ADDENDUM – EXCERPTS AND FIGURES FROM

O'Connor, J.E., and Grant, G.E., eds., 2003, A peculiar river: geology, geomorphology, and hydrology of the Deschutes River, Oregon: American Geophysical Union, Water Science and Application 7, 219 p.

O'Connor and Grant, 2003
Deschutes Geology

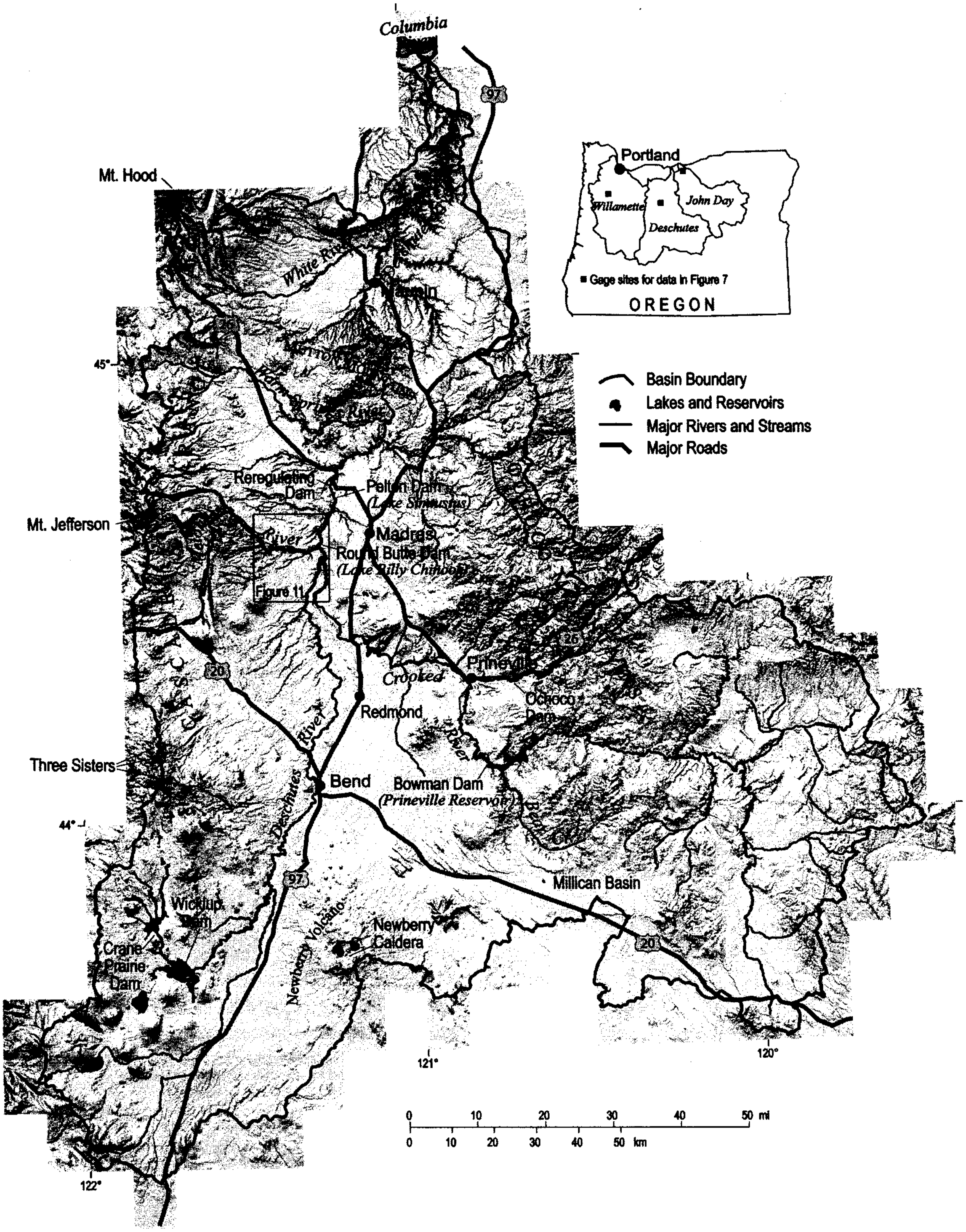

Figure 1. Location map showing major physiographic and cultural features of the Deschutes River basin. Hillshade topographic base derived from U.S. Geological Survey 30-m resolution digital elevation data.

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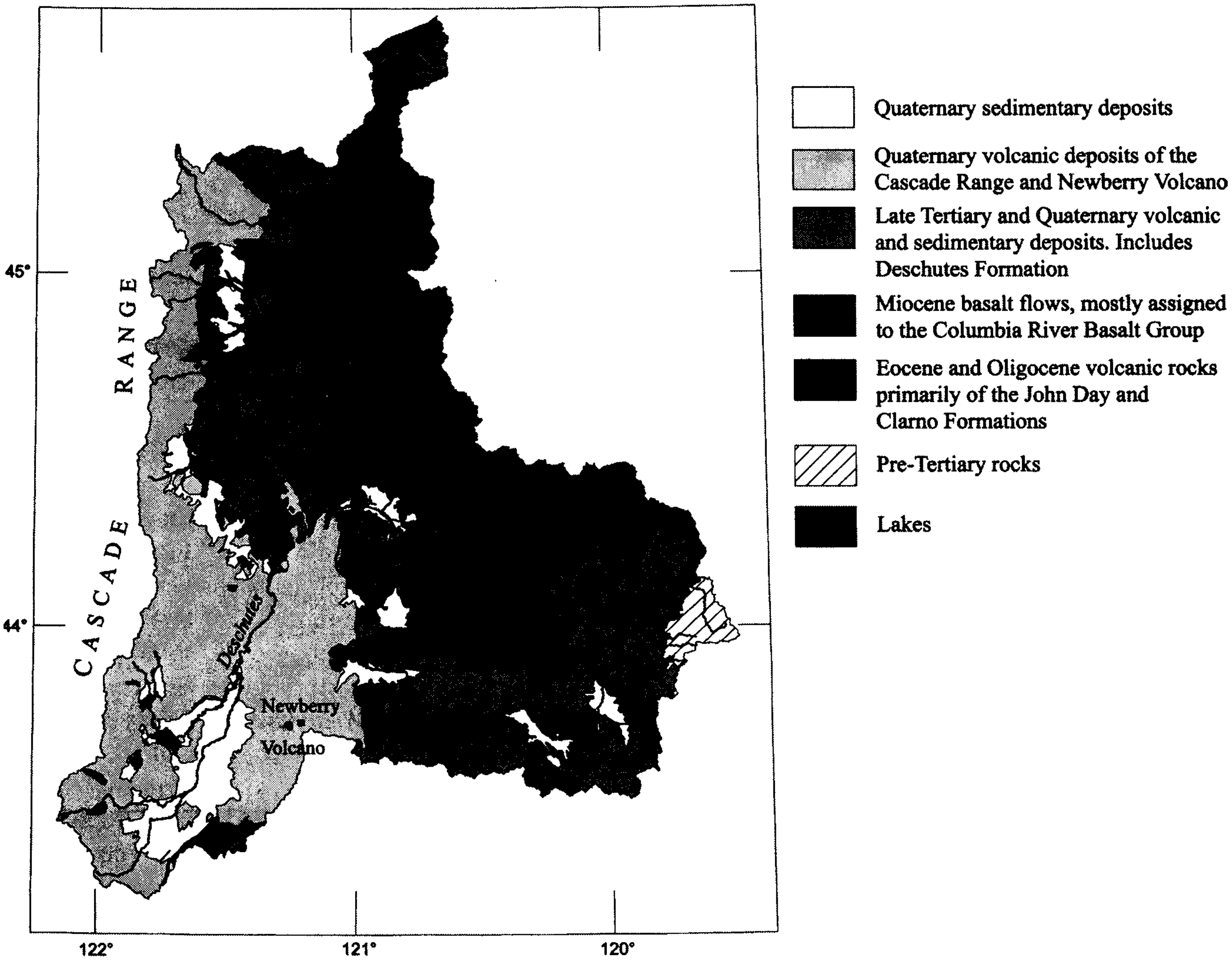

Figure 3. Generalized geologic map of the Deschutes River basin.

sed primarily of andesitic and rhyolitic lava, mudflows, d tuffaceous sediments [*Orr et al.*, 1992]. These units are posed in a northwest-trending belt extending from the utheastern part of the basin to the Mutton Mountains north Warm Springs. This belt of Eocene to early Miocene rock rms the boundary of the basin into which the younger scade-derived materials were deposited.

Regional groundwater flow into the Deschutes River sys- n occurs almost exclusively in the late Miocene to iocene Deschutes Formation and younger deposits of the scade Range and Newberry Volcano. These deposits are nerally permeable, and the volcanic upland and large aks of the Cascade Range form the principal recharge area r the basin. The John Day and Clarno Formations, in con- st, have very low permeability due to extensive devitrifi- tion and secondary mineralization. These older deposits und the permeable younger units. Where deposits of the hn Day and Clarno Formations occur upgradient of the younger more permeable deposits, they contribute only minimal water to the regional groundwater system due to their low permeability and the fact that they occur primarily in the drier, eastern parts of the basin where little recharge occurs. Where the John Day and Clarno Formations occur downgradient from the younger more permeable deposits, they impede subsurface flow, diverting most groundwater flow out to springs and streams.

The principal area of regional groundwater flow, therefore, includes the southwestern part of the Deschutes River basin extending from the crest of the Cascade Range to the contact with the low-permeability early Tertiary rocks of the John Day and Clarno Formations. In the south-to-north direction, the area extends from Newberry Volcano northward to the point at which the Deschutes River system has cut down to the low permeability rocks. This is the area considered in this paper, and is henceforth referred to as the "upper Deschutes River basin."

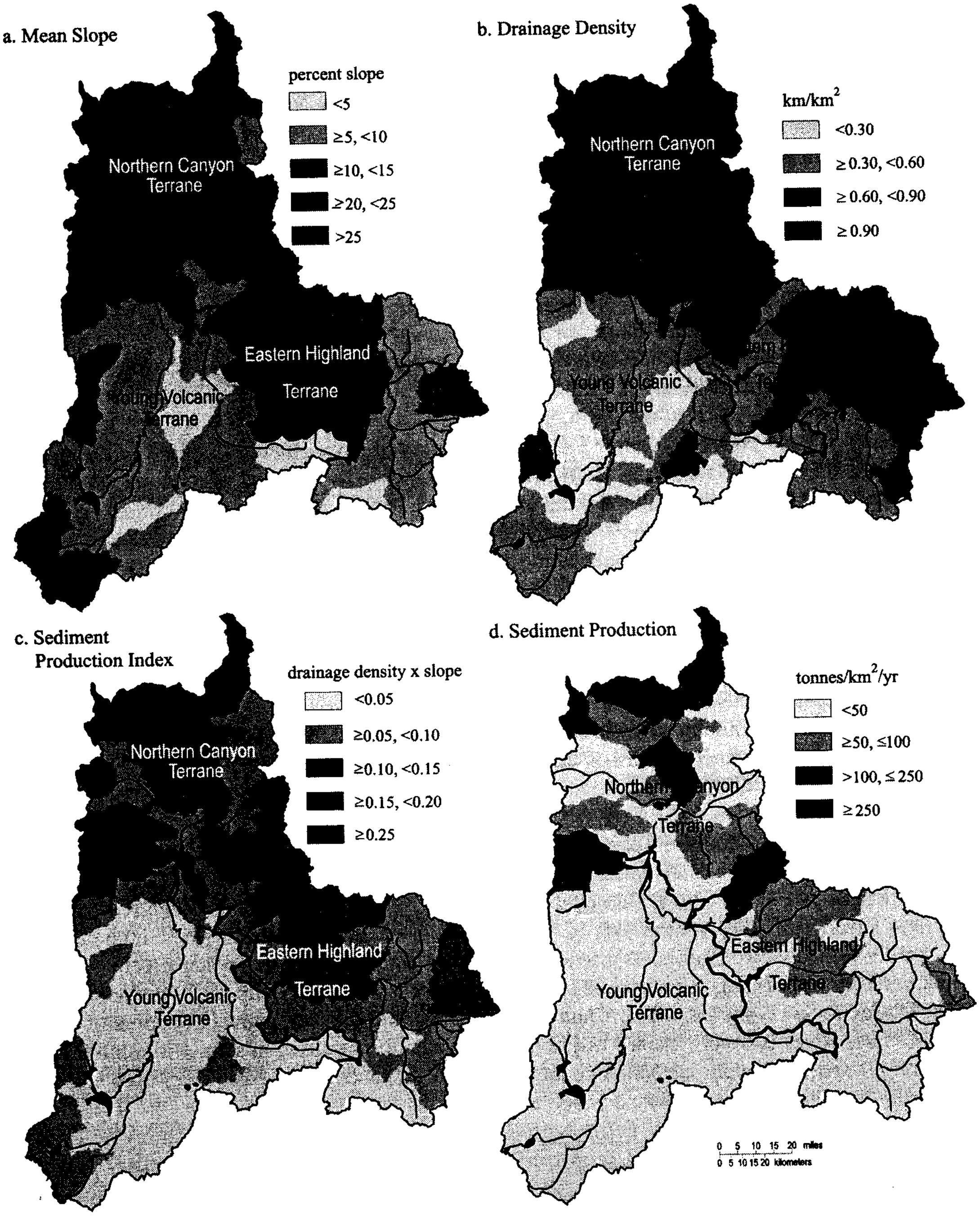

Figure 4. Distribution of geomorphic attributes and estimated sediment production for 100 approximately equal-sized subbasins of the Deschutes River basin. (a) Mean subbasin hillslope gradient, calculated from U.S. Geological Survey 30-meter digital elevation data (depicted in Figure 1). In many subbasins there are areas of significantly higher and lower slopes. (b) Subbasin drainage density, from mapped watercourses shown by U.S. Geological Survey 1:100,000 digital hydrography (shown on Figure 6). (c) Sediment Production Index (SPI), calculated as the product of mean gradient and drainage density as depicted (in a generalized fashion) in 4a and 4b (where slope is expressed as a fraction). (d) Calculated sediment yields, developed from empirical relation between SPI and surveyed accumulations in Deschutes River basin reservoirs (shown in Figure 14).

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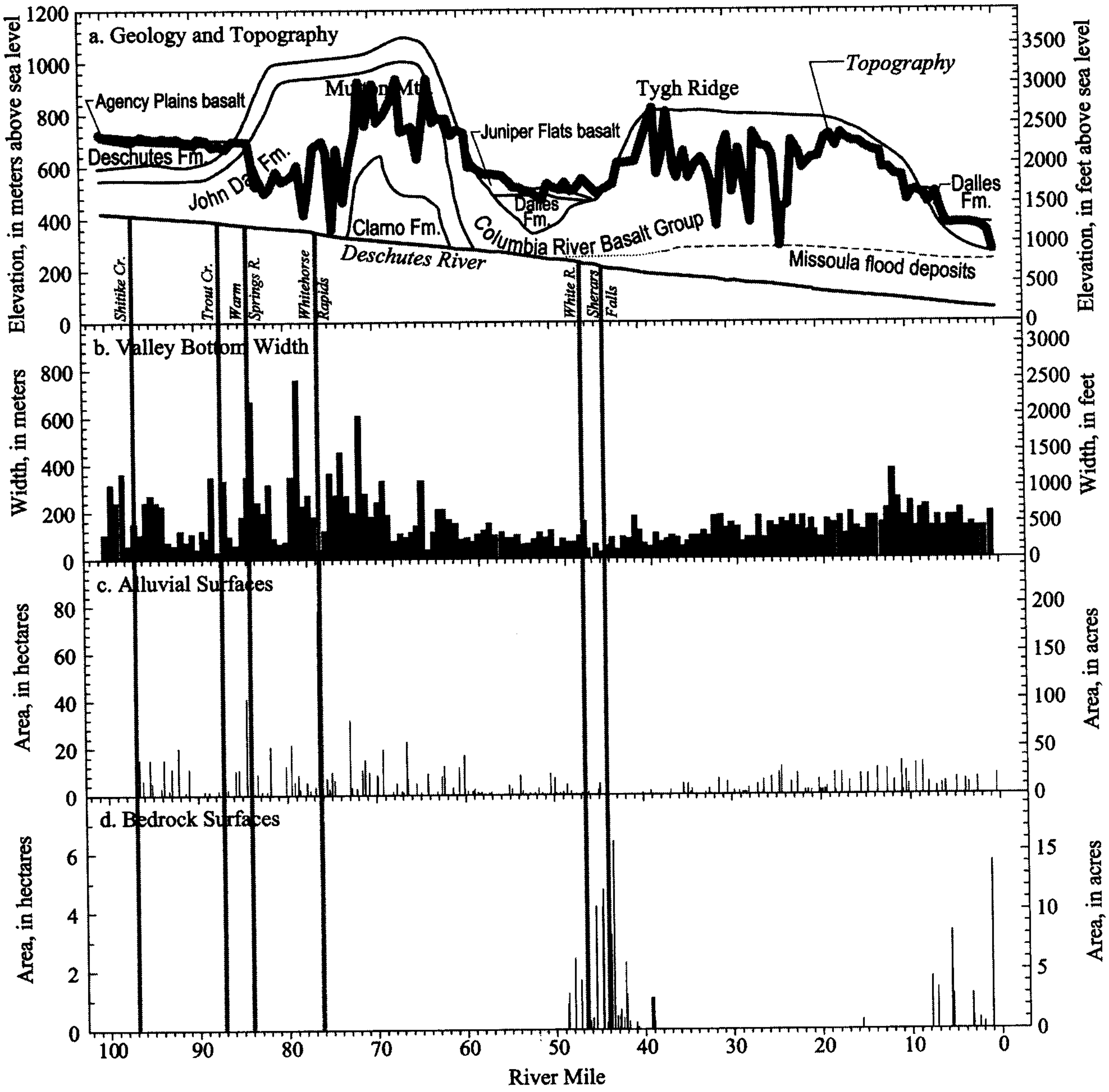

Figure 3. Canyon and valley-bottom characteristics of the lower Deschutes River. (a) Deschutes River profile and generalized geology and topography. River profile from elevation data on USGS 7.5-minute topographic maps. Topography is represented by the highest point within 2 km of the Deschutes River channel, measured from transects placed orthogonal to the channel and spaced at 1 km increments on USGS 7.5-minute topographic maps. Pre-Quaternary geology of the valley walls along the river generalized from position of contacts on 1-km spaced transects oriented perpendicular to the channel. Contact positions, in downstream order, after *Smith* [1987], *Smith and Hayman* [1987], *Waters* [1968a, b], *Bela* [1982], *Sherrod and Scott* [1995], and *Newcomb* [1969]. The distribution of Missoula flood deposits blanketing older rocks was mapped from aerial photographs and field reconnaissance. (b) Width of the valley bottom, as measured from transects oriented perpendicular to the channel and spaced at 1-km increments. (c) Distribution and size of alluvial surfaces within the valley bottom. (d) Distribution and size of bedrock surfaces within the valley bottom.

