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Potential Salmonid Distributions In the Chiwawa River Basin

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INTRODUCTION

The EPA (2001) has recommended a process to establish thermal potential for different salmonid guild structures. That process includes development of numeric criteria for temperature based on multiple lines of evidence. As one part of that process, GIS-generated maps need to identify the potential distribution for each guild and life-stage on a subbasin-by-subbasin approach. These guild structures categorize salmonids in similar groups that reflect similar thermal requirements.

As noted by the EPA (2001), potential distribution should not be confused with present or known distributions of salmonids. Although the latter may aid one in assessing the potential distribution for a given species, salmonid distributions assessed from stream survey techniques (e.g., snorkeling or electrofishing) are subject to sampling intensity, accuracy, and seasonal or climatic cycles. Therefore, this type of information should not be the only criteria used to assess potential distributions. However, it is important in describing the types and ranges of habitats that can be occupied.

There has been considerable effort to describe the habitat salmonids use (habitat preferences) and their distribution in streams or watersheds. Some of the work has focused on the relationship between specific variables (e.g., depth, velocity, LWD, substrate composition etc.) that describe habitat requirements for different life stages such as spawning and juvenile rearing. While others have investigated broad scale associations (e.g., gradient, habitat area, flow etc.) for salmonid production within a basin. The natural extension of much of this work has been to provide managers with information to better manage streams and watersheds. Recent ESA-listings of Pacific Northwest salmonids has made these evaluations even more applicable today than in the past.

For example, National Marine Fisheries Service (NMFS) has designated critical habitat for a number of salmonid species and different ESUs (Evolutionary Significant Unit). For all ESUs, critical habitat includes all waterways, substrate, and adjacent riparian zones, below longstanding, naturally impassable barriers (i.e., natural waterfalls in existence for at least several hundred years). This is a necessarily broad holistic approach to designating critical habitat. However, NMFS also considers the following requirements of the species: (1) Space for individual and population growth, and for normal behavior; (2) food, water, air, light, minerals, or other nutritional or physiological requirements; (3) cover or shelter; (4) sites for breeding, reproduction, or rearing of offspring; and generally, (5) habitats that are protected from disturbance or are representative of the historical geographical and ecological distribution of the species. In additions to these factors, NMFS also focuses on:

> *"The known physical and biological features (primary constituent elements) within the designated area that are essential to the conservation of the species and that may require special management considerations or protection. These essential features may include, but are not limited to, spawning sites, food resources, water quality and quantity, and riparian vegetation."*

Investigators from NMFS have recognized the need to identify essential fish habitat (EFH) for Pacific salmon that emphasizes fine-scale (1:24,000) geographic information systems (GIS) for freshwater salmon distribution and habitat quality (Roni et al. 1999). Unfortunately, researchers from NMFS noted that fine-scale (1:24,000) GIS databases, habitat surveys and habitat quality databases were not useful in determining distribution because they were comprised of many small, disparate, incompatible databases with incomplete geographic coverage (Roni et al. 1999). Thus, to identify EFH they used a multistage approach that included describing life histories, and habitat requirements for each species. They then reviewed and gathered existing GIS and other information on freshwater distribution and mapped overall species distribution, and described essential habitats for individual species. Important features of essential habitat for spawning, rearing, and migration include the following:

1) Substrate composition;
2) Water quality (e.g., dissolved oxygen, nutrients, temperature, etc.);
3) Water quantity, depth, and velocity;
4) Channel gradient and stability;
5) Food availability;
6) Cover and habitat complexity (e.g., large woody debris, pools, channel complexity, aquatic vegetation etc.);
7) Space (habitat area);
8) Access and passage; and
9) Floodplain and habitat connectivity.

Roni et al. (1999) noted that many GIS databases preclude identification of specific stream reaches as EFH, but suggest that information exists on the type of stream reaches preferred by Pacific salmon for holding, spawning, incubation and rearing. Roni et al. (1999) state that, "It is generally accepted that Pacific salmon spawn and rear in stream reaches and channels with a gradient (slope) less than 4-5% (Lunetta et al. 1997)."

There are several methods that can be used to describe the potential distribution of fish within a basin. A logical approach is to map fish distribution according to biological and physical/environmental criteria. Several studies have demonstrated relationships between certain biological and physical/environmental conditions and fish occurrence, abundance, biomass, and community structure within streams (e.g., Platts 1979; Beecher 1988; Fausch et al. 1988; Issak and Hubert 2000; Waite and Carpenter 2000; Dunham and Chandler 2001). Although, parameters correlated with fish distribution in one drainage may not correlate with the distribution of the same fish in another drainage. As a result, there will always be some uncertainty associated with potential distributions generated from using biological and physical/environmental criteria.

In this study, we developed mapping rules to delineate the potential distribution of salmonids within the Chiwawa River basin, a subbasin within the Wenatchee River basin in north-central Washington. We established mapping rules for "keystone" species within each guild based on biological and physical/environmental criteria. There are two guilds within the Chiwawa Basin; the "Char Guild," which includes bull trout *Salvelinus confluentus,* and the "Cold Water Guild," which includes spring chinook salmon *Oncorhynchus tshawytscha*, steelhead/rainbow trout *O. mykiss*, and westslope cutthroat trout *O. clarki lewisi*. These species currently reside in the Chiwawa River basin.

We based our mapping rules on the following assumptions:

(1) We assumed that channel gradient defined the upstream boundary for accessible habitat within the basin. This assumption removes the effects of man-made barriers (e.g., culverts or diversions) and some natural obstructions (e.g., beaver dams) in limiting the potential distribution of salmonids. We reasoned that these obstructions are transitory and can be removed with appropriate engineering or dislodged during high flow events.

(2) We assumed that not all accessible habitats would be used by all life stages. That is, not all habitats accessible to salmonids will be used equally for spawning, rearing, and migration.

(3) We assumed that streams or reaches of streams currently occupied by keystone salmonids reflect their minimum historic or potential distribution.

(4) We assumed that habitats occupied by non-native salmonids that have the potential to displace or hybridize with native fish would be occupied by native salmonids if the non-native species were absent.

STUDY AREA

The Chiwawa River is a fourth-order[1] stream with a drainage area of about 182 mi^2 (471 km^2). The Chiwawa River flows primarily through the Wenatchee National Forest with 96% of the basin managed by the Forest Service (32% is wilderness). The basin lies within Chelan County in north-central Washington. The Chiwawa River originates on the southwestern slopes of the Entiat Mountains and flows southeasterly for about 37 miles (60 km) to its confluence with the Wenatchee River near the town of Plain. The Chiwawa River is a cold, low conductive stream

[1] Stream order and perennial/intermittent stream delineations were determined from USGS 71/2 minute topographic quadrangle maps.

bounded within a U-shaped valley by steep-sided, heavily forested mountains (Mullan et al 1992). Snowfields and glaciers sustain flows in summer and fall (Mullan et al. 1992).

The modest amount of land-use activities may affect fish distributions within the Chiwawa River basin. There are presently two irrigation diversions, one at RM 3.6 on the Chiwawa River and one on lower Phelps Creek. Timber harvest occurs in only 15% of the basin (Petersen et al. 1994). Two 6^{th}-field watersheds in the Chiwawa Basin have experienced harvest on 25% or more of their total acres (USFS 1997). The main concern is monitoring harvest units and stream condition on the lower mainstem of the Chiwawa River and in Meadow Creek. Mining activity in the early 1900s occurred primarily in the headwaters near Trinity. A pumice mine in the Chikamin drainage closed in 1997.

Fish species in the Chiwawa Basin included: spring chinook salmon, steelhead/rainbow, cutthroat trout, bull trout, brook trout *S. fontinalis*, mountain whitefish *Prosopium williamsoni*, dace *Rhinichthys sp*., and sculpin *Cottus sp.* (Hillman and Miller 2001). The State stocked catchable rainbow trout in the mainstem Chiwawa River as a put-and-take fishery until 1992. They also stocked trout in Rock, Chikamin, and Phelps creeks. Hatchery rainbow trout have not been observed in the basin since 1993 (Hillman and Miller 2001). Plantings of brook trout in Schaefer Lake may have been the original source of brook trout to the Chiwawa River.

LIFE HISTORIES

Bull Trout

Bull trout life-history patterns exhibited in the Chiwawa River Basin may include adfluvial, fluvial, and resident forms. Some adfluvial bull trout that mature in Lake Wenatchee may spawn in the Chiwawa Basin. Fluvial bull trout that mature in the Columbia, Wenatchee, and Chiwawa rivers may spawn in tributaries of the Chiwawa Basin. We have identified in the Chiwawa River at least one bull trout that was tagged in the Columbia River. Finally, smaller resident forms may occupy tributary streams in the Chiwawa Basin and complete their entire life cycle there.

Both adult and juvenile bull trout occur throughout the mainstem Chiwawa River and in many tributary streams (Figure 1).

Trapping near the mouth of the Chiwawa River suggests that adult bull trout migrate into the Chiwawa River from May to August (Rick Stillwater, WDFW, personal communication) and then migrate downstream after spawning is complete in October (Table 1). Spawning ground surveys in the Chiwawa River basin indicate that bull trout spawn from August to October with the peak in September (Ken McDonald, USFS, personal communication) (Table 1). The majority of bull trout redds occurs in Rock, Chikamin, and Phelps creeks (USFS 1997). Spawning has also been noted in Buck, Alpine, and James creeks and the upper Chiwawa River.

Sexauer (1993) found young-of-year bull trout in Chiwawa River tributaries during the months of March through May. This indicates that some fry emerge as early as February. Thus, the incubation period may extend from August to May (Table 1). Most young-of-year bull trout occupy quiescent water along the channel margins (Sexauer 1993). As they grow, they move into deep water. They use pools, glides, and riffles but most often occur along channel margins in open pocket pools, backwaters, and eddies of riffles (Sexauer 1993). Hillman and Miller (2001) observed bull trout throughout the mainstem Chiwawa River, but the highest numbers consistently occur in the Chiwawa River upstream from the confluence of Brush Creek. They also found bull trout in Phelps, Chikamin, Rock, Big Meadow, and an unnamed stream. In the Chiwawa River most juvenile bull trout select multiple channels, pools, and riffles.

The age at which juvenile bull trout emigrate from the Chiwawa Basin has not been investigated. However, we can roughly estimate the age of migrants based on the size of fish captured in a trap near the mouth of the Chiwawa River. Petersen et al. (1994) reported the mean size of downstream migrants as about 6 inches (15 cm). If we compare this mean size to the length-age function reported by Mullan et al. (1992) for bull trout in the Methow Basin, we find that the age of bull trout migrants in the Chiwawa Basin ranges from 1-4 years. This suggests that the juvenile fluvial and adfluvial bull trout may rear for up to four years in streams on the Chiwawa Basin (Table 1). The downstream movement of juveniles appears to be bimodal with a late spring/early summer egress followed by another downstream movement in the fall (Petersen et al. 1994).

Spring Chinook Salmon

Spring chinook salmon spawn and rear in the Chiwawa River Basin. Spring chinook are distributed throughout the mainstem Chiwawa River and occur in several tributaries (Figure 2). Adults enter the Wenatchee River in May and June and typically hold there in large pools until June or July. They enter the Chiwawa Basin anytime from June to August and spawn in August and September; peak spawning occurs near the end of August (Mosey and Murphy 2000) (Table 1). The majority of the fish spawn in the Chiwawa River between the mouth and Trinity. Redd densities are highest in the Chiwawa River between the confluences of Big Meadow and Phelps creeks (Mosey and Murphy 2000).

Spring chinook salmon are known as stream-type chinook because juveniles spend one year in freshwater before they head to the ocean. Trapping in the lower Chiwawa River indicates that spring chinook fry emerge as early as mid-March (Petersen et al. 1994). The incubation period will vary with time of redd deposition and stream temperature, but probably extends from August to end of March (Table 1). Subyearlings that remain in the Chiwawa River disperse downstream and even move into smaller tributaries such as Phelps, Chikamin, Rock, Big Meadow, Alder, Brush, and one unnamed creek (Hillman and Miller 2001). Hillman and Miller (1994) observed that juvenile chinook also moved several hundred meters upstream from spawning areas. In general, juvenile abundance is directly related to seeding levels and their distribution is positively correlated with the distribution of redds (Hillman and Miller 2001). Most juvenile spring chinook salmon rear in multiple channels and pool habitats.

After a year of residence in freshwater, spring chinook smolts begin their downstream migration in the spring with the peak emigration occurring in April and May (Petersen et al. 1994) (Table 1). Spring chinook from the mid-Columbia Basin typically spend two years growing in the ocean before they migrate back to their natal streams at four years of age (Mullan 1987; Fryer et al. 1992).

Steelhead/Rainbow

There appears to be both resident and anadromous (steelhead) forms of rainbow trout in the Chiwawa Basin. The resident form was likely derived from the anadromous form (Lee et al. 1997). Indeed, Mullan et al. (1992) provided evidence that both forms can produce progeny of the opposite form. Therefore, we do not consider the two forms as distinct subspecies. This is consistent with Behnke (1992), who did not distinguish between the resident and anadromous forms of interior rainbow trout in the Columbia Basin. We do believe that the resident form in the Chiwawa Basin is genetically and evolutionarily distinct from the resident redband trout that live in arid regions of the Columbia Basin. The EPA (2001) placed the latter fish in a separate temperature guild, which does not exist in the Chiwawa Basin.

