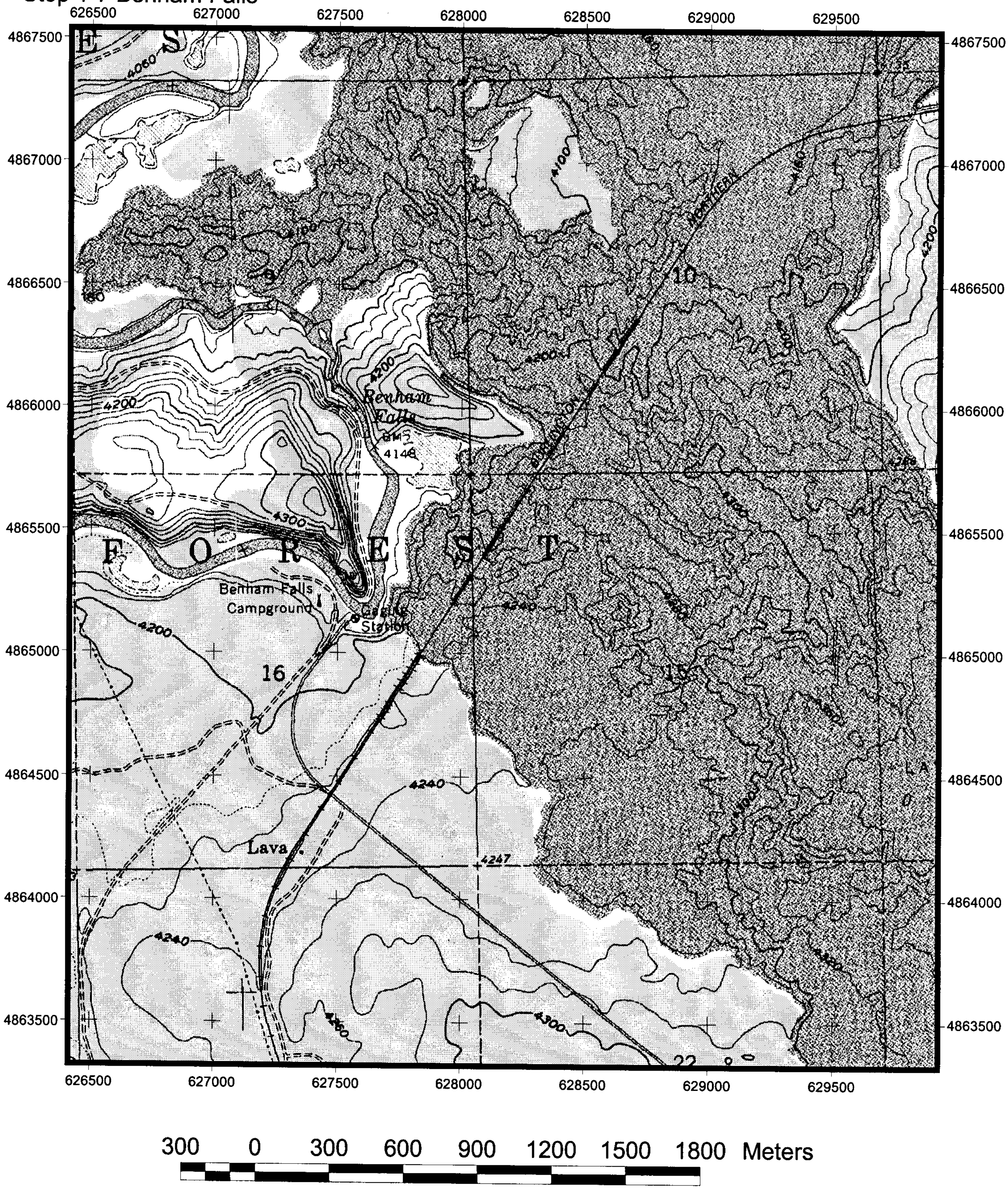
Stop 1-7 Benham Falls



Stop 1-9 and 1-10 - Paulina Lake

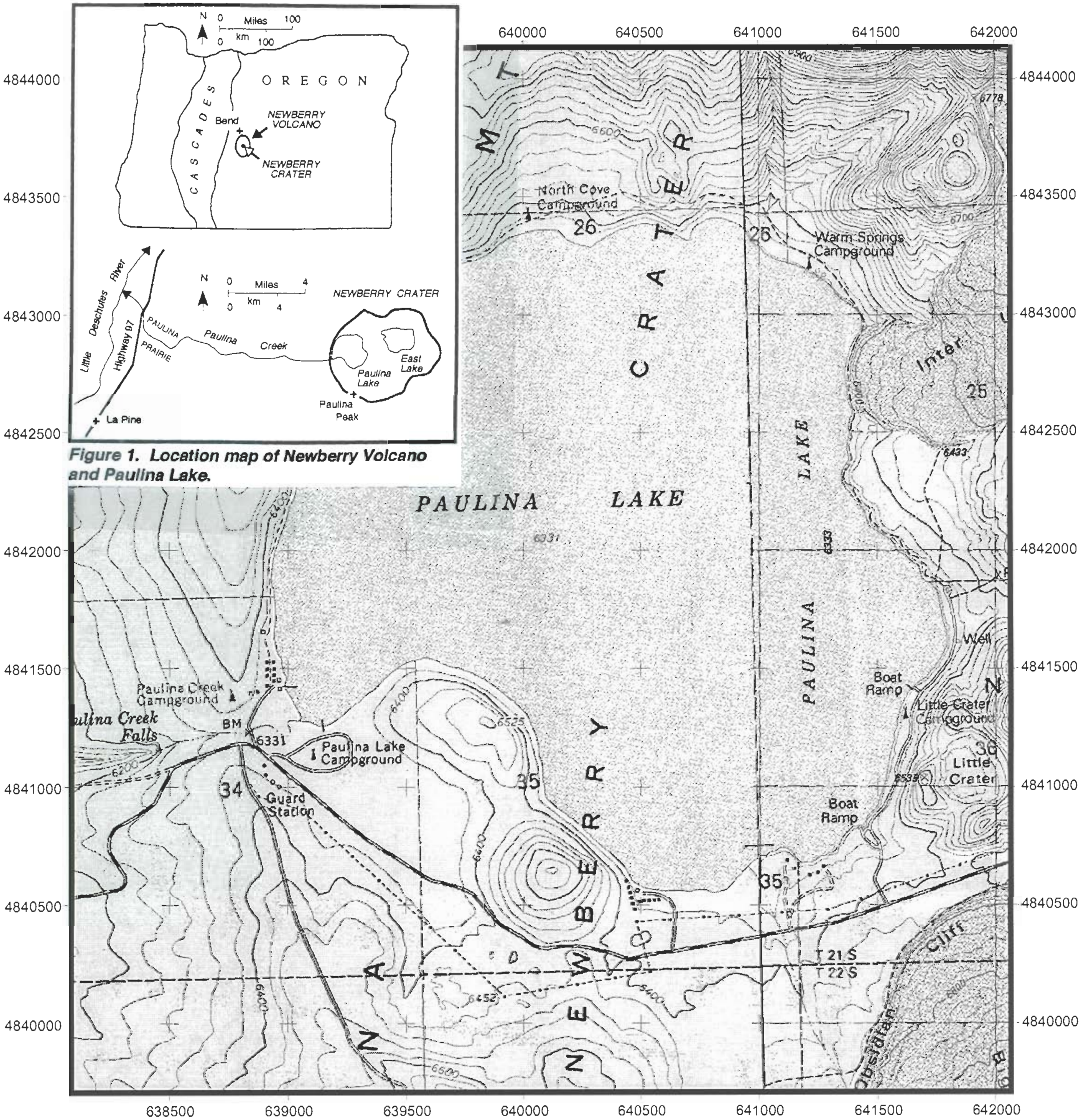
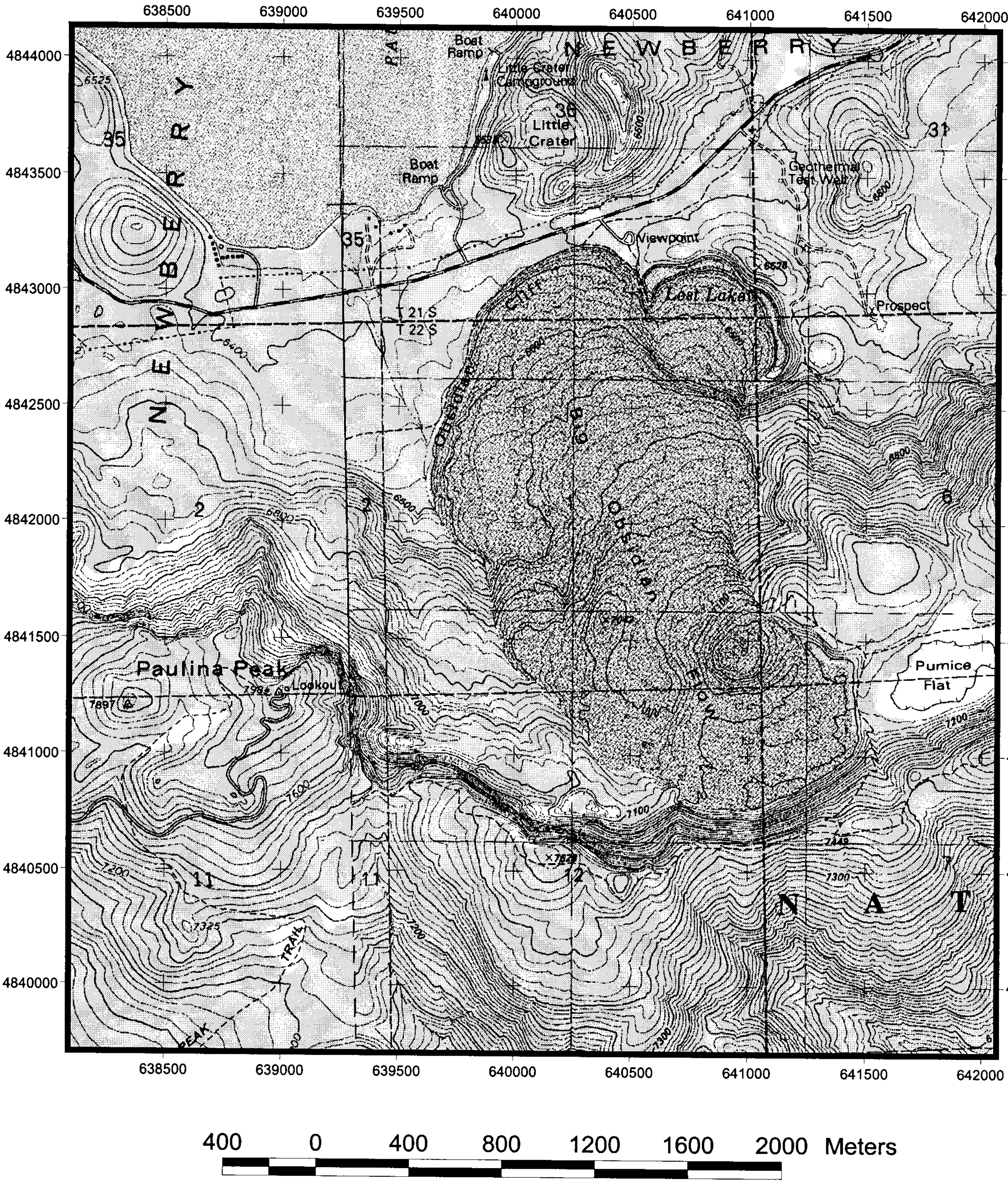
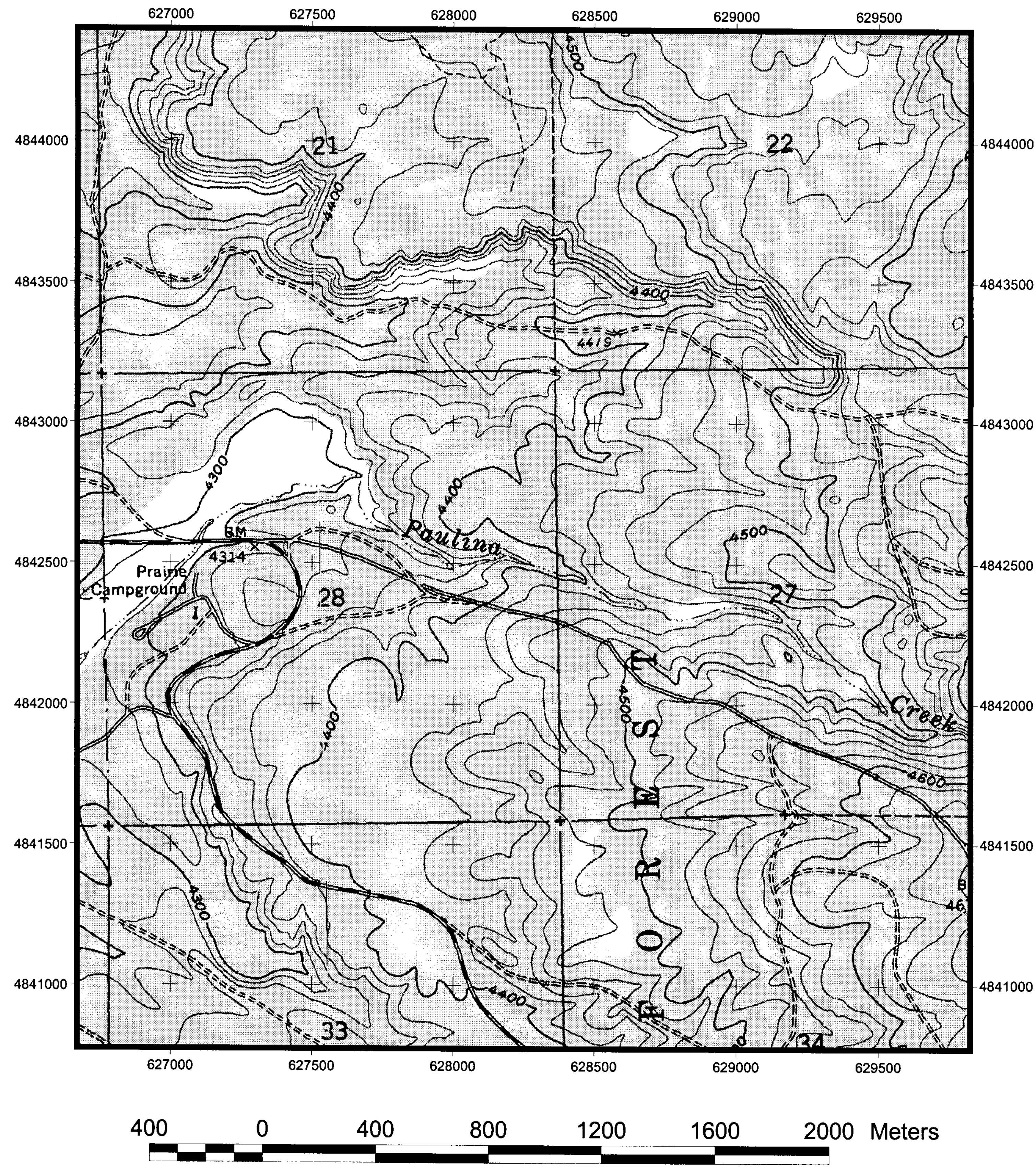


Figure 1. Location map of Newberry Volcano and Paulina Lake.