Table 2. Surficial processes active in forming the Deschutes River valley-bottom and channel features and defining characteristics of the resulting landforms.

Formative Process	Description	Defining Characteristics of Landforms Created
Outsized flood (> 1000 year flood)	Deschutes River flood with recurrence interval on the order of 1000 years; includes the Outhouse Flood [*Beebee and O'Connor,* this volume] and breaches of channel-damming landslides [*O'Connor et al.,* this volume]	Deposits include rounded, imbricated boulders; top elevation of deposit is above the 1996 flood level; features are convex in cross section; features are lenticular in planform or have a bar shape
Annual- to century-scale flood	Deschutes River flood with recurrence interval less than 1000 years, more typically 10 to 100 yrs; includes historical floods of 1996, 1964, and 1861. The 1996 flood is used as a model for this category of flooding because the flood was well documented and high water marks were still evident at the time of field studies.	Deposits do not include boulders; top elevation of deposit is near or below the 1996 flood level
Undifferentiated flood	Deschutes River flood of undetermined magnitude	Lacks characteristics sufficient to categorize as result of outsized flood or annual- to century-scale flood but includes rounded clasts and other fluvial features
Tributary flood	Floods and debris flows emanating from a tributary into the Deschutes River	Fan-shaped deposits at tributary mouths; deposits may include angular and sub-angular clasts
Bedrock erosion	Slow removal of bedrock by fluvial erosion	Exposed bedrock straths at or near river level; zones of bedrock channel bed with small bedrock islands
Colluvial processes	Distributed transport of hillslope material onto valley bottom by gravity; includes rockfall and talus slopes	Angular, coarse clasts with few fines
Mass movements	Discrete transport of hillslope material onto valley bottom by roughly simultaneous movement of a large mass of earth; includes landslides and debris flows not at tributaries	Coherent blocks of landslide material; coarse remnants of landslide dams
Undetermined	Process not clearly identifiable	Characteristics not unique enough to categorize under a single process

recreationists attracted to the river's remote and scenic setting as well as its coldwater fishery. The entire Deschutes River between the Pelton-Round Butte dam complex and the Columbia River is a congressionally designated Wild and Scenic River.

DISTRIBUTION AND FORMATION OF VALLEY-BOTTOM AND CHANNEL FEATURES

The valley bottom of the Deschutes River downstream from the Pelton-Round Butte dam complex is composed of a suite of landforms that have developed from Quaternary hillslope and fluvial processes. To better develop understanding of the relation between current valley-bottom and channel morphology and formative processes downstream of the dam complex, we have systematically inventoried landforms from maps, aerial photographs and field observations (Table 1). On the basis of feature morphology and reconnaissance observations of composition and stratigraphy, we have inferred the primary formative processes responsible for each valley and channel feature (Table 2).

The lower Deschutes River valley bottom, defined as the relatively flat area between canyon walls or colluvial slopes, has a total area of about 2600 hectares (ha) (Table 3). The val-

Table 3. Surface area of lower Deschutes River valley-bottom and channel features.

Feature	Area (ha)	Area (% of total)
Islands	56	2
Channel (excluding islands)	1100[1]	43
Alluvial surfaces	960	38
Fluvially stripped bedrock surfaces	55	2
Tributary fans	240	9
Other surfaces[2]	140[3]	5

[1] Channel area calculated from measured channel widths (Figure 2) applied over 1 km intervals.

[2] Landslide debris, colluvial surfaces, bedrock not modified by fluvial processes, and railroad ballast.

[3] Area obtained by subtracting area of all measured features from area of valley bottom.

ley bottom has an average width of 165 m (Figure 2), and is occupied primarily by the channel and flanking alluvial surfaces (Table 3). Fluvially modified (stripped or eroded) bedrock surfaces are in and adjacent to the channel in discrete reaches. Tributary fans locally protrude into the river and constrict the channel (Figure 3c). Alluvial and bedrock islands (Figure 3a) are a small part of the valley but are ecologically important because of the aquatic habitat provided by their flanking side channels. Rapids are found throughout most of the study reach and are an important element of the river's recreational value. The remainder of the valley bottom is composed of landslide debris, colluvial surfaces, bedrock outcrops not clearly modified by fluvial processes, and railroad ballast. The distribution of these features along the river corridor, their prominent characteristics, and their implications for surficial processes are discussed in the following sections.

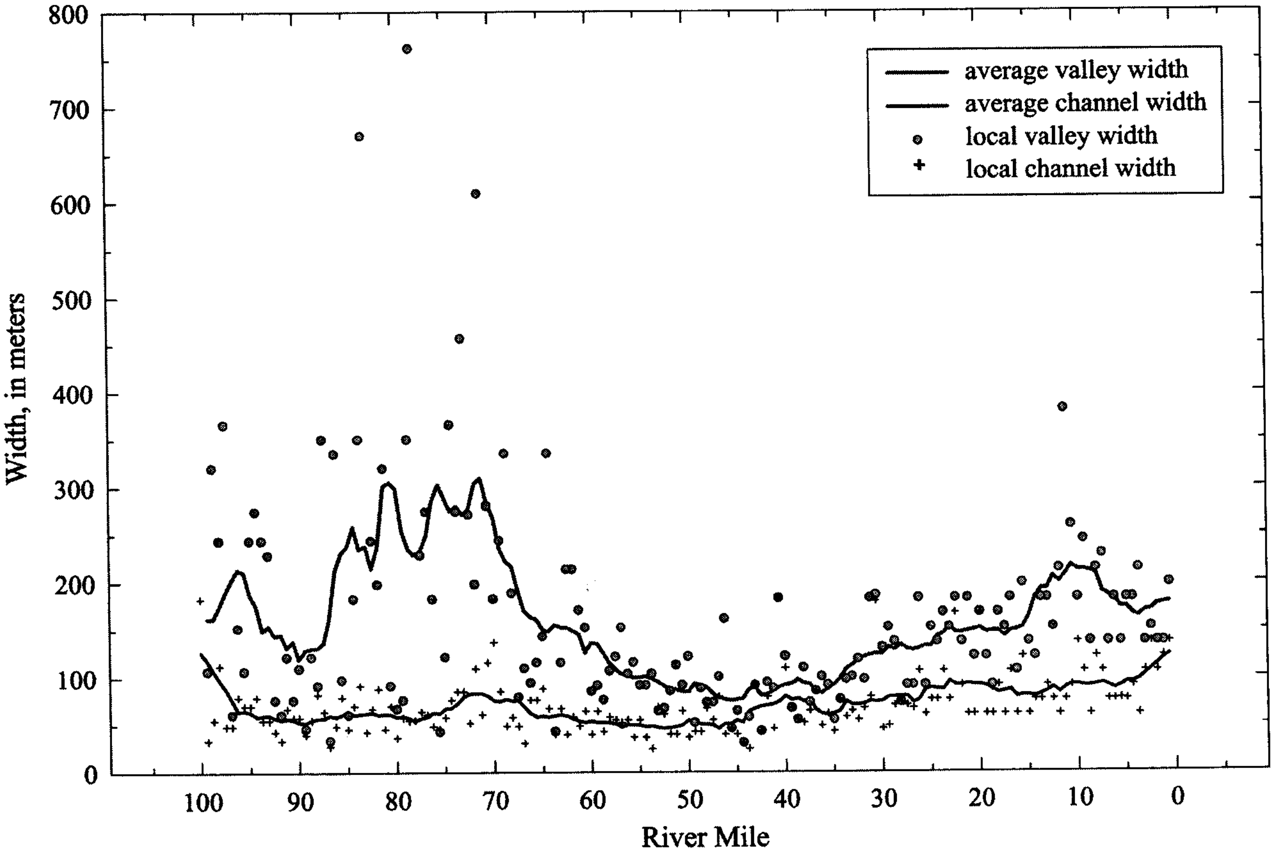

Figure 2. Lower Deschutes River valley width and channel width. Extensive landsliding in the less resistant upper canyon has resulted in a wider valley, on average. Average channel width does not parallel the valley width trends of the upper canyon, but increases gradually over the length of the lower canyon. Local widths shown are from USGS 1:24,000-scale topographic maps. Averages shown are 11-value running averages of local widths.

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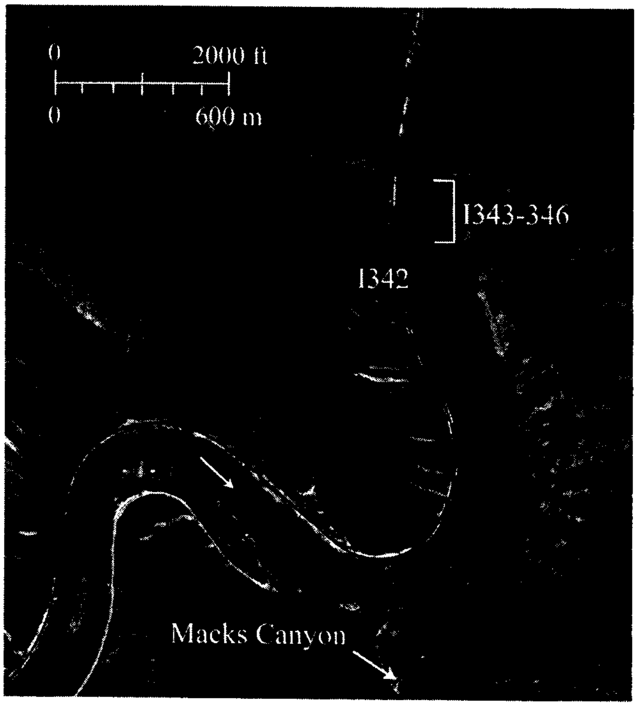

Figure 10. Airstrip Island (Island 342) is cored by gravel, cobbles, and boulders up to 0.5 m in diameter and was not overtopped in the February 1996 flood, evidence that it was formed by outsized flooding. Islands 343 through 346 are inferred to have been deposited at the same time, such that the entire group of five islands is an erosively modified transverse bar. Aerial photograph dated 1995, Portland General Electric.

Large Quaternary mass movements directly or indirectly account for the six named rapids between RM 100 and 50 [*O'Connor et al.*, this volume]. Trout Creek Rapids is composed of 2- to 3-m-diameter boulders deposited during a flood that apparently resulted from a landslide-dam breach. Whitehorse Rapids is the remnant of a landslide dam formed by a large, late Pleistocene mass movement at RM 76 (Figure 11c). Similarly, mass movement from the left valley slope near Dant temporarily dammed the Deschutes River at RM 64 and left a lag of large boulders that now form Buckskin Mary Rapids (Figure 11a). Four Chutes Rapids, 1 km downstream, is composed of remnants of coarse debris brought to the valley bottom and redistributed by floodwaters escaping the breached dam at Buckskin Mary Rapids. Wapinitia and Boxcar Rapids (Figure 11d) formed where large landslides moved onto the valley bottom and have either blocked or partially diverted the channel.

Table 4. Name, location, rating, and formative process for major Deschutes River rapids

Rapid	Location (RM)[1]	Class[2]	Formative Process
Upper Trout Creek	87.0	3	outsized flood
Lower Trout Creek	86.9	3	outsized flood
Whitehorse	76.1	4	mass movement
Buckskin Mary	63.8	3	mass movement
Four Chutes	63.4	3	mass movement
Wapinitia	54.7	3	bedrock
Boxcar	53.7	3	mass movement
Oak Springs	47.3	4	bedrock
White River	46.3	3	outsized flood
Upper Rollercoaster	45.7	3	bedrock
Lower Rollercoaster	45.4	3	bedrock
Osborne	45.0	3	bedrock
Sherars Falls	44.0	6	bedrock
Bridge	43.6	3	bedrock
Wreck	40.0	3	bedrock
Bull Run	18.4	3	outsized flood
Jet Pump	15.5	3	bedrock
Harris	11.4	3	outsized flood
Washout	7.8	4	tributary
Gordon Ridge	5.9	3	bedrock
Colorado	4.2	4	outsized flood
Rattlesnake	2.7	4	bedrock
Moody	0.8	3	bedrock

[1] River mile

[2] Rating obtained from BLM brochure "Welcome to the Lower Deschutes River," undated. Scale varies from Class 1, beginner, to Class 6, unrunnable. Only rapids Class 3 or greater are included.

White River Rapids, Bull Run Rapids, Harris Rapids (Figure 9d), and Colorado Rapids are all reaches where the Deschutes River flows over and through accumulations of large boulders. In each instance, these boulder fields are near termini of Outhouse Flood bars, leading us to infer that the rapids developed in lags of coarse deposits of the Outhouse Flood (Table 4).

Coarse debris delivered by tributaries has formed just one major rapid on the lower Deschutes River. Washout Rapids

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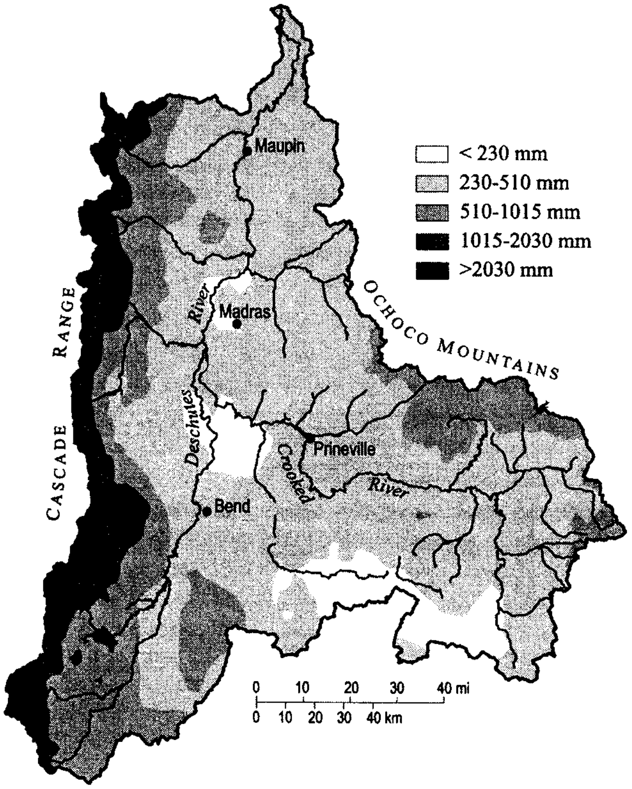

Figure 5. Mean annual precipitation in the Deschutes River basin for the period 1961-1990. From data provided by the Spatial Climate Analysis Service, Oregon State University. (http://www.ocs.orst.edu/prism/prism_new.html; August, 2001).

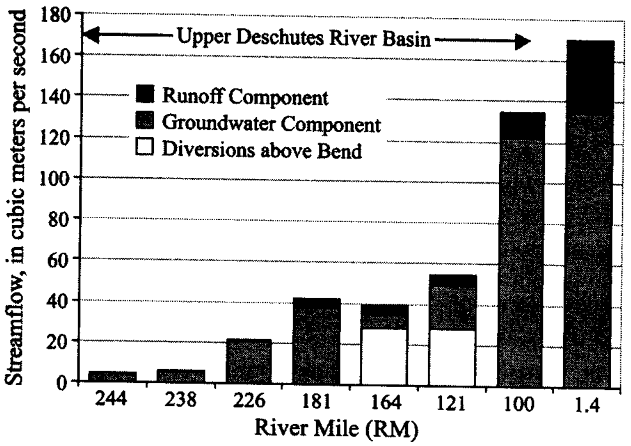

Figure 2. Flow of the Deschutes River broken down by surface water and groundwater components at selected gaging stations. The flows at RM 164 and 121 are offset to reflect diversions above RM 164. Approximately half of the water diverted infiltrates through leaking canals and returns to the river as groundwater discharge above RM 100. For gage locations, see Table 2.

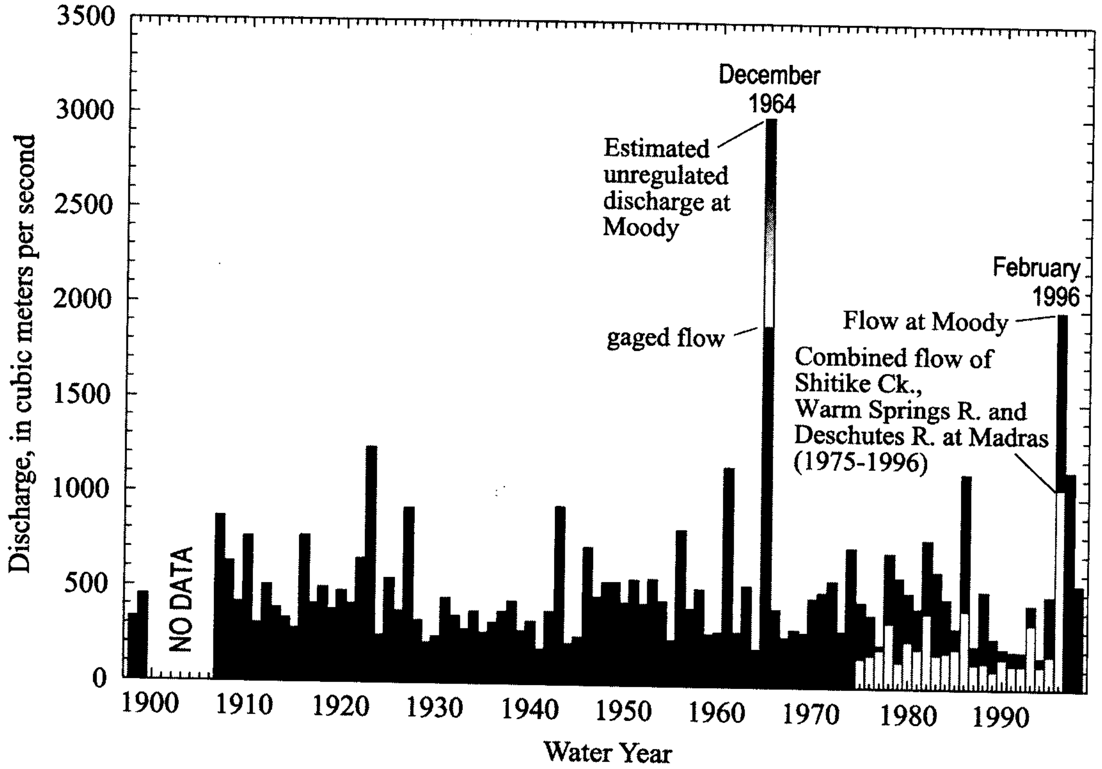

Figure 2. Annual peak flows of the Deschutes River at Moody, Oregon (USGS gage station 14103000). The unregulated discharge for the December 1964 flood was estimated by *Waananen et al.* [1971] from filling rates of Lake Billy Chinook (behind Round Butte Dam) and Prineville Reservoir (behind Bowman Dam on the Crooked River). Dark bars represent the flow at Moody, open bars represent the combined flow of three upstream gages used to estimate the peak flow at the Axford study site.

