

EVALUATION OF STREAM HABITAT ENHANCEMENT PROJECTS IN
THE UMATILLA NATIONAL FOREST, NORTHEAST OREGON
AND SOUTHEAST WASHINGTON

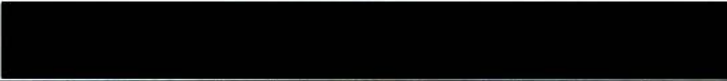
by
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A THESIS

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and the Graduate School of the University of Oregon
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Master of Arts

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"Evaluation of Stream Habitat Enhancement Projects in the Umatilla National Forest, Northeast Oregon and Southeast Washington," a thesis prepared by Cynthia H. Taylor in partial fulfillment of the requirements for the Master of Arts degree in the Environmental Studies Program. This thesis has been approved and accepted by:



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Title: EVALUATION OF STREAM HABITAT ENHANCEMENT PROJECTS IN
THE UMATILLA NATIONAL FOREST, NORTHEAST OREGON AND
SOUTHEAST WASHINGTON

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Dr. Patricia F. McDowell

The effectiveness of habitat enhancement projects using in-stream habitat structures (ISSs) was evaluated in 13 stream reaches in the Umatilla National Forest. The effect of ISSs on channel morphology was also evaluated at specific ISS locations. Pools were developed or maintained downstream from ISSs in most of the reaches. Pools at ISSs were significantly deeper than other pools in the reach in Rosgen type B reaches, and in reaches with higher gradient and larger bed material size. All of the reaches met only half or fewer of the target values for stream conditions defined in previous studies or agency documents. This result suggests that some of the reaches were in good condition, while others were in fair or poor condition. In addition, ISS contributed to local channel widening, bank erosion, and decreased bank vegetation at specific ISS locations, especially in habitat units downstream from ISSs. The analysis suggests that ISSs may impair channel habitat improvement, especially in streams with small drainage area, low gradient, and small bed material.

ISS survival and ISS performance were also evaluated using watershed, channel, stream-type and ISS control variables in contingency table analysis and logistic regression analysis. 105 ISSs in 13 reaches (data collected for this thesis) and 904 ISSs in 43 stream reaches (data provided by the Forest Service) in the Umatilla National Forest were evaluated. The results indicated that ISSs that survived did not always function to meet the project objective of pool development and maintenance. ISSs were more likely to survive in stream reaches in "soft rock" geology (sedimentary), with small drainage area, low stream order, in Rosgen type A and type E reaches, and when they were anchored. ISSs were more likely to be functioning to maintain a pool in stream reaches with larger drainage areas, high sinuosity, low width-to-depth ratio, high bank stability, large bank material, when they were anchored, and when the ISS was log-boulder or multiple-boulder.

ISSs have been important in providing additional pool habitat in streams, but they are not sufficient to enhance other aspects of stream channel habitat. Other types of habitat enhancement projects, such as riparian corridor fencing or riparian vegetation management, might be more appropriate in some stream reach types. Additional monitoring of habitat projects is needed, as well as assessment and development of target values for specific geomorphic and ecological settings. Additional research is needed to better understand the role of land-use, mass movements and other landscape disturbances in shaping channel form.

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DEDICATION

To future generations of people and salmon . . .

in the hope that we humans

learn to live in harmony

with all living creatures

on this beautiful planet

TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION	1
Background on Salmon and Habitat Management	1
Evaluation of Habitat Enhancement Projects.....	5
Research Goals and Questions.....	9
Approaches to Answering the Research Questions	10
Structure of the Thesis	15
Contributions Made by this Study	16
II. IN-STREAM STRUCTURE PURPOSE, DESIGN AND EVALUATION....	17
Land Use Impacts on Stream Habitat	17
ISS Objectives in the Study Area.....	18
ISS Purpose and Function.....	19
ISS Design and Construction.....	21
Fish Response to ISSs.....	24
ISS Impacts on Channel Morphology.....	25
Watershed and Channel Impacts on ISSs	29
ISS Survival after Floods	30
Summary	32
III. STUDY AREA	34
Geology.....	34
Watersheds.....	37
Climate.....	38
Vegetation	41
Fish.....	46
Land-Use Impacts	47
IV. CONTROL AND RESPONSE VARIABLES.....	49
Control Variables	53
Response Variables.....	79
V. IN-STREAM STRUCTURE EFFECTIVENESS AND CHANNEL MORPHOLOGY.....	102
Approaches to Answering the Research Questions	103
Site Selection.....	110
Data Collection	111
ISS Effectiveness: Analysis, Results and Discussion	116

Channel Morphology and Vegetation: Methods, Results and Discussion.....	144
Summary and Conclusions.....	186
VI. IN-STREAM STRUCTURE SURVIVAL AND PERFORMANCE.....	191
Site Selection.....	193
Data Collection	194
Data Analysis	201
Contingency Table Analysis: Methods, Results and Discussion.....	202
Logistic Regression Analysis: Methods and Results	223
ISS Survival and ISS Performance: Summary and Discussion	249
Conclusions	263
VII. CONCLUSIONS.....	267
ISS Effectiveness	267
ISSs and Channel Morphology	269
ISS Survival and Performance	271
Future Research.....	275
APPENDIX	
A. BED AND BANK MATERIAL CATEGORIES	277
B. ROSGEN AND MONTGOMERY-BUFFINGTON STREAM TYPE CLASSIFICATION CRITERIA AND REACH CHARACTERISTICS	280
C. FOREST SERVICE FORM FOR 1996 AND 1997 SURVEYS OF ISS SURVIVAL AND PERFORMANCE	283
D. LOCATIONS AND MAPS OF REACHES IN TAYLOR DATA SET	286
E. CHARACTERISTICS OF REACHES, ROSGEN AND MONTGOMERY-BUFFINGTON STREAM-TYPES, GEOLOGY AND MAPPED UNITS OF REACHES IN THE TAYLOR DATA SET	298
F. TARGET VALUES TABLES.....	311
G. LOCATIONS AND MAPS OF REACHES IN FOREST SERVICE DATA SET.....	317
H. CHARACTERISTICS OF REACHES IN FOREST SERVICE DATA SET AND TAYLOR DATA SET FOR ANALYSIS OF ISS SURVIVAL AND ISS PERFORMANCE.....	351
BIBLIOGRAPHY	354

LIST OF FIGURES

Figure	Page
1. Anadromous Salmon and Steelhead habitat in the Columbia River Basin.....	4
2. Location of the Umatilla National Forest in Oregon and Washington	6
3. In-Stream Structure Types	7
4. ISS Cross-section	22
5. ISS Perspective	22
6. Major rivers in the Columbia River Basin	37
7. Average Temperature for Elgin, La Grande, Heppner, Mitchell and Pendleton, Oregon, and Pomeroy and Pleasant View Washington	39
8. Average Precipitation for Elgin, La Grande, Heppner, Mitchell and Pendleton, Oregon, and Pomeroy and Pleasant View Washington	39
9. Potential Vegetation Types of the Blue Mountains	42
10. Habitat Units Associated with ISSs	109
11. Example of a Bivariate Plot	150
12. Residual Pools Depth at Structure and Non-Structure Pools.....	152
13. Bivariate Plots for Residual Pool depth	153
14. Additional Bivariate Plots for Residual Pool Depth	154
15. WU, WD, UD and W-UD Analyses of Wetted Widths.....	157
16. Bivariate Plots for Wetted Width Analysis (WD)	158
17. Additional Bivariate Plots for Wetted Width Analysis (WD)	159
18. WU, WD, UD and W-UD Analyses of Bank Erosion.....	162
19. Stepped Longitudinal Profile	163
20. Bivariate Plots for Bank Erosion Analysis (UD).....	164
21. Additional Bivariate Plots for Bank Erosion Analysis (UD).....	165

22. WU, WD, UD and W-UD Analyses of Bank Erosion.....	168
23. Bivariate Plots for Bank Vegetation Analysis (UD).....	170
24. Additional Bivariate Plots for Bank Vegetation Analysis (UD).....	171
25. Bivariate Plots for Bank Vegetation Analysis (W-UD).....	173
26. Additional Bivariate Plots for Bank Vegetation Analysis (W-UD).....	174
27. Flow Downstream from Channel Obstruction.....	179
28. Distribution of ISS across Watershed and Reach Characteristics in the Forest Service Data Set.....	196
29. Distribution of ISS across Stream Type and ISS Characteristics in the Forest Service Data Set.....	197
30. Logistic Regression Curve with Positive Constant.....	229
31. Logistic Regression Curve with Negative Constant.....	229
32. Map Showing Location of Upper Bear Wallow.....	288
33. Map Showing Location of Lower Bear Wallow, Camas and Lane.....	289
34. Map Showing Location of Big Wall and Wilson.....	290
35. Map Showing Location of Desolation.....	291
36. Map Showing Location of Dry Camas.....	292
37. Map Showing Location of Hidaway.....	293
38. Map Showing Location of Kelsay.....	294
39. Map Showing Location of North Fork Cable.....	295
40. Map Showing Location of Phillips.....	296
41. Map Showing Location of Thomas.....	297
42. Map Showing Location of Alder 1 and Alder 2.....	320
43. Map Showing Location of Lower Bear Wallow, Camas, and Lane.....	321
44. Map Showing Location of Upper Bear Wallow.....	322
45. Map Showing Location of Big Wall 1.....	323
46. Map Showing Location of Big Wall 2.....	324

47. Map Showing Location of Charley	325
48. Map Showing Location of Cummings	326
49. Map Showing Location of Desolation	327
50. Map Showing Location of Ditch 1 and Ditch 2	328
51. Map Showing Location of Ditch 3 and Ditch 4	329
52. Map Showing Location of Dry Camas	330
53. Map Showing Location of Ellis	331
54. Map Showing Location of Hidaway 1 and Hidaway 2	332
55. Map Showing Location of Kelsay 1 and Kelsay 2	333
56. Map Showing Location of Little Wall 1 and Little Wall 2	334
57. Map Showing Location of Little Wall 3	335
58. Map Showing Location of Meacham	336
59. Map Showing Location of North Fork Cable	337
60. Map Showing Location of Phillips	338
61. Map Showing Location of Porter 1 and Porter 2	339
62. Map Showing Location of South Fork Umatilla 1 and 2	340
63. Map Showing Location of South Fork Umatilla 3	341
64. Map Showing Location of Skookum 1, Skookum 2 and Skookum 3	342
65. Map Showing Location of Skookum 4	343
66. Map Showing Location of Skookum 5	344
67. Map Showing Location of Stalder	345
68. Map Showing Location of Swale	346
69. Map Showing Location of Thomas	347
70. Map Showing Location of Wilson 1	348
71. Map Showing Location of Wilson 2	349
72. Map Showing Location of Wilson 3	350

LIST OF TABLES

Tables	Page
1. Summary of Characteristics Evaluated using Target Values.....	12
2. Characteristics for Ecological Settings in the Blue Mountains.....	43
3. Summary of Control Variables	50
4. Effectiveness Target Value Response Variables	52
5. Channel Morphology and Vegetation Response Variables	53
6. ISS Survival and Performance Response Variables.....	53
7. Watershed Control Variables	54
8. Channel Control Variables.....	60
9. Dominant and Sub-Dominant Bank Material Categories	68
10. Riparian Vegetation Seral Stage	72
11. Stream-Type Control Variables	75
12. ISS Control Variables	77
13. Effectiveness Target Value Response Variables	81
14. Large Woody Debris Complexity (ODFW 1995).....	91
15. ISS Survival Response Variables.....	100
16. ISS Performance Response Variables.....	101
17. Summary of Effectiveness Target Value Variables.....	104
18. Target Values for Healthy Streams (Lamb, 1996).....	105
19. Ebersole (1994) Characteristics of Refugia	106
20. PACFISH Targets for Desired Future Conditions (USDA Forest Service and USDI Bureau of Land Management, 1995)	106
21. PACFISH Targets for Desired Future Conditions (USDA Forest Service and USDI Bureau of Land Management, 1995)	107
22. Camas Watershed Targets for Desired Future Conditions (Howell and McKinney, 1997)	107

23. Summary of Control Variables	110
24. Measured Morphological and Ecological Attributes	113
25. Characteristics Estimated at Every Habitat Unit.....	114
26. Calculated Morphological and Ecological Variables	115
27. Lamb Target Index Values.....	118
28. Ebersole Target Index Values.....	119
29. PACFISH Target Index Values.....	120
30. Howell and McKinney Target Index Values	121
31. Streams Meeting Specific Target Values.....	122
32. Number of Reaches that Met Lamb (1996) Target Values.....	123
33. Number of Reaches that Met Ebersole (1994) Target Values	124
34. Number of Reaches that Met PACFISH Target Values (USDA Forest Service and USDI Bureau of Land Management, 1995)	125
35. Number of Reaches that Met Howell and McKinney (1997) Target Values.....	126
36. Number of Reaches that Met Pool Frequency Target Values.....	129
37. Number of Reaches that Met Pool Depth Target Values.....	130
38. Number of Reaches that Met Vegetation Target Values	132
39. Number of Reaches that Met Stream Temperature Target Values	134
40. Number of Reaches that Met Channel Form and Bank Stability Target Values	135
41. Analyses for Comparisons of Wetted Width, Bank Erosion and Bank Vegetation at Habitat Units with and without ISS	146
42. Factor Analysis Results.....	148
43. Residual Pool Depths (m) at Structure and Non-Structure Pools	152
44. Wetted Width at Individual Habitat Units Relative to ISS Location.....	156
45. Bank Erosion Percent at Individual Habitat Units Relative to ISS Location.....	161
46. Bank Vegetation at Individual Habitat Units Relative to ISS Location	167

47. Control Variables used to Evaluate ISS Survival and ISS Performance	191
48. Additional Channel and Stream Type Control Variables used to Evaluate ISS Survival and ISS Performance for Taylor Data Set	192
49. ISS Survival Response Variables.....	194
50. ISS Performance Response Variables.....	195
51. ISS Control Variables Recorded During Field Surveys in 1996 and 1997.....	198
52. Morphological Attributes Derived from Maps	200
53. Categorical Variables for Contingency Analysis.....	203
54. ISS Survival and Performance Variables for Contingency Analysis.....	204
55. Summary of ISS Survival	205
56. Summary of ISS Performance.....	205
57. Contingency Table Results for ISS Type and ISS Survival.....	207
58. Contingency Table Results for ISS Type and ISS Performance.....	207
59. Contingency Table Results for ISS Gradient and ISS Survival.....	208
60. Contingency Table Results for ISS Gradient and ISS Performance.....	209
61. Contingency Table Results for ISS Anchor and ISS Survival.....	210
62. Contingency Table Results for ISS Anchor and ISS Performance.....	210
63. Contingency Table Results for Geology and ISS Survival.....	212
64. Contingency Table Results for Geology and ISS Performance.....	212
65. Contingency Table Results for Valley Constraint and ISS Survival	213
66. Contingency Table Results for Valley Constraint and ISS Performance	214
67. Contingency Table Results for Rosgen Stream Type and ISS Survival.....	215
68. Contingency Table Results for Rosgen stream type and ISS Performance	216
69. Contingency Table Results for Stream Order and ISS Survival.....	218
70. Contingency Table Results for Stream Order and ISS Performance.....	219
71. Contingency Table Results for Reach Gradient and ISS Survival.....	220

72. Contingency Table Results for Reach Gradient and ISS Performance.....	221
73. Dichotomous Response Variables for ISS Survival and Performance	224
74. ISS Type Ordinal Values	225
75. Ordinal Variables Assigned to ISS Gradient and Rosgen Stream Type	226
76. Dummy Variables used for Geology and ISS Anchor Categories.....	227
77. Categorical Control Variables for ISS Survival and Performance.	227
78. Logistic Regression Results for ISS Survival using Forest Service Data Set: Model 1 (without ISS Control Variables)	235
79. Logistic Regression Results for ISS Survival using Forest Service Data Set: Model 1 (without ISS Control Variables)	235
80. Test Statistics for Logistic Regression for ISS Survival: Model 1 (without ISS Control Variables)	236
81. Logistic Regression Results for ISS Survival using Forest Service Data Set: Model 3 (without Unknowns)	238
82. Test Statistics for Logistic Regression for ISS Survival: Model 3 (without Unknowns)	239
83. Logistic Regression Equation for ISS Performance using Forest Service Data Set: Model 4 (without ISS Control Variables)	241
84. Test Statistics for Logistic Regression for ISS Survival: Model 4 (without ISS Control Variables)	243
85. Logistic Regression Results for ISS Performance using Forest Service Data Set: Model 5 (without Unknowns)	244
86. Test Statistics for Logistic Regression for ISS Survival: Model 5 (without Unknowns)	246
87. Logistic Regression Results for ISS Performance using Taylor Data Set: Model 6	247
88. Test Statistics for Logistic Regression for ISS Survival using Taylor Data Set: Model 6	248
89. Summary of Analysis of ISS Survival: Factors that Contributed to Increased ISS Survival	250
90. Summary of Analysis of ISS Performance: Factors that Contributed to Increased ISS Performance.....	251

91. Bed material categories (after USDA Forest Service, 1996; Wolman, 1954).....	278
92. Soil Texture Test Characteristics.....	279
93. Rosgen Classification Entrenchment, sinuosity and width-to-depth ratios can vary by +/- 0.2 units (Rosgen, 1994).....	281
94. Montgomery-Buffington Reach Types.....	282
95. Reach Names and Locations.....	287
96. Summary 1 of Reach Characteristics (Taylor Data Set).....	299
97. Summary 2 of Reach Characteristics (Taylor Data Set).....	300
98. Summary 3 of Reach Characteristics (Taylor Data Set).....	301
99. Summary 4 of Reach Characteristics (Taylor Data Set).....	302
100. Summary 5 of Reach Characteristics (Taylor Data Set).....	303
101. Summary 6 of Reach Characteristics (Taylor Data Set).....	304
102. Summary 7 of Reach Characteristics (Taylor Data Set).....	305
103. Mapped Geology Units and Geologic Classification.....	306
104. Variables used to Determine Rosgen Stream Type	307
105. Variables used to Determine Montgomery-Buffington Reach Type.....	309
106. Forest Service Data Set, Locations and Number of ISSs.....	318

CHAPTER I

INTRODUCTION

In this thesis, I will evaluate the effectiveness and survival of stream habitat enhancement projects in streams in the Umatilla National Forest, within the Columbia River Basin in North America. These projects have been implemented to create habitat for anadromous salmonids in the Pacific Northwest. Salmon utilize a variety of habitats in freshwater rivers and streams, and the degradation of suitable habitat is one cause of many that have contributed to significant declines in salmon populations in the region (Gregory and Bisson, 1997; Wissmar et al., 1994).

Background on Salmon and Habitat Management

Salmon (*Oncorhynchus* spp.) have long been important to the cultures and economies of people in the Pacific Northwest and play an important biological role as a dominant component of the aquatic fauna of Pacific Northwest rivers and lakes (Kostow, 1997; Smitch, 1997). Salmon populations have been declining in many of the river basins in the Pacific Northwest (Hassemer et al., 1997; Johnson et al., 1997; Kostow, 1997; Northcote and Atagi, 1997; Smitch, 1997; Wertheimer, 1997). In the last century, many stocks of Pacific salmon have gone extinct throughout much of the region, and many other stocks are at risk of extinction (Nehlsen et al., 1991; Frissell, 1992; Gregory and Bisson, 1997). In a 1991 American Fisheries Society (AFS) report, Nehlsen and others (1991) identified 214 stocks of naturally reproducing fish in Oregon, Washington, California and Idaho that were at risk of extinction or of special concern (USDA Forest Service and UDI Bureau of Land Management, 1995). Of the 214 stocks, 76 were from the Columbia River Basin in Idaho,

Oregon and Washington (USDA Forest Service, 1994). Of the 192 stocks of anadromous fish in the Columbia River Basin, 35% are extinct and 39% are at high or moderate risk of extinction or of special concern (Williams et al., 1992). Summer steelhead (*Oncorhynchus mykiss*) are federally protected in the mid-Columbia River Basin since the March 1999 threatened species listing under the U.S. Endangered Species Act (NOAA, 1999).

Land uses and management practices over the last 150 years have resulted in habitat loss and the simplification of stream channel structure (Crispin et al., 1993; Wissmar et al., 1994). Logging, grazing, channelization, mining, road building and active removal of logs and log-jams have all contributed to habitat simplification. This has resulted in decreases in side channel habitat, the number of pools and large, deep pools, the amount of large woody debris, riparian vegetation, bank vegetation, spawning gravels and bank stability (Sullivan et al., 1987; USDA Forest Service 1994; Crispin et al., 1993; Beechie et al., 1994; McIntosh et al., 1994; Oliver et al., 1994; Wissmar et al., 1994; USDA Forest Service and USDI Bureau of Land Management, 1995; Kostow, 1997).

High water temperatures in summer are an additional concern in streams in the region because of the stressful effects of high temperatures on aquatic organisms (NPPC 1987; USDA Forest Service, 1991; Ebersole, 1994; Boyd, 1997). During summer, many streams in the region reach temperatures that are potentially lethal to salmon. Since fish are cold blooded, their body temperature is closely related to the surrounding water temperature, and high temperatures increase their metabolic rate (Beschta, 1997b). Salmon and trout are adapted to and depend on colder water temperatures and on high concentrations of dissolved oxygen which increases as water temperature decreases (Wetzel, 1983; Gordon et al., 1992; Grant et al., 1992). As temperatures increase and the amount of oxygen is reduced, fish experience stress (Beschta, 1997b).

To address some of these concerns, the Northwest Power Planning Council in conjunction with Bonneville Power Administration (BPA), implemented the Columbia River

Basin Fish and Wildlife Program in 1995 (USDA Forest Service 1987a). Through this program, BPA supplied funds for projects to enhance riparian and in-stream habitat in many rivers and streams in the Columbia River Basin. These projects were intended to mitigate for the decline in available habitat that has resulted from the placement and operation of hydropower dams in the Columbia River system (NPPC, 1982). These dams have decreased the area that is accessible to migrating salmon (Figure 1) and have altered habitat conditions in the mainstem of the Columbia River (NPPC, 1982). Funds for habitat enhancement and restoration have also been generated from revenues from timber harvesting on federal lands in order to mitigate for any detrimental effects on stream channels and biota due to timber harvesting activities (Roper et al., 1998).

The USDA Forest Service and other state and federal agencies have used the available funds to implement stream habitat enhancement projects in the Columbia River Basin. These projects frequently involved constructing habitat structures in streams (NPPC, 1982; Frissell and Nawa, 1992; Neal et al., 1993). Many types of in-stream structures (ISSs) and habitat enhancement techniques have been used to create or improve habitat for fish in streams in the United States since the 1930s (Wesche, 1985; Roper et al., 1998). Some of these techniques included in-stream boulder placement, large wood and log placement, riparian corridor fencing, log bank stabilization, juniper or rock bank rip-rap, bank revegetation, log-weir placement, boulder-weir placement, excavation of pools downstream from weirs, and the construction of deflectors for bank protection (Reeves et al., 1987b; Northrup et al., 1991). Many of these techniques have been used in rivers and streams in the Columbia River Basin. The use of ISSs has increased in the Pacific Northwest in the 1980s. 2400 ISSs were built by Forest Service personnel in 1987 alone (Frissell and Nawa, 1992). A 1996 survey of ISSs in Region 6 (Pacific Northwest Region) of the USDA Forest Service included 3946 ISSs (Roper et al., 1998).

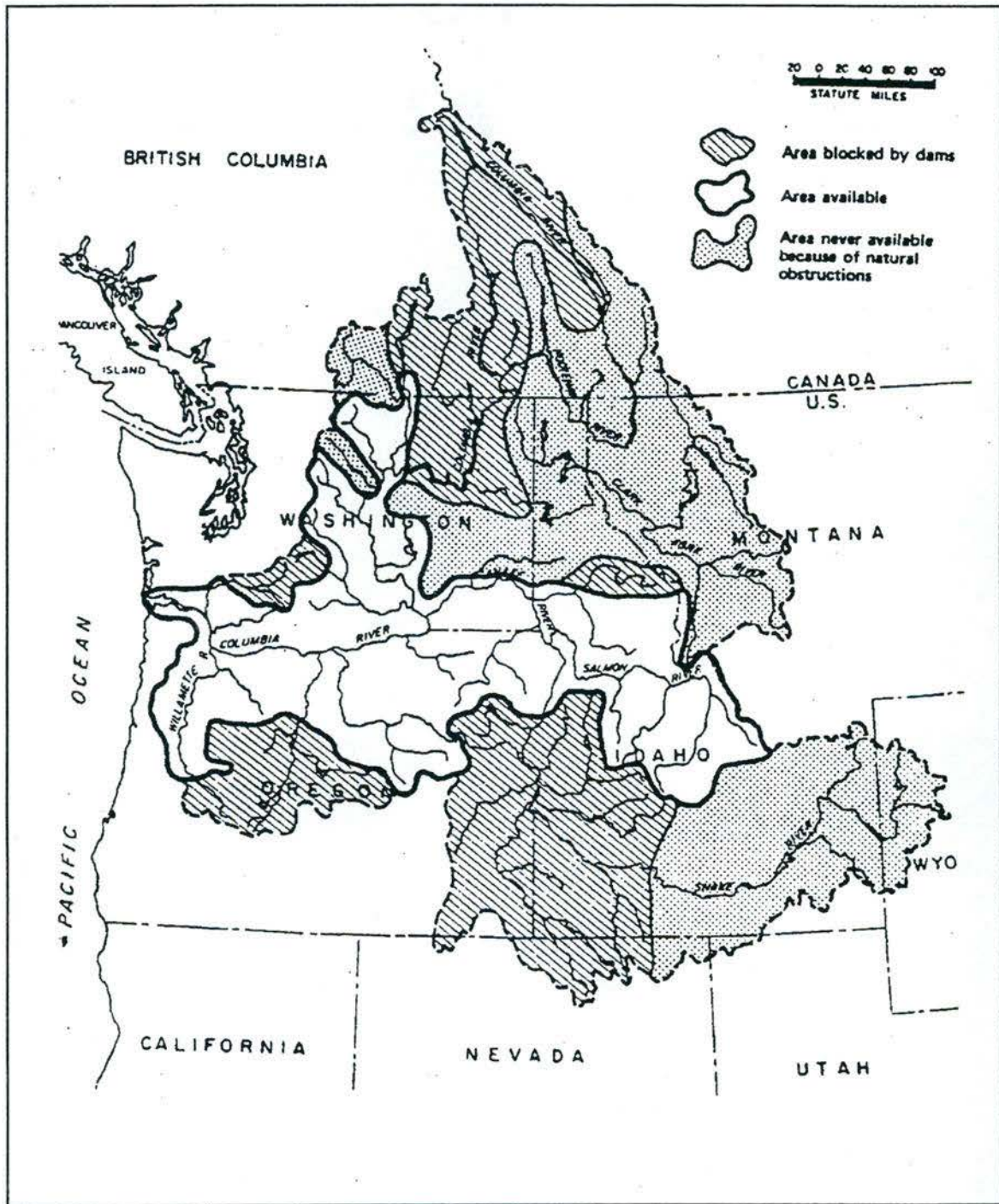


Figure 1. Anadromous Salmon and Steelhead habitat in the Columbia River Basin (Northwest Power Planning Council, 1982, p. 52).

The projects evaluated in this thesis utilize ISSs to create additional habitat. These projects are in streams that are still accessible to anadromous fish migrating upstream from the Pacific Ocean. Study reaches are in tributaries of the Tucannon, Umatilla, Grand Ronde, North Fork John Day and John Day within the Umatilla National Forest (NF) in northeast Oregon and southwest Washington (Figure 2).

The John Day River Basin supports the largest remaining wild runs of spring chinook (*Oncorhynchus tshawytscha*) and summer steelhead (*Oncorhynchus mykiss*) in the Columbia River Basin (Neal et al., 1993). The construction of pools for rearing habitat and adult holding areas for steelhead (*Oncorhynchus mykiss*), the anadromous form of rainbow trout, has been the focus of a majority of habitat enhancement projects in the John Day River Basin (NPPC, 1982). The same types of projects have been implemented in many watersheds in the study area. Log and boulder weirs are the most common types of ISSs used to create pool habitat in the study area (Figure 3).

Evaluation of Habitat Enhancement Projects

There have been many studies to evaluate the response of fish populations to ISSs and habitat modification (Hamilton, 1986; Reeves et al., 1987a). Federal and state agencies have recognized the importance of monitoring stream enhancement and restoration projects (Federal Interagency Stream Restoration Working Group, 1998), but few ISS projects have been monitored or evaluated to assess their effectiveness in achieving improved habitat conditions or to examine the impacts on channel morphology (Beschta et al., 1991; House et al., 1991; Kondolf and Micheli, 1995; Beschta et al., 1996). There are concerns that habitat enhancement has not produced positive changes in fish populations or habitat conditions (Gillilan, 1995), and the criteria for evaluating the effects of ISSs on channel morphology are not well defined (Klingeman, 1997; Robison, 1997).

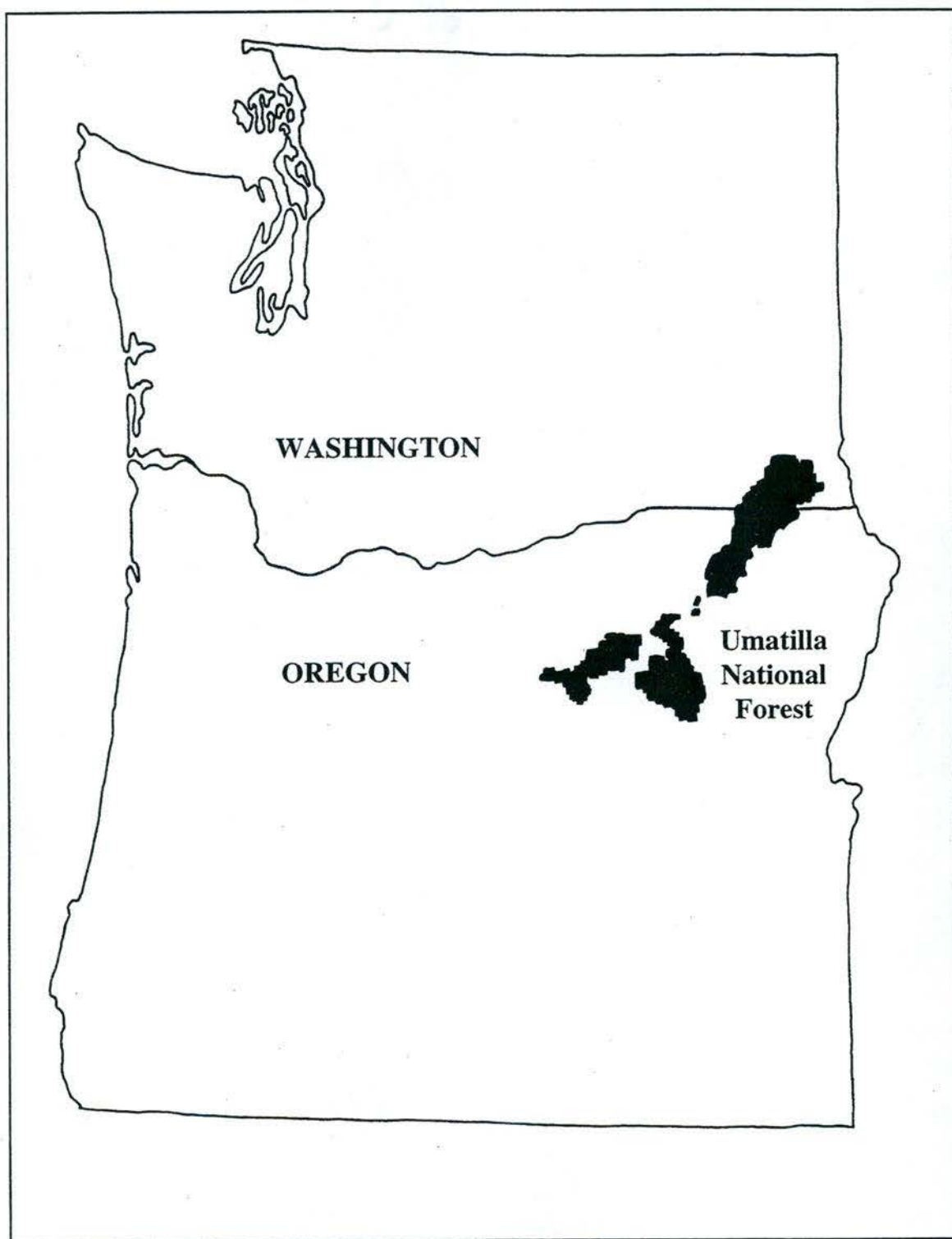
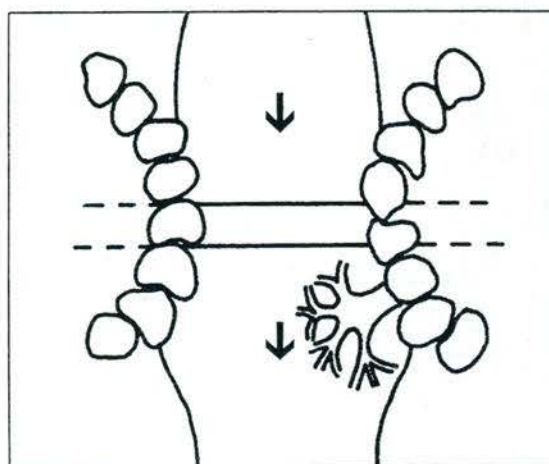
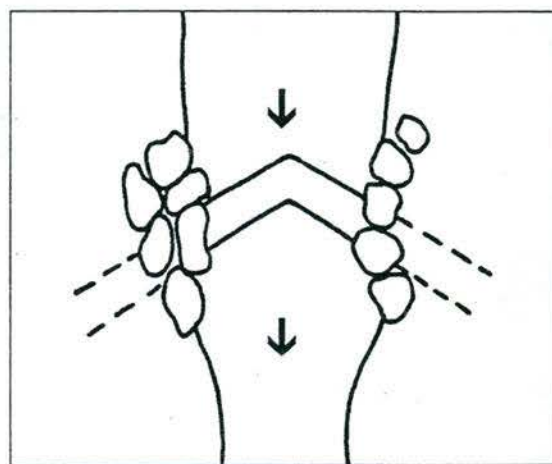


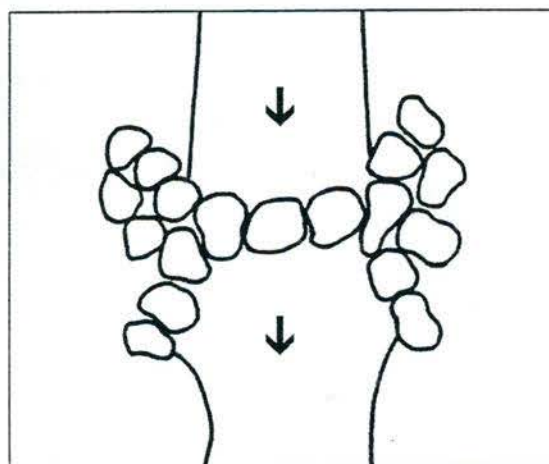
Figure 2. Location of Umatilla National Forest in Oregon and Washington.



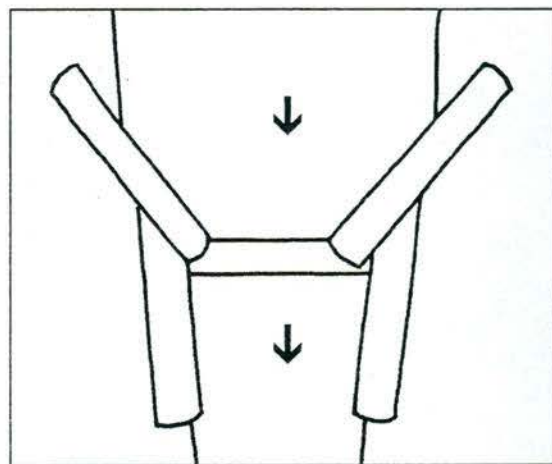
Log-Boulder with Rootwad



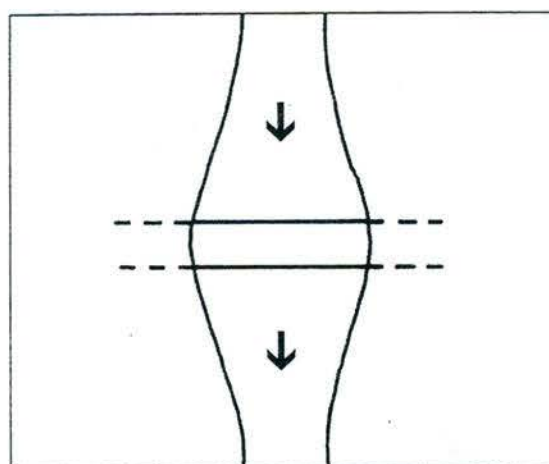
Log-Boulder



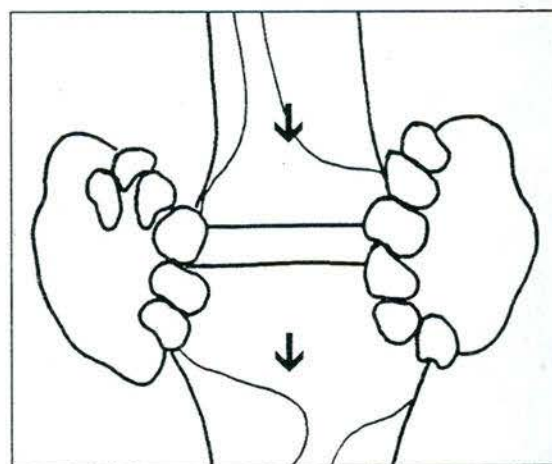
Multiple-Boulder



Multiple-Log



Single-Log



Log-Boulder with earth hills

Figure 3. In-Stream Structure types.

Many of the studies to evaluate ISSs have been qualitative and have shown mixed results (Hanson, 1987; Hamilton, 1989; Connon, 1991; Beschta et. al., 1991). Some studies reported that ISSs have been beneficial to fish populations (Anderson, 1981; Ward and Staney, 1981). Other studies have shown that there are few benefits, and these results have not been widely reported (Hamilton, 1989; Frissell and Nawa, 1992).

Research that has quantified the impacts of ISSs on channel morphology has been limited to the evaluation of only a few channel variables that are specifically related to fish habitat such as pool depth, water surface area, pool volume and number of pools (House and Boehne, 1986; Hamilton, 1989; Crispin et al., 1993; Armantrout, 1991; Bjornn and Reiser, 1991). It is important to evaluate other channel morphology characteristics because some researchers have suggested that ISSs can be damaging or that they impair channel forming processes by contributing to stream bank erosion, channel widening, changes in channel cross-section shape, and that they limit natural channel migration and adjustment (Beschta et al., 1991; Frissell and Nawa, 1992; Fitzgerald, 1997).

Recent studies conducted by Frissell and Nawa (1992) and in Region 6 (Pacific Northwest Region) of the USDA Forest Service (Fitzgerald, 1997; Roper et al., 1998) examined ISS survival and failure in streams in Oregon and Washington relative to watershed characteristics such as stream order, channel gradient and flood return intervals. The results of these and other studies (Hamilton, 1989; Beschta et al., 1991; Beschta et al., 1996) suggest that if ISSs are used to modify channel habitat, they need to be designed for the specific geomorphic context (Hamilton, 1989; Frissell and Nawa, 1992). Specific results of these and other studies are discussed in greater detail in chapter II.

Additional research is needed to better understand channel response to management techniques that involve channel modification using ISSs. Frissell and Nawa (1992) suggested that complex, multi-scale interactions affect the success and performance of ISSs.

They stressed the need for analyses that take the interactions of watershed, channel and ISS characteristics into account Frissell and Nawa (1992). Research to evaluate a wider range of channel and habitat characteristics, such as that undertaken in this thesis, can contribute to better integration of principles of fluvial geomorphology into habitat management and watershed restoration (Wissmar, 1993; Montgomery, 1997). It is also important to know whether stream habitat enhancement techniques are an effective allocation of financial resources (Frissell and Nawa, 1992; Frissell, 1993; Kondolf and Micheli, 1995; Beschta et al., 1996), in what ways they are affecting stream form and function, and if they are re-establishing or improving the morphological and ecological conditions associated with habitats used by anadromous and resident salmonids.

Research Goals and Questions

Research Goals

One goal of this research was to investigate the effectiveness of specific habitat enhancement projects using ISSs in providing habitat for anadromous and resident salmonids in stream reaches. These enhancement projects have been designed primarily to produce habitat features that contribute to fish population survival (Beschta, 1997a).

A second goal was to utilize a geomorphic approach to investigate the interactions between watershed, channel, stream-type and ISS characteristics, and to examine the effects of these characteristics on channel morphology and on ISS survival and performance. Geomorphologists are interested in understanding the mechanisms that control and constrain channel morphology and behavior (Petts, 1983).

Each stream habitat enhancement project evaluated in this study included several ISSs within a stream reach. Some projects in the region also incorporated bank stabilization

structures, altered land-use regimes or riparian fencing, but these were not evaluated. The research goals were addressed by answering the following research questions:

Research Questions

1. Are habitat enhancement projects involving ISSs effective in meeting empirically derived and agency defined target values for salmonid habitat characteristics?
2. To what extent do ISSs affect stream channel morphology by contributing to differences in pool depth, wetted width, bank erosion or the amount of bank vegetation?
3. What are the watershed, channel, stream-type and ISS characteristics that are associated with differences in pool depth, channel width, bank erosion or the amount of bank vegetation associated with ISSs.
4. What are the watershed, channel, stream-type and ISS characteristics that affect the survival and performance of ISSs?

Approaches to Answering the Research Questions

Analyses of the effectiveness, channel morphology, survival and performance of ISSs were done at two levels: (1) the stream reach and; (2) the individual habitat unit or individual ISS. Reaches are stream segments with relatively homogeneous hydrological, morphological and sedimentological characteristics (Grant et al., 1990; Montgomery and Buffington, 1998, Naiman, 1998). Geomorphic indicators used to discriminate between reaches include tributary junctions, and changes in geology, valley form, valley width, gradient, channel pattern, and predominant bed and bank material. At the scale of the reach,

the habitat unit, and the individual ISS, the morphological and ecological features of interest were those that contribute to specific physical habitat characteristics that are associated with desired conditions for anadromous salmonids.

Question 1 was used to evaluate reach scale conditions, and addresses the effectiveness of enhancement projects that used ISSs in stream reaches. For the analysis, I collected data from 13 reaches during field surveys conducted in 1997 (Taylor data set), and from map analysis. Each reach contained at least five ISSs and as many as twenty-one ISSs.

Questions 2 and 3 were used to evaluate habitat unit scale conditions. The analysis to answer question 2 was done using the Taylor data set. During field surveys, each reach was divided into one of three habitat unit types, pools, riffles or glides, following the criteria described in the USDA Forest Service (1996) and in the Oregon Department of Fish and Wildlife (ODFW, 1995). In the analysis, habitat units were categorized by their location relative to ISS location rather than by habitat unit type. The analysis for research question 3 used watershed and reach-scale characteristics to evaluate the factors that influenced channel morphology in habitat units associated with ISSs.

Question 4 was used to evaluate the response of individual ISS, and addresses ISS survival and ISS performance. Watershed, reach, and ISS characteristics were used as control variables to evaluate the factors that influenced ISS responses. One analysis was done using data from 150 ISSs in the Taylor data set. Another analysis was done using data from 904 ISSs in 43 reaches where ISS survival and ISS performance were surveyed in 1996 and 1997 (Forest Service data set). Each reach in the Forest Service data set contained from 5 to 125 ISSs.

Research Question 1: Comparison of Reach Characteristics with Target Values

In an ideal study to evaluate channel habitat, the preferred method of analysis might be a comparison between treated reaches and unaltered streams or streams in very good or pristine condition that were known to support fish populations. However, streams in this study have been significantly altered and few reference reaches in very good or pristine condition exist for analysis and comparison, so another approach was needed. In this thesis, the effectiveness of stream habitat enhancement projects was evaluated by comparing stream and habitat characteristics in reaches with ISSs to empirically derived and agency defined target values. The target values define the stream and habitat characteristics required by anadromous salmonids. The reach characteristics evaluated included the morphological and ecological characteristics summarized in Table 1.

TABLE 1. Summary of Characteristics Evaluated using Target Values

Bank Stability
Canopy Cover
Bank Vegetation
Habitat Unit Frequency
Pool Frequency
Residual Pool Depth
Average Maximum Pool Depth
Width-to-Depth Ratio
Large Woody Debris Frequency
Bank Undercut (lower bank angle)
Temperature

Measured characteristics in treated reaches were compared with target values identified through empirical, quantitative analyses (Ebersole, 1994; Lamb, 1996), and in agency documents (USDA Forest Service and USDI Bureau of Land Management, 1995; Howell and McKinney, 1997). Lamb (1996) defined target values for healthy streams in the Blue Mountains in the Umatilla NF. Healthy streams were identified by fisheries biologists in

the Umatilla NF as those that supported diverse populations of resident and anadromous salmonids. A second set of target values comes from a study by Ebersole (1994) conducted in the Joseph Creek Basin in the Blue Mountains in northeast Oregon. Ebersole (1994) identified empirically derived, quantitative values of channel features in streams that serve as potential refugia for resident and anadromous fish or that were within relatively unaltered remnant patches of old growth conifers or alder riparian forests. Additional target values included desired future conditions defined in USDA Forest Service (FS) and USDI Bureau of Land Management (BLM) management plans and agency documents such as PACFISH (USDA Forest Service and USDI Bureau of Land Management, 1995; Williams and Williams, 1997) and the Aquatic Biology Module for Camas Watershed Analysis (Howell and McKinney, 1997).

Research Questions 2 and 3: ISSs and Channel Morphology

This study will provide a quantitative analysis of channel characteristics that might be directly affected by the presence of ISSs. The watershed, channel, stream-type and ISS factors will be identified that may contribute to the differences in these channel characteristics when ISSs are present. These factors include among others, drainage area, gradient and bank material size.

Some researchers have reported increased channel widening, bank erosion and decreased vegetation at the specific locations of ISSs in a stream (Beschta, 1991; Frissell and Nawa, 1992; Beschta, 1996). Other researchers have reported increased pools depths associated with ISSs (House and Boehne, 1986; Gore and Hamilton, 1989; Hamilton, 1989; Armantrout, 1991; Crispin et al., 1993;).

The channel morphology and associated characteristics evaluated in this study included channel wetted width, bank erosion, bank vegetation and pool depth. Reaches were divided into habitat units and these channel characteristics were measured in each habitat unit.

Comparisons were made between habitat units with ISSs (immediately upstream and downstream from an ISS) and habitat units without ISSs. Habitat units upstream from ISSs were also compared with habitat units downstream from ISSs.

Research Question 4: Analysis of ISS Survival and Performance

This study expanded upon a recent regional analysis of ISS survival and performance conducted by USDA Forest Service Region 6 (Pacific Northwest Region) (Roper et al., 1998) and in the Umatilla NF (Fitzgerald, 1997). Large magnitude flood events occurred throughout much of the Blue Mountains region and in the Umatilla NF in late 1995, early 1996, and in localized areas in 1997. These floods provided the opportunity to assess the response of ISSs to large magnitude discharges (Fitzgerald, 1997; Roper et al., 1998). This analysis also tested the conclusions of a study by Frissell and Nawa (1992) who evaluated ISS failure in coastal Oregon streams after the occurrence of moderate floods of 2 to 7 year recurrence intervals (RI). Frissell and Nawa (1992) extrapolated their results to large magnitude floods (> 50 year RI) and concluded that ISS failure would most likely be greater following larger, less frequent floods. The results of these studies will be discussed in more detail in chapter II.