Stop 1-11 Paulina Peak

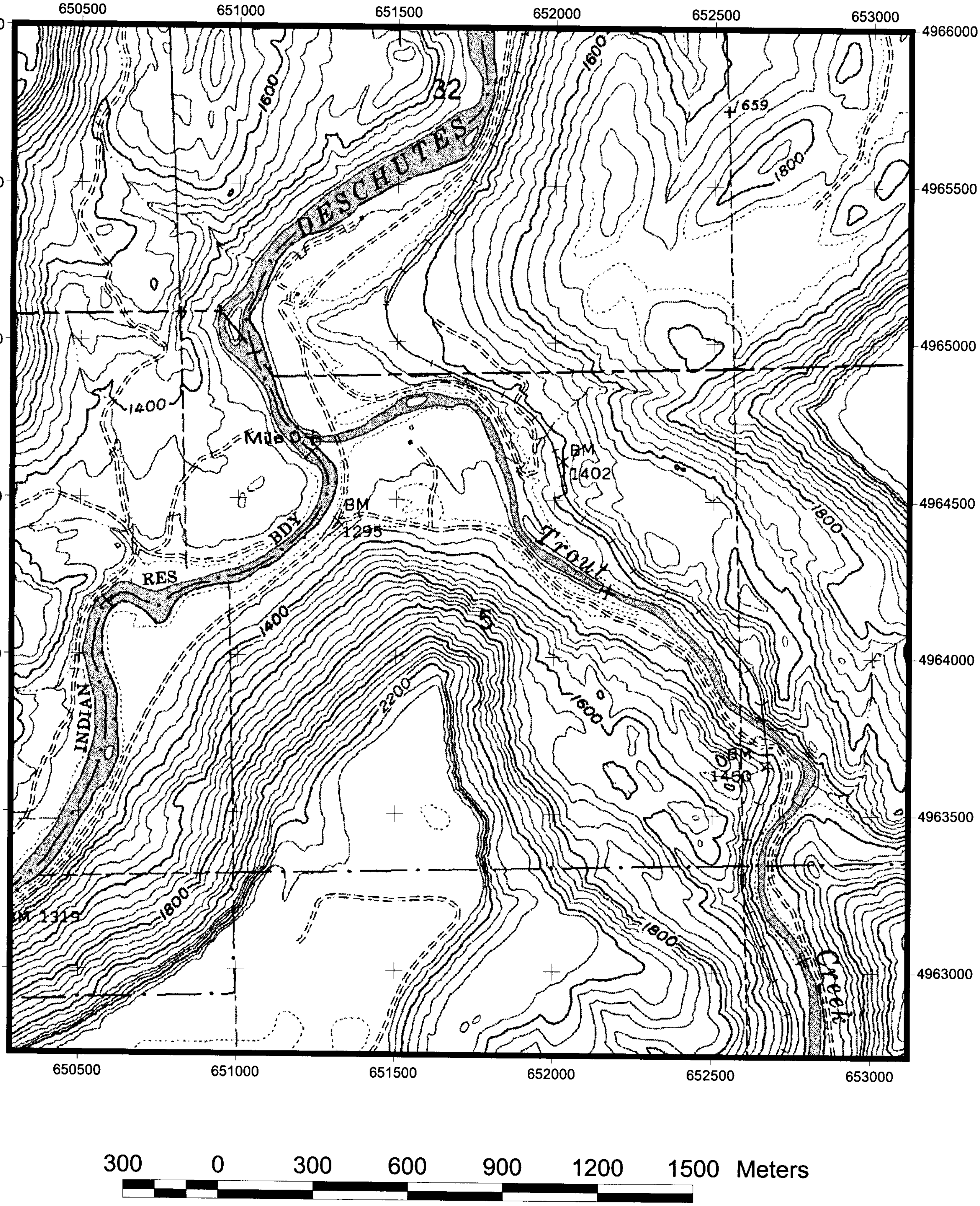


Stop 2-1 Lower Paulina Creek



165

Stop 2-2 Lower Trout Creek



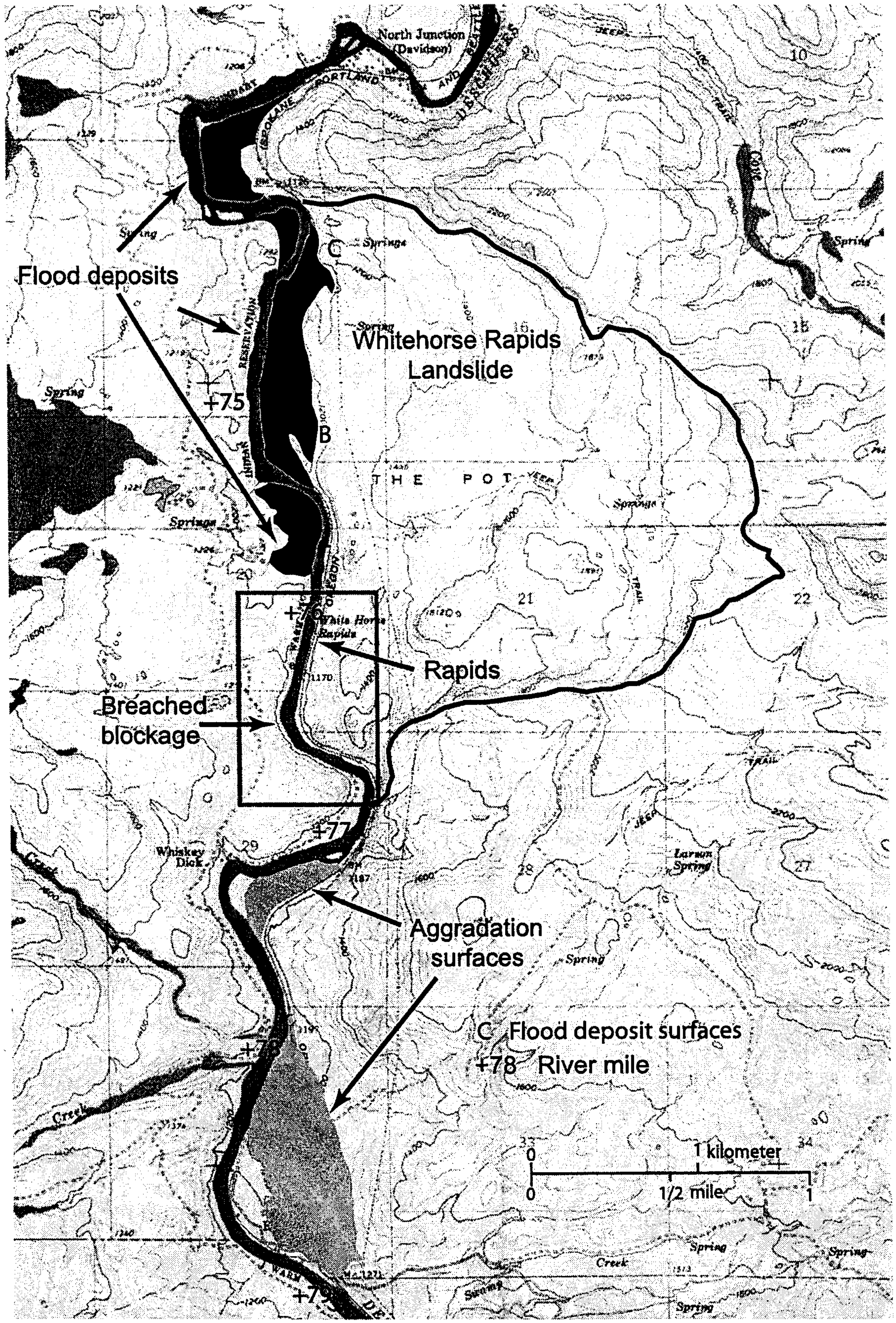
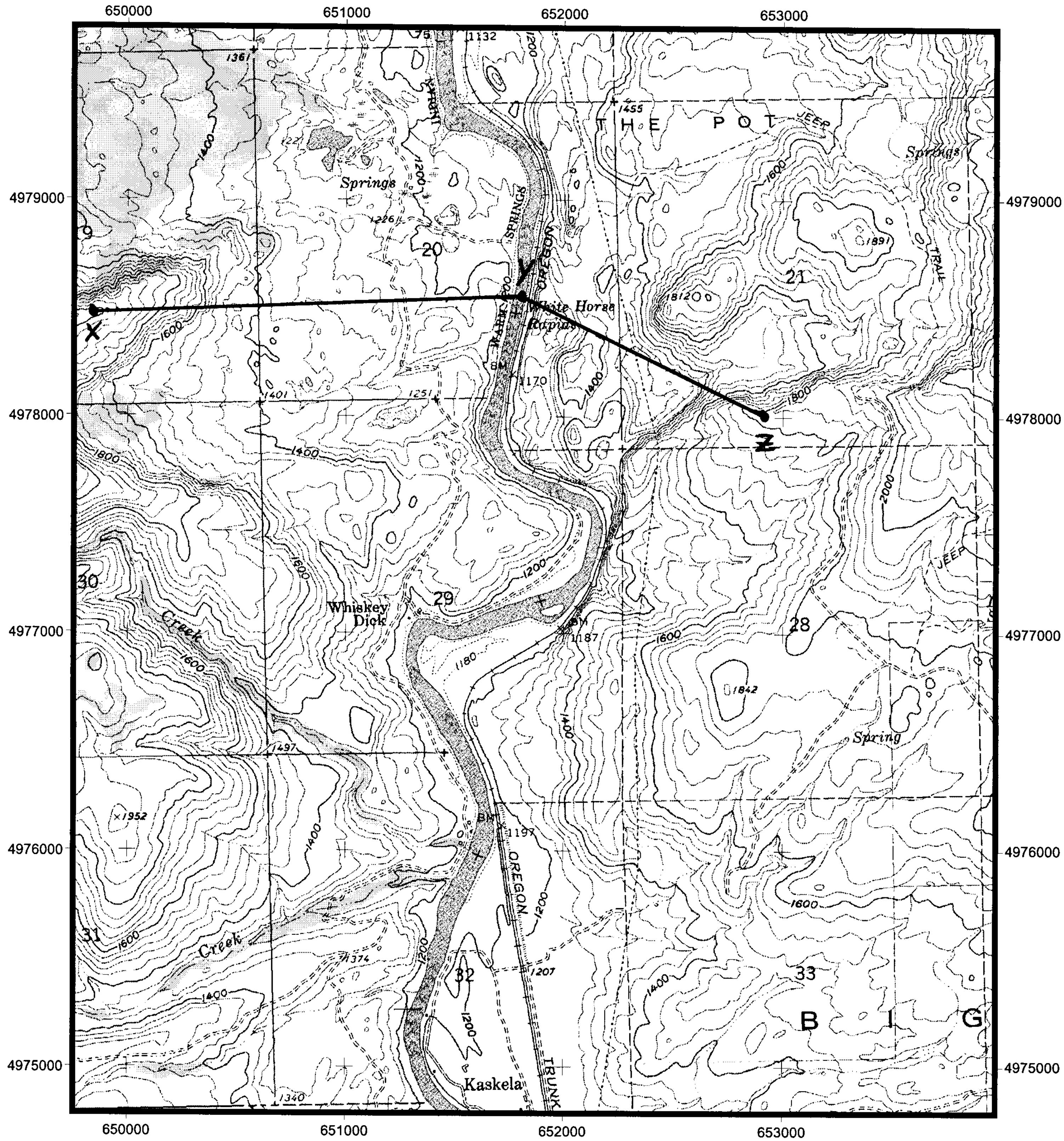
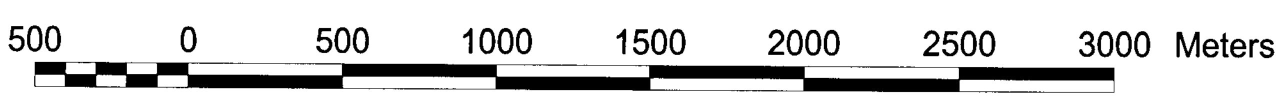


Figure 6. Geomorphic features related to the dam produced by the Whitehorse Rapids Landslide and the area of its outburst flood deposits plotted on the U.S. Geological Survey Kaskela 7.5-Minute Quadrangle.