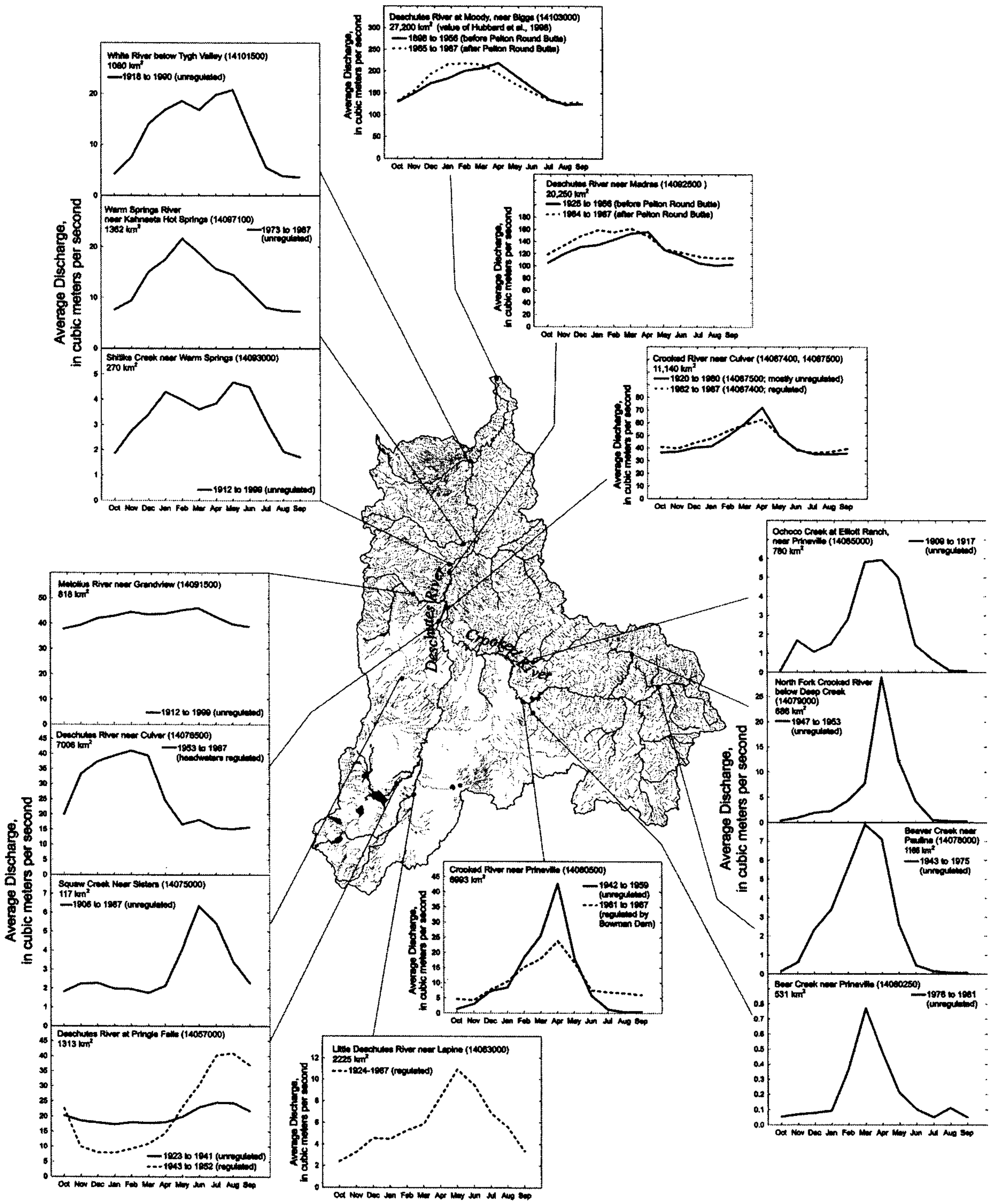

Figure 6. Hydrography and representative annual hydrographs for U.S. Geological Survey stream gaging stations in the Deschutes River basin. Data from *Moffatt et al.* [1990] and the U.S. Geological Survey National Water Information System (http://water.usgs.gov/nwis).

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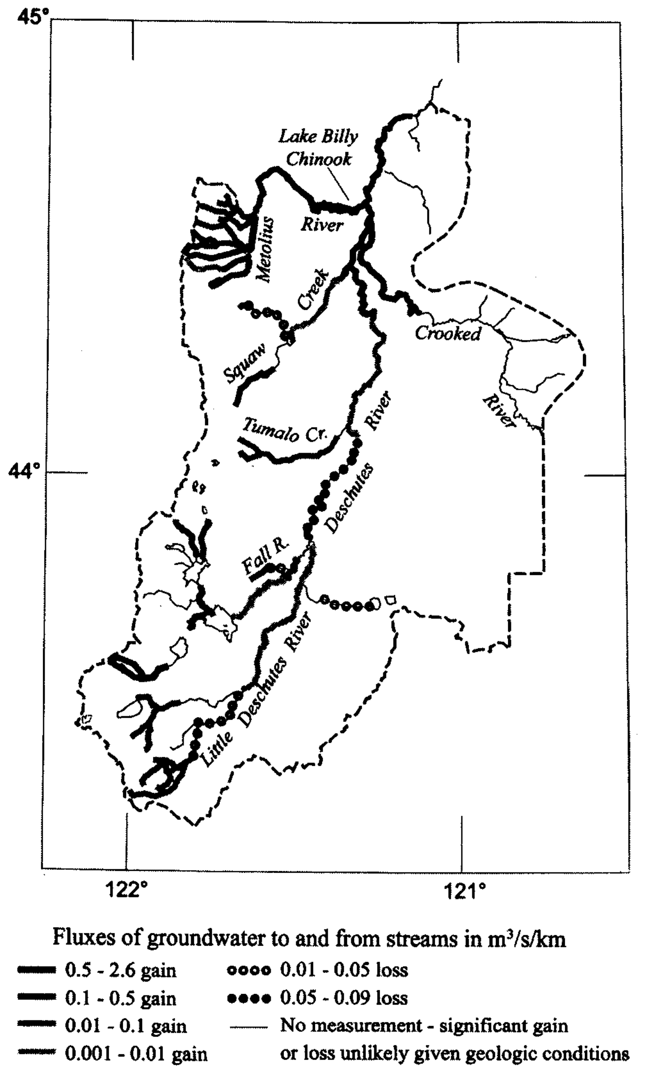

Figure 4. Estimated average fluxes of groundwater to and from streams in the upper Deschutes River basin [modified from *Gannett et al.*, 2001]

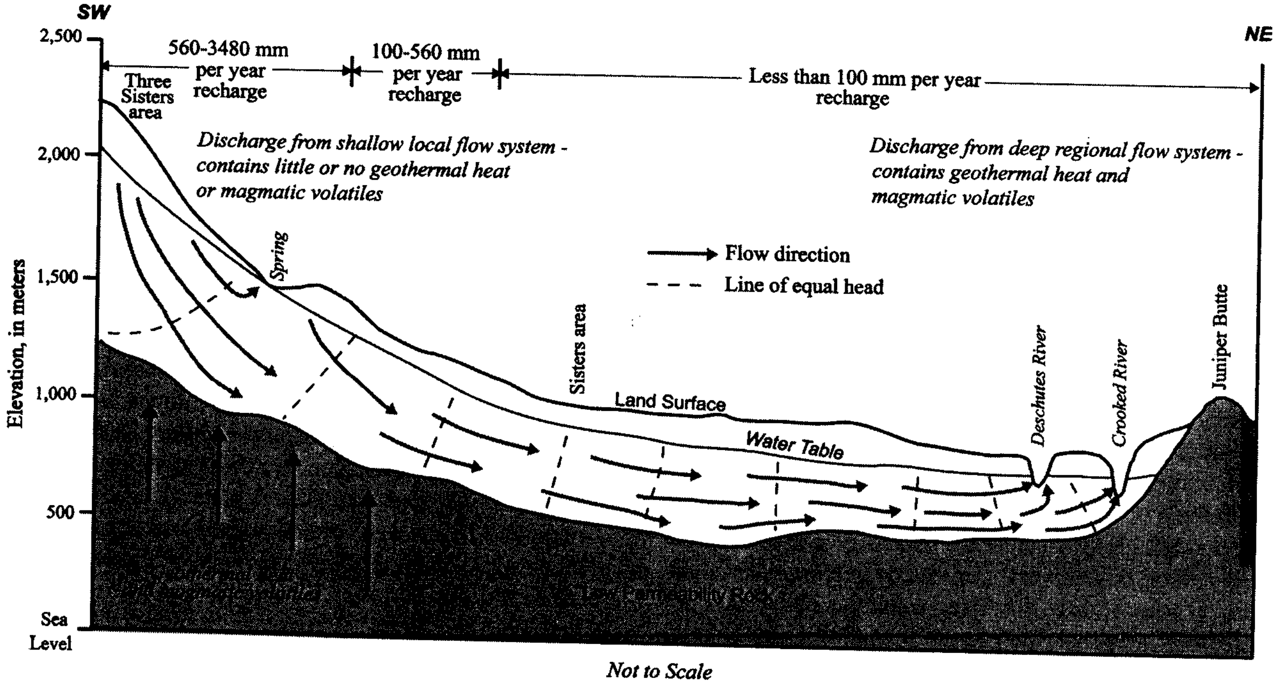

Figure 10. Schematic east-west section across the upper Deschutes River basin showing the generalized hydrogeologic setting, head distribution, and flow directions.

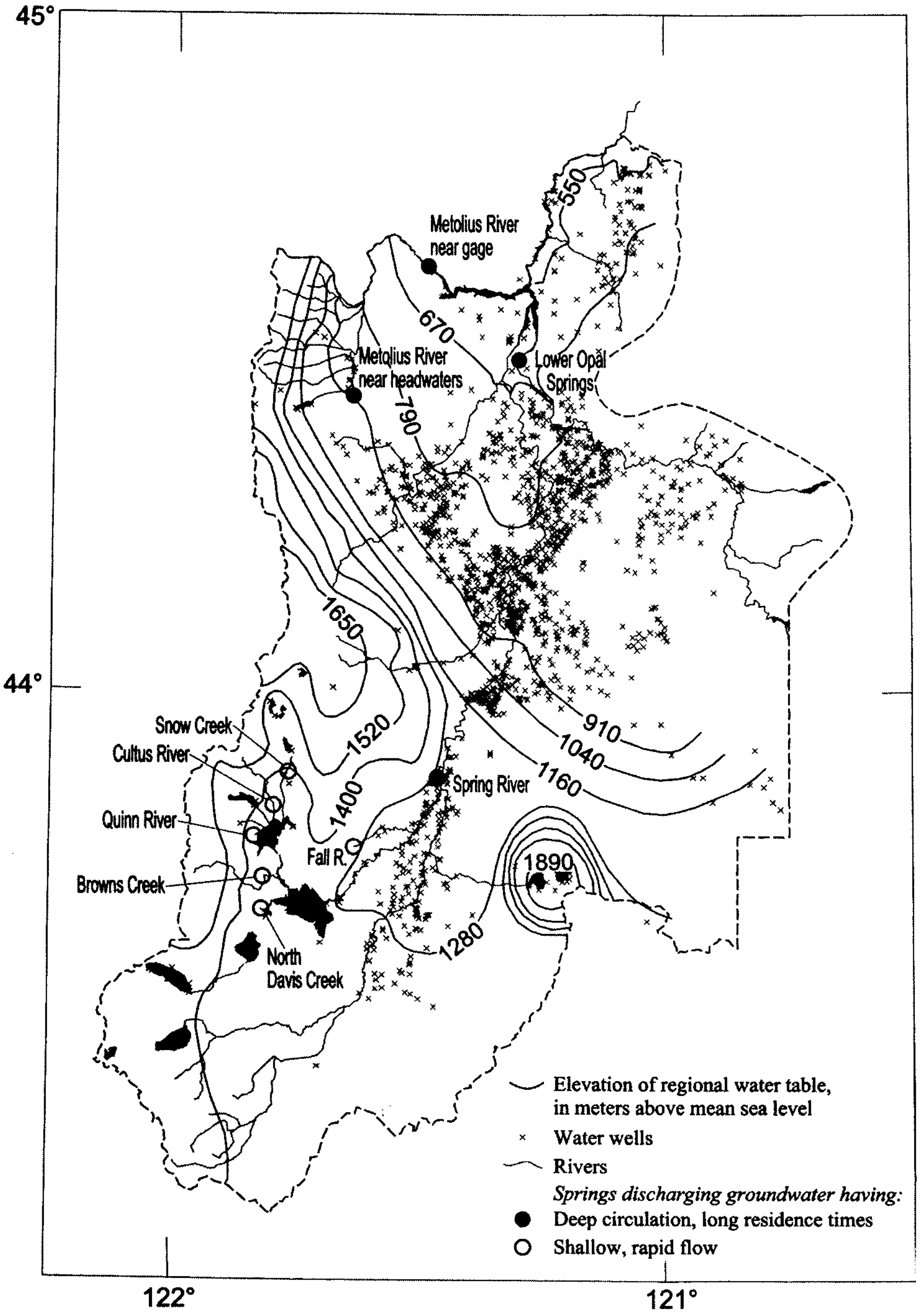

Figure 9. Generalized lines of equal elevation of the regional water table (in meters above mean sea level) and groundwater sampling locations in the upper Deschutes River basin. The water-table elevation is constrained by measurements in water wells and by elevations of major springs and gaining stream reaches. Deeply circulating water with long residence times contains magmatic volatiles and geothermal heat; shallow rapidly flowing groundwater contains no magmatic volatiles, and little or no geothermal heat.

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Deschutes/Holocene Paleoflood Studies

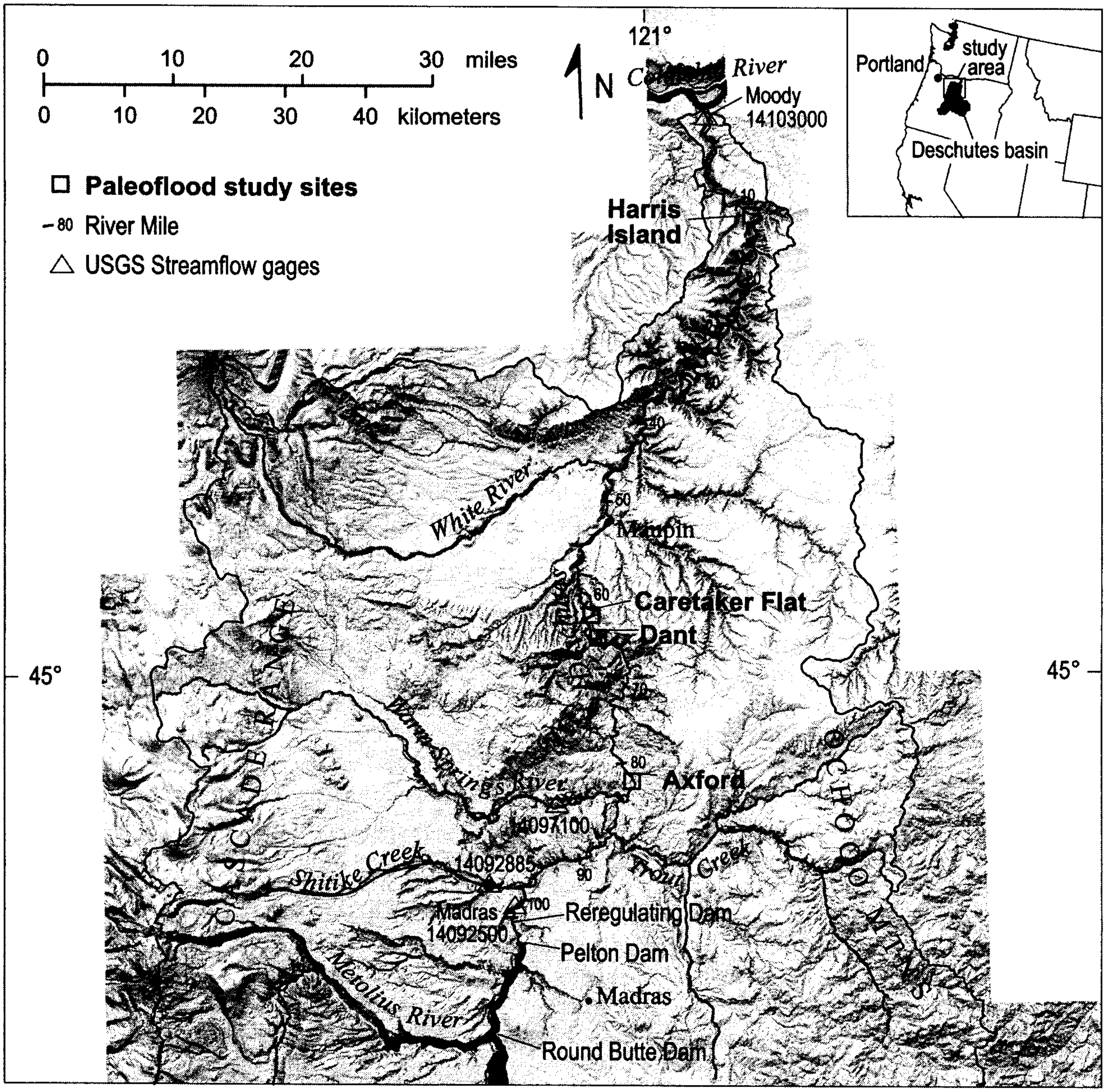

Figure 1. Area map showing study sites, major watercourses, streamflow gage sites, and major dams.

hydrology" by *Kochel and Baker* [1982], can reduce the uncertainty in estimates of long return-period floods, providing information pertinent to the design or retrofitting of dams and other floodplain structures that require robust information on high-magnitude, low-frequency floods [*Baker et al.*, 2002]. On the lower Deschutes River of central Oregon, relicensing of the Pelton-Round Butte dam complex has motivated examination of the frequency of large and rare floods so as to assess the adequacy of existing spillway capacity. The results also bear on regional flood climatology and the effects of large floods on channel geomorphology, two other common applications of paleoflood information [*Ely et al.*, 1993; *O'Connor et al.*, 1986].

