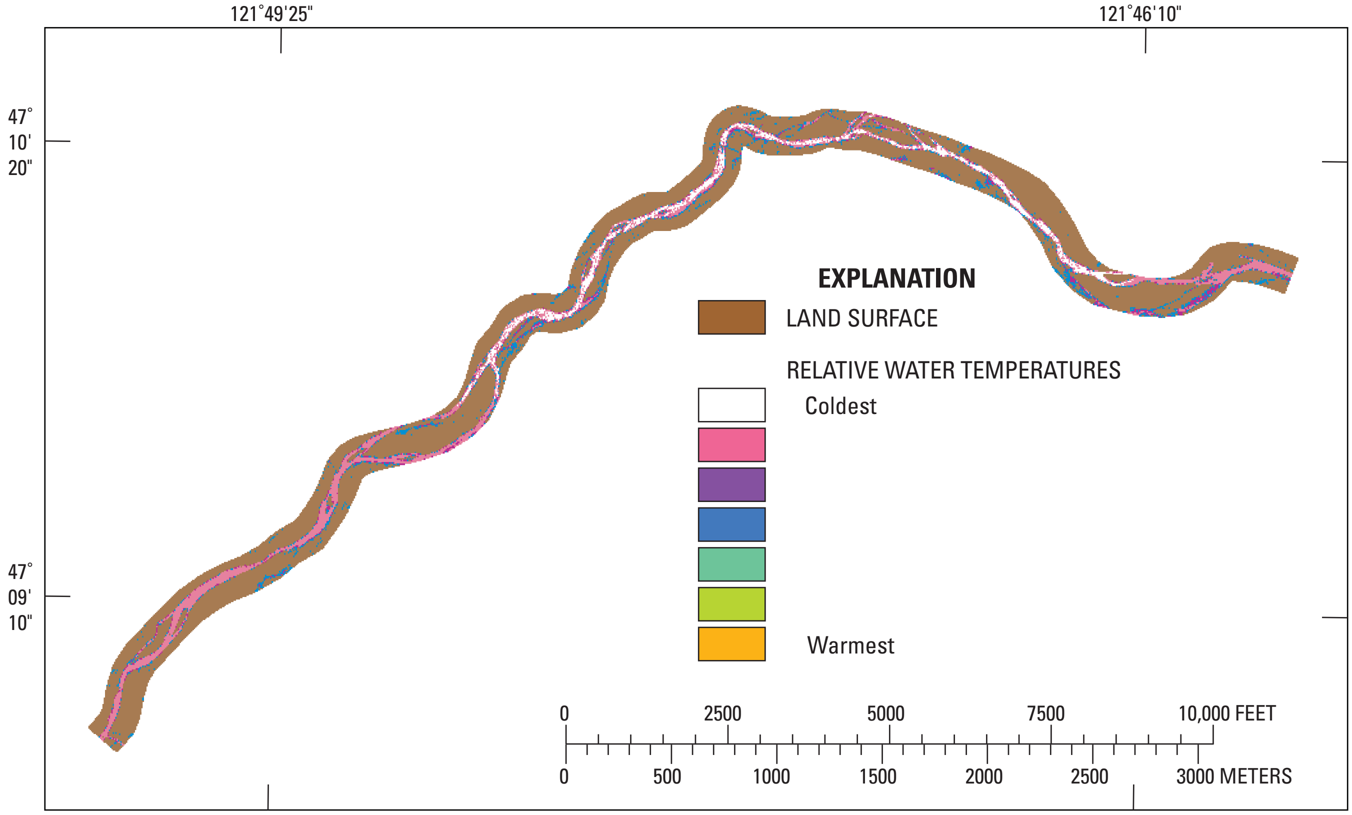


Figure 33. Characterization of thermal conditions in the entire White River segment in the Upper White River Basin, Washington, September 1999.

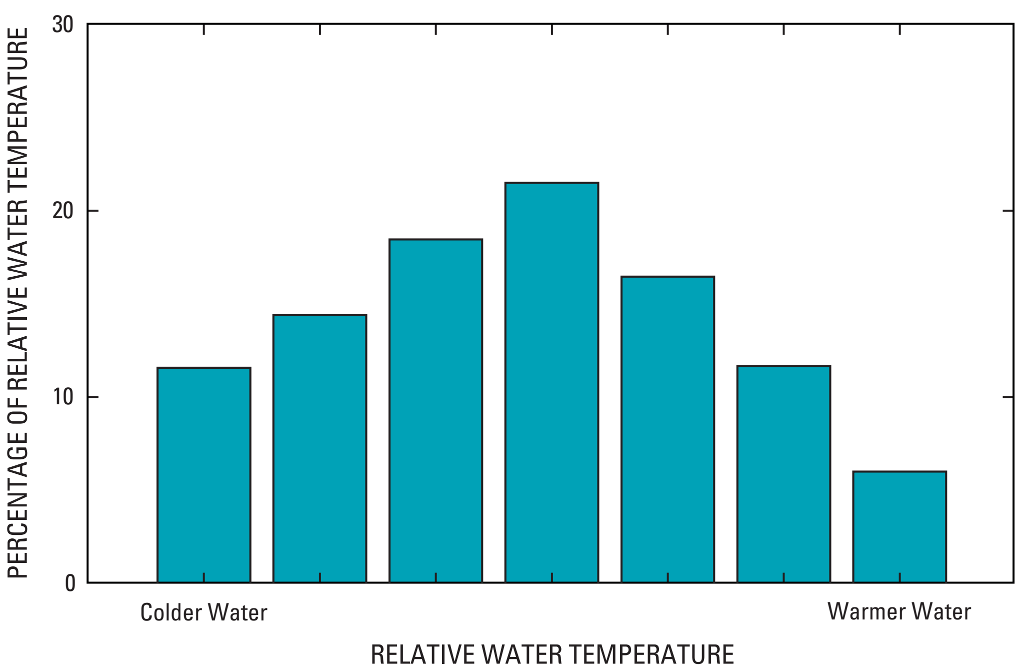


Figure 34. A proportional distribution of relative water temperatures in the entire White River segment in the Upper White River Basin, Washington, September 1999.

West Fork White River

Entire Segment

Unlike the other stream segments in this study, a study reach was not established in the West Fork of the White River due to cost constraints. Multispectral information collected from the other study reaches was used to train the computerized supervised classification approach described in the "Methods" section in order to classify the multispectral imagery generated for the West Fork of the White River. This approach was assumed to be appropriate given how similar the study reaches were throughout the basin. The results from the classification of multispectral imagery are shown in table 7. According to the supervised computer classification, the West Fork is entirely characterized as riffle habitat (fig. 35*A*, table 7). This is highly unlikely and the results of the turbulent and non-turbulent classification presented in table 7 and figure 35*B* may be a better representation of habitat condition in this segment. Some of the pool habitat types in this segment may be small and spatially isolated from one another, thus the computer program was unable to identify these spatially distinct habitats and merged them into riffle habitat types. Further refinement of the supervised classification approach through the use of field data for this segment might alleviate this shortcoming. In addition, the extensive shadows in this imagery also could have affected the accurate identification of pools.

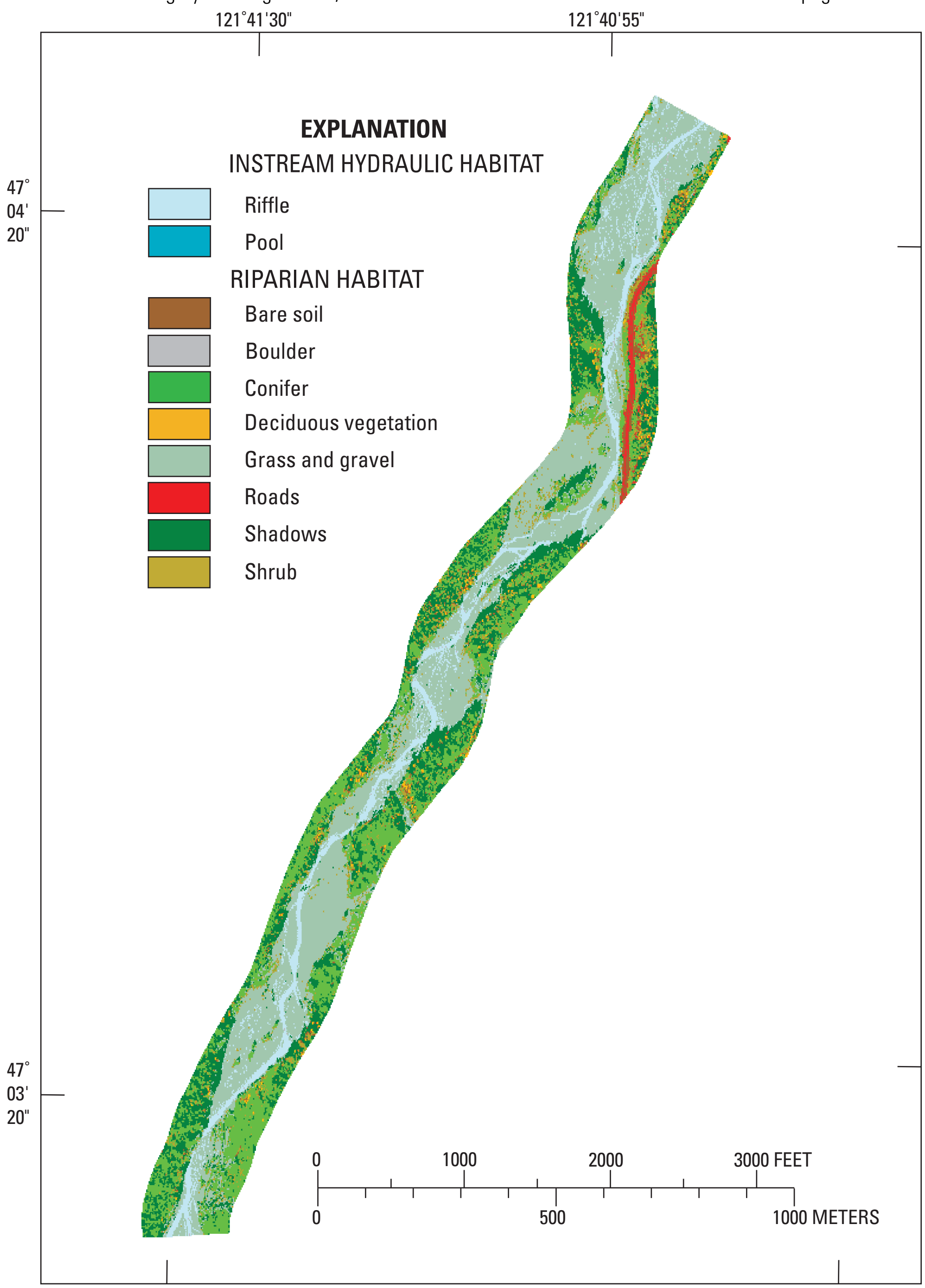
As shown by the relative thermal imagery and a proportional distribution of relative water temperatures, this segment exhibited two distinct temperature peaks at colder and intermediate relative temperatures (figs. 36 and 37). A distinct temperature increase appeared near mid-segment, but without field temperature data, this water temperature increase may not reflect actual water temperature conditions; however, it does suggest an area for further investigation.