In this study, I evaluated the survival of ISSs following the extreme flow events of 1995, 1996 and 1997 (Fitzgerald, 1997; Roper et al., 1998) and identified the watershed characteristics (drainage area and geology), channel characteristics (channel gradient, sinuosity and bank material size) or ISS characteristics (ISS type, local gradient) that were associated with ISS survival. ISS survival categories were defined by whether an ISS remained in place, shifted on site or left the original site (Roper et al., 1998). I also evaluated the performance of ISSs in meeting initial project objectives and identified the characteristics associated with ISS performance. The most frequent initial project objective was the creation of a pool. ISS performance categories for meeting initial project objectives

included whether or not an ISS was functioning, partially functioning or not functioning (Roper et al., 1998). ISSs were also considered to be functioning if they were providing quality fish habitat. For instance, if an ISS had shifted or left the site, but was creating complex cover for fish, it was considered to be functioning. I then identified watershed, channel, stream-type and ISS factors associated with ISS performance.

Structure of the Thesis

In chapter II, I provide a detailed description of the purpose, types and construction of ISSs in the study area. I also provide a summary of the results of studies that have evaluated enhancement projects using ISSs. I discuss the results of studies that evaluate fish response to ISSs and impacts of ISSs on channel morphology. I summarize the results of the Forest Service studies in Region 6 (Pacific Northwest Region) and in the Umatilla NF that evaluated ISS survival and performance following large magnitude floods and the study of ISS survival conducted by Frissell and Nawa (1992).

In chapter III I describe the study area, focusing on geology, climate, vegetation and land use impacts, and briefly describe the fish in the region. In Chapter IV, I discuss the significance of the specific variables that are used in the analyses that address the research questions. Chapter V addresses the first three research questions to evaluate ISS effectiveness, and the impacts of ISSs on channel morphology. Chapter V includes sections on site selection, data collection, analysis methods, results, discussion and conclusions. Chapter VI addresses the fourth research question to evaluate ISS survival and ISS performance, and includes sections on site selection, data collection, analysis methods, results, discussion and conclusions. Chapter VII provides overall conclusions of the study and possibilities for future research.

Contributions Made by this Study

The results of this analysis will be useful in future projects to enhance riparian and stream habitat. This study will provide a better understanding of the impacts of specific ISS types and may identify the characteristics of streams that are most sensitive or responsive to the presence of these ISSs. The field data collected at specific stream reaches will also provide a baseline by which to measure future changes in channel morphology and habitat conditions in these stream reaches. In addition, the statistical analysis of morphological and ecological variables of the streams and watersheds in this study will provide insight into the controls that operate at a variety of spatial scales and influence stream morphology in the Blue Mountains. By utilizing principles of geomorphology to understand stream form and behavior in streams with constructed ISSs, this analysis will contribute to a greater understanding of the mechanisms influencing channel form in this region.

CHAPTER II

IN-STREAM STRUCTURE PURPOSE, DESIGN AND EVALUATION

Many projects designed to improve habitat conditions for fish have been implemented in the Pacific Northwest. Constructing in-stream structures (ISSs) is one common approach to address habitat loss and degradation, widely recognized as factors contributing to the decline of salmon in the region. ISSs have been used for creating fish habitat since the 1930s (Wesche, 1985; Roper et al., 1998), and their use increased during the 1980s and early 1990s in the Pacific Northwest (LaMarr, 1996). Construction plans and instructions for building ISSs are available from many sources (Klingeman, 1984, Wesche, 1985; Reeves et al., 1987b; Hunter, 1991).

Land Use Impacts on Stream Habitat

Channel structure has been simplified as a result of land management practices and land uses such as logging, grazing, channelization, mining, road building and the active removal of logs and log-jams (Crispin et al., 1993; Wissmar et al., 1994). Land uses have also resulted in loss of spawning gravel and decreased bank stability. In addition, land managers removed large wood from channels before it was recognized as an important mechanism for pool formation in forested streams (Montgomery, 1997). This has resulted in reduced pool frequency, depth and quality (Armantrout, 1991; Myers and Swanson, 1996a), and has reduced the amount of habitat for fish (House and Boehne, 1986). ISSs may provide an increase in habitat availability and complexity.

Land managers have tried to imitate the natural occurrence of large wood by constructing ISSs to increase aquatic habitat (House and Boehne, 1986; Armantrout, 1991;

Crispin, 1993). There has been an increased understanding of the role of large wood for habitat creation (Bisson et al., 1987; Nakamura and Swanson, 1994; Ralph et al., 1994; Fetherston et al., 1995; Naiman et al., 1995; Beechie and Sibley, 1997). Managers are increasingly using bioengineering techniques which incorporate natural, physical channel forming processes and materials to create aquatic habitat (Sedell and Beschta, 1991; Roper et al., 1998). In many cases ISSs have been shown to have a positive effect on fish population numbers (House and Boehne, 1986; Fontaine, 1987; House et al., 1991). These projects have been viewed as a short term solution to the problem of habitat loss that has resulted from lack of available large wood for pool formation (Frissell and Nawa, 1992; Sanchez, 1997). Land managers are currently implementing management practices that are intended to lead to improved habitat conditions over the long term. These include management for the growth of streamside trees for later recruitment as in-channel large wood, grazing strategies that limit grazing in riparian areas (USDA Forest Service, 1987b ; USDA Forest Service and USDI Bureau of Land Management, 1995), and road improvement to reduce the input of sediment to streams. Large wood from riparian forests provides natural inputs of wood to create pools and complex in-stream habitat. Until that occurs, managers are using ISSs to take the place of large wood for pool formation.

ISS Objectives in the Study Area

The goals and objectives of stream habitat enhancement projects are varied. In the Umatilla National Forest (NF), the main objective of ISS projects was to provide habitat for anadromous salmon, especially focusing on the needs of two *Oncorhynchus mykiss* subspecies, anadromous steelhead salmon (*O. mykiss gairdneri*) and resident redband trout (*O. mykiss irideus*). They are indicator species for other anadromous and resident fish in the Umatilla basin and throughout much of the study area (USDA Forest Service, 1987c). Habitat enhancement projects have focused on creating more pools (NPPC, 1982) primarily

because the number of pools relative to riffles has decreased from 50:50 to 20:80 or 10:90 in many streams (USDA Forest Service and USDI Bureau of Land Management, 1994). This has reduced the amount and variety of suitable habitat for fish to use as cover and resting area (Brookes, 1990).

Specific project objectives are known for some basins in the study area. In Thomas and Meacham Creeks, ISSs were designed to increase low-flow pool rearing habitat for steelhead trout (Calame, 1997; Fitzgerald, 1997). In the South Fork Umatilla River, project objectives included increasing adult holding pool habitat for spring chinook, and low-flow pool rearing habitat for steelhead trout and chinook salmon (Northrop, 1990). In Thomas, Phillips, and Wilson Creeks, ISSs were located in places where the pools would potentially intercept ground water (indicated by the presence of wetland vegetation), bring cool water to the surface, and provide pool refuge in streams typically dry in the summer (Northrop, 1991; Calame, 1997). Additional objectives included increased bank stability, decreased bedload movement, and improved adult fish passage upstream (Northrop, 1990). Similar objectives were defined for Cummings and Charley Creeks in the Walla Walla District of the Umatilla NF (Fitzgerald, 1997), and for other streams in the Walla Walla District, in the North Fork John Day District, and in the Heppner District of the Umatilla NF (Calame, 1997; Sanchez, 1997). In Wilson Creek in the Heppner District, deeper pools also provide winter habitat in this stream which is typically frozen solid in winter (Calame, 1997).

ISS Purpose and Function

In general, habitat enhancement projects are designed to address one or a few components of the stream system such as improved fish habitat and the response of fish species, improved riparian vegetation, or improved channel morphology (Gregory, 1996). Projects that use ISSs are intended to provide increased habitat area and diversity, and to contribute to accelerated biological recovery of aquatic organisms (Shields, 1983). In the

Umatilla NF, ISSs were specifically intended to provide rearing habitat for juvenile and adult steelhead salmon (*Oncorhynchus mykiss*) during low-flow periods (summer).

Stream habitat enhancement projects are often designed to mimic natural channel conditions and processes. Newberry and Gaboury (1993) defined a successful stream enhancement as one where complex habitats are created by reproducing natural material, geometry and hydraulics. Crispin and others (1993) suggested that ISSs imitate natural inputs of large wood, restore habitat diversity and return streams to more natural conditions. The stream reaches included in this thesis contain constructed ISSs that are similar to logs or boulders that move into the stream by natural processes, and affect hydraulic and sediment transport processes within the channel to influence channel form.

Naturally occurring large wood that spans the stream channel often forms a stepped longitudinal profile where log-steps contribute to pool formation, reduce channel gradient and trap sediment (House et al., 1991). Many ISSs in the study area were constructed using large logs that spanned the channel width. They created steps that influenced fluvial processes and channel form in ways that are similar to naturally occurring large wood. However, ISSs such as those used in the study area are less complex than naturally introduced wood which usually has root wads, limbs and branches attached, and often accumulates in log-jams and creates complex habitat (Beschta et al., 1996). Straight logs with branches and root wads removed were used to construct the ISSs evaluated in this thesis, and therefore created less complex habitat than naturally introduced large wood.

Some of the ISSs that were constructed used large boulders to span the channel rather than large logs. Naturally occurring large boulders within stream channels are important elements of bed and channel morphology. Microhabitats, such as backwater and plunge pools form around large boulders when hydraulic action scours the bed and bank material (Grant et al., 1990). Accumulations of boulders that span the channel width create sequences of steps and pools (Grant et al., 1990). These step-pool sequences create pool

habitat, and reduce channel gradient and stream power. Boulder ISSs operate in much the same way as naturally occurring boulder step-pool sequences.

Large, placed logs and boulders will affect channel hydraulics and the response of the channel to water flow and sediment transport processes. Some researchers (Beschta et al., 1992) have suggested that when ISSs do not mimic the natural channel material, the ISSs may inappropriately alter fluvial processes and channel form. For example, in low-gradient streams with grass and sedge vegetation (meadow systems), large diameter (> 0.5 m), channel-spanning ponderosa pine logs are not present unless placed by human action. Similarly, where stream bed and bank material is cobble size or smaller, large boulders (> 0.5 m) that are human-placed affect channel hydraulics differently than cobble, gravel, sand or silt bed and banks. Boulders placed in these streams may initiate hydraulic action that causes increased scouring of the bed and banks and contribute to channel widening. When ISSs cause further channel degradation or limit channel recovery from disturbance, they may not be appropriate for enhancing channel habitat.

ISS Design and Construction

The general design of the ISSs included in this study was typically a log or boulder weir with a plunge pool downstream (Figures 4 and 5). The plunge pool was usually excavated using a backhoe with the expectation that hydraulic action from stream flow would maintain, and possibly increase pool depth (Calame, 1997). There were four basic types of ISSs for creating pools used in streams in the study area. These included the log-boulder (LB), multiple-boulder (B), multiple-log (ML) and single-log (SL) ISS types as well as variations of these basic types (Figure 3, chapter I).

ISSs were constructed by first placing a log or a number of boulders across the width of the channel as a weir. In ISSs with a log-weir, the log was anchored into the banks. In

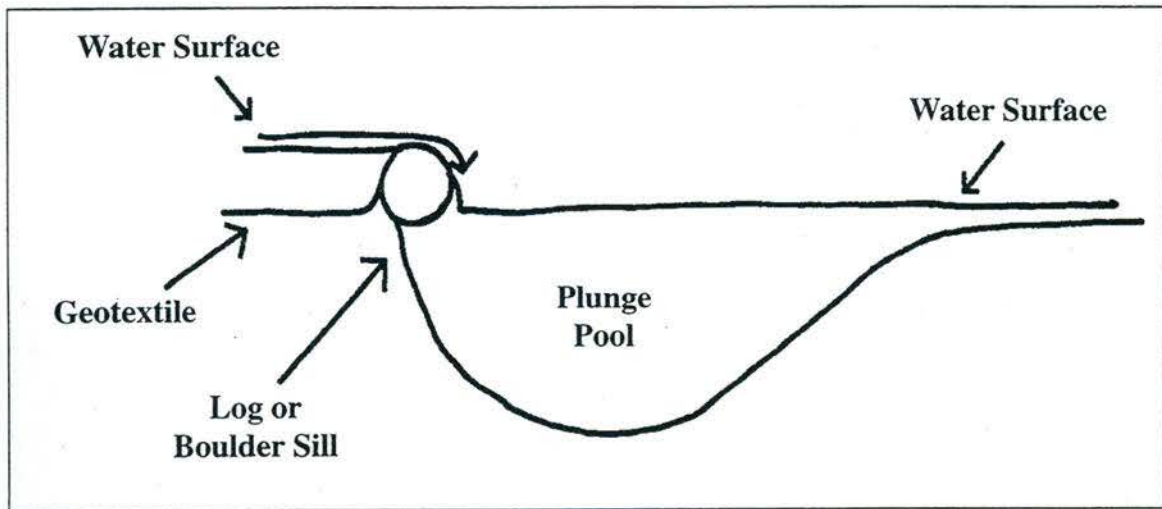


Figure 4. ISS Cross-section.

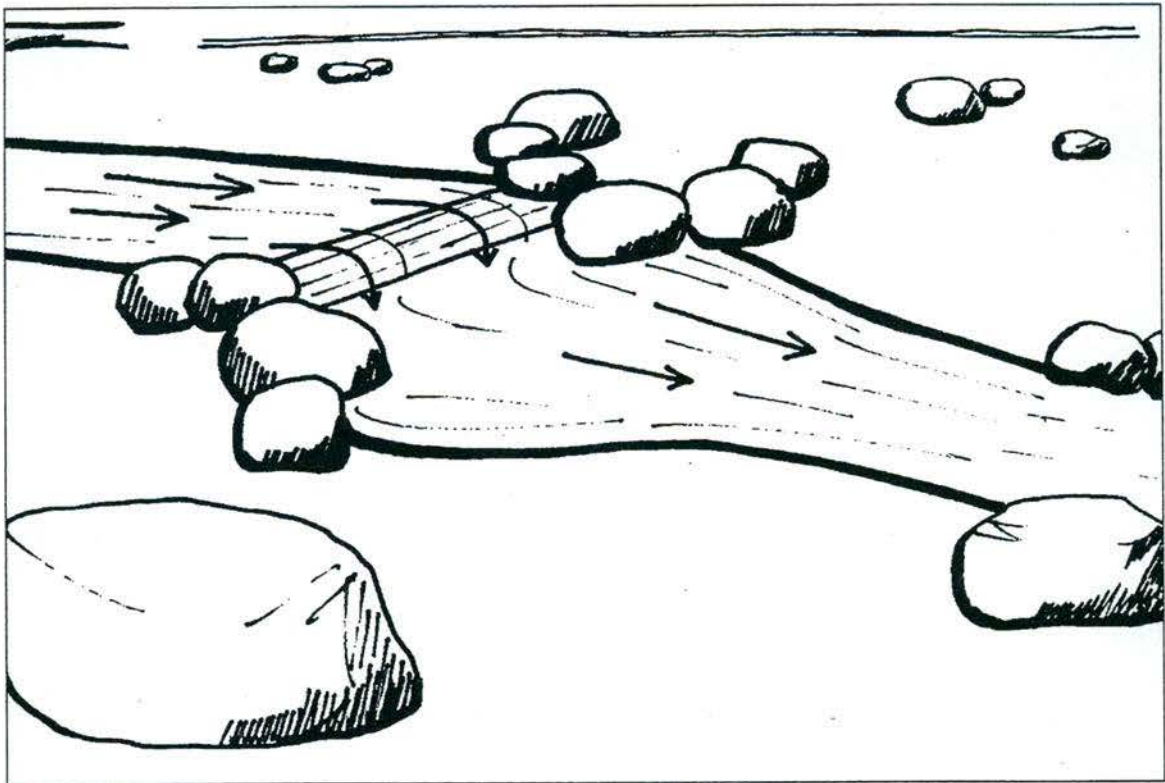


Figure 5. ISS Perspective.

the log-boulder ISSs, large boulders (0.75 - 1.25 m in diameter) were placed on and near the bank to anchor the ends of the log. Additional boulders were placed upstream and downstream along the bank to protect the bank from erosion. The number of boulders along the banks varied from as few as one or two per side up to a dozen or more. In the multiple-log ISSs, additional logs were placed along the bank to provide some protection from bank erosion.

In multiple-boulder ISSs, one to several large boulders formed the weir and large boulders flanked these along the bank. A geotextile was sometimes placed along the banks lateral to the boulders and covered with soil to stabilize the banks. This was intended to minimize bank erosion until vegetation became established on the disturbed site.

Single-log ISSs were simply anchored into the bank. Some single-log ISSs were further held in place by large berms constructed on the banks. The berms appeared to be constructed of cobble, gravel and soil. Geotextile material or fine wire mesh was sometimes laid on top of the berm and covered with soil to stabilize the surface and resist erosion. A geotextile covering was usually placed on the upstream side of the logs in both single-log and multiple-log ISSs. This geotextile extended upstream onto the channel bed to prevent fluvial erosion under the log and to intercept sediment (Figure 4). The intercepted sediment filled the space upstream of the log between the channel bed and the bottom surface of the log-weir. Pools were excavated downstream of the weir to create sufficient depth (Northrup, 1991; Calame, 1997).

The top of the log and boulder weirs were established at a height just below the low-flow water level. Water flowing over the weir plunges into the pool below and maintains the pool through hydraulic action (Figure 4). In many log-boulder, multiple-log and multiple-boulder ISSs, tree trunks with attached rootwads were anchored into the bank with the root wad projecting into the pool to create in-stream cover for fish. Boulders were sometimes placed in the pools to provide additional cover (Northrup, 1991).

Most log-boulder and multiple-boulder ISSs constructed since 1989 were cabled together with half-inch steel cable. The cabling was intended to hold the ISSs in place and prevent further damage or displacement of logs and boulders (Northrup and Sanchez, 1990; Northrup, 1991; Northrup, 1992). Holes were drilled into the logs and boulders where the cable was inserted and secured with epoxy resin. In Thomas Creek, ISSs were constructed without cabling during 1986, 1987 and 1988. These ISSs were damaged by high spring flows in 1988 and 1989 (Northrup and Sanchez, 1990; Northrup, 1991; 1992). This type of damage very likely occurred in other streams at ISSs built before 1989 in other streams. In 1989 and 1990, the ISSs in Thomas Creek were repaired and new ISSs were built. Both the repaired and new ISSs were cabled together and secured with epoxy.

Fish Response to ISSs

Many studies have been done to evaluate fish response to the presence of ISSs. Most studies have reported positive effects on fish population numbers and spawning activities, although this is not always the case. House and Boehne (1986) observed significantly higher numbers of coho salmon (*Oncorhynchus kisutch*) in streams in an older-growth section of Tobe Creek in western Oregon than in an adjacent young-alder section that had been logged and cleared of large wood. They concluded that if ISSs were installed to increase scouring action and pool formation in the young-alder stream section, the amount of coho habitat would increase and provide benefits to coho populations. The installed gabion ISSs in the young alder stream section resulted in increased pool habitat and available spawning gravels. Following gabion installation, the coho were more evenly distributed between the older-growth and young-alder sections (House and Boehne, 1986).

House and others (1991) reported higher spawning densities for coho salmon in coastal Oregon streams in the upper Nestucca watershed after ISSs were added. The ISSs used in this rehabilitation project included several types of channel-spanning ISSs as well as ISSs

that partially spanned the channel. All ISSs were made of logs, boulders and rootwads. The logs were cabled to boulders or bedrock with steel cable inserted into drilled holes and secured with polyester adhesive resin (House et al., 1991).

In Elk Creek in western Oregon, adult coho spawning activity increased by a factor of four after the installation of channel-spanning habitat ISSs, even though coho spawning activity in other streams near Elk Creek did not increase during the same time period (Crispin et al., 1993). Some ISSs that have been constructed for purposes other than for the creation of fish habitat have been found to be beneficial to fish populations. In some eastern Oregon streams, log ISSs intended to reduce channel gradient and improve fish passage through culverts also caused gravel deposition upstream from the log and pool creation downstream (Reeves et al., 1987a). At these sites, salmon spawned in the gravel, and the pools held up to five times more fish than adjacent, non-structure pools.

Results of a study by Hamilton (1984) in Nooning Creek in the Mattole River basin in northern California showed that the number of steelhead decreased after the installation of in-stream deflectors. He suggested that studies showing negative effects of ISSs on fish populations and activity are not widely reported in the literature but should be in order to increase awareness and add to the understanding of the range of results of habitat manipulation (Hamilton, 1989).

ISS Impacts on Channel Morphology

Some researchers have suggested that human-made alterations to stream channels and constructed ISSs can initiate adjustment processes and change channel morphology (Heede, 1986; Heede and Rinne, 1990; Osborne et al., 1993). These changes may contribute to increased erosion, sediment deposition, channel widening or changes in channel planform, changing the physical characteristics in stream channels and the habitat for fish. Rigid ISSs, firmly anchored together and to the banks, may lock the channel into place and limit

potential channel adjustment in response to changes in discharge and sediment supply (Beschta and Platts, 1986; Beschta et al., 1996). ISSs may also initiate localized channel adjustment and cause permanent changes in channel morphology. Physical indicators of channel adjustment include bank erosion, exposure of fresh materials in the lower bank, silt deposition on riffles, erosion immediately downstream from or lateral to ISSs, channel enlargement (Downs and Gregory, 1993), increased lateral migration, and bank aggradation (Magilligan and McDowell, 1997). Other indicators of channel adjustment include changes in channel location, and channel widening where the channel migrates laterally around an ISS, increasing active channel width (Beschta, 1993).

Many studies that evaluated the effect of ISSs on channel morphology have been limited to a few characteristics that are specifically related to fish habitat, such as changes in the number of pools, channel and pool volume, pool depth, and habitat unit types. House and Boehne (1986) found that ISSs placed in a young alder stream section increased pool habitat and slowed water velocities in shallow riffle areas which led to increased deposition of spawning gravel. They suggested that gabion ISSs can create channel habitat similar to that found in a stream section largely influenced by the presence of large wood in the channel (House and Boehne, 1986). Results from a study by House and others (1991) in the Upper Nestucca watershed in coastal Oregon showed that channels became wider and deeper where channel-spanning ISSs were installed. In the channels studied, wetted surface area and channel volume increased, and the amount of pool area increased due to the conversion of riffle and glide areas to dammed pools. Large amounts of gravel and finer material were deposited just behind, and for a distance upstream of channel-spanning ISSs, increasing potential spawning gravel (House et al., 1991). Crispin and others (1993) also reported increased surface area, water volume and pool habitat area, and a conversion of glide and riffle area to pool area. Gore and Hamilton (1996) found that channel-spanning log ISSs created greater water depths and increased total available habitat volume under low-

flow conditions, and increased shelter during high flow. Some researchers have also reported increased deposition and accumulation of large wood behind ISSs (House et al., 1991), especially when the ISSs are located in riparian areas with mature conifers (Crispin et al., 1993).

It is important to critically evaluate such changes in channel morphology to determine whether bank erosion and channel widening are a positive benefit to the stream system, or if channel widening is an indicator of channel instability and further channel degradation. Beschta and others (1991; 1996) have suggested that ISSs limit the long-term recovery of degraded streams. In several recent studies, researchers have evaluated the effects of ISSs on other channel morphological features, or have identified some channel changes that may have adverse impacts on channel recovery from degradation (Beschta et al, 1991; Frissell and Nawa, 1992). Wesche (1987) noted undercutting and end cutting (erosion) as possible causes of ISS failure.

During a field review of sixteen habitat improvement projects located in the Grande Ronde and John Day River basins of northeast Oregon, Beschta and others (1991) noted problems associated with ISSs. All of the projects they evaluated were in unconstrained reaches (valley width at least twice as wide as channel width) with moderate sinuosity, low gradient (less than 2%), and predominately meadow vegetation (grasses and sedges). These streams are typically highly productive for fisheries. In the streams that they observed, ISSs often caused stream reaches to be wider and shallower (Beschta et al., 1991) than reaches without ISSs. In Camp Creek, the channel was widest and shallowest where log-weirs were placed, but deeper and narrower in a section without ISSs. In addition, pools had not formed below the ISS. The ISSs focused stream energy at a specific bank location, increased the rate of bank scour and erosion, and were the probable cause of wide channel widths. They concluded that sinuosity had decreased in these reaches because of the ISSs (Beschta et al., 1991). They suggested that the interactions of the ISSs with the

channel were dramatically different from natural wood inputs because the log-steps created by ISSs were out of geomorphic context (Beschta et al., 1991; Beschta et al., 1996). First, the log-steps were much less complex than natural wood input would be, if wood were available. Trees that fall into streams are structurally more complex than the logs used in ISSs because of the branches and roots wads that remain attached. They provide more complex habitat and hydraulic patterns. Second, unless log-steps are added by human action, large wood would typically not be found in the stream reaches that they observed, and thus are out of both ecological and geomorphic context. Third, log-step ISSs altered natural fluvial processes, locked the streams into place, and prevented natural channel lateral migration and adjustment (Beschta, 1991). Fourth, Beschta and others (1991) noted increased reach gradient due to the vertical drop created by the placed log-weirs. In effect, they suggested that ISSs shifted the geomorphic potential in these unconstrained reaches to that of streams in a constrained, high gradient environment (Beschta et al., 1991; Beschta et al., 1996). Other researchers have observed high rates of ISS failure resulting from hydrologic and channel dynamics (Frissell and Nawa, 1992). These studies suggest that when streams are locked into place and channel adjustment through lateral migration is limited, stream energy is focused and then dissipated at ISS locations rather than through lateral migration.

Several studies have noted changes in sediment deposition associated with ISSs. Beschta and others (1991) noted increased sediment deposition upstream from ISSs and concluded that this was a negative impact. This contrasts with the observations of House and others (1991) and Reeves and others (1987a) who suggested that deposition upstream from ISSs provided additional spawning habitat and had a beneficial effect.

The processes and materials used in ISS construction may impact habitat conditions. Beschta and others (1991) and Frissell and Nawa (1992) observed loose wire and cable, and

found pieces of geotextile and epoxy particles in the stream, and warned that this may have detrimental effects on aquatic fauna.

Watershed and Channel Impacts on ISSs

Several studies have identified watershed and channel factors that influence changes in channel morphology associated with ISSs. Frissell and Nawa (1992) conducted a study to evaluate ISSs in 15 streams in southwestern Oregon and southwestern Washington following floods with recurrence intervals of 3 to 7 years. In their evaluation, they considered a variety of factors, including drainage area, channel slope, active channel width and depth, valley segment type (alluvial, alluvial fan influenced, terrace bound, alluviated canyon, and incised, U-shaped with high gradient), ISS type, land use, and hydrologic regime. These factors were used as control variables in evaluating specific types of damage, which they concluded were caused by ISSs. Drainage areas of the reaches were less than 65 km² except in one reach where drainage area was 632 km². In some cases bank erosion and bed-load deposition appeared to be a direct consequence of hydraulic conditions created by ISSs. Log-weirs caused the greatest changes in channel morphology and hydraulics. In particular, there was bank erosion at the ends of the log-weirs and along the banks adjacent to ISSs. Bed-load deposition of sand and silt associated with ISSs caused natural pools to become shallower. In some cases, active landslides, road failures, and precipitation effects contributed to increased bank erosion and bed-load deposition (Frissell and Nawa, 1992).

Frissell and Nawa (1992) also observed that the impacts on ISSs varied with differing hydrological and sedimentological regimes. Southwestern Oregon has intense winter precipitation, flashy stream flow and very high sediment yields. Greater sediment yield and channel instability occurred in southwestern Oregon where winter precipitation is more intense and peak discharges are higher than in southwestern Washington. Bed load deposition and stream bank erosion was the most common types of damage in wide, low

gradient alluvial valley and alluvial fan-influenced segments, especially in southwestern Oregon. ISSs were buried and channels shifted laterally due to high rates of bedload transport and deposition. In southwestern Washington, high peak flows are a result of winter rain-on-snow events rather than from intense precipitation, and sediment yields are moderate. Erosion and deposition was less common in the Washington streams than in the Oregon streams, although some ISSs were buried in the Washington streams.

ISS Survival after Floods

Several recent studies have assessed ISS survival after floods of both small and large magnitudes (Frissell and Nawa, 1992; Fitzgerald, 1997; Roper et al., 1998).

Frissell and Nawa (1992) divided ISS impairment into three categories: failed, impaired, and successful. Failed ISSs were either gone, fragmented or grossly dislocated. Impaired ISSs were in place but were not functioning. Successful ISSs were not damaged and were functioning. ISS types included lateral log deflectors, cross-stream log-weirs, multiple log-weirs, cabled natural-like debris jams, and single and clustered boulders. A number of watershed and channel control variables were considered in evaluating ISS failure. Failure rates were higher in southwestern Oregon where winter precipitation is intense and there are high peak discharges. These streams were constrained, which increased the effect of scouring due to high-energy water flows. The high energy flows in constrained channels contributed to ISS failure because of the breakage of anchoring devices. Frissell and Nawa (1992) found that failure rates were higher in wide stream, and they suggested that this may be because wider streams had more erodible bank material, and that this would contribute to ISS failure. Frissell and Nawa (1992) also evaluated ISS failure by ISS type and concluded that log-weir ISSs had the highest failure rates. ISSs that failed the least were those that modified the channel the least, such as lateral log deflectors and single or clustered boulders. They did not find a relationship between ISS failure and channel gradient or

drainage area. However, the range in gradient and drainage area in the study reaches was small. Few streams with gradient greater than 2% or drainage area greater than 65 km² were included in the study. In southwestern Washington, ISSs in streams with the lowest gradients failed because they were buried (Frissell and Nawa, 1992). They also found that watershed influences and land uses had an impact on ISS failure. Failure rates were the highest in watersheds with many roads or that were affected by logging and associated landslides (Frissell and Nawa, 1992).

After the floods of 1995, 1996 and 1997, personnel in Region 6 of the Forest Service (Pacific Northwest Region) (Washington, Idaho, Oregon) implemented an extensive flood assessment project. Forest Service personnel collected data on the durability (survival) and performance of 3,946 ISSs in 94 streams where flood return intervals exceeded 5 years. The majority of streams experienced floods with return intervals greater than 20 years, and many streams experienced floods with greater than a 100 year return interval. The results of this study showed that flood magnitude had a significant effect on ISS survival (Roper et al., 1998). Overall, 80% of ISSs either remained in place or shifted on site (ISSs that shifted but remained at the original site). ISS survival was examined in relation to flood magnitude, stream size, ISS gradient, ISS position and ISS anchor. In streams where flood return intervals were less than 65 years, 65% of ISSs remained in place, but where flood recurrence intervals were larger, only 47% remained in place. ISS survival rates also varied by stream size. In small streams (1st order), 89% remained in place while only 15% remained in place in large streams (> 6th order) (Roper et al., 1998). Local ISS gradient also had an effect on ISS survival. When local ISS gradient was 2% to 4% (medium gradient), ISSs were more likely to stay in place than ISSs where local ISS gradient was either less than 2% (low gradient) or greater than 4% (high gradient). ISS position in the channel also had an effect on ISS survival. ISSs connected to the channel margin, either on the channel edge or spanning the channel, were more likely to remain in place or to shift on site than

ISSs that were not connected to the channel edge. ISSs that were either attached to the bank or cabled in place were also more likely to remain in place or to shift on site (Roper et al., 1998). Landslide frequency was another factor that affected ISS survival. ISSs survived more often in drainage basins with low upland landslide frequencies than in basins with high upland landslide frequencies.

Data on ISSs in the Umatilla NF were included in the region-wide analysis (Roper et al., 1998). However, when the survival of ISSs only in the Umatilla NF was evaluated, the results differed (Fitzgerald, 1997). Roper and others (1998) concluded that ISSs will have the greatest chance of surviving in small streams (low order). Results from streams only within the Umatilla NF indicated that ISSs survived more often in larger streams (higher order) (Fitzgerald, 1997). However none of the streams in the Umatilla NF were 1st, 2nd or 3rd order. In addition, results showed that ISS survival rates varied significantly among different streams regardless of stream size and stream order. In four stream reaches where there was more than one flood with greater than 100 year return interval, 50% of the ISSs survived (Fitzgerald, 1997). Two other reaches had a single flood event with a return interval of 100 years but only 26% of the ISSs survived. In one of these two reaches, ISSs were not anchored. In the other reach, channel stability was low, and bank erosion was extreme (Fitzgerald, 1997). These findings suggest that additional factors affect ISS survival, and as a result, additional factors such as channel gradient, geology, bed and bank material and drainage area are included in the study presented in this thesis.

Summary

Analyses of stream habitat enhancement projects using ISSs are presented in the following chapters. The ISSs in the study reaches were designed to create pool habitat, to imitate naturally occurring channel structure and habitat, and to improve habitat for fish in the region. Some studies discussed in this chapter have shown that ISSs have resulted in

increases in the number of pools, pool depth, pool volume and the number of habitat units. Other studies have suggested that ISSs have contributed to channel instability through increased erosion, sediment deposition, channel widening or changes in channel planform, and that ISSs may have negative impacts on channel habitat and have contributed to channel degradation. Several studies examined the watershed and channel variables, such as drainage area, flood occurrence and channel gradient, that were associated with specific ISS responses. The analyses presented in this thesis will consider a greater number of channel characteristics than any of the studies of ISSs that have been done to date, and will provide quantitative assessments of channel response to ISSs that previously have been only descriptive or qualitative observations. These analyses will add to our knowledge and will provide quantitative assessments of stream behavior in response to the presence of ISSs.

CHAPTER III

STUDY AREA

This study was focused on in-stream structure (ISS) projects in streams in the Umatilla National Forest (NF) (Figure 2, chapter I), a 1.5 million acre forest in the Blue Mountain physiographic province of northeastern Oregon and southeastern Washington (Franklin and Dyrness, 1973; USDA Forest Service, 1987). There are over 1,000 in-stream structures (ISSs) in over 25 streams in the Umatilla NF (USDA Forest Service, unpublished data). The streams are located in a range of physiographic settings, thus providing the potential for a stratified sample of streams with characteristics representing a range of variables that influence ISS effectiveness, channel morphology, ISS survival and ISS performance.

Geology

The Blue Mountains province includes several mountain ranges that are separated by faulted valleys and synclinal basins (Franklin and Dyrness, 1973). These ranges include the Strawberry, Ochoco, Aldrich, Elkhorn, Greenhorn, Wallowa and Blue Mountains (Orr et al., 1992). Elevations in the Blue Mountains increase from west to east, ranging from 750 meters (2440 ft) to 2,100 meters (6,800 ft) in the Ochocos in the west up to 2,900 meters (9,400 ft) in the Wallowa Mountains in the northeast (Orr et al., 1992). As a management unit, the Blue Mountains are considered to include all of the above named ranges except for the Ochoco Mountains (Brookes, 1996).

The Blue Mountains have ancient origins. The volcanic rocks of the Blue Mountains are underlain by oceanic crust and accreted terranes (Mullen and Sarewitz, 1983; Walker and Robinson, 1990). Present day Oregon and portions of Washington were covered by

ocean waters until exotic terranes were first accreted to the shoreline of the North American coast (in what is now Eastern Washington and Idaho) in the early Mesozoic era, 200 to 250 million years ago (mya) (Orr et al., 1990; Walker and Robinson, 1990). Additional accreted exotic terranes from the Pacific Ocean collided with the continental plate. These, along with uplift, faulting, metamorphism, intrusion and volcanic activity continued through the Mesozoic era (67 to 250 mya) and formed the Blue Mountains coastal ranges (Hooper and Swanson, 1990; Orr et al., 1992). The four major terranes have been called the Wallowa, Baker, Izee and Olds Ferry terranes, although they have also been identified by other names (Mullen and Sarewitz, 1983; Blome et al., 1986; Walker and Robinson, 1990). Faulting in the terranes was sometimes caused by southward movement and at other times by northward movement, resulting in a complex, dissected landscape. The crust continued to be folded and uplifted, and the shoreline moved westward during the late Mesozoic era (the Cretaceous period, 67 to 140 mya), when mud, silt and sand were deposited in a shallow sea that covered much of the land east of the day Blue Mountains (Orr et al., 1992). The Blue Mountains are separated from the High Lava Plains to the south by the Brothers fault zone. Basaltic and rhyolitic vents of the late Miocene through Pleistocene age are abundant near the fault zone (Walker and Robinson, 1990).

Volcanic and sedimentary activity were common throughout the Cenozoic era (Paleocene through Pliocene periods, 2 to 67 mya) (Hooper and Swanson, 1990; Walker, 1990a; Walker and Robinson, 1990; Orr et al., 1992). Lava flowed from vents and fissures and covered much of the landscape. The composition of lava flows varied both spatially and temporally throughout the period (Walker and Robinson, 1990). The volcanism beginning around 50 mya during the Eocene period (38 to 55 mya) occurred near the Blue Mountains uplift south of Heppner, Oregon leaving the Clarno Formation. The magma forming the Clarno formation was from subducting ocean lithosphere (Walker and Robinson, 1990). Stream deposition and erosion of sediments in local basins also occurred during this time

resulting in sedimentary facies within the Clarno Formation (Orr et al., 1992). Volcanic activity during the Oligocene period (25 to 38 mya) and the early Miocene period (5 to 25 mya) resulted in lava flows from fissures in the Blue Mountains which covered much of the land in central and northeastern Oregon (Goles, 1986; Orr et al., 1992). Much of this is the John Day formation, which formed from about 37 mya to 18 mya (Robinson et al., 1990; Walker and Robinson, 1990). Another period of volcanism ensued during the Miocene period (Walker and Robinson, 1990). Most rocks from these flows are part of the Columbia River Basalt group and erupted between about 17.5 and 6 mya (Hooper and Swanson, 1990). In the Blue Mountains province these include the Imnaha, Grande Ronde and Wanapum Basalts in the northeastern region, and the Picture Gorge Basalts in the John Day River Basin and the basalts of Prineville in the southern region (Hooper and Swanson, 1990; Walker and Robinson, 1990). Other flows that are not included in the Columbia River Basalt group occurred along the margins of the Blue Mountains (Walker, 1990b). Deformation and deposition have continued during the Pliocene (2 to 5 mya) and the Pleistocene (beginning 2 mya) up to the present (Spencer and Carson, 1995)

Periods of glaciation occurred during the Pleistocene, and alpine glaciers formed in the Blue Mountains in higher elevations in the Wallowa, Elkhorn and Strawberry Mountains many times (Kiver, 1974; Burke and Birkeland, 1983; Bevis, 1995). Alpine glaciers retreated significantly by 13,000 years ago (Bevis, 1995). In the Strawberry mountains and the Wallawas, evidence points to a brief re-advance of alpine glaciers shortly after the eruption of Mt. Mazama around 6,000 years ago (Kiver, 1974; Bevis, 1995).

Watersheds

The Grande Ronde, Imnaha, Wallowa and John Day rivers are the largest rivers that drain the Blue Mountains (Orr et al., 1992). Other significant rivers include the Umatilla, and Tucannon. Reaches in this study are in tributaries of the Tucannon, Umatilla, Grande Ronde, North Fork John Day and John Day Rivers (Figure 6).

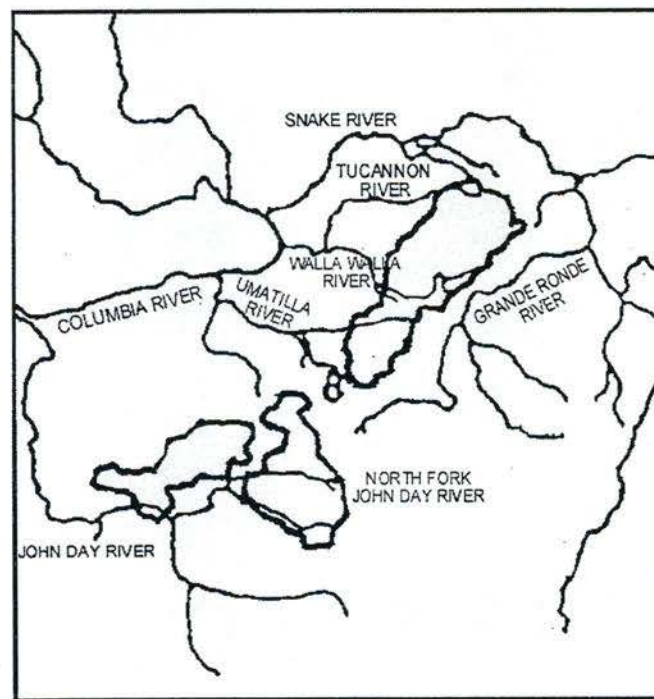


Figure 6. Major rivers in the Columbia River Basin. Shaded areas represent the Umatilla National Forest.

A significant amount of streamflow in this region is generated by run-off from snowmelt in spring and early summer, and is sustained into the summer. Water temperatures tend to be cool year-round (USDA Forest Service and USDI Bureau of Land Management, 1994).

Climate

The present day climate regime in the Blue Mountains is characterized by wet, cool winters and warm, dry summers (Figures 7 and 8). The climate regime also shows local variation between the northern and southern portions of the Blue Mountains (Crowe and Clausnitzer, 1997). A discussion of climate is relevant to this study because climate, over both long and short time intervals, is important in controlling hydrologic regimes, which in turn affect the amount of water available for stream flow. Ultimately, climate can affect channel morphology because of its control over water availability and flow magnitudes. In addition, climate has been important in influencing the geographic distribution, evolution and adaptation of species and populations of salmon to local and regional environments.

Present day climate in the Pacific Northwest is influenced by Pacific air masses which move over the continent, moderate temperatures, and provide moisture to coastal and inland regions (Heusser, 1983). The seasonal strength and position of atmospheric cells of the western North America and North Pacific (the North Pacific High, the Aleutian Low and the North American Low) generate weather and climate of western North America (Gardner et al., 1997). The low pressure cells follow the westerlies and bring precipitation inland (Thompson, 1988). These pressure systems change positions throughout the year and generate the seasonal moisture pattern of wet winters and dry summers in the Pacific Northwest. In winter, the Aleutian low pressure system is a strong control of circulation over the North Pacific and generates storms that move inland and across Washington and Oregon. In summer, the North Pacific high-pressure cell replaces the Aleutian low resulting in less frequent storms and precipitation in the summer (Heusser, 1983). The windward side of the Coast, Olympic, and Cascade Mountains ranges in western Washington and Oregon receive more moisture than the leeward side of these ranges as the dominant westerly winds blow storm systems into and over the mountains (Huesser,

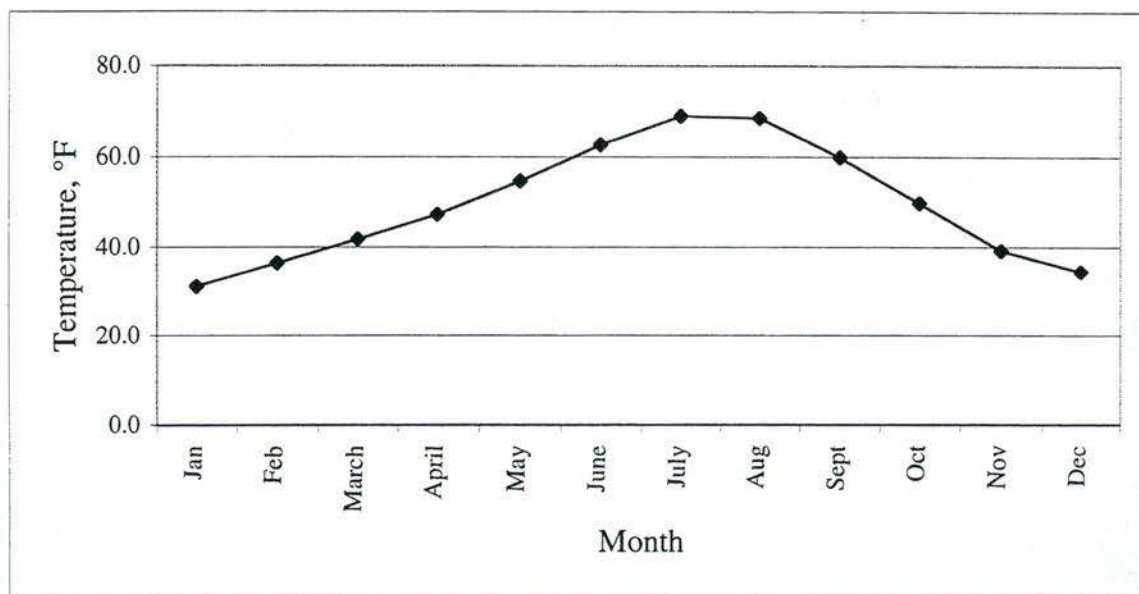


Figure 8. Average Temperature for Elgin, La Grande, Heppner, Mitchell and Pendleton, Oregon (Oregon Climate Service, 2000), and Pomeroy and Pleasant View, Washington (Washington Climate Information, 2000).

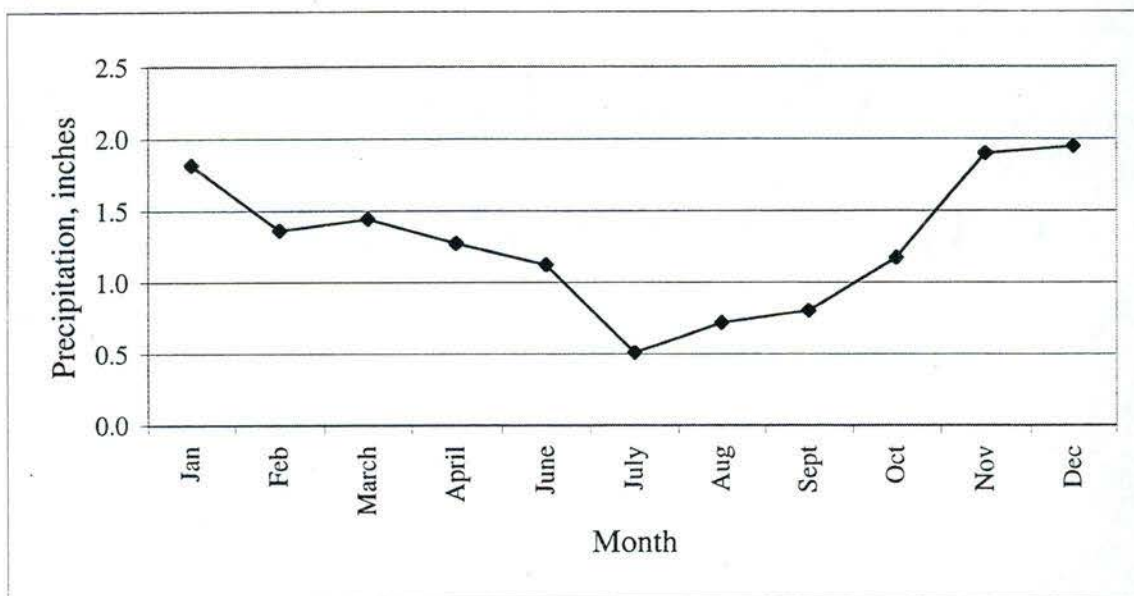


Figure 7. Average Precipitation for Elgin, La Grande, Heppner, Mitchell and Pendleton, Oregon (Oregon Climate Service, 2000), and Pomeroy and Pleasant View, Washington (Washington Climate Information, 2000).