Mullan et al. (1992) opined that the resident form may be fish that did not emigrate downstream early in life from the coldest environments. In other words, these fish are thermally-fated to a resident life history regardless of parentage. Both Peven (1990) and Mullan et al. (1992) reported delayed smolting in steelhead in the colder headwater streams. They found that most steelhead smolted after two years in the warmer streams, while those in the colder headwater streams could spend up to seven years before smolting (Table 1). Their point was that the length of residence before smolting in the mid-Columbia region depends upon the temperature regime of the rearing habitat. This extended time spent in freshwater, combined with 1-3 years in the ocean, contributes to 10 overlapping brood years and 16 age classes of steelhead (Mullan et al. 1992).

The known occurrence of steelhead/rainbow in the Chiwawa River Basin suggests an extensive distribution (Figures 3). Hillman and Miller (2001) found juvenile steelhead/rainbow (age-0 and 1+) in nearly all the perennial tributaries that they sampled. Fish larger than 8 inches (20 cm) occur primarily in the mainstem Chiwawa River with few individuals observed in tributary streams. At this time there is no way to separate the resident form from the anadromous form in areas of sympatry.

Adult steelhead may pass Rock Island Dam on the Columbia River from July through the following May (Chapman et al. 1994). Most, however, pass Rock Island Dam between August and September (Peven 1992). Some steelhead have been observed in the Chiwawa River as early as August and will probably spawn the following spring. However, most steelhead probably overwinter in the Wenatchee River and enter the Chiwawa the next spring. For the Chiwawa River, this suggests a period of migration that may extend from August through end of February of the following year (Table 1). Steelhead/rainbow generally spawn over a 4-5 month period that coincides with spring run-off and is believed to be between March and June (Chapman et al. 1994) (Table 1). Most probable spawning areas include third and fourth-order tributary streams and mainstem reaches of the Wenatchee and Chiwawa rivers (Chapman et al. 1994). Spawning and rearing areas identified by the Forest Service (14602) include the mainstem Chiwawa River and Buck, Alpine, James, Phelps, Rock, Chikamin and Minnow creeks.

The eggs usually hatch in 4-7 weeks and fry emerge from the gravel 2-3 weeks after hatching (Pauley et al. 1986; Shapovalov and Taft 1954; Barnhart 1986). Observations of steelhead/rainbow fry by Hillman et al. (1989) and Mullan et al. (1992) suggest that the incubation period may range from March to the end of August (Table 1). The movements of juvenile steelhead are complex and not easily explained (Mullan et al. 1992). After fry emerge, usually in May through July, some may be displaced downstream and others may move upstream to reduce local densities and maximize available food and space. Hillman and Chapman (1989) reported that most movement occurs during early summer and speculated that decreased stream flows reduces rearing habitat along the stream margins forcing fry to seek suitable habitat elsewhere. During summer, movement decreases as fry grow and they select habitat commensurate to their size. As temperatures begin to decrease in fall, steelhead often move downstream in search of suitable over wintering habitat (Chapman et al. 1994). The following spring or perhaps after several years of juvenile rearing, steelhead smolts start their downstream migration to the ocean in April and May (Petersen et al. 1994).[2]

Chapman et al. (1994) reported that juvenile steelhead select deeper and faster water as size increases. Larger juveniles tend to select turbulent fast water with boulders and overhead turbulent water for cover while fry occupy shallower water with lower velocities and cobbles and boulders for cover. In the Chiwawa River basin, steelhead densities were greatest in riffles and multiple channels and were distributed throughout the mainstem and many tributaries (Hillman and Miller 2001).

Westslope Cutthroat Trout

There is virtually no information on the life-history characteristics of cutthroat in the Chiwawa River basin. Their known distribution in the Chiwawa River basin includes the Chiwawa River and Chikamin, Phelps, Big Meadow, and Rock creeks, and several other smaller tributaries (Figure 4). Like bull trout, cutthroat can have adfluvial, fluvial, or resident forms. We suspect that fluvial and resident forms occur in the Chiwawa Basin. Resident forms usually occur in headwater streams, while migratory forms are most common in larger streams (Rieman and Apperson 1989; McIntyre and Rieman 1995). Westslope cutthroat trout mature at age three, but first spawning occurs mostly at age four or five. Therefore, juvenile rearing extends to age three but may be longer in colder less productive systems (Table 1). Fluvial and adfluvial trout move near spawning tributaries in fall and winter where they remain until migrating upstream in the spring (Table 1). Spawning typically occurs between March and July (Behnke 1992; McIntyre and Reiman 1995) (Table 1). Thus, incubation would extend from March to August (Table 1).

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[2] The EPA draft guidance suggests a 7 day mean maximum 14^{o}C temperature criteria for steelhead smoltification. However, steelhead rear extensively throughout the mainstem Chiwawa and several tributaries for as many as several years, often moving downstream into larger habitat as they grow larger. It does not appear that they actually smolt within the Chiwawa system.

METHODS

We reviewed the literature on the Chiwawa River basin and relied upon our experience and that of others (USFWS, WDFW, and Chelan PUD) to develop criteria to designate potential fish distributions. In some cases there was very little information to predict potential distributions. For example, cutthroat trout distributions and steelhead/rainbow spawning distributions are mostly unknown in the Chiwawa Basin. Moreover, as stated earlier, existing information that would help us separate the different forms (resident and anadromous) of rainbow trout in the Chiwawa River Basin are lacking.

To assess the potential distribution of salmonids in the Chiwawa Basin we used mapping rules to define accessible and available habitat. Here, we define accessible habitat as all areas downstream from natural, "geologic" barriers and sustained high gradients. Available habitat is simply the length of stream for a specific life stage within the accessible habitat.

We followed the WDFW (1998) definition of gradient barriers to describe the upstream boundary of accessible habitat. They defined a gradient barrier as a sustained gradient >20% for a distance ≥160 m, or a natural point barrier >3.6 vertical meters. For channels less than 3-ft wide in Eastern Washington, they defined a gradient barrier as a sustained gradient >16% for a distance ≥ 160 meters. Because we have virtually no information on widths of tributary channels in the basin, we defined upstream gradient barriers as a sustained gradient of >20%. Therefore, we used the >20% criteria (or a natural point barrier >3.6 vertical meters) for our "first-cut" at delineating the potential distribution of salmonids within the basin.

This criteria for delineating accessible habitat is appropriate for anadromous, fluvial, and adfluvial fish, but may not be adequate for resident forms of bull trout, cutthroat trout, and rainbow trout. These forms may exist upstream from gradient barriers if suitable habitat is available upstream from the barriers. Therefore, we expanded the potential distribution for these species if we found information indicating that they live in stream segments upstream from gradient barriers. We expanded the potential accessible habitat up to the next geological or gradient barrier. Because of the geomorphology of the Chiwawa Basin (steep valley walls), this "second-cut" at delineating the potential distribution was rarely necessary.

After delineating the accessible habitat, we then developed mapping rules to identify potential distributions for each species life stage within the accessible range. These rules integrated known distributions, channel gradient, and stream order[3]. We used known fish distributions in

[3] We did not use criteria like depth, velocity, cover, substrate composition, pool-riffle ratio etc. to qualify available habitat. Instead, mapping rules are intended to reflect the maximum estimate of available habitat to capture the distribution for a given species and life stage. Numbers of fish and actual habitat use within the available habitat will depend largely on the quality of habitat and the expression of all its components.

the Chiwawa Basin as an indicator to select appropriate stream gradients and stream orders for different life stages within accessible habitat. Stream gradient was the main predictor within the accessible areas, but was qualified by stream order, a surrogate for stream size. We selected a gradient criterion for each species and life stage. We relied on stream gradient values reported in the literature as well as known distributions to define life-stage criteria.

Stream gradient was estimated from 1:24,000 scale Digital Line Graphs (DLGs) and 10-meter Digital Elevation Models (DEMs). DEMs were used to generate slope classes for the Chiwawa Basin. We used GIS to intersect stream courses (DLGs) and slope classes. We used Strahler's (1957) definition of stream order to categorize different stream segments. Mapping rules consisting of gradient and stream order criteria were applied to the shortest stream gradient reaches (10 meters) to calculate the lineal miles of available habitat. What follows is a more detailed description of the mapping rules used to delineate potential distributions of salmonids in the Chiwawa Basin.

Char Guild

Migratory Populations

We defined the distribution of migratory bull trout (fluvial and adfluvial forms) as all accessible stream reaches of the Chiwawa Basin with stream gradients ≤20%, or reaches not interrupted by a natural point barrier >3.6 vertical meters. Thus, a stream reach is considered inaccessible if the calculated gradient is >20% for a distance ≥160 m.

Mapping Rule: *Potential migratory distribution for fluvial and adfluvial bull trout includes all perennial, 2nd-order and larger streams in the Chiwawa River basin with reaches ≤20% gradient (Table 2).*

Spawning, Incubation, and Juvenile Rearing

Stream size and gradient probably govern the potential distribution of bull trout in the Chiwawa Basin. Typically, bull trout spawn in third-order streams such as Rock, Chikamin, Phelps, and

Buck creeks and the upper Chiwawa River. However, spawning has also been noted in the lower reaches of second and first-order streams like Alpine and James creeks, respectively (Brown 1992; Sexauer 1993; USFS 1996). Based on the known spawning distribution in the basin, most bull trout spawn in stream reaches with gradients <10% (USFS 1996).

The potential distribution of juvenile bull is also affected by stream gradient. Most juvenile bull trout occupy stream reaches with gradients less than 10% in the Chiwawa Basin, although complete surveys have not been conducted in many headwater streams (USFS 1997). Sexauer (1993) found juvenile bull trout in reaches of Chikamin and Rock creeks with gradients that ranged from 0-10%. Dunham and Chandler (2001) surveyed numerous bull trout streams in Washington and noted that juveniles occupied stream reaches with gradients up to 7%. Extensive sampling in Montana, Idaho, and Washington indicated that juvenile bull trout occurred in reaches with gradients less than 17%, but the majority occupied channels with gradients less than 3% (Figure 5).

Mapping Rule: *Potential spawning, incubation, and rearing distributions for bull trout includes perennial, 1st-order and larger streams in the Chiwawa Basin with reaches ≤17% gradient. Stream reaches ≤17% gradient upstream from natural geologic barriers or gradient barriers (>20%) were included if resident populations were noted (Table 2).*

Cold Water Salmonid Guild

Adult Migration

We defined the potential adult migration distribution for spring chinook salmon, steelhead (anadromous form), and westslope cutthroat trout (fluvial and adfluvial forms) as all accessible stream reaches of the Chiwawa Basin that had channel gradients ≤20%, or were not interrupted by a natural point barrier >3.6 vertical meters. Thus, we considered a stream reach inaccessible if the calculated gradient was >20% for a distance ≥160 m. For adult chinook salmon, the gradient criterion applies to third-order and larger steams. For steelhead and fluvial and adfluvial cutthroat trout, the gradient criterion applies to second-order and larger streams in the basin.

Mapping Rule: Potential adult migration distribution for chinook salmon includes all 3rd-order and larger streams with reach gradients ≤20% and reaches not interrupted by natural point barriers >3.6 vertical meters. A stream reach is considered inaccessible if the gradient is >20% for a distance ≥160 m (Table 2).

Mapping Rule: *Potential adult migration distribution for steelhead (anadromous form) includes all 2nd-order and larger streams with reach gradients ≤20% and reaches not interrupted by natural point barriers >3.6 vertical meters. A stream reach is considered inaccessible if the gradient is >20% for a distance ≥160 m (Table 2).*

Mapping Rule: *Potential adult migration distribution for fluvial and adfluvial cutthroat trout includes all 2nd-order and larger streams with reach gradients ≤20% and reaches not interrupted by natural point barriers >3.6 vertical meters. A stream reach is considered inaccessible if the gradient is >20% for a distance ≥160 m (Table 2).*

Spawning and Incubation

Most anadromous salmonids spawn in low to moderate-gradient stream reaches. Stream reaches greater than 4% slope are generally not used by Pacific salmon for spawning because of the reaches' high bed-load transport rate, deep scour, and coarse substrate (Roni and Weitkamp 1999). That is, most high gradient stream reaches transport smaller suitable gravels and cobbles, which leaves exposed bedrock or large substrate. Our mapping rules for spawning and incubation do not separate the different life-history forms (e.g., anadromous, resident, fluvial, and adfluvial). Thus, the mapping rule for, say steelhead/rainbow, identifies the combined or "lumped" potential spawning and incubation distribution of resident and anadromous rainbow trout.

Spring Chinook Salmon

Spring chinook spawn in the mainstem Chiwawa River and in Rock and Chikamin creeks. Most spawning occurs in mainstem reaches of the Chiwawa River with gradients less than 2%. Chinook also spawn in reaches of Rock and Chikamin creeks with gradients that vary from 1-4%. Because spring chinook are large salmonids that spawn in August and September during low-flow conditions, we believe that first and second-order streams would not provide suitable spawning habitat (depth, velocity, and substrate) for these fish. Spawning ground surveys conducted in the Chiwawa River during the past 41 years validate this assumption. Although spring chinook salmon typically do not spawn in third-order streams in the Chiwawa Basin, these streams could be used at higher escapement levels.