Table 7. Instream hydraulic and riparian habitat conditions in the entire segment of the West Fork of the White River in the Upper White River Basin, Washington, September 1999

[**Instream habitat**: The total area of instream habitat is the sum of either riffles and pools or turbulent and non-turbulent conditions. **Abbreviations**: ft, feet; m^2, square meter; m, meter. —, no data]

	Ecology Segment Cripple Creek	
	Riparian buffer size = 91.5 m (300 ft)	
	Latitude	Longitude
Beginning of reach	47°03'49"	121°41'15"
End of reach	47°03'09"	121°41'40"
	Entire river segment	
Habitat conditions	**Multispectral data**	
	Sept. 21, 1999	
	Square meters	**Percent**
Instream		
Riffle	182,519.6	100.0
Pool	0.0	0.0
Turbulent	160,013.9	87.6
Non-turbulent	22,605.6	12.4
Riparian		
Bare soil	9,588.1	3.2
Boulder	708.4	0.2
Conifer	109,217.2	36.3
Deciduous vegetation	1,919.5	0.6
Grass and gravel	52,350.5	17.4
Roads	4,564.3	1.5
Shadows	95,525.0	31.8
Shrub	26,869.7	8.9
Wood	0.0	0.0
Total instream area (m^2)	182,619.6	—
Total reach length (m)	2,647.5	—

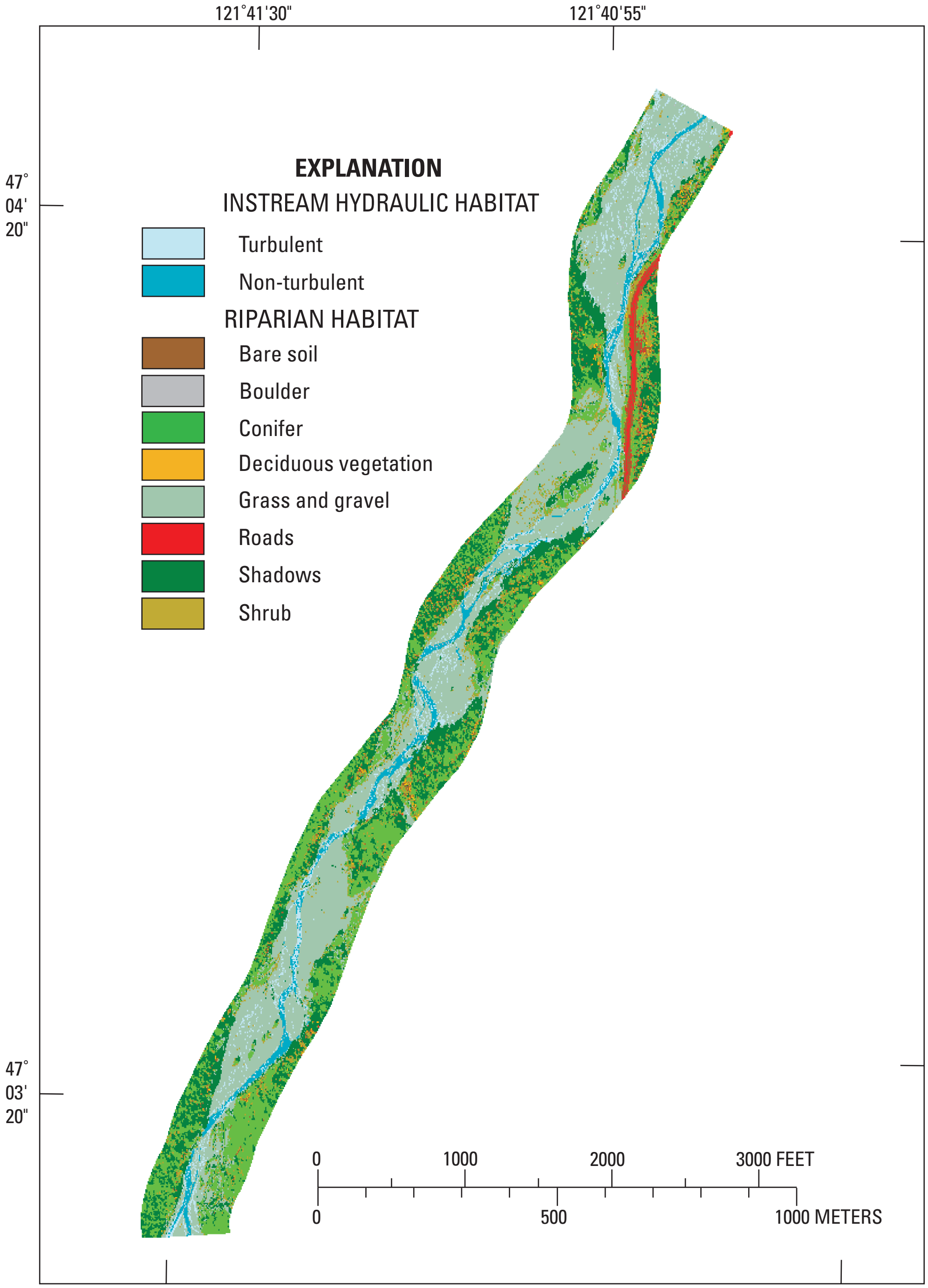
To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



A. Instream habitat conditions characterized as either riffle or pool.

Figure 35. Characterization of hydraulic and riparian habitat conditions in the West Fork of the White River segment in the Upper White River Basin, Washington, September 1999.

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.



B. Instream habitat conditions characterized as either turbulent or non-turbulent.

Figure 35.—*Continued.*

To view this imagery at a larger scale, select the zoom tool on the Acrobat tool bar and click on page.

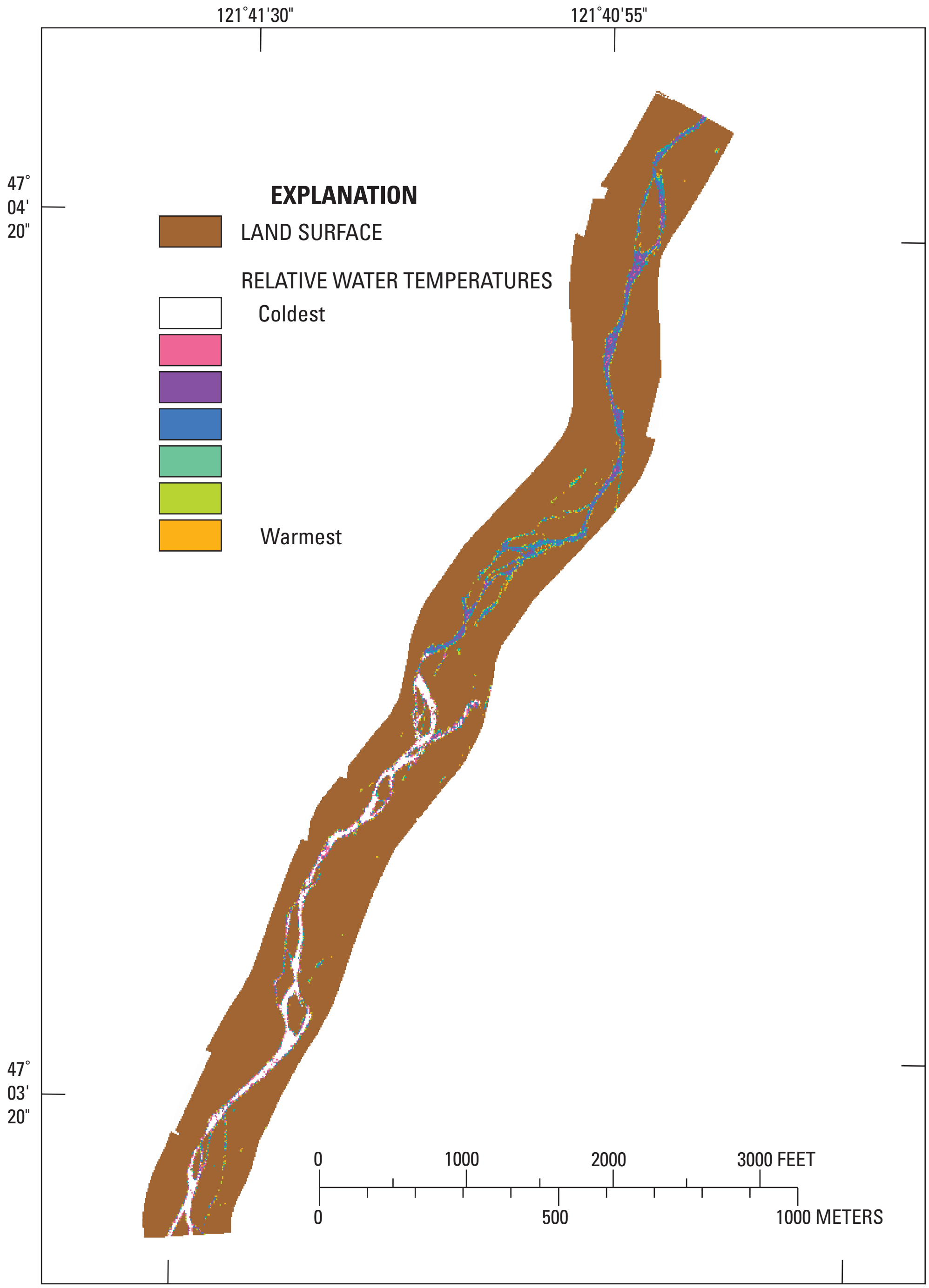


Figure 36. Characterization of thermal conditions in the entire West Fork of the White River segment in the Upper White River Basin, Washington, September 1999.