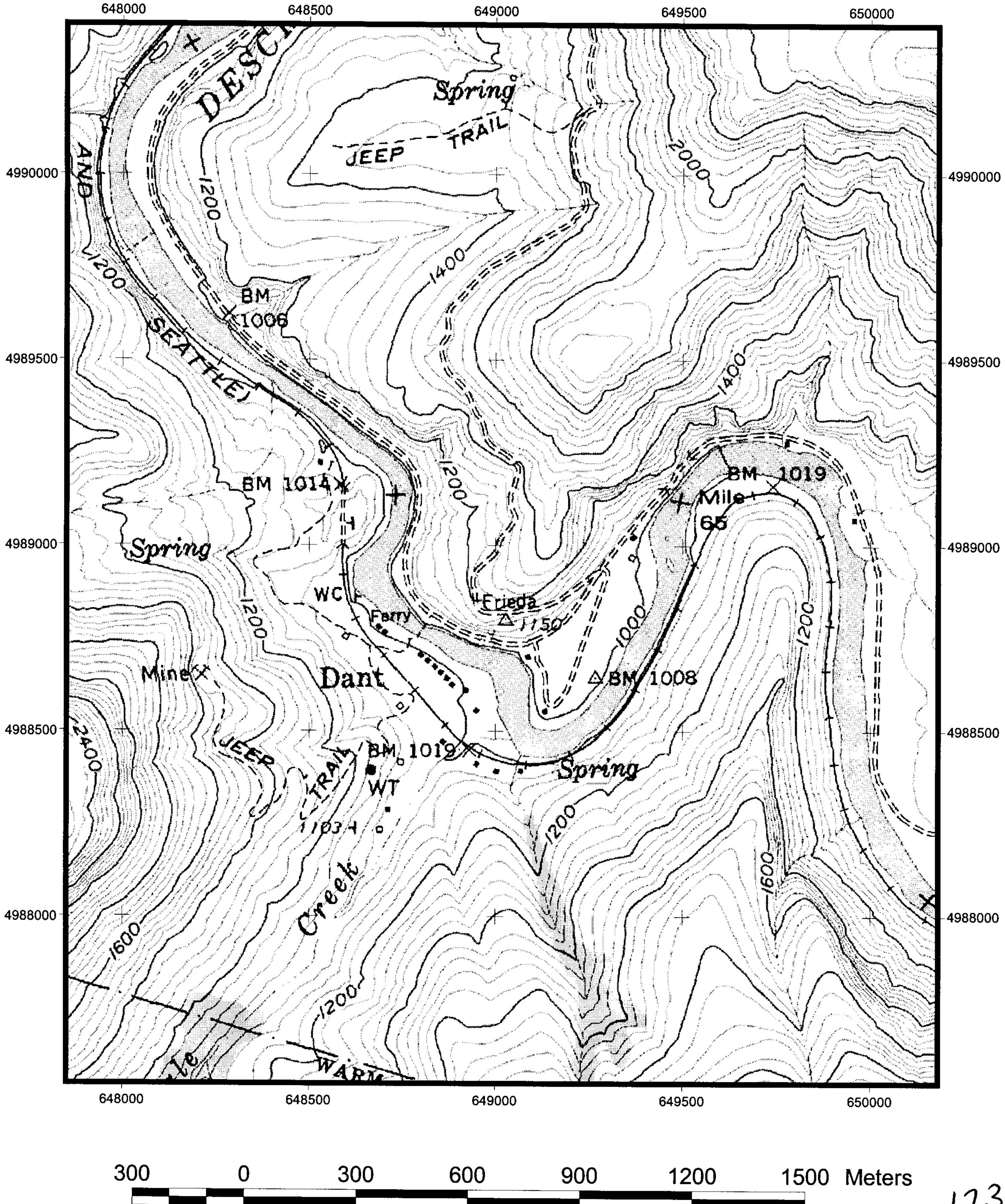
169

Stop 3-3 Whiskey Dick

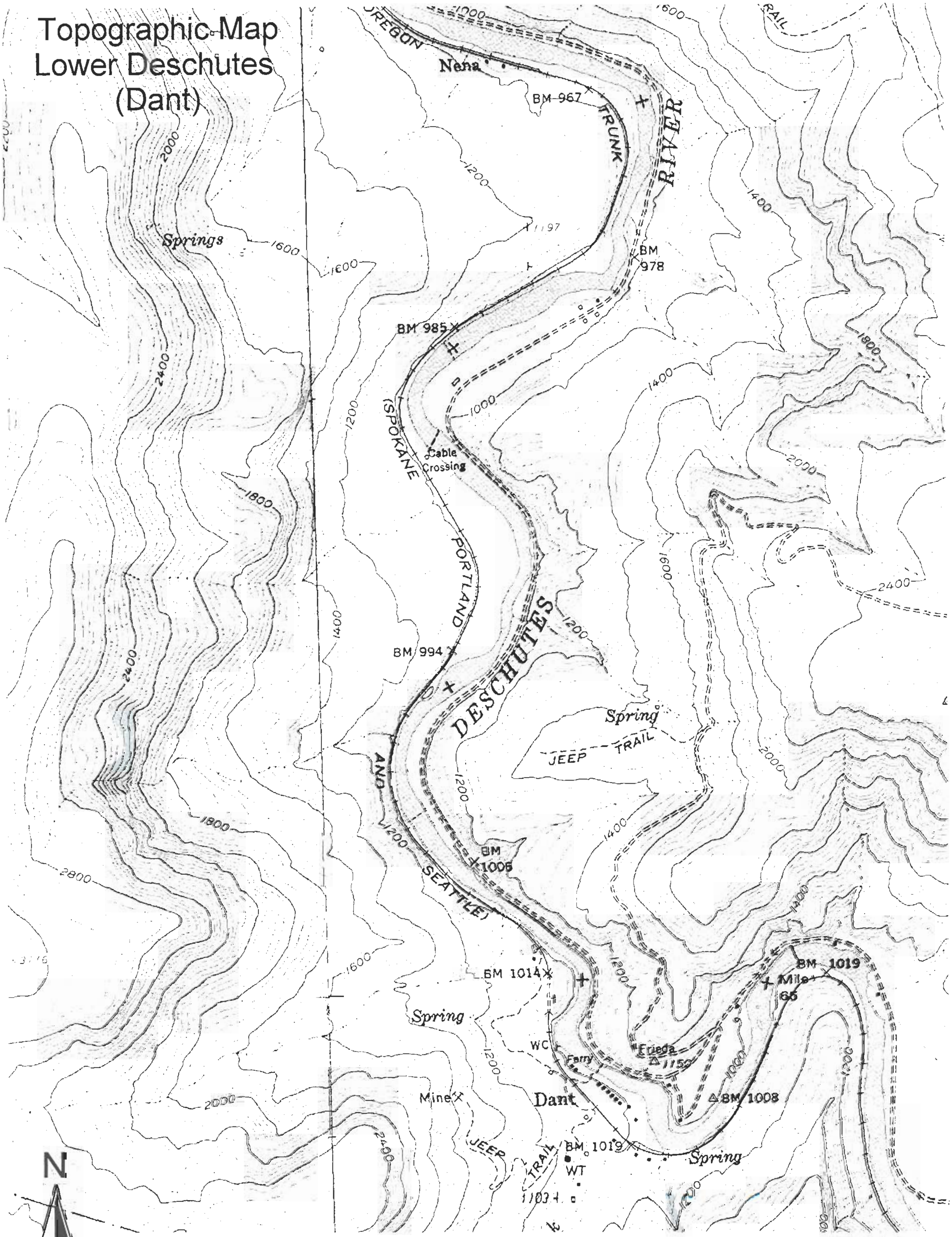




Stop 4-3 and 4-4 Dant / Buckskin Mary

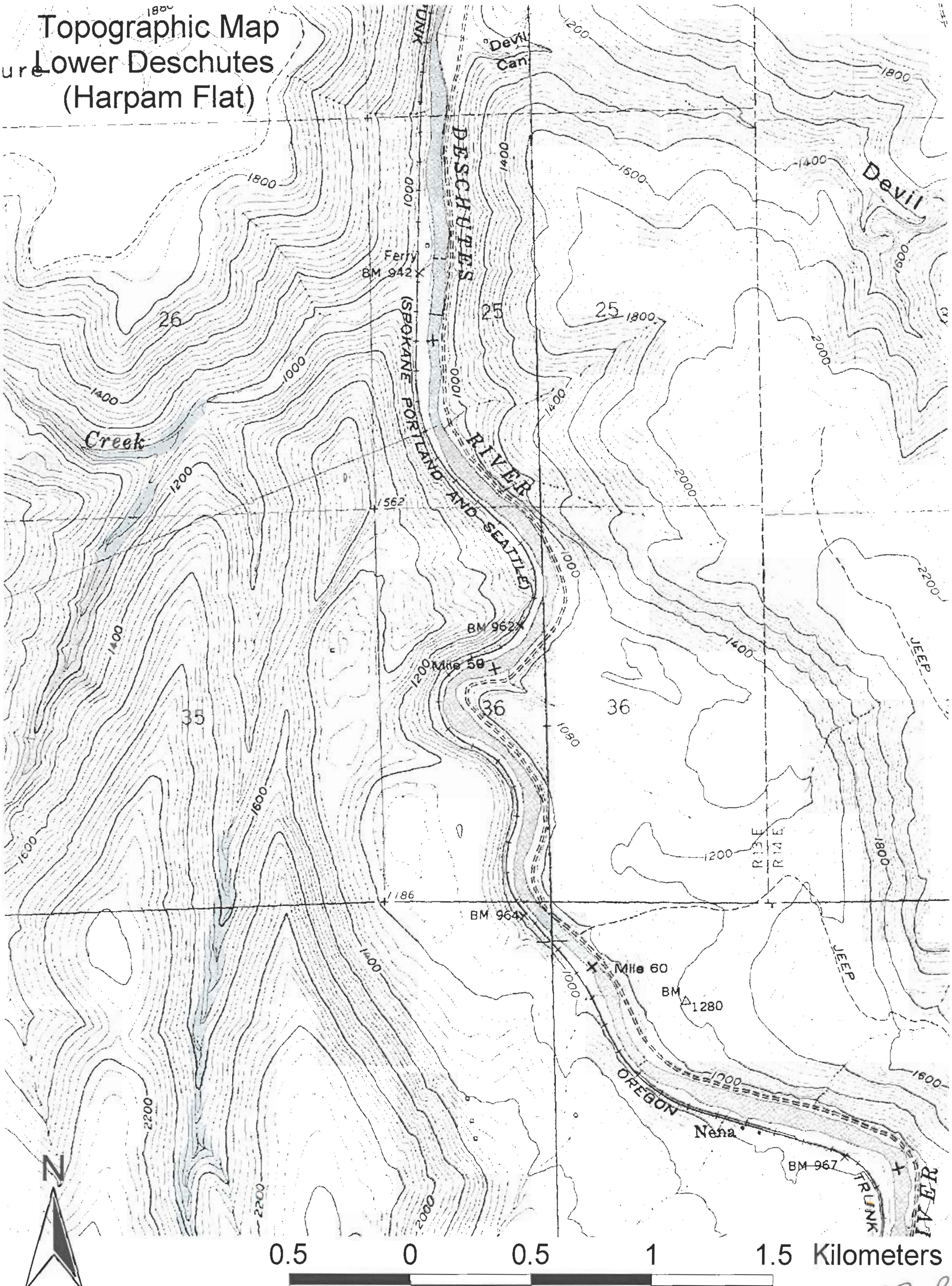


Topographic Map
Lower Deschutes
(Dant)

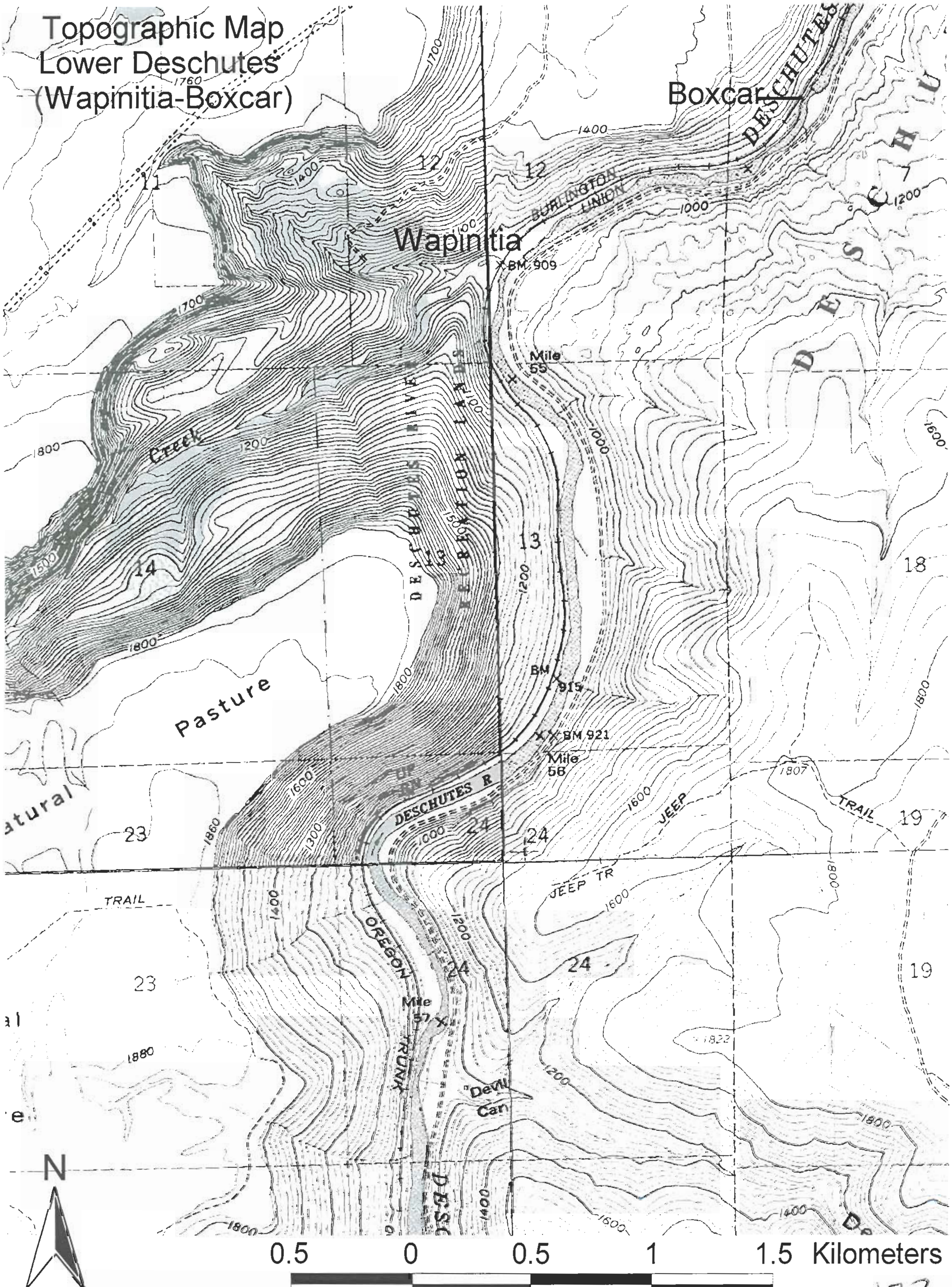


0.5 0 0.5 1 1.5 Kilometers

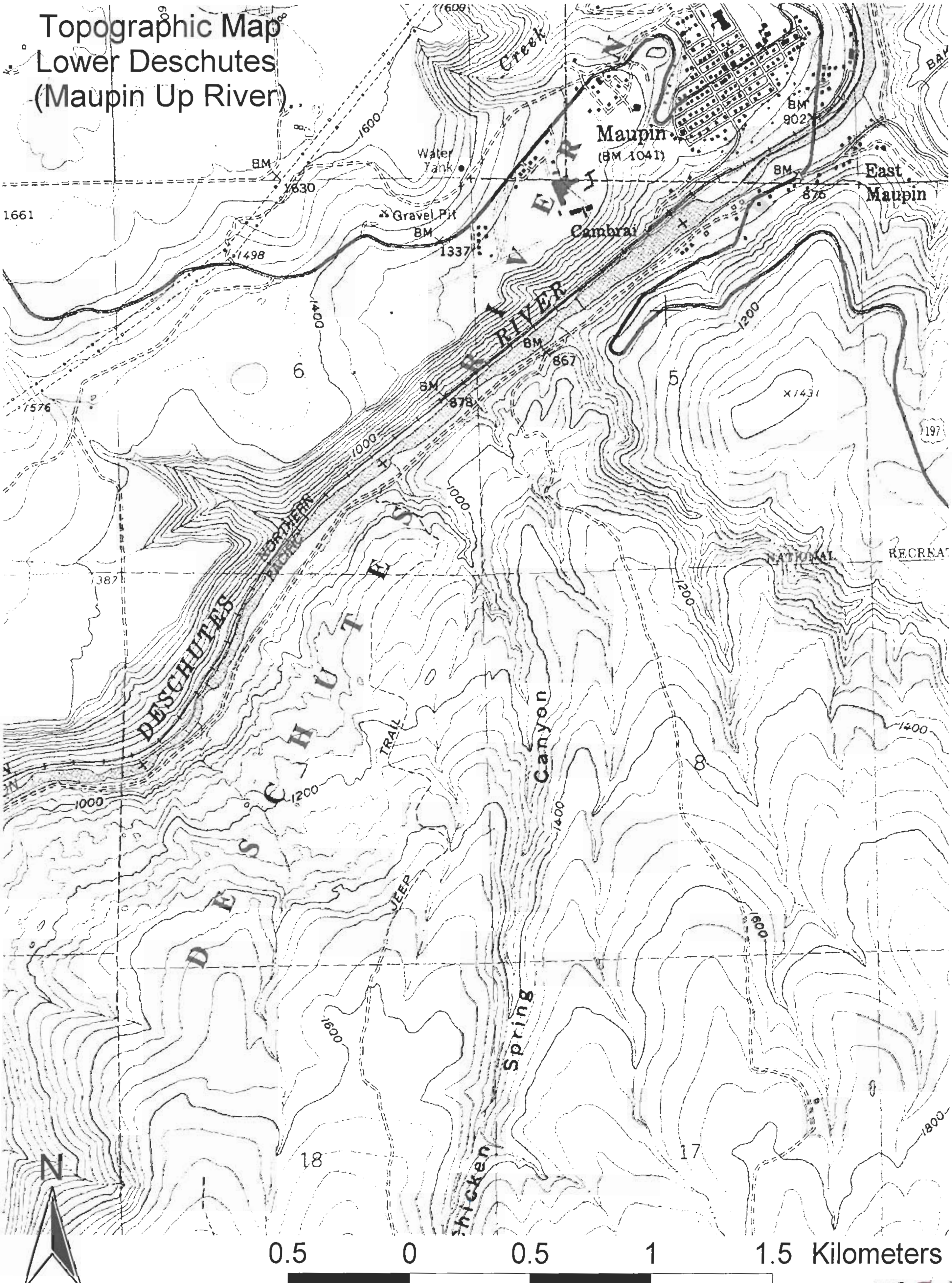
173 A


Topographic Map
Lower Deschutes
(Harpam Flat)
DESCHUTES
RIVER
(SPOKANE PORTLAND AND SEATTLE)
Devil Can
Devil
Creek
Ferry
BM 942
BM 962
BM 964
BM 967
BM 1280
Mile 59
Mile 60
OREGON
TRUNK
Nena
JEEP
R13E
R14E
26
25
35
36
1562
1186
0.5
0
0.5
1
1.5
Kilometers
N

73 B

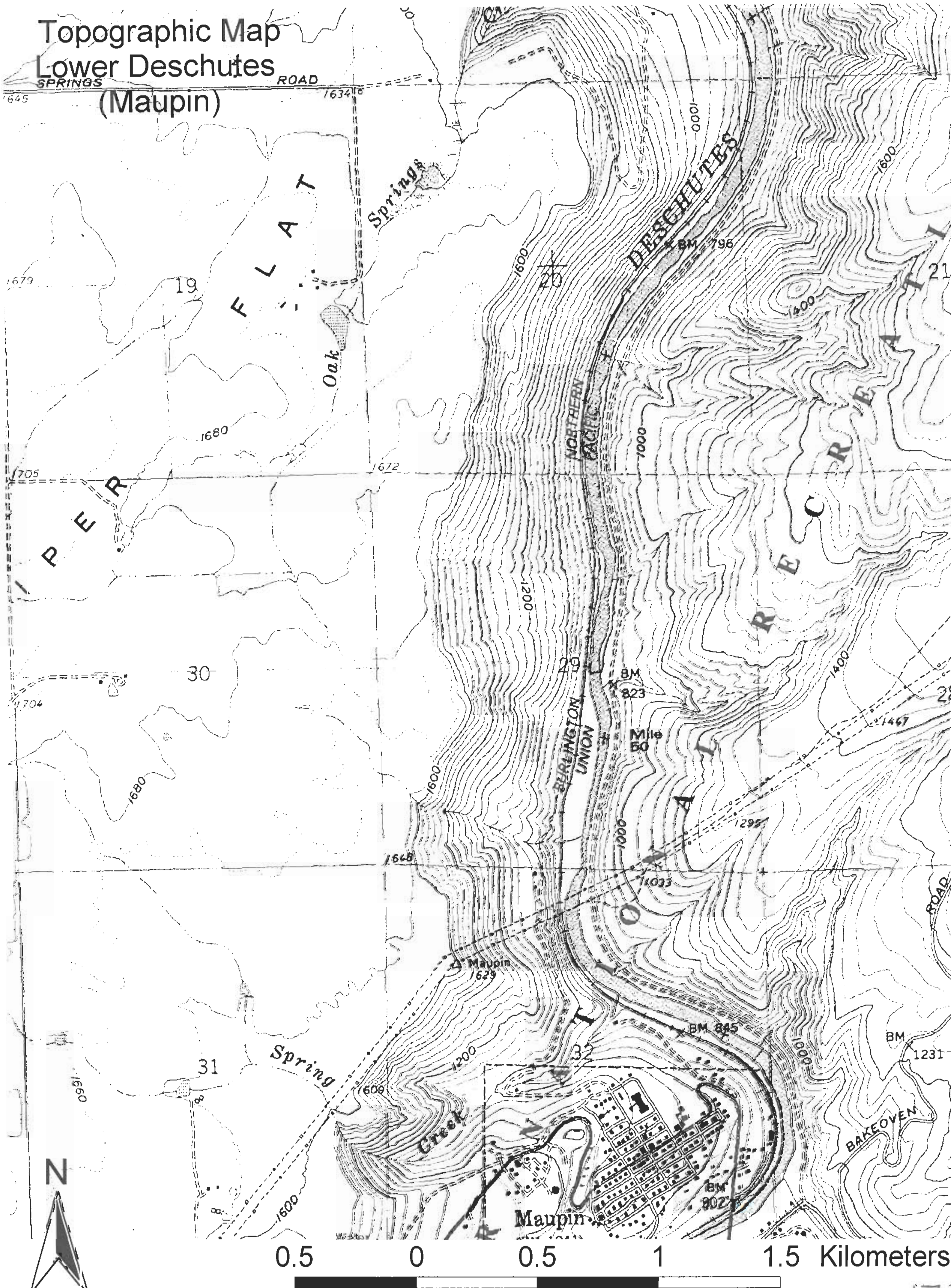

Topographic Map
Lower Deschutes
(Wapinitia-Boxcar)
Boxcar
Wapinitia
DESCHUTES
BURLINGTON
UNION
BM 909
Mile 55
Creek
DESCHUTES RIVER
RECREATION LANDS
Pasture
BM 915
BM 921
Mile 56
DESCHUTES R
JEEP
TRAIL
JEEP TR
OREGON
TRUNK
Mile 57
Devil Can
N
0.5 0 0.5 1 1.5 Kilometers

173 C



Topographic Map
Lower Deschutes
(Maupin Up River)
Creek
Maupin
(BM 1041)
BM
902
East
Maupin
BM
876
Cambrai
Water
Tank
Gravel Pit
BM
1337
BM
1630
1600
1661
1498
1400
RIVER
BM
867
BM
878
6
5
1431
197
1000
NORTHERN PACIFIC
NATIONAL
RECREAT
1387
1200
DESCHUTES
8
Canyon
TRAIL
JEEP
Spring
Chicken
18
17
1800
N
0.5 0 0.5 1 1.5 Kilometers