Mapping Rule: *Potential spawning and incubation distribution for spring chinook includes 3rd-order and larger streams with reaches ≤4% gradient. Stream reaches with gradients ≤4% upstream from natural barriers or gradient barriers (>20%) are not included because they exceed adult migration distribution (Table 2).*

Steelhead/Rainbow

To the best of our knowledge, no one has conducted steelhead/rainbow spawning ground surveys in the Chiwawa Basin. The most probable spawning areas for steelhead (anadromous form) include third and fourth-order tributary streams (Chapman et al. 1994). A notable exception reported by Mullan et al. (1992) was that steelhead spawned in the lower 0.4 miles of Black Canyon Creek, a second-order stream of the Methow River. The resident form, however, could spawn in second-order streams. Therefore, because we lump the anadromous and resident forms together, the potential spawning and incubation distribution for steelhead/rainbow includes reach gradients ≤5% in second-order and larger streams.

Mapping Rule: *Potential spawning and incubation distribution for steelhead/rainbow includes 2nd-order and larger streams with reaches ≤5% gradient. Stream reaches with gradients ≤5% upstream from natural barriers or gradient barriers (>20%) are included if resident populations are present (Table 2).*

Westslope Cutthroat Trout

There is little information on spawning habits of cutthroat trout in the Chiwawa Basin. Like other salmonids, cutthroat tend to spawn in low to moderate gradient stream reaches. Schmetterling (2000) reported that cutthroat trout spawned in stream reaches with gradients up to 3% in tributaries of the Blackfoot River, Montana. In Bristow Creek, a tributary to Lake Koocanusa, cutthroat spawned in a reach with a 4.4% gradient (Marotz and Fraley 1986). Researchers have noted that cutthroat trout tend to occupy high elevations and low stream orders (Platts 1974, 1979; Fraley and Graham 1981). Cutthroat trout have been found in at least one first-order stream in the Chiwawa Basin (USFS 1997). We believe that cutthroat could spawn in the lower portions of perennial, first-order streams in the Chiwawa Basin. Therefore, to capture the potential range of spawning habitat for all forms of cutthroat trout, we included reaches with gradients ≤5% in perennial, first-order and larger streams.

Mapping Rule: *Potential spawning and incubation distribution for cutthroat trout includes perennial, 1st-order and larger streams with reaches ≤5% gradient. Stream reaches with gradients ≤5% upstream from natural barriers or gradient barriers (>20%) are included if resident populations are present (Table 2).*

Juvenile Rearing

We limit juvenile salmonid rearing to perennial stream reaches in the Chiwawa Basin. Moreover, migration barriers apply to juvenile salmonid distributions except where existing information identifies fish upstream from a natural or gradient barrier. Work conducted by Platts (1974 and 1979) suggests that juvenile salmonids can occupy some small, first-order steams (Table 2). His studies offer an ideal correlation between stream order and fish populations, because the streams he studied were near pristine conditions and fish harvest was considered insignificant. The streams he studied also have fish assemblages similar to those in the Chiwawa Basin. Based on the work of Watson and Hillman (1997), we established different stream-gradient criteria for juvenile spring chinook, steelhead/rainbow, and cutthroat trout (Figure 5).

Spring Chinook Salmon

Juvenile chinook salmon are seldom found in stream reaches exceeding 6% gradient (Figure 5). Juvenile chinook in the Chiwawa River prefer pools and multiple channels and are less abundant in riffles and high-gradient habitat types (Hillman and Miller 2001). We believe that all perennial, third-order and larger streams downstream from known migration barriers could provide potential juvenile rearing habitat. In addition, some perennial, second-order streams could provide rearing habitat. For example, USFS (14206) and Hillman and Miller (2001) found juvenile chinook in Minnow Creek and an unnamed stream, both second-order streams in the Chiwawa Basin. There is no evidence that juvenile chinook rear in first-order streams in the basin. In the South Fork Salmon River drainage, Platts (1979) found that all juvenile chinook salmon reared in third-order and larger streams (Table 2).

Mapping Rule: *Potential juvenile chinook salmon distribution includes second-order and larger streams with reaches ≤6 % gradient (Table 2).*

Steelhead/Rainbow

Juvenile steelhead/rainbow generally select fast-water habitats in the Chiwawa River. Hillman and Miller (2001) most often found them in riffles and multiple channels. Similar to Platts (1979), Hillman and Miller (2001) observed these fish in third and fourth-order streams. However, they also found a few rearing in small, second-order streams in the basin. Most steelhead/rainbow in the Chiwawa Basin occupy stream reaches that have a gradient ≤10% (Hillman and Miller 2001; USFS 1996). Extensive sampling in Montana, Idaho, and Washington indicates that most steelhead/rainbow occur in reaches with gradients <10% (Figure 5). For this reason, we include in our mapping rule second-order and larger streams with reaches with a gradient ≤10%.

Mapping Rule: *Potential juvenile rearing distribution includes second-order and larger streams with reaches ≤10% gradient. Stream reaches ≤10% gradient upstream from natural barriers or gradient barriers (>20%) are included if resident populations are present (Table 2).*

Cutthroat Trout

Information on rearing habitat of juvenile cutthroat trout in the Chiwawa Basin is very limited. Cutthroat trout have been found in many high-gradient, second-order streams in the Chiwawa Basin. This comports with other studies that note the presence of cutthroat in small streams with gradients as high as 27% (Fausch 1989). It is difficult to select a gradient that encompasses the rearing habitat occupied by cutthroat trout. Extensive sampling in Montana, Idaho, and Washington indicates that cutthroat are most abundant at stream gradients <5%, but readily occur in reaches with gradients ≤18% (Figure 5). On the other hand, McIntyre and Reiman (1995) report that cutthroat are most abundant in reaches with gradients of 6-14%. We believe the rearing distribution for cutthroat trout in the Chiwawa Basin should include perennial, first-order streams with reach gradients ≤18%.

Mapping Rule: *Potential juvenile rearing distribution for cutthroat trout includes perennial, first-order and larger streams with reaches ≤18% gradient. Stream reaches ≤18% gradient upstream from natural barriers or gradient barriers (>20%) are included if resident populations are present (Table 2).*

RESULTS

We estimated that the Chiwawa River Basin had 327.4 stream miles. As expected the amount of stream miles in the Chiwawa River basin was greatest for small order streams. Stream miles by stream order were as follows: first-order streams 187.2 miles (57.2%), second-order stream 67.9 miles (20.7%), third-order streams 40.0 (12.2%), and one fourth order stream at 32.3 miles (9.9%). Most of the small streams that drain the west-side portion of the Chiwawa River Basin between Big Meadow and Buck creeks were steep and had gradient barriers (>20%) short distances upstream from their confluence with the Chiwawa River. Streams that drain the east-slopes of the basin were lower gradient and tended to have more potential habitat for salmonids. In general, the mapping rules estimated the greatest potential life-stage habitat for juvenile rearing followed by adult migration and then spawning and incubation. Below we provide estimates of the stream miles for known distributions and potential distributions by species and life stage.

Bull Trout

We plotted known and potential distribution of bull trout in the Chiwawa River Basin. The known distribution includes 52.8 lineal miles within streams of the basin (Table 4, Figure 1). This is about 16% of the total stream miles. We estimated potential distribution for two-life stages of bull trout. First, we estimated the length of streams accessible to adult migration for fluvial and adfluvial bull trout. Next, we estimated the length of stream available for spawning, incubation, and juvenile rearing habitat for all life forms. According to the map rule, 101 lineal miles were accessible to adult fluvial and adfluvial bull trout or about 31% of the Chiwawa River Basin (Table 4, Figure 6). Stream miles available for spawning, incubation and rearing were the same at 101 lineal miles (Table 4, Figure 7). We did not adjust potential distribution based on fish observed upstream from natural barriers or gradient barriers. Only minor adjustments were made to the known distribution from work conducted by Hillman and Miller (2001).

Chinook Salmon

The known distribution of chinook salmon includes 39.5 lineal miles or about 12% of the Chiwawa River Basin (Table 5, Figure 2). Potential habitat for life-stages in the Chiwawa River basin was greatest for juveniles followed by adult migration and then spawning and incubation. Juvenile rearing had the most extensive distribution at 56.6 lineal stream miles or roughly 17% of the Chiwawa River Basin (Table 5, Figure 8). We estimated that the Chiwawa River Bain contained 56.2 lineal miles of adult migration habitat or about 17% of the basin (Table 5, Figure 9). Spawning and incubation habitat in the basin was about 30 lineal miles or about 9% of the basin (Figure 10). We adjusted spawning and incubation habitat in both Big Meadow and Buck creeks. There, we reduced potential spawning and incubation habitat to only the lower portions of the streams. This estimate is consistent with observations noted by Mullan et al. (1992) for potential anadromous habitat. Minor adjustments were also made to the known distribution based on surveys conducted by Hillman and Miller (2001).

Steelhead/Rainbow

The documented distribution of steelhead/rainbow included 43.3 lineal miles or about 13% of the Chiwawa River Basin (Table 6, Figure 3). For anadromous steelhead, we estimated 102.3 lineal miles (31%) for adult migration potential (Table 6, Figure 11). For spawning and incubation, we included some areas upstream from natural barriers to reflect potential habitat for resident fish. According to the map rule, we estimated that there was 51.6 miles of spawning and incubation habitat available or about 16% of the Chiwawa River Basin (Table 6, Figure 12). Likewise, for juvenile rearing habitat we included areas upstream from known migration barriers to encompass both resident and anadromous life forms. We estimated 72.9 lineal miles of rearing habitat potential in the Chiwawa River Basin (Table 6, Figure 13). This represents about 22% of the total basin stream miles. Adjustments to spawning and incubation and juvenile rearing were based on the presence of resident steelhead/rainbow upstream from a natural barrier on the

Chiwawa River. We also made adjustments to the known distribution based and surveys conducted by Hillman and Miller (2001).

Cutthroat Trout

The known distribution of cutthroat trout in the Chiwawa River Basin includes 82.3 lineal miles or about 25% of the basin (Table 7, Figure 4). Stream length accessible to migratory forms of cutthroat trout includes 122.8 lineal miles (Table 7, Figure 14). This estimate is more than a third (37.5%) of the stream miles available in the basin. For spawning and incubation, we included some areas upstream from natural barriers and gradient barrier to reflect potential habitat for resident fish. According to the map rule, we estimated that there was 56.4 miles of spawning and incubation habitat available or about 17.2% of the Chiwawa River Basin (Table 7, Figure 15). Our estimate of potential juvenile rearing habitat encompassed some areas upstream from known migration barriers and gradient barriers to include resident fish. We estimated 107.4 lineal miles of rearing habitat potential or about a third of the Chiwawa River Basin (Table 7, Figure 16).

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TABLES

Table 1. Estimated time period for migration, spawning and incubation, and juvenile rearing for salmonids in the Chiwawa River basin.

Adult Migration

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Char Guild Bull Trout					X	X	X	X 7-Months	X	X	X	
Cold Water Salmonids Spring Chinook						X	X 4-Months	X	X			
Steelhead/Rainbow	X	X						X	X	X 7-Months	X	X
Cutthroat Trout	X	X	X							X	X 6-Months	X

Spawning

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Char Guild Bull Trout								X	X 3-Months	X		
Cold Water Salmonids Spring Chinook								X 2-Months	X			
Steelhead/Rainbow			X	X 4-Months	X	X						
Cutthroat Trout			X	X	X 5-Months	X	X					

Incubation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Char Guild Bull Trout	X	X	X	X				X	X	X 9-Months	X	X
Cold Water Salmonids Spring Chinook	X	X	X					X	X	X 8-Months	X	X
Steelhead/Rainbow			X	X	X 6-Months	X	X	X				
Cutthroat Trout			X	X	X 6-Months	X	X	X				

Juvenile Rearing

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Char Guild Bull Trout	X	X	X	X	X	X 1-4 Years	X	X	X	X	X	X
Cold Water Salmonids Spring Chinook	X	X	X	X	X	X 1-Year	X	X	X	X	X	X
Steelhead/Rainbow	X	X	X	X	X	X 2-7 Years	X	X	X	X	X	X
Cutthroat Trout	X	X	X	X	X	X 3-Years	X	X	X	X	X	X

Table 2. Coarse scale criteria used to map potential distributions of salmonids in the Chiwawa Basin.

Species	Life Stage	Criteria: Stream Order	Criteria: Gradient
		Char Guild	
Bull Trout	Spawning, Incubation, and Juvenile Rearing	Second-order perennial streams and higher	Stream slope ≤17%
	Migratory Populations	Second-order perennial streams and higher	Stream slope ≤20% for at least 160 meters
		Cold Water Salmonids	
Spring Chinook	Spawning-Incubation	Third-order streams and higher	Stream slope ≤4%
	Juvenile Rearing	Third-order streams and higher	Stream slope ≤6%
	Adult Migration	Third-order streams and higher	Stream slope ≤20% for at least 160 meters
Steelhead/Rainbow	Spawning-Incubation	Second-order perennial streams and higher	Stream slope ≤5%
	Juvenile Rearing	Second-order perennial streams and higher	Stream slope ≤10%
	Adult Migration	Second-order perennial streams and higher	Stream slope ≤20% for at least 160 meters
Westslope Cutthroat	Spawning-Incubation	First-order perennial streams and higher	Stream slope ≤5%
	Juvenile Rearing	First-order perennial streams and higher	Stream slope ≤18%
	Adult Migration	Second-order perennial streams and higher	Stream slope ≤20% for at least 160 meters

Table 3. Average fish numbers per station by species and stream order in the South Fork Salmon River (from Platts 1979).