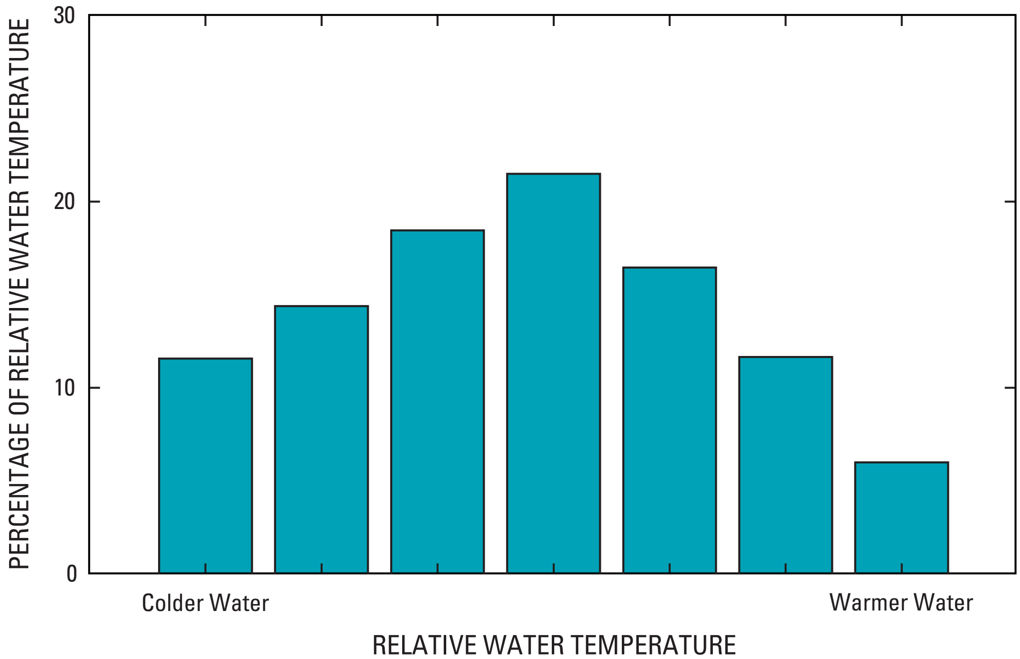


Figure 37. A proportional distribution of relative water temperatures in the entire West Fork of the White River segment in the Upper White River Basin, Washington, September 1999.

Measurement Error Comparisons

For the most part, all multi-spectral imagery-based estimates of total instream riffle and pool area were less than field measurements. The imagery-based estimates for riffle habitat area ranged from 35.5 to 83.3 percent less than field measurements. Pool habitat estimates ranged from 139.3 percent greater than field measurements to 94.0 percent less than field measurements (table 8). Multispectral imagery-based estimates of turbulent habitat types ranged from 9.3 percent greater than field measurements to 81.6 percent less than field measurements. Multispectral imagery-based estimates for non-turbulent habitat types ranged from 27.7 to 74.1 percent less than field measurements (table 8). The absolute average percentage of difference between field and imagery-based habitat type areas was less for the turbulent and non-turbulent habitat type categories (table 8). The percentage of difference between the total instream areas measured in the field and the total instream area measured from the thermal imagery ranged from +14.2 to -37.9 percent. The percentage of difference between field measured study reach length and imagery-based length was small (table 8). The estimate of woody debris using the multispectral imagery was substantially different than field measurements; percentages of differences ranged from +373.1 to -100 percent (table 8).

The total area of riffles, pools, and turbulent and non-turbulent habitat conditions measured in the field were all significantly higher (p-value < 0.1) than those estimated from the multispectral imagery (table 9). Numerous shadows covering the stream channel in many of the measurement error study reaches prevented an accurate estimate of the total area of each of the habitat conditions. In contrast to the estimates of total area of habitat type, the percentage of composition of each habitat type was not significantly different between the field and imagery-based estimates (table 9). Without imagery unaffected by shadows, it is difficult to determine if this lack of significant difference is creditable or not. Estimates of reach and segment lengths recorded in the field and derived from the imagery were not significantly different (table 9). The area of total woody debris also was not significantly different between the field measurements and imagery-based estimates. However, the imagery-based estimate of woody debris for the Upper Greenwater measurement error study reach was an outlier and has a large influence on the paired t-test (table 9). If this pair of observations was removed from the statistical test, the difference between the area of woody debris measured in the field and estimated from the imagery was significantly different.

Table 8. Percentage of differences between field and multispectral data from measurement error study reaches and river segments in the Upper White River Basin, Washington, August through October 1999

[**Absolute average percentage of difference**: Negative percentage of differences indicate that multispectral measurements for each variable were less than those for field data and positive values indicate they were greater. **Abbreviations**: na, not applicable]

Measurement error study reaches	Total riffle area (square meters)	Total pool area (square miles)	Total turbulent area (square miles)	Total non-turbulent area (square miles)	Total instream area (square miles)	Study reach/ segment length (meters)	Total woody debris area (square meters)
Huckleberry Creek	-83.3	-52.1	-81.6	-74.1	-9.4	-1.9	-100.0
Huckleberry Creek (entire segment)	-74.0	139.3	na	na	na	48.0	-100.0
Lower Greenwater River	-35.5	-83.7	9.3	-64.6	14.2	4.6	-100.0
Upper Greenwater River	-71.2	-59.9	na	na	na	-26.0	373.1
Clearwater Creek	-40.2	-94.0	-60.3	-27.7	-23.4	8.1	-53.1
White River	na	na	-45.9	-42.0	-37.9	-1.5	-100.0
Absolute average percentage of difference	60.9	85.8	49.3	52.1	21.2	15.0	137.7

Table 9. Summary of field and multispectral data for habitat variables by study reach and statistical significance of measurement errors by habitat variable in the Upper White River Basin, Washington, August through October 1999

[**Percentages:** Paired *t*-test statistics in **bold** type are based on a two tailed test. All other test statistics are a one tailed test. **Abbreviations**: na, not applicable]

Measurement error study reach	Total riffle area (square meters)		Percentage of riffle area		Total pool area (square meters)		Percentage of pool area	
	Field data	Multi-spectral data	Field data	Multi-spectral data	Field data	Multi-spectral data	Field data	Multi-spectral data
Huckleberry Creek	3,420.1	570	89.8	75.5	387	185.4	10.2	24.5
Huckleberry Creek (total segment)	11,420.1	2,964.6	93.8	61.9	761.2	1,821.2	6.3	38.1
Lower Greenwater River	7,567.8	4,881.3	73.5	91.7	2,730.4	444	26.5	8.3
Upper Greenwater River	24,731.9	7,117.3	88.6	84.8	3,175.7	1,273.8	11.4	15.2
Clearwater Creek	11,522.4	6,892.4	77.9	78	3,261.6	195.1	22.1	22
White River	na	na	na	na	na	na	na	na
Paired *t*-test statistic	0.14		**0.77**		1.71		**0.76**	
p-value for paired *t*-test	0.05		**0.48**		0.08		**0.49**	

Measurement error study reach	Total turbulent area (square meters)		Percentage of turbulent area		Total non-turbulent area (square meters)		Percentage of non-turbulent area	
	Field data	Multi-spectral data	Field data	Multi-spectral data	Field data	Multi-spectral data	Field data	Multi-spectral data
Huckleberry Creek	3,092.1	570	81.2	75.5	714.9	185.4	18.8	24.5
Huckleberry Creek (total segment)	na	na	na	na	na	na	na	na
Lower Greenwater River	2,267.1	2,478.4	22	46.5	8,031.1	2,846.9	78	53.5
Upper Greenwater River	na	na	na	na	na	na	na	na
Clearwater Creek	11,062.9	4,395.7	74.8	62	3,721.2	2,691.9	25.2	38
White River	9,058	4,901.7	45.4	43.8	10,869.4	6,298.9	54.6	56.2
Paired *t*-test statistic	2.27		**0.13**		2.37		**0.13**	
p-value for paired *t*-test	0.05		**0.9**		0.05		**0.9**	

Measurement error study reach	Total instream area (square meters)		Study reach/segment length (meters)		Total woody debris area (square meters)	
	Field data	Multi-spectral data	Field data	Multi-spectral data	Field data	Multi-spectral data
Huckleberry Creek	3,807.1	3,449	300	294.4	378.4	0
Huckleberry Creek (total segment)	12,181.3	na	989	1,464	280.2	0
Lower Greenwater River	10,298.2	11,764.8	500	523	393.7	0
Upper Greenwater River	27,907.6	na	2,100	1,554.6	1,266.2	5,990.9
Clearwater Creek	14,784	11,325.8	900	973	349.4	163.9
White River	19,927.4	12,369.8	700	686.6	223.5	0
Paired *t*-test statistic	1.25		0.01		0.65, [1]709	
p-value for paired *t*-test	0.15		0.99		0.73, [1]0.00	

[1]Test results after the removal of the Upper Greenwater River data.