1983). The eastern side of the Cascades, including the study area, is drier than the western side, and the decline in precipitation and effective moisture produces a shift in vegetation from wetter to drier types (Barnosky, 1987).

Significant differences in climate exist between the northern and southern Blue Mountains (Crowe and Clausnitzer, 1997). The division between these two regions coincides roughly with a major climatic boundary, that of the Pacific air masses. This boundary occurs between Lat. 40° and 44° in winter and shifts northward in the summer. This boundary is the northern range limit of many western plant species (Barnosky et al., 1987). In addition, many maritime species are able to grow east of their coastal range along the southern boundary of these air masses in summer as moist ocean-influenced air penetrates further into the interior up the Columbia River Gorge (Barnosky et al., 1987).

The climate of the northern portion of the Blue Mountains is strongly influenced by marine air and has more cloudy days, higher relative humidity, and less fluctuation in winter temperatures than the southern region (Crowe and Clausnitzer, 1997). Precipitation is predominantly from snow in winter and from rain in spring and fall (McNab and Avers, 1994). Run-off events in winter are dominated by rain-on-snow events, at other times by frequent convective storms, and by infrequent spring snowmelt events (Clifton, 1997) which result in localized, intense precipitation (USDA Forest Service, 1996). The moist, marine air influences the climate in the uplands north and west of the Grande Ronde River Flows of moist, marine air and summer convection storms build up against the west side of the Wallowa Mountains and provide cool, humid air and high precipitation. Annual precipitation ranges from 20 to 40 inches (50 to 100 cm). Mean annual air temperature ranges from 36° to 45° F (2° to 7° C) (McNab and Avers, 1994).

A more temperate, continental-type climate dominates the southern portion of the Blue Mountains with fewer cloudy days, less precipitation, lower relative humidity, rapid evapotranspiration and wider temperature fluctuations than the northern portion (Crowe and

Clausnitzer, 1997). The continental climate regime in the southern Blue Mountains is characterized by low precipitation, high evapotranspiration, abundant sunshine and temperature extremes. Run-off events occur predominantly during spring and summer. Spring snowmelt events dominate the runoff pattern, especially above 4,000 feet (1,200 m) elevation. Summer convective storms generate significant precipitation and run-off events (Clifton, 1997). Near the town of John Day, the mean annual precipitation ranges from 14 inches (35 cm) in the lower elevations at the western edge in the rainshadow of the Cascades to 30 inches (75 cm) north of the Elkhorn highlands. Mean annual air temperature ranges from 28° to 52° F (-2° to 11° C) (McNab and Avers, 1994).

Vegetation

The variability in climate regimes at sub-regional and local scales in the Blue Mountains has considerable influence on ecosystem processes and vegetation. Temperature and precipitation influence potential vegetation type to a great extent (Figure 9). The variety of climate conditions has allowed for numerous types of ecological communities to become established, including mesic and xeric forests, grassy meadows, and wet meadows. Vegetation composition, fire regimes and disturbance processes vary across the landscape with climate conditions, and at various elevations and site specific locations (Table 2). A discussion of vegetation is relevant to this study because stream environments are affected by conditions within a particular ecological community. Streams in this study were located within both forest and meadow communities. These vegetation communities offer site specific limitations on certain geomorphic and ecosystem processes, such as the availability of large wood to the channels, or the amount of bank stabilization due to the root strength of plants along the bank. Since this study uses target values for several vegetation characteristics to evaluate effectiveness, it is possible that ecological conditions may limit some streams in meeting specific target values.

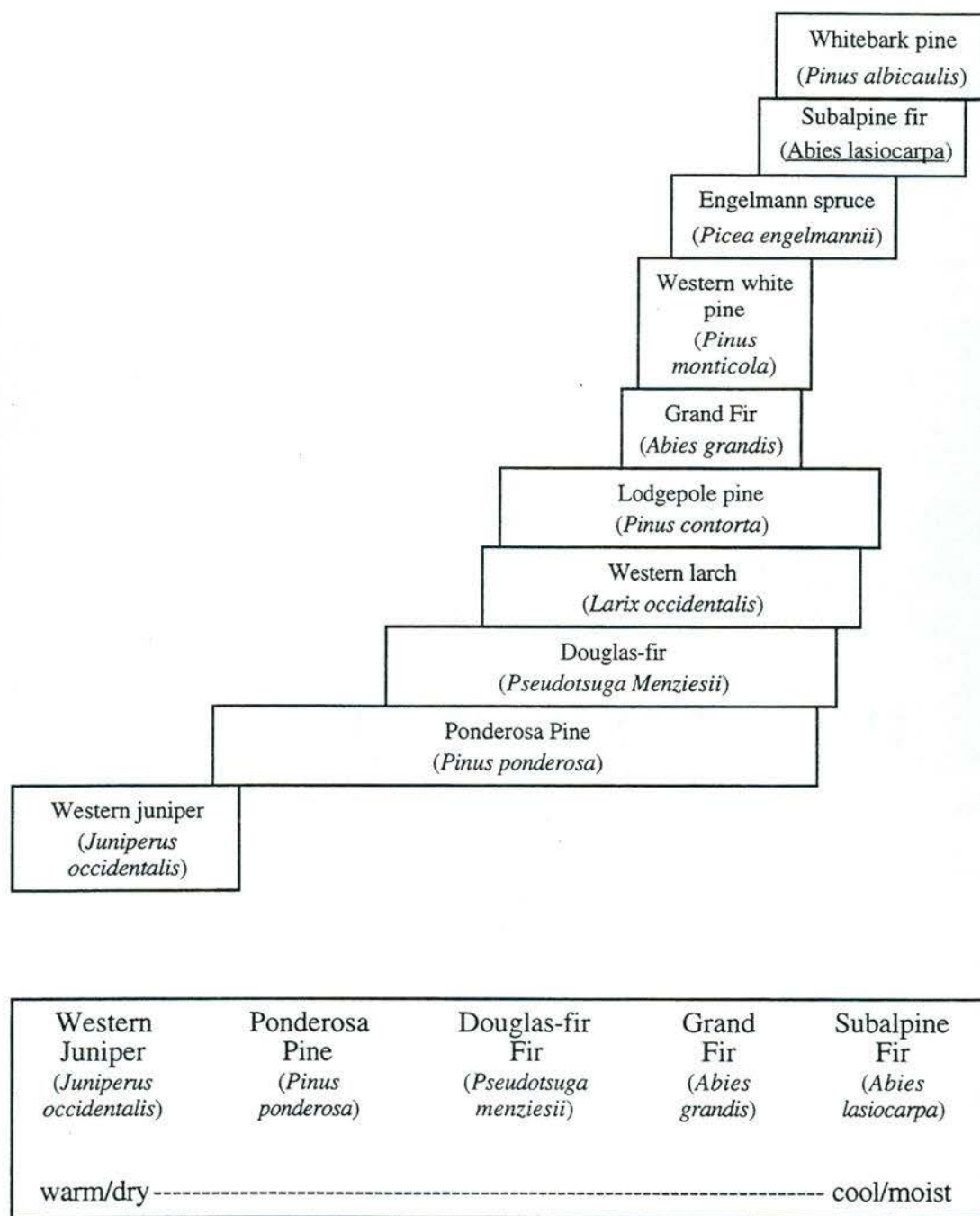


Figure 9. Potential Vegetation Types of the Blue Mountains (after Heyerdahl, 1997; Agee, 1994; Johnson and Clausnitzer, 1992; Johnson and Simon, 1987).

TABLE 2. Characteristics for Ecological Settings in the Blue Mountains
(USDA Forest Service 1996; Agee, 1993; Heyerdahl, 1997)

Ecological Setting	Tree Species	Disturbance Agents	Fire Interval	Fire Mortality	Patch Sizes	Primary landform	Elevation Zone	Typical Aspect
CD Cold, Dry	Subalpine Fir Englemann Spruce Lodgepole Pine	Wind Insects Fire Diseases	> 100 years	> 70% of large trees	5 - 1,000 acres	Gentle Tablelands	High > 5800'	North East Flat
CM Cool, Moist	Grand Fir White Pine Western Larch Lodgepole Pine Mixed	Wind Fire Insects Diseases	26 - 100 years	20 - 70% of large trees	300 - 10,000 acres	Dissected Sideslopes	Moderate 4800 - 5800'	North East West
WD Warm, Dry	Ponderosa Pine Douglas-fir Grand Fir	Fire Insects Diseases	1 - 25 years	0 - 20% of large trees	150 - 2,000 acres	Dissected Sideslopes	Low < 4800'	South West
PP Ponderosa Pine	Ponderosa Pine Douglas-fir	Fire Insects Diseases	1 - 25 years	0 - 20% of large trees	10 - 200 acres	Dissected Sideslopes	Low < 4500'	South East
LP Lodgepole Pine	Lodgepole Pine	Insects Fire Diseases	> 100 years	> 70% of large trees	40 - 1,000 acres	Gentle Tablelands	Moderate > 5000'	East North Flat

There are four major forest zones in the Blue Mountains region, Western Juniper (*Juniperus occidentalis*), Ponderosa Pine (*Pinus ponderosa*), Grand Fir (*Abies grandis*) and Subalpine Fir (*Abies lasiocarpa*). Isolated stands of predominantly Ponderosa Pine and of predominantly Lodgepole Pine (*Pinus contorta*) also occur. The Western Juniper zone is not typically found in the Umatilla NF (Franklin and Dyrness, 1973).

The Ponderosa Pine (*Pinus ponderosa*) zone is typically found in lower elevations, from 900 to 1,500 m (2,900 to 4,900 ft), in dry sites and is often associated with coarse, sandy soils rather than with fine, clayey soils. Much of the annual precipitation falls as snow and accumulates in the Ponderosa Pine region. Summer precipitation is minimal and often comes in high-intensity convective storms. Daily temperatures vary widely. Ponderosa Pine (*Pinus ponderosa*) occur with Douglas-fir (*Pseudotsuga menziesii*) and Grand Fir (*Abies grandis*) in higher elevations, or with only Douglas-fir in lower elevations (Franklin and Dyrness, 1973; USDA Forest Service, 1996). There is abundant evidence that fire has been important in the past in maintaining populations of Ponderosa Pine which are more fire resistant than Douglas-fir or Grand Fir. Management policies prescribing fire suppression over the last century have resulted in Ponderosa Pine being replaced by other tree species (Franklin and Dyrness, 1973; Agee, 1993). Riparian vegetation in the Ponderosa Pine zone includes willow (*Salix* spp.), sedge (*Carex* spp.) and shrubby cinquefoil (*Potentilla* spp.) associations (Crowe and Clausnitzer, 1997).

The Grand Fir (*Abies grandis*) zone occurs between 4,800 and 5,800 feet (1,500 and 2,000 meters) in the Blue Mountains (Franklin and Dyrness, 1973; USDA Forest Service, 1996). Precipitation is higher and temperatures are lower than in the Ponderosa Pine zone. Soils are often thick and have developed in volcanic ash. Grand Fir occurs mainly with Ponderosa Pine (*Pinus ponderosa*), Lodgepole Pine (*Pinus contorta*), Western Larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*) and Whitebark Pine (*Pinus*

Pine (*Pinus lambertiana*), Western White Pine (*Pinus monticola*), and Mountain Hemlock (*Tsuga mertensiana*). Fire has been important in the Grand Fir zone, though not as important as in the Ponderosa Pine zone (Franklin and Dyrness, 1973; Agee, 1994; USDA Forest Service, 1996). Riparian vegetation includes black cottonwood (*Populus balsamifera trichocarpa*), mountain alder (*Alnus incana*), currents (*Ribes* spp.), red-osier dogwood (*Cornus stolonifera*), black hawthorn (*Crataegus douglasii*) and shrubby cinquefoil (*Potentilla* spp.) (Crowe and Clausnitzer, 1997).

The Subalpine zone (*Abies lasiocarpa*) begins as low as 4,200 feet (1,300 meters) up to 5,500 feet (1,700 meters) and extends upward in elevation (Franklin and Dyrness, 1973). Soils may be well-developed but with fairly thin humus layers. Temperatures are typically lower than the Ponderosa Pine or Grand Fir zones in both summer and winter, and there is greater snowpack in winter. Subalpine Fir (*Abies lasiocarpa*) occurs with Englemann Spruce (*Picea engelmannii*) and Lodgepole Pine (*Pinus contorta*). Fires do occur in this zone, but less frequently than in the Grand Fir or Ponderosa Pine zones and the trees in this zone are typically not resistant to fire and are easily killed by fire (USDA Forest Service 1996; Agee, 1994). Red alder (*Alnus rubra*) and Grand Fir (*Abies grandis*) may occur in the moister areas (Crowe and Clausnitzer, 1997).

Perennial grasses found in the uplands in the region include Bluebunch wheatgrass (*Agropyron inerme*), Idaho fescue (*Festuca idahoensis*), Western wheatgrass (*Agropyron spicatum*), and Giant wild rye (*Elymus cinereus*). Various forbs are common. In non-forested areas vegetation consists mainly of herbaceous species (USDA Forest Service and USDI Bureau of Land Management, 1994).

Fish

The habitat enhancement projects in this study are intended to improve habitat conditions primarily for steelhead (*Oncorhynchus mykiss gairdneri*). This is the anadromous form of *Oncorhynchus mykiss* and is also known as redband trout. Most of the anadromous steelhead in the inland Columbia River Basin are summer-run. They are sympatric with resident redband trout (*Oncorhynchus mykiss irideus*) and have different life histories and breeding populations, though they are not completely reproductively isolated from one another (Kostow, 1997). Other fish in the study area may also benefit from habitat enhancement. These include bull trout (*Salvelinus confluentus*), brook trout (*Salvelinus fontinalis*), cutthroat trout (*Oncorhynchus clarki*) and chinook salmon (*Oncorhynchus tshawytscha*).

In addition to habitat degradation, there are other factors that have contributed to problems for salmon in the Columbia River Basin. Overharvesting and the effects of interbreeding and competition from hatchery-bred salmon have contributed to declines of salmon in the region (Kostow, 1997). Fish are blocked from upstream migration above Hells Canyon dam on the Snake River and in the Deschutes river basin above the Pelton/Round Butte dam complex. They must pass through up to four hydroelectric dams on the main Columbia River and through four dams on the Snake River as adults on their way to spawning habitat, and as juveniles migrating to the ocean (Berggren and Filardo, 1993). This results in mortalities and stress. Streamflow in the waterways is decreased due to diversion of water for irrigation in all of the major subbasins including the Deschutes, Umatilla, Walla Walla, John Day and Grande Ronde and the mainstem of the Columbia River (Kostow, 1997).

Land-Use Impacts

Land uses have affected streams in the Blue Mountain region since Euro-American settlement (Wissmar et al., 1994). A majority of the forested land in the Blue Mountains province is managed as National Forests and include the Malheur, Umatilla, and Wallowa-Whitman National Forests (Brookes, 1996). Grazing, logging, and road building have all contributed to destabilized stream banks and resulted in bank erosion, loss of stream cover and shade, channel widening and accelerated lateral migration. Unstable slopes are a common feature of the landscape in the region and erosion and sedimentation from logging and road building associated with logging are common (USDA Forest Service and USDI Bureau of Land Management, 1994). Grazing is another activity carried on in the National Forests in the Blue Mountains, and has affected channel stability and channel condition. Grazing in riparian areas can change the vigor, composition and amount of the natural vegetation, and can reduce erosion, bank stability and canopy cover. Soil compaction from land uses can cause bank sloughing and erosion, lead to channel widening, alter channel migration, increase channel erosion, and contribute to increased sedimentation (USDA Forest Service and USDI Bureau of Land Management, 1994). Impacts to riparian areas and stream banks can also be caused by recreation uses in the area.

Channel structure has also been modified by the removal of large woody debris and logging has influenced the amount of large woody debris available for recruitment into stream systems. Removal of trees and stream-side brush have reduced stream shading, which can affect water temperature regimes and eliminate cover over stream habitat (USDA Forest Service and USDI Bureau of Land Management, 1994).

Recently implemented management practices have attempted to reduce the causes of stream destabilization (USDA Forest Service and USDI Bureau of Land Management, 1994). Based on the PACFISH strategy, managers have evaluated and modified projects to

accomplish the proposed goals and objectives. Modifications have resulted in reductions in resource outputs such as reductions in timber harvest or fewer AUMs (animal units per month) of permitted grazing. Some recreation sites have been closed to allow recovery in riparian areas and streams. Reductions in timber harvest or grazing may result in improved soil stability, increased streamside vegetation, canopy cover and shade, increased availability of large woody debris in the riparian area and stream, and decreased sediment production. This would potentially stop or slow habitat degradation while contributing to recovery. Since PACFISH was implemented in 1995, improvements resulting from this strategy may not be measurable since recovery processes may take longer than a few years (USDA Forest Service and USDI Bureau of Land Management, 1994).

This discussion of the geology, watersheds, climate, vegetation and fish in the study area provides the context in which habitat enhancement projects have been implemented in streams in the region. Stream habitats have developed within this context, and fish have adapted to these landscape conditions over many thousands of years. Stream habitat enhancements must function within this context in order to be effective in creating suitable aquatic habitat for salmonids.

CHAPTER IV

CONTROL AND RESPONSE VARIABLES

The analysis presented in this thesis focuses on the influences of watershed, channel, stream-type and in-stream structure (ISS) characteristics on ISS effectiveness, channel morphology and vegetation, ISS survival and ISS performance. Both control and response variables are discussed in this chapter. Control variables were used to explain channel and ISS responses in reaches in the study area where ISSs were used to enhance habitat. The significance of specific control variables used to explain channel and habitat form and condition, and ISS responses are discussed in this chapter. Many of the control variables are important in controlling or influencing channel forming processes and resulting channel form, which then affect habitat conditions. In addition, I will discuss the significance of the control and response variables to channel and habitat form and condition.

Drainage basins operate as systems with interrelated physical components (Huggett, 1980), and this systems concept is the basis for evaluating the response of streams to the presence of ISSs. Drainage basin area, valley width, geology, vegetation, and the amount and timing of precipitation all contribute to water runoff patterns, and affect the delivery of water and sediment to the stream channel. Streams that are morphologically stable are able to transport sediment without aggrading or enlarging (Schumm and Lichty, 1965; Brookes, 1990). When a physical change to the system occurs, it affects parts of the system that adjust to these changes (Heede, 1981). Channel instability can result from activities and events that disrupt stream flow, and sediment delivery and transport processes (Simon, 1995). This may cause erosion and adjustment in channel form (Schumm and Lichty, 1965). ISSs may be a cause of channel instability and channel adjustment.

In this study, specific control variables were chosen based on the idea that the morphology of stream channels is controlled by components of the physical landscape (extrinsic controls) and by components of the channel itself (intrinsic controls) (Schumm, 1973; Schumm, 1979). Climate and geology are extrinsic control variables that influence channel form because they influence water and sediment supply to the channel (Montgomery et al, 1996). Intrinsic controls influencing channel morphology include characteristics such as channel width, depth and bank material size. Watershed, channel, stream-type and ISS control variables (Table 3) were used to evaluate channel and ISS responses.

TABLE 3. Summary of Control Variables

Watershed Control Variables	
	Geology
	Valley Constraint
	Drainage Area
	Stream Order
	Fire Occurrence
Channel Control Variables	
	Reach Gradient %
	Median (D_{50}) Bed Material (mm)
	D_{84} size Bed Material (mm)
	Entrenchment Ratio
	Sinuosity
	Bankfull Width-to-Depth Ratio
	Bank Material Size
	Bank Stability %
	Bank Vegetation %
	Riparian Vegetation Seral Stage
Stream-Type Control Variables	
	Rosgen Stream-Type
	Montgomery-Buffington Stream-Type
ISS Control Variables	
	ISS Type
	ISS Gradient

Control variables also operate within a hierarchy of spatial and temporal scales to influence channel form (Schumm and Lichty, 1965; Chorley and Kennedy, 1971; Huggett, 1980; Frissell et al., 1986; Sedell et al., 1990; Benda et al., 1998). Controls operating at one scale affect the processes and responses at other scales. Channel dimensions, especially channel widths, depths and slopes, adjust over short periods of time (10 to 100 years) (Simon, 1989; Downs and Gregory, 1993; Knighton, 1998). Hydrologic regime, inputs of woody material and sediment, landscape position, geologic parent material and local vegetation influence the magnitude of sediment and water inputs (Schumm, 1979; Brookes, 1990; Gregory, 1992; Montgomery et al., 1995; Church, 1996). Channel shape, gradient and pattern are directly related to sediment and water inputs (Schumm and Lichty, 1965; Knighton, 1998).

Large-scale controls operate over longer time scales (100 to 100,000 years), and channel adjustments may be slow (Simon, 1989). Some of these controls include geology, climate, intensive land-use, and base level changes caused by tectonic processes (Schumm and Lichty, 1965; Petts, 1983; Allison and Thomas, 1993; Renwick, 1992; Werritty, 1997; Knighton, 1998). When large-scale changes occur, streams often cross geomorphic thresholds and shift to new equilibrium states adjusted to altered flow regime and sediment input (Leopold and Maddock, 1953; Schumm and Lichty, 1965; Schumm, 1979; Petts, 1983; Werritty, 1997). This results in altered channel form and channel pattern, and affects the structure of in-stream habitat (Cooke and Reeves, 1976; Benda et al., 1992).

Channel form and pattern result from the interrelationships of extrinsic control variables that operate at regional and watershed scales, and intrinsic controls operating at smaller scales of the reach and habitat (or channel) unit (Naiman et al., 1995; Rosgen, 1994; Meyer et al., 1995; Church, 1996; Werritty, 1997; Benda et al., 1998). Watershed control variables also affect reach scale characteristics. ISSs are influenced by these same controlling

variables and also operate within the channel to influence channel form (Heede, 1981; Osborne et al., 1993).

The response variables in this study are measures of ISS effectiveness (Table 4), channel morphology and vegetation (Table 5), ISS survival and performance (Table 6), and were evaluated at the scale of the reach. Channel form was evaluated at the scale of the individual habitat unit. ISS survival and ISS performance were evaluated at the scale of the individual ISS.

TABLE 4. Effectiveness Target Value Response Variables

Target Values for Healthy Streams (Lamb 1996)
Habitat units / wetted width
Deep pools / wetted width
Average maximum pool depth
Residual pool depth
Width-to-Depth of riffle, bankfull
Canopy Cover
Small LWD per mile
Large LWD per mile
Total LWD per mile
Characteristics of Refugia (Ebersole, 1994)
Active Bank Erosion
Overhanging Bank Vegetation
Canopy Cover (reach canopy density)
Pool Temperature
Pool Depth
PACFISH Desired Future Conditions (USDA Forest Service and USDI Bureau of Land Management, 1995)
Pools per km
Water temperature, spawning habitat
Water temperature, rearing habitat
Large LWD per km
Bank Stability
Width-to-Depth ratio
Bank Undercut (lower bank angle)
Camas Watershed Assessment Desired Future Conditions (Howell and McKinney, 1997)
Bank Stability
Bank Shrub Cover, all shrubs
Bank Shrub Cover, > 8 ft. tall (2.46 m)

TABLE 5. Channel Morphology and Vegetation Response Variables

Pool Depth
Wetted Width
Bank Erosion
Bank Vegetation

TABLE 6. ISS Survival and Performance Response Variables

ISS Survival
In Place
Shifted on Site
Left Site
ISS Performance
Functioning
Partially Functioning
Not Functioning

Control Variables

Some of the control variables used in this study have been found by other researchers to be significant in influencing channel form. Additional control variables that were used have the potential to influence reach, ISS and habitat unit scale responses to habitat enhancement involving ISSs. The watershed, channel, stream-type and ISS control variables used in this study will be discussed in detail in the following section.

Watershed Control Variables

Watershed scale factors that are important influences on channel form include geology, valley form, disturbance processes, sediment supply, vegetation condition, and the volume and timing of water supply (Petts, 1983; Morisawa, 1985; Naiman et al., 1992; Church, 1996; Benda et al., 1998; Knighton, 1998). Measurable characteristics that quantify some of these were used in this study as control variables (Table 7).

TABLE 7. Watershed Control Variables

Variable	Type	Category or Dimensions
Geology	nominal	A B
Valley Constraint	nominal	C = constrained (< 100 ft) U = unconstrained (> 100 ft.)
Drainage Area	continuous	km ²
Stream Order	continuous	1, 2, 3, 4, or 5
Fire Occurrence	nominal	Y = yes N = no

In this study, geology type was categorized in one of two types. Valley form variables included valley constraint, drainage area and stream order. Fire occurrence is one disturbance process that was included as a control variable to describe vegetation and landscape condition.

Many streams in the Umatilla National Forest (NF) experienced large magnitude floods in 1995, 1996 and 1997, but flood magnitude was not used as a control variable in this study. It was assumed that all stream reaches in this study were located in watersheds that experienced floods with frequencies greater than a 25 year return interval (RI). Some of the reaches experienced floods with RIs greater than 100 years. However, flood magnitudes were not known in many reaches due to the absence of nearby gaging stations from which to calculate flood stage.

Geology

Lithology of the geologic parent material exerts control on mechanical weathering processes and the resulting physical landscape forms. Differences in channel form are related to the geology through which the channel flows (Naiman et al., 1992). The

erodability, size, and texture of bed and bank materials in a stream channel are direct products of local geology and can influence sediment delivery (Kelson and Wells, 1989).

Several channel characteristics have been found to vary with geology. These include discharge characteristics, sediment entrainment and transport, pool length, pool depth, pool area, low-flow width-to-depth ratio, number of riffles and glides, and the amount of large woody debris. Geology controls run-off production and permeability which directly affects flow volume and timing, sediment transport capability and the amount of sediment transported (Kelson and Wells, 1989). Kelson and Wells (1989) found that basins with different lithologies had different discharge characteristics, specifically bankfull discharge and the length of time that peak discharges are sustained. In a study conducted in the Three Sisters Wilderness area in the high Cascades of Oregon, Duckson and Duckson (1995) found that lithology was a significant variable related to pool length, depth and area. Lamb (1996) found that geology was significantly related to the number of pieces of large woody debris (total LWD, large LWD and small LWD). Low-flow width-to-depth ratio and relative number of riffles and glides also differed by geology type (Lamb, 1996).

In this study, geology was used as a categorical control variable, and was classified into two geology types using the method outlined by Lamb (1996). The two geology categories were based on hardness and composition. Geology A included the "hard" rock types, igneous and metamorphic rocks such as the members of the Columbia River Basalt Group, the intrusive ultramafics and the older metamorphosed volcanics, mapped as Tcg, Tcs, T_rPzu and T_rPv by Walker and MacLeod (1991). Geology B included the "soft" sedimentary and volcanoclastic rock types such as the John Day and Clarno formations, fluvial and lacustrine deposits, siltstones, and sandstones mapped as Tlf, Qal, Tsjf and Tca (Walker and MacLeod, 1991). In this thesis, the "hard" rock types were considered to be less erodible, while the "soft" rock types were considered less susceptible to erosion.

Valley Constraint

Valley constraint is an important control of channel adjustment processes and channel form (Frissell et al., 1986; Rosgen, 1996). In this study, valley width was defined as constrained if valley width measured on USGS 1:24,000-scale quadrangles was less than 100 feet (31 m). Valley constraint influences stream flow characteristics which affects channel form and sinuosity. The degree of valley constraint also influences the ability of the channel to migrate laterally (sinuosity), potential channel width, sinuosity (Grant et al., 1990; Nakamura and Swanson, 1994), and the interaction of the active channel with the floodplain (Fetherston et al., 1995). In constrained valleys, stream flow is concentrated within the channel during high flows, increasing the potential for erosion and streambed degradation (Sedell et al., 1990). Valley constraint also influences sediment transport and storage. A more constrained channel transports sediment more readily, while more sediment is stored in an unconstrained reach (USDA Forest Service, 1994).

Constrained valleys with steep slopes are efficient in delivering debris to the stream. Mass wasting and debris flows occur in steep-walled, narrow valleys in tributary watersheds in general, and in many streams in the study area (Clifton, 1996). This affects channel structure and sediment distribution (Swanson et al., 1987). These processes may be more important in influencing channel form in 1st and 2nd order streams than in larger streams (Swanson et al., 1987).

Valley constraint also affects the development of vegetation (McKenney et al., 1995) and large woody debris production, transport and storage (Nakamura and Swanson, 1994). Vegetation is more limited in constrained valleys than in unconstrained valleys because it is subject to more frequent damage by flood flows (Ebersole, 1994; McKenney et al., 1995). Wider, unconstrained valleys allow for greater floodplain development through lateral

channel migration and overbank flooding and deposition. This results in the development of wide and complex areas of riparian vegetation.

Drainage Area

This study used drainage area as a watershed control variable to assess ISS effectiveness, channel form, ISS survival and ISS performance. Drainage area is an important control variable because many channel characteristics, such as channel width and depth, can be expressed as power functions of drainage area (Dury, 1973; Knighton, 1998). Bankfull discharge and stream power increase with drainage area (Knighton, 1998). As drainage area and stream power increase, more energy is available to do geomorphic work. Drainage areas in the study reaches ranged from 1.37 km² to 176.08 km².

In this study, drainage area was measured using a planimeter (Dunne and Leopold, 1978). The drainage areas at both the upstream and downstream ends of each reach were measured and averaged to provide the drainage area for each reach.

Stream Order

In many studies, stream order is used as a surrogate for drainage area to evaluate stream characteristics and responses (Naiman et al., 1992). It was used in this study to evaluate channel morphology, ISS survival, and ISS performance, and to compare results with those from other USDA Forest Service studies in the region that used stream order to evaluate ISS survival. Stream order was determined using the Horton method as modified by Strahler (Knighton, 1998) using the blue line stream network shown on USGS 1:24,000-scale quadrangle maps. Stream order in the study reaches varied from 1 to 5.

In previous studies, the Forest Service used stream order to evaluate the durability (survival) of ISSs in the Columbia River Basin and drew conclusions about survival relative to stream order (Fitzgerald, 1997; Roper et al., 1998). One Forest Service study found ISS

survival was highest in larger streams (greater than 4th order) (Fitzgerald, 1997). Another study in the Umatilla NF found ISS survival was highest in smaller streams (less than 3rd order) (Roper et al., 1998).

Other stream characteristics have been found to vary with stream order and also indicate its usefulness as a control variable. Marston (1982) found that the frequency of log-jams and log-steps varied with stream order. Keller and Swanson (1979) found that the frequency of pools formed by large woody debris varied with stream order. This study will use stream order as a control variable primarily to compare and contrast results with those described by the Umatilla NF (Fitzgerald, 1997), and to evaluate its influence on other channel characteristics.

Fire Occurrence and Vegetation Condition

Fire occurrence was used in this study as a watershed control variable to categorize vegetation condition in relation to recent fire events, and was used to evaluate ISS effectiveness, channel morphology, ISS survival and ISS performance. Reaches were categorized by whether or not a had fire occurred within the last few years. Two watersheds in this study (North Fork Cable and Hidaway) experienced a severe fire event and high tree mortality in 1996 (USDA Forest Service, 1997). Fires were followed by intense rainfall and runoff events in 1997. As a result, mass wasting and debris flows occurred in the upper North Fork Cable watershed (Clifton, 1997; USDA Forest Service, 1997), and delivered large amounts of LWD. A comparison of the responses between stream reaches in these watersheds with responses in watersheds where no fire occurred suggest interesting differences in project effectiveness, channel morphology, ISS survival and ISS performance.

The type and condition of the vegetation in the watershed plays a role in controlling the delivery of both water and sediment to the channel, and may be altered by both natural disturbances and land use practices (Schumm and Lichty, 1965; Benda et al., 1998).

Vegetation condition could be classified in many ways. For example, it could be classified by the intensity and extent of timber extraction, by grazing intensity, or by the severity and extent of recent fire events in the watershed. Wild fires influence erosion by killing vegetation and reducing the stabilizing effect of root strength. Fire reduces the rate of water infiltration into soil, increasing surface flow and surface erosion potential (Benda et al., 1998). Basins which have been severely burned experience high tree mortality (Agee, 1993), and will experience increased erosion and sedimentation following intense rainfall events. After a fire, rainfall/run-off events may promote debris flows, entraining and delivering fine sediment and ash which is deposited in-channel and on adjacent floodplains (Meyer et al., 1992; Meyer et al., 1995). This may have a significant effect on stream channel morphology.

Channel Control Variables

The importance of each of the channel control variables is discussed in the following section. Channel controls used in this study (Table 8) include gradient, sinuosity, entrenchment ratio, (floodprone width/bankfull width), bankfull width-to-depth ratio, bed material, bank material, bank stability, bank vegetation and riparian vegetation seral stage.

Channel characteristics were used as control variables in this study because they can account for some of the variability in the form of channel and habitat units (Schumm and Lichty, 1965). In a study of streams in New Zealand, Mosley (1981) concluded that only 53% of the variability in channel morphology was explained by hydrologic regime (represented by mean annual discharge) and sediment characteristics (represented by mean diameter of bed sediment size). Several channel characteristics accounted for a portion of the remaining variability (Mosley, 1981). These included gradient, perimeter roughness, cross-sectional area, cross-sectional shape and sinuosity.

TABLE 8. Channel Control Variables

Variable	Type	Category or Dimensions
Reach Gradient	continuous	percent
Bed Material	ordinal	D ₅₀ sediment size
Bed Material	ordinal	D ₈₄ sediment size
Entrenchment Ratio	continuous	Floodprone Width/ Bankfull Width - dimensionless
Sinuosity	continuous	Reach Length/Valley length - dimensionless
Bankfull Width-to-Depth Ratio	continuous	Bankfull Width/Bankfull Depth - dimensionless
Bank Material	ordinal	1 = Silty Clay 2 = Silty Clay Loam 3 = Clay Loam 4 = Silty Loam 5 = Sandy Loam 6 = Sand 7 = Gravel 8 = Cobble 9 = Boulder 10 = Bedrock
Bank Stability	continuous	percent
Bank Erosion	continuous	percent
Bank Vegetation	continuous	percent
Riparian Vegetation Seral Stage	ordinal	1 = No vegetation 2 = Grass/Forb 3 = Shrub/Seedling (1-4.9 in. dbh) 4 = Sapling Pole (5-8.9 in. dbh) 5 = Small Tree (9-20.9 in. dbh) 6 = Large Tree (21-31.9 in. dbh) 7 = Mature Tree (> 32 in. dbh)

At the scale of the stream reach and habitat unit, the physical configuration of the channel and the size and character of the substrate through which the channel flows reflect watershed scale controls and also exert control over stream and habitat unit form and function. Physical form and ecological conditions of the channel are important to aquatic organisms. Vannote and others (1980) have proposed that aquatic organisms and biological

communities are adapted to, and are at equilibrium with, the physical conditions of the channel. Fish in the Pacific Northwest have survived in a complex and dynamic environment which has produced varied and complex channel morphology and habitat conditions (Benda et al., 1998).

Gradient

In this study, reach gradient percent was used as a control variable. Local gradient was measured at irregular intervals throughout each reach using a clinometer. The sections that were chosen for measurement were representative of the typical reach gradient. Each gradient measurement spanned several habitat units. These measurements were averaged to provide a reach average gradient. In addition to its use as a control variable, gradient was also used to determine Rosgen (1994, 1996) and Montgomery-Buffington (1997) stream-type. Reach gradients in the study reaches ranged from 1% to 7%.

Gradient is a significant control of channel form. Channel forming processes and channel morphology vary with channel gradient (Montgomery and Buffington, 1993; Grant et al., 1990). It affects stream power and stream competence in mobilizing and transporting sediment (Church, 1996). Stream power increases with increasing channel gradient (Thompson, 1995). High gradient reaches have more energy available at a given discharge to move bed and bank material than low gradient reaches.

Many channel features have been shown to vary with gradient. Gradient is related to channel pattern (Leopold and Wolman, 1957; Schumm and Kahn, 1972), channel shape, sediment load (Schumm and Kahn, 1972), bed material size (Brussock et al., 1985), dominant bedform type (Montgomery and Buffington, 1993; Bisson and Montgomery, 1996), pool type, pool depth, and the effects of large wood on the channel. Channels with steep gradients tend to be wider and shallower than channels with low gradients (Knighton, 1998). In a study of unaltered streams in the Medicine Bow NF in Wyoming, Kozel and

others (1989) found significant differences in habitat features correlated with trout abundance between low-gradient and moderate-gradient channels. There were significant differences in channel width and depth, bank angle (bank undercut), and depth near the banks between low- and moderate-gradient channels. Channels with low gradients were narrower and deeper, had a higher percentage of banks with undercuts, and had greater water depths near the bank.

The delivery mechanisms, amount, and function of LWD have been shown to vary with channel gradient (Keller and Swanson, 1979). In streams in northwestern Washington, the influence of large woody debris on pool formation and on percent of gravel on the bed changed with gradient (Beechie and Sibley, 1997). Beechie and Sibley (1997) found that woody debris formed 24% of the pool habitat in moderate-gradient channels but only 4% in low-gradient channels. Kozel and others (1989) found that substrate varied with gradient and that moderate gradient streams had more cobble substrate and a greater number of plunge pools than low or high gradient streams (Kozel et al., 1989). Wohl and others (1993) found differences based on gradient in the depths of pools relative to the depths of riffles and glides created by channel scour.

Sinuosity

Sinuosity is a ratio of channel length to valley length, and also the ratio of valley slope to channel slope (Schumm and Lichty, 1965; Knighton, 1998). It was used as a control variable in this study to assess ISS effectiveness, channel morphology, ISS survival and ISS performance. Sinuosity was calculated as the ratio of reach length to valley length (Knighton, 1998). Reach length is the sum of the lengths of all habitat units. Habitat unit length along the thalweg was measured during field surveys using a measuring tape. Valley length was measured as the distance between the upper and lower reach ends and was

measured directly from USGS 1:24,000-scale quadrangle maps. Sinuosity in the reaches in this study ranged from 1.1 to 1.65.

As a control variable for the effectiveness target values, it was expected that streams with similar sinuosities might have similar target value characteristics such as width-to-depth ratio, bank stability and bank vegetation. In streams with similar sinuosities, ISS response was also expected to be similar. Sinuosity was also used as a delineative criteria for Rosgen (1996; 1994; 1985) stream-type, and was used to categorize Montgomery-Buffington stream-types.

Sinuosity is closely related to several channel form characteristics, and the development of sinuosity can be a mechanism for channel slope adjustment. Excess stream energy beyond that used to transport sediment is expended through bank erosion and channel migration (Brussock et al., 1982) resulting in increased sinuosity and a meandering channel planform (Church, 1996). With relatively constant discharge and sediment transport, slope is lowered by increased meandering (Knighton, 1998). Pool development is related to sinuosity (Brussock et al., 1985) where pools form through lateral scour at bends in channels (Keller and Melhorn, 1978). Sinuosity is also related to bed and bank particle size, increasing as particle size decreases (Knighton, 1998).

Entrenchment

Channel entrenchment describes the relationship of the channel and the floodplain, and the extent to which the channel is incised. In this study, entrenchment ratio was used as a channel control variable and to determine Rosgen channel type (1985; 1994; 1996). In stream reaches in this study, entrenchment ranged from 1.6 to 11.7.

The entrenchment ratio used to determine Rosgen stream-type is the floodprone width divided by bankfull width (Rosgen, 1985; Rosgen, 1994; Rosgen, 1996). Floodprone depth is twice bankfull depth, and is assumed to represent the depth of a flood occurring about

every fifty years (Rosgen, 1985; Rosgen, 1994; Rosgen, 1996; USDA Forest Service, 1996). In this study, floodprone width was measured by stretching a tape at the height of the floodprone depth across the floodplain until the tape touched the ground on either side of the floodplain (USDA Forest Service, 1996). Floodprone depth and width were measured three to four times in each reach in locations that were characteristic of the average reach floodprone width.

In the Rosgen system (Rosgen, 1985; Rosgen, 1994; Rosgen, 1996), lower values of entrenchment indicate that the stream is entrenched, and that peak discharges are confined to a single channel and result in more energy available to do geomorphic work on the banks (Church, 1996). As discharge increases, greater stream power in entrenched channels provides more energy to erode the bed and banks, and potentially has a greater impact on ISS effectiveness, channel morphology, ISS survival and ISS performance.

Width-to-Depth Ratio

Bankfull width-to-depth ratio was used in this study as a channel control variable to evaluate channel morphology, ISS survival and ISS performance. Bankfull width-to-depth ratio was used to evaluate ISS effectiveness using Lamb (1996) target values, and was also used to determine Rosgen (1994; 1996) stream-type. ISS effectiveness in meeting the PACFISH width-to-depth ratio target value was evaluated using a different measure, a ratio of reach average wetted width and average low-flow pool water depth (USDA Forest Service and USDI Bureau of Land Management 1995). In the reaches in this study, bankfull width-to-depth ratio ranged from 7.9 to 41.5. PACFISH width-to-depth ratio ranged from 5.2 to 20.9.

In this study, bankfull width and depth were measured at every riffle habitat unit. In the field, identification of bankfull level can be based on a number of indicators including a change in bank vegetation, height of the active floodplain, stain lines on substrate, debris

lines, scour lines, a change in bank topography, a change in particle size and the height of channel bar tops (USDA Forest Service, 1994; 1996; Rosgen 1996). Once bankfull level was located, a tape was stretched across the channel, and the width at bankfull level was measured. Bankfull depth was recorded at one-quarter, one-half and three quarters of the distance across the channel. A maximum bankfull depth was also measured and recorded (USDA Forest Service, 1996). Bankfull width and depth at each riffle, weighted by the length of each riffle, were used to calculate reach average values for bankfull width and depth. Reach average bankfull width and depth were then used to calculate the bankfull width-to-depth ratio.

The width-to-depth ratio used for comparison with the PACFISH target value was calculated from reach average wetted width and average low-flow pool water depth. These values were calculated from actual measurements made during field surveys. Mean bankfull depth in pool habitat units was calculated from actual water depths measured in the field. Reach average values for wetted width were calculated from field measurements of wetted widths at all habitat units. Reach average values of wetted width and water depth, weighted by habitat unit length, were then used to calculate PACFISH width-to-depth ratio.

Width-to-depth ratio is an index of channel morphology and can be used as an indicator of the balance between discharge, sediment transport capacity and sediment load (USDA Forest Service, 1994; Rosgen, 1994; Rosgen, 1996). A change in width-to-depth ratio indicates a change in the relationship between discharge and sediment transport. A high width-to-depth ratio describes a wide, shallow channel and indicates bank erosion and sediment transport. Low width-to-depth ratio describes a narrower, deeper channel and indicates stable banks and less erosion. Bankfull width and depth are often used for analysis of changes in channel morphology because the bankfull channel provides a geometry that allows for continued water and sediment transport and results in a relatively stable channel (Knighton, 1998).

Bed Material Size

The median (50th) and 84th percentile gravel sizes were used in this study as measures of bed material size. They were calculated from a frequency distribution graph of bed material size class data (Wolman, 1954; USDA Forest Service, 1996). The median size (D_{50}) is expected to be mobile during bankfull flows, while particles larger than the eighty-fourth percentile (D_{84}) are immobile during bankfull flows. Many of the streams in this study experienced high magnitude flows (50 to 100 year return intervals) in late 1995, early 1996 or in 1997 which may have moved both small and large bed material, and may have affected ISS effectiveness, channel morphology and/or ISS survival and performance. Bedforms in channels with gravel-size and smaller bed material are constantly forming and re-forming under frequent, low magnitude flows, while bedforms in channels with cobbles and boulders form during less frequent flows when moderate to high discharges are able to mobilize these larger bed materials (Williams, 1978; Grant et al., 1990). The variability in the mobility of bed material of different sizes that occurs under a range of flow conditions, such as those that have occurred in the study area, make bed material an important control variable to use to evaluate ISS effectiveness, channel morphology, ISS survival and ISS performance.

Bed material size was determined using the Wolman (1954) pebble count technique (USDA Forest Service, 1996). Pebble counts were done at two riffle locations that were representative of bed material, flow conditions and channel orientation (e.g. straight channel sections) of most riffles in the reach. Transects were placed across the channel from bankfull to bankfull, and a measuring tape was stretched and secured. Bed material was measured at regular intervals along the transect until a sample size of one hundred pebbles was reached. Typically, observers measure the particle that they find at the toe of their boot as they proceed across the channel (Wolman, 1954; USDA Forest Service, 1996).

However, this technique seemed to introduce bias because the observer had to step only on certain rocks in order to walk across the channel safely. Because of this, the method was modified as follows. The observer selected pebbles at equal intervals along a measuring tape stretched across the channel by lowering a long, pointed object (a surveying pin) to the channel bottom and selecting the particle at the tip of the pin. The length of the intermediate axis (USDA Forest Service, 1996) of each selected pebble was recorded in a size class category (Table 91, appendix A). Median (D_{50}) bed material size in reaches in this study ranged from < 2 mm (0.08 inches) to 96 mm (3.8 inches). The D_{84} bed material size ranged from < 2 mm (0.08 inches) to 192 mm (7.6 inches).

Bed material size is a product of geology and landscape position, and is an important control of channel form. Channel form and function depend on the interaction of bed material with other control variables. Bed material size is often correlated with drainage area and tends to decrease in a downstream direction as channel gradient decreases (Brussock et al., 1985; Knighton, 1998). Channels develop characteristic bed morphology such as riffle-dunes, pool-riffle sequences, cascades and boulder-steps based on bed material size, channel gradient and discharge (Keller and Melhorn, 1978; Grant et al., 1990; Bisson and Montgomery, 1996). Bed material can also be an important roughness element. In channels with larger size bed materials such as cobbles and boulders, these roughness elements dissipate energy, leaving less energy to scour pools and develop pool-riffle sequences (Wohl et al., 1993).

Many studies suggest that large magnitude discharge, infrequent flood events (≥ 50 year return interval) are required to transport sediment and shape channel form (Baker, 1977; Lisle, 1982; Benda, 1990; Grant et al., 1990; Madej and Ozaki, 1996), and that moderate magnitude and frequency flood events are relatively unimportant. The effects of large magnitude flooding may be especially important in small drainage basins, in streams where discharge is highly variable, and when bed material is coarse (Baker, 1977; Pitlick,

1993; Nash, 1994). In mountainous regions in the Pacific Northwest, streams with these characteristics are common, and large magnitude flooding may be the most important mechanism causing morphological change (Grant et al., 1990; Easterbrook, 1993; Church, 1996; Knighton, 1998). Large boulders influence the hydraulics in these streams, influencing flow and sediment transport rates, small-scale bedforms and habitat unit type and arrangement (Grant et al., 1990; Knighton, 1998).

Bank Material

Bank material size was used in this study as a channel control variable to evaluate ISS effectiveness, channel morphology, ISS survival and ISS performance. In this study, bank material size class was recorded at each habitat unit using ocular estimates of the dominant or most frequent size bank material, and the sub-dominant or second most frequent size bank material. The size classes, gravel, sand, cobble, boulder and bedrock come from the Stream Inventory Handbook (USDA Forest Service, 1996), and are listed in Table 9. Particles sizes less than 2 millimeters along the intermediate axis were further categorized by using a hand-texture test to determine the predominance of sand, silt, clay or loam soil type (Table 92, appendix A).