	Stream Order				
Species	**1**	**2**	**3**	**4**	**5**
Bull Trout	5.0	0.5	0.5	0.3	
Cutthroat Trout		0.1	0.2	0.1	0.05
Steelhead/Rainbow		0.5	0.7	2.7	10.9
Chinook Salmon			0.3	2.3	8.2

Table 4. Lineal stream miles estimated for bull trout distributions in the Chiwawa Basin. Lineal miles for potential adult migration, spawning and incubation, and juvenile rearing habitat were estimated from mapping rules (Table 2). Potential distributions were adjusted to include documented distribution.

	Current Distribution				Potential Distribution				
	Documented Present		Unknown Presence/Absence		Accessible Adult Migration		Available Spawning, Incubation, Juvenile Rearing		Total
Order	**Miles**	**Percent**	**Miles**	**Percent**	**Miles**	**Percent**	**Miles**	**Percent**	**Miles**
1	1.7	0.9	185.5	99.1	0.0	0.0	14.7	7.9	187.2
2	2.7	4.0	65.2	96.0	32.2	47.4	24.3	35.8	67.9
3	16.1	40.3	23.9	59.8	36.6	91.5	30.3	75.8	40.0
4	32.3	100.0	0.0	0.0	32.3	100.0	31.7	98.2	32.3
Total	**52.8**	**16.1**	**274.6**	**83.9**	**101.1**	**30.9**	**101.0**	**30.9**	**327.4**

Table 5. Lineal stream miles estimated for chinook salmon distributions in the Chiwawa Basin. Lineal miles for potential adult migration, spawning and incubation, and juvenile rearing habitat were estimated from mapping rules (Table 2). Potential distributions were adjusted to include documented distribution.

	Current Distribution				Potential Distribution						
	Documented		Unknown		Accessible		Available				
Stream	Present		Presence/Absence		Adult Migration		Spawning & Incubation		Juvenile Rearing		Total
Order	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent	Miles
1	0.0	0.0	187.2	100.0	0.0	0.0	0.0	0.0	0.5	0.3	187.2
2	1.6	2.4	66.3	97.6	0.9	1.3	0.0	0.0	10.7	15.8	67.9
3	5.6	14.0	34.4	86.0	23.0	57.5	4.5	11.3	17.4	43.5	40.0
4	32.3	100.0	0.0	0.0	32.3	100.0	25.4	78.6	28.0	86.7	32.3
Total	**39.5**	**12.1**	**287.9**	**87.9**	**56.2**	**17.2**	**29.9**	**9.1**	**56.6**	**17.3**	**327.4**

Table 6. Lineal stream miles estimated for steelhead/rainbow trout distributions in the Chiwawa Basin. Lineal miles for potential adult migration, spawning and incubation, and juvenile rearing habitat were estimated from mapping rules (Table 2). Potential distributions were adjusted to include documented distribution.

	Current Distribution				**Potential Distribution**						
	Documented		**Unknown**		**Accessible**		**Available**				
Stream	**Present**		**Presence/Absence**		**Adult Migration**		**Spawning & Incubation**		**Juvenile Rearing**		**Total**
Order	**Miles**	**Percent**	**Miles**	**Percent**	**Miles**	**Percent**	**Miles**	**Percent**	**Miles**	**Percent**	**Miles**
1	0.7	0.4	186.5	99.6	1.5	0.8	0.5	0.3	0.8	0.4	187.2
2	2.1	3.1	65.8	96.9	32.0	47.1	9.0	13.3	17.9	26.4	67.9
3	8.2	20.4	31.8	79.6	36.6	91.4	15.2	37.9	23.8	59.3	40.0
4	32.3	100.0	0.0	0.0	32.3	100.0	26.9	83.2	30.5	94.2	32.3
Total	**43.3**	**13.2**	**284.2**	**86.8**	**102.3**	**31.2**	**51.6**	**15.8**	**72.9**	**22.3**	**327.4**

Table 7. Lineal stream miles estimated for cutthroat trout distributions in the Chiwawa Basin. Lineal miles for potential adult migration, spawning and incubation, and juvenile rearing habitat were estimated from mapping rules (Table 2). Potential distributions were adjusted to include documented distribution.

	Current Distribution				Potential Distribution						
	Documented		Unknown		Accessible		Available				
Stream	Present		Presence/Absence		Adult Migration		Spawning & Incubation		Juvenile Rearing		Total
Order	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent	Miles
1	4.2	2.3	183.0	97.7	21.7	11.6	4.3	2.3	16.6	8.9	187.2
2	16.2	23.9	51.7	76.1	32.2	47.4	10.0	14.7	28.1	41.4	67.9
3	29.5	73.6	10.6	26.4	36.6	91.4	15.3	38.1	31.0	77.4	40.0
4	32.3	100.0	0.0	0.0	32.3	100.0	26.9	83.3	31.8	98.4	32.3
Total	**82.3**	**25.1**	**245.2**	**74.9**	**122.8**	**37.5**	**56.4**	**17.2**	**107.4**	**32.8**	**327.4**

FIGURES

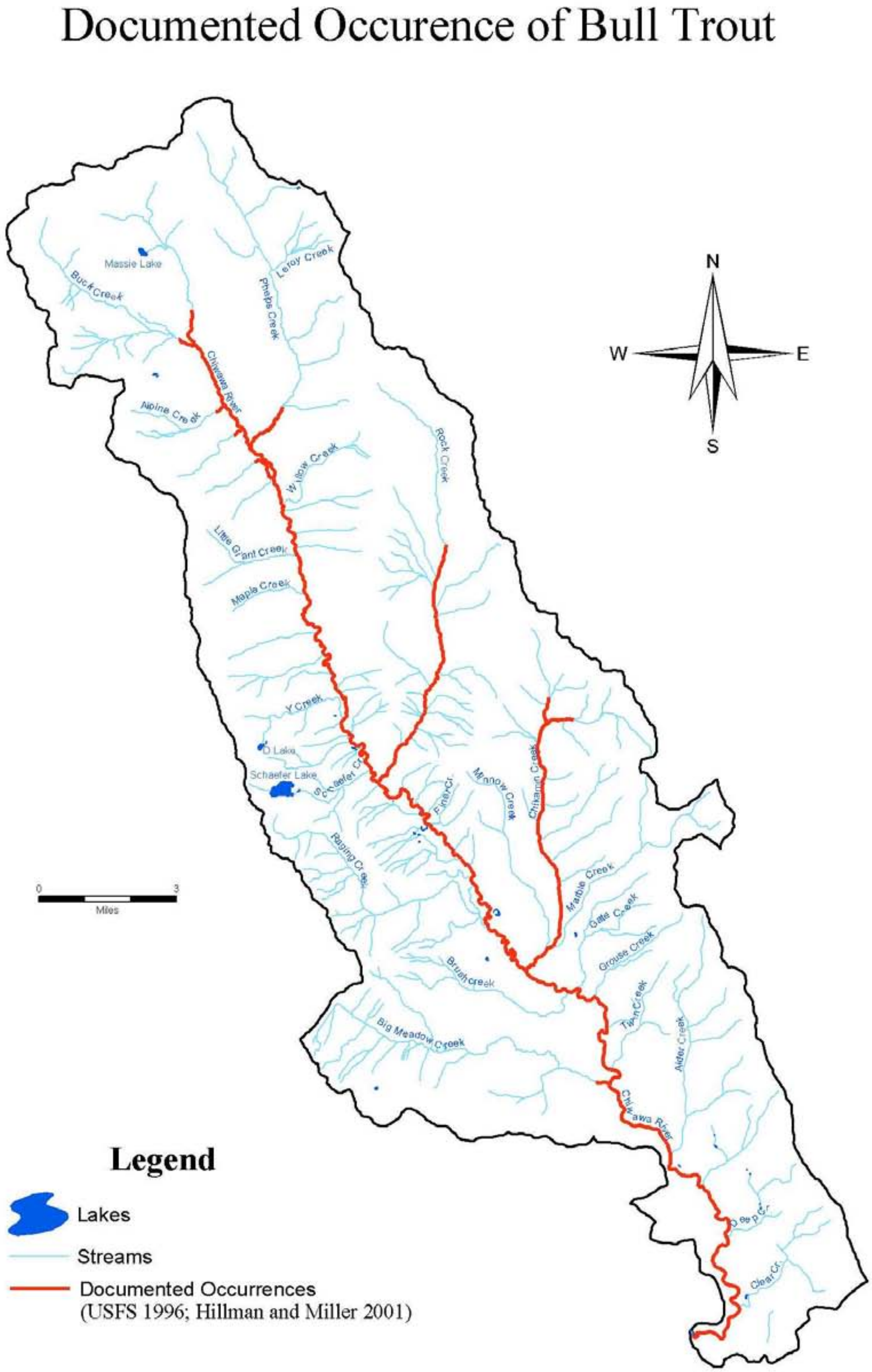

Figure 1. Documented occurrence of bull trout in the Chiwawa River Basin.

Documented Occurence of Chinook Salmon

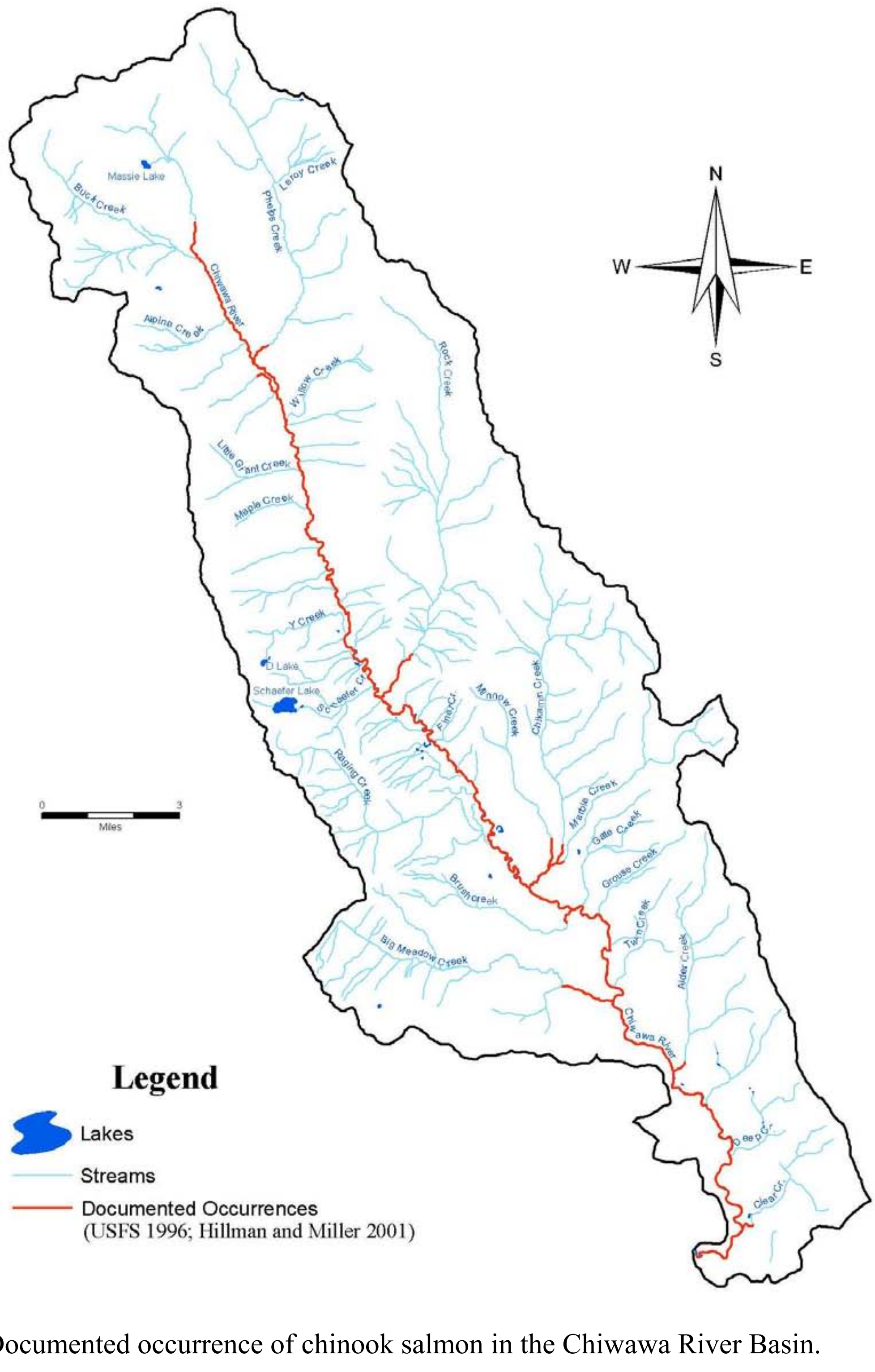

Figure 2. Documented occurrence of chinook salmon in the Chiwawa River Basin.