SUMMARY AND CONCLUSIONS

The benefits of using multispectral imaging to characterize instream hydraulic and riparian habitat conditions were evaluated during this study. The instruments collected large amounts of unbiased georeferenced data in a few hours. After a few days of processing, the data were used to quantitatively assess the abundance and location of hydraulic and vegetation features. During the field component of this project, field crews of three to four individuals covered about 300 meters of stream per day. A field crew would take about 80 days at a rate of 300 meters per day to characterize 24.6 kilometers. The aerial-based multispectral imaging system took under 3 hours to photograph the same distance resulting in complete georeferenced digital information. The processed multispectral imagery was digitally stored so it can be evaluated in the future as new imagery processing tools become available. Field data were limited to the information that was collected at that time. The digital multispectral imageries also can be used to evaluate future changes in habitat conditions in the Upper White River system in an unbiased manner by comparing the current imageries with imageries collected in the future using similar technologies. The advantage of this type of imaging acquisition technology is that the level of accuracy of the instruments used is known. The use of field crews to collect similar types of information over time could be influenced by the individual biases of the members of the collection crew. The multispectral imageries also could be incorporated into management databases such as the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) database.

Although there are theoretical benefits of multispectral imaging to characterize instream habitat, the results of this study suggest such an approach has a number of limitations. The extent of these limitations are difficult to fully address given the limited budget of this study. A limited budget prevented the implementation of a more traditional remote sensing accuracy assessment. Nevertheless, a number of conclusions can be drawn from this study.

- The time of year during which such aerial evaluations are performed significantly influences the outcome. In this study, the low sun angle during the month of September resulted in extensive shadows throughout all studied imageries. These shadows reduced visibility of the streams examined and limited the ability to accurately quantify instream habitat. As was shown in a number of the study reaches, shadows were more of interference than overhanging vegetative cover. When thermal imageries were combined with the classified multispectral imageries, total instream area was often similar to field measurements. By adding the area identified by the thermal imaging to that of the multispectral imageries, calculations of total instream area were within 21 percent of field measurements on average as compared to 59 percent on average when thermal imageries were not used. For those segments in which field measurements of instream area were substantially greater than the thermal and multispectral imagery-based instream area, these differences likely were the result of extensive overhanging vegetative cover. Additional studies will need to be performed to determine if such a hypothesis can be accepted.
- The multispectral imaging approach could not accurately identify instream woody debris even though the resolution of the imagery was 0.5 meter or less. Clearly, the extent of shadows and overhanging vegetation could have had an impact on the capability of using multispectral imaging to identify wood. However, the supervised classification approach used to classify the multispectral imageries could be refined to better identify large instream wood where it was visible from the air. This would require modifying the mathematical approaches used in the supervised classification approach. Given the

extensive shadowing and vegetative cover in most of the imageries, the number of opportunities to refine the supervised classification routine to identify instream wood was insufficient. However, further refinement of the classification routine will never permit the identification of woody debris obscured from the sensor by overhanging vegetation. Pieces of wood smaller than the resolution of each pixel also would be difficult to identify with this method.

- Great care needs to be taken when evaluating thermal imageries. Thermal imageries represent relative stream temperatures and may not be representative of conditions throughout the water column. In order to calibrate the thermal imageries, a number of georeferenced temperature probes at the surface and deeper in the water column would have to be installed during the thermal imaging flights. Furthermore, thermal imaging of a stream segment with extensive areas obscured by vegetative cover and other areas with open canopy might produce an imagery suggesting that the stream had elevated water temperatures throughout when in fact only the areas with an open canopy had high temperatures.
- The multispectral imageries were more accurate for identifying turbulent and non-turbulent habitat types than for pools and riffles. For example, total pool and riffle areas determined by the multispectral approach on average were within 86 and 61 percent of the areas determined in the field. Total turbulent and non-turbulent areas determined by the multispectral imaging approach were within 49 and 52 percent of corresponding field data. Although these results appear to indicate that this approach is more suitable for identifying habitat types based on surface turbulence, further refinement of the computer supervised classification routines might more accurately identify pools and riffles.

The most appropriate use of this technology and methodology is in those streams with limited overhead cover, such as in significantly degraded systems and, particularly, large rivers. Large rivers present a unique challenge to fisheries biologists, hydrologists, and geomorphologists. Many of the large rivers are too deep or swift to use traditional instream habitat sampling approaches. Given that the imageries acquired using this approach are georeferenced and multispectral in contrast to traditional aerial photographs, they might provide an excellent source of information for future evaluations of management options. The results of this study identified a number of limitations of this approach for classifying instream habitat and stream temperatures. Further refinement of the imaging-data resolution and computer classification routines may allow this approach to be viable for preliminary classification of instream and riparian habitats of western Washington streams.

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Table 10. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August through October 1999

[Field methods used to generate the field data are based on Pleus and Schuett-Hames (1998); Pleus and others (1999); and Schuett-Hames and others (1999). **Abbreviations**: cm, centimeter; m, meter; m^3, cubic meter; m^3/s, cubic meter per second; m^2, square meter; km, kilometer. <, actual value is less than value shown. >, actual value is greater than value shown. —, no data]

Stream	Date	Segment	Reference point range	Survey length (m)	Survey leader	Affiliation	Number of reference points	Discharge (m^3/s)
Study reach	10/01/99	1	4 to 7	300	Allen Pleus	Northwest Indian Fisheries Commission	4	1.25
Entire Creek segment 1	10/12/99	1	0 to 10	989	Stan Zyskowski	U.S. Forest Service	11	1.1

Stream	Bankfull width (m)			Bankfull depth (m)			Mean width to depth ratio	Canopy closure (percent)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum		Mean	Minimum	Maximum
Study reach	18.1	9.9	32.2	0.50	0.20	0.66	36.3	55.2	51.7	58.5
Entire Creek segment 1	14.4	2.1	22.8	0.4	0.2	0.5	33.5	50.1	19.0	100

HABITAT UNIT SUMMARY BY SEGMENT

Habitat condition	Total number	Percentage of total	Total surface area (m^2)	Percentage of surface area	Habit units/km	Habitat units/mean bankfull width	Pools or non-turbulent/km	Bankfull width/pool
Study reach								
Pool	6	27.3	387.0	10.2	73.3	1.2	20.0	3.0
Riffle	16	72.7	3,420.1	89.8				
Turbulent	7	31.8	3,092.1	81.2				
Non-turbulent	15	68.2	714.9	18.8				
Entire Creek segment 1								
Pool	15.0	32.6	761.2	6.2	46.5	46.5	15.2	1.0
Riffle	31.0	67.4	11,420.1	93.8				
Turbulent	–	–	–	–				
Non-turbulent	–	–	–	–				

HABITAT UNIT LOCATION

Primary number	Primary total length	Secondary number	Secondary total length	Side number	Side total length
Study reach					
9	305.6	9	75.6	4	59.1
Entire Creek segment 1					
25	983.1	11	155.3	9	305.6

Table 10. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August through October 1999—*Continued*

FACTORS CONTRIBUTING TO POOL FORMATION (PFF)

Description	Total number	Percentage of units	Number identified as primary PFF	Percentage of primary PFF	Areas associated with primary PFF	Percentage of pool area associated with primary PFF
Study reach						
Log	1	9.1	–	0	–	0
Other	2	18.2	2	33.3	173.0	51.6
Debris jam	4	36.4	4	66.7	162.1	48.4
Roots or stump	1	9.1	–	0	–	0
Rock or boulder	3	27.3	–	0	–	0
Entire creek segment 1						
Other	2	12.5	2	13.3	164.6	21.6
Rootwads	6	37.5	6	40.0	309.6	40.7
Roots or stump	2	12.5	2	13.3	146.7	19.3
Rock or boulder	5	31.3	4	26.7	116.8	15.3
Resistant Bank	1	6.3	1	6.7	23.5	3.1

RESIDUAL POOL DEPTH (RPD)

RPD category (m)	Number of pools	Percentage of total	Surface area (m^2)	Percentage of surface area	Mean residual pool depth (m)	Maximum residual pool depth (m)
Study reach					1.0	3.6
<=0.249	0	0	0	0		
0.250 to 0.4	1	14.3	37.4	8.8		
0.41 to 0.7	4	57.1	237.5	56.0		
0.71 to 0.9	1	14.3	97.5	23.0		
0.91 to 1.2	1	14.3	52.0	12.2		
Entire creek segment 1					1	1
<=0.249	0	0	0	0		
0.250 to 0.4	5	33.3	221.3	28.1		
0.41 to 0.7	8	53.3	387.2	50.9		
0.71 to 0.9	1	6.7	49.1	6.6		
0.91 to 1.2	1	6.7	103.5	13.6		

Table 10. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August through October 1999—*Continued*

TOTAL IN-CHANNEL PIECES OF LARGE WOODY DEBRIS (LWD) — Individual and Debris Jam Pieces								
Type of instream LWD	**Number of pieces LWD**	**Percentage of total pieces**	**LWD per channel width**	**LWD per km**	**Number of key LWD pieces**	**Percentage of key LWD pieces**	**Key LWD pieces per channel width**	**Key LWD pieces per km**
Study reach								
Rootwads	7	4.4	0.4	23.3	0	0.0	0.0	0.0
Logs 10-20 cm	51	31.9	2.8	170.0	0	0.0	0.0	0.0
Logs 20-50 cm	90	56.3	5.0	300.0	0	0.0	0.0	0.0
Logs >50 cm	12	7.5	0.7	40.0	2	16.7	0.1	6.7
Total	160	100.0	8.8	533.3	2	1.3	0.1	6.7
Entire creek segment 1								
Rootwads	25	21.2	1.7	25.3	0	0.0	0.0	0.0
Logs 10-20 cm	20	16.9	1.4	20.2	0	0.0	0.0	0.0
Logs 20-50 cm	55	46.6	3.8	55.6	0	0.0	0.0	0.0
Logs >50 cm	18	15.3	1.3	18.2	2	11.1	0.1	2.0
Total	118	100	8.2	119.3	2	1.7	0.1	2.0