The Deschutes River drains approximately 26,860 km^2 of north-central Oregon, delivering an average annual runoff of 125 m^3/s to the Columbia River at its confluence 160 km

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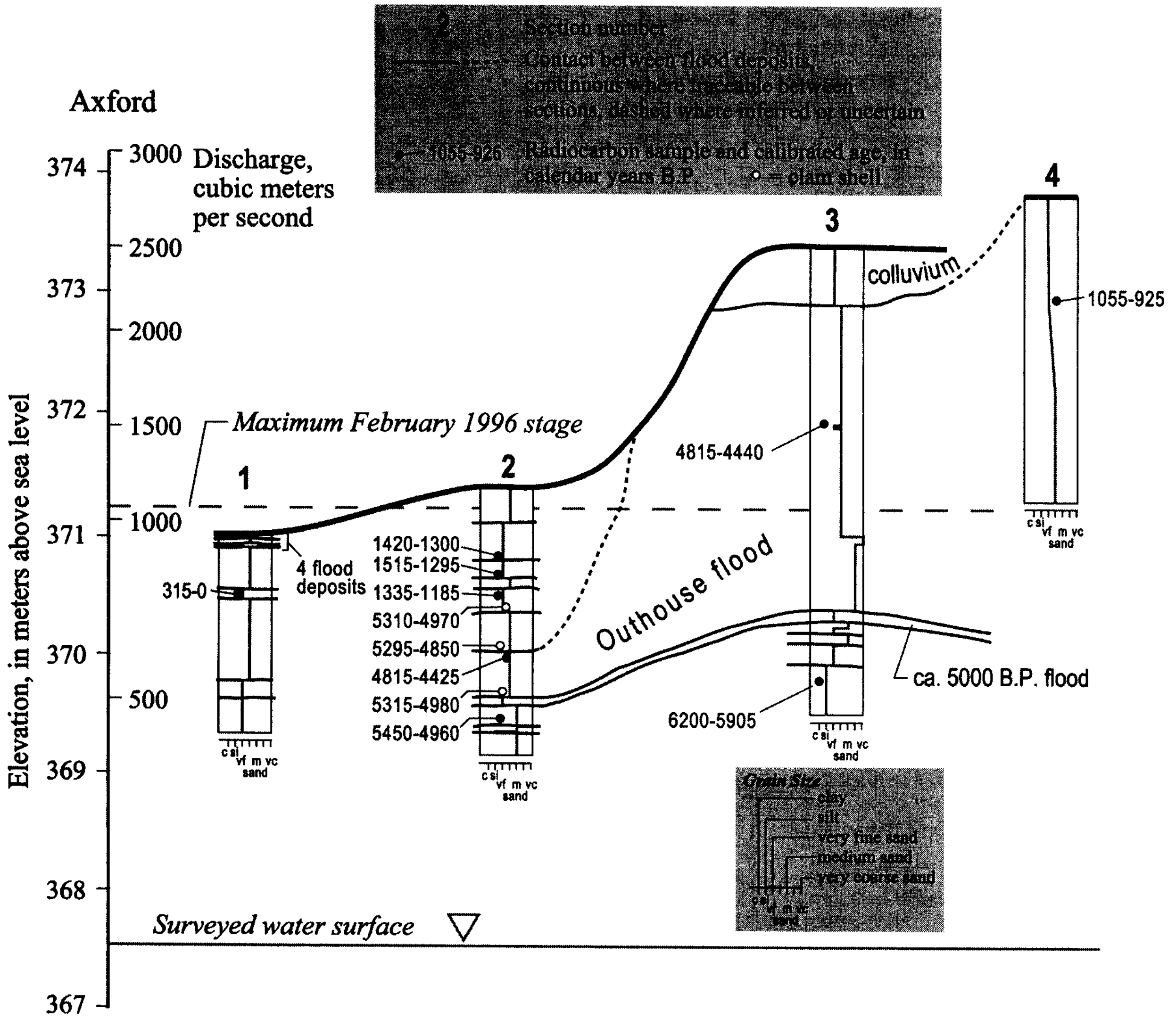

Figure 4. Stratigraphy of slackwater flood sediments at Axford site. Scale at base of sections indicates grain size.

Radiocarbon ages from units above and below in Section 2 constrain this deposit to be about 5000 cal yr BP (Figure 4)

The thin orange bed is overlain in Section 3 by a 2.5-m thick deposit of gray, medium-to-coarse sand with pebbly zones, grading up to a tan fine sand with silt lenses. This thick bed forming much of Section 3 can be traced to a 35-cm thick deposit of fine sand overlying the ~5000 cal yr BP flood bed near the bottom of Section 2. Detrital charcoal sampled from this unit in both Section 2 and 3 gave ages of about 4600 cal yr BP, consistent with a 5315-4980 cal yr BP age from a clamshell also collected from this deposit. At Section 2, the deposit is capped by an accumulation of clamshells (5295-4850 cal yr BP) exposed for 10 m along the cutbank. Associated pieces of tooled flint indicate that this shell midden is a cultural feature left by aboriginal humans who occupied the site after the deposition of this unit.

We infer that this high, thick, and coarse deposit of ~4600 cal yr BP records a single, exceptionally large, flood. Apparent stratigraphic boundaries within the deposit are gradational zones of changing grain size without any of the common indicators of depositional hiatus, such as incipient soils, colluvium, or erosional surfaces [*Kochel and Baker*, 1988; *Retallack*, 1988]. This is the highest and thickest slackwater deposit at Axford, with a deposit top nearly 1.5 m higher than any other flood deposit. Additionally, the deposit also contains the coarsest clasts of any mainstem

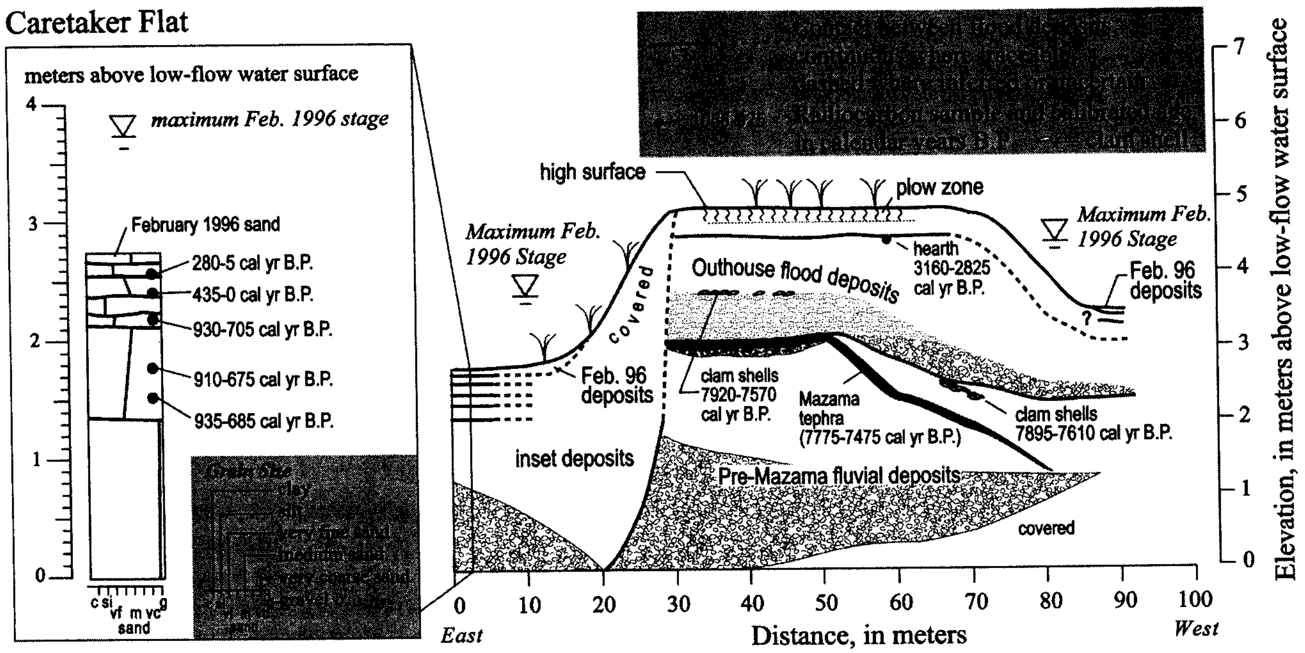

Figure 10. Schematic diagram of exposure at Caretaker Flat, showing primary stratigraphic relations and locations of dated samples.

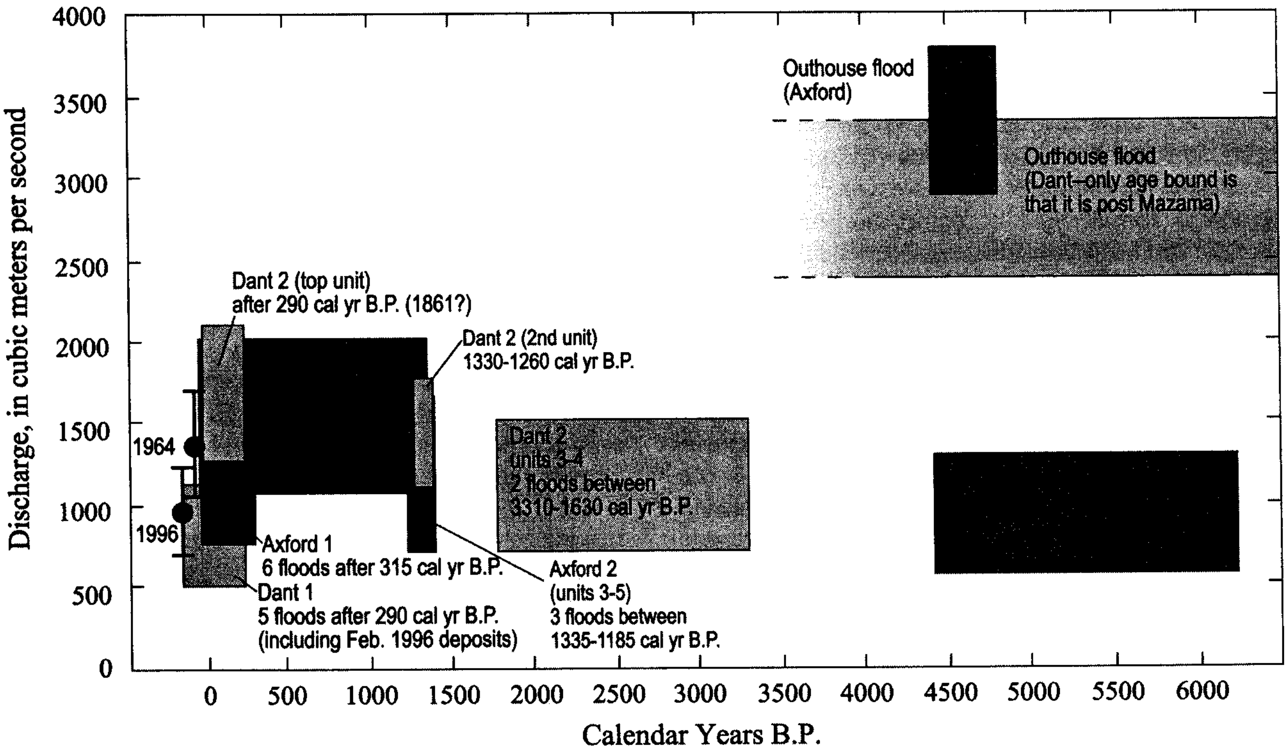

Figure 16. Summary diagram of stratigraphic record of flooding at Axford (dark gray boxes) and Dant (light gray boxes) study sites, showing ages, discharges and numbers of floods. Ages are in calendar years BP (with A.D. 1950 regarded as "present"). Also shown are estimates for the 1964 (adjusted for regulation) and 1996 flood discharges at the Axford study site.

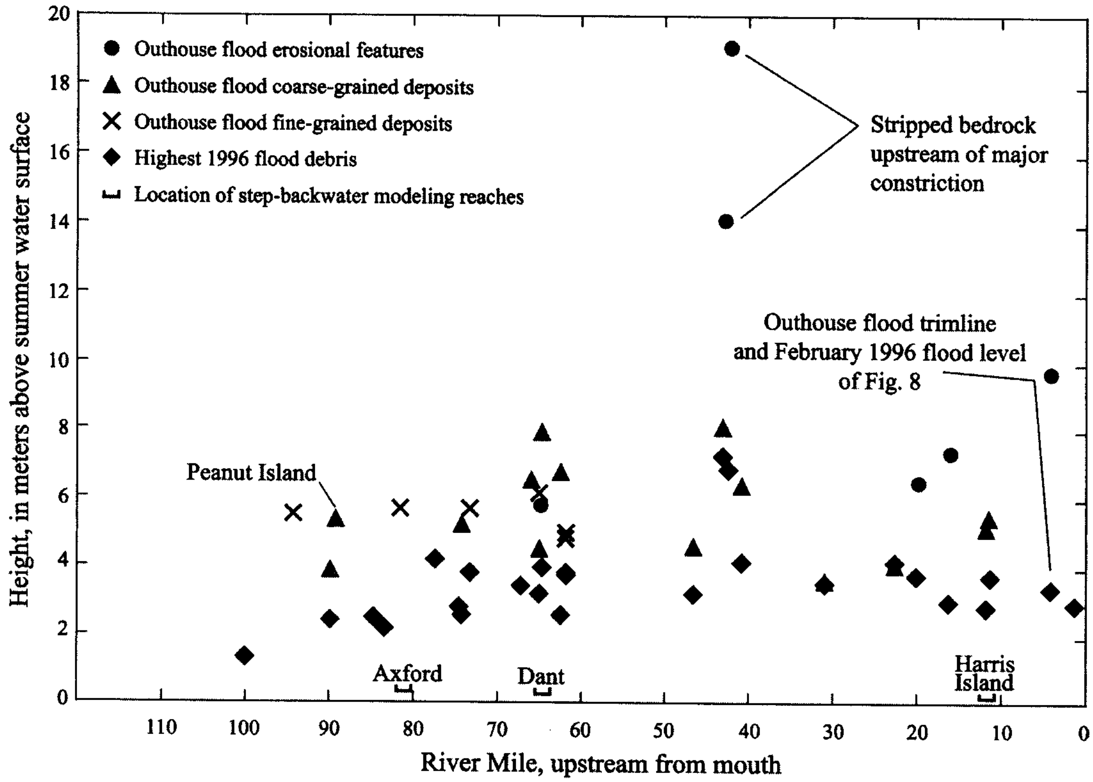

Figure 2. Height of Outhouse flood features (boulder bars and fine-grained deposits) and 1996 flood debris (primarily flotsam and fine woody debris) above summer water level.

Deschutes River (Figures 1 and 2). Depositional features include bouldery cobble bars and fine-grained slackwater deposits. Erosional features, more common in the lower 80 km, include stripped bedrock surfaces and trimlines in thick Pleistocene silt deposits that mantle the banks in the lower canyon. Variation in the height of these features above summer water surface[1] has no discernable downstream trend, but rather is highly dependent on local channel and floodplain width, in a manner similar to the elevations of 1996 flood debris (Figure 2).

Coarse-grained Outhouse flood deposits with surfaces well above historic flood limits are found on the insides of meander bends, and as mid-valley bars and islands (Figures 3 and 4). Maximum bar height varies from 3.5 to 8 m above summer water surface, depending on local channel and floodplain width (Figure 2). The cobbles and boulders are all volcanic rocks, but many of the larger boulders are traceable to local canyon wall lithologies. Boulders are subrounded to rounded, and cobbles are usually well rounded to very well rounded. Limited exposures into coarse-grained Outhouse flood deposits reveal imbricated cobbles and boulders.

Although some of these coarse-grained Outhouse flood deposits could be interpreted as terrace deposits, several attributes point to genesis by an exceptional flood or floods. The bars generally have streamlined shapes and surfaces that begin near summer water level and ramp up in the downstream direction unlike terrace treads, which have steep cut banks facing the river, and are typically flat or gently sloped downstream. The upstream ends of many Outhouse flood bars are mantled with boulders with diameters as great as a meter—much larger than the 3-10 cm gravels found in fill terraces (Figure 5). Maximum clast size consistently diminishes in the downstream direction, similar to patterns observed on other flood-formed bars [e.g. *O'Connor*, 1993]. Individual bars are positioned in zones of diminished flow velocity on insides of valley bends and at canyon expansions, consistent with the hydraulics of a large flood (Figure 4).

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[1] Analysis of stages and discharges along the lower Deschutes River indicate that summer water surface (May through September) fluctuates 10-30 centimeters, while discharge fluctuates 15-40 m^3/s.

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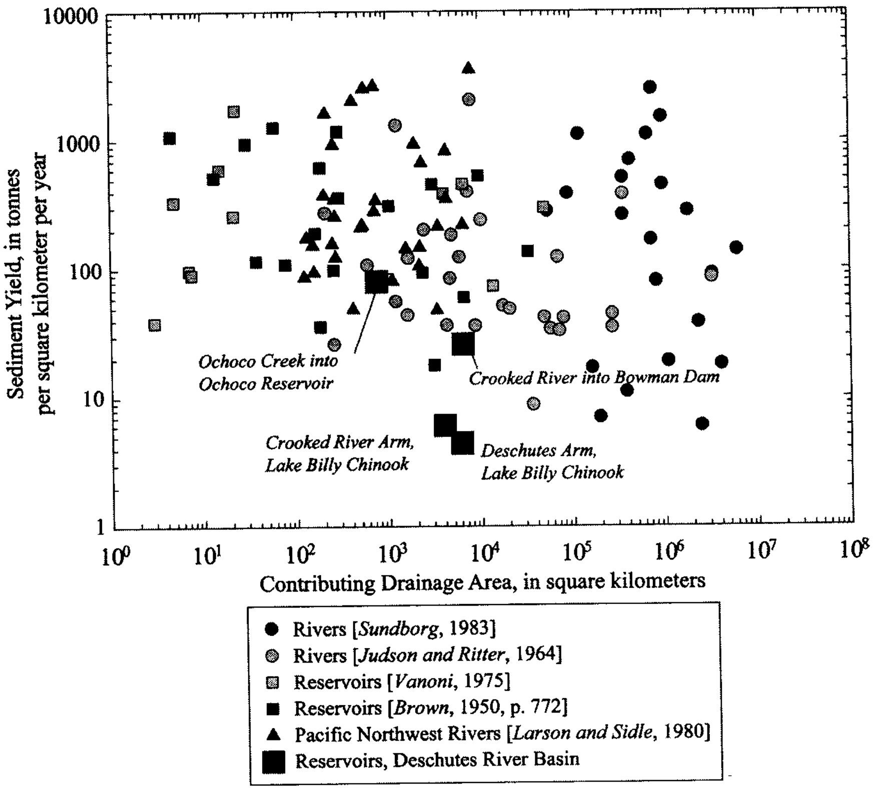

Figure 13. Compilation of sediment yield data from various sources, comparing sediment yield from parts of the Deschutes River basin to yields from other basins. Ochoco Creek and Crooked River sediment yields derived from surveyed sediment volumes behind Ochoco and Bowman Dams (Table 1; Ronald Ferrari, U.S. Bureau of Reclamation, 1999 written communication). Lake Billy Chinook (LBC) volumes measured by Portland General Electric survey crews in 1998 (Figures 10 and 11).