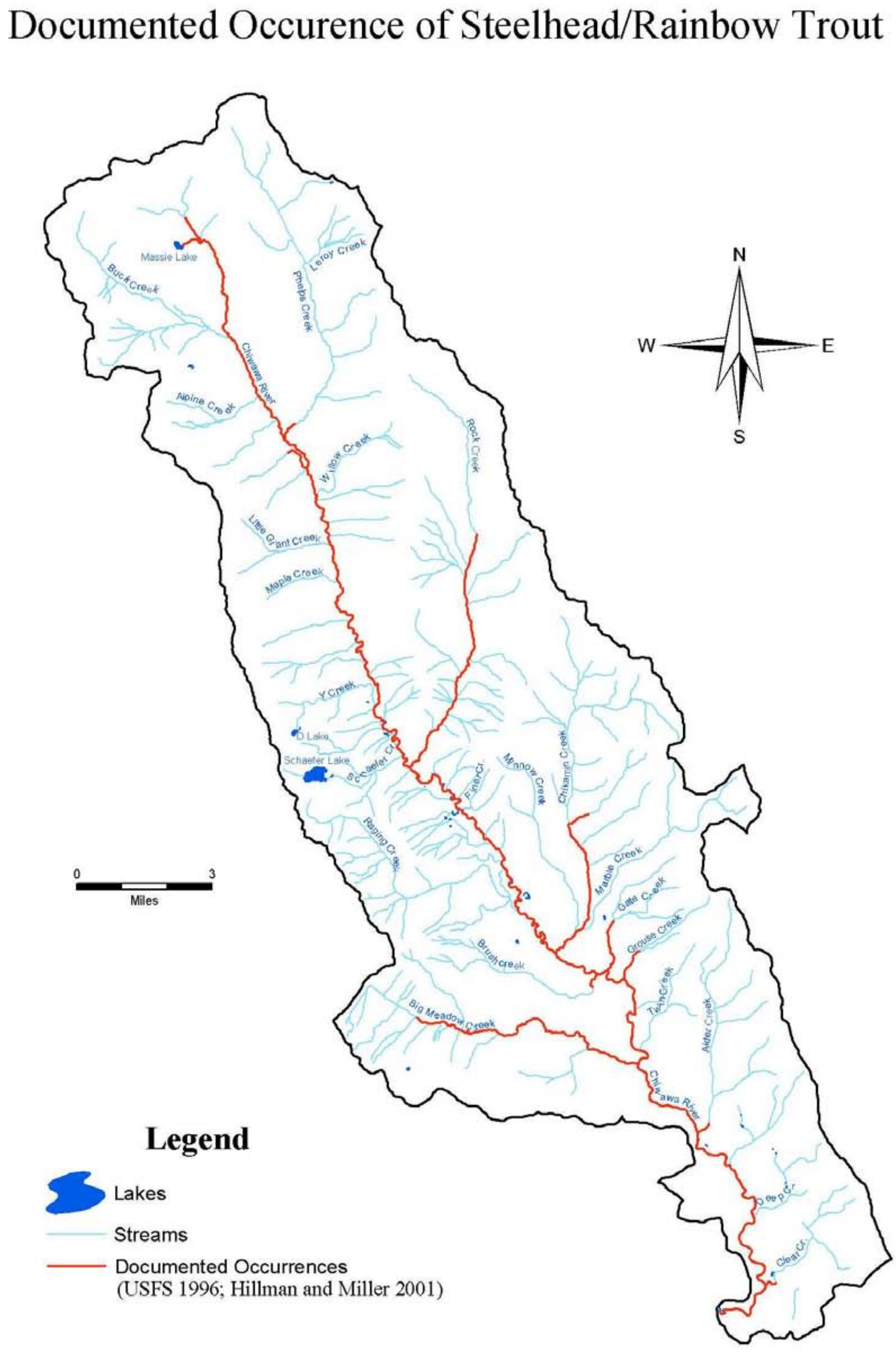

Figure 3. Documented occurrence of steelhead/rainbow in the Chiwawa River Basin.

Documented Occurence of Cutthroat Trout

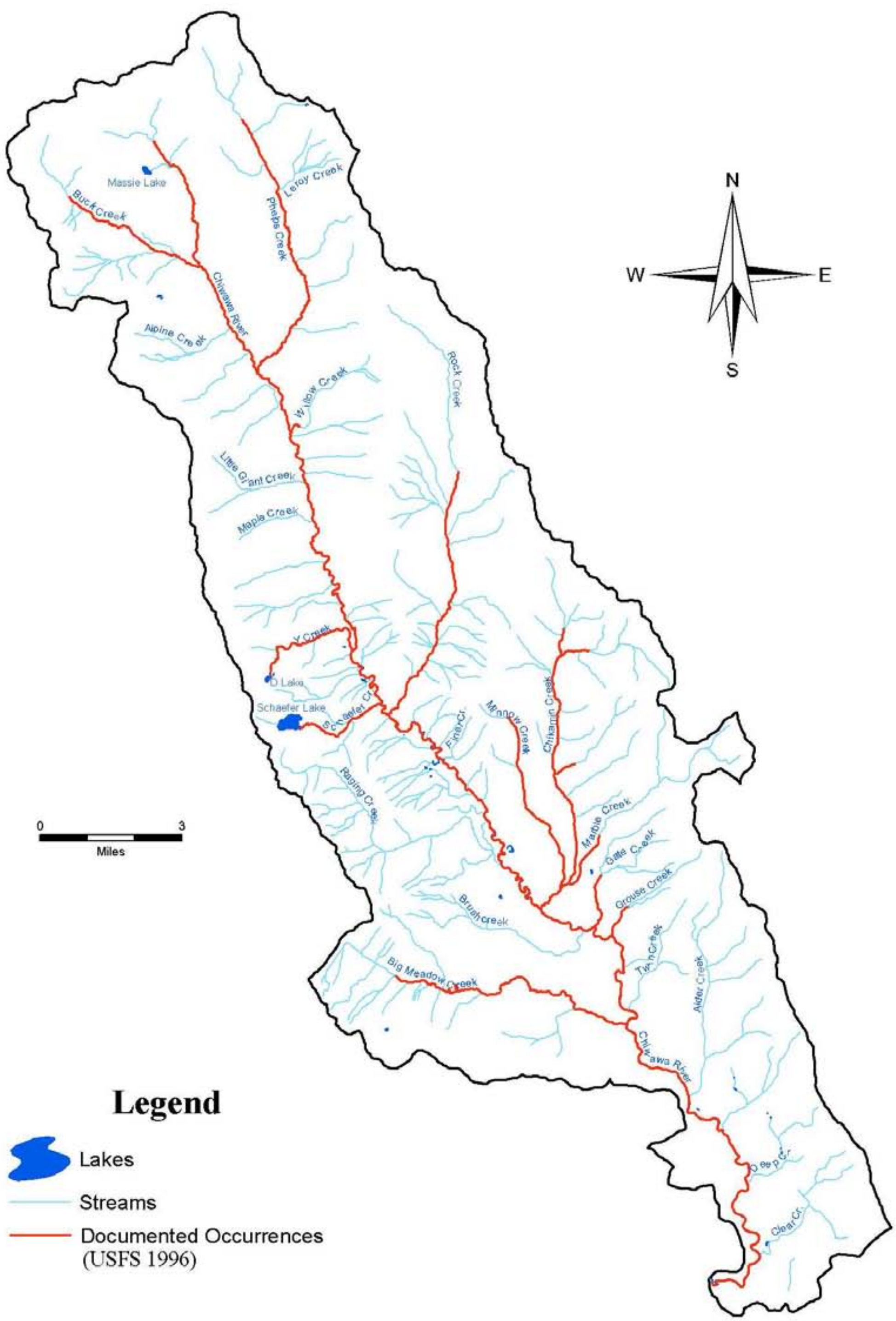

Figure 4. Documented occurrence of cutthroat trout in the Chiwawa River Basin.

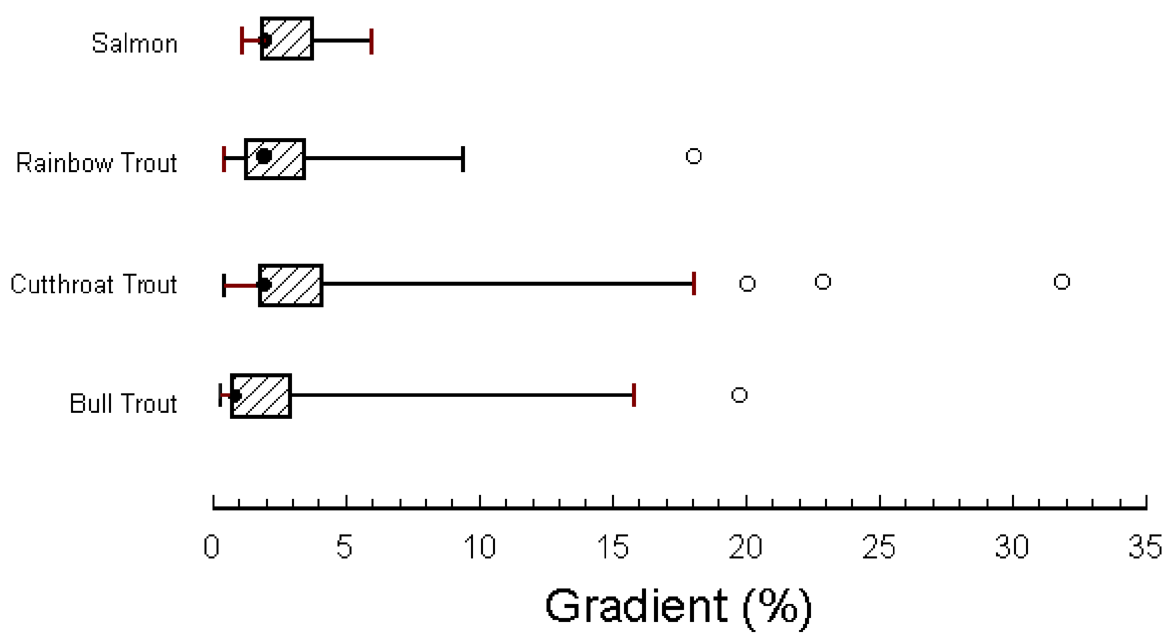

Figure 5. Modified box plots of salmonids across stream gradients sampled from 976 sites in Montana, Idaho, and Washington (Plum Creek Timber Company, unpublished data).

Solid circles (•) represent the most frequently occurring values (mode), boxes represent the middle 50% of observations (bounded by the 25th and 75th percentiles), solid horizontal lines represent the continuous range of gradients occupied by a species, and empty circles (o) indicate discrete gradients occupied by a species. For example, bull trout occupied sites with gradients ranging from 0.5-16%. Most, however, occupied sites with a 1.0% gradient, while the middle 50% of the observations occurred between 1.0-3.0%. Bull trout also used a site with 20.0% gradient, but not sites with gradient >20% or between 16% and 20%.

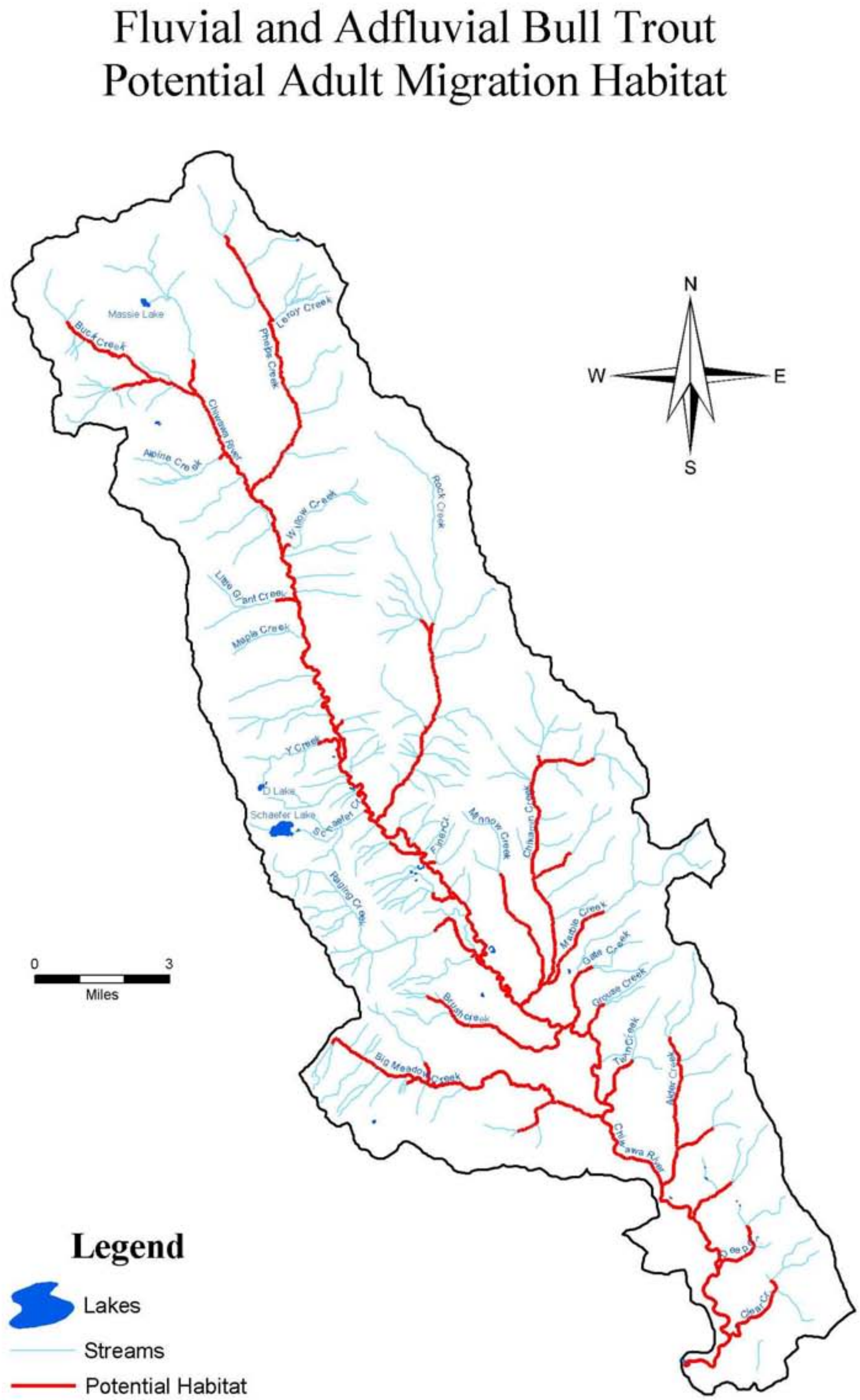

Figure 6. Adult migration potential for fluvial and adfluvial bull trout in the Chiwawa River Basin