Type of instream LWD	**Number of pieces LWD**	**Mean diameter (cm)**	**Mean length (m)**	**Total volume (m^3)**	**Mean volume (m^3)**	**Total in-channel LWD volume (m^3)**	**Mean in-channel LWD volume (m^3)**	**In-channel vol/channel width (m^3)**	**In-channel vol/km**
Study reach									
Rootwads	7	68.0	1.0	2.5	0.4	2.2	0.3	0.4	7.3
Logs 10-20 cm	51	14.9	7.9	7.2	0.1	7.0	0.1	2.8	23.4
Logs 20-50 cm	90	37.9	7.0	72.0	0.8	61.2	0.7	5.0	203.9
Logs >50 cm	12	63.0	9.9	37.6	3.1	28.5	2.4	0.7	95.0
Total	160	–	–	119.4	0.7	98.9	0.6	8.8	329.5
Entire creek segment 1									
Rootwads	25	88.7	1.7	27.9	1.1	17.5	0.7	1.7	17.7
Logs 10-20 cm	20	14.3	6.4	2.1	0.1	1.7	0.1	1.4	1.7
Logs 20-50 cm	55	32.0	7.2	31.3	0.6	26.4	0.5	3.8	26.7
Logs >50 cm	18	59.8	9.2	48.9	2.7	21.1	1.2	1.3	21.3
Total	118	–	–	110.1	0.9	66.7	0.6	8.2	67.5

Table 10. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August through October 1999—*Continued*

DEBRIS JAM SUMMARY

Stream	Number of debris jams	Debris jams per kilometer	Logs 10-20 cm	Logs 20-50 cm	Logs >50 cm	Rootwads	Total number of pieces	Number of key pieces	Percentage of key pieces
Study reach									
	5	16.7	43	66	6	6	121	2	2.0
Entire creek segment 1									
	5	0.3	10	20	1	0	31	0	0

INDIVIDUAL IN-CHANNEL LWD PIECE SUMMARY

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Study reach							
Rootwads	1	0.1	3.3	0	0.0	0.0	0.0
Logs	38	2.1	126.7	0	0.0	0.0	0.0
Total	39	2.2	130.0	0	0.0	0.0	0.0
Entire creek segment 1							
Rootwads	25	1.7	25.3	0	0.0	0.0	0.0
Logs	62	4.3	62.7	2	0.0	0.1	2.0
Total	87	6.0	88.0	2	0.0	0.1	2.0

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Study reach							
Rootwads	1	0.1	3.3	0	0.0	0.0	0.0
Logs 10-20 cm	8	0.4	26.7	0	0.0	0.0	0.0
Logs 20-50 cm	24	1.3	80.0	0	0.0	0.0	0.0
Logs >50 cm	6	0.3	20.0	0	0.0	0.0	0.0
Entire creek segment 1							
Rootwads	25	1.7	25.3	0	0.0	0.0	0.0
Logs 10-20 cm	10	0.7	10.1	0	0.0	0.0	0.0
Logs 20-50 cm	35	2.4	35.4	0	0.0	0.0	0.0
Logs >50 cm	17	1.2	17.2	2	0.1	0.1	2.0

Table 10. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August through October 1999—*Continued*

INDIVIDUAL IN-CHANNEL LARGE WOODY DEBRIS (LWD) VOLUME SUMMARY

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Study reach								
Rootwads	68.0	1.0	0.4	0.4	0.0	0.0	0.0	0.0
Logs	36.3	7.8	39.9	1.0	19.7	0.5	1.1	65.8
Total	–	–	40.3	1.0	19.7	0.5	1.1	65.8
Entire creek segment 1								
Rootwads	88.7	1.7	27.9	1.1	17.5	0.7	0.0	0.7
Logs	36.8	7.6	67.1	1.1	34.1	0.6	2.4	34.5
Total	–	–	95.0	1.1	51.6	0.6	3.6	52.2

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Study reach								
Rootwads	68.0	1.0	0.4	0.4	0.0	0.0	0.0	0.0
Logs 10-20 cm	14.9	7.9	1.1	0.1	0.9	0.1	0.0	0.5
Logs 20-50 cm	37.9	7.0	19.7	0.8	8.8	0.6	0.0	2.0
Logs >50 cm	63.0	9.9	19.0	3.2	9.9	2.5	0.1	8.3
Entire creek segment 1								
Rootwads	88.7	1.7	27.9	1.1	17.5	0.7	0.0	0.7
Logs 10-20 cm	14.3	6.4	1.1	0.1	0.7	0.1	0.0	0.1
Logs 20-50 cm	32.0	7.2	19.8	0.6	14.8	0.4	0.0	0.4
Logs >50 cm	59.8	9.2	46.3	2.7	18.5	1.1	0.1	1.1

Table 10. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August through October 1999—*Continued*

INDIVIDUAL IN-CHANNEL PIECE CHARACTERISTICS SUMMARY

Woody type	Number of pieces	Percentage of total	Total volume (m^3)	In-channel volume (m^3)	Percentage of volume in-channel
Study reach					
Conifer	29	72.5	38.3	18.7	48.8
Deciduous	6	15.0	0.9	0.8	85.7
Unknown	5	12.5	1.0	0.3	25.2
Total	40	–	40.3	19.7	49.0
Entire creek segment 1					
Conifer	75.0	86.2	90.2	46.9	52.0
Deciduous	0.0	0.0	0.0	0.0	0.0
Unknown	12.0	13.8	4.8	4.7	98.3
Total	87.0	–	95.0	51.6	54.3

Woody type	Number of pieces/ stability types	Percentage of stable pieces	Percentage of stable pieces due to roots	Percentage of stable pieces due to buried	Percentage of stable pieces due to pinned	Percentage of pieces forming pools
Study reach						
Conifer	23.0	79.3	47.8	26.1	26.1	2.2
Deciduous	6.0	100.0	0.0	50.0	50.0	0.0
Unknown	4.0	80.0	0.0	25.0	75.0	0.0
Total	33.0	82.5	33.3	30.3	36.4	15.2
Entire creek segment 1						
Conifer	43.0	57.3	41.9	18.6	39.5	23.2
Deciduous	0.0	0.0	0.0	0.0	0.0	0.0
Unknown	2.0	16.7	50.0	50.0	0.0	0.0
Total	45.0	51.7	42.2	20.0	37.8	22.2

Table 11. Summary of field data for the Lower Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999

[Field methods used to generate the field data are based on Pleus and Schuett-Hames (1998); Pleus and others (1999); and Schuett-Hames and others (1999). **Abbreviations**: cm, centimeter; m, meter; m^3, cubic meter; m^3/s, cubic meter per second; m^2, square meter; km, kilometer. <, actual value is less than value shown. >, actual value is greater than value shown. —, no data]

Stream	Date	Segment	Reference point range	Survey length (m)	Survey leader	Affiliation	Number of reference points	Discharge (m^3/s)
Lower Greenwater River	09-22-99	3	0 to 5	500	Allen Pleus	Northwest Indian Fisheries Commission	6	1.3e

Stream	Bankfull width (m)			Bankfull depth (m)			Mean width to depth ratio	Canopy closure (percent)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum		Mean	Minimum	Maximum
Lower Greenwater River	18.5	9.1	26.6	0.5	0.2	0.9	37.3	22.8	0.0	38.5

HABITAT UNIT SUMMARY BY SEGMENT

Habitat condition	Total number	Percentage of total	Total surface area (m^2)	Percentage of surface area	Habit units/km	Habitat units/mean bankfull width	Pools or non-turbulent/km	Bankfull width/pool
Lower Greenwater River								
Pool	11	27.5	2,730.4	26.5	80.0	2.2	22.0	1.7
Riffle	29	72.5	7,567.8	73.5				
Turbulent	10	25.0	2,267.1	22.0				
Non-turbulent	30	75.0	8,031.1	78.0				

HABITAT UNIT LOCATION

Primary number	Primary total length	Secondary number	Secondary total length	Side number	Side total length
Lower Greenwater River					
20	516.0	17	570.2	3	159.0

Table 11. Summary of field data for the Lower Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

FACTORS CONTRIBUTING TO POOL FORMATION (PFF)

Description	Total number	Percentage of units	Number identified as primary PFF	Percentage of primary PFF	Areas associated with primary PFF	Percentage of pool area associated with primary PFF
Lower Greenwater River						
Log	2	10.0	1	12.5	76.7	3.8
Rootwads	3	15.0	3	37.5	713.3	34.9
Debris jam	2	10.0	1	12.5	457.1	22.4
Roots or stump	6	30.0	2	25.0	396.9	19.4
Rock or boulder	1	5.0	–	0.0	–	0.0
Channel bedform	4	20.0	–	0.0	–	0.0
Resistant bank	2	10.0	1	12.5	399.1	19.5

RESIDUAL POOL DEPTH (RPD

RPD category (m)	Number of pools	Percentage of total	Surface area (m^2)	Percentage of surface area	Mean residual pool depth (m)	Maximum residual pool depth (m)
Lower Greenwater River					0.9	1.6
<=0.249	0	0.0	0.0	0.0		
0.250 to 0.4	0	0.0	0.0	0.0		
0.41 to 0.7	3	30.0	440.8	17.9		
0.71 to 0.9	3	30.0	479.2	19.4		
0.91 to 1.2	4	40.0	1,548.9	62.7		

TOTAL IN-CHANNEL PIECES OF LARGE WOODY DEBRIS (LWD) — Individual and Debris Jam Pieces