173D


Topographic Map
Lower Deschutes
(Maupin)
SPRINGS ROAD
1645
1634
Springs
Oak
FLAT
IPER
19
20
21
1679
1680
1705
1672
1600
1000
1400
DESCHUTES
BM 796
NORTHERN PACIFIC
BURLINGTON UNION
RECREATI
NATIONAL
29
30
28
BM 823
Mile 50
1704
1200
1467
1295
1033
1648
Maupin 1629
BM 845
32
31
Spring Creek
1609
BM 1231
BAKEOVEN
ROAD
BM 902
Maupin
N
0.5 0 0.5 1 1.5 Kilometers

173E

Significance of the site: Besides the Missoula flood deposits of latest Pleistocene age, deposits we attribute to much older Missoula flood events are preserved here. Evidence for the antiquity of these latter deposits are the well-developed paleosols they contain. Each paleosol contains a Bk or K horizon ranging in carbonate development from Stage II to Stage IV, in contrast to the mod-

STOP 6-2 HWY 197 PALESOL ROAD CUT

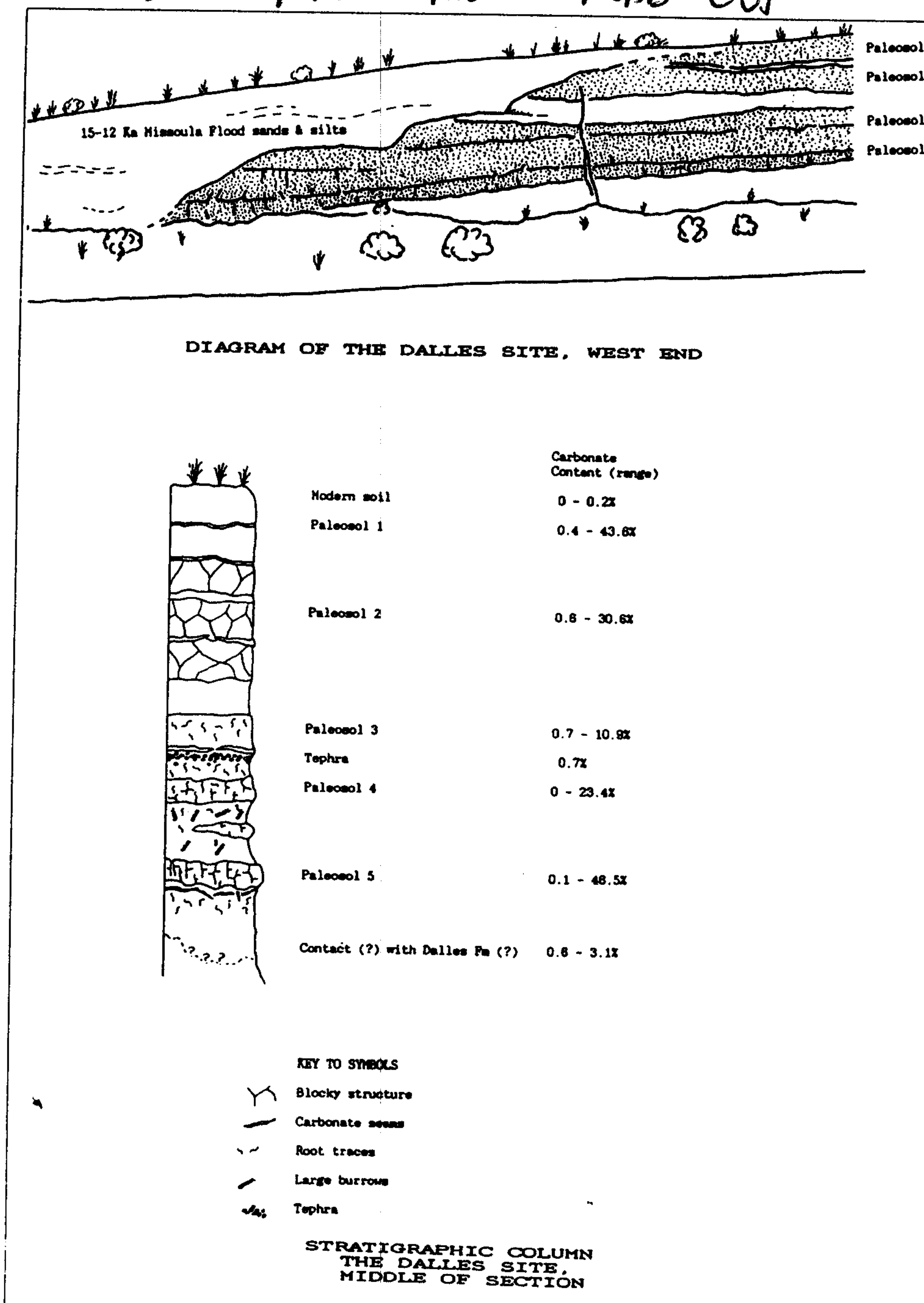


Figure 27. Sketch and stratigraphic column of exposure at Stop 3.2.

Davis (1984), a 400-ka fine ash of unk
ern Nevada. As the tephra here is fairl
correct, may help to reveal the source

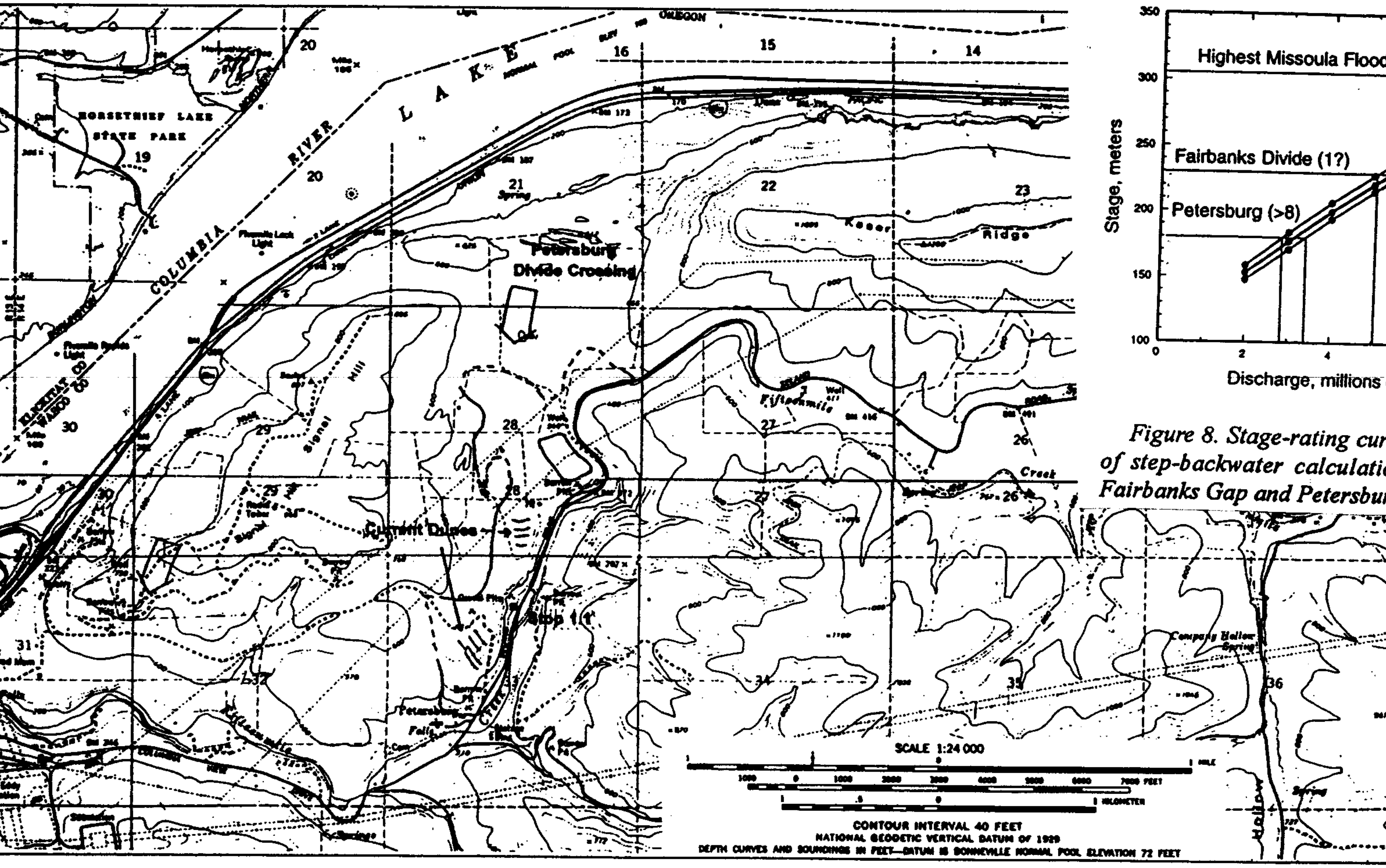
En route to Stop 3.3

Proceed back to Interstate 84 and
The Dalles. The Columbia
to the south and then north
basin and crosses the Colu
trends southwest across th
Columbia River Basalt G
Formation, which dips dov
of the city. Some recently a
ment as great as 5 cm/yr hav
of The Dalles (Rosenfield, 1

Past The Dalles, where
north, is butte-and-basin sc
the west is the rising flank o
Point, defining the south liml
cline (also called the Ortley
breached by the Columbia F
has been etched into the hill
stripped loess from the top o
Group. This trimline is at 31
southwest end of the slope
(960±40 ft) at the Rowena C
Point. Small granitic erratic
(940±40 ft) at Crates Point.

The Columbia River Go
managed by the U.S. Fore
east as the Deschutes Ri
physiographic gorge is betw
land, where the Columbia
Range. The core of the rang
hundred meters during the
Columbia River Basalt Grou
tiary volcanic, volcaniclasti
below. These uplifted ro
folded, are capped by the pr
late Tertiary and Quaternary

Pass through Rowena Ga
Rowena (Exit 76). From he
ment of the historic Columb
The scenic highway, the fi
cross the Cascade Range,
1913 and 1915, largely by th
It was essential to Hill and
Lancaster that the road harn
the Gorge. It was also im
serve as a functional crossi
the engineering specificati
width of 24 ft, a maximum



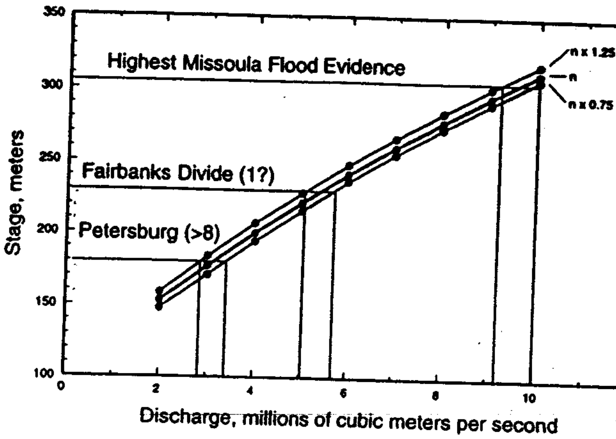
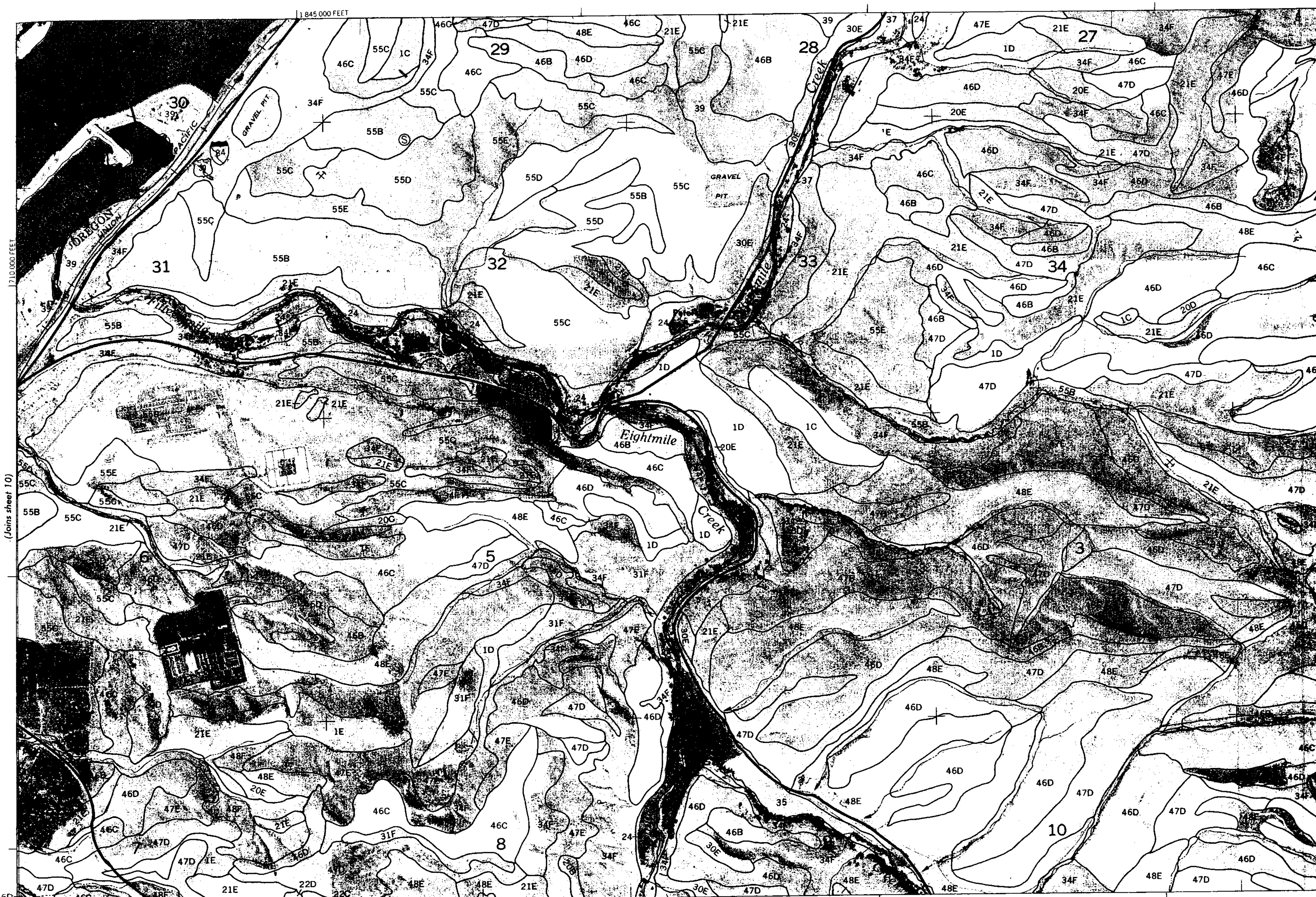


Figure 8. Stage-rating curves constructed on the basis of step-backwater calculations for the reach near the Fairbanks Gap and Petersburg divide crossings. The sen-

STOP 6-3 PETERSBURG BAR / FIFTEEN MILE CREEK

7. Topographic map of the settings of Petersburg and Fairbanks divide crossings, with approximate extent of the rs that were deposited as flow (arrows) spilled into the valley of Fifteenmile Creek. Topographic base from Stacker / Petersburg USGS 7½′ quadrangles.

SOIL MAP STOP 6-1



1 ¾ ½ ¼ 0 1 Mile
5000 4000 3000 2000 1000 0 5000 Feet
Scale 1:20000

plastic; few very fine roots; many very fine tubular pores; 10 percent nodules; strongly calcareous; moderately alkaline; abrupt wavy boundary.

IIR—51 inches; basalt bedrock with a thin indurated capping.

The A horizon is loam or silt loam. The B horizon is loam or heavy loam. Depth to bedrock is 40 to 60 inches or more.

33—Maupin variant loam. A representative mapping unit is in the NW¼NE¼SW¼ section 9, T. 4 S., R. 13 E. This soil is on uplands. Slopes average about 2 percent.

Included with this soil in mapping were areas of Maupin and Bakeoven soils. These soils make up about 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIe-3, nonirrigated and IIe-2, irrigated; Shrubby Rolling Hills range site.

Nansene Series

The Nansene series consists of well drained soils formed in loess on uplands. Slopes are 35 to 70 percent. Elevation is 300 to 1,500 feet. The vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 11 to 13 inches, the average annual air temperature is 48° to 52° F, and the frost-free period is 140 to 170 days at 32° and 170 to 200 days at 28°.

In a representative profile the surface layer is very dark brown silt loam about 22 inches thick. The subsoil is dark brown silt loam about 10 inches thick. The upper 20 inches of the substratum is dark brown silt loam, and the lower 10 inches is grayish brown silt loam. Basalt bedrock is at a depth of about 62 inches. The surface layer and subsoil are neutral, and the substratum is neutral to moderately alkaline.

Permeability is moderate, and the available water capacity is 6 to 11 inches. Water-supplying capacity is 8 to 12 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for range and wildlife habitat.

Representative profile of Nansene silt loam, 35 to 70 percent slopes, in NW¼NW¼NE¼ section 29, T. 1 N., R. 15 E.:

A11—0 to 4 inches; very dark brown (10YR 2/2) coarse silt loam, dark grayish brown (10YR 4/2) dry; weak thin platy structure parting to weak fine granular; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; neutral; clear smooth boundary.

A12—4 to 14 inches; very dark brown (10YR 2/2) coarse silt loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; common very fine tubular pores; neutral; clear smooth boundary.