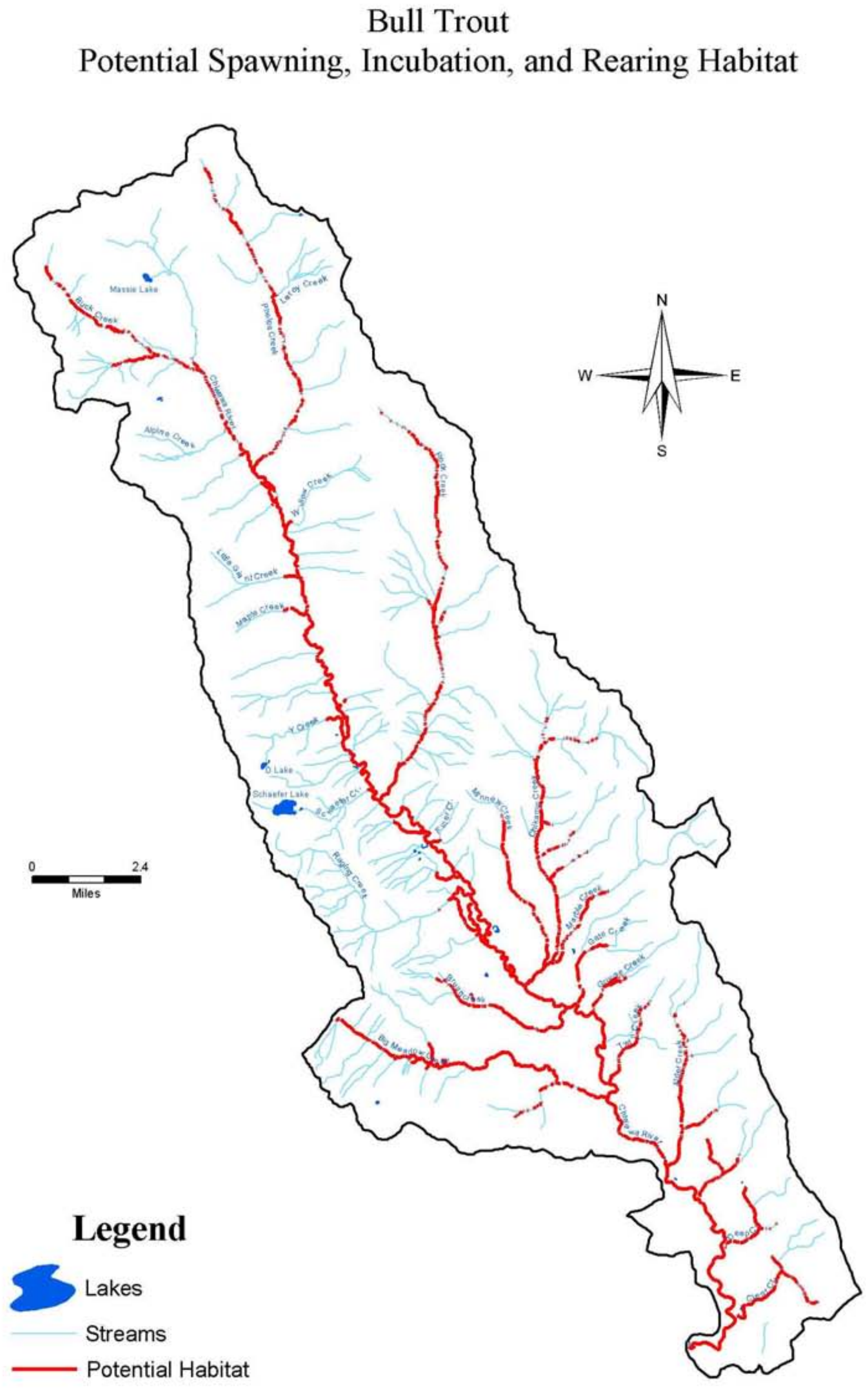

Figure 7. Bull trout potential spawning and incubation, and juvenile rearing habitat in the Chiwawa River Basin

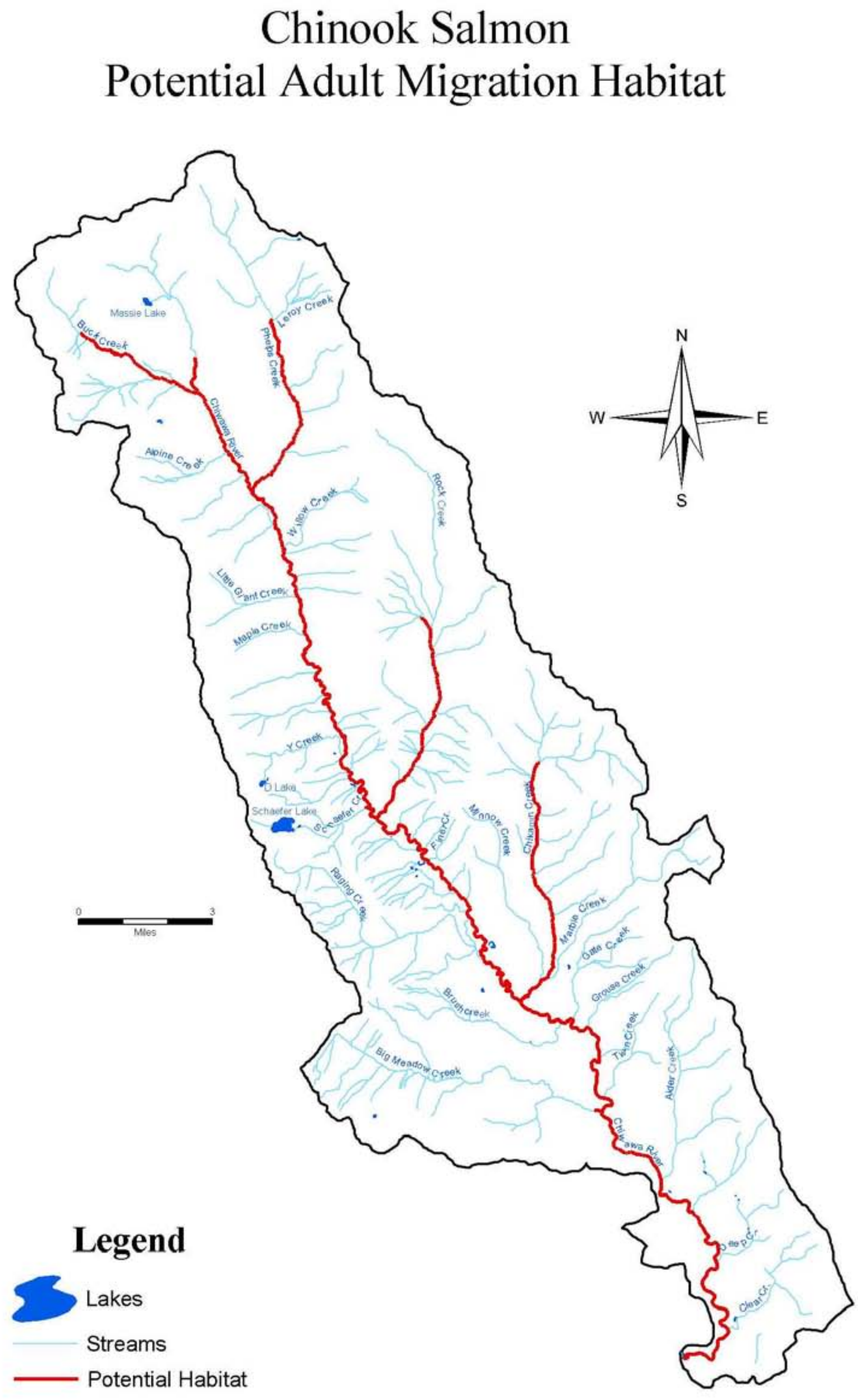

Figure 8. Chinook salmon adult migration potential in the Chiwawa River Basin.

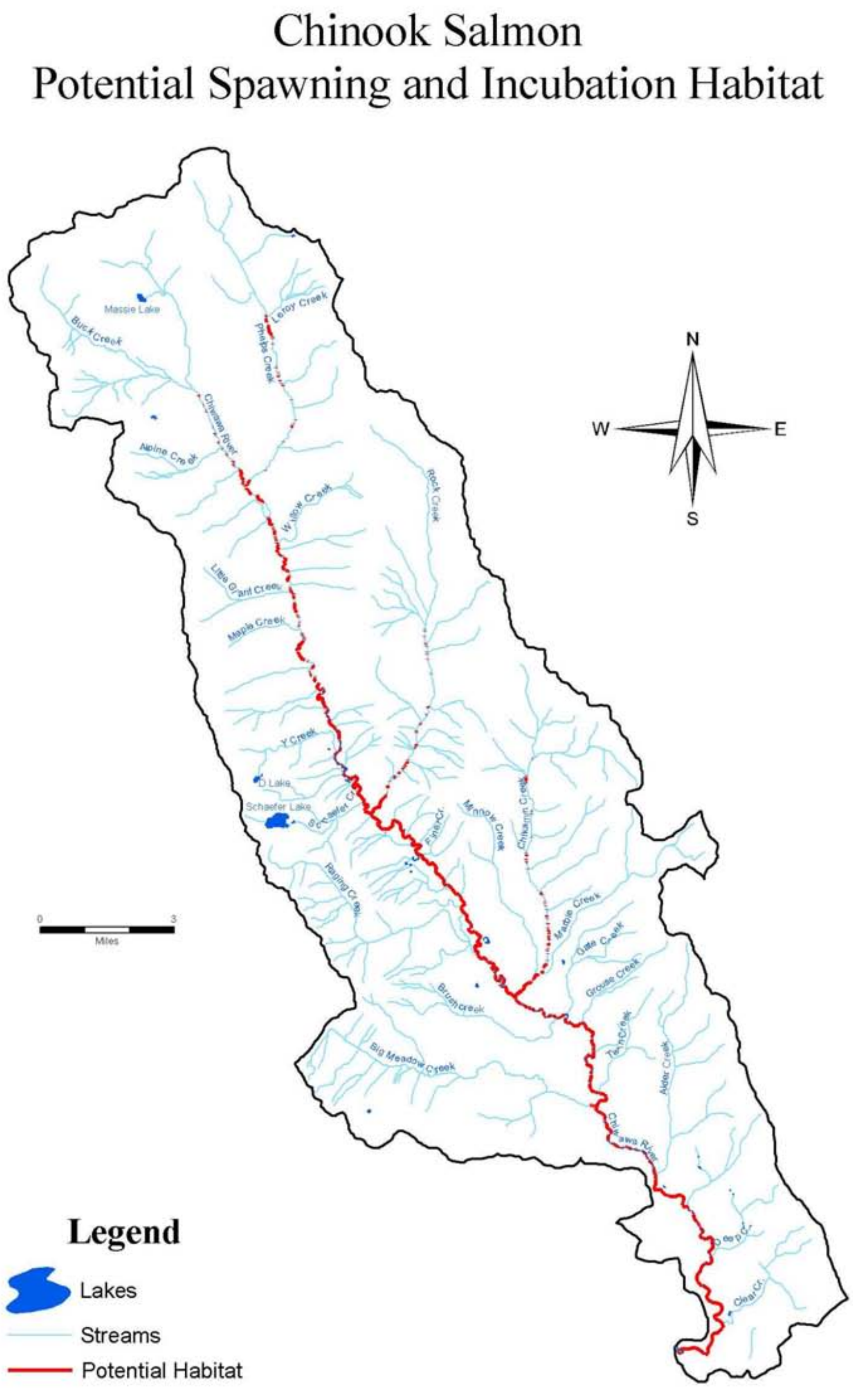

Figure 9. Chinook salmon potential spawning and incubation habitat in the Chiwawa River Basin.