Type of instream LWD	Number of pieces LWD	Percentage of total pieces	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Lower Greenwater River								
Rootwads	16	0.1	0.9	32.0	0	0.0	0.0	0.0
Logs 10-20 cm	43	0.3	2.3	86.0	0	0.0	0.0	0.0
Logs 20-50 cm	78	0.5	4.2	156.0	0	0.0	0.0	0.0
Logs >50 cm	29	0.2	1.6	58.0	1	0.0	0.1	2.0
Total	166	100	9.0	332.0	1	0.6	0.1	2.0

Table 11. Summary of field data for the Lower Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

TOTAL IN-CHANNEL PIECES OF LARGE WOODY DEBRIS (LWD) — Individual and Debris Jam Pieces—*Continued*

Type of instream LWD	Number of pieces LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Lower Greenwater River									
Rootwads	16	42.2	1.4	5.7	0.4	3.4	0.2	0.2	6.9
Logs 10-20 cm	43	14.6	4.0	2.3	0.1	2.1	0.1	0.1	4.3
Logs 20-50 cm	78	32.1	5.3	34.2	0.4	27.0	0.4	1.5	54.0
Logs <50 cm	29	72.4	10.8	129.2	4.5	101.3	3.5	5.5	202.5
Total	166	–	–	171.3	1.0	133.9	0.8	7.2	267.7

DEBRIS JAM SUMMARY

Stream	Number of debris jams	Debris jams per kilometer	Logs 10-20 cm	Logs 20-50 cm	Logs >50 cm	Rootwads	Total number of pieces	Number of key pieces	Percentage of key pieces
Lower Greenwater River									
	6	12.0	28	60	22	10	120	1	0.8

INDIVIDUAL IN-CHANNEL LWD PIECE SUMMARY

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Lower Greenwater River							
Rootwads	6	0.3	12.0	0	0.0	0.0	0.0
Logs	40	2.2	80.0	1	2.5	0.1	2.0
Total	46	2.5	92.0	1	2.2	0.1	2.0

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Lower Greenwater River							
Rootwads	6	0.3	12.0	0	0.0	0.0	0.0
Logs 10-20 cm	15	0.8	30.0	0	0.0	0.0	0.0
Logs 20-50 cm	18	1.0	36.0	0	0.0	0.0	0.0
Logs >50 cm	7	0.4	14.0	1	100.0	0.1	2.0

Table 11. Summary of field data for the Lower Greenwater River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

INDIVIDUAL IN-CHANNEL LWD VOLUME SUMMARY

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Lower Greenwater River								
Rootwads	42.2	1.4	3.8	0.6	1.5	0.4	0.1	3.1
Logs	32.0	5.9	42.0	1.0	6.5	0.2	0.4	13.0
Total	–	–	–	–	–	–	–	–

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Lower Greenwater River								
Rootwads	42.2	1.4	3.8	0.6	1.5	0.4	0.1	3.1
Logs 10-20 cm	14.6	4.0	0.9	0.1	0.5	0.0	0.0	1.0
Logs 20-50 cm	32.1	5.3	8.3	0.5	1.2	0.1	0.1	2.4
Logs >50 cm	72.4	10.8	32.7	4.7	4.8	1.6	0.3	9.6

INDIVIDUAL IN-CHANNEL PIECE CHARACTERISTICS SUMMARY

Woody type	Number of pieces	Percentage of total	Total volume (m^3)	In-channel volume (m^3)	Percentage of volume in channel
Lower Greenwater River					
Conifer	18	38.3	39.6	5.4	13.6
Deciduous	1	2.1	0.1	0.0	20.0
Unknown	28	59.6	6.1	2.6	42.6
Total	47	–	45.8	8.0	17.5

Woody type	Number of pieces/ stability types	Percentage of stable pieces	Percentage of stable pieces due to roots	Percentage of stable pieces due to buried	Percentage of stable pieces due to pinned	Percentage of pieces forming pools
Lower Greenwater River						
Conifer	15	83.3	60.0	0.0	40.0	13.3
Deciduous	1	100.0	100.0	0.0	0.0	0.0
Unknown	18	64.3	16.7	44.4	46.7	22.2
Total	34	72.3	38.2	23.5	38.2	17.6

Table 12. Summary of field data for the Upper Greenwater River (ECOLOGY Segments 8 and 9) measurement error study reach in the Upper White River Basin, Washington, August 1999

[Field methods used to generate the field data are based on Pleus and Schuett-Hames (1998); Pleus and others (1999); and Schuett-Hames and others (1999). **Abbreviations**: cm, centimeter; m, meter; m^3, cubic meter; m^3/s, cubic meter per second; m^2, square meter; km, kilometer. <, actual value is less than value shown. >, actual value is greater than value shown. —, no data]

Stream	Date	Segment	Reference point range	Survey length (m)	Survey leader	Affiliation	Number of reference points	Discharge (m^3/s)	Discharge date
Segment 8	08-23-99	8	15 to 18	400	Tyler Patterson	U.S. Forest Service	4	1.5	08-24-99
Segment 9	08-23-99	9	0 to 21	1,700	Tyler Patterson	U.S. Forest Service	22	1.5	08-23-99

Stream	Bankfull width (m)			Bankfull depth (m)			Mean width to depth ratio	Canopy closure (percent)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum		Mean	Minimum	Maximum
Segment 8	22.1	18.5	30.0	1.3	0.5	2.0	17.5	49.3	40.0	62.0
Segment 9	20.1	5.0	37.0	1.1	0.3	1.8	19.0	45.4	6.0	100

HABITAT UNIT SUMMARY BY SEGMENT

Habitat condition	Total number	Percentage of total	Total surface area (m^2)	Percentage of surface area	Habit units/km	Habitat units/mean bankfull width	Pools or non-turbulent/km	Bankfull width/pool
Upper Greenwater River (Segment 8)								
Pool	5	35.7	867.6	20.9	35	0.6	12.5	4.4
Riffle	9	64.3	3,287.5	79.1				
Turbulent	–	–	–	–				
Non-turbulent	–	–	–	–				
Upper Greenwater River (Segment 9)								
Pool	20	33.3	2,308.1	9.7	35.3	3.0	11.8	1.0
Riffle	40	66.7	21,444.5	90.3				
Turbulent	–	–	–	–				
Non-turbulent	–	–	–	–				

HABITAT UNIT LOCATION

Primary number	Primary total length	Secondary number	Secondary total length	Side number	Side total length
Upper Greenwater River (Segment 8)					
12	393.3	1	22.0	0	0.0
Upper Greenwater River (Segment 9)					
38	1,830.1	6	120.5	15	394.9

Table 12. Summary of field data for the Upper Greenwater River (ECOLOGY Segments 8 and 9) measurement error study reach in the Upper White River Basin, Washington, August 1999 —*Continued*

FACTORS CONTRIBUTING TO POOL FORMATION (PFF)

Description	Total number	Percentage of units	Number identified as primary PFF	Percentage of primary PFF	Areas associated with primary PFF	Percentage of pool area associated with primary PFF
Upper Green River (Segment 8)						
Other	1	14.3	–	0.0	0.0	0.0
Rootwads	1	14.3	1	20.0	102.6	11.8
Debris jam	3	42.9	3	60.0	558.2	64.3
Resistant bank	2	28.6	1	20.0	206.9	23.8
Upper Green River (Segment 9)						
Log	3	11.5	3	14.3	319.7	13.8
Other	3	11.5	2	9.5	316.0	13.7
Rootwads	2	7.7	1	4.8	47.2	2.0
Debris jam	3	11.5	3	14.3	204.1	8.8
Roots or stump	1	3.8	1	4.8	47.7	2.1
Rock or boulder	4	15.4	3	14.3	146.4	6.3
Resistant Bank	10	38.5	8	38.1	1,227.1	53.2

RESIDUAL POOL DEPTH (RPD

RPD category (m)	Number of pools	Percentage of total	Surface area (m^2)	Percentage of surface area	Mean residual pool depth (m)	Maximum residual pool depth (m)
Upper Green River (Segment 8)					0.7	0.9
<=0.249	0	0.0	0.0	0.0		
0.250 to 0.4	0	0.0	0.0	0.0		
0.41 to 0.7	2	40.0	203.8	23.5		
0.71 to 0.9	3	60.0	663.8	76.5		
0.91 to 1.2	0	0.0	0.0	0.0		
Upper Green River (Segment 8)						
<=0.249	0	0.0	0.0	0.0	0.9	1.5
0.250 to 0.4	0	0.0	0.0	0.0		
0.41 to 0.7	10	66.7	1,372.8	59.5		
0.71 to 0.9	2	13.3	529.6	22.9		
0.91 to 1.2	3	20.0	405.7	17.6		

Table 12. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August 1999 —*Continued*

TOTAL IN-CHANNEL PIECES OF LARGE WOODY DEBRIS (LWD) — Individual and Debris Jam Pieces

Type of instream LWD	Number of pieces LWD	Percentage of total pieces	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Upper Green River (Segment 8)								
Rootwads	14	9.7	0.6	35.0	0	0.0	0.0	0.0
Logs 10-20 cm	63	43.4	2.8	157.5	0	0.0	0.0	0.0
Logs 20-50 cm	39	26.9	1.8	97.5	0	0.0	0.0	0.0
Logs >50 cm	29	20.0	1.3	72.5	24	82.8	1.1	60.0
Total	145	100.0	6.6	362.5	24	16.6	1.1	60.0
Upper Green River (Segment 9)								
Rootwads	35	12.4	1.7	20.6	0	0.0	0.0	0.0
Logs 10-20 cm	86	30.4	4.3	50.6	0	0.0	0.0	0.0
Logs 20-50 cm	128	45.2	6.4	75.3	0	0.0	0.0	0.0
Logs >50 cm	34	12.0	1.7	20.0	1	2.9	0.1	0.6
Total	283	100.0	14.1	166.5	1	0.3	0.1	0.6