This result is only strictly applicable to transported bedload and suspended sand and silt (>0.002 mm) that drops out rapidly in these large reservoirs. Clay-sized particles probably stay in suspension long enough bypass the reservoirs. This result is also broadly consistent with the central tendencies (on a logarithmic plot) of the annual volumes of suspended load recorded at four U.S. Geological Survey gaging stations for short periods (Figure 14), although these gages also depict the substantial year-to-year variation in sediment transport. The results of a single year of suspended load measurements for White River, a large tributary draining the eastern Cascade Range and entering the Deschutes River downstream of the Pelton-Round Butte dam complex, are consistent with extrapolation of this relation to even higher values of SPI.

By applying this relation to the SPI calculated for each of the 100 subwatersheds (Figure 4d) and summing the resulting estimates of sediment yield downstream, we may estimate the overall downstream sediment flux and the incremental effects of impoundment in the Deschutes River basin (Figure 15). Under pre-impoundment conditions, modern sediment flux downstream of the confluence of the Deschutes, Crooked, and Metolius Rivers, 180 km upstream of the Columbia River confluence, is estimated to have been about 480,000 tonnes/yr. More than half of this volume was from the Crooked River basin. Downstream at the Columbia River confluence, the total annual sediment flux under pre-impoundment conditions is estimated to have been slightly more than 1,200,000 tonnes/yr, indicating that 60 percent of Deschutes River pre-impoundment sediment flux into the Columbia River is derived from below the Pelton-Round Butte dam complex. On the basis of this analysis, Trout Creek, Warm Springs River, and White River are likely to be major sources of sediment along the lower Deschutes River (Figure 15). In addition, the steep and dissected terrain formed where the Deschutes River has incised through the Mutton Mountains, between 120 and 90 km from the Columbia River confluence, (Figures 1 and 4) is also predicted to be an area of substantial sediment production and delivery. Consistent with this prediction is a concentration

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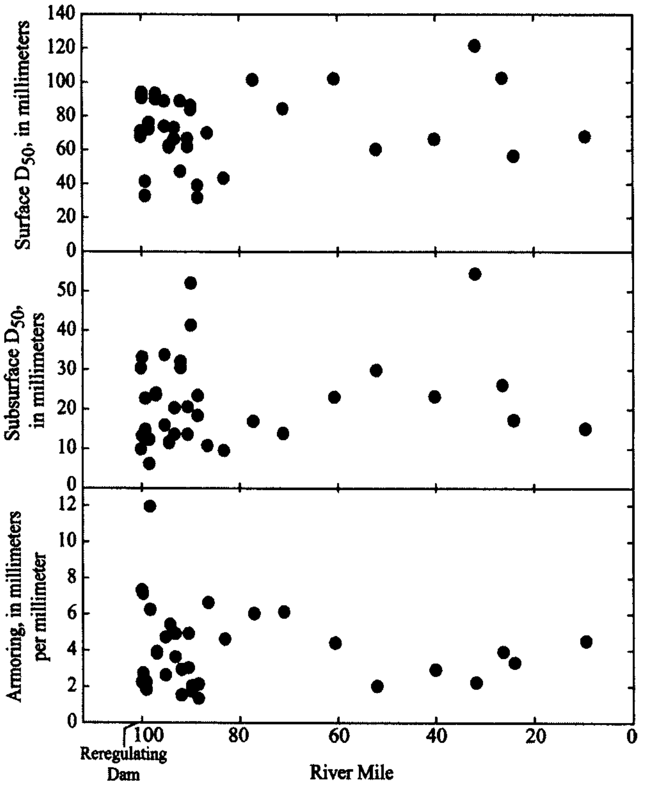


Figure 21. Surface D_{50} values, subsurface D_{50} values, and armoring ratios for bar and island heads along the entire study area in 1996. Note that scales are different for each plot.

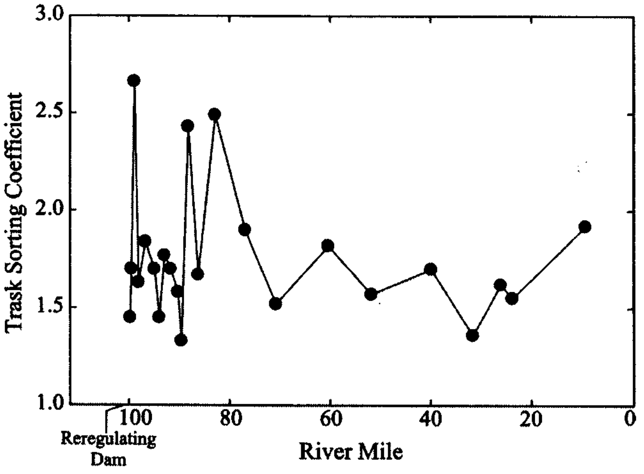


Figure 22. Trask sorting coefficients for surface bed material at bar and island heads along entire study area in 1996.

Deschutes. Sediment derived from the White and Warm Springs Rivers represents material with the largest size deviations from that of the mainstem, but for the most part is not incorporated into mainstem bed material (Figure 24). Some inputs of gravel from Shitike Creek, whose bed material more closely resembles that of the mainstem, appear to be deposited locally within the mainstem, inducing local, minor morphologic changes (for instance, island growth) and textural shifts in the channel bed.

High armoring ratios near the Project (up to 11.9 at RM 98.1) after the 1996 flood appear to have resulted from subsurface fining, as the surface layer did not change significantly between years. This apparent increase in armoring via subsurface fining is contrary to most models of armor development [i.e., *Parker et al.*, 1982; *Dietrich et al.*, 1989]. If sediment supply below the Project were substantially reduced, one would expect selective erosion to cause downstream winnowing of bed material. This would cause the surface grain size to coarsen with time near the Project and for the coarsening front to prograde downstream, particularly during high flow events. Such changes were not observed. Erosion of channel banks and islands by floodwaters may have introduced fine material into the sediment load, although no apparent or adequate source of fine sediment exists in this reach. Fine sediment from sources upstream of Pelton Dam (i.e., Seekseequa Creek; Figure 1) may have contributed fine material to downstream sample sites through turbid water releases from the Project during the February 1996 flood. The flood caused several large headcuts, and substantial erosion and sediment transport out of Seekseequa Creek into the reservoir behind Pelton Dam (C. Gannon, Confederated Tribes of Warm Springs, oral communication, 1999). Consequently, the three high armoring ratios measured near the Project may not be correlated with the Project itself.

Another possible explanation for the apparent fining of subsurface bed material between years is that subsurface sample sizes were smaller than necessary for accurately distinguishing temporal changes. While good precision in the sample mean can be achieved with sample sizes less than those suggested by *DeVries* [1970] and *Church et al.* [1987] for moderately sorted material, the accuracy is much less certain for smaller samples of poorly sorted materials such as fluvial gravel [*Ferguson and Paola,* 1997]. Following the criteria of *Church et al.* [1987], the requisite size of a representative bulk sample of channel-bed subsurface material may be estimated by the largest particles in the surface population, as long as the surface constitutes the same deposit. Using the average surface D_{95} value of 150 mm for sites in the primary study reach, the proposed 0.1% of sample size

Table 9. Sediment discharges for selected North American rivers.

		Drainage Area (10^6 km^2)			Sediment Discharge (10^6 t/yr)			Unit Sediment Discharge (t/km^2/yr)		
River, Country	Location	*Judson & Ritter* [1964]	*Milliman & Meade* [1983][a]	*This paper*	*Judson & Ritter* [1964]	*Milliman & Meade* [1983][a]	*This paper*	*Judson & Ritter* [1964]	*Milliman & Meade* [1983][ab]	*This paper*
Eel, USA	Scotia, California	0.0081	0.008	...	16	14	...	2048	1750	...
Mad, USA	Arcata, California	0.0013	...	...	2	...	...	1300	...	...
Trinity, USA	Hoopa, California	0.0073	...	...	3	...	...	400	...	...
Snake, USA	Central Ferry, Washington	0.27	...	...	12	...	...	44	...	...
Columbia, USA	Pasco, Washington	0.27	0.67	...	9	8	...	35	12	...
Green, USA	Palmer, Washington	0.0006	...	...	0.06	...	...	108	...	...
Fraser, Canada		...	0.22	...	...	20	...	...	91	...
Yukon, USA		...	0.84	...	...	60	...	...	71	...
Copper, USA		...	0.06	...	...	70	...	...	1167	...
Deschutes, USA	Madras, Oregon	...	...	0.0095	...	...	0.10	...	...	11

[a] Location not provided for these data.

[b] Unit sediment discharge calculated here from data derived from *Milliman and Meade* [1983].

Table 10. Channel-bed degradation rates below dams for selected U.S. rivers[a].

						Total Change in Mean Bed Elevation			
River, Dam, State	Year Dam Closed	Reference Year[b]	Last Year of Data Evaluated	# Dates[c] for which Data Evaluated	Cross-section Distance from Dam (km)	Range for Years Evaluated (m)	Mean (m)	Standard Deviation (m)	Average Rate of Channel Elevation Change (mm/yr)
Arkansas, John Martin, Colorado	1942	1943	1972	3	3.5	-0.10 to –1.95	-0.82	0.99	-27
Missouri, Fort Peck, Montana	1937	1936	1973	7	9.2	-0.65 to –0.90	-0.74	0.09	-20
Medicine Cr., Medicine Creek, Nebraska	1949	1950	1977	5	0.8	-0.10 to –0.20	-0.18	0.04	-6.4
Smoky Hill, Kanopolis, Kansas	1948	1946	1971	4	0.8	-0.80 to –1.45	-1.16	0.28	-51
Middle Loup, Milburn, Nebraska	1955	1950	1971	13	0.2	-0.60 to –2.65	-1.88	0.58	-115
North Canadian, Canton, Oklahoma	1948	1947	1976	6	1.8	-0.90 to –3.00	-2.05	0.94	-73
Red, Denison, Oklahoma-Texas	1942	1942	1969	4	0.6	-1.25 to –1.60	-1.41	0.15	-52
Deschutes, Pelton-Round Butte, Oregon	1956[d]	1957	1998	211	0.1	0.12 to –0.33	-0.06	0.06	-1.4
channel thalweg only						*0.15 to –0.39*	-0.09	*0.08*	*-2.2*

[a] Data used in calculations obtained from Table 13, *Williams and Wolman* [1984], except data presented for the Deschutes River.

[b] For this year, total change of channel bed is shown as 0 m, and therefore, acts as a reference point for later measurements.

[c] Not including reference year.

[d] Round Butte Dam closed 1962, see Table 2, this paper.

Excerpts from OWEB Watershed Assessment Manual

Basics of Fisheries Resources in Western Oregon

Quality 1995) have been published by state agencies to help understand the technical basis for the standard, and what managers and land owners can do to meet the standard. High dissolved oxygen is a basic physiological requirement of cold-water fishes. Critical dissolved oxygen levels for various ***life stages*** have been evaluated in laboratory and field studies. The early larval stages of fish are wholly dependent on the transfer of oxygen within the ***redd***, the salmonid gravel nest. When oxygen is below saturation, salmonid embryos are smaller than usual and hatching is either delayed or is premature. Salmonid juveniles survive in dissolved oxygen less than saturation, but growth, food conversion efficiency, and swimming performance are adversely affected. Water quality criteria are established to provide for the natural fluctuations below saturation while assuring sufficient dissolved oxygen to protect aquatic life. The concentration of dissolved oxygen is a function of many factors: water temperature, surface and intragravel water interchange, water velocity, substrate permeability, and the oxygen demand of organic material. The content of oxygen in water is directly related to water temperature and barometric pressure, and therefore, temperature and pressure (estimated through elevation) must be measured at the same time.

Toxic Contaminants

Toxic contaminants refer to chemicals introduced by human activities that may be deleterious to people or aquatic organisms. Organic compounds are man-made chemicals that are used for a variety of industrial purposes and as pesticides and herbicides. Metals often occur naturally, but when introduced into the environment or concentrated during mining or industrial processes, they can reach a toxic level. Toxicity covers a range of responses in aquatic organisms, from lethal to sublethal effects. Water quality criteria based on lethal effects are determined by exposing aquatic organisms to the chemical in a laboratory and determining at what concentration 50% of the organisms die. Tests for setting sublethal criteria follow an organism through its life cycle and evaluate the effects on growth and reproduction. These standard toxicity tests are the basis for the majority of water quality criteria recommended by US Environmental Protection Agency (EPA). The State of Oregon has adopted criteria recommended by EPA and listed in a document called the EPA "Goldbook."

Because of the wide variety of organic chemicals, it is not feasible to list the criteria for each chemical in a screening assessment. Establishing the "safe" level for these chemicals is the subject of continuing debate among scientists and there is often little agreement. Therefore, for the screening assessment, the suggested approach is to record the number of times an organic chemical exceeds the detection limits. If a number of these exceedences are recorded, then a water quality specialist or toxicologist should be consulted.

Metals mining, such as gold and silver mines, are located in mineralized zones that may contain other elements such as cadmium, zinc, copper, lead, mercury, and arsenic. These metals can reach groundwater in dissolved form, or in surface waters as dissolved or particulate material. Criteria for metals are expressed as acute and chronic values. Toxicity for most metals is based on the hardness of the receiving water, and therefore the criteria are expressed as a function of hardness.

FISHERIES RESOURCES

Because modifications to watershed process tend to "roll downhill" and influence the stream channel network, it is important to understand the patterns of fish use and the habitat requirements of fish in the watershed. The *Biennial Report on the Status of Wild Fish in Oregon* (Hooten et al. 1995) contains information on over 40 native fish species occurring in Oregon. The salmonids are the most widespread group of fish in the state and best-recognized as an indicator of watershed health. These are a class of fish that include salmon, trout, and ***char***. This assessment process focuses on evaluating salmonid populations and habitat conditions. In areas where there are sensitive nonsalmonid fish species, this approach may be adapted to evaluate the specific needs of those species.

Salmonids have a wide variety of life history patterns (Figure 16). They may be ***anadromous***—spending some portion of their life history in the ocean and returning to freshwater streams to spawn. They may be ***resident*** and spend their entire lives in the stream network. Or they may move between large river systems or reservoirs and the stream network where they were born.

Chinook, coho, steelhead, and cutthroat trout are the most common anadromous salmonids occurring in Oregon. Anadromous chum salmon and kokanee/sockeye salmon also occur in Oregon, but have more limited distributions. Redband (rainbow) trout and interior cutthroat trout are the most common resident salmonids; bull trout also occur in Oregon but have a limited distribution. The life history patterns and distribution in the stream network of the most common salmonids are summarized in Table 1 and described in the following paragraphs (Figure 17). These descriptions are general in nature; it is not uncommon for fish species to have life history patterns adapted to the watershed of origin. For this reason the Fish and Fish Habitat Assessment component asks users to describe the known life history patterns of fish occurring in their watershed. The *Biennial Report on the Status of Wild Fish in Oregon* provides some watershed-specific information and contains more detailed information on the life history patterns of nonsalmonid fish species that may occur in your watershed.

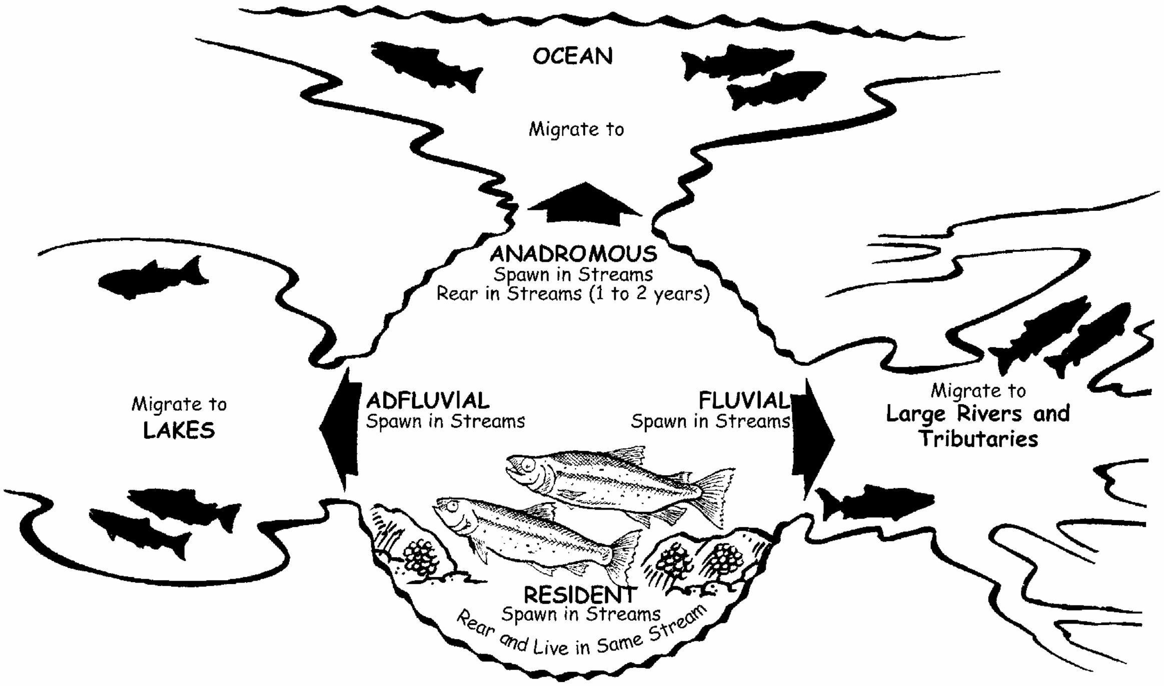


Figure 16. Salmon and trout have three distinct life history patterns: (1) "anadromous," spending some portion of their life history in the ocean and returning to freshwater streams to spawn; (2) "resident," spending their entire lives in the stream network; or (3) fluvial or adfluvial, moving between large river systems or reservoirs and the stream network where they were born.