TABLE 9. Dominant and Sub-Dominant Bank Material Categories

1	= Silty Clay
2	= Silty Clay Loam
3	= Clay Loam
4	= Silty Loam
5	= Sandy Loam
6	= Sand
7	= Gravel (2 - 64 mm., BB to tennis ball size)
8	= Cobble (64 - 256 mm., tennis ball to basketball size)
9	= Boulder (256 - 4096 mm., basketball size to small car)
10	= Bedrock

Dominant and sub-dominant bank material size classes at each habitat unit, weighted by habitat unit length, were used to calculate reach averages. Bank material size in the study reaches ranged from silty-clay to boulder size with occasional bedrock outcrops. Reach average bank material size category in reaches in this study ranged from 2.0 to 7.71.

Bank material particle size is one of the most important factors controlling bank stability, bank erosion and channel form (Brussock, 1985; Morisawa, 1985). Channel form and channel forming processes depend on bank particle size. Banks composed of coarse to medium sand are the least stable. Resistance to erosion increases when particle size is either larger or smaller than sand. Cohesive, less erodible bank materials tend to result in deep and narrow channels, while banks composed of larger size material tend to be shallower and wider (Gordon et al., 1992). Soil porosity, permeability, moisture content, and clay content also affect erodability but were not considered.

Bank Stability

Bank stability was used as a channel control variable to evaluate ISS effectiveness, channel morphology, ISS survival and ISS performance. Bank stability in the reaches in this study ranged from 40% to 91%. Bank stability was recorded as the portion of the bank that was not eroding. In the field, portions of the bank were either eroding or stable, and a total of the two equaled 100% of the length of the reach. The percent of the bank that was eroding was recorded for each habitat unit, and bank stability was calculated by subtracting the percent bank erosion from 100%. Habitat unit values for bank stability, weighted by habitat unit length, were used to calculate reach average bank stability.

The Stream Inventory Handbook (USDA Forest Service, 1996) defines bank erosion as active sloughing, or banks with tension cracks or exposed mineral soil above the bankfull channel (USDA Forest Service, 1996). Other features used to identify bank erosion included loose, bare soil or bank material that was easily removed from the bank. In this

study, the length of the bank within the bankfull channel where the soil was bare and appeared to be loose and recently exposed was also included in bank erosion estimates.

Erosion of the banks is an important indicator of channel adjustment to changes in discharge and sediment supply (Downs and Gregory, 1993). Bank stability and erosion have an effect on channel cross-section parameters (Millary and Quick, 1993), and influence channel width-to-depth ratio, channel geometry and channel planform (Rosgen, 1994; Gordon et al., 1992).

Bank Vegetation

Vegetation has a significant impact on channel morphology (Hickin, 1984; Sedell and Beschta, 1991), and is used as a control variable in this study to evaluate ISS effectiveness, channel morphology, ISS survival and ISS performance. Bank vegetation on both right and left banks of each habitat unit was recorded. In each habitat unit, the length of the bank just above the bankfull channel that was covered with vegetation was recorded as a percent of the total habitat unit length. Bank vegetation percent of right and left banks was averaged for each habitat unit. Reach average bank vegetation was calculated using these habitat unit average values, weighted by habitat unit length. Reach average bank vegetation in reaches in this study ranged from 30% to 88%.

Bank vegetation plays a role in the development of channel form since channel form adjustments depend on bank erosion, and vegetation increases bank resistance to erosion (Smith, 1976; Sedell and Beschta, 1991; Knighton, 1998). Lack of bank vegetation can lead to channel widening, channel incision, and lowering of the water table (Abt et al., 1994). Disturbance of the riparian zone and decreased riparian vegetation has been associated with pool loss (McIntosh et al., 1994; Magilligan and McDowell, 1997). Clifton (1989) found that in streams where exclosures eliminated cattle grazing, vegetation increased, channels

were narrower and deeper (smaller width-to-depth ratios), had smaller cross section area, greater bankfull depth, and larger hydraulic radius than channels that not exclosed.

Woody vegetation forms a zone of rapidly growing roots just below the soil surface, and becomes important in channel recovery from disturbance and instability (Hupp and Simon, 1991), and in improving channel form and function (Magilligan and McDowell, 1997). Bank vegetation increases local roughness and bank resistance to flow, slowing the rate of water flow and providing sites for sediment deposition (Baker, 1977; Hupp and Simon, 1991; Sedell and Beschta, 1991; Gordon, 1992; Beschta, 1993; McKenney et al., 1995; Knighton, 1998). As vegetation traps sediment along the bank, and deposition sites grow, channel narrowing occurs (Hupp and Simon, 1991). In their study of unstable, eroding streams in loess and sand in west Tennessee, Hupp and Simon (1991) found that once depositional surfaces formed along the bank, woody vegetation became established and was part of the recovery process, trapping additional sediment and stabilizing banks from further erosion.

The relationship between trees on the bank and bank erosion and channel shape are complex and variable, suggesting that other controlling factors are important, and that interrelated variables, complex feedback, and threshold responses are involved (Montgomery, 1997). In their study of streams in Great Britain, Murgatroyd and Ternan (1983) found that stream banks in forested reaches eroded more, and became wider and shallower than in adjacent stream reaches with grass-covered banks. Trimble (1997) reported similar results in a study of reaches in Wisconsin. Sedell and Beschta (1991) also suggested that channels with grassy vegetation tend to be narrow and deep while channels with forested banks are wide and shallow. Myers and Swanson (1996a) found that in Rosgen B4 streams in Nevada, banks covered with trees were more stable than banks covered with shrubs or grasses. Because of the complexity and variability in the effects of

bank vegetation, another vegetation control variable was used in this thesis, riparian vegetation seral stage.

Riparian Vegetation Seral Stage

In this study, riparian vegetation seral stage provided a method for distinguishing among vegetation types. Riparian vegetation seral stage (Table 10) was recorded during surveys in one of several vegetation categories using the protocol described in the Stream Inventory Handbook (USDA Forest Service, 1996). In this protocol, the inner riparian zone is that portion of a 100 foot riparian zone where vegetation is noticeably different than in the outer riparian zone. In some streams in the study area, vegetation adapted to or tolerant of wet conditions such as *Carex* spp. or *Salix* (willow) was identified in the inner riparian zone. In other streams, conifers were abundant along the stream bank in both inner and outer riparian zones. The reach average category for riparian vegetation stage in reaches in this study ranged from 2.38 to 6.74.

TABLE 10. Riparian Vegetation Seral Stage Category

1 = No vegetation
2 = Grass/Forb
3 = Shrub/Seedling (1-4.9 in. diameter at breast height - dbh)
4 = Sapling Pole (5-8.9 in. dbh)
5 = Small Tree (9-20.9 in. dbh)
6 = Large Tree (21-31.9 in. dbh)
7 = Mature Tree (> 32 in. dbh)

Riparian areas are an integral part of stream systems (Van Haveren and Jackson, 1986; Gregory et al., 1991). Riparian vegetation seral stage appeared to be correlated with stream-type in the study area, and therefore was used as a control variable. The seral stage of the vegetation determines the function and influence of the riparian vegetation in contributing to

a number of channel characteristics including bank stability, stream temperature, LWD, habitat complexity and channel structure (Gregory et al., 1991). Vegetation seral stage influences the effectiveness of the vegetation in contributing to these characteristics.

Riparian vegetation is considered to be important in regulating stream temperature primarily because of the shade it provides, which varies with seral stage. The amount of shade provided by shrubs and trees also varies with stream width and orientation. Shade from shrubs and trees is most effective in intercepting solar radiation in narrow streams but becomes less effective in larger order, wider streams (Beschta et al., 1987; Beschta, 1997b). Sedges, rushes and other herbaceous plants (grasses and forbs) hang over the water surface and are important in providing shade in small streams in meadow systems (Beschta, 1997b). Riparian forests provide shade, organic matter and large woody debris (Fetherston et al., 1995). Because of their height and overall size, conifers and deciduous trees, especially mature trees, provide shade (usually measured as canopy cover) in a range of stream sizes, while shrubs are important in providing shade in intermediate size streams (Beschta, 1997b).

Mature trees are the most important for pool formation, as sources of large woody debris (LWD) for the development of log-steps (Heede, 1981), and for storing sediment and organic matter (Trotter, 1990). In streams in northwestern Washington, the size of the LWD that formed pools increased as channel width increased (Beechie and Sibley, 1997). In streams in the southern Appalachian Mountains, LWD loading was greater in late-successional and old-growth systems than in early successional systems (Hedman et al., 1996). In the Cascades in Western Oregon and Washington, LWD amount is highest in old growth forests greater than five hundred years old, and in early successional forests less than eighty years old (Spies et al., 1988).

Stream-Type Control Variables

Stream-type or class was an additional control variable used in this study to evaluate channel morphology, ISS survival and ISS performance. Stream classification systems organize stream reaches into groups based on similar characteristics (Naiman et al., 1995). Stream classification can be useful in predicting channel form and behavior (Woolfe and Balzary, 1996; Simon, 1992), and many stream classification systems have been proposed over the years (Davis, 1890; Leopold and Wolman, 1957; Schumm, 1963; Schumm, 1977; Naiman et al., 1992; Whiting and Bradley, 1993; Naiman, 1998). These classification systems often focus on physical characteristics such as channel pattern, width, depth, gradient, sediment type (Leopold and Wolman, 1964; Rosgen, 1985; Rosgen, 1994; Rosgen, 1996), and dominant geomorphic processes such as sediment supply and transport (Schumm, 1963; 1977; Montgomery and Buffington, 1993; 1997). Systems are sometimes used to classify streams based on landscape position within the watershed, a bioclimatic region, or the spatial-temporal scales associated with geomorphic characteristics and processes (Strahler, 1952; Frissell et al., 1986).

Reaches in this study were classified using two systems, the Rosgen classification system (Rosgen, 1985; Rosgen, 1994; Rosgen, 1996), and the Montgomery-Buffington system (Montgomery and Buffington, 1993; Bisson and Montgomery, 1997; Montgomery and Buffington, 1997) (Table 11). In each of these systems, stream reaches are separated into categories based on specific physical properties such as bankfull width-to-depth ratio, gradient, sinuosity, bed material size, valley morphology and landscape position.

TABLE 11. Stream-Type Control Variables

Classification System	Variable Type	Stream-Type
Rosgen Stream-Type	ordinal	A B C D E F G
Montgomery and Buffington Stream-Type	ordinal	Colluvial Bedrock Cascade Step-pool Plane-bed Pool-riffle Dune-Ripple (Regime) Braided

These two systems were chosen because they focus on similar characteristics such as channel form, gradient, fluvial processes, and channel bed and bank material. Rosgen (1996; 1994) has proposed that his classification system is useful for predicting channel behavior. The Montgomery and Buffington (1993) classification system has not been suggested for use as a diagnostic tool (Bisson and Montgomery, 1996). However, it was used as such in this study in order to compare channel form and behavior among stream-types, and to assess its value in predicting stream response.

Rosgen Stream-Type

The Rosgen system (1985; 1994; 1996) classifies streams based on measured channel and valley features. There are seven major stream-types in the Rosgen system: A, B, C, D, E, F, and G. They are based on measured values of entrenchment (floodprone width/bankfull width), gradient, width-to-depth ratio and sinuosity (Table 93, appendix B). These can be further subdivided by dominant channel material (Rosgen, 1994).

Rosgen suggests that streams and stream reaches of one type will respond to watershed and channel processes in the same general way and will have the same general form and pattern. The objectives of this system are to predict river behavior, develop hydraulic and sediment relations, extrapolate data from one reach to similar reaches, and "to provide a consistent and reproducible frame of reference of communication" (Rosgen, 1994: 170) among professionals. In this study, Rosgen stream-type was used to evaluate relationships between stream-type and ISS effectiveness, channel morphology, ISS survival and ISS performance. The stream-types in this thesis included Rosgen types A, B, C, and E.

The Rosgen system is well known and widely used by the USDA Forest Service (USDA Forest Service, 1992; USDA Forest Service, 1996), and is being adopted by other land managers such as the BLM and by private watershed consultants (Naiman et al., 1992). Classification can be done at more than one level of detail. Level I and level II classifications were used in this study. Level I classification is done using 1:24,000-scale USGS quadrangle maps and aerial photos to measure valley gradient and sinuosity, and to evaluate valley form and channel landscape position. Level II classification is done using field measurements of bankfull width and depth, floodprone width, gradient, reach length, valley length, and calculated values of bankfull width-to-depth ratio, entrenchment and sinuosity. Stream-type is selected using these reach characteristics.

A few studies have shown similar behaviors in streams that are the same Rosgen type. Myers and Swanson (1996a) found that channel morphology and bank vegetation in Rosgen B4 streams responded in a similar way to the elimination of grazing. They suggested that stream-type may limit the potential range of values of pool frequency, stream width, and stream depth, and that rates of change in channel geometry may vary by stream-type. In another study, Myers and Swanson (1992) evaluated Rosgen types A2, A3, A4, B1, B2, B3, B4, C3, and C4 and found that stream-type was the most significant indicator of stream stability. Few other studies have evaluated stream response by stream-type.

Montgomery-Buffington Stream-Type

Montgomery-Buffington guidelines were used to classify stream reaches into classes or types (Table 94, appendix B) based on valley confinement, landscape position, hillslope materials and processes, channel form, channel material and dominant channel-forming processes (Montgomery and Buffington, 1993; 1997; Bisson and Montgomery, 1996). Specifically, eight reach types are defined on the basis of typical bed material, bedform, dominant roughness elements, dominant sediment sources, sediment storage elements, typical confinement, and typical pool spacing and typical slope (Bisson and Montgomery, 1996). They applied this classification to an assessment of channel condition and response in reaches in Oregon and Washington in order to explain particular channel morphologies (Montgomery and Buffington, 1993; 1997; Bisson and Montgomery, 1996). Montgomery-Buffington streams types in this study were plane-bed and pool-riffle.

ISS Control Variables

Three ISS characteristics were used as control variables to assess ISS survival and performance. These included ISS type, ISS gradient and ISS anchor (Table 12).

TABLE 12. ISS Control Variables

Variable	Type	Category
ISS Type	nominal	SL = Log, single piece ML = Log, multiple piece B = Boulder, multiple piece LB = Log Boulder, multiple piece
ISS Gradient	ordinal	L = 0 - 2% M = > 2 - 4% H = > 4%
ISS Anchor	nominal	Y = Yes N = No

In-Stream Structure (ISS) Type

There are four main types of ISSs in the study area: log-boulder (LB), multiple-boulder (B), multiple-log (ML) and single-log (SL) (Figure 4, chapter I). ISS type is a control variable to assess which ISS types survive or perform best. Each type of ISS may be affected differently by watershed, channel and stream-type characteristics.

ISS Gradient

The gradient of each ISS was measured from the pool tail crest just downstream of the ISS pool to just above the upstream side of the weir. A clinometer was used to measure ISS gradient. Gradient was recorded in one of three categories; low (0 - 2%), medium (> 2 - 4%) and high (> 4%). It was expected that ISS gradient was an important variable affecting ISS survival and performance. As gradient increases, stream velocity increases and the flowing water has more power to erode and adjust channel width and depth, and to transport sediment (Easterbrook, 1993). Greater slopes and water velocities also apply greater force against an ISS and may have greater ability to move it. Water flowing over ISSs with lower gradients would have less power to erode and transport sediment. In low gradient conditions, sediment may be deposited in ISS pools as the sediment transport capability of the water decreases.

ISS Anchor

ISSs in the study reaches were anchored in two ways. The most common ISS anchoring technique was to cable logs and boulders together with half inch steel cable, secured with epoxy. Log-weirs were usually anchored into the banks through burial in the bank. Whether an ISS was anchored (Y) or not-anchored (N) was recorded during the surveys of ISS survival and performance. Previous Forest Service studies evaluated ISS

survival using ISS anchor as a control variable and found that the survival rate of ISSs was higher when ISSs were anchored than when they were not anchored (Fitzgerald, 1997; Roper et al., 1998).

Response Variables

Response variables used in this study will be discussed in three groups: those that measure effectiveness in meeting target values (for research question 1), ISS effects on local channel morphology and vegetation (for research questions 2 and 3), and ISS survival and performance (for research question 4). Sources for the target values will be discussed first, followed by a discussion of the target value response variables used in this study.

ISS effectiveness, and channel morphology and vegetation were measured in 13 stream reaches surveyed in 1997. ISS survival and performance were recorded for 150 ISSs in 12 stream reaches surveyed in 1997 (Taylor data set), and for 904 ISSs in 43 stream reaches during the 1996 and 1997 Forest Service assessment of ISS durability (survival) and performance (appendix C).

ISS effectiveness was evaluated at the level of the reach. Effectiveness target values were selected from empirical, quantitative studies and from land management agency documents and are used for comparison to actual reach characteristics measured in the field. Channel morphology and vegetation at ISS locations were evaluated at the level of individual habitat units. ISS survival and ISS performance were evaluated at the level of the reach and at the level individual ISS.

Data Sources for Effectiveness Target Values

Comparison of the morphological and ecological attributes of reaches to effectiveness target values is one approach to evaluating the effectiveness of habitat enhancement projects involving ISSs. Target values define the stream characteristics that, if attained, might

provide conditions favorable to native fish species in the Columbia River Basin. This study used four sets of target values for comparison to measured attributes in reaches with ISSs (Table 13). These include: (1) target values that have been defined for healthy streams (containing diverse and abundant populations of fish) in a recent study by Lamb (1996); (2) empirically derived, quantitative values of features in streams that were considered to be refugia for anadromous or resident fish, or that were within relatively unaltered remnant habitat in patches of old growth conifers or alder riparian forests (Ebersole, 1994); and (3) desired future conditions and targets defined by the USDA Forest Service (FS) and USDI Bureau of Land Management (BLM) in management plans and agency documents such as PACFISH (USDA Forest Service and USDI Bureau of Land Management, 1995); and (4) the Aquatic Biology Module for Camas Watershed Analysis (Howell and McKinney, 1997). The following section describes each of the four target value sources in more detail.

TABLE 13. Effectiveness Target Value Response Variables

Target Values for Healthy Streams (Lamb 1996)	
	Habitat units / wetted width
	Deep pools / wetted width
	Average maximum pool depth
	Residual pool depth
	Width-to-Depth of riffle, bankfull
	Canopy Cover
	Small LWD per mile
	Large LWD per mile
	Total LWD per mile
Characteristics of Refugia (Ebersole, 1994)	
	Active Bank Erosion
	Overhanging Bank Vegetation
	Canopy Cover (reach canopy density)
	Pool Temperature
	Pool Depth
PACFISH Desired Future Conditions (USDA Forest Service and USDI Bureau of Land Management, 1995)	
	Pools per km
	Water temperature, spawning habitat
	Water temperature, rearing habitat
	Large LWD per km
	Bank Stability
	Width-to-Depth ratio
	Bank Undercut (lower bank angle)
Camas Watershed Assessment Desired Future Conditions (Howell and McKinney, 1997)	
	Bank Stability
	Bank Shrub Cover, all shrubs
	Bank Shrub Cover, > 8 ft (2.46 m) tall

Lamb Study

In a recent study conducted using stream data from reaches in the Blue Mountains within the Umatilla NF, Lamb (1996) evaluated channel characteristics that were thought to play a significant role in the quality of fish habitat and healthy fish populations. Monitoring protocol for fish habitat in the Columbia River Basin suggests that site-specific data from representative "healthy" streams should be used to develop target values for specific regions, and that these values should be used in place of target values identified by PACFISH whenever possible (USDA Forest Service 1994).

Lamb (1996) developed target values from data specific to this region, providing appropriate site-specific data for comparison with measured reach characteristics. Lamb (1996) separated study streams into two groups, healthy and less-healthy, based on the abundance and diversity of fish species that are sensitive to environmental conditions. Healthy streams were defined as those that supports populations of bull trout (*Salvelinus confluentus*), brook trout (*Salvelinus fontinalis*), cutthroat trout (*Oncorhynchus clarki*), steelhead/redband trout (*Oncorhynchus mykiss*), chinook salmon (*Oncorhynchus tshawytscha*) or a combination of these species, and with higher diversity of species than in other streams in the study area. Of thirty variables evaluated, ten were found to be significantly different in streams that supported healthy populations of fish versus streams that were less-healthy (Lamb, 1996). Nine of these effectiveness target values were used in this study.

Ebersole's Refugia

Ebersole (1994) identified reaches that could serve as potential refugia or that were within relatively unaltered remnant patches of old growth conifers or alder riparian forests in Joseph Creek basin in the Blue Mountains in northeastern Oregon. He compared these

reaches to reaches that have been altered by human land uses, such as grazing and logging. The characteristics of refugia identified by Ebersole were used in this study as effectiveness target values and may represent the expression of habitat capacity in some stream systems.

Ebersole (1994) suggested that restoration should allow "natural" processes within a landscape to operate in such a way that optimal habitat condition can occur, and the structures and processes to which native fauna have adapted can develop (Ebersole, 1994). Reaches having refugia or remnant habitats were identified and chosen for analysis (Ebersole, 1994). Refugia are remnant or recovering habitat patches within landscapes disturbed by natural processes (e.g. floods and fires) or intensive land-uses that affect habitat (Sedell et al., 1990). In streams, potential refugia and remnant habitat for fish are patches of complex, functioning habitat within stream reaches. Ebersole (1994) found that cold pools are an important component of refugia and remnant habitat, providing seasonal refuge for coldwater fish, particularly during summer low-flow periods. Cold pools were more frequent in reaches with vigorous riparian vegetation and low amounts of bank erosion than in reaches with less vegetation and greater bank erosion.

PACFISH

Several effectiveness target values used in this study come from the document commonly known as PACFISH (USDA Forest Service and USDI Bureau of Land Management, 1994; 1995). In this study, I compared reach attributes with target values outlined by PACFISH. PACFISH riparian goals establish characteristics of healthy, functioning watershed, riparian areas and fish habitats. PACFISH management objectives define target values that describe the desired future conditions (DFCs) of streams. These target values are considered elements that are diagnostic of overall habitat conditions and that are sensitive to land uses. Based on PACFISH goals and objectives, management activities have been designed that will maintain or restore water quality, channel integrity,

channel processes, sediment regimes, in-stream flows, natural timing and variability of the water table in meadows and wetlands, and the diversity and productivity of plant communities. PACFISH suggests that streams are to be monitored and their characteristics compared to the DFCs.

Howell and McKinney

Howell and McKinney (1997) developed desired future conditions (DFCs) to be used for watersheds and streams in the Camas Watershed in addition to the PACFISH DFCs. Camas Creek is a tributary of the North Fork John Day River. Seven of the 13 reaches surveyed in 1997 are in the Camas Creek watershed. Populations of chinook salmon, steelhead trout and bull trout have been declining in the Camas watershed and this is directly related to habitat degradation. Three DFC effectiveness target values are used in this study

In the Camas Watershed Analysis, Howell and McKinney (1997) recommended that stream characteristics should be compared with DFCs that are developed from measurements made in local, reference watersheds that are functioning within the "natural" range of variability. If reference watersheds are not available, then comparisons can be made with the PACFISH DFCs.

Effectiveness Response Variables to Compare with Target Values

Reach characteristics were compared with target values to address research question 1 to evaluate ISS effectiveness. The general significance of the characteristics that were used to assess effectiveness will be discussed briefly in the next section. The importance of several reach characteristics, including bank stability and canopy cover, have already been discussed earlier in this chapter (see sections about riparian vegetation and seral stage). These will only be mentioned briefly here.

Habitat Unit Frequency

Lamb (1996) used habitat unit frequency as an indicator of channel complexity. He found that healthy streams had a greater habitat unit frequency than less-healthy streams, and established a target value for healthy streams.

Habitat unit number and type is a typical component of stream surveys conducted by land management agencies (USDA Forest Service 1996). Pools, riffles and glides are three major habitat unit categories that are most easily identified during low-flow conditions (Bisson et al., 1982; ODFW, 1995; Montgomery and Bisson, 1996). In this study, habitat units were identified as pools, riffles or glides during field surveys using methods described in the Stream Inventory Handbook (USDA Forest Service, 1996) and in the Methods for Stream Habitat Surveys (ODFW, 1995). Habitat units were identified using morphological and hydraulic features such as water depth, water surface slope, water flow characteristics and turbulence, and bed morphology (Keller and Melhorn, 1978; Bisson et al., 1982; ODFW, 1995; USDA Forest Service 1996). Pools have little or no water surface gradient, a concave bedform created by scour, and a higher bed elevation that acts as a hydraulic control at the downstream end (ODFW, 1995; USDA Forest Service, 1996). Riffles generally have a noticeable water surface gradient, protruding gravel, cobbles or boulders, fast moving water and surface turbulence (Hawkins et al., 1993; Bisson and Montgomery, 1996; USDA Forest Service, 1996). Glides are units with relatively uniform water depth, little or no turbulence in the surface flow with little, and with few bed surface areas that are scoured (ODFW, 1995). In streams where little or no water was present, habitat unit identification was based on bed morphology alone.

Complex channels are important for fish because fish utilize a variety of channel habitat types at different life stages, and patterns of utilization vary among fish species (Bisson et

al., 1982; Bjornn and Reiser, 1991). Habitat unit frequency may be an important characteristic to monitor over time.

Pool Frequency

Pools are very important for fish habitat. Lamb (1996) derived a target value for the number of deep pools per wetted width after finding that deep pools were important in healthy streams. PACFISH recognized the importance of pools for fish habitat and included a target value for the total number of pools per kilometer. Both are a measure of pool frequency, though Lamb (1996) suggested that deep pools were more important than other pools. The number of pools in a stream is influenced by discharge and stream size (as discharge and stream size increase, the number of pools in a given distance decreases), and many National Forests use a procedure to correct for the effects of stream size or drainage area on pool frequency (Lamb, 1996). In this procedure, the number of pools is divided by the reach length expressed in wetted widths.

The PACFISH targets for pool frequency are expressed in pools per kilometer, but are adjusted for differences in stream size or drainage area by varying the pool frequency target for streams of different widths. The target number of pools per kilometer is lower in narrow streams than in wider streams (USDA Forest Service and USDI Bureau of Land Management, 1995; Williams and Williams, 1997).

Pools are areas of deeper and slower moving water in the stream (Gordon et al., 1992). During low flows, pools are the deepest part of the channel (Beschta and Platts, 1986; Bjornn and Reiser, 1991). Pools are important as resting habitat for adult fish, rearing habitat for juveniles, and refuge from drought or cold winter temperatures (USDA Forest Service and USDI Bureau of Land Management, 1995).

Pools are found in most streams and are formed during high flows through scour by turbulence. Pools occur at relatively consistent frequencies in some streams (Keller and

Melhorn, 1978; Keller and Swanson, 1979), especially in streams with mobile beds with particles that are gravel-size or smaller. In these streams, pools also form at bends in channels through lateral scour of bed and banks (Keller and Melhorn, 1978).

In streams with less mobile bed material, larger than gravel size (64 mm), pools are often formed by hydraulic action associated with large obstructions such as large woody debris and boulders (Sullivan et al., 1987; Montgomery et al., 1995) which deflect and direct the flow toward the bed (Beschta and Platts, 1986). In these channels, pool frequency varies and depends on the frequency of the large obstructions (Montgomery et al., 1995). In many channels where pools formed at large obstructions, land managers have removed large woody debris from channels (Montgomery, 1997), and this has resulted in reduced pool frequency and pool quality (Myers and Swanson, 1996a). Reduction in the number and frequency of pools reduces the amount of pool habitat for fish, while increases in LWD will lead to more pool habitat, and greater pool frequency. Keller and Swanson (1979) found that, in western Oregon, pools formed by LWD were spaced every one to two channel widths in 3rd, 4th and 5th order streams. Beechie and Sibley (1997) and Montgomery and others (1995) found that in forested streams in Alaska and Washington, pool frequency decreased as the amount of LWD increased, resulting in a greater number of pools.

Gradient is another factor that influences pool frequency. Beechie and Sibley (1997) found that the percent of the stream in pools was more strongly correlated with moderate gradient than with low gradient channels.

Average Maximum and Residual Pool Depth

In this study, reach average maximum pool depths were compared with Lamb (1996) and Ebersole (1994) target values. Residual pools depths were compared with Lamb target values. During field surveys, maximum pool depth was measured in every pool. Pool tail crest depth was measured at the hydraulic control at the downstream end of the pool, where

the water surface slope breaks into the next downstream unit (USDA Forest Service, 1996). Residual pool depth was calculated by subtracting pool tail crest depth from the maximum pool depth. For each reach, average maximum pool depth and residual pool depth were calculated.

Residual pool depth and maximum pool depth have been found to be positively correlated with fish biomass and influence fish diversity and abundance (Bjornn and Reiser, 1991). Pools of different sizes are important at different salmon life stages, and deeper pools are particularly important (Bjornn and Reiser, 1991). Lamb (1996) found that residual pool depths and average maximum pool depths were greater in healthy streams than in less-healthy streams. Ebersole (1994) found that average pool depth was at least 0.27 meters in reaches that were potential refugia.

Residual pool depth was used to monitor pool depth because it is a measure that is not dependent on discharge (Lisle, 1987), as are pool width, depth, volume and area. Residual pool depth is the depth the pool would be if the stream flow were so low that pools were isolated and not connected to other pools in the stream.

Width-to-Depth Ratio

Lamb (1996) found bankfull width-to-depth ratio measured at riffles was significantly lower in healthy streams than in less-healthy streams, and he proposed a target value for this measure of channel form. PACFISH includes a width-to-depth ratio as a target value for the desired future condition (USDA Forest Service and USDI Bureau of Land Management, 1995). In PACFISH stream wetted width and mean low-flow pool depth are used to calculate width-to-depth ratio.

PACFISH considers width-to-depth ratio to be an indicator of changes in channel morphology related to land-uses in the watershed (USDA Forest Service, 1994; USDA Forest Service and USDI Bureau of Land Management, 1995). An increasing width-to-

depth ratio indicates high sediment loads, high peak flows and associated bank erosion (USDA Forest Service, 1994). Width-to-depth ratio is an index of channel morphology, and it can be used as an indicator of the balance between sediment transport capacity and sediment load (Rosgen 1994; 1996; USDA Forest Service and USDI Bureau of Land Management, 1995). Stream widening results in shallower channels, reduced pool depth and losses in pool habitat. Wider, shallower channels could result in decreased stream shading in forested reaches, leading to increased incidence of solar radiation and increased stream temperatures (USDA Forest Service, 1994). These changes related to width-to-depth ratio could greatly affect fish habitat conditions.

Canopy Cover and Reach Canopy Density

Canopy cover and reach canopy density are measures of the amount of stream surface area that is shaded by streamside shrubs and trees; therefore it is an important control of stream temperature. Canopy cover was found to be greater in healthy streams than in less-healthy streams (Lamb, 1996). Reach canopy density was higher in reaches identified as refugia and remnant patches than in disturbed watersheds (Ebersole, 1994). The importance of stream side forests and shrubs is included in the discussion earlier in this chapter about the riparian seral state control variable.

Canopy cover and reach canopy density both represent the percent of the stream water surface obscured by surrounding topography or forest, shrub or overhanging vegetation. Canopy cover percent was converted to a categorical variable in this study and in the Lamb (1996) study. A corresponding measurement, reach canopy density, is a target value identified using data from the Ebersole (1994) study. Canopy cover percent and reach canopy density in this thesis were measured using a convex, spherical densiometer (Platts et al., 1987). In both the Lamb (1996) and Ebersole (1994) studies, canopy cover and reach canopy density were also measured using a convex, spherical densiometer. While

measurements of canopy cover made with spherical densiometers may overestimate canopy cover (Cook et al., 1995), it is assumed that its use in these three studies provide consistent data for comparison.

Large Woody Debris

Large woody debris (LWD) is an important component of stream systems (Maser et al., 1988; Bilby and Bisson, 1998). PACFISH set a target value for total LWD frequency, and Lamb (1996) found significantly higher frequencies of small LWD, large LWD and total LWD in healthy streams than in less-healthy streams.

In this study, the number of pieces of small and large LWD within the bankfull channel were counted. In forests east of the Cascade mountains, large LWD is greater than 20 inches (50.8 cm) in diameter at a length 35 feet (11 m) from the large end (USDA Forest Service, 1996). The number of pieces of small LWD includes both small and medium large woody debris. Small LWD is at least 6 inches (15.2 cm) in diameter at a length of 20 feet (6.2 m) from the large end (USDA Forest Service, 1996).

For descriptive purposes, large woody debris complexity was noted using Oregon Department of Fish and Wildlife categories (Table 14) (ODFW, 1995). This measure of complexity indicates the provision of fish cover and habitat, and provides a qualitative description of large wood accumulations in the channel.

TABLE 14. Large Woody Debris Complexity (ODFW, 1995)

1	Woody debris absent and in very low abundance; little or no habitat created.
2	Wood present but mostly small, single pieces which contribute little to habitat complexity; ineffective at moderate to high discharge.
3	Wood present as single pieces and/or small accumulations; Provides some cover and habitat complexity at low to moderate discharges but ineffective at high discharge.
4	Wood present as medium to large pieces in accumulations incorporating small pieces and root wads; provides good cover and habitat complexity at most discharges.
5	Wood present as single large pieces, accumulations and jams trapping large amounts of additional material creating a variety of cover and complex habitats; creates complex flow patterns and persists at all discharges.

The number of log-jams and surface area covered by each was recorded in each reach. These were not specific effectiveness target values, but were recorded to provide insight into the relationships between watershed vegetation condition, large woody debris, channel dynamics, and to characterize the interaction of wood with the stream.

LWD is important because it interacts with channel processes to form complex aquatic habitat, creates and maintains pools, reduces stream velocities and traps and stores organic material for later processing (Sedell and Beschta, 1991). LWD is an important control of channel morphology and hydraulics and influences ecological features and the diversity of stream habitats and aquatic species (Keller and Swanson, 1979; Gregory and Davis, 1992). It is associated with high quality habitat for fish, provides protection from predators and refuge in winter and during high flows (Sedell and Beschta, 1991).

LWD accumulation in streams ranges from individual pieces and small accumulations to large debris jams, and varies with watershed and channel characteristics (Keller and Swanson, 1979; Sedell and Beschta, 1991). The amount, distribution and function of LWD

varies with channel size. Bilby and Ward (1989) found greater accumulations in small channels (less than seven meters wide) than in wide channels in streams in western Washington. As channel size increased (in streams greater than 3rd order), LWD occurred less frequently. The USDA Forest Service (1994) reported that accumulations and log-jams were common in unconstrained, depositional reaches (Schumm, 1977), but can also occur in constrained channels which usually impede the downstream transport of the wood. In a study in the Oregon Coast Range, Marston (1982) found that log-jams and log-step frequency were related to stream order. Log-jams were generated in 1st order streams, created stable log-steps in 2nd and 3rd order streams, and were less stable and more easily breached in 4th and 5th order streams (Marston, 1982). The relationships between stream order and accumulations of LWD as log-jams may be related to greater erosion and tree fall in 1st order streams, greater channel width and valley constraint in 2nd and 3rd order reaches, and related to greater transport capacity in 4th and 5th order streams.

LWD can affect channel form. In low gradient channels, debris jams of LWD can increase local channel width by more than 50% by creating a diversion and erosion around the obstruction (Keller and Swanson, 1979). Thompson (1995) found that channels were wider and deeper upstream and downstream from LWD, and that LWD diverted water onto the floodplain creating a morphologic and hydraulic connection (Sedell and Beschta, 1991). This increases groundwater recharge and raises the water table (DeBano and Heede, 1987).

LWD is important in pool formation and the creation of complex habitat in mountainous streams in the Pacific Northwest (Montgomery et al., 1995), especially in smaller streams (Bisson et al., 1987). Channels with riparian forests have complex channel habitat because of this (Montgomery, 1997). Trotter (1990) found that reaches with LWD had greater depth, width, and morphologic and hydraulic heterogeneity than reaches without LWD. Ralph and others (1994) found that pool area and depth decreased due to lack of large LWD in watersheds where timber was intensively harvested.

Log-steps created by LWD promote the development of plunge pools. They also lower channel gradient by forming a water surface profile similar to a step-pool bed morphology (Montgomery and Buffington, 1997; Thompson, 1995; Montgomery and Buffington, 1993; Keller and Swanson, 1979). Lowering channel gradient and stream power is especially important in reducing the erosive power of stream flow, especially in steep channels (Keller and Swanson, 1979; Heede, 1981; Marston, 1982; DeBano and Heede, 1987; USDA Forest Service, 1994; Thompson, 1995; Hedman, 1996). The formation of step-pools decreases shear stress (Grant et al., 1990), reduces stream velocity upstream from the LWD, and provides storage for sediment and organic matter (Trotter, 1990; Abbe and Montgomery, 1996). Sediment fills in behind LWD which creates the stepped channel profile and reduced channel gradient (Heede, 1981). Trotter (1990) found that reaches with LWD stored twice the amount of organic matter as reaches without LWD. Log-steps also reduced water velocities during spring runoff, reducing the potential energy available for erosion, channel incision and bank scour (Montgomery et al., 1996).

Bank Stability and Bank Erosion

Bank stability is considered to be a strong indicator of fish habitat condition especially in unconstrained, alluvial, meandering channels in easily eroded materials (Platts et al., 1987). In this study, bank stability was an effectiveness target value from PACFISH (USDA Forest Service and USDI Bureau of Land Management, 1995) and Ebersole (1994). Bank stability is used to monitor bank condition in the PACFISH strategy and in the Camas Watershed Assessment (Howell and McKinney, 1997). Ebersole (1994) identified highly stable banks (< 3% active erosion) as a characteristic of refugia. Bank erosion was also evaluated in this study as an indicator of the possible impacts on channel morphology resulting from the placement of ISSs in stream reaches.

Bank stability and its measurement in the field were discussed earlier in this chapter in the channel control variables section. As an effectiveness response variable, low levels of bank stability (high levels of bank erosion) indicate channel adjustment to changes in discharge and sediment supply (Downs and Gregory, 1993), which can reflect larger scale changes in watershed condition. Bank stability is important in influencing channel form characteristics such as width-to-depth ratios and channel plan form (Gordon et al., 1992).

Overhanging Bank Vegetation

Ebersole (1993) identified overhanging bank vegetation as a characteristic associated with refugia and remnant habitat for fish. In addition to enhancing bank stability and channel form, overhanging bank vegetation provides shade and insulation, keeping streams cooler in summer and warmer in winter (Beschta et al., 1987; Beschta, 1993; Beschta, 1997b). It is important to fish habitat because it provides cover and protects fish from predation (Gordon et al., 1992). It may be more important in smaller streams than it is in larger streams.

Overhanging bank vegetation included woody (mostly shrubs) and herbaceous plants (mostly sedges, grasses and shrubs). Vegetation was considered to be overhanging if the vegetation covered at least 15 cm (6 inches) of water surface. Overhanging bank vegetation was recorded in the field in the same way as was bank stability and bank vegetation. The portion of the each bank in a habitat unit that was covered by overhanging bank vegetation was recorded as a percent of the total habitat unit length. Right and left banks were averaged for each habitat unit. Habitat unit values, weighted by habitat unit length, were used to calculate reach average. In streams where there was a large amount of overhanging vegetation, grasses and sedges were the predominant vegetation type, and typically a greater water surface area than 15 cm was covered by overhanging bank vegetation.

Bank Undercut

Reach average bank undercut (indicated by lower bank angle of less than 90%), is an effectiveness target value used to monitor bank condition in PACFISH (USDA Forest Service and USDI Bureau of Land Management, 1995). It is suggested in PACFISH that both bank angle and bank stability are indicators of local land use impacts such as grazing, especially in unconstrained alluvial reaches, but that they are not as useful for indicating the impacts of timber harvest and roads. The amount of bank undercut was recorded on right and left banks of each habitat unit. Reach average values were calculated using each habitat unit values weighted by habitat unit length.

A bank with an angle less than 90 degrees promotes the development of undercut banks (USDA Forest Service and USDI Bureau of Land Management, 1995). Stream bank undercuts provide cover for fish (Brookes, 1990; Platts et al., 1987), and some amount of bank undercutting is expected in streams. The angle and amount of undercutting will vary depending on bank material. Bank undercuts occur frequently in streams with banks composed of cohesive materials such as clay and clay-mixtures. However, excessive amounts over-steepened banks caused by fluvial undercutting may indicate instability and excessive erosion (Simon, 1989; Simon, 1995). Stream flow can remove lower bank toe material resulting in bank collapse (Harvey and Watson, 1986; Simon, 1989). This increases channel width and causes significant changes in channel form including decreased water depth (Harvey and Watson, 1986), increased width-to-depth ratio, and losses in the amount of fish habitat.

Temperature

Temperature is an effectiveness target value from Ebersole (1994) and from PACFISH (USDA Forest Service and USDI Bureau of Land Management, 1995). Ebersole (1994)

recorded the minimum temperature in 183 cold pools. In this thesis, an effectiveness target value was calculated from this data (Ebersole, 1994). Mean minimum pool temperature in each reach was compared to this effectiveness target value. To compare reach average temperatures to PACFISH effectiveness target values, an average water temperature was calculated from the temperatures of all habitat units. PACFISH identifies a DFC effectiveness target value for temperature in both spawning and rearing habitat.

Water temperature is important to aquatic organisms which have a limited range of temperature tolerance. Fish are cold blooded and their temperature is closely related to the surrounding water temperature which affects metabolic rates, growth, development and survival. As water temperature increases, their metabolic rate increases (Beschta, 1997b). Salmon and trout require cold water temperatures and depend on high concentrations of dissolved oxygen which increases as water temperature decreases (Wetzel, 1983). As temperatures become higher, the amount of dissolved oxygen is reduced and causes stress for cold water fish (Gordon et al., 1992; Grant et al., 1992; Beschta, 1997b).

During field surveys, a standard thermometer was used to measure water temperature in the deepest part of each pool. Water temperature was also recorded in the deepest part of all other habitat units. Air temperature was recorded at random times throughout the day, and this provided a way to compare variations in stream water temperatures relative to air temperature at the time of the survey. Typically, seven day temperature averages are used to evaluate temperature trends. The approach used in this study, where temperatures were recorded on only one day, may not provide the most representative indicator of stream temperature trends over longer time periods.

Bank Shrub Cover

The Camas Watershed Assessment (Howell and McKinney, 1997) identified a DFC for bank shrub cover, and this was used in this thesis as an effectiveness target value. The

Camas Watershed Assessment addresses conditions in stream reaches in meadows with shrubs or that have the ecological potential for shrub vegetation. In this thesis, bank shrub cover was recorded in all reaches, rather than just in meadow systems. The potential for shrub cover was also considered in the analysis. The significance of bank shrub cover was discussed earlier in this chapter in the section about the bank vegetation control variable.

Reach average bank shrub cover was determined in the same way as bank stability, bank vegetation, and overhanging bank vegetation. During field surveys, estimates were made of all shrubs along the bank, and of shrubs along the bank greater than 8 ft (2.46 m) tall. Shrubs types varied among the reaches and included alder (*Alnus* spps.), red osier dogwood (*Cornus stolonifera*), *Vaccinium* spps. and some willow species (*Salix* spps.).

Local Channel Morphology and Vegetation Response Variables

Local channel morphology and vegetation at specific ISS locations were evaluated to address research question 2. The specific characteristics evaluated included residual pool depth, wetted width, bank erosion and bank vegetation. The values of these characteristics at habitat units with ISSs (upstream and downstream of ISSs) were compared to the values at habitat units without ISSs. Research question 3 addresses the influence of watershed, channel, stream-type and ISS controls on local channel morphology and vegetation in habitat units with ISSs. Residual pool depth was evaluated as an indicator of ISS effectiveness in creating a pool. Wetted width and bank erosion indicate channel adjustment and are important to investigate because ISSs have been reported to contribute to increased erosion, channel widening and changes in channel planform (Heede and Rinne, 1990). Channel widening and bank erosion have been identified by researchers as possible responses to ISSs in streams in eastern Oregon (Beschta et al., 1991; Beschta et al., 1996). The amount of bank vegetation may be affected by ISS presence, and it was evaluated because of its importance as a control of bank erosion.

Residual Pool Depth

The creation of pool habitat under low-flow conditions was the primary objective of the habitat enhancement projects evaluated in this thesis. Residual pool depth was used for this analysis, and is discussed in a previous section in this chapter. In each reach, the residual pool depth at ISS pools was compared with residual pool depth at non-ISS pools to evaluate whether ISS pools were deeper than other pools.

Wetted Width

Wetted width is the width measurement of the water surface perpendicular to the banks, and is typically measured at low-flow conditions. In this thesis, wetted width was measured in habitat units just upstream and downstream of habitat units with ISSs. These wetted widths were compared to those in habitat units not adjacent to ISSs to examine relationships between ISSs and channel widening. Watershed, channel and stream-type control variables were used to evaluate the characteristics of reaches where there were significant differences in wetted width among habitat units with and without ISSs.

Evaluation of wetted widths associated with ISSs is important because greater wetted widths at ISSs than in other parts of stream reaches has been observed (Beschta et al., 1991). This may prevent channel narrowing as vegetation becomes established and channels begin to recover from degradation, and cause additional channel degradation.

Bank Erosion

Greater wetted widths at ISS locations may be associated with increased bank erosion. This study compared bank erosion in habitat units just upstream and downstream from ISSs with bank erosion at habitat units that are not adjacent to ISSs. Watershed, channel and stream-type control variables were used to evaluate reaches where there were significant

differences in bank erosion among habitat units with and without ISSs. While there may be other causes of bank erosion within a channel, there may be significant patterns of bank erosion associated with ISSs. It is important to monitor indicators of channel adjustment and/or degradation that might have resulted from ISS presence. For example, Downs and Gregory (1993) identified greater bank erosion immediately upstream and downstream from ISSs. Increased bank erosion at ISSs indicates channel adjustment and possible channel degradation in response to ISS presence. Bank erosion associated with changes in channel location at ISSs, such as lateral migration around the ISS, also indicates channel adjustment due to ISS presence.

Bank Vegetation

Bank vegetation is important in controlling bank erosion and was discussed earlier in this chapter in the channel control variables section. Bank vegetation in habitat units with ISSs is important to evaluate. If bank vegetation along the bank is decreased due to ISS presence, bank erosion may increase as a result. Bank vegetation percent in habitat units upstream and downstream of ISSs was recorded during field surveys and compared with bank vegetation percent in habitat units without ISSs. Estimates of vegetation along the bank included all vegetation types, such as grasses, sedges, forbs, shrubs and trees.

ISS Response Variables

ISS survival and ISS performance were recorded for 150 ISSs in 12 reaches surveyed in 1997 (Taylor data set) and for 904 ISSs in 43 reaches surveyed in 1996 and 1997 (Forest Service data set). Watershed, channel, stream-type and ISS control variables were examined to identify the most influential control variables.

ISS Survival

ISS survival was divided into three categories: (1) in place (I), (2) shift on site (S) and (3) left site (L) (Table 15). In some analyses, these were reduced to two categories: (1) survived (Sv), (all the ISSs that remained in place or shifted on site, and (2) failed (Fd) (all ISS that left the site). These ISS responses were evaluated to assess whether ISSs survived in some types of streams better than in other types of streams, and if some types of ISSs survived more often than other types of ISSs. Influential control variables that influenced ISS survival were then identified.