Type of Instream LWD	Number of pieces LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Upper Green River (Segment 8)									
Rootwads	14	72.8	2.0	12.1	0.9	12.1	0.9	0.6	30.3
Logs 10-20 cm	63	15.2	8.0	9.1	0.1	7.0	0.1	2.8	17.4
Logs 20-50 cm	39	28.0	10.3	24.7	0.6	24.1	0.6	1.8	60.3
Logs >50 cm	29	64.0	22.6	213.2	7.4	196.9	6.2	1.3	492.3
Total	145	–	–	259.2	1.8	240.1	1.7	6.6	600.3
Upper Green River (Segment 9)									
Rootwads	35	78.8	2.0	148.3	2.3	129.1	2.0	6.4	75.9
Logs 10-20 cm	86	14.0	8.4	11.3	0.1	10.4	0.1	0.5	6.1
Logs 20-50 cm	128	32.9	6.6	77.8	0.6	59.5	0.5	3.0	35.0
Logs >50 cm	34	70.2	8.6	2.2	1.1	1.5	0.8	0.1	0.9
Total	283	–	–	239.6	0.9	200.4	0.8	10.0	117.9

Table 12. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August 1999 —*Continued*

DEBRIS JAM SUMMARY

Stream	Number of debris jams	Debris jams per kilometer	Logs 10-20 cm	Logs 20-50 cm	Logs >50 cm	Rootwads	Total number of pieces	Number of key pieces	Percentage of key pieces
Upper Green River (Segment 8)									
	4	10.0	44	38	27	10	119	23	19.3
Upper Green River (Segment 9)									
	7	4.1	60	85	28	19	192	1	0.5

INDIVIDUAL IN-CHANNEL LWD PIECE SUMMARY

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of Key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Upper Green River (Segment 8)							
Rootwads	4	0.2	10.0	0	0.0	0.0	0.0
Logs	22	1.0	55.0	1	4.5	0.0	2.5
Total	26	1.2	65.0	1	3.8	0.0	2.5
Upper Green River (Segment 9)							
Rootwads	16.0	0.8	9.4	0.0	0.0	0.0	0.0
Logs	75.0	3.7	44.1	0.0	0.0	0.0	0.0
Total	91.0	4.5	53.5	0.0	0.0	0.0	0.0

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Upper Green River (Segment 8)							
Rootwads	4	0.2	10.0	0	0.0	0.0	0.0
Logs 10-20 cm	19	0.9	47.5	0	0.0	0.0	0.0
Logs 20-50 cm	1	0.0	2.5	0	0.0	0.0	0.0
Logs >50 cm	2	0.1	5.0	1	100	0.0	2.5
Upper Green River (Segment 9)							
Rootwads	16.0	0.8	9.4	0.0	0.0	0.0	0.0
Logs 10-20 cm	26.0	1.3	15.3	0.0	0.0	0.0	0.0
Logs 20-50 cm	43.0	2.1	25.3	0.0	0.0	0.0	0.0
Logs >50 cm	6.0	0.3	3.5	0.0	0.0	0.0	0.0

Table 12. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August 1999 —*Continued*

INDIVIDUAL IN-CHANNEL LWD VOLUME SUMMARY

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Upper Green River (Segment 8)								
Rootwads	72.8	2.0	3.8	1.5	3.8	1.5	0.0	2.3
Logs	20.2	9.4	20.8	20.3	1.8	1.8	0.1	4.4
Total	–	–	24.6	0.9	5.5	0.2	0.2	13.8
Upper Green River (Segment 9)								
Rootwads	78.8	2.0	17.8	1.1	15.1	1.2	0.8	8.9
Logs	29.3	7.4	55.1	0.7	18.7	0.3	0.9	11.0
Total	–	–	72.9	1.8	33.7	1.4	1.7	19.9

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Upper Green River (Segment 8)								
Rootwads	72.8	2.0	3.8	1.5	3.8	1.5	0.0	2.3
Logs 10-20 cm	15.2	8.0	2.8	0.3	0.7	0.1	0.0	0.2
Logs 20-50 cm	28.0	10.3	0.6	0.6	0.0	0.0	0.0	0.0
Logs >50 cm	64.0	22.6	17.3	11.6	1.0	0.7	0.0	2.6
Upper Green River (Segment 9)								
Rootwads	78.8	2.0	17.8	1.1	15.1	1.2	0.8	8.9
Logs 10-20 cm	14.0	8.4	3.5	0.1	2.6	0.1	0.1	1.5
Logs 20-50 cm	32.9	6.6	29.0	0.7	11.0	0.4	0.5	6.5
Logs >50 cm	70.2	8.6	22.6	3.8	5.1	1.3	0.3	3.0

Table 12. Summary of field data for the Huckleberry Creek measurement error study reach and the entire creek segment 1 in the Upper White River Basin, Washington, August 1999 —*Continued*

Individual In-Channel Piece Characteristics Summary

Woody type	Number of pieces	Percentage of total	Total volume (m^3)	In-channel volume (m^3)	Percentage of volume in-channel
Upper Green River (Segment 8)					
Conifer	16	61.5	22.4	5.1	22.9
Deciduous	10	38.5	2.1	0.4	17.8
Unknown	0	0.0	0.0	0.0	0.0
Total	26	–	24.6	5.5	22.4
Upper Green River (Segment 9)					
Conifer	60	65.9	65.0	28.9	44.5
Deciduous	31	34.1	7.9	4.9	61.4
Unknown	0	0.0	0.0	0.0	0.0
Total	91	–	72.9	33.8	46.3

Woody type	Number of pieces/ stability types	Percentage of stable pieces	Percentage of stable pieces due to roots	Percentage of stable pieces due to buried	Percentage of stable pieces due to pinned	Percentage of pieces forming pools
Upper Green River (Segment 8)						
Conifer	10	62.5	50.0	20.0	30.0	40.0
Deciduous	7	70.0	100.0	0.0	0.0	0.0
Unknown	0	0.0	0.0	0.0	0.0	0.0
Total	17	65.4	70.6	11.8	17.6	23.5
Upper Green River (Segment 9)						
Conifer	11.0	18.3	0.0	63.6	36.4	45.4
Deciduous	16.0	51.6	87.5	12.5	0.0	0.0
Unknown	0.0	0.0	0.0	0.0	0.0	0.0
Total	27.0	29.7	51.8	33.3	14.8	18.5

Table 13. Summary of field data for the Clearwater River measurement error study reach in the Upper White River Basin, Washington, September 1999

[Field methods used to generate the field data are based on Pleus and Schuett-Hames (1998); Pleus and others (1999); and Schuett-Hames and others (1999). **Abbreviations**: cm, centimeter; m, meter; m^3, cubic meter; m^3/s, cubic meter per second; m^2, square meter; km, kilometer. <, actual value is less than value shown. >, actual value is greater than value shown. —, no data]

Stream	Date	Segment	Reference point range	Survey length (m)	Survey leader	Affiliation	Number of reference points	Discharge (m^3/s)	Discharge date
Clearwater River	09-01-99	2	0 to 9	900	Ted Turner	Weyerhaeuser	10	0.4	09-24-99

Stream	Bankfull width (m)			Bankfull depth (m)			Mean width to depth ratio	Canopy closure (percent)		
	Mean	Mini-mum	Maxi-mum	Mean	Mini-mum	Max-imum		Mean	Mini-mum	Maxi-mum
Clearwater River	–	–	–	–	–	–	–	36.1	8.1	99.8

HABITAT UNIT SUMMARY BY SEGMENT

Habitat condition	Total number	Percentage of total	Total surface area (m^2)	Percentage of surface area	Habit units/km	Habitat units/mean bankfull width	Pools or non-turbulent/km	Bankfull width/pool
Clearwater River								
Pool	7	21.2	3,261.6	22.1	36.7	–	7.8	–
Riffle	26	78.8	11,522.4	77.9				
Turbulent	25	75.8	11,062.9	74.8				
Non-turbulent	8	24.2	3,721.2	25.2				

HABITAT UNIT LOCATION

Primary number	Primary total length	Secondary number	Secondary total length	Side number	Side total length
Clearwater River					
30	1,336.5	13	257.1	0	0.0

Table 13. Summary of field data for the Clearwater River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

FACTORS CONTRIBUTING TO POOL FORMATION (PFF)

Description	Total number	Percentage of units	Number idenfified as primary PFF	Percentage of primary PFF	Areas associated with primary PFF	Percentage of pool area associated with primary PFF
Clearwater River						
Log	3	15.0	3	17.6	524.4	16.1
Rootwads	3	15.0	3	17.6	311.8	9.6
Rock or boulder	14	70.0	11	64.7	2,425.5	74.4

RESIDUAL POOL DEPTH (RPD

RPD category (m)	Number of pools	Percentage of total	Surface area (m^2)	Percentage of surface area	Mean residual pool depth (m)	Maximum residual pool depth (m)
Clearwater River					0.6	1.8
<=0.249	0	0.0	0.0	0.0		
0.250 to 0.4	5	50.0	1,199.3	55.7		
0.41 to 0.7	3	30.0	665.8	30.9		
0.71 to 0.9	1	10.0	42.1	2.0		
0.91 to 1.2	1	10.0	244.6	11.4		

TOTAL IN-CHANNEL PIECES OF LARGE WOODY DEBRIS (LWD) — Individual and Debris Jam Pieces

Type of Instream LWD	Number of pieces LWD	Percentage of total pieces	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Clearwater River								
Rootwads	3	3.1	–	3.3	0	0.0	–	0.0
Logs 10-20 cm	31	32.3	–	34.4	0	0.0	–	0.0
Logs 20-50 cm	45	46.9	–	50.0	0	0.0	–	0.0
Logs >50 cm	17	17.7	–	18.9	3	17.6	–	3.3
Total	96	100.0	–	106.7	3	3.1	–	3.3

Table 13. Summary of field data for the Clearwater River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