A13—14 to 22 inches; very dark brown (10YR 2/2) coarse silt loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common fine to medium tubular pores; neutral; gradual smooth boundary.

B2—22 to 32 inches; dark brown (10YR 3/3) coarse silt loam, dark brown (10YR 4/3) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tubular pores; neutral; gradual smooth boundary.

C1—32 to 52 inches; dark brown (10YR 3/3) coarse silt loam, brown (10YR 5/3) dry; massive; slightly hard, friable, slightly sticky and slightly plastic; common very fine tubular pores; neutral; gradual smooth boundary.

C2ca—52 to 62 inches; grayish brown (10YR 5/2) silt loam, light brownish gray (10YR 6/2) moist; massive; slightly hard to hard, friable, slightly sticky and slightly plastic; few very fine roots; 5 percent fragments 1/16 inch in diameter; calcareous nodules; moderately calcareous; disseminated and segregated lime; moderately alkaline.

IIR—62 inches; basalt bedrock.

The A horizon is dark grayish brown or dark brown when dry. The B horizon is dark brown or dark grayish brown when dry and moist. The C horizon is dark brown to grayish brown when moist. Clay content of the soil is 10 to 18 percent. The soil is less than 5 percent fragments 1 inch or less in diameter. Rock is exposed on as much as 10 percent of the surface layer in places. Depth to basalt bedrock is 40 to 60 inches or more.

34F—Nansene silt loam, 35 to 70 percent slopes. A representative mapping unit is in the NW¼NW¼NE¼ section 29, T. 1 N., R. 15 E. This soil is in long, narrow areas and has north-facing slopes.

Included with this soil in mapping are areas of Walla Walla, Lickskillet, and Wrentham soils and Rock outcrop that make up as much as 15 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability subclass VIIe; Steep North range site.

Pedigo Series

The Pedigo series consists of somewhat poorly drained soils formed in alluvium derived from loess and volcanic ash on bottom lands. Slopes are 0 to 3 percent. Elevation is 200 to 2,700 feet. In uncultivated areas, the vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 10 to 13 inches, the average annual air temperature is 50° to 53° F, and the frost-free period is 130 to 180 days at 32° and 180 to 200 days at 28°.

In a representative profile the surface and subsurface layers are black silt loam to a depth of 40 inches. The upper 9 inches of the underlying material is very dark gray silt loam, and below this is dark grayish brown loam to a depth of 60 inches or more. The soil material in the profile is moderately alkaline to neutral.

Permeability is moderate, and the available water capacity is 10 to 11 inches. Water-supplying capacity is 9 to 13 inches. Effective rooting depth is more than 60 inches.

These soils are used for hay, pasture, dryfarmed small grain, range, and wildlife habitat.

Representative profile of Pedigo silt loam in the SE¼NW¼ section 21, T. 1 S., R. 13 E.:

Ap—0 to 8 inches; black (10YR 2/1) silt loam, dark grayish brown (10YR 4/2) dry; weak fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; moderately calcareous; moderately alkaline; abrupt smooth boundary.

A12—8 to 21 inches; black (10YR 2/1) silt loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many fine tubular pores; weakly calcareous; moderately alkaline; abrupt smooth boundary.

176

AC—21 to 40 inches; black (10YR 2/1) silt loam, grayish brown (10YR 5/2) dry; massive; hard, friable, slightly sticky and slightly plastic; many very fine roots; many fine tubular pores; neutral; clear smooth boundary.

C1—40 to 49 inches; very dark gray (10YR 3/1) silt loam, light brownish gray (10YR 6/2) dry; massive; hard, friable, slightly sticky and slightly plastic; few roots; many fine and few medium tubular pores; neutral; clear smooth boundary.

C2—49 to 60 inches; dark grayish brown (10YR 4/2) loam; massive; hard, friable, slightly sticky and slightly plastic; few roots; many fine and few medium tubular pores; neutral.

The A horizon is dark grayish brown or dark brown when dry and very dark brown, dark grayish brown, black, or very dark grayish brown when moist. It is silt loam, coarse silt loam, or loam and is moderately calcareous to strongly calcareous. The AC horizon is light gray, light brownish gray, or grayish brown when dry and very dark gray, very dark grayish brown, or black when moist. It is coarse silt loam, silt loam, or silty clay loam.

35—Pedigo silt loam. A representative mapping unit is in the SE¼NW¼ section 21, T. 1 S., R. 13 E. This soil is in long, narrow areas on alluvial bottom lands adjacent to streams. Slopes are 0 to 3 percent.

Included with this soil in mapping are areas of Hermiston, Endersby, and Tygh soils.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIw-1; Alkaline Bottom range site.

Quincy Series

The Quincy series consists of soils formed in sandy alluvium from mixed material on bottom lands. Slopes are 0 to 3 percent. Elevation is 1,400 to 1,500 feet. In uncultivated areas, the vegetation is cottonwoods, forbs, and shrubs. The average annual precipitation is 10 to 12 inches, the average annual air temperature is 48° to 52° F, and the frost-free period is 120 to 170 days at 32° and 170 to 200 days at 28°.

In a representative profile the surface layer is very dark gray loamy fine sand about 6 inches thick. The underlying material to a depth of 35 inches is very dark grayish brown sand, the next 9 inches is dark gray fine sand, and below this to a depth of 60 inches or more is dark gray very fine sand. The surface layer is medium acid, and the underlying material is slightly acid to neutral.

Permeability is rapid, and the available water capacity is 3 to 6 inches. Water-supplying capacity is variable and depends upon the depth to the water table. Effective rooting depth is 40 to 60 inches.

This soil is used for irrigated hay and pasture, crops, range, and wildlife habitat.

Representative profile of Quincy loamy fine sand, wet, in the NW¼SW¼NW¼ section 12, T. 4 S., R. 13 E.:

Ap—0 to 6 inches; very dark gray (10YR 3/1) loamy fine sand, gray (10YR 5/1) dry; weak fine granular structure; soft, very friable, nonsticky and nonplastic; many very fine roots; many very fine irregular pores; medium acid; clear smooth boundary.

C1—6 to 41 inches; very dark grayish brown (10YR 3/2) sand, grayish brown (10YR 5/2) dry; single grained; loose; many very fine roots; 10 percent very fine pebbles; slightly acid; clear wavy boundary.

C2—41 to 50 inches; dark gray (10YR 4/1) fine sand, gray (10YR 5/1) dry; single grained; loose; common fine roots; common dark brown (7.5YR 4/4) moist, mottles; slightly acid; clear wavy boundary.

C3—50 to 60 inches; dark gray (10YR 4/1) very fine sand, gray (10YR 6/1) dry; single grained; loose; very few roots; neutral.

The A horizon is gray or grayish brown when dry and very dark gray or very dark grayish brown when moist. It is loamy fine sand or loamy sand and is as much as 20 percent coarse fragments 2 to 10 millimeters in size. The C1 horizon is gray to grayish brown when dry. It is loamy sand or sand and is 10 to 20 percent pebbles. The C2 horizon is gray or light gray when dry and has common to many dark brown mottles. It is sand or very fine sand.

Quincy soils are excesively drained or somewhat excessively drained. However, this Quincy soil is on bottom land and remains wetter throughout the year than is normal for the Quincy series because of a water table at a depth of 40 to 60 inches.

36—Quincy loamy fine sand, wet. A representative mapping unit is in the NW¼SW¼NW¼ section 12, T. 4 S., R. 13 E. This soil is on bottom lands along major streams. Slopes are 0 to 3 percent.

Included with this soil in mapping were areas of Endersby, Tygh, and Pedigo soils. These soils make up as much as 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Depth to a water table is 40 to 60 inches in spring and early in summer. Some areas are subject to overflow. Capability unit IIIw-1; Semi-Moist Bottom range site.

Riverwash

37—Riverwash. A representative mapping unit is in the NE¼SW¼NW¼ section 11, T. 4 S., R. 13 E. Riverwash is in narrow, irregularly shaped strips in the bends of stream channels along the Columbia and Deschutes Rivers and along drainageways in the survey area. It is 2 to 10 feet above the normal waterline. The strips are 40 to 200 yards wide. Riverwash consists of well-rounded sand, gravel, stones and boulders, chiefly basalt. The surface layer generally is uneven. This area has little or no vegetation.

Riverwash is subject to overflow when the water is high and is extremely droughty when the water is low. During each overflow, new deposits are received and some material is removed. Adjacent river sandbars are included in the unit.

Riverwash is used for wildlife habitat and as a source of sand and gravel. Capability subclass VIIIw; not placed in a range site.

Rock Outcrop

38—Rock outcrop-Rubble land complex. A representative mapping unit is in the NW¼NE¼ section 17, T. 3 S., R. 15 E. This complex is about 65 to 75 percent Rock outcrop and 20 to 30 percent Rubble land. It is on uplands in basalt outcrop and rubble (fig. 5). Elevation is 200 to 3,600 feet. Rock outcrop-Rubble land complex has little or no vegetation except on included soils. The average annual precipitation is 10 to 22 inches, the average annual air temperature is 45° to 52° F, and the frost-free period is 70 to 210 days.

and slightly plastic; many very fine roots; many very fine irregular pores; slightly acid; abrupt smooth boundary.

A12—5 to 11 inches; dark brown (10YR 3/3) loam, brown (10YR 5/3) dry; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tubular pores; slightly acid; clear smooth boundary.

B1—11 to 21 inches; dark brown (10YR 3/3) loam, grayish brown (10YR 5/3) dry; weak medium subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common very fine roots; many very fine tubular pores; slightly acid; clear smooth boundary.

B21t—21 to 33 inches; dark brown (10YR 3/3) heavy loam, brown (10YR 6/3) dry; moderate medium subangular blocky structure; very hard, friable, slightly sticky and slightly plastic; few very fine roots; many very fine tubular pores; few thin clay films on ped faces and common moderately thick clay films in pores; many gray (10YR 7/2) sand coatings on peds; slightly acid; gradual smooth boundary.

B22t—33 to 49 inches; dark brown (10YR 3/3) clay loam, pale brown (10YR 6/3) dry; moderate medium subangular blocky structure; very hard, firm, sticky and slightly plastic; few very fine roots; many very fine tubular pores; few thin clay films on ped faces and common thin clay films in pores; many gray (10YR 7/2) sand coatings on peds; neutral; gradual smooth boundary.

C—49 to 60 inches; dark brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; massive; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; neutral.

The A horizon is grayish brown or brown when dry and very dark grayish brown or dark brown when moist. It is very fine sandy loam, fine sandy loam, or loam. The B2 horizon is light brownish gray, pale brown, brown, or yellowish brown when dry and dark brown, dark yellowish brown, or dark grayish brown when moist. It is clay loam, sandy clay loam, or heavy loam and is 22 to 35 percent clay.

45B—Van Horn loam, 0 to 8 percent slopes. A representative mapping unit is in the NW¼SE¼NW¼ section 7, T. 2 N., R. 12 E. This soil is in broad, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIe-1; Pine-Oak-Fescue range site.

45C—Van Horn loam, 8 to 12 percent slopes. A representative mapping unit is in the NE¼SW¼NW¼ section 18, T. 2 N., R. 11 E. This soil is in broad, irregularly shaped areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-2; Pine-Oak-Fescue range site.

45D—Van Horn loam, 12 to 20 percent slopes. A representative mapping unit is in the NW¼NW¼ NW¼ section 7, T. 2 N., R. 12 E. This soil is in long, narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-2; Pine-Oak-Fescue range site.

45E—Van Horn loam, 20 to 35 percent slopes. A representative mapping unit is in the SE¼SE¼SW¼ section 6, T. 2 N., R. 12 E. This soil is in narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-1; Pine-Oak-Fescue range site.

Walla Walla Series

The Walla Walla series consists of well drained soils formed in loess on uplands. Slopes are 3 to 50 percent. Elevation is 300 to 2,000 feet. In uncultivated areas, the vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 12 to 14 inches, the average annual air temperature is 49° to 52° F, and the frost-free period is 150 to 170 days at 32° and 170 to 210 days at 28°.

In a representative profile the surface layer is very dark brown silt loam about 13 inches thick. The subsoil is dark brown and brown silt loam about 18 inches thick. The substratum is dark yellowish brown silt loam to a depth of 82 inches or more. The surface layer is slightly acid and neutral, the subsoil is neutral, and the substratum is neutral and mildly alkaline.

Permeability is moderate, and the available water capacity is 7 to 12 inches. Water-supplying capacity is 8 to 12 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for dryfarmed small grain, hay, pasture, range, and wildlife habitat.

Representative profile of Walla Walla silt loam, 12 to 20 percent north slopes, about 600 feet north of the line between sections 12 and 13 in the SE¼SW¼SW¼ section 12, T. 1 N., R. 14 E.:

Ap—0 to 7 inches; very dark brown (10YR 2/2) silt loam, dark grayish brown (10YR 4/2) dry; weak thin platy structure parting to weak fine granular; soft to slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; slightly acid; abrupt smooth boundary.

A12—7 to 13 inches; very dark brown (10YR 2/2) silt loam, grayish brown (10YR 5/2) dry; weak medium platy structure parting to weak fine granular; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; neutral; abrupt smooth boundary.

B1—13 to 20 inches; dark brown (10YR 3/3) silt loam, brown (10YR 5/3) dry; weak coarse prismatic structure parting to very weak medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine pores; neutral; clear smooth boundary.

B2—20 to 31 inches; brown (10YR 4/3) silt loam, brown (10YR 5/3) dry; weak coarse prismatic structure parting to very weak medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; neutral; gradual smooth boundary.

C11—31 to 44 inches; dark yellowish brown (10YR 3/4) silt loam, pale brown (10YR 6/3) dry; massive;

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slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many fine tubular pores; neutral; gradual smooth boundary.

C12—44 to 82 inches; dark yellowish brown (10YR 3/4) silt loam, pale brown (10YR 6/3) dry; massive; slightly hard, very friable, slightly sticky and slightly plastic; common very fine roots; many very fine tubular pores; mildly alkaline.

The A horizon is dark grayish brown, grayish brown, or brown when dry and very dark brown, very dark grayish brown, or dark brown when moist. It is silt loam or coarse silt loam. The B horizon is silt loam or coarse silt loam. The C horizon is light brownish gray or pale brown when dry and dark yellowish brown or brown when moist. It is silt loam or coarse silt loam. Lime in mycelium form is below a depth of 55 inches in some places. Depth to bedrock is 40 to more than 60 inches.

46B—Walla Walla silt loam, 3 to 7 percent slopes. A representative mapping unit is in the SW¼SW¼SW¼ section 2, T. 1 N., R. 15 E. This soil is on ridgetops in broad, smooth, convex areas.

Included with this soil in mapping were areas of Anderly and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIe-3; Rolling Hills range site.

46C—Walla Walla silt loam, 7 to 12 percent slopes. A representative mapping unit is in the SW¼SW¼ SW¼ section 3, T. 1 N., R. 15 S. This soil is on ridgetops in broad, smooth, convex areas.

Included with this soil in mapping were areas of Anderly and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-1; Rolling Hills range site.

46D—Walla Walla silt loam, 12 to 20 percent north slopes. A representative mapping unit is in the SE¼ SW¼SW¼ section 12, T. 1 N., R. 14 E. This soil is in long, broad, convex areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Anderly and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-4; Droughty North Exposure range site.

47D—Walla Walla silt loam, 12 to 20 percent south slopes. A representative mapping unit is in the SW¼ SW¼SW¼ section 6, T. 1 N., R. 15 E. This soil is in long, broad, convex areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-4; Rolling Hills range site.

47E—Walla Walla silt loam, 20 to 35 percent north slopes. A representative mapping unit is in the NE¼ SW¼SW¼ section 9, T. 1 N., R. 14 E. This soil is in long, broad, irregularly shaped areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-3; North Exposure range site.

48E—Walla Walla silt loam, 20 to 35 percent south slopes. A representative mapping unit is in the NW¼ NW¼NW¼ section 10, T. 1 N., R. 14 E. This soil is in long, broad, irregularly shaped areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-2; Droughty South Exposure range site.

48F—Walla Walla silt loam, 35 to 50 percent south slopes. A representative mapping unit is in the SW¼ SE¼NE¼ section 7, T. 1 N., R. 14 E. This soil is in long, narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of this mapping unit.

Runoff is rapid, and the hazard of erosion is severe. Capability subclass VIe; Drougthy South Exposure range site.

Wamic Series

The Wamic series consists of well drained soils formed in volcanic ash, and loess overlying alluvium or colluvium weathered from basalt or andesite on uplands. Slopes are 1 to 70 percent. Elevation is 1,000 to 3,600 feet. In uncultivated areas, the vegetation is ponderosa pine, Douglas-fir, oak forbs, and shrubs. The average annual precipitation is 14 to 20 inches, the average annual air temperature is 46° to 50° F, and the frost-free period is 100 to 150 days at 32° and 150 to 200 days at 28°.

In a representative profile the surface layer is very dark grayish brown loam about 7 inches thick. The subsoil is dark brown loam about 21 inches thick. The substratum is dark brown heavy loam 16 or more inches thick. The soil material throughout the profile is neutral.

Permeability is moderately slow, and the available water capacity is 6.5 to 11 inches. Water-supplying capacity is 8 to 12.5 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for dryfarmed small grain, hay, pasture, range, timber, and wildlife habitat.