TABLE 15. ISS Survival Response Variables

Variable	Type	Category
Survival	nominal	I = In Place S = Shift on site L = Left Site
Survival	nominal	Sv = Survived (same as I above) Fd = Failed (combines S and L above)

ISS Performance

ISS performance was evaluated based on whether or not ISSs were functioning and met initial project objectives. During field surveys, ISS performance was recorded in one of three categories: (1) functioning (F), (2) partially functioning (P), or (3) not functioning (N). In several of the analyses presented in this study, the three ISS function categories have been reduced to two categories: (1) functioning (Fc) (all the ISSs that were functioning), and (2) not functioning (Fn), (all of the ISS that were partially functioning and not functioning) (Table 16).

TABLE 16. ISS Performance Response Variables

Variable	Type	Category or Dimensions
Performance	nominal	F = Functioning P = Partially Functioning N = Not Functioning
Performance	nominal	Fc = Functioning Fn = Not Functioning
Pool Depth (maximum)	continuous	meters

In the Umatilla NF, the main objective of stream habitat enhancement projects and, in particular, ISSs was to provide habitat for anadromous and resident steelhead salmon. Habitat enhancement projects have focused on creating more pools (NPPC, 1982), primarily because the number of pools relative to riffles has decreased from 50:50 to 20:80 or 10:90 in many streams (USDA Forest Service and USDI Bureau of Land Management). This has reduced the amount and variety of suitable habitat for fish to use as cover and resting area (Brookes, 1990).

The variables described in this chapter were used for the analysis of ISS effectiveness, and channel morphology described in chapter V, and for the analyses of ISS survival and ISS performance described in chapter VI.

CHAPTER V

IN-STREAM STRUCTURE EFFECTIVENESS AND CHANNEL MORPHOLOGY

This chapter includes the analyses of ISS effectiveness and channel morphology with sections on site selection, data collection, analysis methods, results, discussion and conclusions. The analyses address the first three research questions:

1. Are habitat enhancement projects involving ISSs effective in meeting empirically derived and agency defined target values for salmonid habitat characteristics?
2. To what extent do ISSs affect stream channel morphology by contributing to differences in pool depth, wetted width, bank erosion or the amount of bank vegetation?
3. What are the watershed, channel, stream-type and ISS characteristics that are associated with differences in pool depth, channel width, bank erosion or the amount of bank vegetation associated with ISSs.

Data came from field surveys of 13 reaches conducted in 1997 (Taylor data set), and from map analysis. Effectiveness was evaluated at the level of the stream reach. Channel morphology was evaluated at the level of the individual habitat unit. At either the reach or habitat unit scale, the morphological and ecological features of interest are those that contribute to specific physical habitat characteristics that are associated with desired conditions for anadromous salmonids.

Approaches to Answering the Research Questions

Research Question 1: Effectiveness

The first research question was addressed by comparing actual reach characteristics with effectiveness target values (Table 17). The importance of each characteristic, and its measurement in field surveys were discussed in chapter IV.

The effectiveness target values used in this study define channel and habitat conditions necessary for anadromous and resident salmonids, or are found in streams that they use. Target values came from four sources: 1) target values that have been defined for healthy streams (containing healthy populations of fish) (Lamb, 1996) (Table 18); 2) empirically derived, quantitative values of features in streams considered to be refugia or relatively unaltered remnant habitat in patches of old growth conifers or alder riparian forests (Ebersole, 1994) (Table 19); 3) desired future condition (DFC) targets in PACFISH Interim Strategies for Managing Anadromous Fish-producing Watersheds in Eastern Oregon and Washington (Tables 20 and 21) (USDA Forest Service and USDI Bureau of Land Management 1995); and 4) the Aquatic Biology Module for Camas Watershed Analysis, Umatilla NF, North Fork John Day District (Howell and McKinney, 1997) (Table 22).

An evaluation of ISS effectiveness using these four sets of target values provides an opportunity to evaluate reach condition, and an opportunity to evaluate the usefulness and appropriateness of each set of target values. For example, target values for some characteristics, such as pool frequency and bank stability have been identified in more than one target value source. Some sources provide more complete or more stringent criteria for evaluating channel condition, and some target values may be most applicable in specific geomorphic and ecological settings. In addition, some target value characteristics may be interdependent with other characteristics. Comparisons and relationships between similar target value characteristics and interdependent target value characteristics will be addressed.

TABLE 17. Summary of Effectiveness Target Value Variables

Target Values for Healthy Streams (Lamb 1996)
Habitat units / wetted width
Deep pools / wetted width
Average maximum pool depth
Residual pool depth
Width-to-Depth of riffle, bankfull
Canopy Cover
Small LWD per mile
Large LWD per mile
Total LWD per mile
Characteristics of Refugia (Ebersole, 1994)
Active Bank Erosion
Overhanging Bank Vegetation
Canopy Cover (reach canopy density)
Pool Temperature
Pool Depth
PACFISH Desired Future Conditions (USDA Forest Service and USDI Bureau of Land Management, 1995)
Pools per km
Water temperature, spawning habitat
Water temperature, rearing and migratory habitat
Large LWD per km
Bank Stability
Width-to-Depth ratio
Bank Undercut (lower bank angle)
Camas Watershed Assessment Desired Future Conditions (Howell and McKinney, 1997)
Bank Stability
Bank Shrub Cover, all shrubs
Bank Shrub Cover, > (2.46 m) tall

TABLE 18. Target Values for Healthy Streams (Lamb, 1996)

Channel Feature	Target Values	
	Drainage Area	mean
Habitat Unit Frequency; # of habitat units per wetted width	0-20 km ²	0.07900
	20-100 km ²	0.13290
Pool Frequency; # of deep pools per wetted width	0-20 km ²	0.00357
	20-100 km ²	0.00750
Pool Depth; average maximum (ft)	0-20 km ²	1.63
	20-100 km ²	2.23
Residual Pool Depth (ft)	0-20 km ²	1.31
	20-100 km ²	1.70
Width-to-depth ratio of riffles, bankfull	0-20 km ²	9.22
	20-100 km ²	12.279
Canopy Cover Category 1 = 0-19% 2 = 20-30% 3 = 31-60% 4 = 60%	0-20 km ²	3.06
	20-100 km ²	2.83
Large LWD Frequency, # of pieces per mile > 20 inches (50.8 cm) diameter > 35 feet (11 m) long	0-100 km ²	30.59
Small LWD Frequency; # of pieces per mile > 6 inches (15.2 cm) diameter > 20 feet (6.2 m) long	0-20 km ²	64.67
	20-100 km ²	33.12
Total LWD Frequency; # of pieces per mile	0-20 km ²	222.15
	20-100 km ²	127.09

TABLE 19. Ebersole (1994) Characteristics of Refugia

Channel Feature	Target Values
Pool Temperature; median	14.73 °C
Pool Depth; maximum	0.27 meters
Reach Canopy Density (average); mean	43.67%
Overhanging Bank Vegetation %; mean	26.25%
Actively Eroding Bank %; mean	3.75%

TABLE 20. PACFISH Targets for Desired Future Conditions (USDA Forest Service and USDI Bureau of Land Management, 1995)

Channel Feature	Target Values		
	Wetted width (m)	Pools per km	Pools/ wetted width
Pool Frequency; (all pools)	3	154	0.462
	6	90	0.540
	8	76	0.608
	15	42	0.630
	23	37	0.851
	30	29	0.870
	38	23	0.874
	46	19	0.874
	61	14	0.854

TABLE 21. PACFISH Targets for Desired Future Conditions (USDA Forest Service and USDI Bureau of Land Management, 1995)

Channel Feature	Target Values
Width-to-depth ratio bankfull	< 10
Bank Undercut (bank angle)	< 75% of banks with < 90° bank angle
Bank Stability	> 80% stable
Temperature	< 18° C (64.4 °F) (rearing and migratory habitat) < 16° C (61.8° F) (spawning habitat)
Total LWD Frequency; # per km > 20 inches (50.8 cm) diameter > 35 feet (11 m) long	> 20 pieces per mile

TABLE 22. Camas Watershed Targets for Desired Future Conditions (Howell and McKinney, 1997)

Channel Feature	Target Value
Bank Shrub Cover % (length of bank where shrubs are growing along the bank)	> 80%
Bank Shrub Cover % (length of bank where shrubs > 8 feet (2.46 m) tall are growing along the bank)	> 50%
Bank Stability %	> 90% stable

Research Questions 2 and 3: Channel Morphology

Channel morphology and vegetation at ISS locations were evaluated in this study to address the second research question, "To what extent do ISSs affect stream channel morphology by contributing to increased residual pool depth, channel width, bank erosion or the amount of bank vegetation?"

Residual pool depth, channel width (evaluated as wetted width), bank erosion and bank vegetation were chosen for evaluation to examine the characteristics of pools created by ISSs, and to see if there were direct, local effects on channel form associated with ISSs. Wetted width and bank erosion indicate channel adjustment, and are important to investigate because ISSs have been reported to contribute to increased erosion, channel widening and changes in channel planform (Heede and Rinne, 1990). Channel widening and bank erosion have been identified by researchers as possible responses to ISSs in streams in eastern Oregon (Beschta et al., 1991; Beschta et al., 1996). The amount of bank vegetation may be affected by ISS presence and was evaluated because of its importance as a control of bank erosion, and because of the connection between bank erosion and channel widening. Comparisons were made between pools associated with ISSs and other pools in a reach. Wetted width, bank erosion and bank vegetation were compared in habitat units adjacent to ISSs (upstream and downstream from ISSs) and in habitat units that were not adjacent to ISSs (Figure 10). Wetted width and residual pool depth are direct measures of channel form. Bank erosion is a characteristic that may indicate that channel form is changing in response to ISSs, and constructed ISSs may be a trigger of channel form adjustment through bank erosion.

Control variables that might influence channel form, such as drainage area, gradient and bank material size, were included in an analysis to address research question 3, "What are the watershed, channel and stream-type characteristics that are associated with differences in

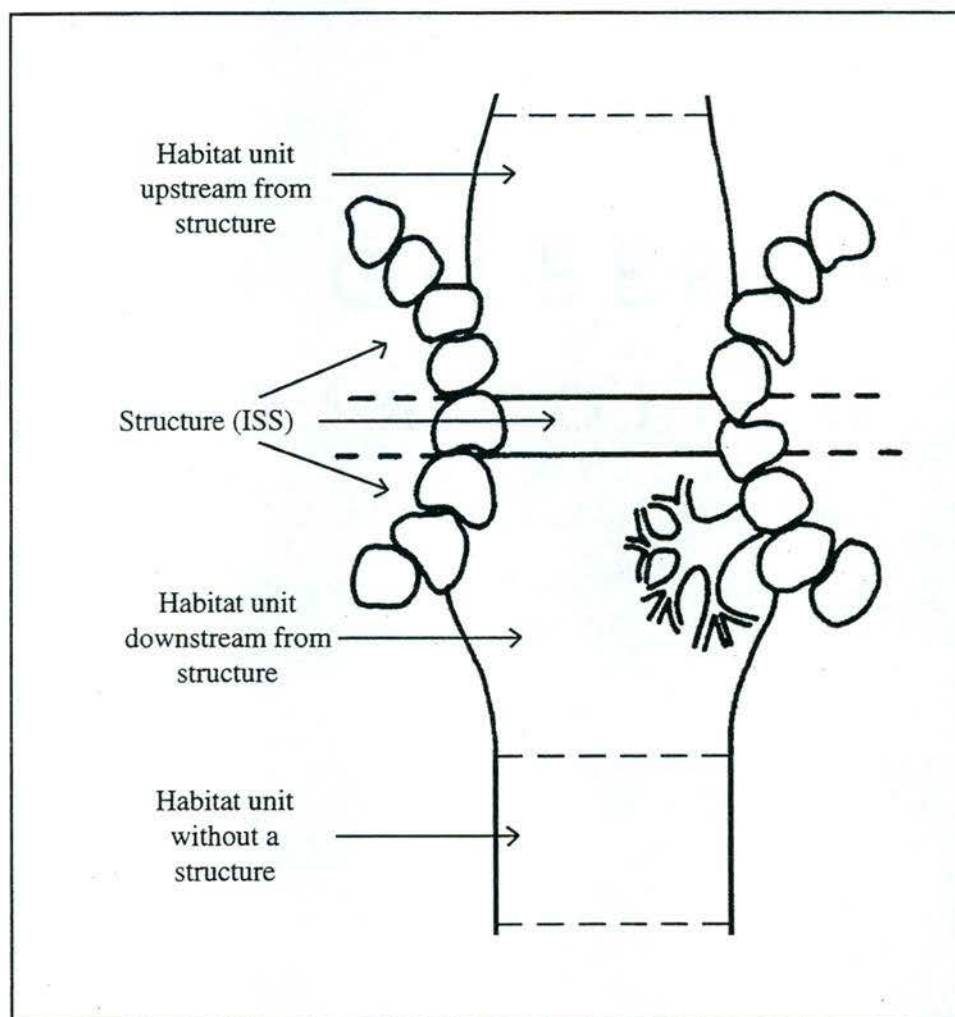


Figure 10. Habitat units associated with ISSs.

pool depth, channel width, bank erosion or the amount of bank vegetation associated with ISSs.” The control variables used are summarized in Table 23 and discussed in chapter IV.

TABLE 23. Summary of Control Variables

Watershed Control Variables
Geology
Valley Constraint
Drainage Area
Stream Order
Fire Occurrence
Channel Control Variables
Reach Gradient %
Median (D_{50}) Bed Material (mm)
D_{84} size Bed Material (mm)
Entrenchment Ratio
Sinuosity
Bankfull Width-to-Depth Ratio
Bank Material Size
Bank Stability %
Bank Vegetation %
Riparian Vegetation Seral Stage
Stream-Type Control Variables
Rosgen Stream-Type
Montgomery-Buffington Stream-Type

Site Selection

The stream reaches analyzed in this study were selected (in consultation with Umatilla NF staff) if: (1) they had experienced a large flow event in 1995, 1996 or 1997 (greater than 25 year flood return interval); (2) they contained channel spanning ISSs; (3) drainage area was less than 200 km²; (4) stream order was less than 4th order; and (5) Rosgen stream-type was B, C or E (Rosgen, 1985; Rosgen, 1994; Rosgen 1996). Thirteen reaches were selected for field survey and measurement (Taylor data set). Reach names and locations are listed in Table 95, appendix D. Each reach is illustrated on a section from a USGS 1:24,000-scale quadrangle in Figures 32 to 41, appendix D. Reach characteristics

are listed in Tables 96 to 102, appendix E. A reach is stream segment with relatively homogeneous geomorphic characteristics (Grant et al., 1990; Montgomery and Buffington, 1998; Naiman, 1998). Geomorphic indicators used to delineate reaches included tributary junctions, valley form, valley width, gradient, channel pattern and predominant bed and bank material. All of the reaches selected were located in watersheds that experienced greater than 25 year flood events in 1995, 1996 or 1997, with the exception of two reaches. In Wilson and Big Wall, flood magnitudes were not known due to the absence of gaging stations near those sites. The selected sites contained channel spanning ISSs that were designed to create pools for fish habitat at low-flow. In 12 of the 13 selected sites, drainage area was within the range of drainage areas of the reaches evaluated by Lamb (1996) ($< 100 \text{ km}^2$) and provided valid data comparisons. Sinuosity of the surveyed reaches ranged from 1.10, slightly sinuous, to 1.65, moderately sinuous. Median bed material ranged in size from silt ($< 2 \text{ mm}$) to small cobble (64 - 96 mm).

Data Collection

Data were collected using field surveys and map analysis of the 13 streams reaches (Taylor data set). Surveys were conducted during July, August and September 1997 during low-flow conditions. The following section describes the general protocol used to obtain data during field surveys, and how those data were used to calculate control and response variables for analysis. Details about measuring each individual variable in the field were discussed in chapter IV. Variables that were measured, estimated, derived from maps and aerial photos, or calculated are summarized in this chapter.

Field Surveys

Habitat Unit Identification

Reaches were divided into habitat units and most of the variables were recorded at each habitat unit. Habitat units were identified as pool, riffle or glide using methods described in the Stream Inventory Handbook (USDA Forest Service, 1996), and in Methods for Stream Habitat Surveys (ODFW, 1995). Habitat units are most easily identified during low-flow conditions. A habitat unit must be greater in length than in width to be considered a single habitat unit (USDA Forest Service, 1996). Habitat unit type identification was based on bed morphology and on hydraulic characteristics such as water surface slope and turbulence. In streams where little or no water was present, habitat unit type identification was based on bed morphology alone. Pools are relatively deep, have little or no water surface gradient, a concave bedform created by scour, and a higher bed elevation that acts as a hydraulic control at the downstream end (ODFW, 1995; USDA Forest Service, 1996). Riffles are relatively shallow, and generally have a noticeable water surface gradient, protruding gravel, cobbles or boulders, fast moving water, and surface turbulence (Bisson and Montgomery, 1996; USDA Forest Service, 1996). Glides are units with relatively uniform, intermediate water depth, little or no surface turbulence, and few scoured bed surface areas (ODFW, 1995).

Reach averages were calculated for many of the variables. When these variables were measured at each habitat unit and used to calculate reach averages, each habitat unit value were weighted by habitat unit length. For some variables (wetted width, bank erosion percent and bank vegetation percent), reach averages of habitat units specifically associated with ISSs were also calculated. Reach averages were calculated for habitat units upstream from ISSs, for habitat units downstream from ISSs and for habitat units without ISSs.

Measured Variables

Variables measured during field surveys are summarized in Table 24. Many were measured and recorded at each habitat unit. Others were recorded less frequently. Some were recorded only at pools, some only at riffles and others at irregular intervals.

Many of these variables were measured using the protocol outlined in the Stream Inventory Handbook (USDA Forest Service, 1996), with one important difference. In the Forest Service method, most dimensions are ocularly estimated, and the estimated values are corrected using a smaller set of measured values. For this thesis, variables were measured at every habitat unit in order to avoid any inaccuracies due to estimator error.

TABLE 24. Measured Morphological and Ecological Attributes

Recorded at every Habitat Unit
Habitat Unit Length
Habitat Unit Type (pool, riffle, glide)
Stream Wetted Width
Stream Temperature
Large Large Woody Debris
Small Large Woody Debris
Total Large Woody Debris
Number of Log-jams
Log-jam Area
Canopy Cover
Recorded at Pools
Pool Temperature
Pool Depth
Pool Tail Crest Depth
Recorded at Riffles
Floodprone Width at riffles
Floodprone Depth at riffles
Bankfull Width at riffles
Bankfull Depth at riffles
Recorded at irregular intervals within the reach
Fire Occurrence
Gradient
Air Temperature
Bed Material Size (pebble count)

Estimated Variables

Several variables were estimated at all habitat units (Table 25). For example, for bank vegetation, the length of the bank covered by vegetation was recorded as a percent of the total habitat unit length. This was recorded for both the right and left banks of each habitat unit and averaged for vegetation percent in a habitat unit. Habitat unit average values were weighted by habitat unit length to calculate the reach average value for bank vegetation.

TABLE 25. Characteristics Estimated at Every Habitat Unit

Large Woody Debris Complexity
Bank Stability %
Bank Undercut %
Bank Material Size
dominant
sub-dominant
Bank Vegetation %
Bank Shrub %
Bank Shrub % > 8 ft. (~ 2.46 m.) in height
Overhanging Vegetation %
Inner Riparian Vegetation Seral State

Map Analysis

Several variables were obtained from maps. Drainage area was measured on USGS 1:100,000-scale maps. The perimeter of each drainage area was located at the drainage divide, and drainage area was measured using a planimeter. The drainage areas at both the upstream and downstream ends of each reach were averaged to provide the drainage area for each reach.

Stream order, valley constraint, and valley length were measured on USGS 1:24,000-scale maps. Stream order was determined using the Strahler method (Knighton, 1998) using the blue line stream network as shown on USGS 1:24,000-scale quadrangle maps. A valley was considered constrained if the width of the valley floor was less than 100 feet

(31 m). Valley length was measured from the upstream to the downstream ends of the reach.

The dominant geology of the watershed for each reach was classified using the method outlined by Lamb (1996). Geology for each reach was identified using the 1:500,000-scale Geologic Map of Oregon (Walker and McLeod, 1991) (Table 103, appendix E). The two geology categories were based on hardness and composition. Geology A included igneous and metamorphic rocks ("hard" rock types) such as the members of the Columbia River Basalt Group, the intrusive ultramafics and the older metamorphosed volcanics, mapped as Tcg, Tcs, T_rPzu and T_rPv by Walker and MacLeod (1991). Geology B included the sedimentary and volcaniclastic rock types ("soft" rock types) such as the John Day and Clarno formations, fluvial and lacustrine deposits, siltstones, and sandstones. These are mapped as Tlf, Qal, Tsjf and Tca (Walker and MacLeod, 1991).

Calculated Variables

Some variables used in the analysis were calculated from variables measured or recorded in the field and from values obtained from maps (Table 26).

TABLE 26. Calculated Morphological and Ecological Variables

Reach Length
Bankfull Width-to-Depth Ratio (Lamb, 1996)
Width-to-Depth Ratio (wetted width and pool depth) (USDA Forest Service and USDI Bureau of Land Management 1995)
Median Bed Material Size (D_{50})
84th Percentile Bed Material Size (D_{84})
Entrenchment
Sinuosity

Stream-Type Control Variables

Each reach was classified using both Rosgen and Montgomery-Buffington stream-type classification systems (Rosgen, 1985; Montgomery and Buffington, 1993; Rosgen 1994; Rosgen 1996). A level II classification was used to determine Rosgen stream-type (Rosgen 1996) using the criteria outlined in Table 93 (appendix B). Montgomery-Buffington stream-type was selected using the characteristics in Table 94 (appendix B). Reach characteristics used and stream-type are summarized in Tables 104 and 105 (appendix E).

Effectiveness: Analysis Methods, Results and Discussion

The analysis of ISS effectiveness addresses the first research question, "Are habitat enhancement projects in reaches containing ISSs effective in meeting identified target values that are associated with salmonid habitat?" ISS effectiveness is evaluated by comparing actual reach characteristics to target values.

ISS Effectiveness Analysis Methods

Target Value Comparisons

The analysis of target values is a simple comparison of the average value of each actual reach characteristic with the target value for that characteristic. Reach averages were compared with target values by calculating a "target index" for each target value variable. The target index is the difference between actual measured values at each reach and the target value, divided by the target value. The target index has a range of +1.00 to -1.00. A negative target index indicates that the target value was not met, while a positive target index indicates that the reach exceeded the target value. When the desired condition is that a characteristic is to be greater than the target value, the target value is subtracted from the measured value. When the desired condition of a characteristic is to be less than or equal to

the target value, the measured value is subtracted from the target value. In either case, the resulting target index is negative for variables that do not meet the target value.

The following examples illustrate the calculation and interpretation of target value comparisons. In Big Wall, the total large woody debris per mile was 50.1 pieces per mile. This was compared with a target value of 127.09 pieces per mile from the Lamb (1996) study. A reach would need to contain 127.09 or more pieces of large wood per mile to meet this target value. In this example, when 127.09 is subtracted from 50.1 and then divided by 127.09, the resulting target index is -0.61. Big Wall has 61% less large wood than the amount needed to meet the Lamb target value. North Fork Cable had a width-to-depth ratio of 18.4 and a target value index of -2.09. North Fork Cable had a width-to-depth ratio 2.09 times higher than the Lamb target value for bankfull width of 9.22. Upper Bear Wallow has a target value index of 0.14, a 14% smaller width-to-depth ratio than the Lamb target value.

ISS Effectiveness Results

The results of the target value analysis are summarized in Tables 27 to 30. In these tables, values underlined indicate that a reach met the target value. Table 31 summarizes the target values that were met in each reach, and the number of reaches that met each target value. Actual reach values for each characteristic, the target value and the calculated target value index are listed in Appendix F.

Lamb Target Values

The number of reaches that met Lamb (1996) target values are summarized in Table 32. All of the streams in this study met the Lamb target value for the number of habitat units per wetted width. Lamb used this variable as a measure of channel complexity. Most stream reaches had as many pools as did the healthy streams in the Lamb study, and in half of

TABLE 27. Lamb Target Index Values (An Underline Indicates that the Reach Met the Target Value)

Stream Name	Large LWD per mile	Small LDW per mile	Total LDW per mile	Habitat Units / Wetted Width	Pools per Wetted Width	Residual Pool Depth	Average Maximum Pool Depth	Canopy Cover	Width-to- Depth Ratio
Bear Wallow, lower	-0.89	-0.69	-0.89	<u>1.33</u>	<u>1.52</u>	<u>0.04</u>	<u>0.01</u>	-0.12	-1.00
Bear Wallow, upper	-0.73	-0.81	-0.91	<u>1.42</u>	<u>4.60</u>	<u>0.02</u>	<u>0.19</u>	-0.58	<u>0.14</u>
Big Wall (BW)	-0.36	-0.08	-0.86	<u>1.52</u>	<u>9.67</u>	-0.24	-0.21	<u>0.31</u>	-1.23
Camas (CC)	-0.95	-0.50	<u>0.86</u>	<u>0.89</u>	-1.00	<u>0.13</u>	<u>0.25</u>	-0.18	-2.37
Desolation (DS)	-0.44	<u>5.62</u>	-0.61	<u>2.67</u>	<u>3.40</u>	-0.03	<u>0.10</u>	-0.13	-1.77
Dry Camas (DC)	-0.85	-0.72	-0.90	<u>1.06</u>	<u>0.68</u>	-0.79	-0.98	-0.42	-0.06
Hidaway (HD)	-0.18	<u>4.11</u>	<u>0.53</u>	<u>1.11</u>	<u>1.67</u>	-0.14	-0.17	-0.31	-0.91
Kelsay (KL)	-0.85	-0.77	-0.91	<u>1.14</u>	<u>6.28</u>	-0.06	-0.24	-0.62	-1.09
Lane (LN)	-1.00	<u>0.54</u>	-0.60	<u>1.19</u>	<u>0.33</u>	-0.35	<u>0.16</u>	NA	-0.88
North Fork Cable (NFC)	-0.71	<u>2.94</u>	<u>0.21</u>	<u>2.75</u>	<u>4.88</u>	-0.03	<u>0.08</u>	NA	-2.09
Phillips (PH)	-0.51	<u>1.04</u>	-0.35	<u>0.19</u>	<u>0.73</u>	-0.51	-0.59	-0.04	-1.78
Thomas (TH)	-0.94	-0.33	-0.81	<u>1.47</u>	<u>5.93</u>	<u>0.02</u>	<u>0.02</u>	-0.14	-0.82
Wilson (WL)	-0.85	-0.86	-0.93	<u>1.96</u>	<u>0.60</u>	-0.45	-0.27	<u>0.19</u>	-1.39

TABLE 28. Ebersole Target Index Values (An Underline Indicates that the Reach Met the Target Value)

Stream Name	Eroding Banks	Temperature (°C)	Overhanging Vegetation	Reach Canopy Density %	Average Maximum Pool Depth
Bear Wallow, lower (BWL)	-2.47	-0.09	-0.81	-0.22	<u>0.87</u>
Bear Wallow, upper (BWU)	-4.87	-0.02	<u>0.71</u>	-0.79	<u>1.21</u>
Big Wall (BW)	-4.60	-0.19	-1.00	<u>0.53</u>	<u>1.01</u>
Camas (CC)	-5.40	-0.14	-0.89	-0.36	<u>2.18</u>
Desolation (DS)	-3.80	-0.01	-0.96	-0.18	<u>1.80</u>
Dry Camas (DC)	-15.00	-0.27	-0.89	-0.45	-0.67
Hidaway (HD)	-8.87	<u>0.05</u>	-0.92	-0.43	<u>1.11</u>
Kelsay (KL)	-3.53	-0.02	<u>1.70</u>	-0.89	<u>1.15</u>
Lane (LN)	-1.40	-0.19	-0.47	NA	<u>0.94</u>
North Fork Cable (NFC)	-4.07	<u>0.12</u>	-0.09	NA	<u>0.98</u>
Phillips (PH)	-9.93	<u>0.12</u>	-1.00	-0.15	<u>0.01</u>
Thomas (TH)	-7.00	<u>0.15</u>	-0.85	-0.24	<u>1.72</u>
Wilson (WL)	-6.73	-0.49	NA	<u>0.33</u>	<u>0.86</u>

TABLE 29. PACFISH Target Index Values (An Underline Indicates that the Reach Met the Target Value)

Stream Name	Bank Stability	Bank Undercut	Pools per km	Temperature rearing habitat	Temperature spawning habitat	L-LWD/mile	Width-to- Depth Ratio
Bear Wallow, lower (BWL)	<u>0.09</u>	<u>0.93</u>	-0.80	<u>0.01</u>	-0.03	-0.90	-0.02
Bear Wallow, upper (BWU)	-0.03	<u>0.99</u>	-0.77	<u>0.07</u>	<u>0.04</u>	-0.90	<u>0.48</u>
Big Wall (BW)	-0.01	<u>1.00</u>	-0.69	<u>0.12</u>	<u>0.09</u>	-0.75	-0.49
Camas (CC)	-0.05	<u>0.96</u>	-0.88	<u>0.03</u>	-0.01	-0.39	-1.09
Desolation (DS)	<u>0.02</u>	<u>0.96</u>	-0.61	<u>0.09</u>	0.06	-0.95	-1.07
Dry Camas (DC)	-0.50	<u>1.00</u>	-0.73	-0.02	-0.06	-0.47	<u>0.39</u>
Hidaway (HD)	-0.21	<u>0.98</u>	-0.63	<u>0.08</u>	<u>0.04</u>	-0.86	-0.25
Kelsay (KL)	<u>0.04</u>	<u>0.91</u>	-0.85	<u>0.10</u>	<u>0.07</u>	-0.22	<u>0.29</u>
Lane (LN)	<u>0.14</u>	<u>0.97</u>	-0.72	<u>0.04</u>	<u>0.01</u>	-0.86	-0.71
North Fork Cable (NFC)	<u>0.01</u>	<u>0.96</u>	-0.70	<u>0.11</u>	<u>0.08</u>	-0.95	-0.12
Phillips (PH)	-0.26	<u>1.00</u>	-0.82	<u>0.13</u>	<u>0.10</u>	-0.59	-0.25
Thomas (TH)	-0.13	<u>0.99</u>	-0.71	<u>0.15</u>	<u>0.12</u>	-0.54	-0.33
Wilson (WL)	-0.11	<u>0.98</u>	-0.80	-0.13	-0.17	-0.95	-0.84

TABLE 30. Howell and McKinney Target Index Values (An
Underline Indicates that the Reach Met the Target Value)

Stream Name	Bank Shrub Cover	Bank Shrub Cover < 8 ft.	Bank Stability
Bear Wallow, lower (BWL)	-0.88	-0.88	-0.03
Bear Wallow, upper (BWU)	-0.96	-0.94	-0.03
Big Wall (BW)	-0.35	-0.44	-0.13
Camas (CC)	-0.48	-0.44	-0.12
Desolation (DS)	-0.74	-0.76	-0.16
Dry Camas (DC)	-0.96	-0.94	-0.09
Hidaway (HD)	-0.86	-0.90	-0.56
Kelsay (KL)	-0.80	-0.98	-0.30
Lane (LN)	-0.61	-0.66	-0.08
North Fork Cable (NFC)	-0.99	-0.98	<u>0.01</u>
Phillips (PH)	-0.54	-0.56	-0.10
Thomas (TH)	-0.10	-0.18	-0.34
Wilson (WL)	NA	NA	-0.22

TABLE 31. Streams Meeting Specific Target Values

TARGET VALUES	NFC	BWU	DS	HD	LN	TH	BWL	BW	KL	PH	CC	WL	DC	
Bank Undercut (PACFISH)	•	•	•	•	•	•	•	•	•	•	•	•	•	13
Habitat Units per wetted width (Lamb)	•	•	•	•	•	•	•	•	•	•	•	•	•	13
Pools per Wetted Width (Lamb)	•	•	•	•	•	•	•	•	•	•		•	•	12
Average Maximum Pool Depth (Ebersole)	•	•	•	•	•	•	•	•	•	•	•	•		12
Stream Temperature, rearing (PACFISH)	•	•	•	•	•	•	•	•	•	•				10
Stream Temperature, spawning (PACFISH)	•	•	•	•	•	•		•	•	•	•			10
Average Maximum Pool Depth (Lamb)	•	•	•		•	•	•				•			7
Small LWD/mile (Lamb)	•		•	•	•					•				5
Bank Stability (PACFISH)	•		•		•		•		•					5
Residual Pool Depth (Lamb)		•				•	•				•			4
Median Pool Temperature (Ebersole)	•			•		•				•				4
Total LWD/mile (Lamb)	•		•	•										3
Width-to-Depth ratio (PACFISH)		•											•	2
Reach Canopy Density (Ebersole)								•				•		2
Canopy Cover Category (Lamb)								•				•		2
Overhanging Vegetation - min (Ebersole)		•							•					2
Bankfull Width-to-Depth ratio at Riffles (Lamb)		•												1
Bank Stability (Howell and McKinney)	•													1
Large LWD/mile (Lamb)														0
Pools per km (PACFISH)														0
Large LWD (PACFISH)														0
Bank Shrub Cover (Howell and McKinney)														0
Bank Shrub (> 8 ft) Cover (Howell and McKinney)														0
Bank Erosion (Ebersole)														0
# of TARGET VALUES MET	12	11	10	9	9	9	8	8	8	8	7	6	4	

them, the average maximum pool depth was as deep. The reaches in this study met the Lamb target value for residual pool depth in only a few reaches. Less than half of the reaches had as much small and total LWD as healthy reaches, and none had as much large LWD as did healthy streams in the region. These data suggest that the lack of LWD did not prevent the reaches from meeting the Lamb target value for pool frequency. Most reaches were too wide and/or not deep enough to meet the Lamb target value for bankfull width-to-depth ratio. In addition, canopy cover in most of the reaches surveyed in this study was not high enough to meet the canopy cover target value, and this would allow reach water surfaces to intercept solar radiation that might negatively impact water temperatures.

TABLE 32. Number of Reaches that Met Lamb (1996) Target Values

Target Values	# of Reaches Meeting Target Values
Habitat Units per wetted width	13
Deep Pools per Wetted Width	12
Average Maximum Pool Depth	7
Residual Pool Depth	4
Bankfull Width-to-Depth at Riffles	1
Canopy Cover Category	1
Large LWD Frequency	0
Small LWD Frequency	5
Total LWD Frequency	3

Ebersole Target Values

The target values from the Ebersole (1994) study were derived from data collected at streams that were considered to be refugia, or that were within relatively unaltered remnant habitat in patches of old growth conifers or alder riparian forests in Joseph Creek basin in the Blue Mountains in northeastern Oregon. These reaches were compared and contrasted

with reaches that were significantly altered by human activity (Ebersole, 1994). Ebersole (1994) surveyed a total of thirty-one reaches ranging in gradient from 1.5 to 4.2%. The reaches were classified into one of five valley form categories: Alluvial-fan-influenced, alluvial, colluvial canyon, alluviated canyon and leveed-outwash canyon. Reaches in colluvial canyons and alluviated canyons were constrained (flood-plain less than 100 feet or 31 m wide). Ebersole (1994) did not report either stream order or drainage area, so stream size is difficult to compare with that of reaches in this study. Drainage area or stream order may be important controlling factors to consider when comparing reach characteristics to target values. The results of the comparisons with Ebersole target values are summarized in Table 33.

TABLE 33. Number of Reaches that Met Ebersole (1994) Target Values

Target Values	# of Reaches Meeting Target Values
Median Cold Pool Temperature (Ebersole)	4
Reach Canopy Density (Ebersole)	2
Overhanging Vegetation - min (Ebersole)	2
Bank Erosion (Ebersole)	0
Average Maximum Pool Depth (Ebersole)	12

Most of the reaches in this study met the Ebersole (1994) target for average maximum pool depth. However, few of the reaches in this study met the remaining Ebersole target values that were derived from refugia and remnant habitat patches. The Ebersole target value for pool depth is quite shallow (0.27 m), and this may not be an appropriate target value to use to assess reach condition. Just a few reaches met the target value for pool temperature indicating that colder pool temperatures are necessary for these reaches to provide refuge habitat. Very few reaches met the target values for reach canopy density or

for overhanging vegetation indicating a lack of streamside shade to reduce stream heating due the interception of incoming solar radiation.

PACFISH Target Values

The PACFISH interim guidelines (USDA Forest Service and USDI Bureau of Land Management, 1995) outline riparian management objectives and define target values that describe the desired future conditions (DFCs) of streams. The results of the comparisons of reach average values with PACFISH target values are summarized in Table 34.

TABLE 34. Number of Reaches that Met PACFISH Target Values (USDA Forest Service and USDI Bureau of Land Management, 1995)

Target Values	# of Reaches Meeting Target Values
Pools per km (PACFISH)	0
Width-to-Depth ratio (PACFISH)	2
Bank Undercut (PACFISH)	13
Bank Stability (PACFISH)	5
Stream Temperature, rearing (PACFISH)	10
Stream Temperature, spawning (PACFISH)	10
Large LWD Frequency (PACFISH)	0

All of the reaches met the target value for undercut banks (bank angle). Most of the reaches met the target value for stream temperature in both spawning and rearing habitats. Less than half met the target value for bank stability. Most of the reaches were too wide and/or not deep enough to meet the target value for width-to-depth ratio. None of the reaches met the target value for pool frequency (pools per km) or for large large woody debris frequency.

Most PACFISH target values were not met by most streams reaches in this study. This indicates that there is potential for better ecological and morphological condition in these

stream reaches. Alternatively, it could indicate that PACFISH values may not be appropriate for some stream reaches evaluated in this study. For example, PACFISH suggests monitoring pool frequency in Rosgen type C stream reaches which are considered to be more sensitive to changes in bedload and discharge than other reach types (USDA Forest Service, 1994). Several reaches evaluated in this study were type B and type E and are expected to respond differently than type C reaches (Rosgen, 1985; 1994; 1996).

Howell and McKinney Target Values

Howell and McKinney (1997) developed target values for the Camas Watershed (in the study area) to supplement the PACFISH guidelines (USDA Forest Service and USDI Bureau of Land Management, 1995). The results of comparisons with the Camas Watershed target values are summarized in Table 35. Few of the reaches met any of the three Howell and McKinney target values. Only one reach in this study met the Howell and McKinney target value for bank stability. There were no reaches that met the two target values for bank shrub cover.

TABLE 35. Number of Reaches that Met Howell and McKinney (1997) Target Values

Target Values	# of Reaches Meeting Target Values
Bank Shrub Cover (Howell & McKinney)	0
Bank Shrub Cover > 8 ft. tall (Howell & McKinney)	0
Bank Stability (Howell & McKinney)	1

Since the Howell and McKinney target values were primarily for use in meadow systems (low gradient reaches with predominantly grass, forb and sedge vegetation types), it may not be appropriate to use them for stream reaches in all ecological and morphological settings, and it may also be important to re-evaluate their use, even in meadow systems. The

bank shrub cover target value may be too high for meadow settings, especially where grasses and sedges are dominant (e.g. Kelsay Creek). In addition, the reaches in this study with the highest percentages of shrub cover on the banks were not in meadow systems, but were in watersheds dominated by trees with some shrub vegetation (e.g. Thomas Creek). Bank shrub cover may also be important in providing canopy cover and shade in reaches where shrubs are common.

As for bank stability, there are few models indicating what bank stability should be, even in healthy reaches. The Howell and McKinney target value for bank stability is 90%. This target value may be appropriate for meadow reaches with predominantly sedge vegetation and cohesive bank material, and could be expected to be even higher in these reaches. However, 90% bank stability may be too high in other reaches.

ISS Effectiveness Discussion

In order to understand and evaluate the effectiveness of ISSs in contributing to improved channel and habitat conditions for salmonids, I will focus this discussion on specific reach characteristics and what the results can tell us about channel conditions. For this discussion, I grouped target value results into major categories that include target values from different sources for similar reach characteristics in order to facilitate comparisons among them. I will also discuss effectiveness as an indicator of overall reach condition. I have based this portion of the discussion on the idea that reaches that met more of the target values were in better condition than reaches that met few target values. Reaches that met few of the target values have great potential for improvement.

Several characteristics, such as pool frequency or pool depth, have a target value from more than one of the four target value sources, but the actual target value varies among the sources. Some target values are more stringent, aiming for better channel and habitat conditions than less stringent target values. The categories I will discuss include habitat unit

frequency, pool frequency and LWD loading, pool depth, vegetation, temperature, and channel form and bank stability. The relative contribution of habitat enhancement projects using ISSs to specific reach characteristics could be better assessed if reach data from before ISS installation were available to compare with current conditions.

Habitat Unit Frequency

Habitat unit frequency was used as a measure of channel complexity in the Lamb (1996) study, and high frequency indicates variability in the shape of the channel bed. All 13 stream reaches met the Lamb target value for the habitat unit frequency. This indicates that stream reaches are at least as complex and have channel bed morphology as variable as healthy streams in the region. ISSs may have contributed to increased habitat complexity through the addition of habitat units. However, as an indicator of channel condition, this assessment should be regarded with caution. Habitat unit frequency may not be a reliable or replicable indicator of reach complexity or changes in reach complexity because habitat unit identification may be subject to observer bias which can result in overestimation or underestimation of the number of habitat units (Poole et al., 1997).

Pool Frequency and LWD Loading

LWD contributes to pool formation (Montgomery et al., 1995) and the number of pools is often correlated with LWD in a stream. Few of the reaches in the study in this thesis met the Lamb target values for small, large and total LWD or the PACFISH target value for large LWD (Table 36).

TABLE 36. Number of Reaches that Met Pool Frequency Target Values

Target Value	# of Stream Reaches Meeting Target Value
Deep Pools per Wetted Width (Lamb)	12
Pools per km (PACFISH)	0
Small LWD/mile (Lamb)	5
Total LWD/mile (Lamb)	3
Large LWD/mile (PACFISH)	0
Large LWD (PACFISH)	0

Most of the reaches in this study met the Lamb (1996) target value for the number of deep pools, and this suggests that low LWD frequency did not significantly affect the number of deep pools. It is also likely that ISSs have contributed to increasing the number of deep pools in many reaches. The Lamb target values were developed using data from streams in the same study area as the reaches evaluated in this thesis. The fact that most of the reaches in this study met the Lamb target value for deep pool frequency, but not the PACFISH target value for pool frequency suggests that the Lamb target may be a more appropriate target value to use to evaluate channel and habitat conditions in the study reaches. Meeting the Lamb target value suggests that reaches with ISSs in this study were in a healthy condition based on the number of deep pools.

The PACFISH target values are more stringent than the Lamb (1996) target values for pool frequency, but the PACFISH target values refer to all pools in the reach, not just the deep pools as does the Lamb target. None of the reaches in this study met the PACFISH target values for pool frequency. Even though the reaches in this study had as many deep pools as healthy reaches in the region, there is still room for improvement if reaches are to achieve the PACFISH pool frequency target values. PACFISH targets for the desired pool

frequency do not, however, address the issue of pool depth which is important for fish habitat in the region.

Since pool frequency is often correlated with LWD in a stream (Sedell and Beschta, 1991) and contributes to pool formation (Montgomery et al., 1995), the lack of LWD in the reaches in this study could, to some extent, account for an insufficient number of pools to meet PACFISH pool frequency target values.

Pool Depth

Most of the reaches met one of the three target values for pool depth, while half or fewer of the reaches met the other two pool depth target values (Table 37).

TABLE 37. Number of Reaches that Met Pool Depth Target Values

Target Value	# of Stream Reaches Meeting Target Value
Average Maximum Pool Depth (Ebersole)	12
Average Maximum Pool Depth (Lamb)	7
Residual Pool Depth (Lamb)	4

Most reaches met the Ebersole (1994) target value for pool depth (0.27 m or 0.87 ft.) derived from reaches that have characteristics of refugia and remnant habitat. While it is likely that ISSs in the reaches have contributed to pools with greater depth in some reaches, few of the reaches had pools that were as deep as those in healthy streams in the region (Lamb, 1996) in either average maximum pool depth (1.63 ft. or 0.5 m for reaches with drainage area less than 20 km² and 2.23 ft. or 0.69 m for those between 20 and 100 km²) or residual pool depth (1.31 ft. or 0.4 m in reaches with drainage area less than 20 km² and 1.70 ft. or 0.52 m in reaches with drainage area between 20 and 100 km²). A pool depth of 0.27 m (Ebersole target value) is quite shallow and does not provide adequate cover or

resting habitat for fish. Pools with greater depth would be necessary to meet the more stringent Lamb (1996) target values, and would improve habitat conditions in many of the reaches in this study.

Deep pools are important as fish habitat. Residual pool depth and maximum pool depth have been found to be positively correlated with fish biomass and influence fish diversity and abundance (Bjornn and Reiser, 1991). Pools of different sizes are important at the different life stages of salmon, and deeper pools are particularly important (Bjornn and Reiser, 1991).

Vegetation

Target values for several vegetation characteristics were used to evaluate reaches in this study. These characteristics included the amount of small, large and total large woody debris (LWD), canopy cover and reach canopy density, bank shrub cover and overhanging bank vegetation. Vegetation influences a number of channel characteristics including bank stability, stream temperature, presence and amount of LWD, habitat complexity and channel structure (Gregory et al., 1991). Vegetation plays a role in the development of channel form since channel form adjustments depend on bank erosion, and vegetation increases bank resistance to erosion (Smith, 1976; Sedell and Beschta, 1991; Knighton, 1998). Vegetation is also considered to be important in regulating stream temperature, primarily because of the shade it provides which varies with seral stage.

In most reaches in this study, canopy cover was less than the Lamb target value, and reach canopy density was less than the Ebersole target value (Table 38). When there is little canopy cover, streams are exposed to more incoming solar radiation. This is likely to contribute to solar heating of the stream water (Beschta et al., 1987; Beschta, 1997b), warming the water and leading to higher temperatures than might be expected in reaches with greater canopy cover.

TABLE 38. Number of Reaches that Met Vegetation Target Values

Target Value	# of Reaches Meeting Target Values
Canopy Cover Category (Lamb)	1
Reach Canopy Density (Ebersole)	2
Small LWD/mile (Lamb)	5
Total LWD/mile (Lamb)	3
Large LWD/mile (Lamb)	0
Large LWD/km (PACFISH)	0
Bank Shrub Cover (Howell & McKinney)	0
Bank Shrub (> 8ft or 2.46 m) Cover (Howell & McKinney)	0
Overhanging Vegetation - mean (Ebersole)	2

Few of the reaches met the target values for LWD. If there were too few trees in the riparian area to contribute to canopy cover, this lack of trees may be one of the reasons why a sufficient amount of LWD was not found in most of the reaches. Two of the three reaches (Hidaway and North Fork Cable) that met the Lamb target value for LWD were in watersheds where a severe fire, the Tower fire, burned in 1996 (USDA Forest Service, 1997). In the absence of natural fire (since fire suppression management policies have been in place), insect populations are large and they have infested a large number of trees in the area. This contributed to high rates of tree mortality and an abundance of downed wood on the forest floor. This downed wood supplied LWD which moved into these channels and was transported downstream by large magnitude floods (> 25 year return interval) which occurred in 1997. These two reaches had many more log-jams than other reaches. This suggests that disturbances are important mechanisms for the delivery of LWD to the channel. However, the timing of the disturbances and the abundance of large wood may be different than it was prior to fire suppression policies were in place. The frequency and abundance of large wood accumulations may not represent the natural range of variability prior to management intervention and intensive human use of the forest. The third reach where the target for total LWD was met was in a watershed where it appeared that there has

historically been less logging than in many watersheds in the region. In this reach, LWD likely came from downed and dead trees that were delivered to the channel over a period of many years, and not from catastrophic disturbance events.