Table 1. Generalized life history patterns of anadromous salmon, steelhead, and trout in the Pacific Northwest.[1]

Species	Adult Return	Spawning Location	Eggs in Gravel[2]	Young in Stream	Freshwater Habitat	Young Migrate Downstream	Time in Estuary	Time in Ocean	Adult Weight (average)
COHO	Oct-Jan	coastal streams, shallow tributaries	Oct-May	1+yrs	tributaries, main-stem, slack water	Mar-Jul (2nd yr)	few days	2 yrs	5-20 lb (8)
CHUM	Sept-Jan	coastal rivers and streams lower reaches	Sep-Mar	days-weeks	little time in fresh water	shortly after leaving gravel	4-14 days	2.5-3 yrs	8-12 lb (10)
CHINOOK		main-stem large and small rivers			main-stem- large and small rivers		days- months	2-5 yrs	
spring	Jan-Jul		Jul-Jan	1+yrs		Mar-Jul (2nd yr)			10-20 lb (15)
summer	Jun-Aug		Sep-Nov	1+yrs		spring (2nd yr)			10-30 lb (14)
fall	Aug-Mar		Sep-Mar	3-7 months		Apr-Jun (2nd yr)			10-40 lb
STEELHEAD[3]		tributaries, streams, & rivers			tributaries		less than a month	1-4 yrs	
winter	Nov-Jun	Nov-Jun	Feb-Jul	1-3 yrs		Mar-Jun (2nd-5th yr)			5-28 l b(8)
spring	Feb-Jun	Feb-Jun	Dec-May	1-2 yrs		spring & summer (3rd-4th yr)			5-20 lb
summer (Col. R.)	Jun-Oct	Jun-Oct	Feb-Jun	1-3 yrs		Mar-Jun (3rd-5th yr)			5-30 lb (8)
summer (coastal)	Apr-Nov	Apr-Nov	Feb-Jul	1-2 yrs		Mar-Jun (of 2nd-5th yr)			5-30 lb (8)
Inland Columbia STEELHEAD/ REDBAND	Jun-Oct	tributaries	spring	1-3 yrs or resident		1-3rd yr	less than a month	1-4 yrs	
Oregon Basin REDBAND	resident spring		spring	resident		resident	na	na	
Coastal-Sea Run CUTTHROAT	Jul-Dec	tiny tributaries of coastal streams	Dec-Jul	1-3 yrs (2 avg.)	tributaries	Mar-Jun (2nd-4th yr)	less than a month	0.5-1 yrs	0.5-4 lb (1)
Lahontan CUTTHROAT	resident		spring	resident	tributaries, lakes	resident	na	na	
Westslope CUTTHROAT	resident Mar-Jul	small tributaries	Apr-Aug	resident	tributaries	resident	na	na	
BULL TROUT	Jul-Oct	cold headwaters, spring-fed streams	Sep-Apr	1-3 yrs (2 avg.)	prefer water < 15°C	spring, summer, fall (1st-3rd yr)	na	na	0.5-20 lb (varies with form)

[1] Life history patterns vary—fish in each watershed may have unique timing and patterns of spawning, growth, and migration. As part of the fish assessment you will update this chart.

[2] The eggs of most salmonids take 3-5 months to hatch at the preferred water temperature of 50-55ºF; steelhead eggs can hatch in 2 months.

[3] Steelhead, unlike salmon and coastal cutthroat trout, may not die after spawning. They can migrate back out to sea and return in later years to spawn again.

From: StreamNet Web page (www.streamnet.org) – fact sheets

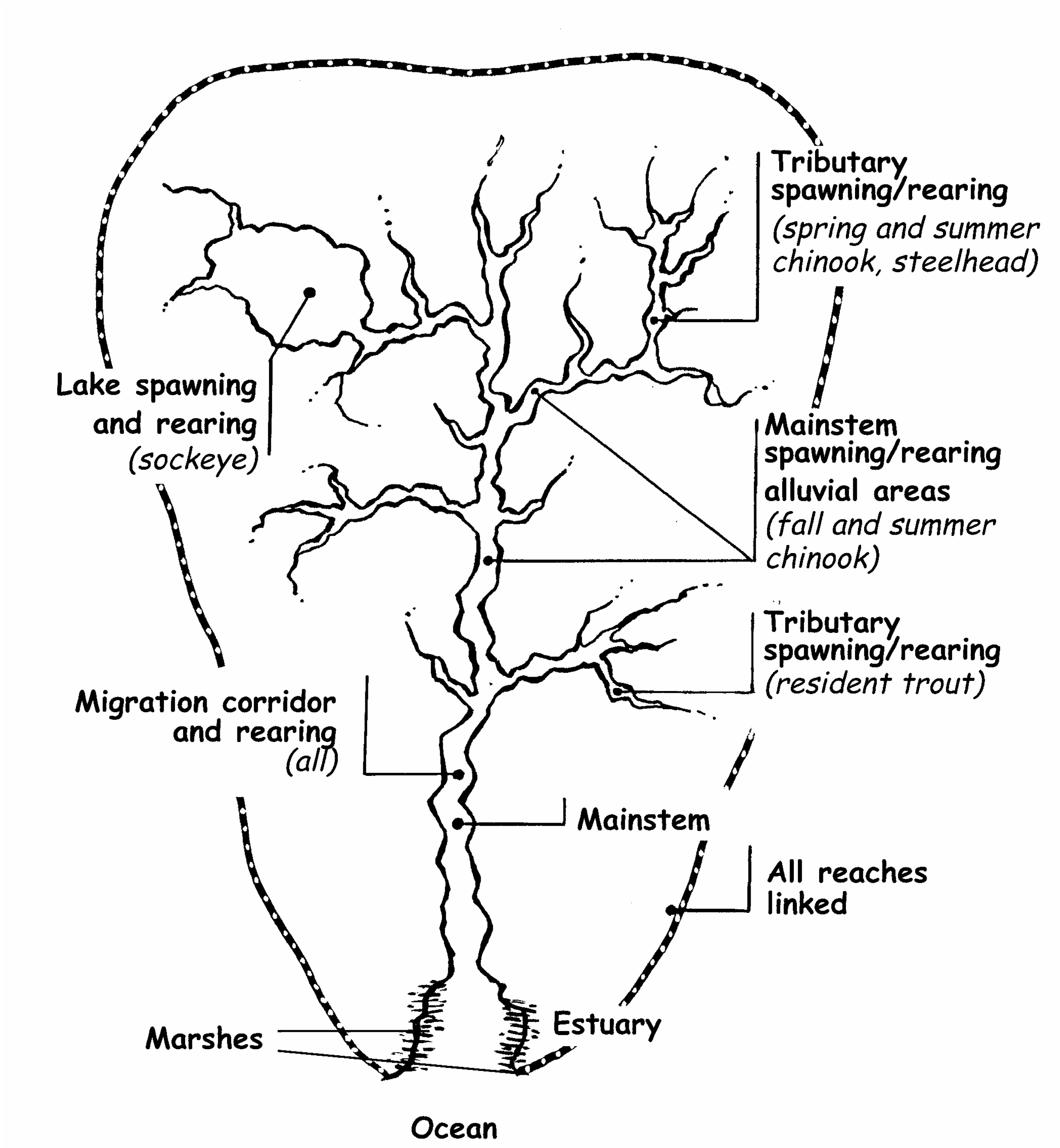


Figure 17. Salmonid distribution in a watershed varies by species and life history stage.

Chinook (king) salmon exhibit a wide range of life history diversity, with variations in the date, size, and age at ocean entry; in adult migration season; in spawning habitat selection; and in age and size at maturity. Chinook have two adult migration seasons, fall or spring, which refers to the period when they return to the watershed. Fall chinook return from the ocean in late August through December and spawn in the late fall and winter. Spring chinook return from the ocean in the spring and adults spend the summer in deep pools until the fall spawning period. Chinook salmon prefer to spawn in large main channels and low-gradient (less than 3%) tributaries. Spring chinook are typically good jumpers and can leap significant barriers in streams that would be impassable to fall chinook. Generally, juvenile chinook of coastal stocks rear in coastal streams from 3 to 6 months and rear in estuaries from 1 week to 5 months. Nearly all coastal chinook stocks enter the ocean during their first summer or fall. Some coastal and Columbia River spring chinook spend one summer and one winter in fresh water. Chinook adults range from 2 to over 70 pounds, with the average size ranging from 10 to 40 pounds.

Coho (silver) salmon usually spawn from November to February. Coho prefer to spawn and rear in small, low-gradient (less than 3%) tributary streams. Adults are good jumpers and often ascend higher-gradient reaches to access spawning areas in the upper portions of a watershed. Adult coho may spend several weeks to several months in fresh water before spawning, depending on the distance they have to migrate to their spawning areas. Juveniles normally spend one summer and one winter in fresh water. They migrate to the ocean in the spring, 1 year after ***emergence***. Most adults mature at 3 years of age, but some males mature as jacks or precocious males. Coho adults rarely exceed 15 pounds.

Steelhead/Rainbow/Redband: The rainbow trout species consists of multiple subspecies that are closely related fish that exhibit differences in life history patterns, distribution, and/or body form. Currently, three subspecies of rainbow trout are recognized in Oregon: (1) coastal steelhead/rainbow trout, (2) inland Columbia Basin redband/steelhead trout, and (3) Oregon Basin redband trout.

> **Coastal steelhead** are seagoing rainbow trout that occur west of the Cascade Mountains and have a wide variety of fresh- and saltwater rearing and adult migration strategies. Juvenile steelhead may rear 1 to 4 years in fresh water before migrating to saltwater. Steelhead may reside in saltwater 1 to 3 years. Adult steelhead that enter fresh water between May and October are called "summer-run" fish. These fish hold several months in fresh water prior to spawning. Adults that enter between November and April are called "winter-run" fish. These fish are more sexually mature when they go upstream and they stay in fresh water for a shorter time before spawning. Steelhead return to saltwater after spawning. Resident rainbow trout remain in the same stream network throughout their entire life. Rainbow trout typically spawn in the winter or spring. Both rainbow and steelhead spawn more than once.
>
> **Inland Columbia Basin redband/steelhead** occur in the Columbia Basin east of the Cascade Mountains. This subspecies includes anadromous steelhead and resident redband trout, both of which can occur in the same stream system. There are also isolated redband trout populations in streams that are above barriers to anadromous fish. Juvenile steelhead before returning to fresh water to spawn. Most inland steelhead are summer-run fish, entering fresh water between March and October and holding for several months prior to spawning. Only four populations of winter-run steelhead are found in Oregon; these populations occur in Fifteenmile Creek and adjacent creeks.
>
> **Oregon Basin redband trout** occur in the following basins: Klamath, Summer Lake, Abert Lake, Fort Rock Valley, Christmas Valley, Fossil Lake, Silver Lake, and Malheur. Populations in each of these basins are completely isolated by natural geological features, except for the Klamath Basin. These trout are adapted to thrive in the often warm and alkali waters of the Great Basin streams where they occur. Historically, these redband trout populations had ***adfluvial*** life histories, which means they migrated between the spawning areas in streams to rearing areas in lakes and marshes. The diking, channeling, irrigation

diversions, and draining of marshlands that have occurred extensively in these basins has resulted in the loss of rearing habitat and functional migration corridors.

Cutthroat trout have three subspecies occurring in Oregon: (1) coastal cutthroat trout, which occur west of the Cascade Mountains; (2) Lahontan cutthroat trout, occurring in southeastern Oregon, and (3) westslope cutthroat trout, which occur in the John Day Basin.

Coastal cutthroat trout have variable life history patterns. Some migrate to the ocean while others remain in the same area of a stream all of their lives. They spawn in the spring or fall and the juveniles emerge by June or July. Cutthroat trout tend to spawn in very small tributaries. Sea-run cutthroat trout rarely exceed a length of 20 inches or a weight of 4 pounds.

Lahontan cutthroat trout occupy remnant streams in the basin of historical Lake Lahontan. These fish have evolved a tolerance to high alkaline conditions. Lahontan cutthroat tend to be small-sized and occupy small streams that usually have no other fish species present.

Westslope cutthroat trout only occur in the John Day Basin in Oregon. These populations all have a resident life history and remain in the same stream system their entire lives. Westslope cutthroat are specialized to feed on insects and other invertebrates, while the other cutthroat subspecies occurring in Oregon prefer to feed on other fish.

Bull trout are a char closely related to trout. Researchers believe the bull trout populations in Oregon became established during the last glacial period, which helps explain why they need cold water to successfully reproduce. Bull trout in Oregon have three distinct life history patterns: They may be (1) adfluvial fish that migrate between lakes or reservoirs and spawn in streams, (2) ***fluvial fish*** that migrate to large rivers and spawn in small tributaries, or (3) resident fish that remain in the same stream network for their entire lives. The migratory forms of bull trout move long distances to reach their spawning tributaries. Typically, bull trout occur farther upstream in the watershed than other salmonids. Bull trout grow slowly, do not mature until age 5 or older and will live for 12 or more years. They typically spawn in the fall as water temperatures are decreasing, and can spawn annually or in alternate years. Bull trout are predatory on other fish and can grow to 30 pounds where adequate food is available.

There are many elements of in-stream fish habitat that affect the production of salmonids during the freshwater phases of their life history (Figure 18). Physical habitat features include depth and water velocity ranges (usually grouped by channel units), cover, spawning gravels, and temperature ranges. The Oregon Department of Fish and Wildlife has compiled extensive amounts of stream habitat data from over 5,000 miles of stream surveys and has developed a series of ***benchmark*** values for key physical habitat conditions. The Fish and Fish Habitat Assessment component uses these benchmark values as a comparison in order to evaluate the current condition of fish habitat in the watershed.

See Fish and Fish Habitat component for habitat evaluation process.

It is clear from the descriptions of the life histories that the anadromous trout and salmon occurring in Oregon watersheds migrate long distances upstream and downstream during their life cycles.

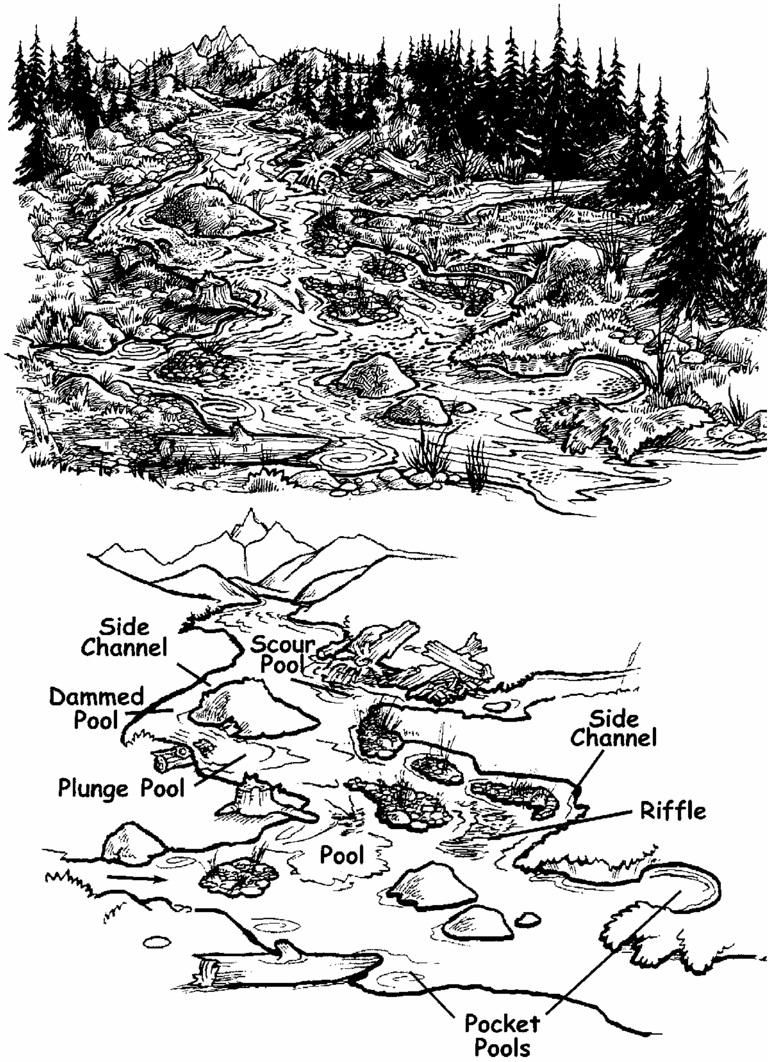
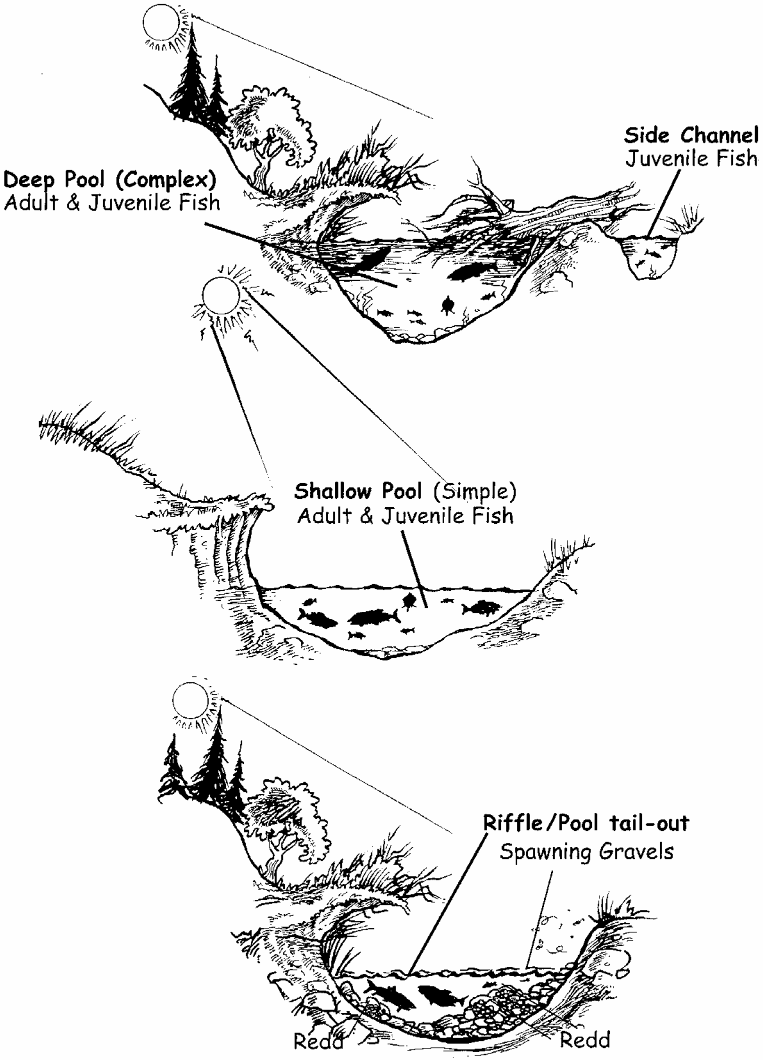


Figure 18. Elements of in-stream fish habitat that affect salmonid production in fresh water include depth and water velocity, cover, spawning gravels, and temperature ranges.



These conditions are dependent on such physical characteristics as pools and side channels, substrate, and riparian vegetation.

Resident trout will also move up and downstream to seek food, shelter, and spawning. Culverts under roads can block fish passage through a number of factors, including jumps, no resting pools, insufficient depth, excessive water velocity, or a combination of these factors (Figure 19). The migration barrier portion of the Fish and Fish Habitat Assessment provides a protocol for mapping potential barriers, and identifying if an existing crossing is a barrier.