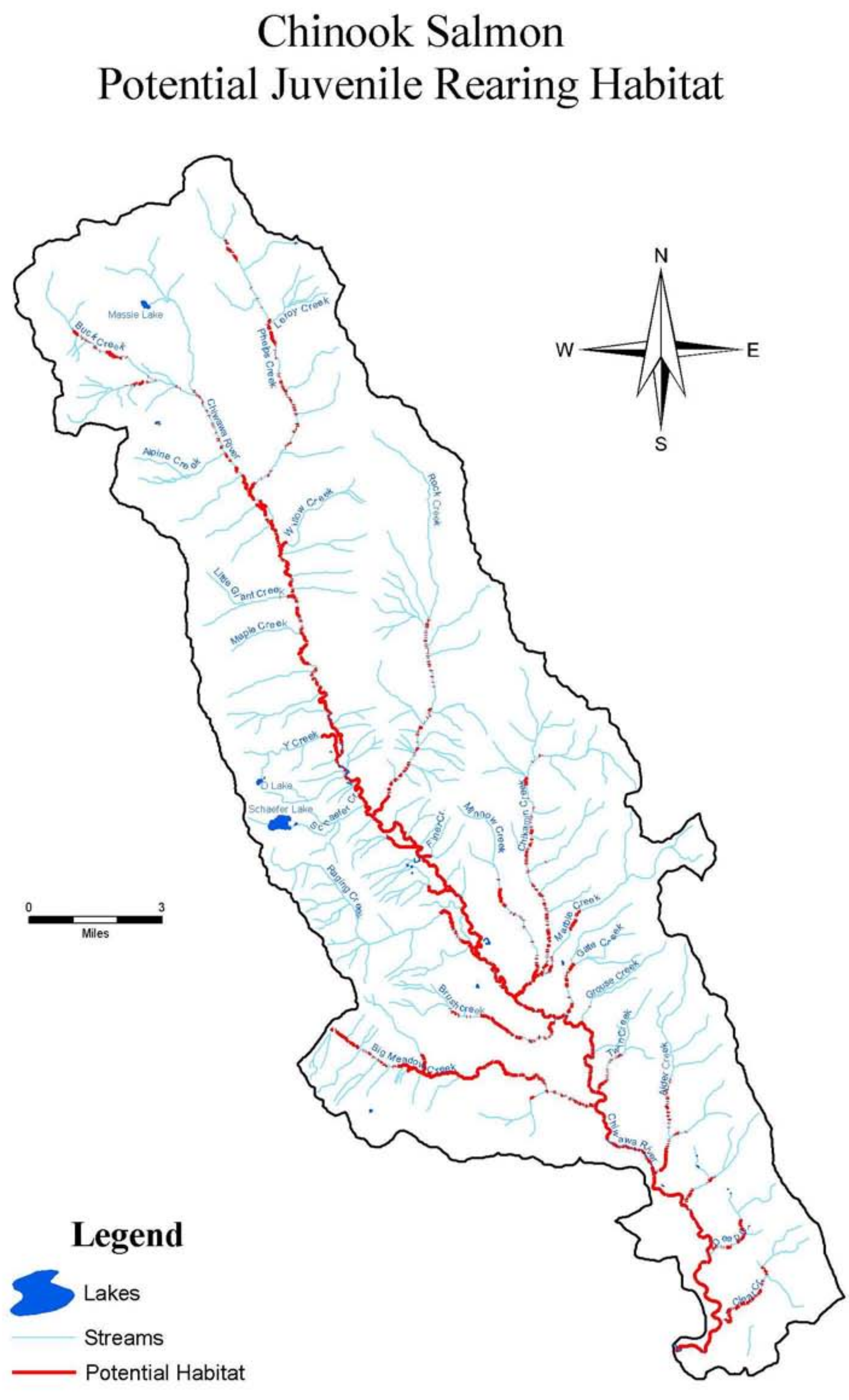

Figure 10. Chinook salmon potential juvenile rearing habitat in the Chiwawa River Basin.

Steelhead/Rainbow Trout
Potential Adult Migration Habitat

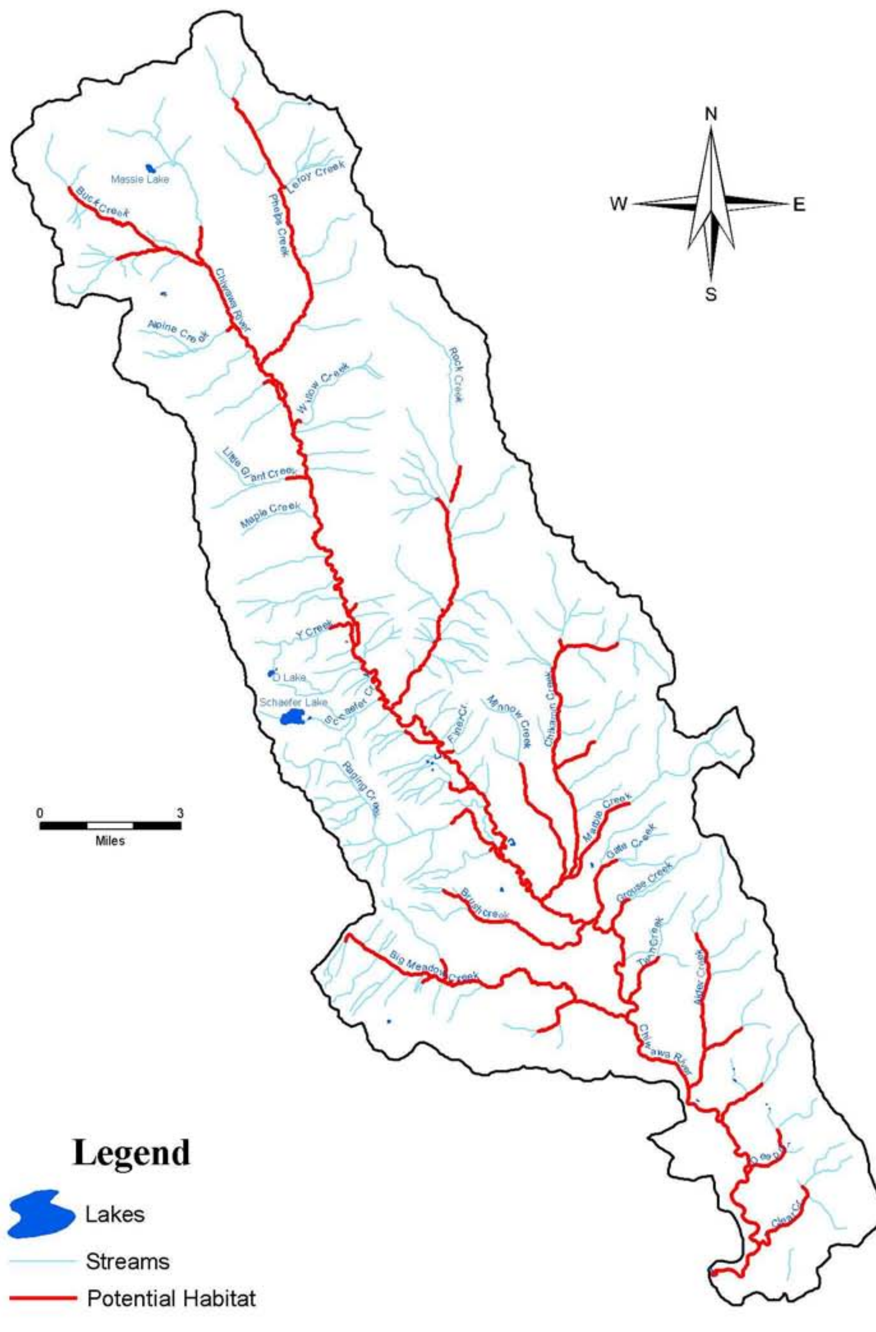

Figure 11. Anadromous steelhead adult migration potential in the Chiwawa River Basin.

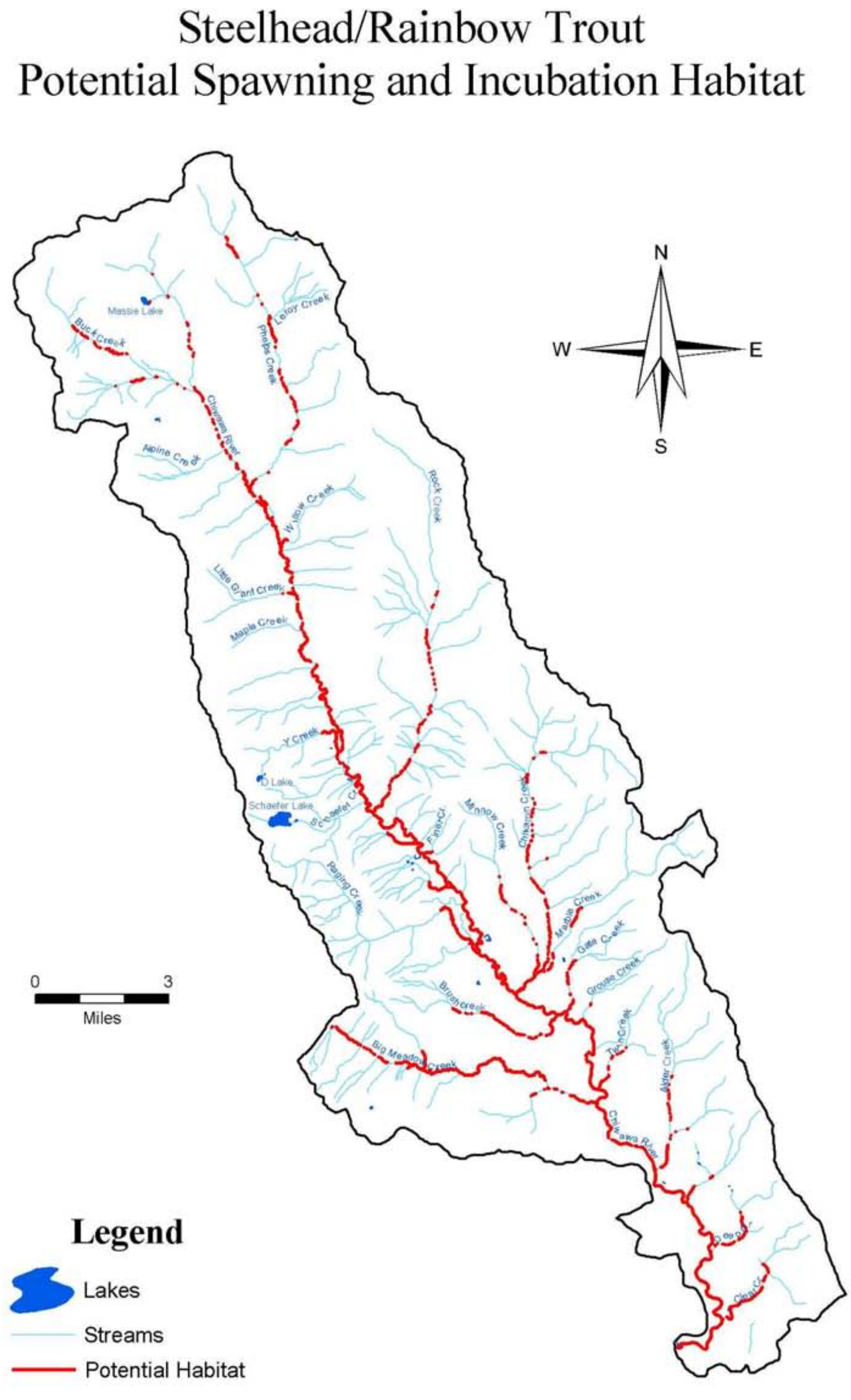

Figure 12. Steelhead/rainbow potential spawning and incubation habitat in the Chiwawa River Basin.

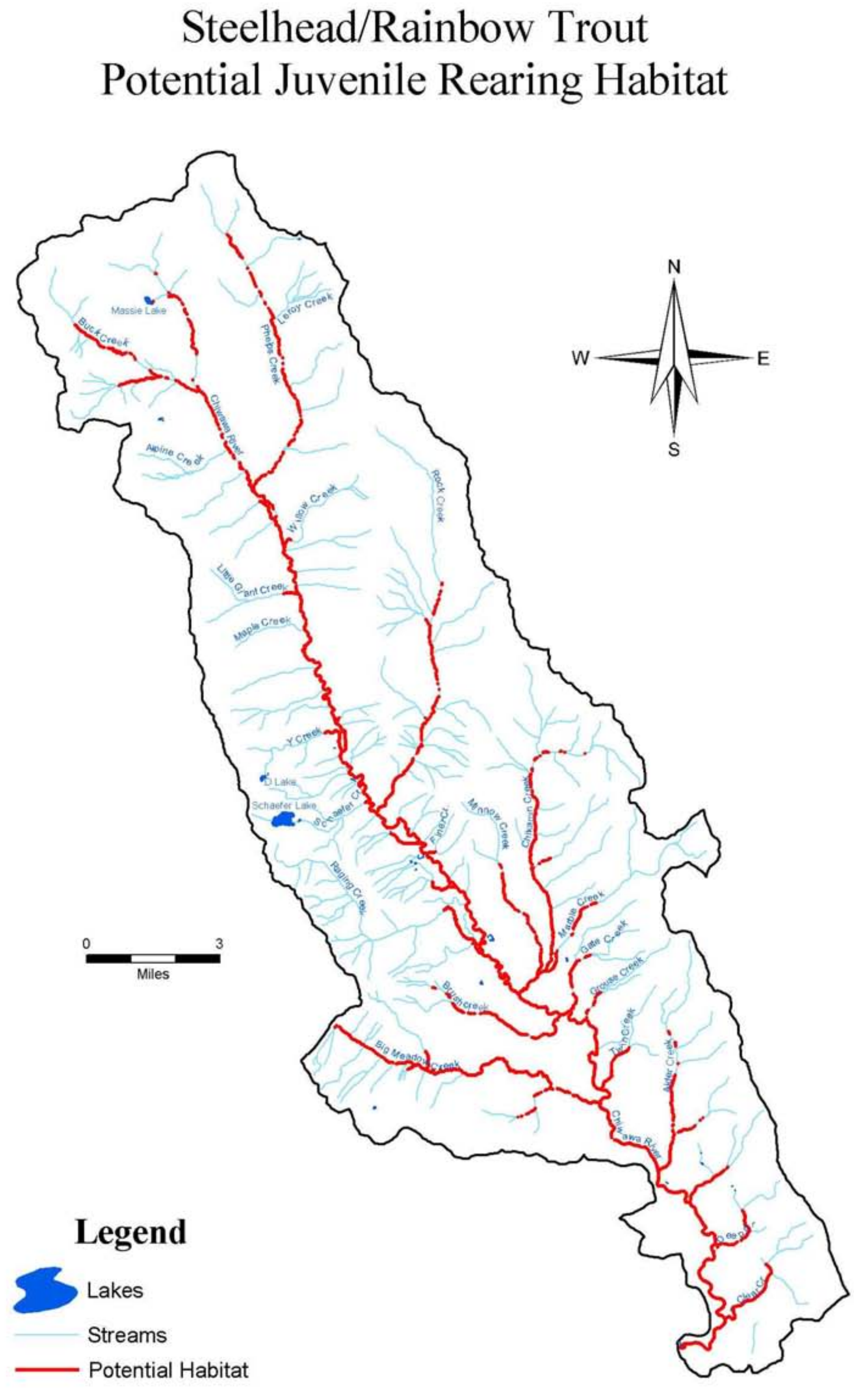

Figure 13. Steelhead/rainbow potential juvenile rearing habitat in the Chiwawa River Basin