The amount of canopy cover is influenced to a large extent by trees in the riparian area, though shrubs can also be important in providing canopy cover. Trees are more important in providing shade in wide streams than in narrow streams, while shrubs on the bank are more effective in contributing to stream shading in narrower streams. The Camas Watershed Assessment identified shrubs as important for providing canopy cover and shade in meadow systems (Howell and McKinney, 1997). In this thesis, none of the reaches met the target values for either bank shrub cover of all shrubs or bank shrub cover of shrubs greater than 8 feet (2.46 m) tall (Howell and McKinney, 1997). The target for bank shrub cover was 80%, and the two reaches with the greatest amount of bank shrub cover (Thomas and Big Wall) had 72% and 52% shrub cover. The target value for bank shrub cover greater than 8 feet (2.46 m) tall was 50%. Four reaches (Big Wall, Camas, Phillips, and Thomas) had more than 20% bank shrub cover greater than 8 feet tall. None of these reaches were in meadow systems, and several of the reaches that were located in meadow systems (Lower Bear Wallow, Upper Bear Wallow, Kelsay, North Fork Cable, Dry Camas) had the lowest amount of bank shrub cover.

The appropriate and expected ecological settings for shrubs could be reevaluated in order to clarify the use of the bank shrub cover target value and to expand its use to non-meadow streams. Shrubs most likely play an important role in settings other than meadow systems. In these other types of reaches, shrubs are likely to be important in providing shade (Beschta et al, 1987; Beschta, 1997b) and enhancing and maintaining bank stability (Hupp and Simon, 1991).

Overhanging bank vegetation (both woody and herbaceous) is important in providing shade in small streams in meadow systems (Beschta, 1997b) and could be quite important

in providing shade in these systems when shrubs or trees are not present. Overhanging bank vegetation is most effective in providing shade in reaches with smaller sized, more cohesive bank material where channels tend to be relatively deep and narrow (Gordon et al., 1992). Two reaches (Upper Bear Wallow and Kelsay), both in meadow systems, met the Ebersole (1994) target for overhanging bank vegetation. Again, the particular ecological setting is important in that herbaceous overhanging bank vegetation (sedges, rushes, grasses and forbs) was the predominant vegetation in these reaches. In two reaches, Kelsay Creek and Dry Camas, there was evidence that cattle grazing had occurred along the stream banks and had reduced the amount of overhanging bank vegetation. The implementation of grazing management strategies that limit grazing near the stream banks or during certain times of the year would probably have a positive effect on the amount of overhanging bank vegetation and could affect overall channel condition.

Temperature

A majority of the reaches in this study met the PACFISH target values for temperatures in spawning and rearing habitat (USDA Forest Service and USDI Bureau of Land Management, 1995) (Table 39). Only four reaches met the Ebersole (1994) temperature target value for cold pools. While most reaches met the PACFISH target values, few reaches in this study have temperatures as low as the Ebersole target value.

TABLE 39. Number of Reaches that Met Stream Temperature Target Values

Target Value	# of Reaches Meeting Target Values
Stream Temperature, rearing and migratory habitat (PACFISH)	10
Stream Temperature, spawning habitat (PACFISH)	10
Median Pool Temperature (Ebersole)	4

While there are many factors that contribute to water temperatures in streams, lack of canopy cover in reaches in the study area may have a significant affect on stream and pool temperatures. Vegetation characteristics, including the amount of canopy cover, bank shrub cover and overhanging bank vegetation, affect stream temperature and few of the reaches in this study met these vegetation target values. Greater amounts of vegetation might contribute to lowering water temperatures to those as low as in refugia and remnant habitat (Ebersole, 1994) and improve channel habitat conditions.

Channel Form and Bank Stability

Bank stability and erosion have an effect on channel cross-section parameters influencing channel width-to-depth ratio, channel geometry and channel planform (Millary and Quick, 1993).

Five of the 13 reaches in this study met the PACFISH target value for bank stability (USDA Forest Service and USDI Bureau of Land Management, 1995) while only one met the more stringent Howell and McKinney (1997) target (Table 40). The Ebersole (1994) target for bank erosion, even more stringent than the other two target values, was not met in any of the reaches.

TABLE 40. Number of Reaches that Met Channel Form and Bank Stability Target Values

Target Value	# of Reaches Meeting Target Values
Bank Stability (PACFISH)	5
Bank Stability (Howell & McKinney)	1
Bank Erosion (Ebersole)	0
Width-to-Depth Ratio (PACFISH)	2
Bankfull Width-to-Depth Ratio (Lamb)	1

Since erosion of the banks (or low bank stability) is an important indicator of channel adjustment (Downs and Gregory, 1993), this suggests that the reaches in this study are in the process of adjusting. Some amount of channel adjustment is expected in stream channels. However, high bank erosion and low bank stability indicate that channel adjustment might be outside the range of what is expected when a channel is in good condition. This is reinforced by the fact that few of the reaches in this study met the target values for width-to-depth ratio. A high width-to-depth ratio indicates a wide, shallow channel often associated with bank erosion and high sediment transport (Gordon et al., 1992). Of the eight reaches that did not meet the PACFISH target value, five had greater than 70% bank stability suggesting that lack of bank stability may not be a serious problem in these reaches, but there is room for improvement in bank stability in these reaches.

Since bank stability is related to other channel characteristics such as bank material size and bank vegetation, it is important to consider these when evaluating whether or not a reach can achieve these high levels of bank stability. Ebersole (1994) did not report bank material size in the reaches studied, so it is difficult to say whether this level of bank stability is possible in reaches with sandy to gravelly banks (i.e. most of the reaches reported in this thesis). If not, then the higher criteria may not be an appropriate target to use in every case.

Few reaches met the vegetation target values and this may also have an important impact on bank stability and channel form. Roots below the soil surface stabilize banks and are important in channel recovery from disturbance and instability (Hupp and Simon, 1991), and in improving channel form and function (Magilligan and McDowell, 1997). Bank vegetation increases local roughness and bank resistance to flow, reducing bank erosion (Hupp and Simon, 1991; Sedell and Beschta, 1991; Beschta, 1993; McKenney et al., 1995; Knighton, 1998). Vegetation also traps sediment along the bank, contributing to deposition and channel narrowing (Hupp and Simon, 1991). In the reaches in this study, greater

amounts of bank vegetation could stabilize the banks, increase bank stability and contribute to channel narrowing and lower width-to-depth ratios.

In one reach (Kelsay), there was evidence of bank trampling by cattle and it appeared that cattle were crossing the stream just downstream from ISSs. The construction of ISSs may have made the stream itself more accessible to cattle. This could contribute to decreased bank stability.

ISS Effectiveness and Reach Condition

The ranking of stream reaches by the number of target values met could be used as an indicator of relative condition in the reaches. In using the target value results this way, a reach would be considered in better condition when more target values were met. It is also important to consider which target values were met and the characteristics associated with that target value. These factors provide an indication of both the current reach condition and the characteristics that could be improved to provide better habitat for salmon.

Data from the 13 reaches were used to evaluate ISS effectiveness in meeting target values. Twenty-four target values were used in this study. The number of reaches meeting each target value and the target values met by each reach are summarized in Table 31. North Fork Cable met the greatest number of target values, 12 out of the twenty-four or 50% of the target values, and could be considered to be the stream reach in the best condition of the 13 surveyed. However, North Fork Cable met only 50% of the target values, so there is room for improvement in habitat conditions in this reach. Upper Bear Wallow and Desolation followed closely, meeting 11 and ten target values respectively. All but one of the 13 reaches met at least 25% (six) of the target values. Dry Camas met only four of the target values (17%), and could be considered to be the stream reach in the worst condition.

The target value comparison indicated that North Fork Cable had very stable banks, variable habitat types, deep and frequent pools, and plenty of large wood. The target values

not met by this reach (canopy cover, bank shrub cover, overhanging vegetation, and width-to-depth ratio) indicate that some characteristics in this reach could improve.

Dry Camas, Wilson and Camas met the fewest number of target values and were considered to be in the poorest condition. This was supported by the data and by field observations. Dry Camas met only four target values and was dry at the time of the field survey, which made it unsuitable for fish habitat. Because of its dry condition, Dry Camas did not meet target values for pool depth or stream temperature. Dry Camas also did not meet many other target values for characteristics which are independent of the dry conditions (Lamb width-to-depth ratio, bank stability, LWD, canopy cover, reach canopy density, bank shrub cover, overhanging vegetation and PACFISH pool frequency).

Wilson met two more target values than Dry Camas. Wilson met the target values for canopy cover, reach canopy density and Ebersole's average maximum pool depth. While having sufficient canopy cover, Wilson provided less than desirable habitat conditions for fish, and did not meet target values for average maximum pool depth, stream temperature, LWD, overhanging vegetation, bank stability, or width-to-depth ratio. Lack of bank vegetation may have contributed to bank instability and channel widening, resulting in higher than desired width-to-depth ratio. Low residual pool depths and a wide and shallow channel shape do not provide adequate habitat for salmon and may have contributed to higher than desired stream temperatures in Wilson.

Camas Creek met seven target values, three more than Dry Camas. Camas Creek did not meet any of the vegetation target values (canopy cover, reach canopy density, overhanging vegetation, bank vegetation, LWD or bank shrub cover). It did not meet any target values for stream temperature and it was the only reach that did not meet the target values for pool frequency. Camas Creek did not meet the target values for average maximum pool depth, but did meet the target for residual pool depth. Camas Creek did not meet the target values for pool frequency but did meet the target values for average

maximum and residual pool depth. Most of the deep pools in this reach were at ISSs, suggesting that the ISSs may provide critical habitat in an otherwise degraded reach.

Phillips was also predominantly dry. It met eight target values but provided little habitat for fish. ISS pools did contain water and met PACFISH temperature target values (USDA Forest Service and USDI Bureau of Land Management, 1995). Some of the pools were not very deep, and all were isolated from other pools and from stream flow. This could be problematic for fish in terms of food availability if they are confined to a single pool during late summer and their habitat is limited and isolated.

Of the stream reaches that met from eight to eleven of the target values, all met the target values for Lamb (1996) habitat unit and pool frequencies, Ebersole (1994) average maximum pool depth, the PACFISH stream temperature target for rearing and migratory habitat, and the PACFISH bank undercut target value. All but one reach met the PACFISH stream temperature target for spawning habitat. A few of these reaches met the Lamb target values for residual pool depth and small LWD. While several reaches met the PACFISH target value for bank stability, none met the more stringent Howell and McKinney (1997) or Ebersole target values for bank stability.

ISS Effectiveness Summary

The results have shown that many target values were not met in the reaches evaluated. North Fork Cable met the greatest number of target values, and could be considered to be the stream reach in the best condition of the 13 surveyed, but it met only 50% of the target values. Many reaches met only a few of the target values. If the target values are valid as indicators of channel and habitat condition, some of the reaches are only in fair condition and many are in poor condition, and there is room for improvement in habitat conditions in all of the reaches in this study.

When compared with healthy streams in the Umatilla NF (Lamb, 1996), few reaches in this study had most of the characteristics of healthy streams, although some reaches did have some of these characteristics. A few of the streams reaches in this study had some of the characteristics of refugia, or of streams that were within relatively unaltered remnant habitat in patches of old growth conifers or alder riparian forests, and these could be considered to be potential refugia (Ebersole, 1994). The Lamb (1996) target values may be the best target values for assessing streams in the study area since they were developed from data from healthy streams in the same region. Most of the PACFISH target values were not met by most stream reaches in this study. This suggests that there is potential for better ecological and morphological condition in the streams in this study. The Ebersole target values were developed from a limited range of stream-types and so may not be as applicable for use in streams with a wider range of characteristics. The Howell and McKinney target values are more stringent and, if met, may identify reaches where conditions are better for some characteristics than can be identified using the target values from the other sources.

Pool and habitat unit characteristics in the study reaches were evaluated using target values from several sources. Almost all stream reaches met target values for habitat unit frequency and pool frequency (Lamb, 1996). ISSs typically add pools, so it is likely that ISSs have contributed to higher frequencies of all pools and all deep pools in the study reaches. The Lamb target value for deep pool frequency is a particularly useful target value because it indicates the specific kind of pool that is associated with healthy fish populations in the region. The higher pool frequency target value in PACFISH suggests that there may be potential for more pools in streams in the region. While most reaches met the Ebersole (1994) target value for pool depth derived from reaches that have characteristics of refugia, this target value is not as useful because the pools that meet this target value are quite shallow and do not provide adequate fish habitat.

Few stream reaches in this study met the target values for LWD. LWD is an important pool forming mechanism in many streams and it is likely that it plays a role in pool formation in stream reaches in the study area, although the role and importance of LWD in forested streams in the Umatilla NF is not well known. If LWD target values were met in these reaches, LWD could contribute to greater pool frequency.

There are many factors that influence stream temperature, many of which were not considered in this study. One stream (Dry Camas) that did not meet the PACFISH target values for temperature was nearly dry, and the isolated and scant pools downstream from some ISSs in this reach were shallow and warm. Another important factor to consider in relationship to stream temperature is the time period over which temperature was recorded. Stream temperatures are usually evaluated using seven day averages rather than using a single temperature, as was done for this study. During the time that the field surveys were conducted in 1997, it was unusually rainy, and air temperatures were cooler than normal. This was likely to have influenced the stream temperatures that were recorded in most of the reaches surveyed. In one stream reach (Wilson) that did not meet PACFISH or Ebersole target values, temperatures were recorded during a brief hot period in late July when air temperatures were in the low to mid 90s (°F). However, air temperature was not the only factor involved in the higher temperatures in this reach. The portion of Wilson surveyed is oriented in a north-south direction and received direct sunlight during midday, when solar radiation is at its peak. This most likely contributed to higher stream temperatures. Wilson is a tributary of Big Wall, another stream that was surveyed during the hot period. Stream temperatures were cooler in Big Wall than in Wilson, and Big Wall met the two PACFISH temperature target values. Big Wall is oriented in an east-west direction and during the surveys in late July, direct sunlight was blocked for most of the day by a high, steep hillside along the south bank of the stream. Both Wilson and Big Wall had high amounts of

canopy cover, but it appears that stream orientation played a crucial role in influencing stream temperature in these reaches.

Given that few reaches met any of the target values for vegetation characteristics, it is possible that current land uses may limit vegetation establishment and growth in some reaches. Vegetation along the bank is quite important to channel and habitat conditions and can affect many other reach characteristics including bank erosion, channel width and depth, canopy cover, the number of pools and habitat complexity. Logging practices may limit the availability of wood for recruitment as LWD. There was evidence of grazing and bank trampling by cattle which appeared to affect vegetation in Dry Camas. Logging and grazing can limit vegetation establishment and may have contributed to this stream reach not meeting the target values for vegetation. Changes in riparian management might increase the amounts of vegetation and lead to more reaches meeting the vegetation target values.

Target values could be developed to apply in different ecological settings. Vegetation is strongly affected by many controls including local and regional climate, land use and ecological factors, and the potential vegetation type will vary among reaches. For example, a target for LWD may not be appropriate in meadow reaches (low gradient reaches with predominantly grass, forb and sedge vegetation types) with small channels where neither local LWD input nor transport of LWD from upstream is possible. Other ecologically appropriate vegetation target values, such as bank shrub cover or overhanging vegetation, may be more important in meadow reaches. Additional target values could reflect other characteristics or processes that contribute to pool formation and complex cover for fish.

Howell and McKinney (1997) had developed target values for bank shrub vegetation for reaches in meadow systems. Several reaches in this study had high percentages of shrub cover on the banks, close to the target value. However, these reaches were not in meadow systems, they were in forests. Because the meadow reaches in this thesis did not meet these two Howell and McKinney target values, the usefulness and appropriateness of the target

values for bank shrub cover needs further evaluation. In addition, the ecological setting where bank shrub cover is appropriate and the function of bank shrub cover could be better defined. Bank shrub cover can be important for bank stability or as canopy cover to provide shade. If it is overhanging the stream, it may also be important as cover to hide fish from predators. Other vegetation target values could be developed that are specific to reaches in a particular range of well-defined ecological and geomorphic settings.

The recent fires in Hidaway and North Fork Cable watersheds imposed temporary limits on potential bank vegetation. The fire also had noticeable effects on the amount of large wood in the channel, leading to increased amounts of LWD. In combination, disturbances provided delivery mechanisms for LWD in these two reaches. However, the range of natural variability in the timing and intensity of disturbance processes may have been altered by land uses and management practices, such as fire suppression. The Tower Fire that occurred in 1996 was thought to have been far more severe than fires that occurred before fire suppression began in the early 1900s (USDA Forest Service 1997). The effects of fire on riparian vegetation and large wood availability in streams in the region is not well known. More research is needed to understand the role of disturbance in providing large wood and in influencing channel forming processes and channel morphology.

Most of the reaches had greater width-to-depth ratios than suggested by the target values, and few reaches met the target values for bank stability, which can affect width-to-depth ratios. However, ten reaches had greater than 70% bank stability. This suggests that channels may be in the process of recovery from degradation resulting from previous land uses. Both width-to-depth ratios and bank stability could be improved using strategies to increase riparian vegetation cover. When vegetation becomes established, it traps sediment and leads to bank building, channel narrowing and decreased width-to-depth ratios. The time for recovery will likely vary depending on other influential control variables.

Channel width varies in response to many factors, including valley form, channel constraint, sediment and water flow, adjacent bank slopes, and riparian vegetation. A constrained channel with banks confined by bedrock will have a different width-to-depth ratio than a channel flowing through a low-gradient, broad floodplain reach. Bed and bank material size, gradient, and vegetation potential are other factors that will influence channel width and recovery time after disturbance. In addition, width and depth vary spatially within the channel and between different types of channel units. If width and depth were collected at a deep pool, for example, the ratio would be different than if it were taken at a wide and shallow riffle. Analysis of width-to-depth ratio could take variation in spatial and site characteristics into account in order to be more useful as a monitoring parameter (USDA Forest Service, 1994).

The usefulness and appropriateness of the target values needs further evaluation, and the specific ecological setting where bank shrub cover is appropriate needs to be better defined. Some target values may only be appropriate in some types of streams or may not be valid or appropriate at all. The ecological and geomorphic settings varied among the reaches in this study and the potential to meet particular target values may also vary. Some target values may be more appropriate in some types of reaches than in others.

Channel Morphology and Vegetation: Methods, Results and Discussion

Channel morphology and vegetation were evaluated at the habitat unit level for each reach to understand the direct local effects of ISSs on channel characteristics. These analyses address the second and third research questions, "To what extent do ISSs affect stream channel morphology by contributing to differences in pool depth, channel width, bank erosion or the amount of bank vegetation?" and "What are the watershed, channel, and stream-type characteristics that are associated with changes in pool depth, channel

width, bank erosion or the amount of bank vegetation associated with ISSs?" This analysis uses data from field surveys of 13 reaches described earlier in this chapter (Taylor data set).

Channel Morphology and Vegetation Methods

Analysis of Habitat Unit Characteristics Associated with ISSs

This analysis addresses the second research question "To what extent do ISSs affect stream channel morphology by contributing to differences in pool depth, channel width, bank erosion or the amount of bank vegetation?" In each reach, residual pool depth at structure pools was compared with residual pool depth at non-structure pools and provides a quantitative measurement of ISS performance in meeting project objectives. Wetted width, bank erosion percent and bank vegetation percent in habitat units with and without ISSs were also compared. Wetted width, bank stability and bank vegetation are possible indicators of channel change associated with ISS (Heede, 1981; Beschta et al., 1991; Osborne et al., 1993). Average values were calculated for wetted width, bank erosion percent and bank vegetation percent for habitat units directly upstream from ISSs (U), habitat units directly downstream from ISSs (D), and habitat units that without ISSs (W) (Figure 10). Table 41 summarizes the comparisons made for habitat unit average values for wetted width, bank erosion percent and bank vegetation percent in each reach.

The channel-spanning weir of the ISS was the dividing point between habitat units. Habitat units upstream and downstream from ISSs may have included portions of the structure (Figure 10). In multiple-piece ISSs (multiple-boulder, log-boulder, and multiple-log), logs and/or boulders that were part of the ISS were located on the banks and extended upstream and downstream from the weir.

TABLE 41. Analyses for Comparisons of Wetted Width, Bank Erosion and Bank Vegetation at Habitat Units with and without ISSs

Analysis		Comparison	
WU	Average at habitat units without ISSs (W)	compared with	Average at habitat units upstream from ISSs (U)
WD	Average at habitat units without ISSs (W)	compared with	Average at habitat units downstream from ISSs (D)
UD	Average at habitat units upstream from ISSs (U)	compared with	Average at habitat units downstream from ISSs (D)
W-UD	Average at habitat units without ISSs (W)	compared with	Average at habitat units upstream and downstream from ISSs (U and D)

One way analysis of variance (ANOVA) computed with Minitab (Minitab, 1998) statistical software was used to determine whether there were significant differences between habitat units associated with ISSs and habitat units not associated with ISSs in the same reach. Differences in wetted width, bank erosion and bank vegetation were evaluated for each comparison shown in table 41. For residual pool depth, differences between ISS pools and non-ISS pools in each reach were evaluated. The null hypothesis was that the averages of the channel morphology response variables were not different between groups. The results of the MINITAB (Minitab, 1998) computation were presented in an ANOVA table showing the F-statistic and the p-value for rejecting or accepting the null hypothesis. Differences between groups were considered to be statistically significant when $p < 0.05$.

Analysis of Influential Control Variables

The analysis to identify influential control variables addresses the third research question, "What are the watershed, channel, and stream-type characteristics that are

associated with differences in pool depth, channel width, bank erosion or the amount of bank vegetation associated with ISSs?" Factor analysis was used to reduce the number of control variables before exploring the influence of these control variables on the differences in channel morphology (residual pool depth, wetted width, bank erosion percent and bank vegetation percent). Reach level observations of the watershed, channel and stream-type control variables were used in a factor analysis performed in Minitab statistical software (Minitab, 1998). Sixteen of the seventeen control variables (Table 23) were used in the factor analysis (valley constraint was not used because all 13 reaches were unconstrained). The nine control variables that were represented in the best factor analysis model were used in bivariate plots. These plots were then used to identify the control variables that most strongly influenced residual depth, wetted width, bank erosion percent and bank vegetation percent in habitat units with and without ISSs.

Factor analysis summarizes a set of variables as a smaller set of variables or factors ($I_1, I_2, \dots, I_n$) that are linear combinations of the original variables and represent the variation in the data (Manly, 1994). A factor loading of each initial variable on each factor are generated by this analysis. Variables that have high loadings on the same factors are correlated. A plot of the loadings provides a visual representation of the first two factors and suggests correlations between variables.

For this analysis, drainage area was log transformed because it was not normally distributed. This provided a data set that was more normally distributed and allowed for better interpretation of linear relationships between variables. Many of the channel control variables had skewed distributions that remained skewed after log transformation, so were not log transformed. Bed material of the D_{50} and D_{84} sediment sizes had been measured in millimeters and recorded in categories (Table 91, appendix A). For analysis purposes, the value at the lower end of the category was used. For example, when the D_{50} bed material size was 64 to 96 mm, 64 mm was used for analysis. Reach averaged values for gradient,

entrenchment, sinuosity, bankfull width-to-depth ratio, bank stability percent and bank vegetation percent were used for analysis. Dominant and subdominant bank material size categories were reduced from eight categories to two groups. The "fine" group included all bank material categories smaller than sand size. The "coarse" group included bank material categories sand size and larger. Reach averaged values of riparian vegetation seral stage category were used. Each Rosgen and Montgomery-Buffington stream-type category was represented by a binomial variable indicating presence (1) or absence (0).

In Minitab (1998), highly correlated variables are identified by the program and Minitab requires that they be removed from the model before the analysis can be completed. Once the highly correlated variables were removed, several factor analyses were completed in Minitab using various combinations of the remaining control variables. The combination of variables that explained the greatest amount of variability in the data were identified. The loadings for each of these variables and the total percent variance for the first three factors are summarized in Table 42.

TABLE 42. Factor Analysis Results

Variable	Factor Loadings (unrotated)		
	Factor 1	Factor 2	Factor 3
Log Drainage Area	0.756	0.107	0.519
Sinuosity	-0.646	0.476	-0.518
Gradient	0.850	-0.150	-0.443
Bankfull Width-to-Depth Ratio	0.585	0.763	0.180
Bed Material (D_{50} Sediment Size)	0.918	-0.042	-0.034
Rosgen Stream-Type E	-0.847	-0.364	0.139
Montgomery Buffington Stream-Type "Plane Bed"	0.970	0.037	-0.080
Dominant Bank Material - Fine (smaller than sand)	-0.871	0.005	0.210
Subdominant Bank Material - Fine (smaller than sand)	-0.692	0.567	0.067
% Variance	0.643	0.144	0.094
Cumulative % Variance	0.643	0.787	0.881

The cumulative % variance of the first three factors explained 88.1% of the variability of the control variables. The first factor alone explained 64.3% of the variability. Many of the nine variables were covariants as indicated by the factor loadings of factor 1. Log drainage area, gradient, bed material size and Montgomery-Buffington stream-type "plane bed" all had high positive loadings and were correlated. These were inversely correlated with sinuosity, or Rosgen stream-type E, which had high negative loadings, and with fine bank material (dominant and subdominant). Factor 2 has the highest positive loading for bankfull width-to-depth ratio. Bankfull width-to-depth ratio was correlated with sinuosity and subdominant bank material. Factor 3 had the highest positive loading for log drainage area. Log drainage area was inversely correlated with sinuosity and gradient which had the highest negative loadings.

The variables listed in Table 42 were then used to construct bivariate plots as illustrated in Figure 11. These plots were examined to identify influential control variables that might explain why there were significant differences in residual pool depth, wetted width, bank erosion percent and bank vegetation percent between habitat units with ISSs and habitat units without ISSs in some reaches but not in others. Each bivariate plot illustrated the values of one variable for the two groups of stream reaches. One group of reaches had significant differences in the characteristic of interest, residual pool depth, wetted width, bank erosion percent or bank vegetation percent, while the second group did not. Data visualization was then used to interpret the results of the bivariate plots. Data visualization was chosen as the analysis method because the number of cases in each group was too small to provide statistically significant results using other methods. The results will be discussed in the next section.

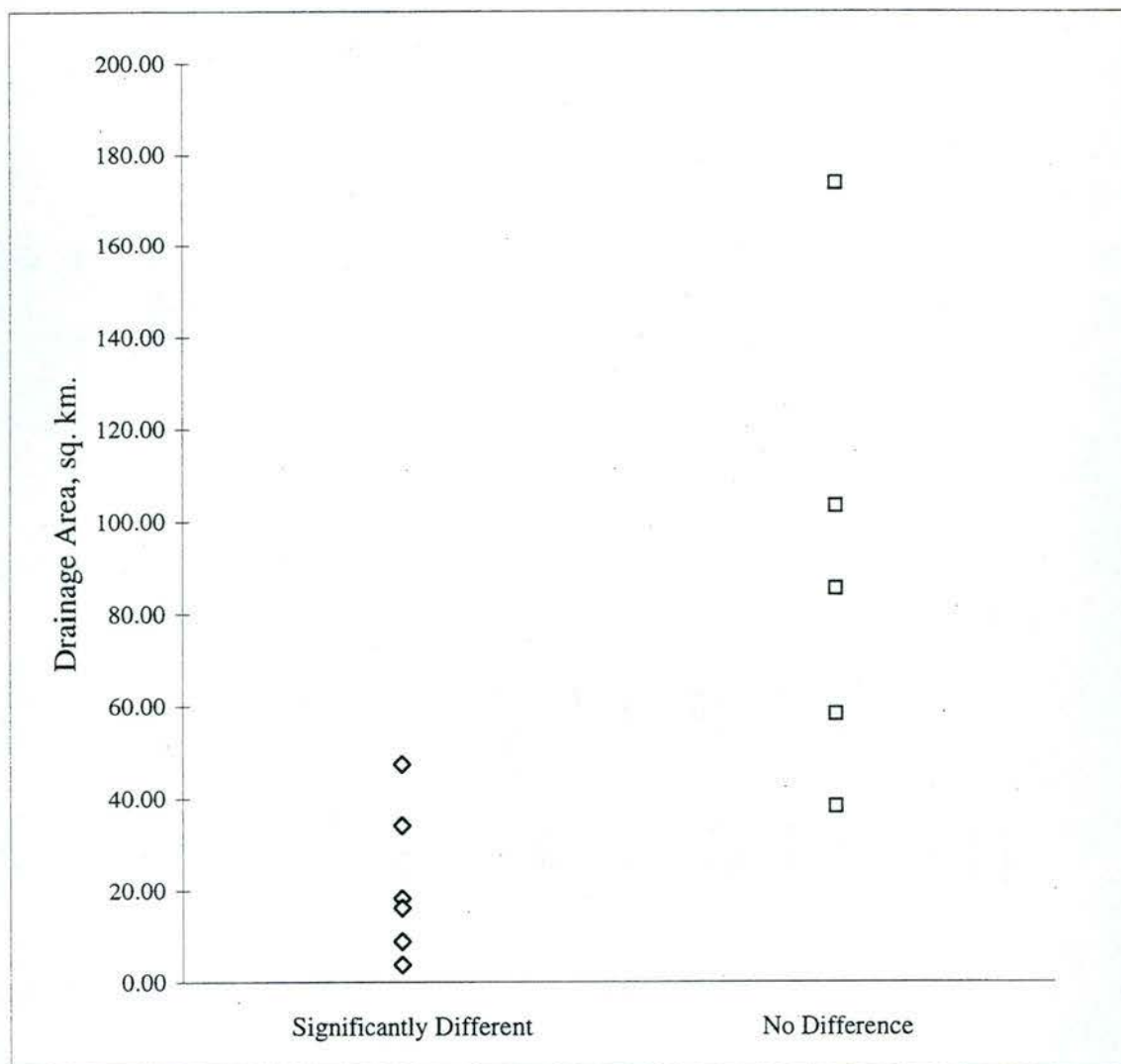


Figure 11. Example of a bivariate plot.

Channel Morphology and Vegetation Results

Comparisons of several characteristics, residual pool depth, wetted width, bank erosion and bank vegetation, were made between habitat units with ISSs and habitat units without ISSs. For each reach, residual pool depth at pools created by ISSs was compared with residual pool depth in pools that were not created by ISSs. Wetted width, bank erosion and bank vegetation at habitat units associated with ISSs (upstream and downstream from ISSs) were compared with these same characteristics at habitat units that were not associated with ISSs (Table 41 and Figure 10)

Residual Pool Depth in ISS Pools

The ISSs in the reaches in this study were designed to create a pool downstream from the ISSs. This analysis compared pools created by ISSs to other pools within a reach. The residual pool depth of pools at ISSs was compared with residual pool depth of pools that were not associated with ISSs. The results are summarized in Table 43 and illustrated in Figure 12. In all of the 13 reaches, residual pool depth in structure pools was greater than in non-structure pools. The differences in residual pool depth ranged from 0.16 ft. to 1.18 ft. In three reaches, Big Wall, Hidaway and Wilson, the difference in residual pool depth was statistically significant at $p \leq 0.05$.

Bivariate plots were examined to explain the factors that influenced the differences in residual pool depth. An examination of the bivariate plots of streams where residual pool depth was greater in structure pools than in non-structure pools (Figures 13 and 14) indicated that structure pools were significantly deeper than non-structure pools in reaches with higher gradient and where bed material, and dominant and subdominant bank material were coarse. None of the reaches with deeper structure pools were Rosgen type E or Montgomery-Buffington pool-riffle reaches.

TABLE 43. Residual Pool Depths (m) at Structure and Non-Structure pools. Underlined values are significantly different at $p \leq 0.05$

Reach Name	Structure Pools	Non-Structure Pools	Difference in depth (ft)	p
Bear Wallow, lower (BWL)	1.55	0.84	0.71	0.061
Bear Wallow, upper (BWU)	1.40	0.93	0.47	0.296
Big Wall (BW)	<u>2.10</u>	<u>0.92</u>	<u>1.18</u>	<u>0.0005</u>
Camas (CC)	2.22	1.54	0.68	0.538
Desolation (DS)	1.72	1.26	0.46	0.249
Dry Camas (DC)	0.35	0.19	0.16	0.412
Hidaway (HD)	<u>1.78</u>	<u>0.81</u>	<u>0.97</u>	<u>0.001</u>
Kelsay (KL)	1.36	0.89	0.47	0.103
Lane (LN)	1.51	0.84	0.67	0.142
North Fork Cable (NFC)	1.36	1.18	0.18	0.417
Phillips (PH)	1.04	0.68	0.36	0.326
Thomas (TH)	1.94	0.86	1.08	0.076
Wilson (WL)	<u>1.26</u>	<u>0.59</u>	<u>0.67</u>	<u>0.028</u>

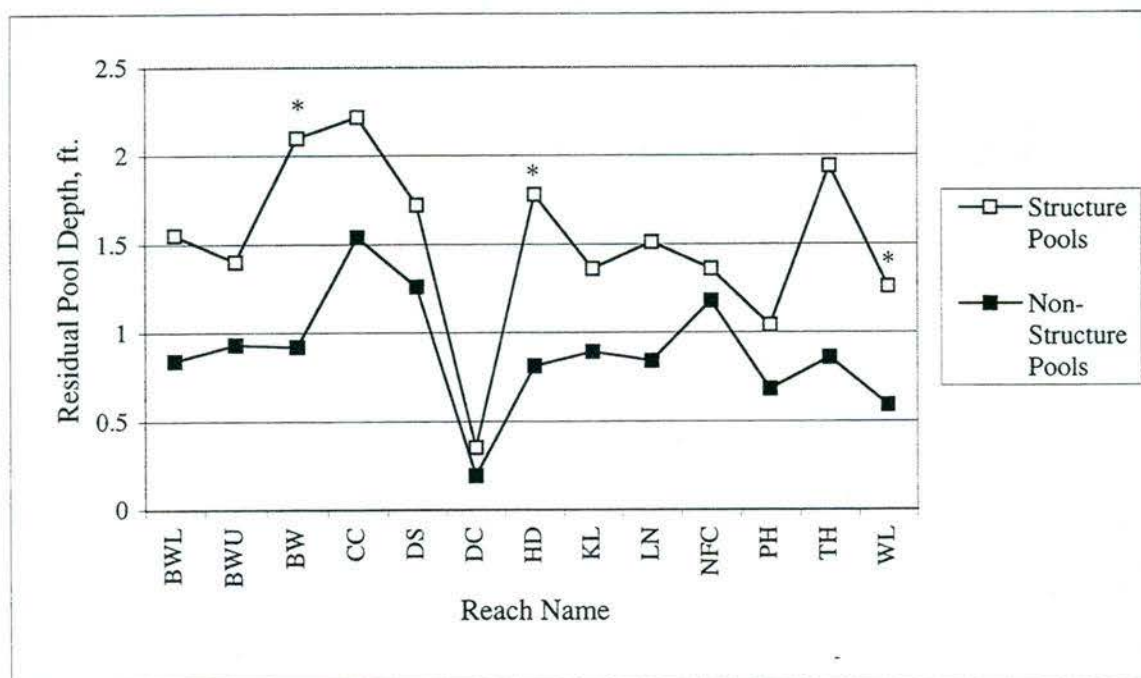


Figure 12. Residual pool depth (reach averages) at structure and non-structure pools (* indicates $p \leq 0.05$).

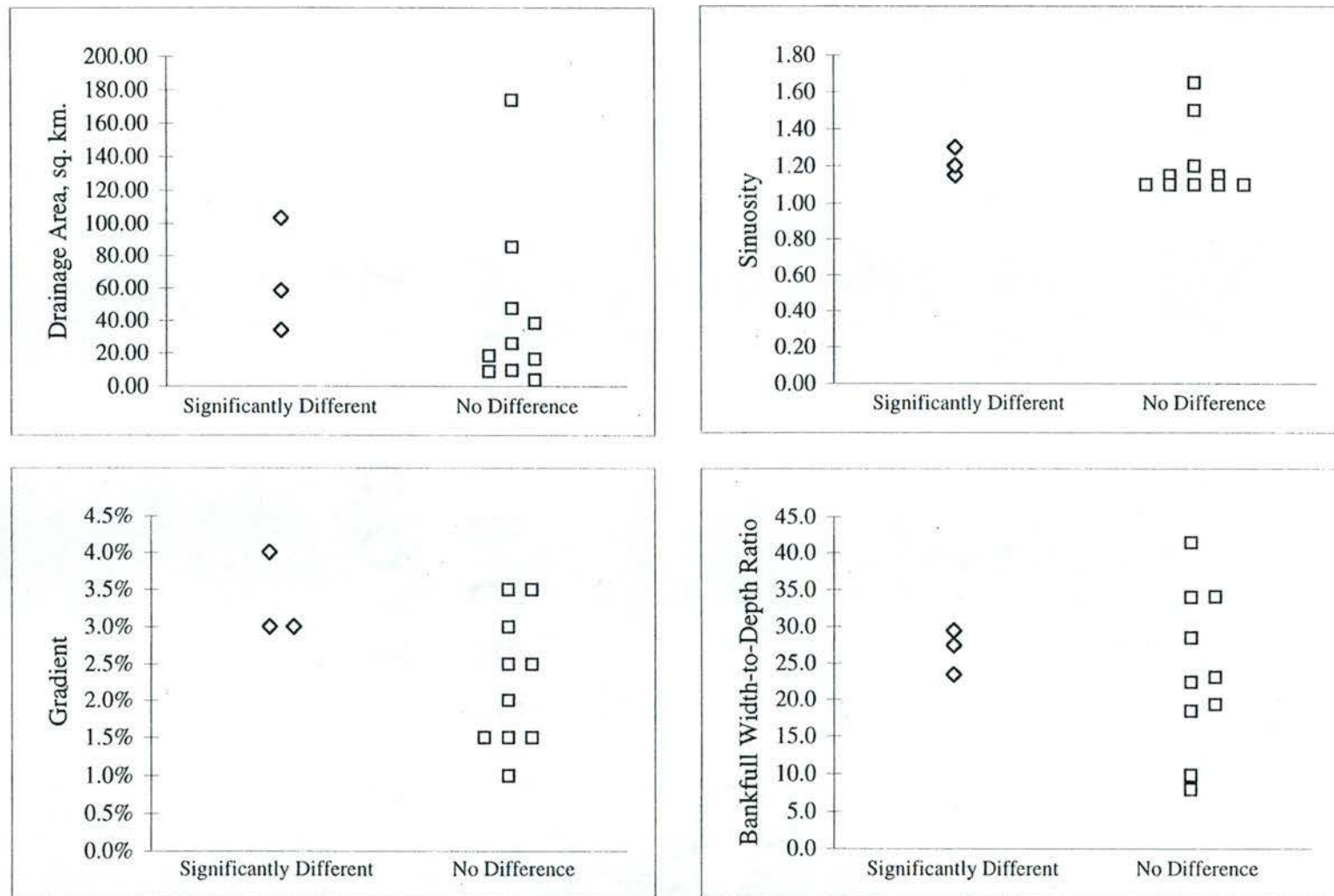


Figure 13. Bivariate plots for residual pool depth.

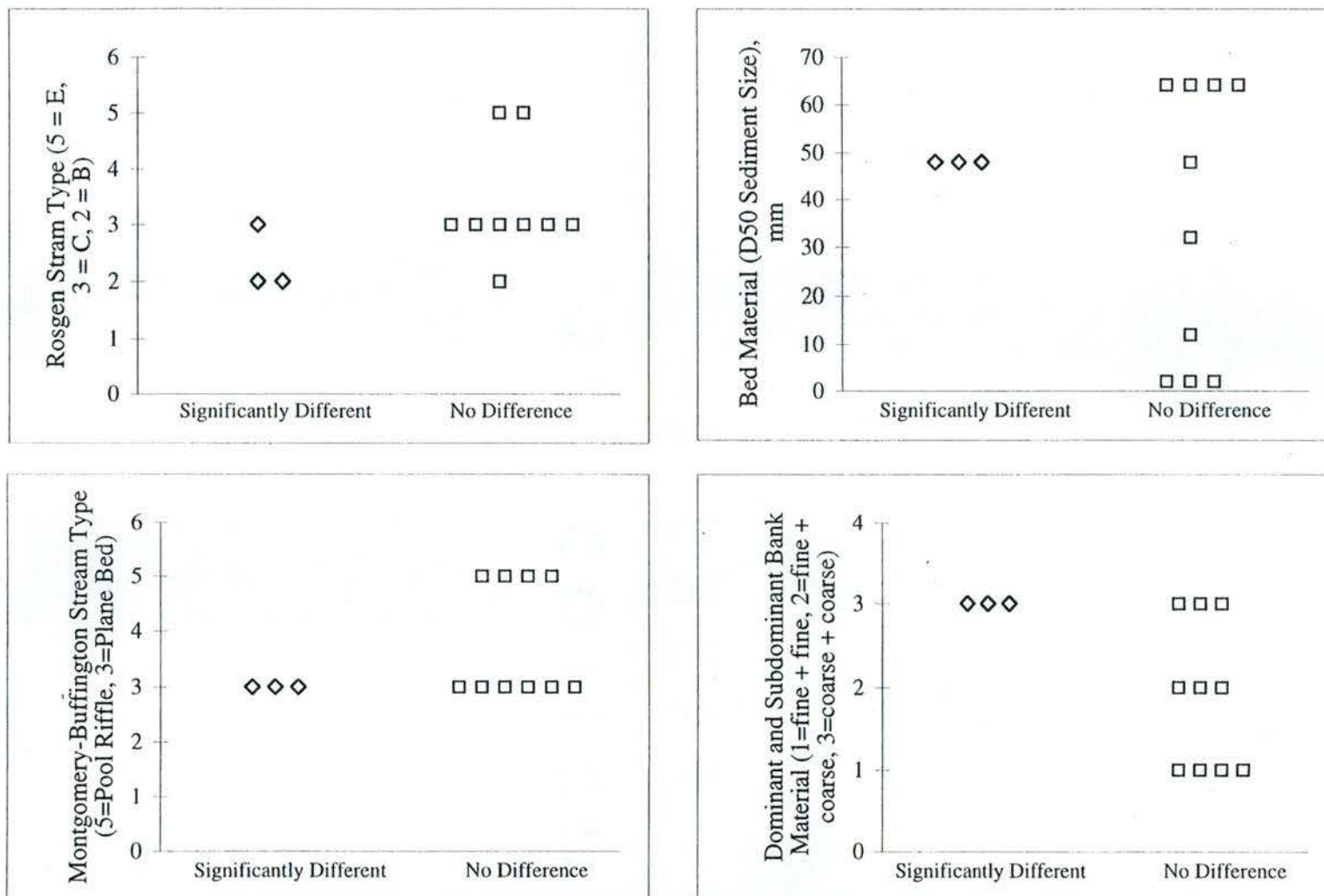


Figure 14. Additional Bivariate plots for residual pool depth.

Wetted Width Results

Comparisons were made between wetted width in habitat units upstream and downstream from ISSs and habitat units without ISSs. This analysis was done to determine whether ISSs tend to cause channel widening. The analyses that were done are summarized in Table 41 and will be referred to here as the WU, WD, UD and W-UD analyses. Eleven of the 13 reaches surveys were evaluated in this analysis. Two reaches, Dry Camas and Philips, were predominantly dry and were not included. The results of the wetted width analyses are summarized in Table 44 and in Figure 15. Overall, wetted widths tended to be greater in habitat units with ISSs (both upstream and downstream) than in habitat units without ISSs. Wetted widths downstream from ISSs tended to be the widest habitat units.

In six of the eleven reaches evaluated, wetted widths were greater in habitat units upstream from ISSs than in habitat units without ISSs (WU analysis), and in three reaches the differences in wetted widths was significantly greater. In nine reaches, wetted widths were wider in habitat units downstream from ISSs than in habitat units without ISSs (WD analysis), and this difference was significant in five reaches. In nine reaches, wetted width in habitat units downstream from ISSs was greater than in habitat units upstream from ISSs (UD analysis), and in four reaches the differences in wetted widths were significant.

The average wetted width of habitat units upstream and downstream from ISSs (with ISSs) were compared with habitat units without ISSs (W-UD analysis). In eight reaches, wetted width in habitat units with ISSs was greater than in habitat units without ISSs. In four reaches, the differences in wetted widths were significant.