TOTAL IN-CHANNEL PIECES OF LARGE WOODY DEBRIS (LWD) — Individual and Debris Jam Pieces—*Continued*

Type of instream LWD	Number of pieces LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD pieces	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Clearwater River										
Rootwads	3	48.0	1.8	1.2	0.4	2.0	0.6	0.3	–	0.3
Logs 10-20 cm	31	14.6	8.4	4.8	0.2	20.0	3.4	0.2	–	0.2
Logs 20-50 cm	45	30.5	10.3	41.5	0.9	29.0	25.9	0.9	–	1.0
Logs >50 cm	17	62.9	15.6	90.0	5.3	12.0	56.4	4.7	–	5.2
Total	96	–	–	137.5	1.4	63.0	86.3	1.4	–	6.7

DEBRIS JAM SUMMARY

Stream	Number of debris jams	Debris jams per kilometer	Logs 10-20 cm	Logs 20-50 cm	Logs >50 cm	Rootwads	Total number of pieces	Number of key pieces	Percentage of key pieces
Clearwater River									
	–	–	–	–	–	–	–	–	–

INDIVIDUAL IN-CHANNEL LWD PIECE SUMMARY

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Clearwater River							
Rootwads	3	–	3.3	0	0.0	–	0.0
Logs	93	–	103.3	3	3.2	–	3.3
Total	96	–	106.7	3	3.0	–	3.3

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
Clearwater River							
Rootwads	3	–	3.3	0	0.0	–	0.0
Logs 10-20 cm	31	–	34.4	0	0.0	–	0.0
Logs 20-50 cm	45	–	50.0	0	0.0	–	0.0
Logs >50 cm	17	–	18.9	3	17.6	–	3.3

Table 13. Summary of field data for the Clearwater River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

INDIVIDUAL IN-CHANNEL LWD VOLUME SUMMARY

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Clearwater River								
Rootwads	48.0	1.8	1.2	0.4	0.6	0.3	–	0.3
Logs	36.3	37.3	136.3	9.4	85.8	1.1	–	1.2
Total	–	–	137.5	9.8	86.3	1.4	–	1.5

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
Clearwater River								
Rootwads	48.0	1.8	1.2	0.4	0.6	0.3	–	0.3
Logs 10-20 cm	14.6	8.4	4.8	0.2	3.4	0.2	–	0.2
Logs 20-50 cm	30.5	10.3	41.5	0.9	25.9	0.9	–	1.0
Logs >50 cm	62.9	15.6	90.0	5.3	56.4	4.7	–	5.2

INDIVIDUAL IN-CHANNEL PIECE CHARACTERISTICS SUMMARY

Woody type	Number of pieces	Percentage of total	Total volume (m^3)	In-channel volume (m^3)	Percentage of volume in-channel
Lower Greenwater River					
Conifer	–	–	–	–	–
Deciduous	–	–	–	–	–
Unknown	–	–	–	–	–
Total	–	–	–	–	–

Woody type	Number of pieces/ stability types	Percentage of stable pieces	Percentage of stable pieces due to roots	Percentage of stable pieces due to buried	Percentage of stable pieces due to pinned	Percentage of pieces forming pools
Clearwater River						
Conifer	–	–	–	–	–	–
Deciduous	–	–	–	–	–	–
Unknown	–	–	–	–	–	–
Total	–	–	–	–	–	–

Table 14. Summary of field data for the White River measurement error study reach in the Upper White River Basin, Washington, September 1999

[Field methods used to generate the field data are based on Pleus and Schuett-Hames (1998); Pleus and others (1999); and Schuett-Hames and others (1999). **Abbreviations**: cm, centimeter; m, meter; m^3, cubic meter; m^3/s, cubic meter per second; m^2, square meter; km, kilometer. <, actual value is less than value shown. >, actual value is greater than value shown. —, no data]

Stream	Date	Segment	Reference point range	Survey length (m)	Survey leader	Affiliation	Number of reference points	Discharge (m^3/s)
White River	09-28-99	1	0 to 7	700	Robert Black	U.S. Geological Survey	8	–

Stream	Bankfull width (m)			Bankfull depth (m)			Mean width to depth ratio	Canopy closure (percent)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum		Mean	Minimum	Maximum
White River	39.8	21.9	64.0	–	–	–	–	–	–	–

HABITAT UNIT SUMMARY BY SEGMENT

Habitat condition	Total number	Percentage of total	Total surface area (m^2)	Percentage of surface area	Habit units/km	Habitat units/mean bankfull width	Pools or non-turbulent/km	Bankfull width/pool
White River								
Turbulent	9	22.5	9,058.0	45.5	57.1	1.0	44.3	–
Non-turbulent	31	77.5	10,869.4	54.5				

HABITAT UNIT LOCATION

Primary number	Primary total length	Secondary number	Secondary total length	Side number	Side total length
White River					
11	699.1	2	130.1	27	929.1

FACTORS CONTRIBUTING TO POOL FORMATION (PFF)

Description	Total number	Percentage of units	Number identified as primary PFF	Percentage of primary PFF	Areas associated with primary PFF	Percentage of pool area associated with primary PFF
White River						
–	–	–	–	–	–	–

Table 14. Summary of field data for the White River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

RESIDUAL POOL DEPTH (RPD

RPD category (m)	Number of pools	Percentage of total	Surface area (m^2)	Percentage of surface area	Mean residual pool depth (m)	Maximum residual pool depth (m)
White River						
–	–	–	–	–	–	–

TOTAL IN-CHANNEL PIECES OF LARGE WOODY DEBRIS (LWD) — Individual and Debris Jam Pieces

Type of Instream LWD	Number of pieces LWD	Percentage of total pieces	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
White River								
Rootwads	0	0.0	0.0	0.0	0	0	0.0	0.0
Logs 10-20 cm	37	33.0	0.9	52.8	0	0	0.0	0.0
Logs 20-50 cm	60	53.6	1.5	85.7	0	0	0.0	0.0
Logs >50 cm	15	13.4	0.4	21.4	0	0	0.0	0.0
Total	112	100	2.8	160.0	0	0	0.0	0.0

Type of Instream LWD	Number of pieces LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD pieces	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
White River									
Rootwads	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Logs 10-20 cm	37.0	13.2	9.0	4.3	0.1	3.5	0.1	0.1	5.0
Logs 20-50 cm	60.0	27.8	8.7	33.2	0.6	23.7	0.4	0.6	33.9
Logs >50 cm	15.0	59.4	3.9	17.3	1.1	11.5	0.7	0.3	16.4
Total	112.0	–	–	54.8	0.5	38.7	0.3	1.0	55.3

DEBRIS JAM SUMMARY

Stream	Number of debris jams	Debris jams per kilometer	Logs 10-20 cm	Logs 20-50 cm	Logs >50 cm	Rootwads	Total number of pieces	Number of key pieces	Percentage of key pieces
White River									
	7	10.0	21	30	7	0	58	0	0.0

Table 14. Summary of field data for the White River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

INDIVIDUAL IN-CHANNEL LWD PIECE SUMMARY

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
White River							
Rootwads	0	0.0	0.0	0	0	0.0	0.0
Logs	54	1.4	77.1	0	0	0.0	0.0
Total	54	1.4	77.1	0	0	0.0	0.0

Type of instream LWD	Number of pieces LWD	LWD per channel width	LWD per km	Number of key LWD pieces	Percentage of key LWD pieces	Key LWD pieces per channel width	Key LWD pieces per km
White River							
Rootwads	0	0.0	0.0	0	0	0.0	0.0
Logs 10-20 cm	16	0.4	22.9	0	0	0.0	0.0
Logs 20-50 cm	30	0.8	42.9	0	0	0.0	0.0
Logs >50 cm	8	0.2	11.4	0	0	0.0	0.0

INDIVIDUAL IN-CHANNEL LWD VOLUME SUMMARY

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
White River								
Rootwads	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Logs	33.3	7.2	28.2	0.5	12.3	0.4	0.3	17.6
Total	–	–	28.2	0.5	12.3	0.4	0.3	17.6

Type of instream LWD	Mean diameter (cm)	Mean length (m)	Total volume (m^3)	Mean volume (m^3)	Total in-channel LWD volume (m^3)	Mean in-channel LWD volume (m^3)	In-channel vol/channel width (m^3)	In-channel vol/km
White River								
Rootwads	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Logs 10-20 cm	13.2	9.0	1.8	0.1	1.0	0.1	0.0	1.5
Logs 20-50 cm	27.8	8.7	17.1	0.6	7.7	0.5	0.2	11.0
Logs >50 cm	59.4	3.9	9.2	1.2	3.6	1.2	0.1	5.1

Table 14. Summary of field data for the White River measurement error study reach in the Upper White River Basin, Washington, September 1999—*Continued*

INDIVIDUAL IN-CHANNEL PIECE CHARACTERISTICS SUMMARY

Woody type	Number of pieces	Percentage of total	Total volume (m^3)	In-channel volume (m^3)	Percentage of volume in-channel
White River					
Conifer	21	39.0	18.0	7.4	41.2
Deciduous	17	31.0	3.5	2.0	58.2
Unknown	16	30.0	6.7	2.9	42.6
Total	54	–	28.2	12.3	43.6

Woody type	Number of pieces/ stability types	Percentage of stable pieces	Percentage of stable pieces due to roots	Percentage of stable pieces due to buried	Percentage of stable pieces due to pinned	Percentage of pieces forming pools
White River						
Conifer	17.0	80.9	58.8	0.0	41.2	0
Deciduous	16.0	94.1	68.8	12.5	18.8	0
Unknown	11.0	68.7	18.2	36.3	45.4	0
Total	44.0	81.5	52.3	13.6	34.1	0

USGS

Black and others

Characterization of Instream Hydraulic and Riparian Habitats and Temperatures, Upper White River Basin, WA, Using Multispectral Imaging Systems

WRIR 03-4022

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