Representative profile of Wamic loam, 5 to 12 percent south slopes, 100 feet south of road in the NE¼ NW¼NW¼ section 26, T. 2 S., R. 12 E.:

Ap—0 to 7 inches; very dark grayish brown (10YR 3/2) loam, light brownish gray (10YR 6/2) dry; weak fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; neutral; abrupt smooth boundary.

B1—7 to 18 inches; dark brown (10YR 3/3) loam, light brownish gray (10YR 6/2) dry; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; neutral; clear wavy boundary.

B2—18 to 28 inches; dark brown (10YR 4/3) loam, light brownish gray (10YR 6/2) dry; weak medium subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common very fine roots; many

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Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIe-3 nonirrigated, and IIe-2 irrigated; Shrubby Rolling Hills range site.

54C—Watama-Wapinitia silt loams, 5 to 12 percent slopes. A representative mapping unit is in the NW¼SW¼SE¼ section 3, T. 5 S., R. 12 E. This complex is about 55 to 65 percent a Watama silt loam and 25 to 30 percent a Wapinitia silt loam. These soils are on ridgetops in long, broad or narrow areas.

Included with this complex in mapping were areas of Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-4; Shrubby Rolling Hills range site.

54D—Watama-Wapinitia silt loams, 12 to 20 percent slopes. A representative mapping unit is in the SE¼SE¼SW¼ section 3, T. 5 S., R. 12 E. This complex is about 55 to 65 percent a Watama silt loam and 25 to 35 percent a Wapinitia silt loam. These soils are in long, narrow, irregularly shaped areas.

Included with this complex in mapping were areas of Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-4; Shrubby Rolling Hills Range site.

54E—Watama-Wapinitia silt loams, 20 to 35 percent slopes. A representative mapping unit is in the NW¼NE¼NW¼ section 3, T. 5 S., R. 12 E. This complex is about 55 to 65 percent a Watama silt loam and 25 to 35 percent a Wapinitia silt loam. These soils are in long, narrow, irregularly shaped areas.

Included with this complex in mapping were areas of Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-2; North Exposure range site.

Wato Series

The Wato series consists of well drained soils formed in loess on uplands. Slopes are 3 to 35 percent. Elevation is 300 to 1,500 feet. In uncultivated areas, the vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 12 to 14 inches, the average annual air temperature is 51° to 54° F, and the frost-free period is 150 to 170 days at 32° and 170 to 210 days at 28°.

In a representative profile the surface layer is very dark grayish brown very fine sandy loam about 15 inches thick. The subsoil is dark brown loam about 27 inches thick. The substratum is dark brown fine sandy loam about 24 inches thick. The soil material throughout the profile is neutral.

Permeability is moderately rapid, and the available water capacity is 6 to 10 inches. Water-supplying capacity is 7 to 10 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for dryfarmed small grain, hay, pasture, range, and wildlife habitat.

Representative profile of Wato very fine sandy loam, 3 to 7 percent slopes, 150 feet west of road in the NW¼NE¼NW¼ section 32, T. 2 N., R. 14 E.:

A11—0 to 3 inches; very dark grayish brown (10YR 3/2) very fine sandy loam, dark grayish brown (10YR 4/2) dry; moderate medium platy structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; neutral; clear smooth boundary.

A12—3 to 15 inches; very dark grayish brown (10YR 3/2) very fine sandy loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure parting to weak medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; 2 percent fragments 1 to 2 millimeters in size; neutral; clear smooth boundary.

B1—15 to 21 inches; dark brown (10YR 3/3) loam, brown (10YR 4/3) dry; weak medium prismatic structure parting to weak medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular and tubular pores; 2 percent fragments 1 to 2 millimeters in size; neutral; clear wavy boundary.

B2—21 to 42 inches; dark brown (10YR 3/3) loam, brown (10YR 5/3) dry; weak medium prismatic and weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; 3 percent fragments 1 to 2 millimeters in size; neutral; clear smooth boundary.

C1—42 to 52 inches; dark brown (10YR 4/3) fine sandy loam, pale brown (10YR 6/3) dry; massive; slightly hard, friable, slightly sticky and slighty plastic; many to common very fine roots; many very fine tubular pores; 5 percent weathered fragments 1 to 2 millimeters in size; neutral; clear wavy boundary.

C2—52 to 66 inches; dark brown (10YR 4/3) fine sandy loam, pale brown (10YR 6/3) dry; massive; slightly hard, friable, slightly sticky and nonplastic; few very fine roots; 10 percent weathered fragments 1 to 2 millimeters in size; neutral; abrupt wavy boundary.

The B horizon is dark brown to brown when dry. It is very fine sandy loam to loam.

55B—Wato very fine sandy loam, 3 to 7 percent slopes. A representative mapping unit is in the NW¼NE¼NW¼ section 32, T. 2 N., R. 14 E. This soil is on ridgetops in broad, irregularly shaped areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is slow. The hazard of water erosion is slight or moderate, and the hazard of soil blowing is moderate. Some areas are moderately eroded and have lower crop yields than noneroded areas. Capability unit IIIe-6; Rolling Hills range site.

55C—Wato very fine sandy loam, 7 to 12 percent slopes. A representative mapping unit is in the SW¼NE¼NE¼ section 3, T. 2 N., R. 14 E. This soil is on ridgetops in broad, smooth, convex areas.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up about 10 percent of the unit.

Runoff is medium. The hazard of water erosion is moderate. Capability unit IIIe-6; Rolling Hills range site.

55D—Wato very fine sandy loam, 12 to 20 percent north slopes. A representative mapping unit is in the NE¼NE¼NW¼ section 32, T. 2 N., R. 14 E. This soil is in long, broad, convex areas.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-4; Droughty North Exposure range site.

55E—Wato very fine sandy loam, 20 to 35 percent north slopes. A representative mapping unit is in the NE¼SE¼NW¼ section 31, T. 2 N., R. 14 E. This soil is in long, narrow, broad, irregularly shaped areas.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up as much as 15 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-3; North Exposure range site.

Wind River Series

The Wind River series consists of well drained soils formed in old alluvium on uplands. Slopes are 0 to 30 percent. Elevation is 200 to 800 feet. In uncultivated areas, the vegetation is Douglas-fir, ponderosa pine, Oregon white oak, forbs, and shrubs. The average annual precipitation is 20 to 30 inches, the average annual air temperature is 49° to 52° F, and the frost-free period is 150 to 180 days at 32° and 180 to 210 days at 28°.

In a representative profile the surface layer is very dark grayish brown fine sandy loam about 10 inches thick. The subsoil is dark brown fine sandy loam about 34 inches thick. The substratum is dark yellowish brown sandy loam to a depth of 60 inches or more. Depth to bedrock is more than 60 inches. The soil material in the profile ranges from medium acid to neutral.

Permeability is moderately rapid, and the available water capacity is 7 to 8 inches. Water-supplying capacity is 10 to 14 inches. Effective rooting depth is more than 60 inches.

These soils are used for fruit orchards, pasture, range, and wildlife habitat.

Representative profile of Wind River fine sandy loam, 0 to 8 percent slopes, 400 feet north of Old Columbia River Highway in the NW¼SE¼NW¼ section 6, T. 2 N., R. 12 E.:

Ap1—0 to 6 inches; very dark grayish brown (10YR 3/2) fine sandy loam, brown (10YR 5/3) dry; weak fine granular structure; slightly hard, very friable, nonsticky and nonplastic; many very fine roots; many very fine irregular pores; medium acid; abrupt smooth boundary.

Ap2—6 to 10 inches, very dark grayish brown (10YR 3/2) fine sandy loam, brown (10YR 5/3) dry; weak medium subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; many very fine roots; many very fine irregular and tubular pores; slightly acid; gradual smooth boundary.

B2—10 to 17 inches; dark brown (7.5YR 3/3) fine sandy loam, brown (10YR 5/3) dry; weak medium subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; many very fine roots; few fine tubular pores; neutral; gradual smooth boundary.

B3—17 to 44 inches; dark brown (7.5YR 3/4) fine sandy loam, brown (10YR 5/4) dry; weak medium subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; common very fine roots; many very fine tubular pores; few 1 to 5 centimeter nodules; neutral; gradual smooth boundary.

C1—44 to 61 inches; dark yellowish brown (10YR 4/4) sandy loam, brown (10YR 5/4) dry; massive, slightly hard, friable, nonsticky and nonplastic; common very fine roots; neutral; clear wavy boundary.

The A horizon is brown, grayish brown, or dark grayish brown when dry and very dark grayish brown, very dark brown, or dark brown moist. It is fine sandy loam or sandy loam. The B horizon is brown, grayish brown, or dark grayish brown when dry and very dark grayish brown, very dark brown, or dark brown moist. It is fine sandy loam, loam, or sandy loam. It has weak coarse prismatic or weak coarse or medium subangular blocky structure. The C horizon is yellowish brown, brown, or light yellowish brown when dry and dark yellowish brown or brown moist. It is fine sandy loam, sandy loam, loamy fine sand, or sand and is 0 to 20 percent rock fragments 2 to 5 millimeters in diameter.

56B—Wind River fine sandy loam, 0 to 8 percent slopes. A representative mapping unit is in the NW¼SE¼NW¼ section 6, T. 2 N., R. 12 E. This soil is on ridgetops in broad, irregularly shaped areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Chenoweth and Van Horn soils. These soils make up about 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIe-1; Pine-Oak-Fescue range site.

56C—Wind River fine sandy loam, 8 to 12 percent slopes. A representative mapping unit is in the NE¼NE¼NW¼ section 6, T. 2 N., R. 12 E. This soil is on ridgetops in broad, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth and Van Horn soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-2; Pine-Oak-Fescue range site.

56D—Wind River fine sandy loam, 12 to 30 percent slopes. A representative mapping unit is in the SE¼SE¼SE¼ section 1, T. 2 N., R. 11 E. This soil is in long, narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth and Van Horn soils. These soils make up about 10 percent of the unit.

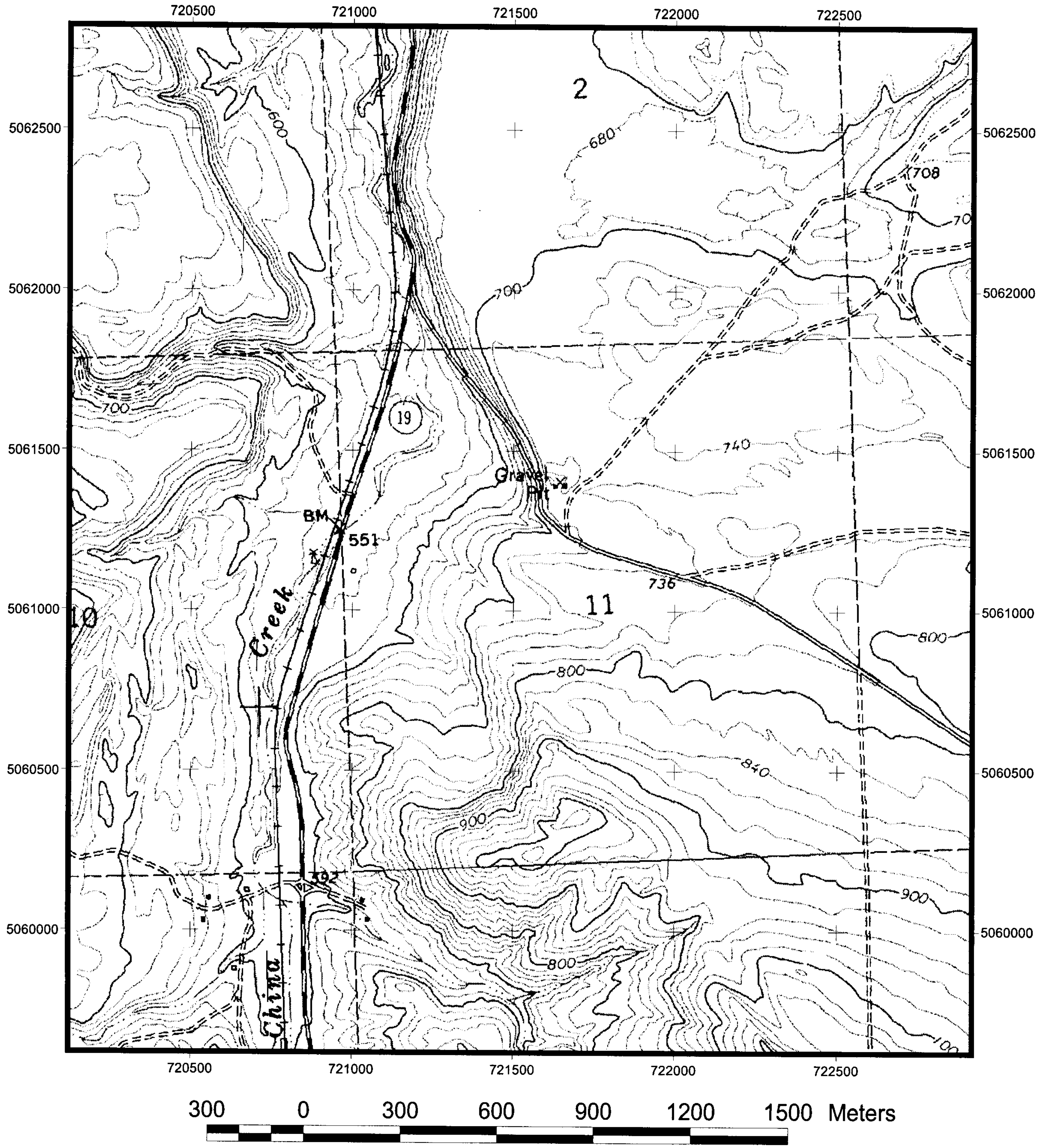
Runoff is medium to rapid, and the hazard of erosion is moderate to severe. Capability unit IVe-1; Pine-Oak-Fescue range site.

Wrentham Series

The Wrentham series consists of well drained soils formed in loess and basalt colluvium on uplands. Slopes are 35 to 70 percent. Elevation is 1,500 to 3,600 feet. The vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 10 to 13 inches, the average annual air temperature is 45° to 52° F, and the frost-free period is 60 to 100 days at 32° and 100 to 150 days at 28°.

In a representative profile the surface layer is very dark brown silt loam about 18 inches thick. The upper

Stop 6-7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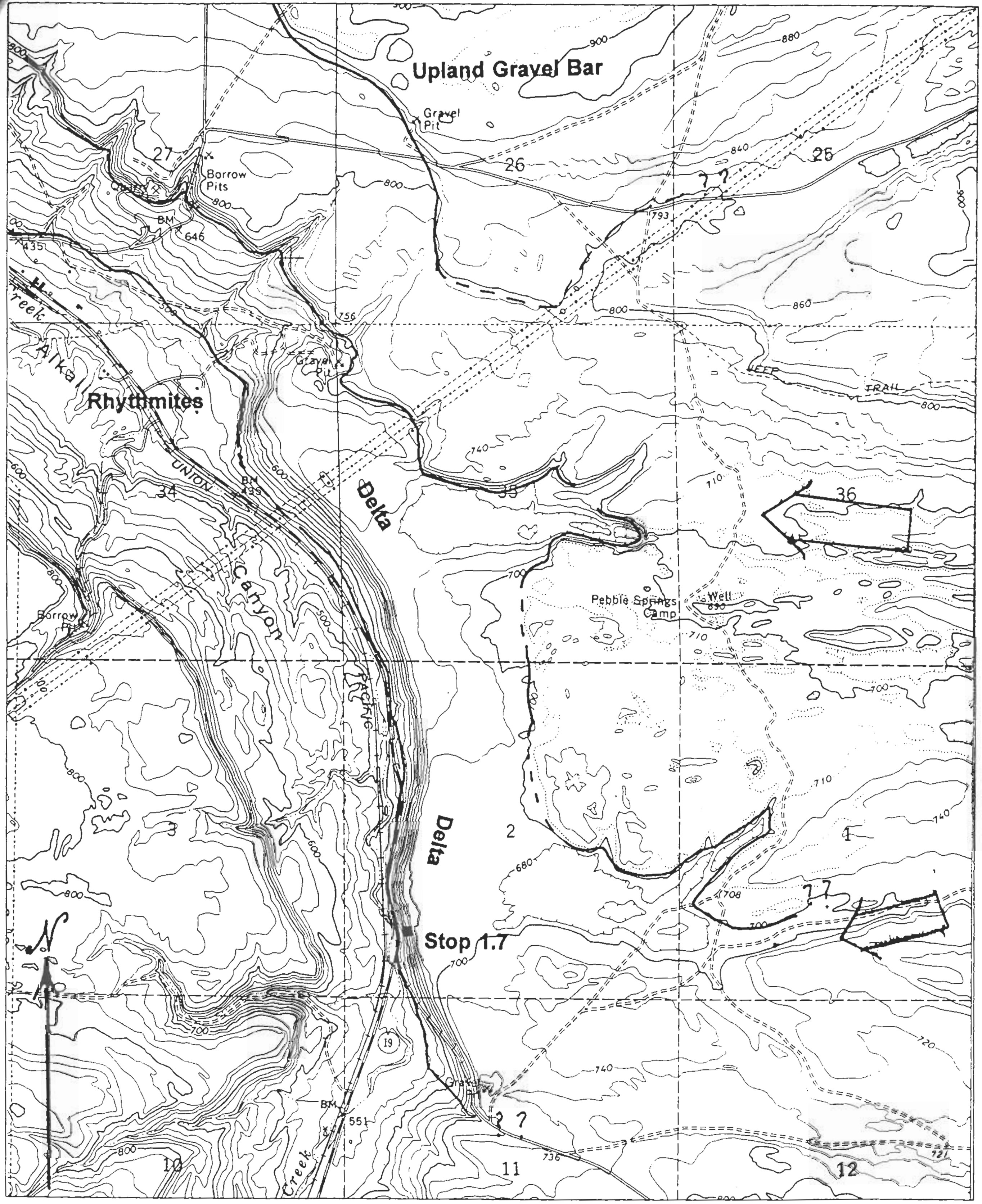

Figure 14. Topographic setting and approximate distribution of Missoula flood deposits southeast of Arlington. The delta bars were mainly deposited by flow spilling into Alkali Canyon from the two upland channels to the east. There was substantial flow over the entire upland surface, however, as evidenced by the large gravel bar deposited on the upland surface that is depicted on the north part of the map. Topographic base from Arlington USGS 7.5' quadrangle. Land sections (numbered) are 1 mi (1.6 km) across.