Fluvial and Adfluvial Cutthroat Trout Potential Adult Migration Habitat

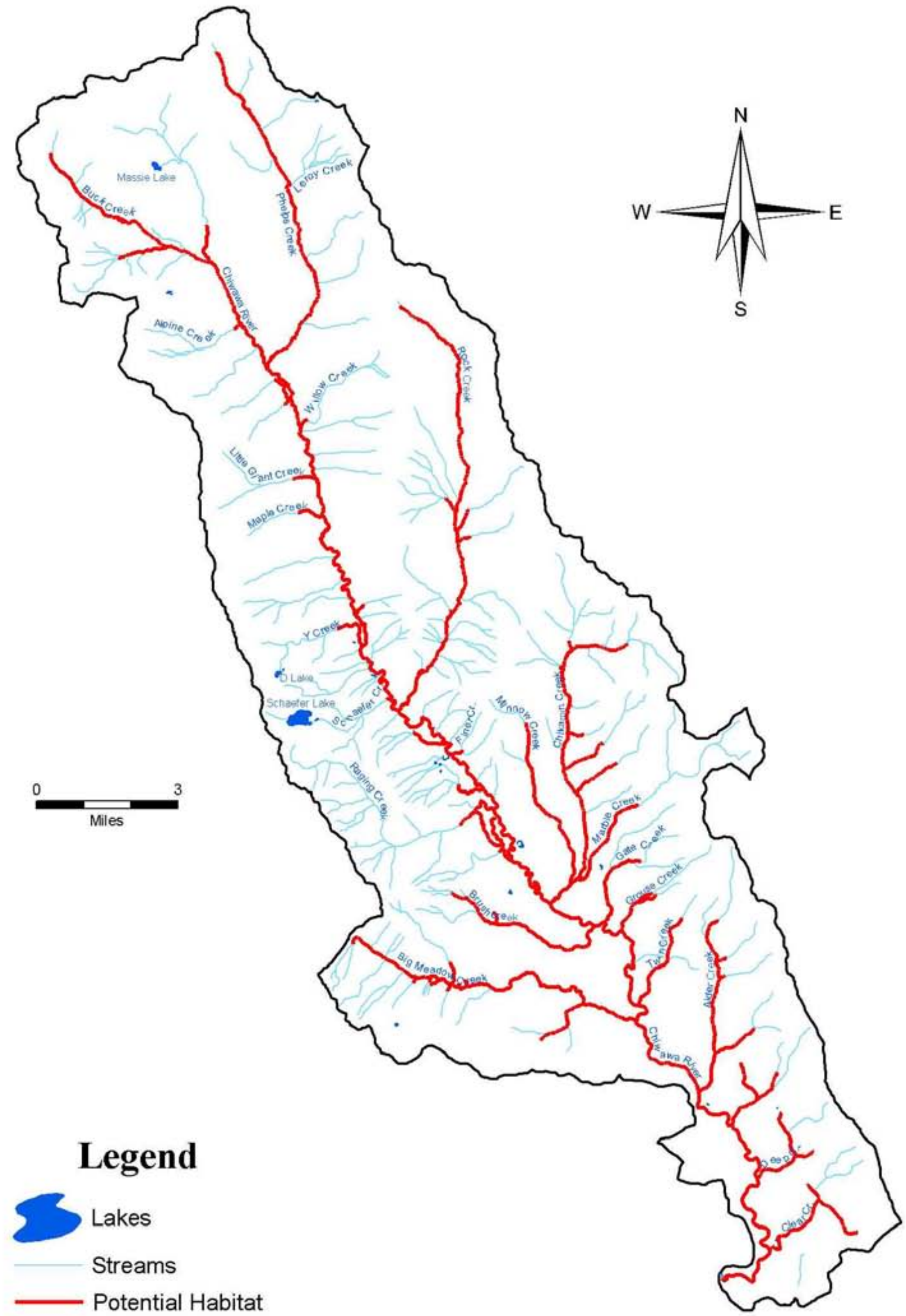

Figure 14. Cutthroat trout adult migration potential in the Chiwawa River Basin.

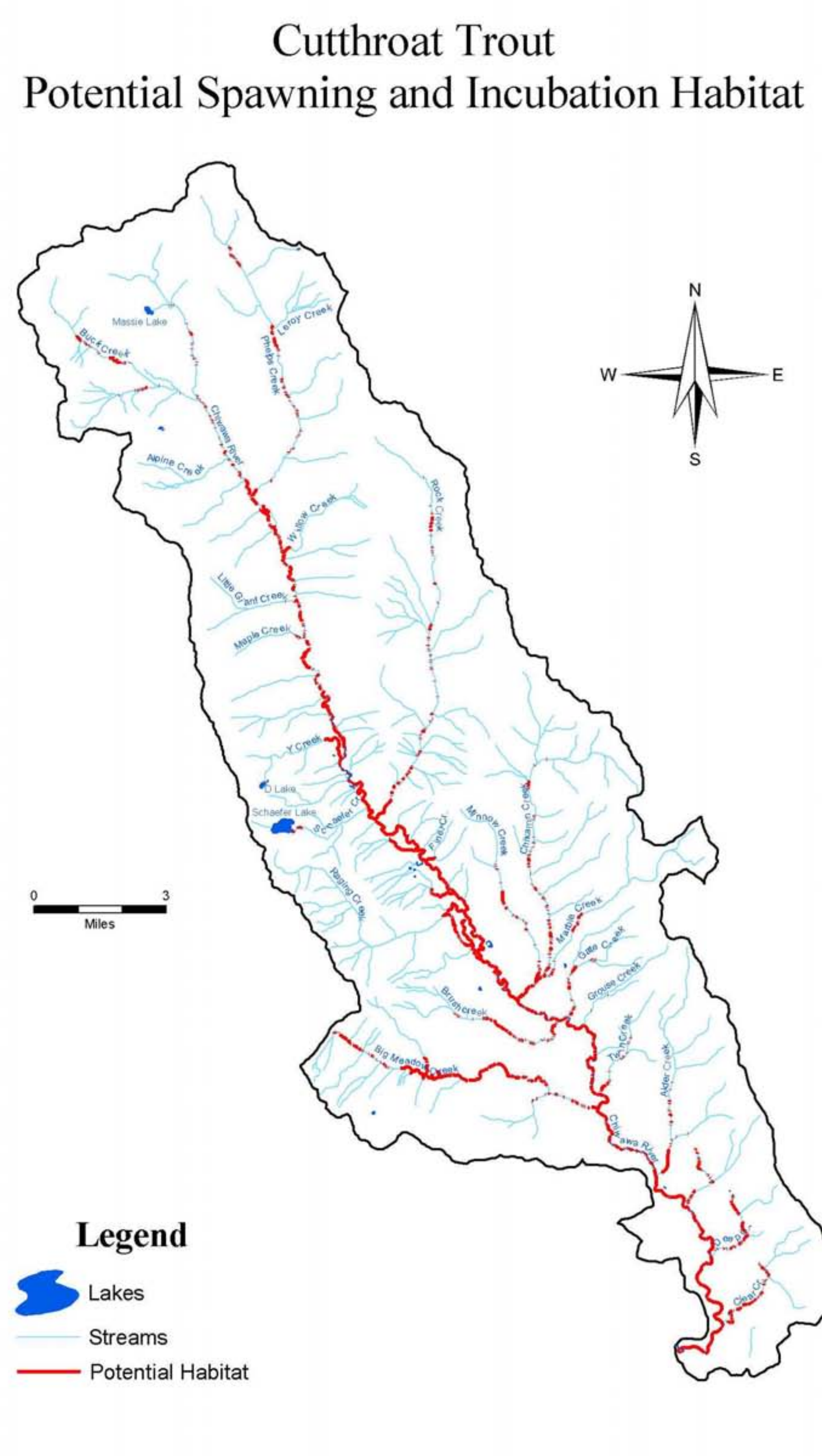

Figure 15. Cutthroat trout potential spawning and incubation habitat in the Chiwawa River Basin.

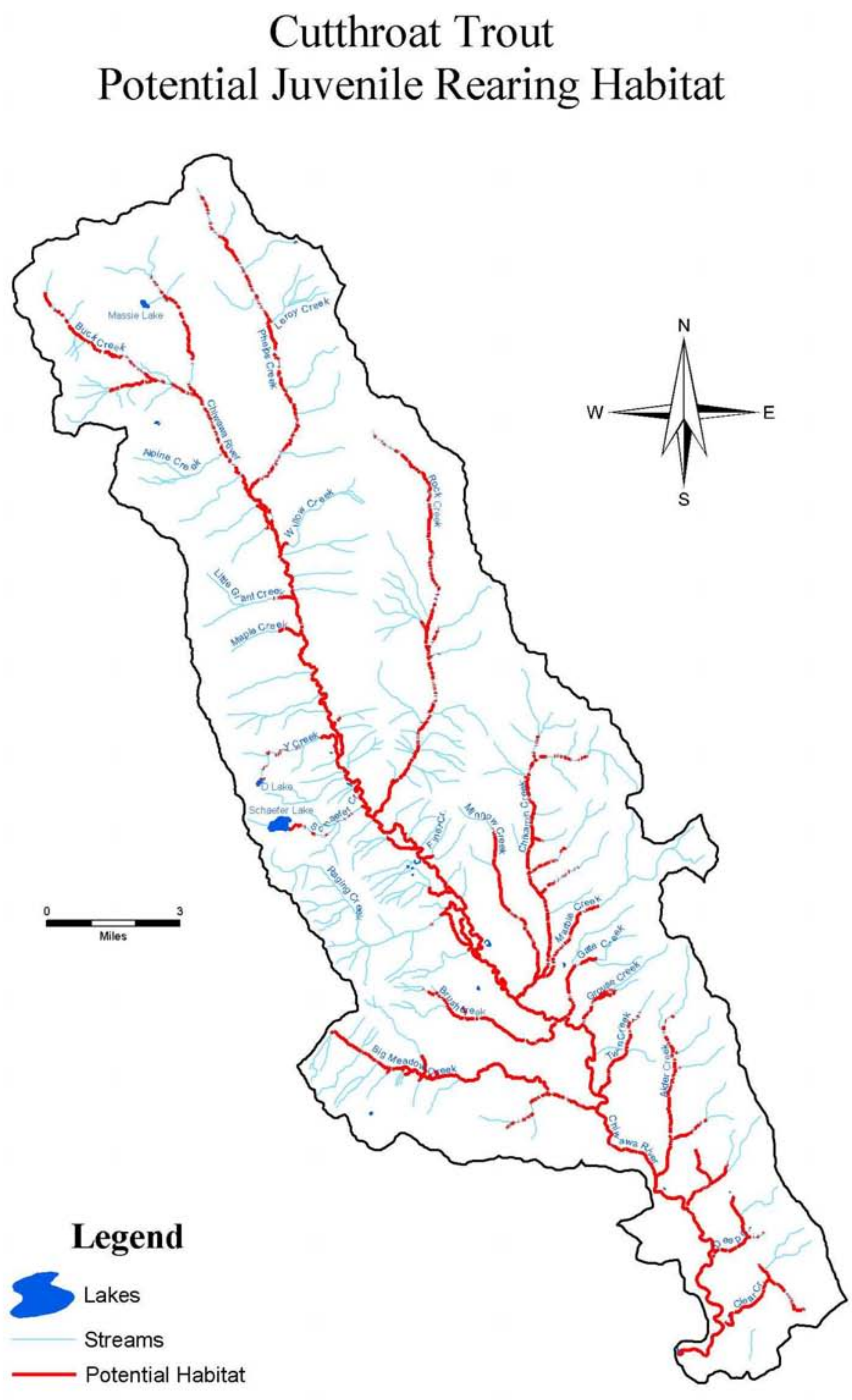

Figure 16. Cutthroat trout potential juvenile rearing habitat in the Chiwawa River Basin.