Bivariate plots were then examined to identify the factors that influenced the significant differences in wetted widths. An examination of the bivariate plots of stream reaches where wetted widths were greater in habitat units downstream from ISSs than in habitat units without ISSs (WD analysis) (Figures 16 and 17) indicated which control variables

TABLE 44. Wetted Width at Individual Habitat Units Relative to ISS Location.
Underlined Values are Significantly Different at $p \leq 0.05$

Stream Name	WU			WD			UD			W-UD		
	reach average wetted width, m		p	reach average wetted width, m		p	reach average wetted width, m		p	reach average wetted width, m		p
	no structure	up-stream		no structure	down-stream		up-stream	down-stream		no structure	up- and down-stream	
Bear Wallow, lower (BWL)	<u>1.93</u>	<u>1.73</u>	<u>0.050</u>	<u>1.92</u>	<u>3.04</u>	<u>0.0005</u>	<u>1.75</u>	<u>3.04</u>	<u>0.0005</u>	1.93	2.40	0.063
Bear Wallow, upper (BWU)	<u>1.16</u>	<u>2.09</u>	<u>0.0005</u>	<u>1.16</u>	<u>2.99</u>	<u>0.0005</u>	<u>2.08</u>	<u>2.99</u>	<u>0.041</u>	<u>1.16</u>	<u>2.58</u>	<u>0.0005</u>
Big Wall (BW)	4.32	3.66	0.187	4.32	4.61	0.543	3.66	4.06	0.128	4.32	4.13	0.607
Camas (CC)	7.06	6.01	0.291	7.06	7.46	0.679	6.01	7.47	0.204	7.06	6.74	0.676
Desolation (DS)	7.49	8.37	0.390	7.49	7.47	0.985	8.37	7.47	0.260	7.49	7.92	0.622
Dry Camas (DC)												
Hidaway (HD)	4.24	3.47	0.057	4.24	4.68	0.334	<u>3.47</u>	<u>4.68</u>	<u>0.005</u>	4.24	4.09	0.691
Kelsay (KL)	<u>1.44</u>	<u>2.60</u>	<u>0.0005</u>	<u>1.44</u>	<u>2.82</u>	<u>0.0005</u>	2.60	2.82	0.690	<u>1.44</u>	<u>2.72</u>	<u>0.0005</u>
Lane (LN)	4.12	4.99	0.156	4.12	4.59	0.440	4.99	4.59	0.646	4.12	4.79	0.161
North Fork Cable (NFC)	2.87	3.11	0.514	<u>2.87</u>	<u>4.27</u>	<u>0.0005</u>	<u>3.11</u>	<u>4.28</u>	<u>0.037</u>	<u>2.87</u>	<u>3.84</u>	<u>0.001</u>
Phillips (PH)												
Thomas (TH)	<u>4.27</u>	<u>4.97</u>	<u>0.040</u>	<u>4.27</u>	<u>5.49</u>	<u>0.0005</u>	4.97	5.79	0.154	<u>4.27</u>	<u>5.24</u>	<u>0.001</u>
Wilson (WL)	5.70	5.71	0.996	5.70	5.80	0.852	5.70	5.84	0.904	5.70	5.77	0.913

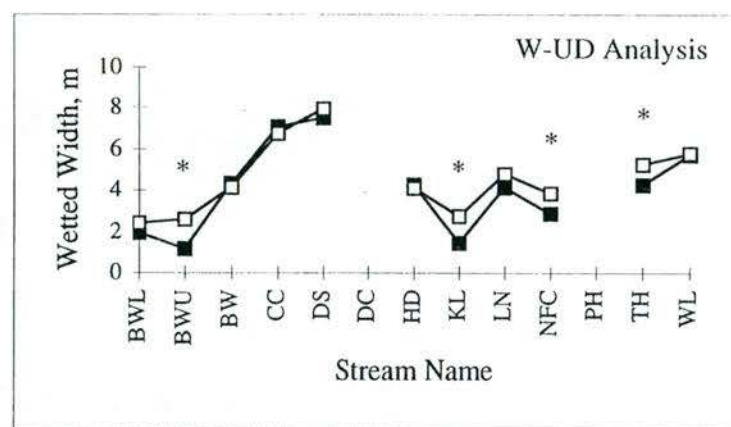
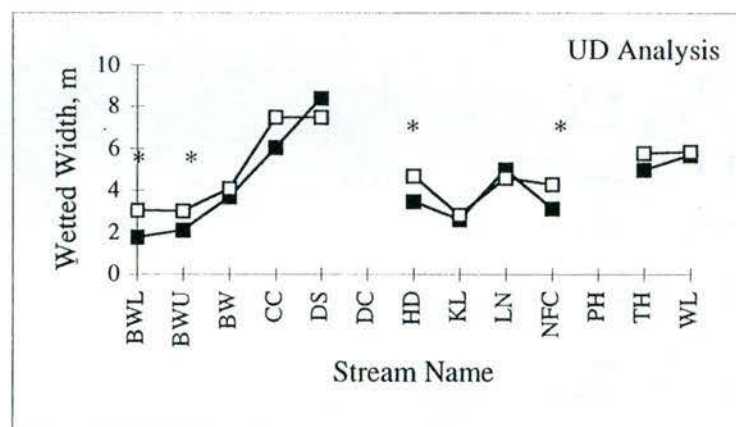
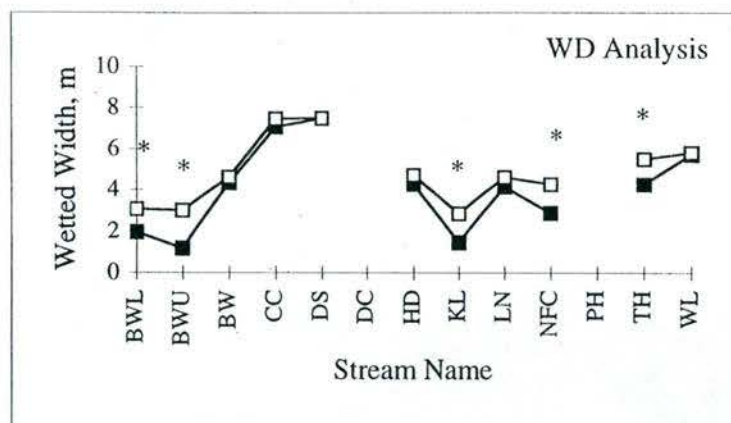
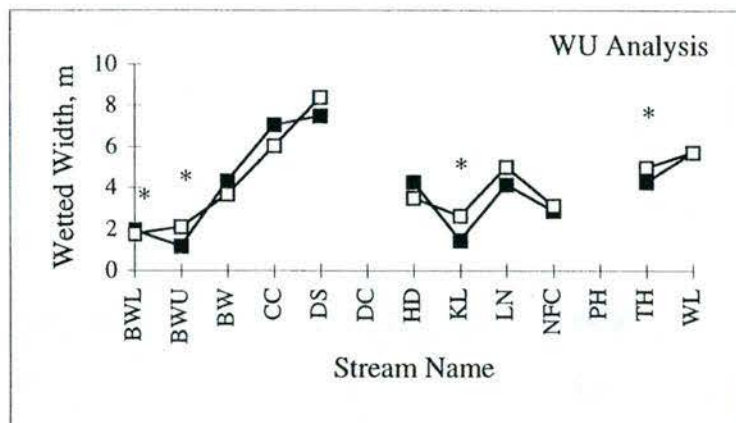


Figure 15. WU, WD, UD and W-UD analyses of wetted widths. * indicates significant difference at $p < 0.05$

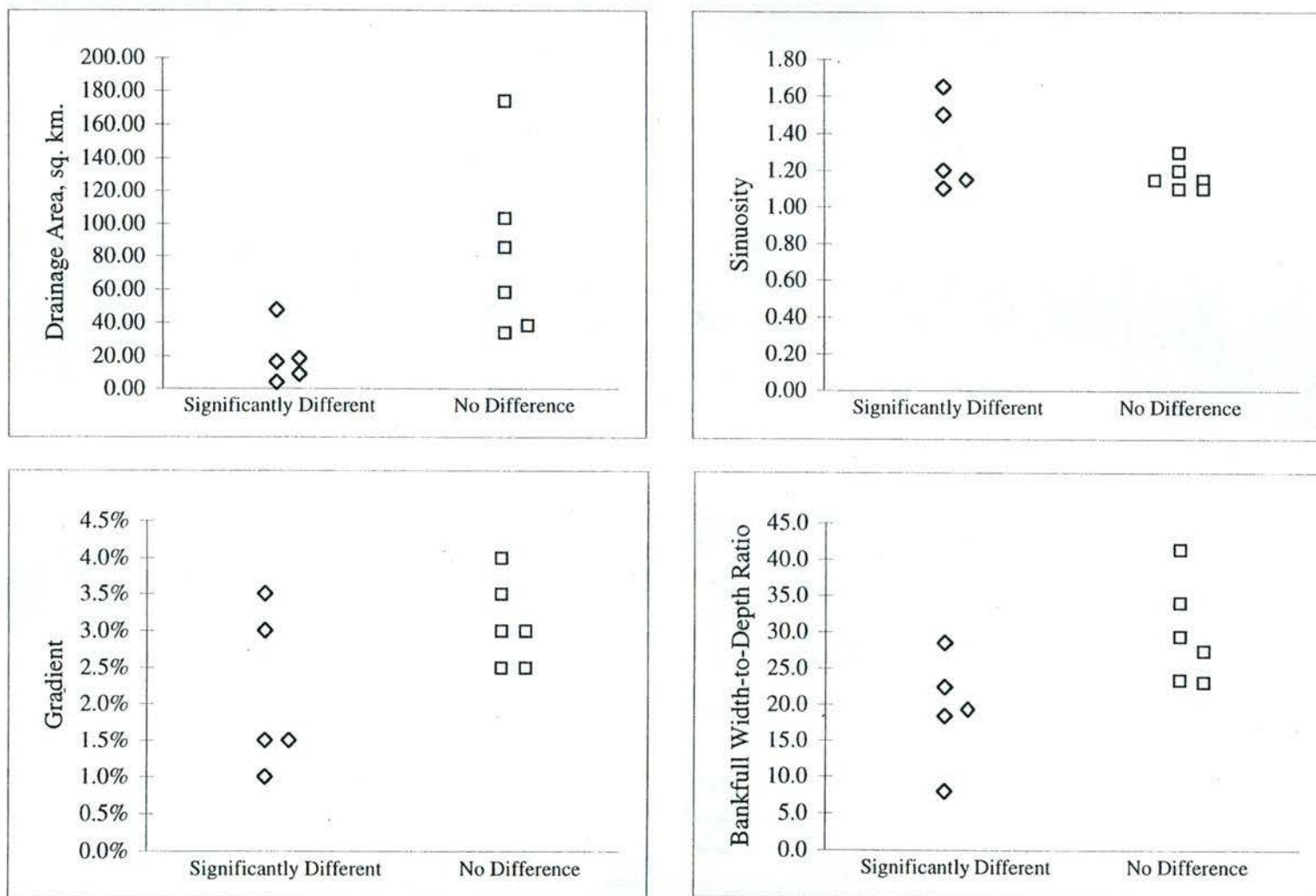


Figure 16. Bivariate plots for wetted width analysis of habitat units downstream and without structures (WD analysis)

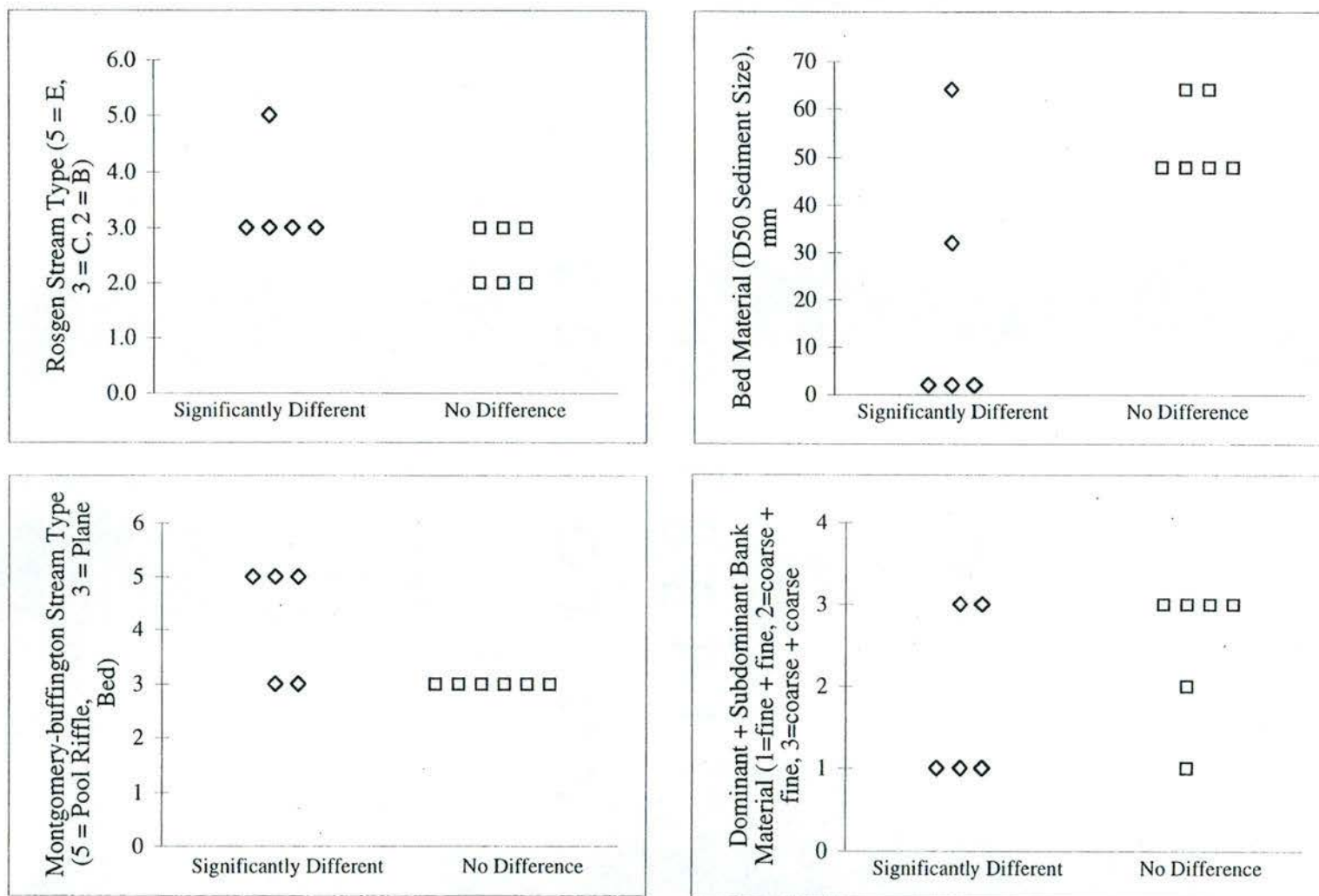


Figure 17. Bivariate plots for wetted width analysis of habitat units downstream and without structures (WD analysis).

had the most influence on the differences in wetted widths. The reaches where wetted widths were greater in habitat units downstream from ISSs tended to have small drainage areas, small bankfull width-to-depth ratio and fine bed material. Stream-type was also important. Greater wetted widths in habitat units downstream from ISSs occurred most often in Montgomery-Buffington pool-riffle stream reaches, but not in Rosgen type B stream reaches. Similar influential control variables were identified after examining bivariate plots for stream reaches in the WU, the UD and the W-UD analyses of wetted width.

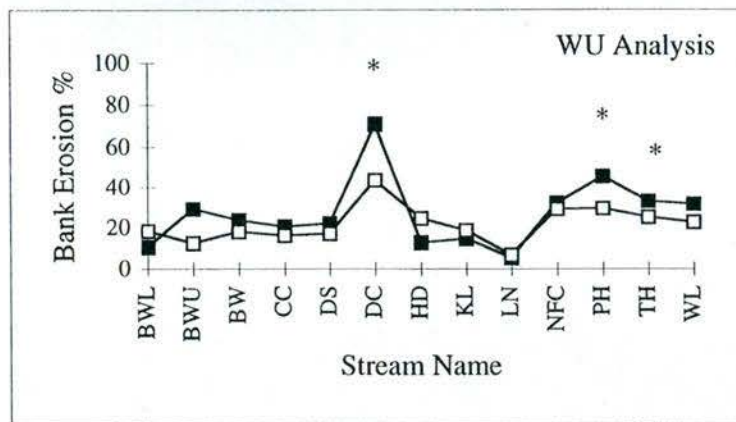
Bank Erosion Results

Comparisons of bank erosion were made between habitat units upstream and downstream from ISSs and habitat units without ISSs. The results of the WU, WD, UD and W-UD analyses are summarized in Table 45 and Figure 18. The purpose of this analysis was to investigate whether ISSs caused localized bank erosion. Results showed that in most reaches there was greater bank erosion in habitat units downstream from ISSs and less bank erosion in habitat units upstream from ISSs than in habitat units without ISSs. Less bank erosion in habitat units upstream from ISSs was not the expected result.

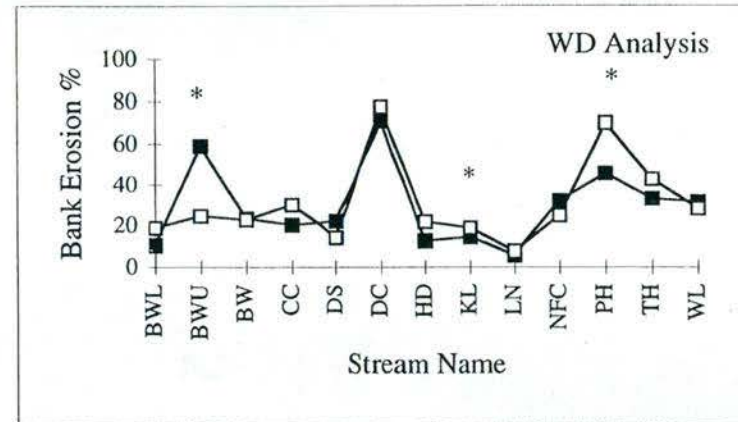
In eight reaches, bank erosion was greater in habitat units downstream than in habitat units without ISSs (WD). In two reaches, the difference was significant. In nine reaches, bank erosion was greater in habitat units downstream from ISSs than in habitat units upstream (UD), and in four reaches the difference was significant. Bank erosion in habitat units with ISSs (upstream and downstream) was compared with bank erosion in habitat units without ISSs (W-UD), but there was no overall pattern of bank erosion in habitat units with ISSs compared habitat units without ISSs. Eight of 13 reaches had greater bank erosion in habitat units without ISSs, while five reaches had greater bank erosion in habitat units with ISSs. In only one reach, bank erosion in habitat units with ISSs (upstream and downstream from ISSs) was significantly greater than at habitat units without ISSs.

TABLE 45. Bank erosion percent at individual habitat units relative to ISS location. Underlined values are significantly different at $p \leq 0.05$.

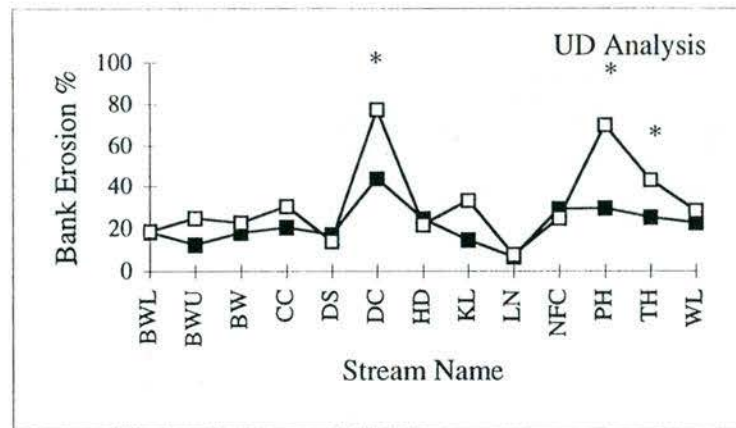
Stream Name	WU			WD			UD			W-UD		
	reach average bank erosion %		p	reach average bank erosion %		p	reach average bank erosion %		p	reach average bank erosion %		p
	no structure	up-stream		no structure	down-stream		up-stream	down-stream		no structure	up- and down-stream	
Bear Wallow, lower (BWL)	10.2	18.0	0.374	10.2	18.4	0.225	18.0	18.4	0.960	10.2	18.2	0.158
Bear Wallow, upper (BWU)	<u>28.8</u>	<u>12.0</u>	<u>0.017</u>	58.8	24.4	0.515	12.0	24.4	0.109	28.8	18.8	0.086
Big Wall (BW)	23.2	17.8	0.449	23.2	22.5	0.925	17.8	22.5	0.697	23.2	20.2	0.591
Camas (CC)	20.1	15.8	0.722	20.1	30.0	0.399	15.8	30.0	0.275	20.1	22.9	0.753
Desolation (DS)	21.7	16.8	0.559	21.7	13.7	0.303	16.9	13.7	0.612	21.7	15.3	0.365
Dry Camas (DC)	70.9	43.6	0.390	70.9	77.2	0.840	<u>43.6</u>	<u>77.2</u>	<u>0.016</u>	70.9	60.4	0.646
Hidaway (HD)	12.3	24.3	0.066	12.3	21.4	0.121	24.3	21.4	0.686	12.3	22.8	0.066
Kelsay (KL)	14.3	18.4	0.397	<u>14.3</u>	<u>32.8</u>	<u>0.001</u>	18.4	32.8	0.064	<u>14.3</u>	<u>32.8</u>	<u>0.008</u>
Lane (LN)	5.4	6.4	0.802	5.4	7.5	0.632	6.5	7.5	0.858	5.4	7.0	0.632
North Fork Cable (NFC)	32.0	28.8	0.767	32.0	24.6	0.394	28.8	24.6	0.643	32.0	26.1	0.408
Phillips (PH)	45.4	29.2	0.062	<u>45.4</u>	<u>70.0</u>	<u>0.007</u>	<u>29.2</u>	<u>70.0</u>	<u>0.003</u>	54.4	50.4	0.524
Thomas (TH)	32.9	25.0	0.218	32.9	42.8	0.117	<u>25.0</u>	<u>42.8</u>	<u>0.006</u>	32.9	34.3	0.793
Wilson (WL)	31.3	22.3	0.216	31.3	28.0	0.654	22.3	28.0	0.592	31.3	25.1	0.280



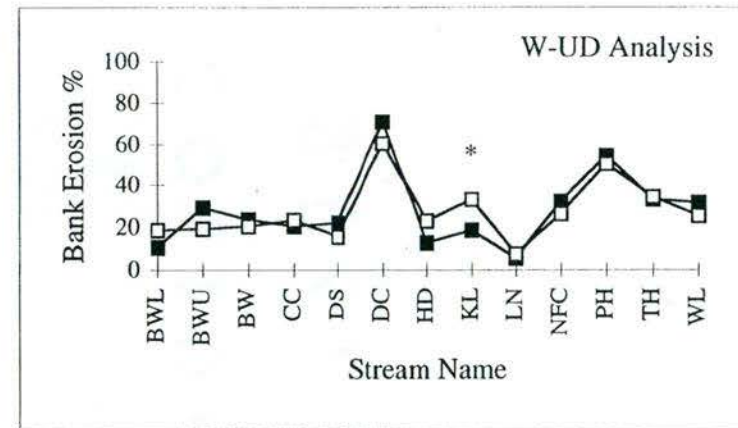
■ Habitat units without structures
□ Habitat units upstream



■ Habitat units without structures
□ Habitat units downstream



■ Habitat units upstream
□ Habitat units downstream



■ Habitat units without structures
□ Habitat units with structures

Figure 18. WU, WD, UD and W-UD analyses of bank erosion. * indicates significant difference at $p < 0.05$

Bank erosion was less in habitat units upstream from ISSs than in habitat units without ISSs in nine reaches (WU), and in one reach the difference was significant. ISSs seem to be lowering gradient in habitat units upstream from ISSs and creating a stepped longitudinal profile similar to that created by LWD or boulder steps (Figure 19) (Keller and Swanson, 1979; Montgomery and Buffington, 1993; Thompson, 1995; Montgomery and Buffington, 1997). This may result in decreased stream velocity and stream power, decreasing the potential for erosion in habitat units just upstream from ISSs in some reaches (Heede, 1981; Grant et al., 1990; Trotter, 1990; Abbe and Montgomery, 1996).

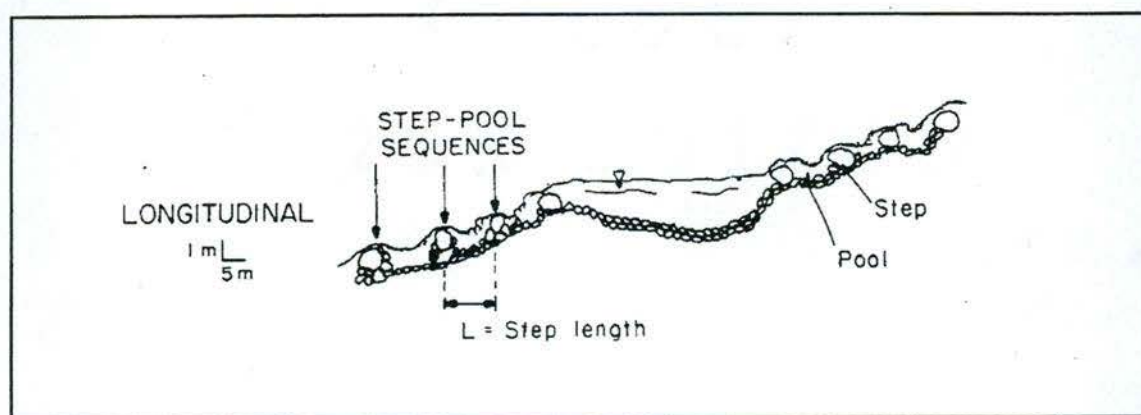


Figure 19. Stepped longitudinal profile (Grant et al., 1990, p. 342).

Bivariate plots were used to examine the influence of control variables on the differences in bank erosion for two of the analyses, the UD (Figures 20 and 21). In stream reaches where bank erosion in habitat units downstream from ISSs was significantly greater than upstream from ISSs (UD), drainage areas were smaller and reaches were not Rosgen type B. Similar results were found for the WD analysis (greater erosion downstream from ISSs than in habitat units without ISSs).

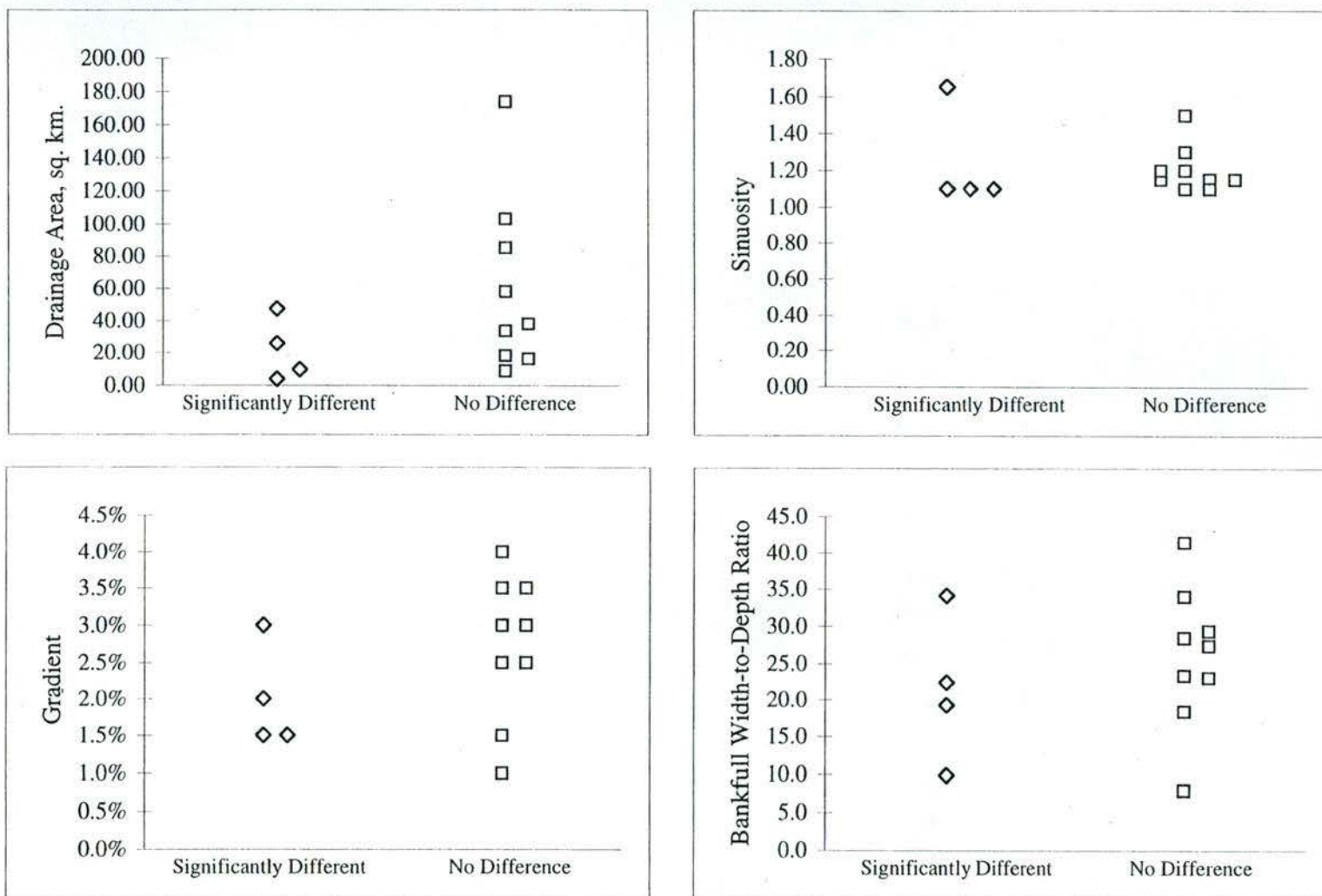


Figure 20. Bivariate plots for bank erosion analysis of habitat units upstream and downstream from structures (UD).

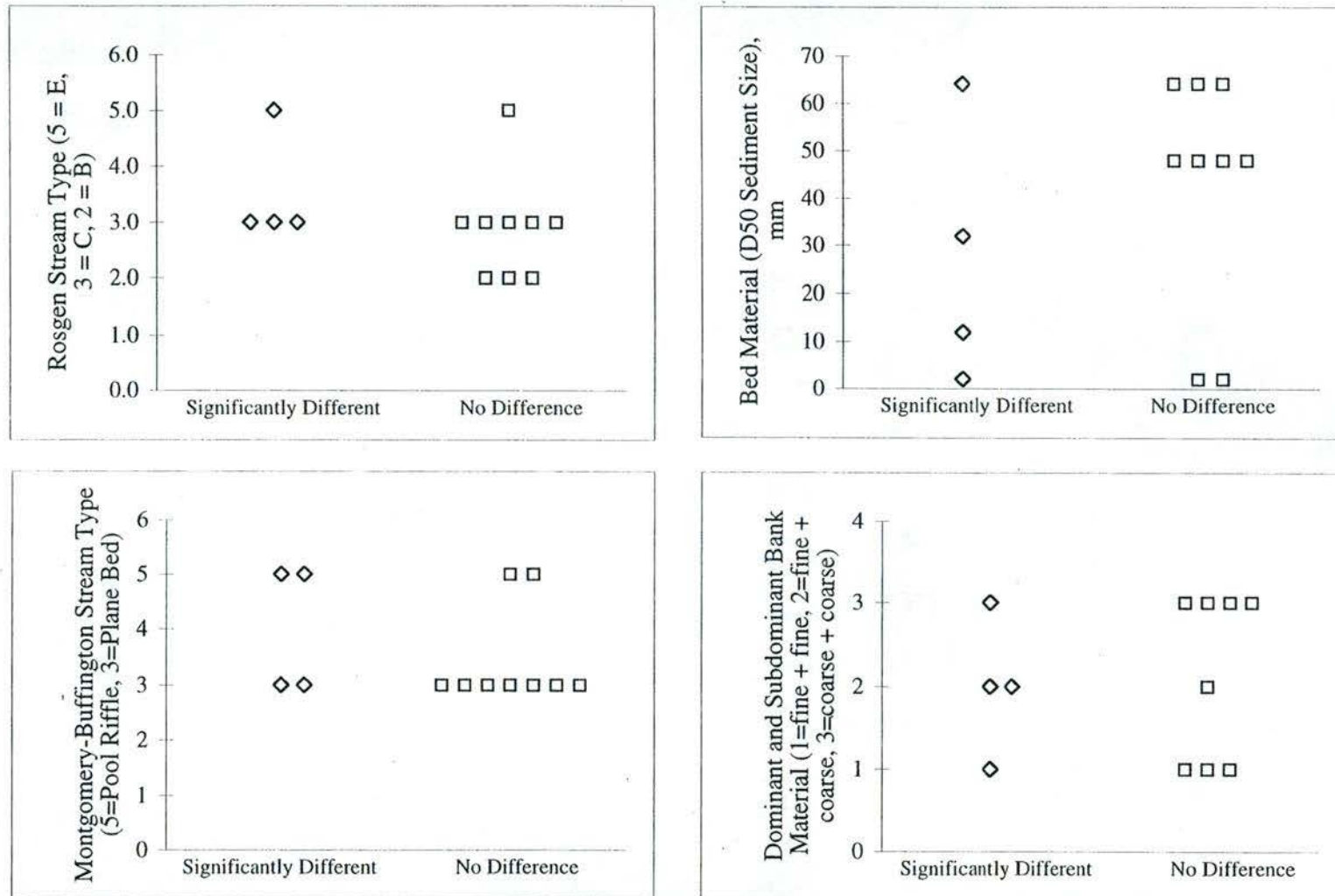


Figure 21. Additional bivariate plots for bank erosion analysis (UD).

Bank Vegetation Results

Comparisons of bank vegetation were made between habitat units upstream (U) and downstream (D) from ISSs, and habitat units without ISSs (W). The purpose of this analysis was to determine whether there was less bank vegetation at habitat units with ISSs. Less bank vegetation at ISS locations could affect channel morphology through the effects on processes that shape channel form, such as bank erosion.

The results of the WU, WD, UD and W-UD analyses are summarized in Table 46 and in Figure 22. The results showed that there was less bank vegetation in habitat units with ISSs than in habitat units without ISSs. The difference in bank vegetation was greatest in habitat units downstream from ISSs. In general, habitat units downstream from ISSs had less bank vegetation than habitat units upstream from or without ISSs.

In seven of the 13 reaches, bank vegetation percent in habitat units upstream from ISSs was slightly less than in habitat units without ISSs (WU) but this difference was not significant in any of the reaches. In four reaches, bank vegetation was greater upstream from ISSs than in habitat units without ISSs and in a couple of these reaches, the difference was fairly large though not significant. In the remaining two reaches, there was no difference in bank vegetation between habitat units upstream and without ISSs.

In one reach, Upper Bear Wallow, where bank vegetation was greater in habitat units upstream from ISSs than in habitat units without ISSs, the level of significance ($p = 0.052$) was very close to the 0.05 significance level used in this study. In this reach, bank erosion in habitat units upstream from ISSs was also significantly less than in habitat units without ISSs. The ISSs in this reach appeared to be trapping sediment upstream of the ISSs and creating a stepped longitudinal profile. If the ISSs are lowering gradient through the creation of a stepped longitudinal profile (Keller and Swanson, 1979; Montgomery and Buffington, 1993; Thompson, 1995; Montgomery and Buffington, 1997) and trapping

TABLE 46. Bank Vegetation Percent at Individual Habitat Units Relative to ISS Location. Underlined Values are Significantly Different at $p \leq 0.05$

Stream Name	WU			WD			UD			W-UD		
	reach average bank vegetation %		p	reach average bank vegetation %		p	reach average bank vegetation %		p	reach average bank vegetation %		p
	no structure	up-stream		no structure	down-stream		up-stream	down-stream		no structure	up- and down-stream	
Bear Wallow, lower (BWL)	86.8	84.8	0.717	<u>86.8</u>	<u>58.9</u>	<u>0.0005</u>	<u>84.4</u>	<u>58.9</u>	<u>0.005</u>	<u>86.8</u>	<u>58.9</u>	<u>0.001</u>
Bear Wallow, upper (BWU)	77.2	89.3	0.052	77.2	74.6	0.641	<u>89.3</u>	<u>74.6</u>	<u>0.006</u>	77.2	81.3	0.403
Big Wall (BW)	30.5	35.0	0.504	30.5	40.6	0.120	35.0	40.6	0.627	35.0	40.6	0.627
Camas (CC)	78.4	73.3	0.534	<u>78.4</u>	<u>56.3</u>	<u>0.016</u>	73.3	56.3	0.163	<u>78.4</u>	<u>64.8</u>	<u>0.050</u>
Desolation (DS)	55.6	52.5	0.773	55.6	51.0	0.614	52.5	51.0	0.856	55.6	51.8	0.665
Dry Camas (DC)	69.6	63.9	0.270	<u>69.6</u>	<u>40.8</u>	<u>0.0005</u>	<u>63.8</u>	<u>40.8</u>	<u>0.011</u>	<u>69.6</u>	<u>52.4</u>	<u>0.005</u>
Hidaway (HD)	68.0	68.9	0.880	68.0	47.4	0.066	<u>68.9</u>	<u>47.4</u>	<u>0.001</u>	<u>68.0</u>	<u>57.6</u>	<u>0.008</u>
Kelsay (KL)	90.7	84.5	0.100	<u>90.8</u>	<u>72.0</u>	<u>0.0005</u>	84.5	72.0	0.086	<u>90.7</u>	<u>78.0</u>	<u>0.001</u>
Lane (LN)	69.1	67.5	0.873	69.1	51.5	0.106	67.5	51.5	0.173	69.1	59.5	0.228
North Fork Cable (NFC)	66.9	73.8	0.450	66.9	62.3	0.540	73.8	62.3	0.280	66.9	66.4	0.946
Phillips (PH)	70.2	69.8	0.946	<u>70.2</u>	<u>59.0</u>	<u>0.049</u>	69.8	59.0	0.220	70.2	64.2	0.207
Thomas (TH)	71.7	80.3	0.092	71.7	69.9	0.711	<u>80.3</u>	<u>69.9</u>	<u>0.048</u>	71.7	74.8	0.467
Wilson (WL)	28.5	23.4	0.534	28.5	16.3	0.132	23.4	16.3	0.387	28.5	19.8	0.153

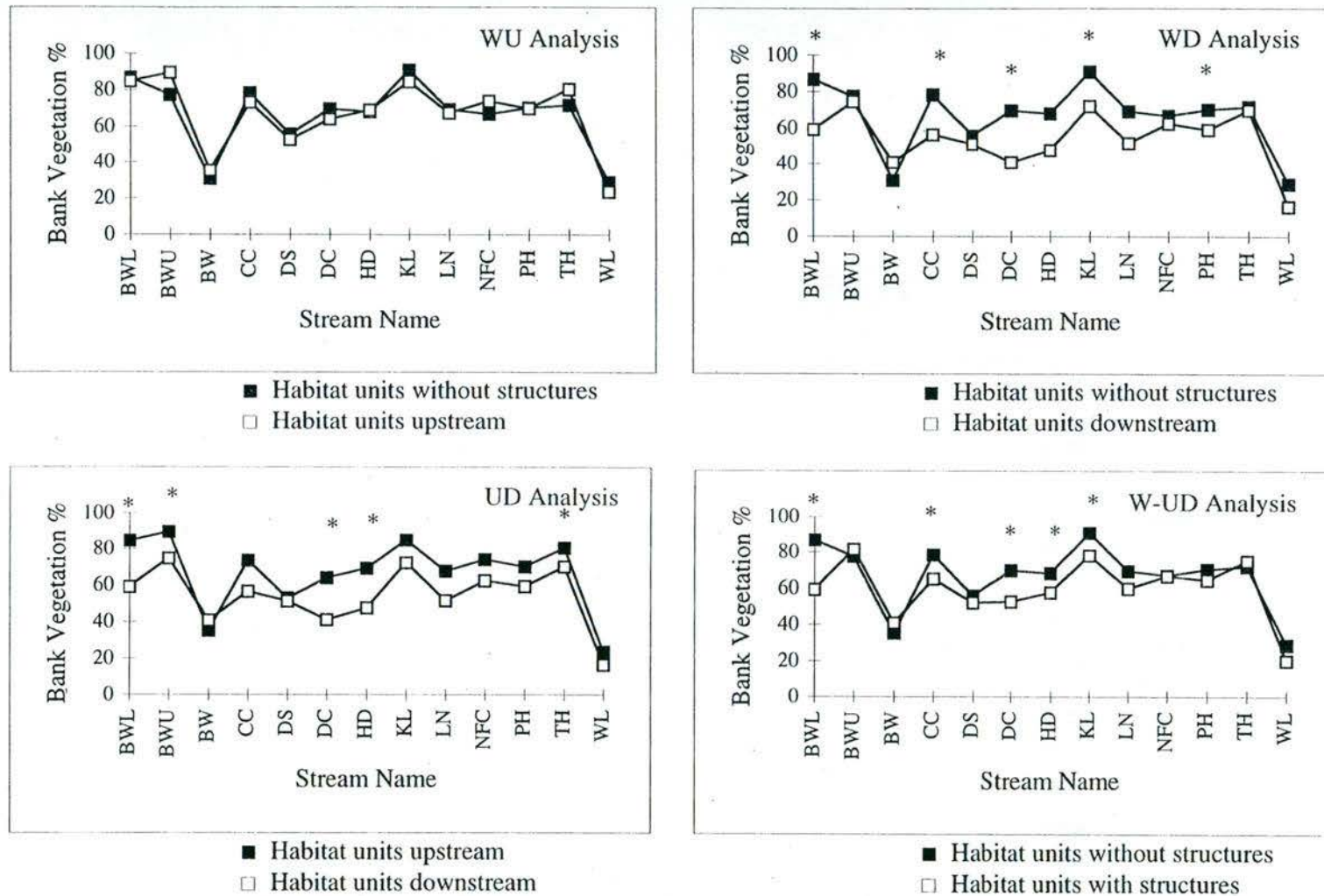


Figure 22. WU, WD, UD and W-UD analyses of bank vegetation. * indicates significant difference at $p < 0.05$

sediment (Heede, 1981; Trotter, 1990), this may provide sites for vegetation establishment. Once vegetation becomes established, additional sediment could be intercepted (Baker, 1977; Hupp and Simon, 1991; Sedell and Beschta, 1991; Gordon, 1992; Beschta, 1993; McKenney et al., 1995; Knighton, 1998). This could stabilize the bank from further erosion and enhance channel recovery (Hupp and Simon, 1991; Magilligan and McDowell, 1997). In Upper Bear Wallow, greater amounts of bank vegetation and less bank erosion appeared to be related characteristics in the habitat units upstream from ISSs. The ISSs appeared to be functioning similar to check dams which lower gradient, trap sediment and prevent erosion and head cuts from progressing upstream.

In 12 of the 13 reaches evaluated, bank vegetation percent in habitat units downstream from ISSs was less than bank vegetation in habitat units without ISSs (WD). The difference was significant in five reaches. In 11 reaches, bank vegetation percent in habitat units downstream from ISSs was less than in habitat units upstream from ISSs (UD). In five reaches, the difference was significant. Again, this result is related to the bank erosion results. Bank erosion was greater and bank vegetation was less in habitat units downstream from ISSs than in habitat units upstream from ISSs. In habitat units downstream from ISSs, lack of bank vegetation could cause increased bank erosion and vice versa. In nine reaches, bank vegetation percent in habitat units with ISSs (upstream and downstream from ISSs) was less than bank vegetation percent in habitat units without ISSs (W-UD). The difference in bank vegetation percent was significant in five reaches.

Bivariate plots were used to identify the control variables that had the greatest influence in reaches where there were significant differences in bank vegetation between habitat units upstream from ISSs compared to habitat units downstream from ISSs (UD analysis) (Figures 23 and 24). In these reaches, drainage area was small, bankfull width-to-depth ratio was small and reaches were not Rosgen type B.

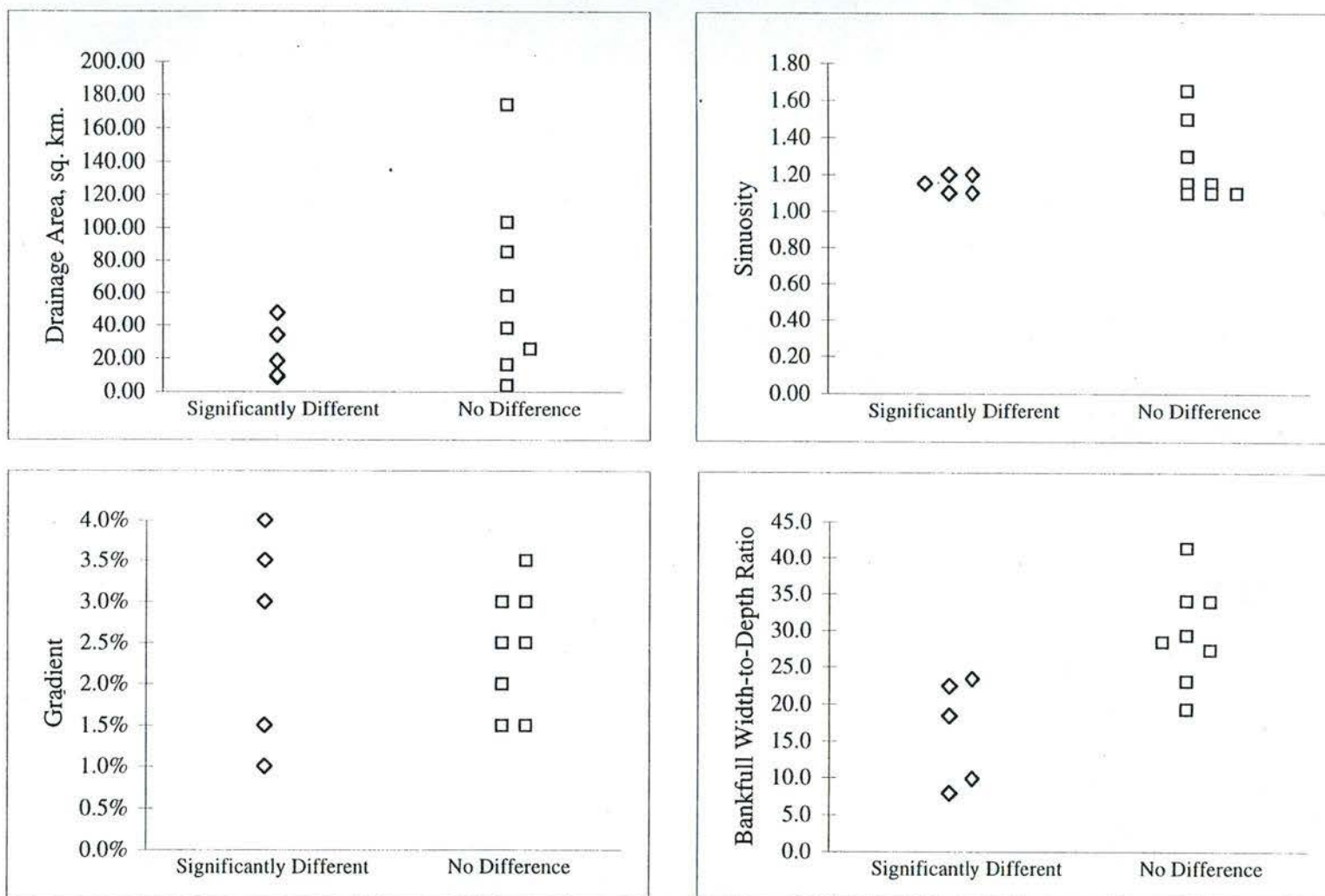


Figure 23. Bivariate plots for bank vegetation analysis of habitat units upstream and without structures (UD analysis).

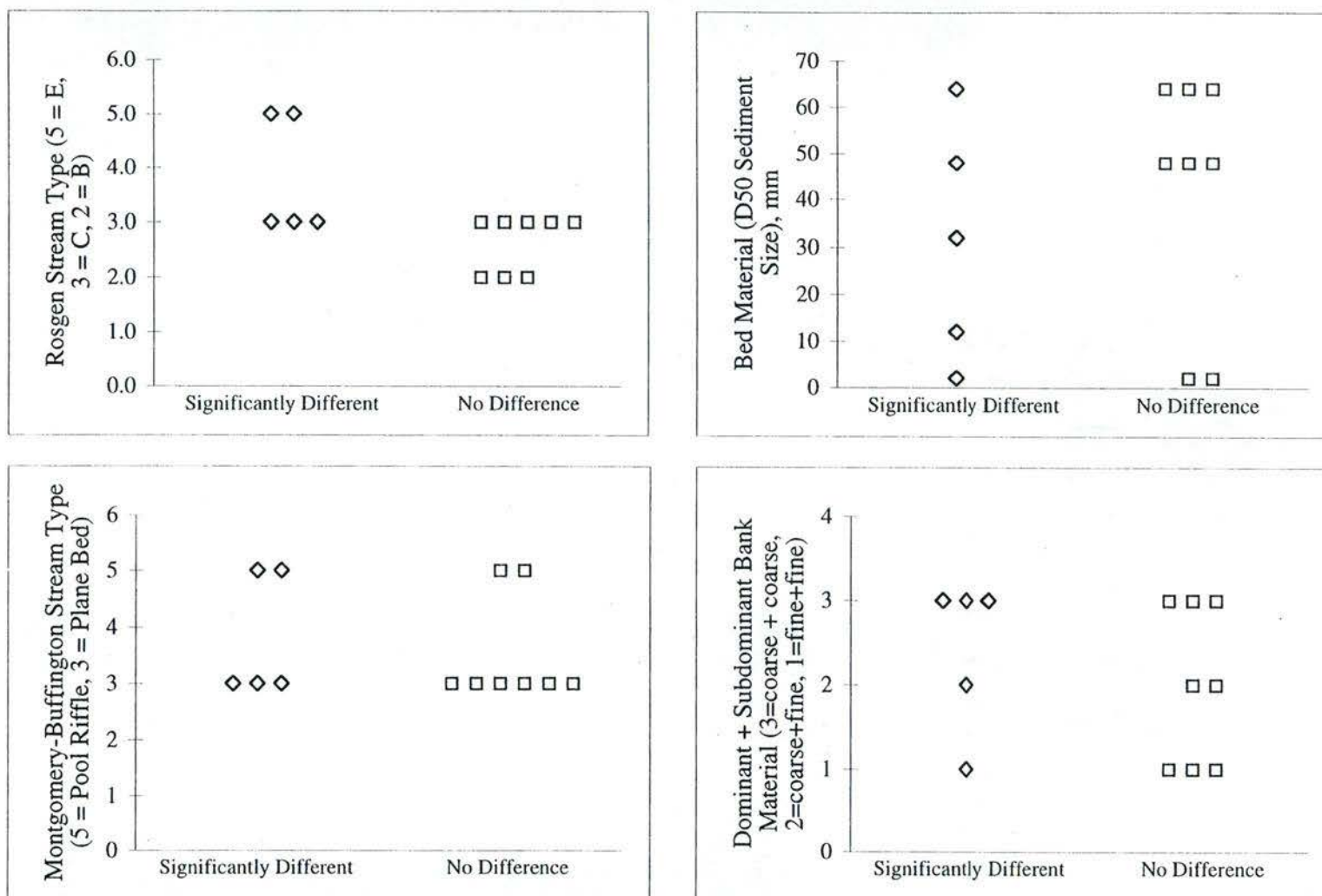


Figure 24. Bivariate plots for bank vegetation analysis of habitat units upstream and without structures (UD analysis).