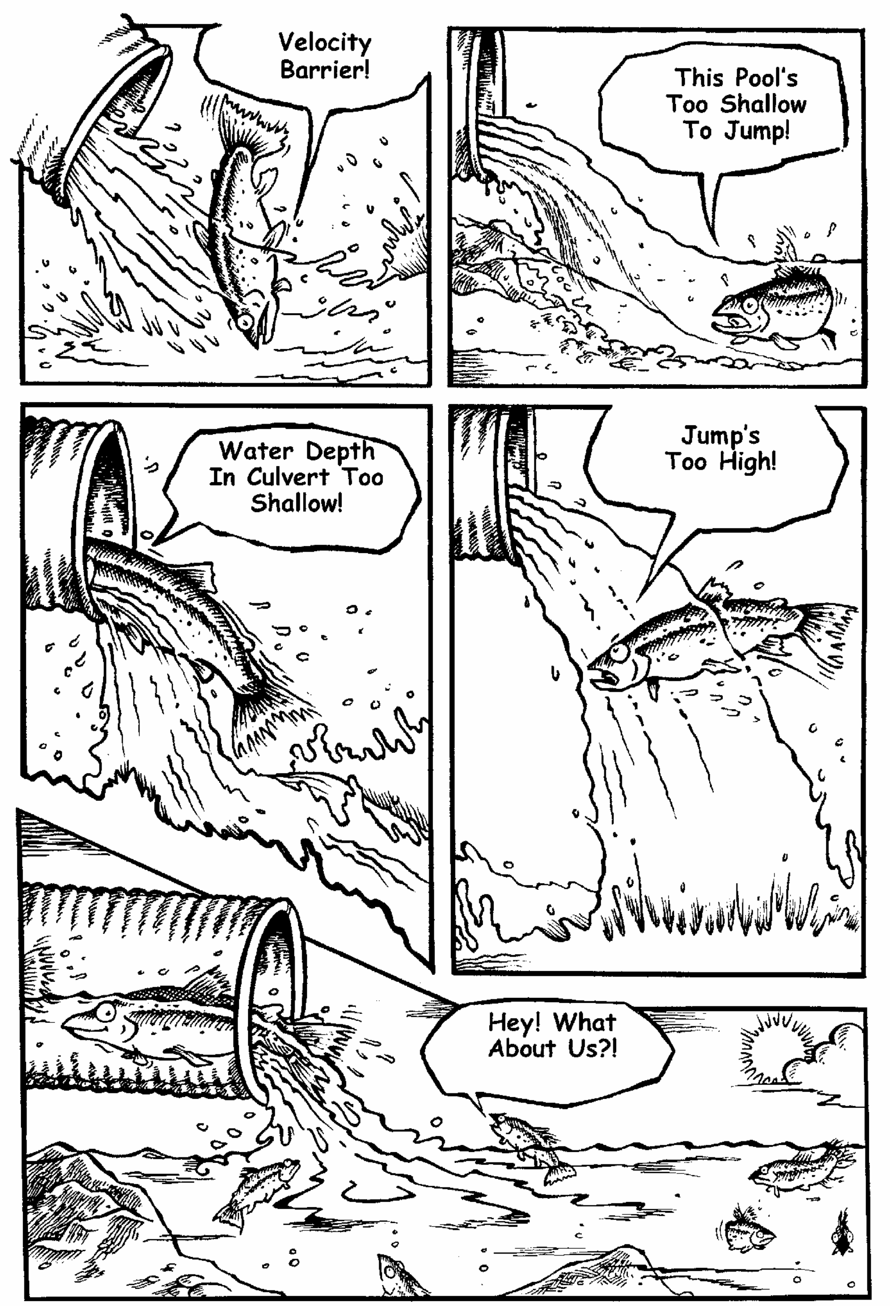


Figure 19. Culverts under roads can block fish passage through a number of factors, including excessive water velocity, insufficient depth, excessively high jumps, or a combination of these factors.

Table 2. Summary of potential stream impacts from human activities.

Human Activity	Potential Disturbances	Potential Habitat/Watershed Process Responses
Timber harvest	• removal of riparian zone canopy cover • soil disturbance, increased erosion of fine sediments • alteration of total basin vegetation cover	• increased summer water temperatures • reduced woody debris recruitment potential • decrease in interstitial spaces and pools (spawning and rearing habitat) • alteration of timing and magnitude of peak flows (hydrology) • change in timing and characteristics of landslides
Transportation (road development, rail, bridges, etc.)	• surface erosion, increased fine-sediment inputs • destabilization of upslope areas increased coarse- and fine-sediment inputs • blockage of migratory corridors (culverts) • loss of riparian vegetation • chemical spills, toxics, nutrient runoff	• decrease in interstitial spaces and pools (spawning and rearing habitat) • major channel disruption & catastrophic loss of habitat with major events • loss of migratory population component • increased summer water temperatures • reduced woody debris recruitment potential • chemical contamination • changes in peak flows
Agriculture/livestock grazing	• bank damage • soil compaction • in-channel stream bed disruption • removal of bank vegetation • changes in vegetation species & distribution	• decreased bank stability & direct inputs of fine sediments • reduced water infiltration, changes in peak flows, reduced baseflows • loss or disruption of summer rearing habitat • loss of cover, increased summer water temperatures & formation of anchor ice • increased stream nutrients
Agriculture/crops	• soil compaction • surface erosion, increased fine-sediment inputs • removal of bank vegetation • chemical, nutrient runoff	• decreased bank stability & direct inputs of fine sediments • reduced water infiltration, changes in peak flows, reduced baseflows • loss of cover, increased summer water temperatures & formation of anchor ice • increased stream nutrients, contamination
Mining	• streambed disturbance • fine-sediment inputs • chemical runoff or seepage to groundwater	• loss or disruption of spawning & summer rearing habitat • creation of chemical barriers &/or direct fish mortality, groundwater contamination
Dams (hydroelectric development, water supply, irrigation diversions)	• blockage of migratory corridors • changes in temperature, sediment delivery, flow regime due to dam regulation • increased temperatures, fine sediments, chemicals and nutrients with wastewater returns • channel dewatering	• loss of migratory/anadromous population component • overall decrease in habitat condition • direct mortality loss of one or more year-classes, reduction of redds, loss of available habitat • loss of anadromous prey base/nutrients • loss or disruption of spawning & summer rearing habitat

Table 2. (continued).

Human Activity	Potential Disturbances	Potential Habitat/Watershed Process Responses
Urbanization, channelization, diking, levees, recreation, & other	• reduction / removal of riparian vegetation • direct streambed modification • dewatering • stormwater runoff, reduced infiltration to soils	• increased summer water temperatures & formation of anchor ice • habitat simplification • reduced channel stability, channel incision • chemical, nutrient, bacterial inputs • increased magnitude and frequency of peak flows • reduced baseflows
UTILIZATION/HARVEST		
Fishing harvest	• direct mortality	• reduced recruitment & loss of nutrients to the stream
SPECIES INTERACTIONS		
Exotic species introductions, hatchery production	• competition • hybridization • predation • disease • water pollution	• displacement from most favorable habitats • sterile or less fit hybrids • direct mortality • weakness • nutrient, dissolved oxygen, and chemical contamination
HISTORICAL HUMAN USES (modifications that may not be apparent without historical research)		
Splash damming & log drives, yarding up stream channels, channel dredging, harvest of stream-bank trees, agriculture	• channel scour • streambed damage • removal of riparian vegetation • bank destabilization	• long-term loss or disruption of spawning & summer rearing habitat • increased summer water temperatures & formation of anchor ice • reduced woody debris recruitment potential • decrease in interstitial spaces and pools (spawning and rearing habitat)
Water withdrawals/ channel dewatering	• dry channel	• migration barriers, loss of one or more year-classes of fish
Stream cleaning to remove wood	• reduced sediment retention • increased channel scour • reduced channel complexity	• loss or disruption of spawning, summer & winter rearing habitat
Placer (hydraulic) mining or gravel quarries	• streambed disturbance • substrate removal	• loss or disruption of spawning & summer rearing habitat
Beaver eradication	• dam deterioration, removal • loss of pond/wetland areas	• loss of rearing habitat • alteration of water retention/floodplain function • temperature increases
Tailings deposits	• fine-sediment inputs • toxic contaminants	• loss or disruption of spawning & summer rearing habitat • creation of chemical barriers &/or direct fish mortality

APPENDIX I-A: BACKGROUND ON STATE AND FEDERAL REGULATORY ISSUES

The Oregon watershed assessment is targeted at "aquatic resource issues." Fish and water quality are the primary drivers for watershed assessment and restoration in Oregon. The assessment process focuses on evaluating watershed processes that influence the ability of the watershed to produce clean water and support fish populations. This appendix summarizes the regulatory policies that direct aquatic resource protection at the state and federal level. Numerous other laws regulate land management activities, such as the National Environmental Policy Act or local planning and zoning regulations, which are not discussed here. These other laws will influence what restoration actions can be taken and how they are conducted.

Fisheries

Federal Endangered Species Act

The Endangered Species Act (ESA) of 1973 provides for listing of native animal and plant species as endangered and provided means for their protection.[1] The US Fish and Wildlife Service (USFWS; responsible for inland fish, wildlife, and plants) and the National Marine Fisheries Service (NMFS; responsible for marine and anadromous fish and marine mammals) are the designated federal agencies responsible for administering the law. The key components of the ESA include the following:

1. Defining categories of "endangered" and "threatened," and listing populations.

2. Requiring all federal agencies to undertake programs for the conservation of endangered and threatened species.

3. Prohibiting these agencies from authorizing, funding, or carrying out any action that would jeopardize a listed species or destroy or modify its "critical habitat."

Before proceeding on any action that may affect endangered species, federal agencies must "consult" with the NMFS or USFWS. Consultation is a formal process that evaluates the effects of the action and determines if the activity needs to be modified to reduce the potential effect on the organism. In addition, the ESA applies broad "taking" prohibitions to all threatened or endangered animal species. In Oregon, there are 25 species of fish, 8 species of birds, 5 species of mammals, and 14 species of plants listed or proposed for listing under the ESA at the time of this writing.

Oregon State Endangered Species Programs

The Oregon Endangered Species Act of 1987 (ORS 496.172) gave the Oregon Department of Agriculture (ODA) responsibility and jurisdiction over threatened and endangered plants. The Oregon Department of Fish and Wildlife (ODFW) has responsibility for threatened and endangered fish and wildlife. Both of these agencies have entered into cooperative (Section 6) agreements with the USFWS to continue research and conservation programs for animal and plant species under the

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[1] The ESA defines endangered as any species (except insects) "in danger of extinction throughout all or a significant portion of it range," and as threatened any likely to become endangered "within the foreseeable future throughout all or a significant portion of its range."

federal ESA. The Oregon Natural Heritage Program (ONHP) has a similar agreement with the USFWS for invertebrates.

The ODFW maintains a list of threatened and endangered species; currently 35 species of fish and wildlife are on the list. The Oregon act requires state agencies to develop programs for the management and protection of endangered species, and requires agencies to comply with guidelines adopted by the Oregon Fish and Wildlife Commission for threatened species. The Oregon Fish and Wildlife Commission has provided criteria for listing and delisting species, and for protecting listed species.

The Oregon Fish and Wildlife Commission has also adopted a rule requiring the department to develop and maintain a state list of sensitive species for vertebrates. Sensitive species constitute naturally reproducing native vertebrates that are likely to become threatened or endangered throughout all or a significant portion of their range in Oregon. The sensitive species list, which is divided into four categories (see sidebar), is for the express purpose of encouraging actions that will prevent further decline in species' populations and/or habitats, thus avoiding the need for listing.

OREGON STATE SENSITIVE SPECIES CATEGORIES

Critical (SC)—Species for which listing as threatened or endangered is pending; or those for which listing as threatened or endangered may be appropriate if immediate conservation actions are not taken.

Vulnerable (SV)—Species for which listing as threatened or endangered is not believed to be imminent and can be avoided through continued or expanded use of adequate protective measures and monitoring.

Peripheral or Naturally Rare (SP)—Peripheral species are those whose Oregon populations are on the edge of their range. Naturally rare species are those which had low population numbers historically in Oregon because of naturally limiting factors. Maintaining the status quo for the habitats and populations of these species is a minimum requirement.

Undetermined Status (SU)—Animals in this category are species for which status is unclear. They may be susceptible to population decline of sufficient magnitude that they could qualify for endangered, threatened, critical, or vulnerable status, but scientific study will be required before a judgement can be made.

Water Quality Laws and Programs

Federal Clean Water Act

The 1972 Federal Clean Water Act (CWA) as amended gives the state responsibility for setting water quality standards and developing water quality management programs which ensure that the goals of the CWA are met. Recent judicial actions have focused attention on listing of impaired waters under Section 303(d) of the CWA. States in the Pacific Northwest, including Oregon, have significantly increased the number of stream segments that are designated as water quality limited under the provisions of the act. Listing of the stream segment as water quality limited requires the state to prepare a Total Maximum Daily Load (TMDLs) plan or a water quality management plan that will function as a TMDL plan for nonpoint sources (e.g., forestry, agriculture, grazing, and untreated urban stormwater runoff). Information collected during a watershed assessment can be used to assist the state in evaluating the status for listing and in developing the management plans required under the act. In addition, Section 404 of this law regulates the discharge of fill material into wetlands and other "Waters of the United States."

O'CONNOR AND GRANT, 2003
DESCHUTES FISH POPULATION

Table 1. Fish species present in the Deschutes River Basin.

Common Name	Scientific Name	Origin
Pacific lamprey	*Entosphenus tridentatus*	Native
Steehead/Rainbow trout	*Oncorhynchus mykiss*	Native
Chinook salmon	*Oncorhynchus tshawytscha*	Native
Sockeye salmon/ Kokanee	*Oncorhynchus nerka*	Native
Bull trout	*Salvelinus confluentus*	Native
Mountain whitefish	*Prosopium williamsoni*	Native
Shorthead sculpin	*Cottus confusus*	Native
Torrent sculpin	*Cottus rhotheus*	Native
Slimy sculpin	*Cottus cognatus*	Native
Mottled sculpin	*Cottus bairdi*	Native
Prickly sculpin	*Cottus asper*	Native
Longnose dace	*Rhinichthys cataractae*	Native
Speckled dace	*Rhinichthys osculus*	Native
Chiselmouth	*Acrocheilus alutaceus*	Native
Largescale sucker	*Catostomus macrocheilus*	Native
Bridgelip sucker	*Catostomus columbianus*	Native
Northern pikeminnow	*Ptychocheilus oregonensis*	Native
Redside shiner	*Richardsonius balteatus*	Native
Threespine stickleback	*Gasterosteus aculeatus*	Unknown
Brook trout	*Salvelinus fontinalis*	Introduced
Brown trout	*Salmo trutta*	Introduced
Atlantic salmon	*Salmo salar*	Introduced
Largemouth bass	*Micropterus salmoides*	Introduced
Smallmouth bass	*Micropterus dolomieu*	Introduced
Yellow perch	*Perca flavescens*	Introduced
Brown bullhead	*Ameiurus nebulosis*	Introduced

salmon have been defined in the Deschutes River basin on the basis of timing of adult migration from the ocean, age at out-migration of juveniles, and location of spawning [*Jonasson and Lindsay*, 1988; *Lindsay et al.*, 1989]. Fall chinook salmon (also known as "ocean-type" chinook salmon) typically spawn in mainstem reaches and the resulting progeny migrate to the ocean within a few months after emergence from the gravel [*Jonasson and Lindsay*, 1988; *Healey*, 1991]. Spring chinook salmon (or "stream-type" chinook salmon) spawn in headwater tributaries, and the juveniles remain in these streams for over a year before migrating to the ocean [*Lindsay et al.*, 1989; *Healey*, 1991]. Returning to their natal streams after about two or three years in the ocean, adult spring chinook salmon enter freshwater during the late spring and hold in cold pool habitats until the fall when they spawn. Fall chinook return to freshwater during the late summer or fall and spawn in October or November.

Spring chinook salmon historically spawned in the west side tributaries to the Deschutes River including the Warm Springs River, Shitike Creek, and the Metolius River (Figure 3). In the Deschutes River, Big Falls at River Mile (RM)[1] 132.2 was the upstream extent of spring chinook salmon [*Nehlsen*, 1995] (Figure 4). Anecdotal reports suggest that spring chinook salmon might have spawned in the Crooked River [*Nehlsen*, 1995]. At maturity, spring chinook are typically 60 to 90 cm long and attain weights of approximately 7 kg.

Fall chinook salmon are the largest salmonids in the Deschutes River basin, attaining lengths of 70 to 110 cm and

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[1] Units given are metric except for locations, which are given as river miles (RM), or miles upstream from the river mouth as marked on USGS topographic maps. These values are close to, but not necessarily the same as, actual distances along the present channel. Fractional river miles given herein are based on interpolations between these published river miles.

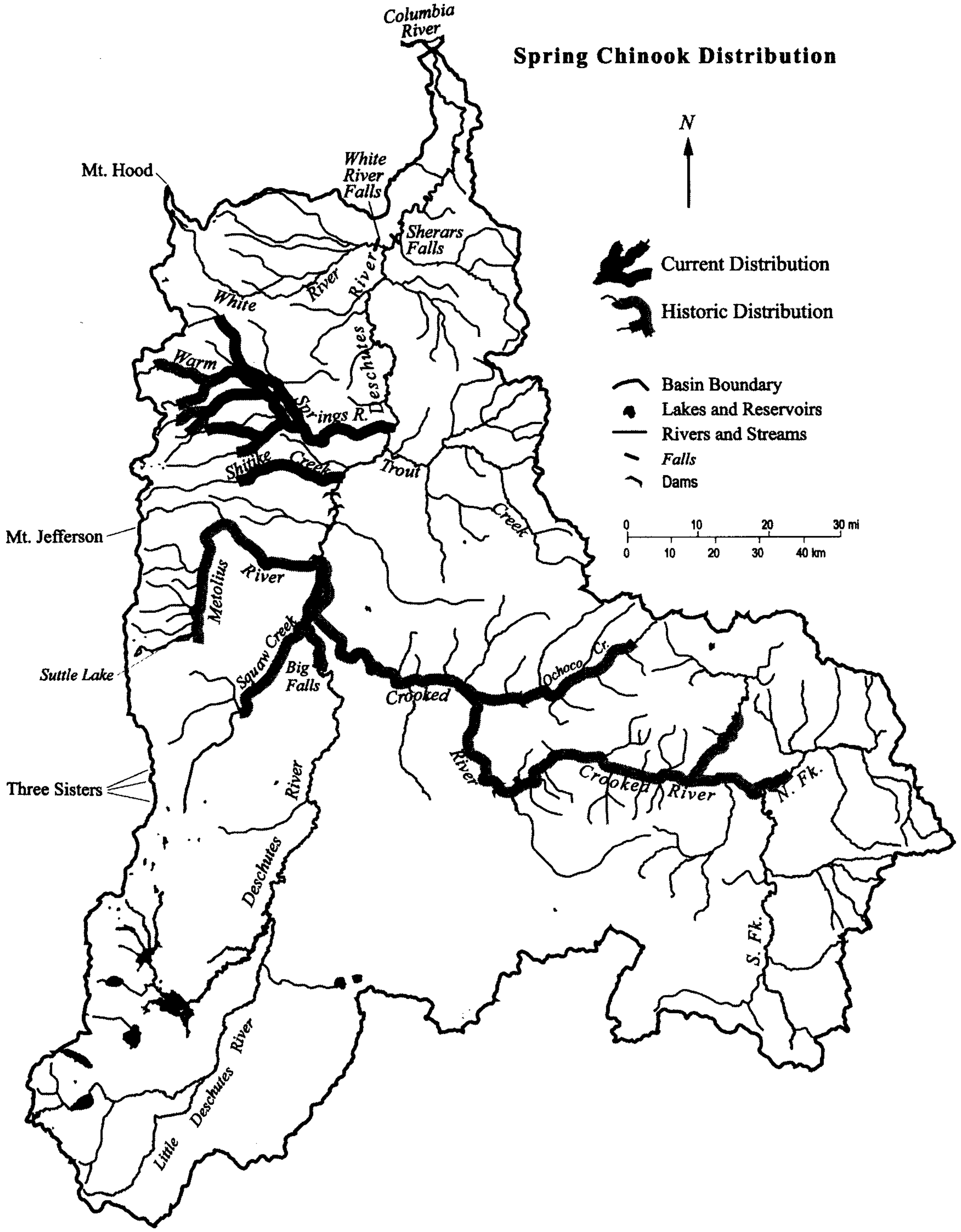

Figure 4. Present and historic distribution of spring chinook salmon (*Oncorhynchus tshawytscha*) in the Deschutes River basin, Oregon.