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n in the Gorge.
' in exposures of eddy deposits northwest and kitat River from Lyle, near the 513-ft benchmark, veral floods achieved stages of 180 m (600 ft). In xposure in the gravel pit north of the bench mark' st seven sets of east-dipping foresets of granule sand. These sets of foresets are capped by pebbly silty matrices. We interpret these silt-gravel hori- result of loess deposition between separate Mis- ome of the foreset sets are unconformably overlain 25 cm of steeply dipping loose l that may be scree deposited be- This gravel deposit is apparently slightly higher (to altitude of 195 coarser unit to the north (Figure ntly represents an older and larger mum discharge required to inun- of 180 m (590 ft) is about 4 mil- 1 indicates that there have been a ls to surpass that discharge, with was perhaps substantially larger. on which we stand at an elevation) has been stripped of its preflood such stripped basalt surfaces and ident to about 290±12 m (960±40 about 25 m lower than maximum The Dalles.

p 3.4

:st on the historic highway, pass- ll and dropping into the town of ies in a synclinal valley. Like the urg and Fairbanks, flow spilling etween the Columbia River and leposited a large delta composed ipping foresets of cobble-pebble l. A discharge of at least 2.5 mil- quired for flow to overtop the di- the delta at Petersburg, several its are separated by erosional un- rhaps evidence of multiple flows. shows at least seven such units. from the top contained a piece of yielded a radiocarbon date of r B.P., indicating that at least two nt to this date were capable of vel over this divide.

town of Mosier, a large eddy bar on the west flank of the Mosier ır is composed of well-sorted sand deposited in east-dipping fore- hat this sediment was part of the of the flood, deposited in a large ne; that zone developed as a part diverted into the topographic low southwest-trending axis of the e. Exposures in this bar do not

White Salmon is built upon a large pendant bar in the lee of the downstream end of Bingen Gap on the north side of the river. One of the larger bars in the Columbia River Gorge, White Salmon bar (Bretz, 1925) rests on a basalt platform, is about 2 km long, and ascends from 120 m (400 ft) at its apex to almost 240 m (800 ft) at its downstream end.

The Hood River valley was inundated by backwater from the Missoula floods. Newcomb (1969, p. 6) reported "fine-grained lacustrine deposits" as high as altitude 245 m (800 ft), probably slackwater deposits of Missoula floods. The highest ice-rafted er-

DAY 7 ROWENA CREST – LYLE, WA

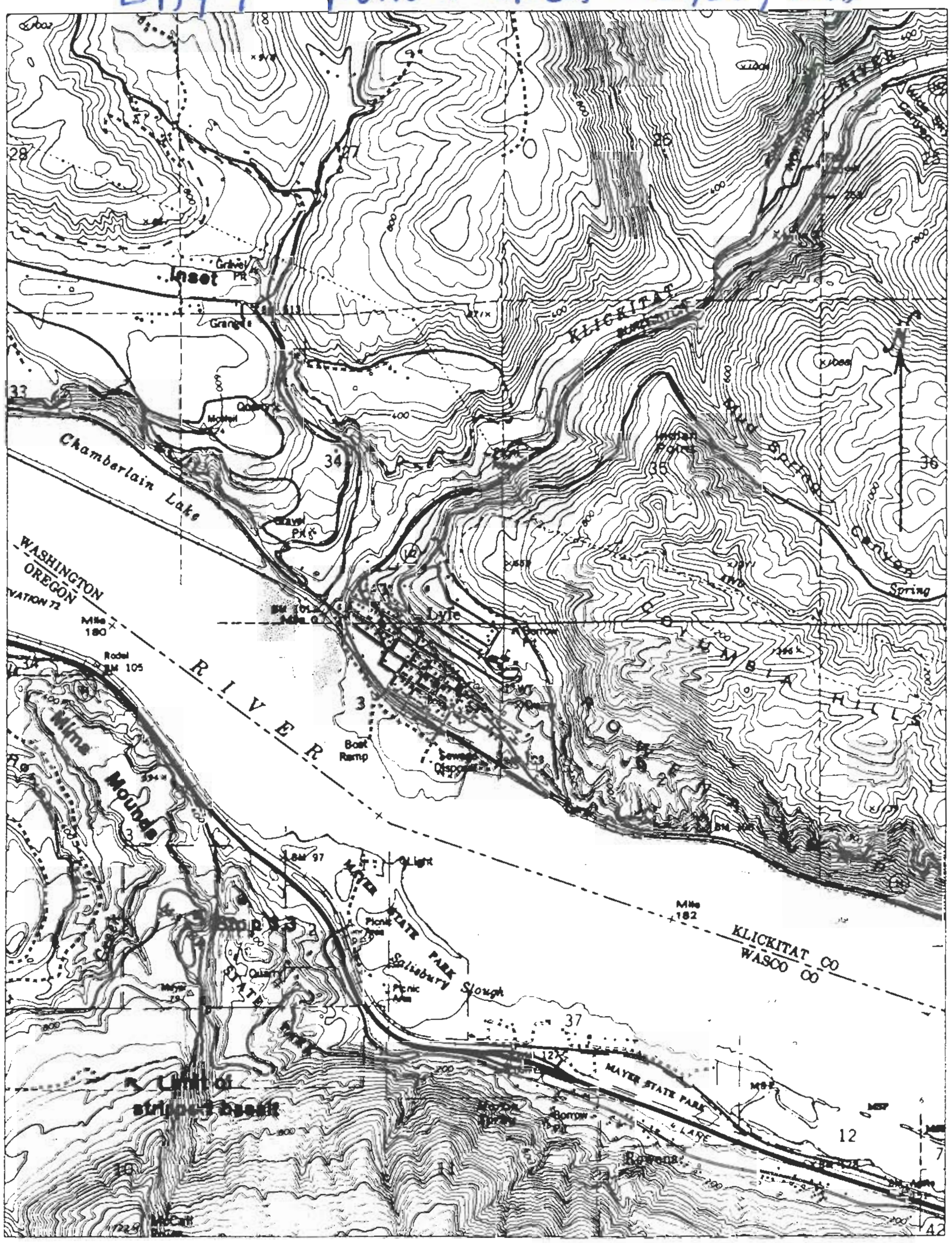

Figure 28. Topographic setting, geomorphic features, and approximate distribution of Missoula flood deposits (outlined by heavy lines) near Lyle. Topographic base from Lyle USGS 7.5' quadrangle. Land sections (numbered) are 1 mile (1.6 km) across.

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DAY 7 - BONNEVILLE LANDSLIDE (BRIDGE OF THE GODS)

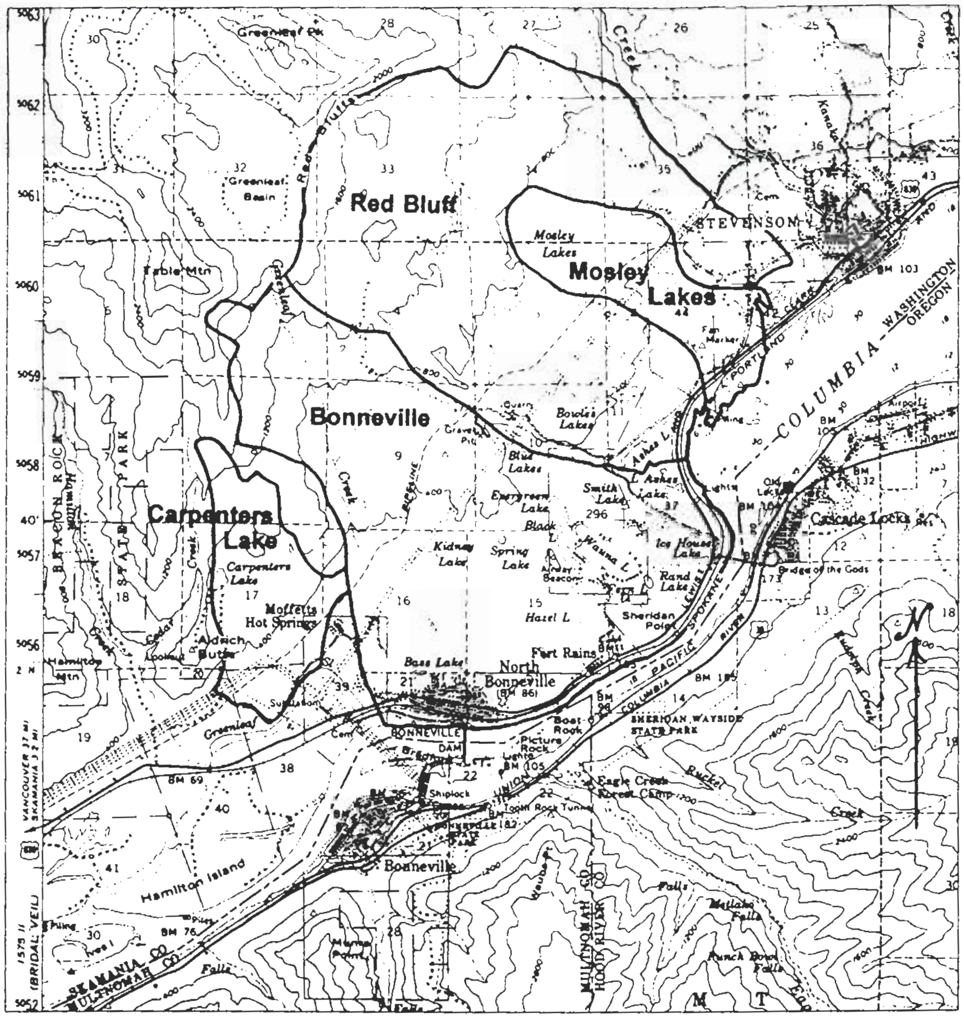

Figure 30. Landslide complex near Cascade Locks. The Bonneville landslide was the most recent one and may have temporarily dammed the Columbia River about 500 years ago. Topographic base is the Bonneville 15′ quadrangle. Land sections (numbered) are 1 mi (1.6 km) across. After Minor, 1984.

flood stage. The combination of dense vegetation and abundant mass wasting hinder the search. It is clear that by Portland, however, the maximum water surface descended to 120 m (400 ft) (Allison, 1935), indicating an average gradient of 0.003. Most of the drop probably occurred near Crown Point, at the downstream end of the Columbia River Gorge.

For several kilometers downstream of Hood River, the valley of the Columbia River is particularly constricted, generally narrower than 2 km. About 5 km downstream of Viento State Park, the Columbia River is encroached upon by the Wind River landslide, one of several recent or presently active landslides in the Columbia River Gorge (Figure 29). The upper part of the Wind River landslide moves as fast as 15 m/yr (Allen, 1984).

Downstream of the Wind River landslide, the Columbia River valley funnels between the twin granodiorite intrusions of Shellrock and Wind Mountains. Shellrock Mountain, with its constant raveling of platy rubble at a repose angle of 42°, was a major obstacle to early road building through the Gorge. On the north side of the river, between Wind Mountain and Wind River, a large pendant bar was deposited in the lee of Wind Mountain as flow expanded out of the constriction. This bar is about 2 km long and 125 m high.

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Early explorers noted large
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ally it became clear that they

DAY 7 - BONNEVILLE LANDSLIDE

...n the Hood River valley are between altitudes of 255 and ...m (840–880 ft). If this was the maximum stage achieved by the largest flood, the water surface dropped substantially through Bingen Gap.

The best examples of polished, fluted, and scoured basalt surfaces known in the Columbia River Gorge are in the gardens of the Columbia River Gorge Hotel, a 1921 structure listed on the National Historic Register.

Between Hood River and the downstream end of the Gorge below Crown Point, we find little conclusive evidence of maximum

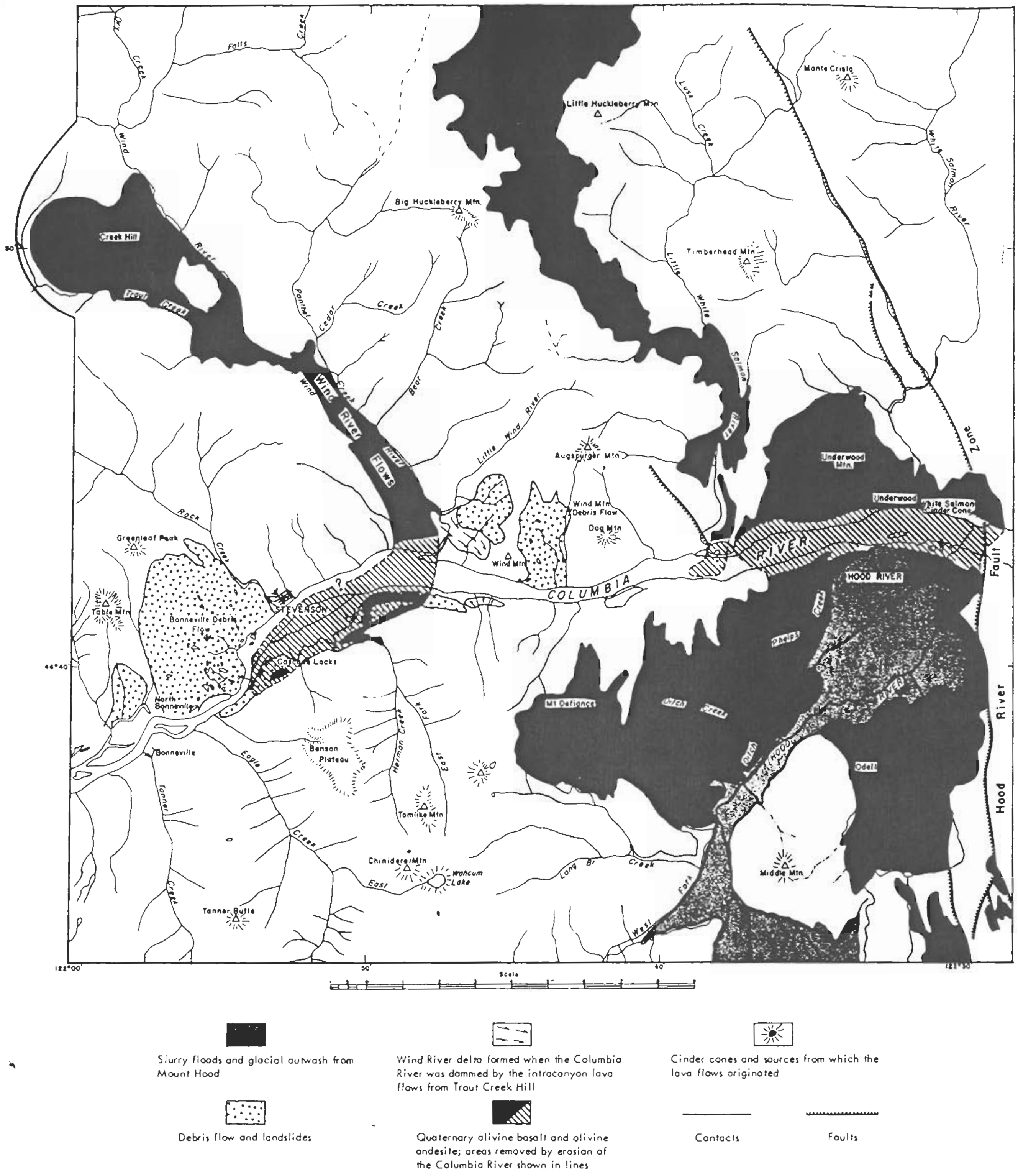

Figure 29. Lava flows and landslides in the Columbia River Gorge, emphasizing flows that may have dammed the Columbia River. From Waters (1973).