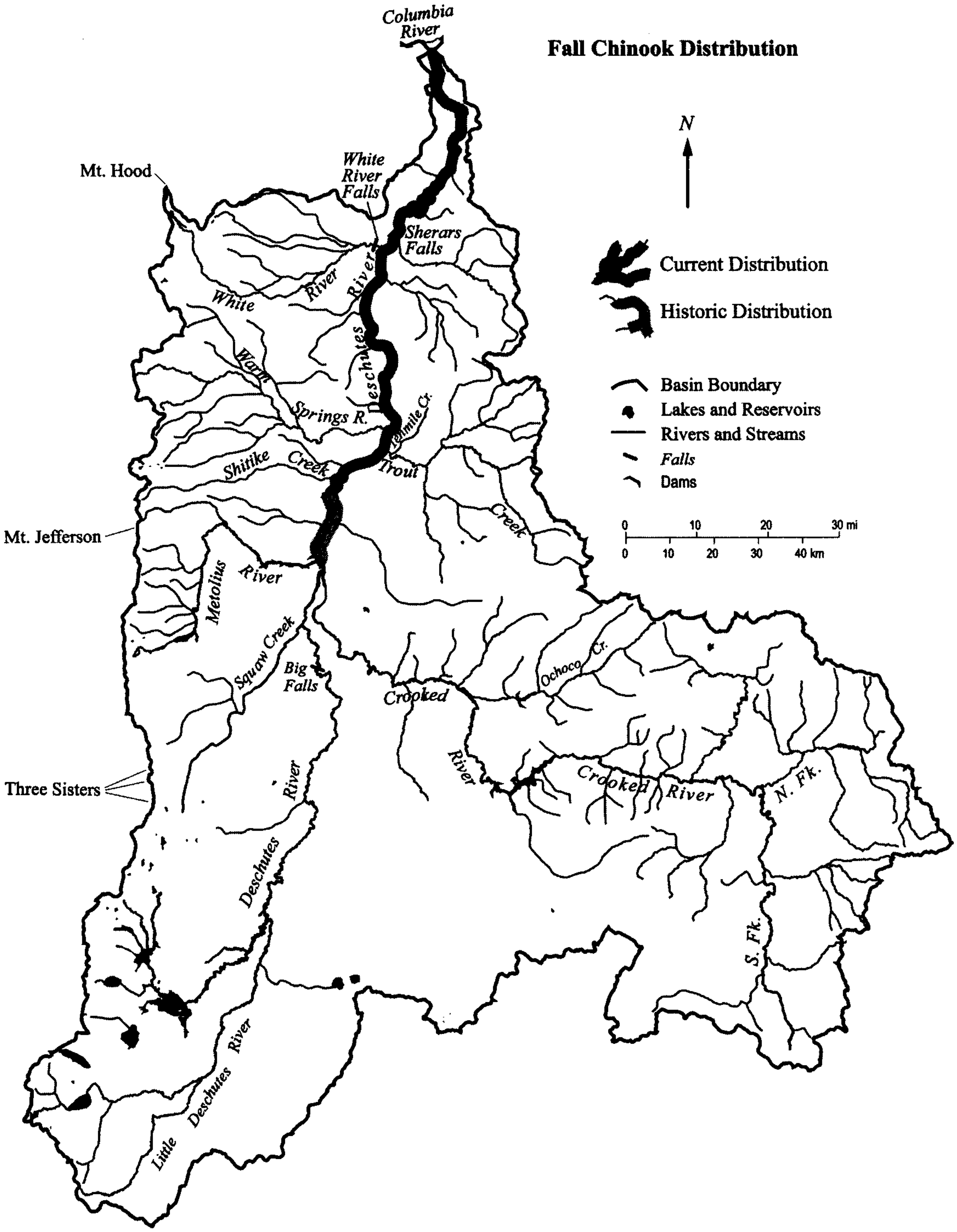

Figure 5. Present and historic distribution of fall chinook salmon (*Oncorhynchus tshawytscha*) in the Deschutes River basin, Oregon.

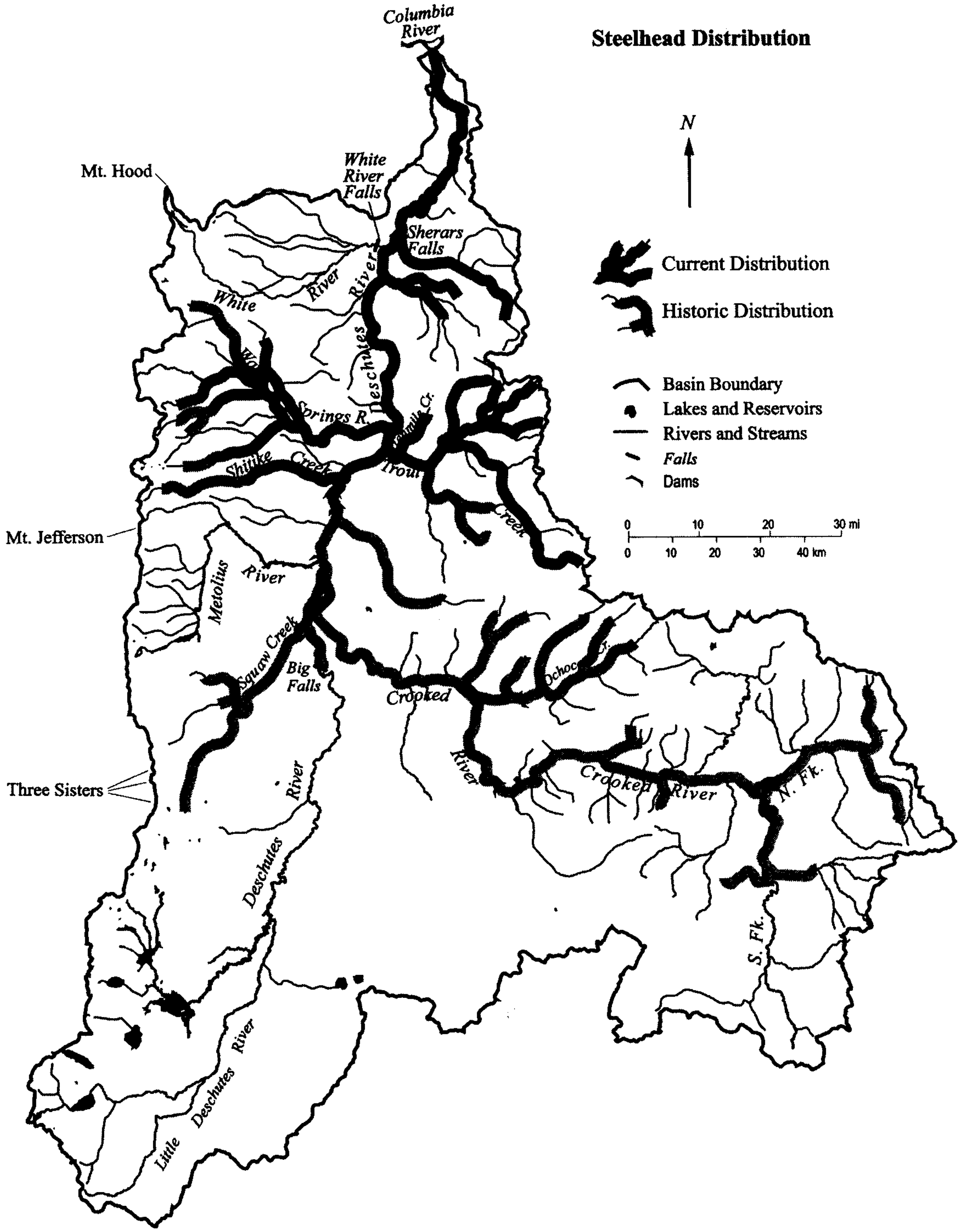

Figure 6. Present and historic distribution of steelhead (*Oncorhynchus mykiss*) in the Deschutes River basin, Oregon.

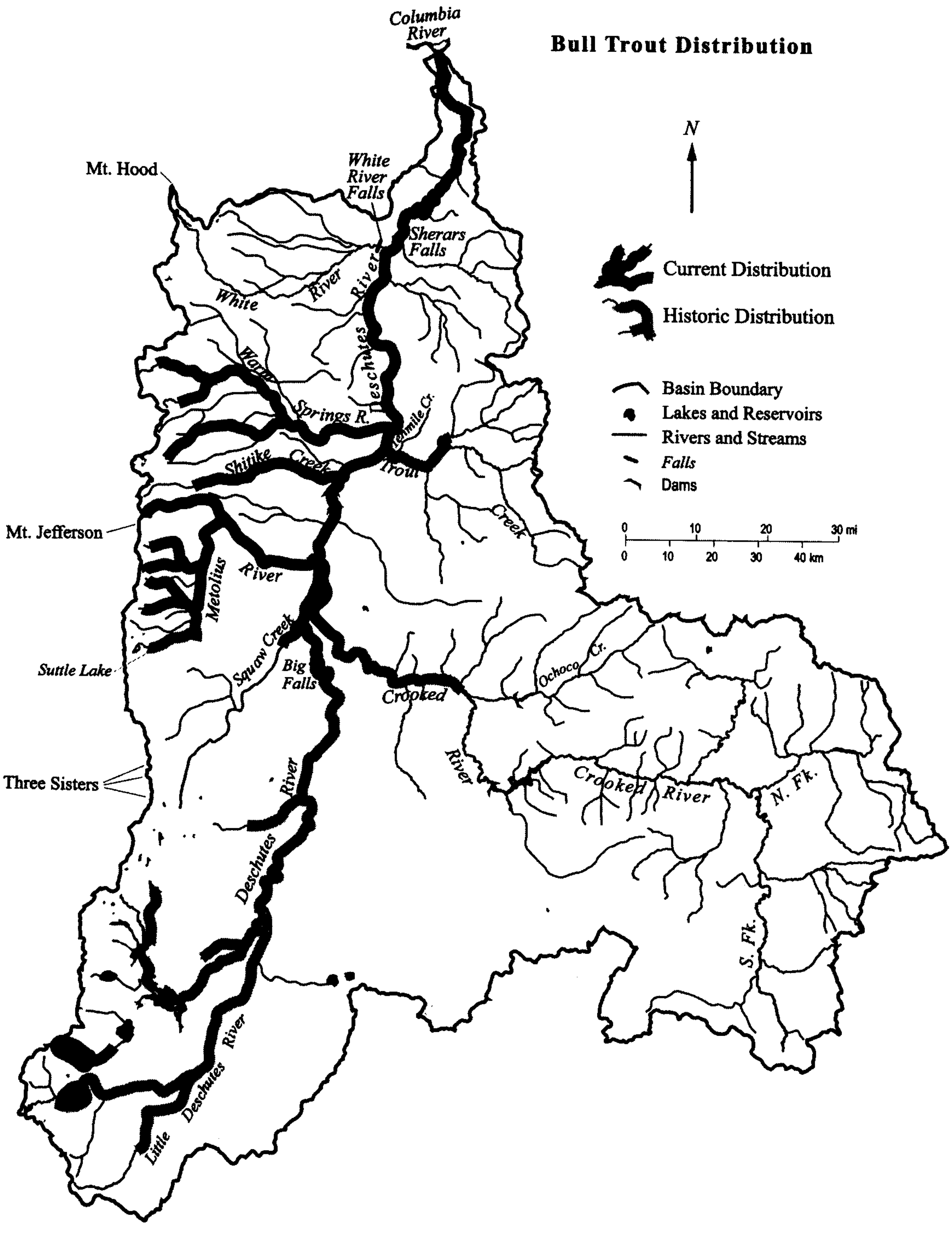

Figure 7. Present and historic distribution of bull trout (*Salvelinus confluentus*) in the Deschutes River basin, Oregon.

Deschutes River Geology, Geomorphology and Hydrology
Summary Notes

O'Connor, J.E., and Grant, G.E., eds., 2003, A peculiar river: geology, geomorphology, and hydrology of the Deschutes River, Oregon: American Geophysical Union, Water Science and Application 7, 219 p.

Foreward (Wolman):

Deschutes River

-80% of mean annual Q is from groundwater sources
-For two largest historic floods: 70% of Qpeak came from 26% of drainage area
-Peak flood flows < five times mean annual flow
-Low annual sediment load: 4-6 ton/sq. km/yr
-Precipitation Range: 2000 mm on west, near Cascades to <200 on eastern portion

Introduction (O'Connor and Grant):

-Groundwater control of discharge renders mean annual flow very stable on Deschutes

-Unique Aspects of Deschutes

- drains east of uplifted Cascade volcanic arc
- basin lies in tectonically-derived rainshadow
- deep groundwater systems supports stable discharge regime
  - cool river temperatures / good fish habitat in otherwise arid landscape
  - stable flows and stable annual hydrographs
  - surface flows buffered by groundwater system
- limited surface runoff / arid conditions
  - low drainage densities
  - low angle slopes
  - low historic / late Holocene sediment production and delivery to channels

Geology, Geomorphology, Hydrology (O'Connor, Grant, and Haluska)

Deschutes Background

-Drainage area = 26860 sq. km
-Drains north for 300 km into Columbia
-Pelton-Round Butte Dam located 160-180 km upstream from mouth

Geologic Setting

-majority of basin underlain by Cenozoic (<65 m.y.) volcanic rocks
- rock ages generally young from east to west across basin

east edge: Mz / Pz metamorphic and sed rks

North-central basin: Eocene-Oligocene John Day and Clarno Fms
(volcanic, volcaniclastic, and sed. rocks)

Northern margin: overlain by Miocene Columbia River Basalts

- eastern Deschutes = Picture Gorge basalts, from John Day area
- northern Deschutes = younger CRBs from eastern WA/OR

Post-CRB (Miocene-Pliocene)
- deformation of CRB
- volcanic eruptions/lahars of Simtustus, Deschutes, and Dalles Formations (15-4 m.y.)
  - plus Rattlesnake Ashflow Tuff in SE part of Deschutes basin
- Rim-capping, Pliocene basalt flows are intermixed with river gravels 275 m above present river level
- Western edge of Deschutes basin marked by < 2 m.y. high cascade volcanic arc rocks

River incision rates: river level / gravels at 275 m elevation = 4 m.y. old, deposits along present river drainge < 1 m.y. old: incision rate from 4 m.y. to 1 m.y. = 0.1 mm/yr = 0.1 m / 1000 yr = 100 m / m.y.

Topography

- Eastern Highlands Terrane (Ochoco Mtns. / Crooked River sub-basin)
  - John Day / Clarno Formations (55-20 m.y. – claystone, siltst, ashflow tuff)
    - Susceptible to landsliding, most landslides spawned from these formations
- Young Volcanic Terrane – southern and southwestern part of basin
  - High Cascades to west / SW
  - Newberry Volcano on east /SE
  - Localized glacial outwash
  - 7000 yr old Mazama ash
  - faulting / channel-damming lava flows
  - low-relief alluvial and lacustrine landscape
- Northern Canyon Terrane
  - Basalt-canyons, rim rock country
  - Cliff-forming CRB's underlain by John Day / Clarno Formations
  - Landslide-dominated uplands of the John Day / Clarno Formations
  - steep canyon slopes and drainage densities

Hydrology

- drainage area = 26860 sq. km
- average annual runoff = 5.2×10^9 m^3 = 0.19 m of runoff over entire basin
- highest precip. on western basin with input from eastern high Cascades
- arid / rainshadow conditions on eastern side of basin
- Gage at mouth of Deschutes / Columbia
  - Avg. Feb. flow = 213 cms
  - Avg. Aug. flow = 124 cms low overall variation, given seasonal snowmelt
  - Wet season / dry season discharge = 1.5 times

For comparison: John Day River: Wet season/dry season discharge = 30 times; Willamette = 10 times

- Largest historic peak flow =540 cms in Feb. 1962 (< 5 times mean flow)

(comparison John Day/Willamette peak flow record = >20 times mean annual flow)

- Interpretation of Steady Annual Flow Conditions
  - Poorly integrated surface drainage in eastern basin
  - Seasonal snowmelt in western basin infiltrates into young volcanic rocks, forms extensive groundwater discharge buffering system
  - Eastern sub-basins show strong seasonal fluctuation/snow melt but have small drainage areas

Sediment Production

- Little work done basin-wide on sediment budgets
- Most historic sediment data collected at Pelton-Round Butte Dam
- Highest long-term sediment yields generally associated with glacial climates / outwash on western boundary (Cascades) of basin and also volcanic eruptions / volcaniclastics (e.g. Mazama ash to south)
- Historic sediment yields from reservoir studies:
    - 4- 6 tons / sq km / yr (i.e. low sediment yields compared to other rivers)

Summary of Important Characteristics

- moral of story: steady discharges and low sediment yields are evident from modern studies
- present topography / geomorphology of Deschutes:
    - present north-flowing course established ~12 m.y. ago
    - Canyon incision occurred between 4 and 1 m.y. ago/ with localized aggradation / incision events
- Southern, upstream portion of basin underlain by permeable young volc. Rocks – results in strong groundwater control on discharge
- Young volcanic rocks to south and east produce little sediment; primarily assoc. with glacial outwash
- Eastern Highlands underlain by John Day / Clarno Formations, results in more extensive landsliding and greater sediment influx
- Steady stream flows and low sediment delivery result in low sed. Yields overall
- Over time scales of thousands to millions of years: most sediment production is associated with (1) volcanic eruptions, lahars, landslides (in John Day/Clarno), glacial climatic episodes, or incision events