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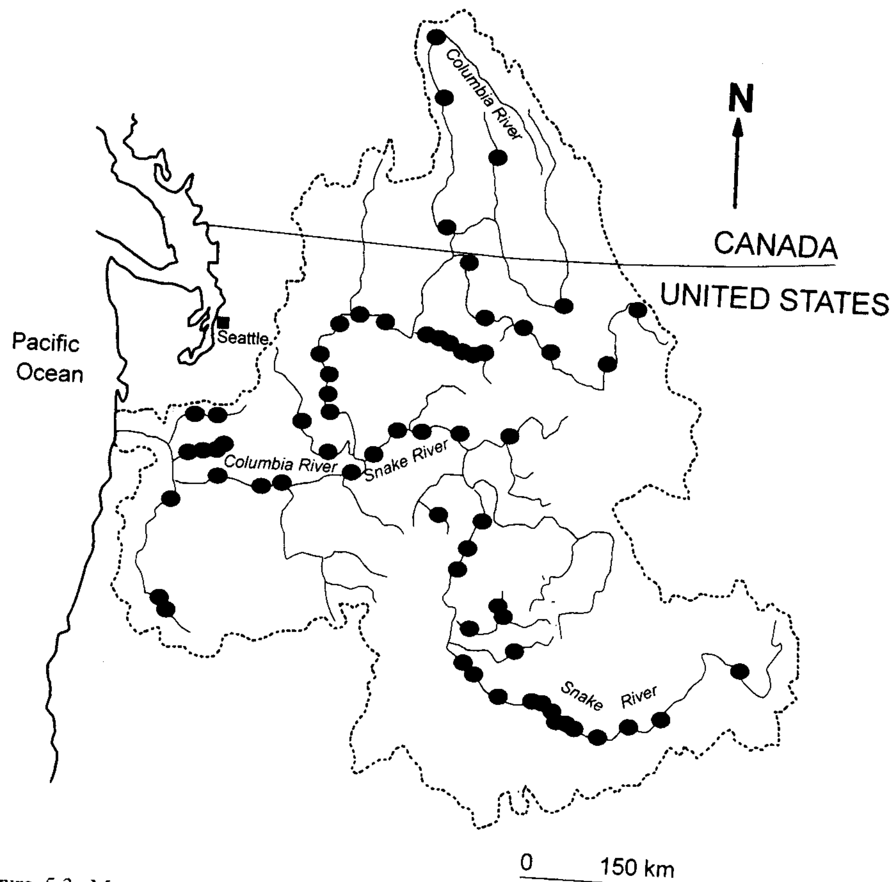

Figure 5.3. Map of the Columbia River basin in the northwestern USA and southwestern Canada. Dark circles represent dams. The majority of the river basin is mountainous.

substantial barrier to salmonid migration. The alteration of flow regime associated with dam operation has also impacted the salmonids, from flooding of spawning and rearing sites by reservoirs to exposure of redds by unnaturally low flows (Ligon et al., 1995).

Overfishing by commercial operators has also been implicated in salmonid decline. The commercial catch of chinook salmon peaked at 19.5 million kilograms in 1883, and then plunged from overfishing (Dietrich, 1995). Native American fishermen noted that the huge salmon runs had disappeared from Priest Rapids on the middle Columbia River by 1905 because of unregulated commercial fishing; this was more than 30 years before the first major dam on the river was completed (Dietrich, 1995).

A third major impact on the salmonids of the Columbia River basin has been the timber harvest in this region of humid climate, tectonic uplift, high relief, and naturally unstable slopes. Timber harvest exacerbates slope instability, leading to mass movements that

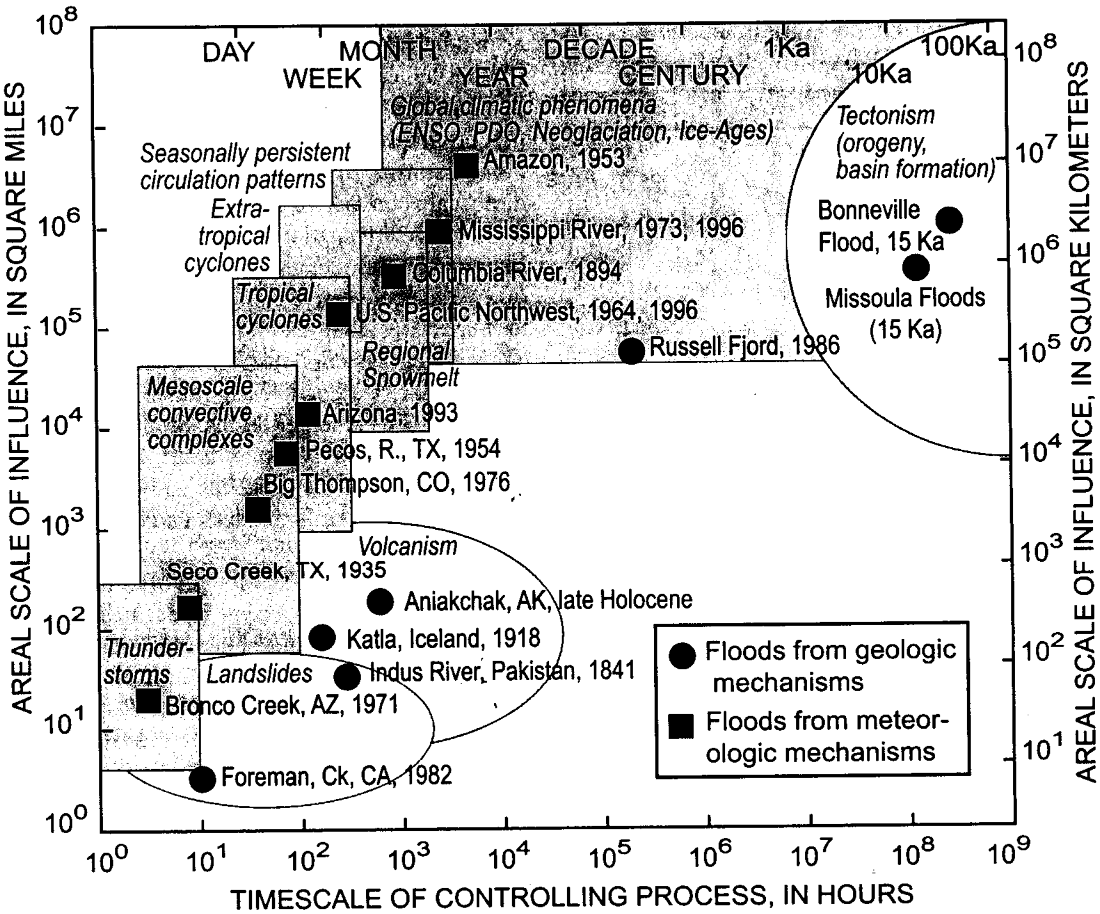

Figure 1. Space-time domain for selected meteorologic and geologic processes that can cause floods. Selected floods also shown. After Hirschboeck (1988).

Mexico, for which total rainfall exceeded volumes ranging between $6.5 \cdot 10^5$ and $4 \cdot 10^7$ m^3. The *World Meteorological Organization* [1986, p. 261-263] has compiled observations of maximum depth-area-duration for individual storms (Figure 2b), for which the largest measured rainfall volume resulted from a 1916 hurricane centered in Florida that delivered an average of 226 mm of rainfall over 260,000 km^2, for a total of $6 \cdot 10^{10}$ m^3 of water. Similarly, $4.3 \cdot 10^{10}$ m^3 of water was precipitated by a 1967 hurricane in Texas. The thunderstorm that produced the record 4.5-hour rainfall at Smethport, Pennsylvania, during July 17-18, 1942 (Figure 2a) had a total storm volume in excess of $2.7 \cdot 10^9$ m^3. Exceptionally large and wet hurricanes not included in the World Meteorological Organization database likely produced even more precipitation. For example, maps of total precipitation resulting from the Oct.-Nov. 1998 Hurricane Mitch in Central America (http://cindi.usgs.gov/hazard/event/mitch/mitch/atlas/hmprecip.html; May 25, 2001) indicate a total precipitation volume of about $2 \cdot 10^{11}$ m^3.

Persistent patterns of moisture delivery. Floods in larger basins more typically result from persistent precipitation-enhancing synoptic weather or climate. Precipitation is still delivered by individual storms or convective cells as described in the previous section, but the frequency, intensity, and duration of such storms can be affected by regional or global atmospheric patterns that can persist for months to decades. Such patterns include quasi-stationary trough-and-ridge patterns of upper atmospheric circulation that can promote continued atmospheric convergence over areas of 10^5 to 10^7 km^2 for several days or weeks. Such a condition over the north-central United States was the cause of the Mississippi River floods of 1973 and 1993 [*Hirschboeck*, 1991; 2000]. Climatic conditions of annual to decadal duration that can cause regionally enhanced precipitation include coupled atmospheric and oceanic phenomena of hemispheric or global scales such as the El Nino/Southern oscillation (ENSO) and the Pacific Decadal Oscillation (PDO; e.g. *Cayan and Peterson*, 1989; *Dettinger and Cayan*, 2000). Even longer-term climate fluctuations,

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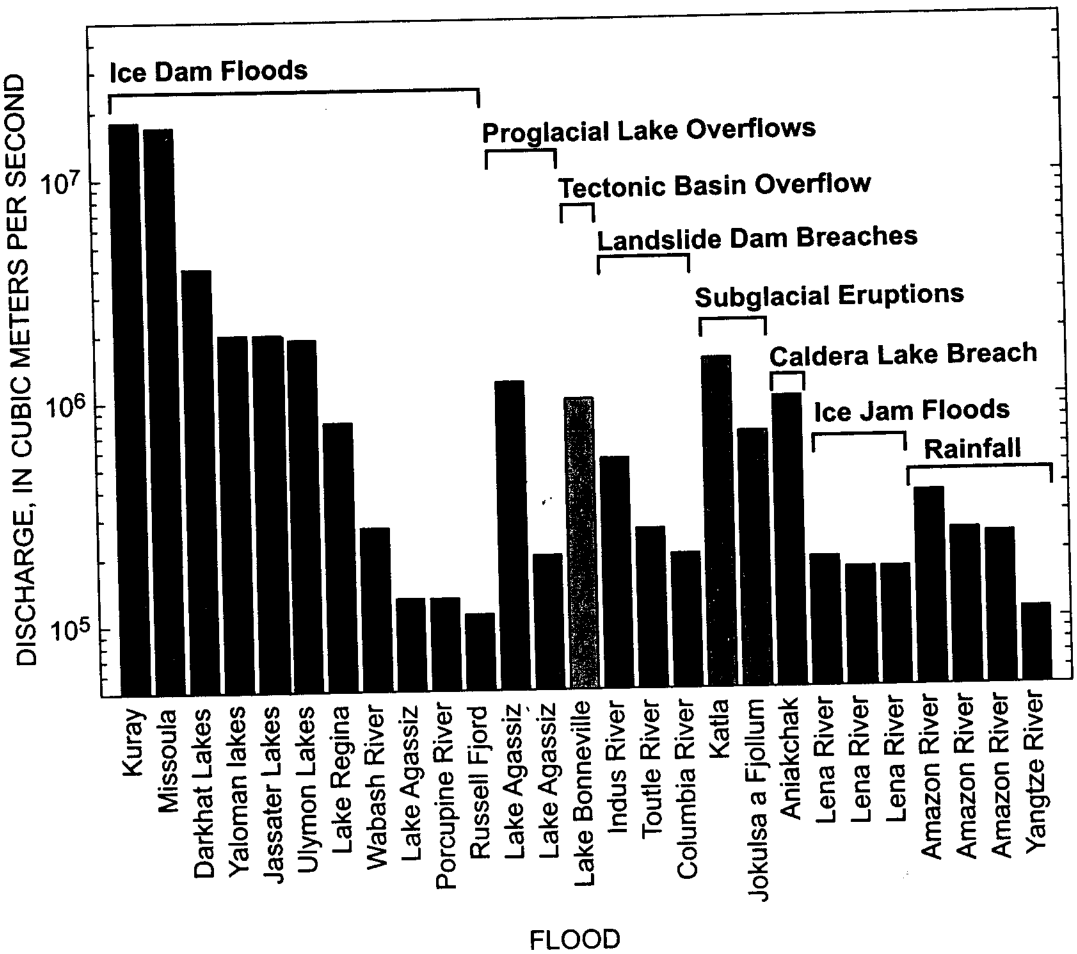

Figure 3. Quaternary floods with discharges greater than 100,000 m^3/s, arranged by causative process. From data of table 4.

measurements. Nevertheless, we can draw some fundamental inferences from this partial list as well as from other documented large floods and paleofloods.

All known terrestrial floods with discharges greater than $5{\cdot}10^5$ m^3/s resulted from rapid release of water stored behind natural dams or within glaciers (Table 4, Figure 3). The largest known floods of the Quaternary had peak discharges of about $2{\cdot}10^7$ m^3/s and resulted from breaches of glacial-age ice dams that blocked large mid-continent drainage systems. Most of the other largest floods ever documented resulted from breaches of natural dams, including landslide dams, ice dams, releases from caldera lakes, and ice-jam floods. Only 4 of the 27 largest documented floods were primarily the result of meteorological conditions and atmospheric water sources. However, if only historic events are considered, the proportion of large meteorological floods rises to 4 of 10.

Floods from Ice-Dammed Lakes

The largest floods in Earth history have resulted from derangement of drainage networks. During the Quaternary, interactions of continental ice sheets with marginal drainage systems have been a primary source of landscape-shaping floods. These floods include the $2{\cdot}10^7$ m^3/s Missoula Floods along the Cordilleran Ice Sheet margin [e.g. *Bretz*, 1923, 1969; *Baker*, 1973; *O'Connor and Baker*, 1992], giant floods along the margins of the Laurentide Ice Sheet [e.g. *Kehew and Lord*, 1987; *Lord and Kehew*, 1987; *Thorson*, 1989; *Teller and Kehew*, 1994], and more recently discovered giant Pleistocene floods in central Asia [e.g. *Baker et al.*, 1993; *Rudoy and Baker*, 1993, *Rudoy*, 1998]. These floods all resulted from rapid release of water impounded either in (1) preexisting river valleys dammed by ice or (2) proglacial lakes formed along isostatically

Table 1. Paleohydraulic parameters for bedrock and alluvial channelways, including cataclysmic flood channels - Chuja, Altay [*Baker et al.*, 1993] and Missoula Flood channels [*Baker*, 1973].

Flood Channel	Discharge Q m^3s^{-1}	Width W km	Depth D m	Slope S	Velocity V ms^{-1}	Bed Shear Stress, τ Nm^{-2}	Power per Unit Area, ω Wm^{-2}
Chuja (Altay)	2×10^7	3	400	0.02	20-45	5×10^3 2×10^4	10^5-10^6
Rathdrum (Missoula)	2×10^7	6	175	0.01	25	1×10^4	2×10^5
Grand Coulee (Missoula)	5×10^6	1.7	100	0.01	30	1×10^4	3×10^5
Amazon River	3×10^5	2	60	1×10^{-5}	2	6	12
Katherine Gorge	6×10^3	0.05	45	3×10^{-3}	7.5	1.5×10^3	1×10^4

These processes generate a sequence of erosional forms on rock surfaces in bedrock stream channels. Initial channels have relatively smooth floors. These are marked by longitudinal grooves, which mimic the longitudinal vorticity of the streaming fluid. Deeper erosion creates irregular surfaces that generate flow separation and/or kolks. As erosive activity concentrates at these sites, the result is greater accentuation of the surface irregularities [see *Hancock et al.* this volume]. A critical threshold has to be crossed to achieve this change from longitudinal forms to the production of irregular potholes.

Experimental studies of fluvial erosion utilizing simulated bedrock [*Shepherd and Schumm*, 1974] indicate that a sequence of erosional bedforms may develop in bedrock as a function of time. First to appear in these experiments were the faint streaks of longitudinal lineations associated with potholes and transverse erosional ripples. The lineations then became enlarged into prominent longitudinal grooves. Eventually the grooves decreased in numbers, and finally one narrow, deep inner channel formed. In the layered basalt bedrock of the Channeled Scabland inner channels develop headwardly by the recession of subfluvial cataracts [*Baker*, 1978b]. Multiple horseshoe-shaped headcuts separate the inner channels from scabland surfaces marked by potholes and longitudinal grooves (Figure 1).

THE KATHERINE GORGE EXAMPLE

The Katherine Gorge is a 20-km long canyon developed in jointed, resistant sandstone. It is located in the north-central part of Australia (Figure 2), 32 km northeast of the town of Katherine, Northern Territory. The gorge is a slot-like chasm averaging 50 to 150 m wide and 40 to 60 m deep (Figure 3). Linear side canyons join the main gorge; these tributary mouths are ideal sites for slackwater sediment accumulation during rare, great flows (Figure 4).

The Katherine Gorge shows many morphological similarities to the Channeled Scabland. Inner channels are cut through broad surfaces of the very resistant quartzite bedrock (Figures 3 and 5). Locally, flood water even exceeds the capacity of the gorge, spilling across adjacent uplands (Figure 6). This latter phenomenon is a type of "overfitness" [*Dury*, 1964]. Overfitness is a characteristic of the Channeled Scabland in which flood flows exceed the capacity of stream valleys. Although such a condition would not persist long in an alluvial valley, the resistance of bedrock provides an opportunity to preserve overfit stream relationships.

EXAMPLES FROM CENTRAL INDIA

The Narmada and Tapi Rivers in central India (Figure 7) are situated in an environment typical of the monsoon tropics, with large floods during the summer monsoon season. Although the two rivers differ in basin size and morphology they have two hydro-geomorphic characteristics in common: high seasonal variability in the volume of flow and sediment load, and high-magnitude floods associated with monsoon depressions originating over Bay of Bengal [*Kale et al.*, 1994].

The Narmada and Tapi are characterized by both alluvial and bedrock channels. The morphological characteristics of the bedrock and alluvial reaches are strikingly different and reflect the control of lithology, gradient and flood processes. The bedrock reaches are characterized by rapids, waterfalls, scablands, inner channels and boulder berms. The

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