Bivariate plots were also used to identify the control variables that had the greatest influence in reaches where there were significant differences in bank vegetation in habitat in habitat units without ISSs compared to habitat units with ISSs (upstream and downstream) (W-UD analysis) (Figures 25 and 26). The analysis indicated that the stream reaches were not Rosgen type B stream reaches.

Channel Morphology and Vegetation Discussion

The results of the channel morphology analysis provided information about channel response to ISSs as well as insight into the factors that influence channel form and channel sensitivity to ISSs.

ISSs did create pools as they were intended to do and residual pool depth was greater in ISS pools than in other pools. However, in a majority of reaches, residual pool depth of ISS pools was not significantly greater than other pools in the reach. Of the three other channel characteristics evaluated, wetted width, bank erosion and bank vegetation, ISSs had the greatest effect on wetted width and bank erosion, and in habitat units downstream from ISSs. In general, in habitat units downstream from ISSs, wetted widths were greater, bank erosion was greater and bank vegetation was less than in other habitat units. Habitat units upstream from ISSs were also affected. In upstream habitat units, wetted widths were also greater than in other habitat units but bank erosion was less than in habitat units without ISSs. Bank vegetation was slightly less in habitat units upstream from ISSs than in habitat units without ISSs. An unexpected result was that bank erosion was less in habitat units upstream from ISSs than in either habitat units downstream from ISSs or habitat units without ISSs. Overall, bank erosion was not significantly greater in habitat units with ISSs than in habitat units without ISSs. A detailed discussion of these results of the analysis of the effects of ISSs on channel morphology and vegetation and the relationships between wetted width, bank erosion and bank vegetation follows.

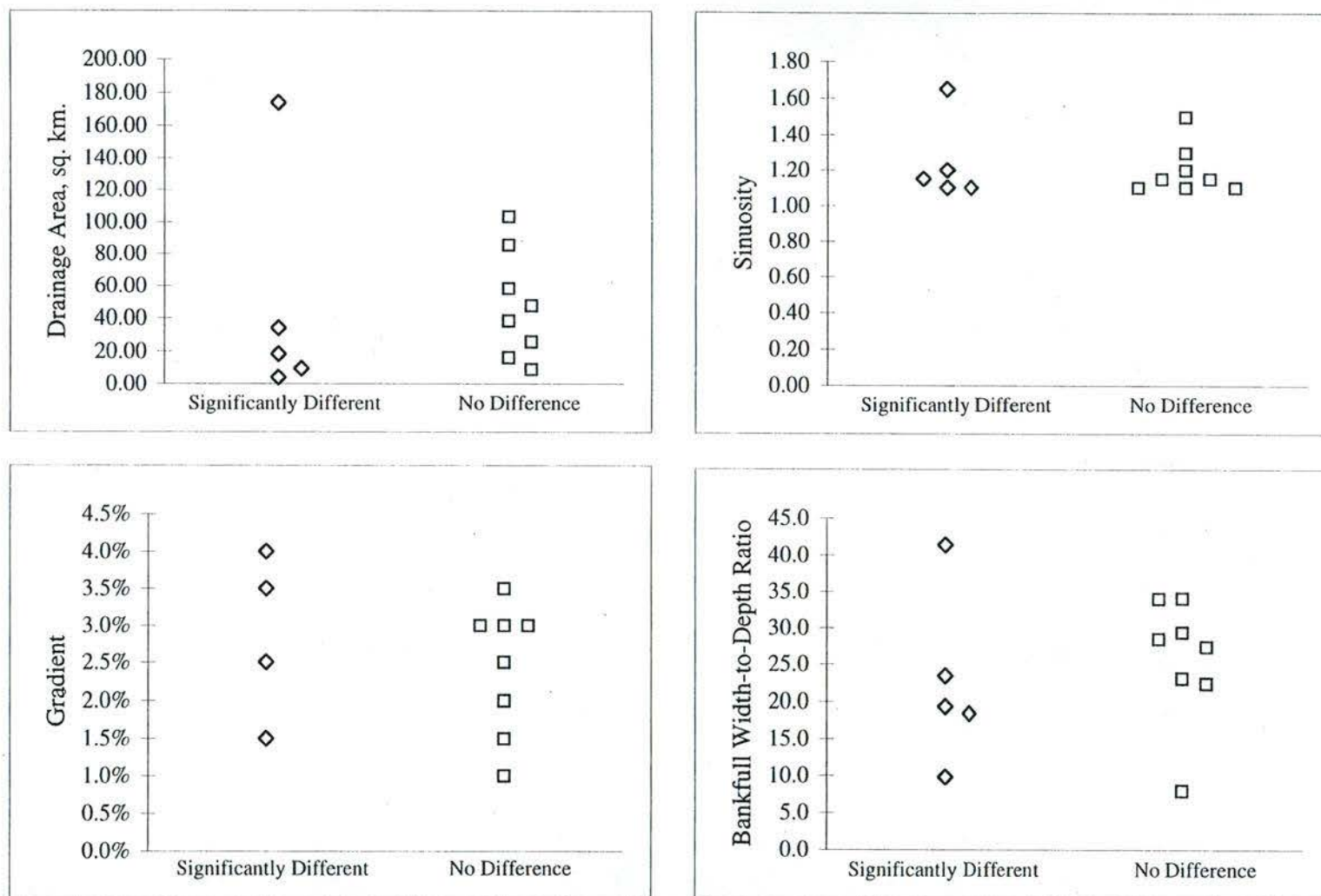


Figure 25. Bivariate plots for bank vegetation analysis of habitat units with and without structures (W-UD analysis).

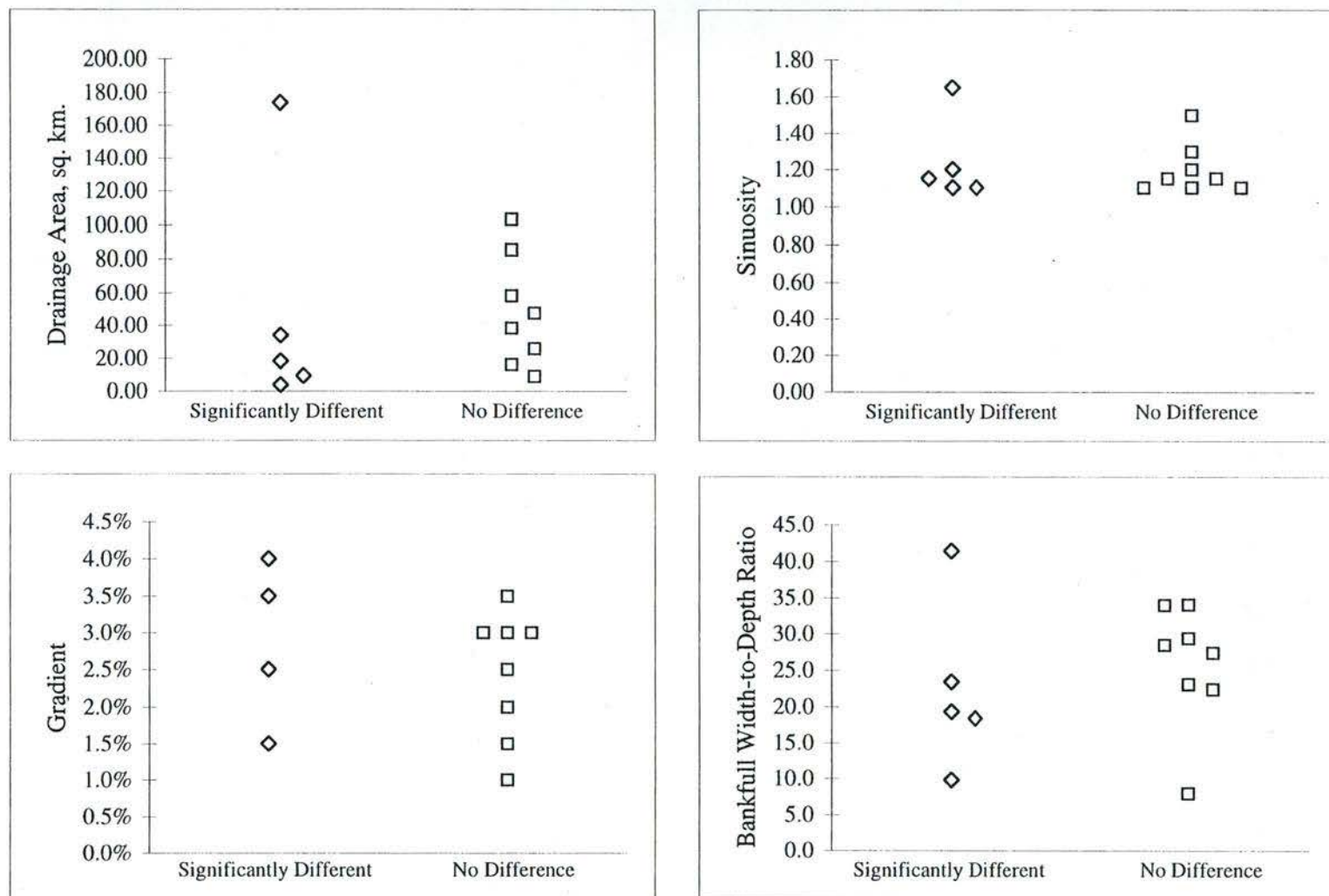


Figure 25. Bivariate plots for bank vegetation analysis of habitat units with and without structures (W-UD analysis).

Residual Pool Depth at ISS Pools

Pools were created when ISSs were installed in the reaches evaluated in this study and in many cases the pools have been maintained. These ISS-created pools were deeper than non-structure pools. However, as the evaluation of ISS effectiveness indicated, most ISSs pools were not as deep as pools in healthy stream reaches (Lamb, 1996) in the Umatilla NF. It has been suggested that ISSs have maintained and enhanced pools and stream flow in reaches that had typically been dry during low-flow periods (Calame, 1997). Some ISSs were installed in locations where they were thought to tap into groundwater. These locations were selected based on the presence of hydrophilic vegetation which indicated subsurface moisture availability. Reaches that typically had been dry during low-flow periods prior to the installation of ISSs (Wilson and Phillips) contained water in pools during low-flow periods after ISSs were installed (Calame, 1997). At the time field work for this thesis was conducted, water was present throughout the channel in Wilson, but in Phillips, water was found only in some ISS pools. This could be a problem for fish if they become isolated in one of these pools and have limited access to food supplies. However, these pools may facilitate fish survival if more and better quality habitat is available.

The results of this analysis might be useful as a guide to predict the effectiveness of ISS pools in reaches with different characteristics. In this study, Rosgen type B reaches with coarser bed and bank material and higher gradient had significantly deeper pools at ISSs than at other pools in a reach. Reaches with these characteristics might be better suited to habitat enhancement using the channel spanning ISSs similar to those in this study. Reaches that were Rosgen type C or type E or Montgomery-Buffington pool-riffle type, with finer bed and bank material, and lower gradient, did not maintain pools that were significantly deeper than non-structure pools. Reaches with these characteristics may be less suited to the addition of cross-channel ISSs to create pools.

This analysis indicated that residual pool depth in pools associated with ISSs was significantly greater than in non-ISS pools in Rosgen type B reaches. Rosgen stream-type reflects characteristics such as sinuosity, bankfull width-to-depth ratio and gradient. Neither sinuosity or bankfull width-to-depth ratio individually were identified as control variables influencing the significant differences in residual pool depth. Gradient was identified as an influential control variable, and it may have had the greatest influence on residual pool depth in these reaches. It is also possible that it is not just one characteristic, but the combination of characteristics that contribute to the interaction between stream-type and residual pool depth.

The pools formed at ISSs were plunge pools which are typically formed below channel obstructions and maintained by the hydraulic action of stream flow which scours the pool downstream of the obstruction. This hydraulic mechanism for creating and maintaining pools is especially prevalent in streams with higher gradients (Montgomery et al., 1995). Streamflow in reaches with high gradient may have greater erosive power, and therefore may be more effective in doing the geomorphic work of scouring pools downstream of an ISS weir. At the same time, coarse bed and bank material tend to be less mobile and more resistant to entrainment than fine material. Reaches with coarse bed and bank material are less sensitive to morphological change, and once a pool has been created by the construction of an ISS, it is likely to be maintained over time because these coarser channel materials resist movement and change. In the reaches with high gradient and coarse bed and bank material, constructed log and boulder ISSs appear to have supplemented the intrinsic pool forming processes.

Pools can be formed by other mechanisms in stream reaches with low gradient or fine bank material. In these reaches, pools are often formed at bends in channels through lateral scour of bed and banks (Keller and Melhorn, 1978). In this study, the reaches where residual pool depth was not significantly greater in structure pools typically had lower

gradients, and some had finer bed and bank material. Log and boulder weirs may not supplement natural pool forming processes in stream reaches with low gradient or in reaches having fine bed and bank material.

In addition to evaluating the difference in pool depths between structure pools and non-structure pools, it would be useful to evaluate whether ISSs had a significant effect on the number of pools in each reach. For example, even if the pools created by ISSs were not significantly deeper than other pools in most reaches, the number of pools may be greater than before ISSs were installed. If this were the case, ISSs would have contributed to a greater amount of pool habitat within a reach. To evaluate the effect of ISSs on the number of pools, it would be necessary to have reach data collected for specific characteristics before ISSs were installed to compare with data collected after ISS installation. That information was not available.

Wetted Width

Overall, wetted widths were greater in habitat units with ISSs (both upstream and downstream) than in habitat units without ISSs. Wetted widths were widest in habitat units downstream from ISSs. Several influential watershed and channel variables were identified in analyses of bivariate plots for the WD analysis. Reaches that showed widening relative to ISSs had smaller drainage area, finer bed material and smaller bankfull width-to-depth ratio. Rosgen type B streams did not have significantly greater wetted widths associated with ISSs. The Rosgen type B streams in this study had coarse bed and bank material. All three of the Montgomery-Buffington pool-riffle reaches showed channel widening related to ISSs. Montgomery-Buffington stream-type incorporates bed material size, and the pool-riffle type has small bed material size as a characteristic. The pool-riffle reaches in this study also had small bank material size. The pool-riffle reaches were most likely more sensitive to morphological change because of their finer bed and bank material.

Bank material size appears to be an important characteristic influencing channel response to ISSs. The effects of bank material on wetted width at habitat units with ISSs were most apparent in reaches with specific bank material sizes. Reaches with coarse dominant and subdominant bank material, and fine dominant and subdominant bank material were both affected, though the reasons for greater wetted widths may be different. Though not evaluated here, the type of ISS also appears to be important in combination with bank material size. Single log ISSs were used in three reaches, Upper Bear Wallow, Kelsay and North Fork Cable, where wetted widths were wider in habitat units upstream and downstream from ISSs. These three reaches had fine bed and bank material (sand size and smaller), and are more sensitive to morphological change than reaches with coarser bed and bank material. Bank material in Upper Bear Wallow and Kelsay was somewhat cohesive. Bank material size in Upper Bear Wallow was predominantly silty-clay-loam, and in Kelsay it was silty-clay-loam, clay-loam and silty-loam. Bank material size in North Fork Cable was less cohesive, predominantly silty-loam and sandy-loam. While Upper Bear Wallow and Kelsay had high bank vegetation (> 80%), North Fork Cable had only 46% bank vegetation.

In reaches in this study, smaller bankfull width-to-depth ratio was a characteristic of reaches where wetted widths were significantly greater in habitat units with ISSs than in habitat units without ISSs. A smaller bankfull width-to-depth ratio (narrow and deep) would concentrate streamflow within the channel and toward the banks, and enhance the effect of streamflow on channel widening. Water flowing over a channel obstruction, such as a weir, is likely to cause bed and bank scour directly downstream as streamflow is directed towards the bed and banks (Figure 27) (Church, 1990; Heede and Rinne, 1990). This could contribute to channel widening. Wetted width is likely to remain wider in habitat units with ISSs because ISSs have directed streamflow towards the banks, possibly limiting

vegetation establishment, sediment deposition and channel narrowing. Channel widening at ISSs may not negatively affect habitat quality if reach width-to-depth ratio is low overall.

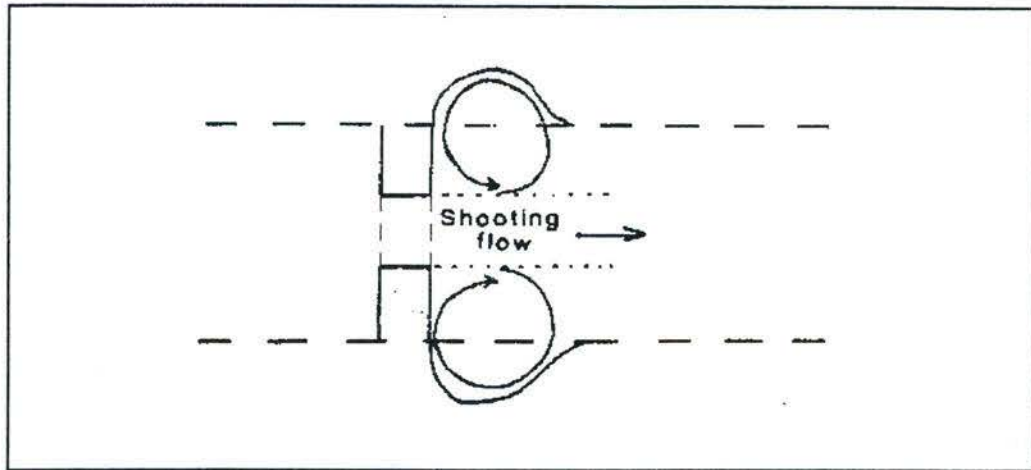


Figure 27. Flow downstream from channel obstruction (Heede and Rinne, 1990, p. 261).

The reaches where log-boulder or multiple-boulder ISSs were used and wetted widths were wider, Hidaway, Lower Bear Wallow and Thomas had coarse dominant and subdominant bank material. Lower Bear Wallow and Thomas had high bank vegetation (> 80%), and Hidaway had 68% bank vegetation. In these three reaches, bank vegetation downstream from ISSs was less than upstream from ISSs. If there were less bank vegetation downstream from ISSs, the banks would be more exposed to the erosive effects of streamflow which could contribute to greater erosion and channel widening. Another possibility is that wider wetted widths downstream from ISSs may be a result of the actual installation of the ISS and may not be due to erosion and associated channel widening. However, in reaches with fine bed and bank material, it is very likely that bank erosion has contributed to channel widening associated with ISSs.

Bank Erosion

Some bank erosion was associated with ISSs in a majority of the reaches. The trend was greater erosion in habitat units downstream from ISSs than in habitat units upstream from ISSs or without ISSs. This was consistent with the wetted width results. In habitat units downstream from ISSs, both wetted width and bank erosion were greater than in other habitat units. An unexpected result was that bank erosion in habitat units upstream from ISSs was less than in other habitat units. Field observations confirmed that some ISSs were trapping sediment upstream of the ISSs. Overall, bank erosion in habitat units with ISSs was not significantly different than in habitat units without ISSs. Greater bank erosion downstream from ISSs seems to be balanced by less bank erosion upstream from ISSs. Perhaps material eroded from the banks downstream from ISSs was trapped behind ISSs further downstream leading to a balance between erosion and deposition. ISSs seem to be functioning in a manner similar to check dams, trapping sediment and preventing erosion and headcuts from progressing upstream.

Three variables were identified as influential in reaches where bank erosion in habitat units downstream from ISSs was significantly greater than in other habitat units. These reaches had smaller drainage area, did not have coarse bank material and were not Rosgen type B. Since the trend was greater bank erosion downstream from ISSs than in other habitat units in all of the reaches in this study, this may be directly associated with hydraulic mechanisms related to the ISS itself rather than with the characteristics of the reaches. Lateral scour, and bed and bank scour downstream from channel obstructions, such as a log or boulders, are common in streams when flow is deflected by the obstructions (Figure 27) (Church, 1990; Heede and Rinne, 1990). Scour and erosion are likely to occur downstream from ISS weirs because they provide an obstruction. This suggests that some downstream

bank erosion should be expected when channel-spanning ISSs are placed in most, if not all, streams.

Stream reaches with some specific characteristics may have a greater potential for bank erosion and a higher magnitude response associated with ISSs than in other stream reaches, but the data from this study do not provide enough information to identify what all of those characteristics might be. Finer bed material (also associated with fine bank material) was identified as an influential control variables in reaches where wetted widths were significantly greater in habitat units associated with ISSs, and it is likely that also affected bank erosion. Variables not included in this analysis such as soil type, vegetation, or climate factors such as freeze-thaw weathering, may also be important. It is possible that control variables interact, and that combinations of variables may have a greater impact on reach response than have been identified using the analyses presented here.

The results from one reach (Kelsay), where bank erosion in habitat units associated with ISSs was significantly greater than in habitat units without ISSs, suggest that bed and bank material, gradient, sinuosity, and bankfull width-to-depth ratio may be important in addition to drainage area and bed material. Kelsay had fine bed material and the smallest drainage area of all the study reaches (3.78 km²). Both dominant and subdominant bank material were very fine and somewhat cohesive (silty clay, silty clay loam and clay loam) and gradient is low (1.5%). It had the highest sinuosity (1.65) and relatively low bankfull width-to-depth ratio. In this reach, the log-weirs were functioning very much like check dams by slowing water velocity, trapping sediment and preventing erosion and headcuts from progressing upstream. Field observations during the surveys conducted for this study and by Forest Service personnel suggest that the single-log ISSs in this reach were trapping sediment and functioning in such a way as to stabilize the reach from erosion (Calame, 1997). In Kelsay, wet meadows with emergent vegetation were forming upstream of the ISSs. In this reach, ISSs may eventually be buried by the sediment trapped by the ISSs. In

this case, the ISSs may have served another unintended purpose besides pool formation and maintenance. The ISSs appeared to be operating like grade control devices which trap sediment and stabilize the channel from further degradation.

Bank Vegetation

Bank vegetation was evaluated in habitat units relative to ISS presence. Overall, the results showed that there was less bank vegetation in habitat units with ISSs than in habitat units without ISSs, and less in habitat units downstream from ISSs than in either habitat units upstream or without ISSs.

In reaches where there was less bank vegetation in habitat units downstream from ISSs than those upstream from ISSs, drainage area, bankfull width-to-depth ratio and Rosgen stream-type were identified as the most influential control variables. In these reaches, drainage area and bankfull width-to-depth ratios were smaller, and the reaches were not Rosgen type B.

It is likely that there are other control variables in addition to those used in this study that have a significant effect on vegetation establishment and growth. Vegetation is strongly affected by other controls such as local and regional climate, land use, and ecological factors which were not used as control variables in this study. Because of the possible influence of these additional factors, different mechanisms, conditions and processes that influence vegetation establishment, growth and survival may be operating in addition to the effects of ISSs. It is also very likely that the impacts of ISSs on vegetation were directly related to the effects of ISSs on wetted width and bank erosion. The relationships between these will be addressed next.

Interactions among Wetted Width, Bank Erosion and Bank Vegetation

ISSs appear to affect wetted width, bank erosion and bank vegetation; however the effects cannot be viewed independently. The results for wetted widths in habitat units downstream from ISSs were consistent with the results for bank erosion and bank vegetation in habitat units downstream from ISSs, and the effects were more severe than in other habitat units. Wetted widths and bank erosion were greater, and bank vegetation was less in habitat units downstream from ISSs than in other habitat units. The impacts of ISSs on bank erosion can affect bank vegetation and vice versa. In combination, the effects on bank erosion and bank vegetation can affect wetted widths. Bank erosion can limit vegetation establishment and when there is less bank vegetation, more erosion can occur and can lead to channel widening and greater wetted widths.

ISSs can limit bank vegetation and facilitate bank erosion and channel widening downstream from ISSs in a couple of ways. First, the boulders or logs that were installed along the banks as part of the ISS may prevent vegetation establishment and growth. This would expose parts of the bank adjacent to and underneath the boulders to the erosive force of stream flow, and lead to bank erosion and channel widening. Vegetation can trap sediment and build banks which leads to channel narrowing and decreased width-to-depth ratios. Habitat units that have less vegetation will be less effective in trapping sediment and in contributing to channel narrowing. Conversely, ISSs may increase local erosion by directing streamflow toward the banks which could then limit vegetation establishment and persistence, expose the banks to further erosion and contribute to channel widening. As previously discussed, bank scour often occurs down stream of a channel obstruction (similar to the weir of these ISSs) when streamflow is directed towards the banks (Church, 1990; Heede and Rinne, 1990). This could explain why wetted widths and bank erosion were greater, and bank vegetation was less in habitat units downstream from ISSs.

The connections between bank vegetation, bank erosion and wetted widths are different in habitat units upstream from ISSs. In a majority of reaches, bank erosion was less in habitat units upstream from ISSs than in other habitat units. In four reaches, bank vegetation was also greater in habitat units upstream from ISSs than in other habitat units. In the remaining reaches, bank vegetation was only slightly less in habitat units upstream from ISSs than in habitat units without ISSs. ISSs appeared to be trapping sediment just upstream from ISSs. If sediment trapping or deposition is occurring upstream from ISSs, this would provide sites for vegetation establishment. Once vegetation is established, this could facilitate more sediment deposition and may eventually lead to channel narrowing in habitat units upstream from ISSs. In many of the reaches where bank erosion was less upstream from ISSs, channel wetted widths were still wider than in habitat units without ISSs, but not as wide as in habitat units downstream from ISSs.

In two reaches, Kelsay and Upper Bear Wallow, wet meadows with a significant amount of deep water and emergent vegetation had formed upstream from some of the ISSs. In these reaches, ISSs may eventually be buried by the sediment trapped by the ISSs. However, Kelsay was also the only reach where bank erosion was significantly greater in habitat units with ISSs than in habitat units without ISSs and also had significantly greater wetted widths in habitat units with ISSs. The greater wetted widths at some ISSs were due to the width of the slow-moving water in the wet meadow upstream from the ISS. At other ISSs, greater wetted widths were accompanied by greater bank erosion, and this seemed to occur when local gradients were higher than at other ISSs. Reaches with finer bed and bank materials, like Kelsay which had the finest bed and bank material, might be more sensitive to the physical forces contributing to morphological change. In addition, Kelsay had less bank vegetation in habitat units upstream and downstream from ISSs than in other habitat units. In combination, these factors may have contributed to a more rapid and larger magnitude response to the presence of ISSs than in reaches with coarser bed and bank material and/or

greater amounts of bank vegetation. The formation of wet meadows may have been the result of sediment deposition and also to the presence of vegetation, such as reeds and sedges, that can establish quickly. In Kelsay, the response to ISSs was complex.

In reaches where ISSs limit the amount of bank vegetation, less vegetation could affect bank erosion. However, in this study only one reach had greater bank erosion in habitat units with ISSs than in habitat units without ISSs and overall, bank erosion in habitat units with ISSs was not significantly different than in habitat units without ISSs. Vegetation can trap sediment and build banks which leads to channel narrowing and decreased width-to-depth ratios. Habitat units with ISSs that have less vegetation are not as effective in trapping sediment, building banks and contributing to channel narrowing. In this scenario, ISSs prevent channel narrowing.

In addition to pool formation and maintenance, ISSs may be serving another unintended purpose. ISSs seem to be operating like grade control devices which trap sediment and stabilize the channel from further degradation. One result of this is that in many of the reaches, vegetation may continue to become established and contribute to greater channel stability over a longer period of time. Another result is that by creating a stepped longitudinal profile similar to that created by LWD or boulder steps (Figure 29) (Keller and Swanson, 1979; Grant et al., 1990; Montgomery and Buffington, 1993; Thompson, 1995; Montgomery and Buffington, 1997). ISSs may be contributing to decreased stream velocity and stream power by lowering the gradient within the reach. This could decrease the potential for erosion in habitat units both upstream and downstream from ISSs (Heede, 1981; Trotter, 1990; Grant et al., 1990; Abbe and Montgomery, 1996).

Summary and Conclusions

In this chapter, I have presented the analysis and results of ISSs effectiveness and channel morphology addressing the first three research questions. Data from field surveys of 13 stream reaches were used for analysis. The results indicate that many of the reaches that have had ISSs installed to enhance channel habitat are only in fair or poor condition. ISSs have provided additional pool habitat, and it is likely that this has been important for the survival of fish in these reaches. However, there is much room for improving channel habitat conditions. While ISSs have added pools to the reaches, they have also contributed to greater wetted widths, greater bank erosion and less bank vegetation in habitat units with ISSs, especially downstream from ISSs.

In the analysis of ISSs effectiveness I compared reach characteristics with target values that came from empirical, quantitative studies and agency documents. The results of this analysis showed that many of the target values were not met by any of the reaches. One reach met half of the twenty-four target values and the remaining reaches met fewer than half of the target values. One reach met only four of the target values. If the number of target values met by a reach is used as an indicator of reach condition, then this analysis shows that none of the reaches evaluated are in excellent condition and only a few are in good condition. The remaining reaches are in fair or poor condition. Few reaches could be considered to be healthy (Lamb, 1996) or as potential refugia (Ebersole, 1994). This suggests that there is room for improvement in habitat condition in these reaches.

While all 13 reaches met the target value for habitat unit frequency, a measure of channel complexity in healthy streams in the Umatilla NF (Lamb, 1996), this target value should be used with caution. The number of habitat units identified during field surveys may be highly subject to observer bias which can result in overestimation or underestimation of the number of habitat units (Poole et al., 1997). Additionally, the relative

contribution of ISSs to increased habitat unit frequency could be better assessed if habitat unit frequency before the addition of ISSs had been determined. Although more time consuming to survey, actual measurements of bed form elevation could provide a better indication of channel complexity.

None of the reaches met the PACFISH target value for pool frequency and this could be related to the amount of large woody debris (LWD) in the reaches. LWD is an important pool forming mechanism and none of the reaches met the target value for large LWD. A few of the reaches met the target values for small LWD or total LWD. Of the three reaches that met the target value for total LWD, two were in watersheds where insect infestation had contributed to high tree mortality and an abundance of downed wood on the forest floor. These watersheds then experienced catastrophic fires in 1996, followed in 1997 by large magnitude floods which delivered LWD to the stream channel. The data on the number of log-jams and the complexity of LWD accumulations (Table 19, chapter IV) indicated that the accumulations of LWD in these channels created a great deal of habitat complexity and variety. However, these forest disturbances are outside the range of natural variability in both timing and intensity because of land uses and management practices such as fire suppression. While undoubtedly important in contributing some LWD to stream channels, little is known about the role of disturbance in providing LWD or in influencing channel forming processes and morphology. This could be a subject for further research.

The channel morphology results showed that residual pool depth at ISSs was greater than residual pool depth in other pools in these reaches, suggesting that ISSs were important in creating pool habitat as they were intended to do. The average ISSs pool had a residual pool depth of 1.51 feet (0.46 m) compared with and 0.88 feet (0.27 m) in non-ISS pools. However, residual pool depth was not as deep as residual pool depth in healthy pools in the region (Lamb, 1996) in nine reaches. The less stringent Ebersole (1994) pool

depth target value of 0.27 m (0.88 ft) was met by all the reaches, but this target value most likely does not indicate the optimum pool depth that is necessary for adequate pool habitat.

Few reaches met any of the target values for vegetation, including canopy cover, bank shrub cover, overhanging bank vegetation or LWD. Due to different ecological potential for vegetation type, some reaches may never be able to meet specific target values such as those for canopy cover or for LWD in streams in meadow systems with predominately grass and sedge vegetation. It may be appropriate to identify different vegetation target values for streams with different ecological potentials. In reaches where vegetation is dominated by grasses, sedges and rushes, overhanging bank vegetation may be very important in providing shading and cover for fish. A target value for overhanging bank vegetation may be more appropriate in these reaches than in reaches dominated by forest. In addition, in a couple of reaches where grasses, sedges and rushes were dominant, it was apparent that cattle grazing had occurred in these reaches and limited the amount of vegetation along the banks. In Dry Camas, bank vegetation was very sparse throughout the reach. In Kelsay, some sections of the reach were affected more than others, and bank erosion was greater where there was less vegetation. Management strategies that limit grazing near the banks or during some times of the year may be needed in these reaches. In some reaches, shrubs can provide streamside shading and an appropriate target value could be set for those reaches. In reaches in ecological settings that have the potential to meet target values for LWD and canopy cover, riparian vegetation management strategies could be developed to achieve the target value levels. With changes in riparian vegetation management, these target values might be met in the future as more trees remain in the riparian area to provide canopy cover, and for recruitment as in-channel LWD.

In all of the reaches, stream temperatures (in spot measurements) met the PACFISH target values. There are many factors that contribute to stream temperatures, many of which could not be considered in this study. It is important to continue to monitor stream

temperatures and evaluate average temperature trends over long periods of time, especially during the summer months and during years where average air temperatures are higher than those during the field surveys in 1997.

Few of the channel form or bank stability target values were met by the reaches evaluated. The channels were wider and shallower than the target values suggest is optimum. In eight reaches, bank stability did not meet the least stringent PACFISH target value and 11 reaches did not meet the PACFISH target value for width-to-depth ratio. This suggests that the reaches are in the process of adjusting through erosion. These results may be related to the vegetation results. Few reaches met the vegetation target values and this suggests that low vegetation amounts might be contributing to bank erosion and wide, shallow channels. More bank vegetation could stabilize the banks, increase bank stability and contribute to channel narrowing and lower width-to-depth ratios.

ISSs have added pools to the reaches, but they have also contributed to greater wetted widths, greater bank erosion and less bank vegetation in habitat units with ISSs, especially downstream from ISSs. In some streams, ISSs seem to behave like grade control structures which lower gradient, trap sediment and prevent erosion and head cuts from progressing upstream. This may indicate that ISSs are lowering gradient in habitat units upstream from ISSs by creating a stepped longitudinal profile similar to that created by LWD or boulder steps (Figure 30) (Keller and Swanson, 1979; Montgomery and Buffington, 1993; Thompson, 1995; Montgomery and Buffington, 1997). This may result in decreased stream velocity and stream power, decreasing the potential for erosion in habitat units just upstream from ISSs in some reaches (Heede, 1981; Trotter, 1990; Grant et al., 1990; Abbe and Montgomery, 1996). In a couple of reaches, increased sediment deposition upstream from ISSs is facilitating vegetation establishment and the creation of wet meadows. This may raise the local water table and have a positive effect on vegetation in the stream valley. When functioning in this manner, ISSs are contributing to increased channel stability. In

these reaches, the ISSs may eventually be buried by sediment. However, in these same reaches, ISSs have also contributed to greater wetted width and bank erosion in habitat units downstream from the ISSs. While erosion and deposition within reaches appeared to be balanced, ISSs are contributing to local channel adjustment.

Channel morphology response was greater in streams with certain characteristics. In general, the greatest negative effects of ISSs on channel morphology have been in reaches with fine bed material (often associated with fine bank material), small drainage area and small width-to-depth ratios. The impact of ISSs on channel morphology was greatest in Montgomery-Buffington pool-riffle reaches, which characteristically have low gradient (0.1 to 2%), and are unconfined and sinuous. Reaches with smaller bed and bank material are more sensitive to the physical forces that contribute to morphological change, and have a more rapid and larger magnitude response. Reaches where ISS pools were significantly deeper were Rosgen type B reaches, and had high gradient, and coarse bed and bank material. In reaches with these characteristics, ISSs may provide necessary habitat without causing extreme morphological changes. ISSs mimicked the intrinsic pool forming processes that occur in reaches with higher gradients and coarser bed and bank material.

These results suggest that ISSs may be useful in some reaches, but it seems clear that ISSs alone will not provide the remedy for all channel habitat degradation. Innovative management strategies are needed to improve the characteristics in these reaches that will contribute to better channel habitat. In almost all reaches, ISSs contribute to greater wetted widths, greater bank erosion and less vegetation in habitat units with ISSs. These effects contribute to greater width-to-depth ratios and may limit potential channel narrowing. In some reaches, specifically those with lower gradient and finer bed and bank material, ISSs have directly contributed to rapid and large magnitude channel adjustments and may not be appropriate in reaches with these characteristics.

CHAPTER VI

IN-STREAM STRUCTURE SURVIVAL AND PERFORMANCE

This chapter includes the analysis methods, results, discussion and conclusions of the assessment of in-stream structure (ISS) survival and performance and addresses the fourth research question:

4. What are the watershed, channel, stream-type and ISS characteristics that affect the survival and performance of ISSs?

Watershed, channel and stream-type and ISS control variables were used to evaluate survival and performance at the scale of individual ISS (Table 47).

TABLE 47. Control Variables used to Evaluate
ISS Survival and ISS Performance

Watershed Control Variables
Geology
Valley Constraint
Drainage Area
Stream Order
Channel Control Variables
Reach Gradient
Sinuosity
Stream-type Control Variables
Rosgen Stream-type
Stream-type Control Variables
ISS Type
ISS Gradient
ISS Anchor

Two ISS data sets were used to evaluate ISS survival and performance, the Forest Service data set and the Taylor data set. ISS data for the Forest Service data set came from

field surveys of 904 ISS in 43 reaches. Reach names and locations are listed in Table 106, appendix G. Each reach is illustrated on a section from a USGS 1:24,000-scale quadrangle in Figures 42 to 72, appendix G. Reach characteristics are summarized in appendix H. These field surveys were conducted in 1996 and 1997 as part of the USDA Forest Service Region 6 (Pacific Northwest Region) Phase II Flood Assessment of ISS Durability (durability is referred to as survival in this thesis). ISSs in thirty-two reaches were surveyed by Forest Service employees. ISSs in 11 reaches were surveyed by the author of this thesis. These 11 reaches were part of the 13 reaches used for analysis in chapter V.

ISS data for the Taylor data set came from field surveys of 150 ISSs in 12 reaches. These ISSs were surveyed during 1997 by the author of this thesis during field surveys for the ISS effectiveness analysis described in chapter IV (Table 95, Figures 32 to 41, appendix D; Tables 96 to 102, appendix E). ISSs from only 12 of the 13 reaches were used because data for one reach (Wilson) was missing. The Taylor data set included additional reach scale control variables (Table 48) that were collected during field surveys.

TABLE 48. Additional Channel and Stream-Type Control Variables used to Evaluate ISS Survival and ISS Performance for Taylor Data Set

Channel Control Variables	
	Median (D50) Bed Material (mm)
	D84 size Bed Material (mm)
	Entrenchment Ratio
	Bankfull Width-to-Depth Ratio
	Dominant Bank Material Size
	Subdominant Bank Material Size
	Bank Stability
	Bank Vegetation
	Riparian Vegetation Seral Stage
Stream-Type Control Variables	
	Montgomery-Buffington Stream-Type

Site Selection

Survival and performance of 904 ISSs were analyzed in streams where ISSs were placed between 1985 and the early 1990s. Each study stream was divided into one to five reaches. A total of 43 reaches were identified based on differences in characteristics such as geology, gradient, valley confinement and sinuosity. Most of the ISSs were located in watersheds that experienced floods with return intervals greater than 25 year flood events in 1995, 1996 or 1997 and some reaches experienced more than one flood. Flood magnitudes for several reaches were not known because there were no gaging stations near those sites.

Most of the ISSs in Umatilla NF that contain log and boulder ISSs have been surveyed, and all of the ISSs that have been surveyed were included in the Forest Service data set. All reaches included in the Forest Service data set met two other criteria: (1) they had experienced a large flow event in 1995, 1996 or 1997 and (2) they contained channel spanning ISSs.

The reaches containing ISSs in the Taylor data set were also selected (in consultation with Umatilla NF staff) if: (1) it was likely that they had experienced a large flow event in 1995, 1996 or 1997 (greater than 25 year flood return interval); (2) they contained channel spanning ISSs; (3) drainage area was less than 200 km²; (4) stream order was less than 4th order; and (5) Rosgen stream-type was B, C or E (Rosgen, 1994; Rosgen, 1996). Eleven of the 12 stream reaches were located in watersheds that experienced greater than 25 year flood events in 1995 or 1996. Flood magnitudes were not known in Big Wall due to the absence of a gaging station data nearby.

Data Collection

Data were obtained during field surveys, and using aerial photography and map and analysis. These data provided control and response variables used to evaluate ISS survival and performance. The field methods used and significance of these variables are discussed in detail in chapter IV.

Field Surveys

Data on ISSs for the Forest Service data set and for the Taylor data set were collected following procedures outlined in the evaluation form in Appendix C. Data for the additional control variables for the Taylor data set were collected in 1997 during field surveys by the author of this thesis. ISS control and response variables were recorded during the surveys. ISS design position was also recorded and was either cross-channel, edge or unknown. ISSs that were in an edge position were not used in this study because they were designed for the purpose of bank stabilization, not to provide fish habitat.

Response Variables

ISS survival was recorded in one of three categories. For some analyses these were reduced to two categories (Table 49).

TABLE 49. ISS Survival Response Variables

Variable	Type	Category
Survival	nominal	I = In place S = Shift on site L = Left Site
Survival	nominal	Sv = Survived (same as I above) Fd = Failed (combines S and L above)

ISS performance was recorded in one of three categories and in several of the analyses presented in this study, the were reduced to two categories (Table 50).

TABLE 50. ISS Performance Response Variables

Variable	Type	Category
Performance	nominal	F = Functioning P = Partially functioning N = Not functioning
Performance	nominal	Fc = Functioning (includes F and P) Fn = Not functioning

ISS performance was evaluated based on whether or not ISSs were functioning and met initial project objectives. In the Umatilla NF, most ISSs were designed to form pools. In a majority of cases, an ISS was considered to be functioning when there was a pool present. In other cases, an ISS was considered to be functioning if it was performing in such a way as to improve or provide habitat. For example if a log-jam had formed at the ISS, it might have created complex cover and a resting area. A partially functioning ISS might have had a pool, but one that was not very deep or that made up a very small portion of the habitat unit. An ISS that was not functioning might not have had a pool because the ISS had shifted on site, the ISS had left the site and no longer functioned to maintain the pool, the pool was filled in with gravel and cobble material, or the pool did not contain water. ISSs that were partially functioning or not functioning may not have had water that was flowing over the log or boulder weir to drop into the habitat unit downstream and maintain the plunge pool.

Control Variable Summary

The distribution of ISSs, relative to a number of control variables, are summarized in Figures 28 and 29. ISSs were not evenly distributed among a number of variables.

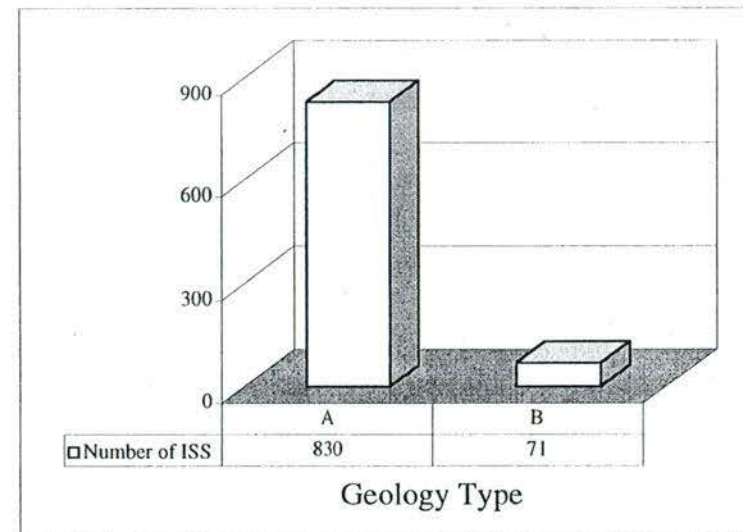
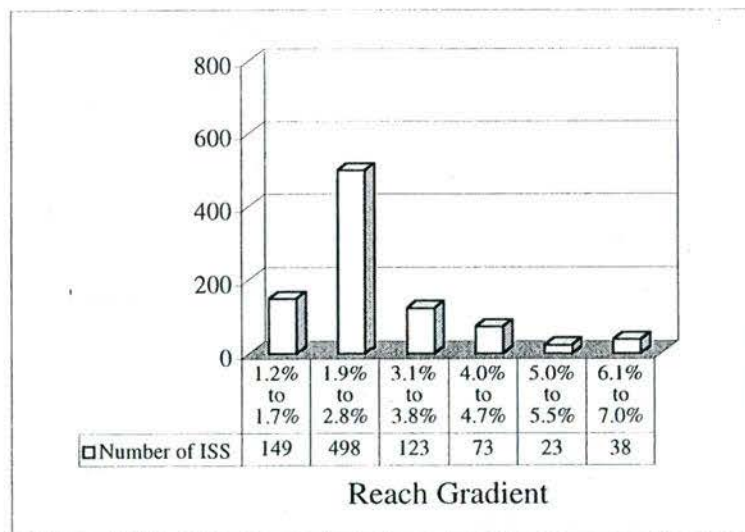
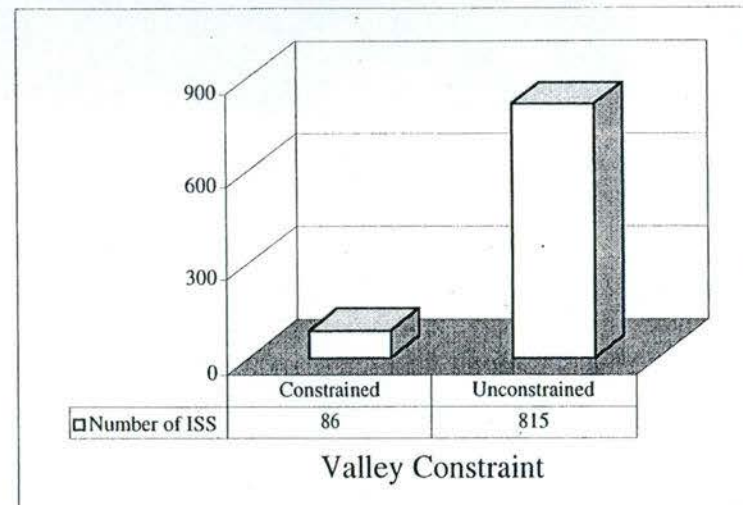
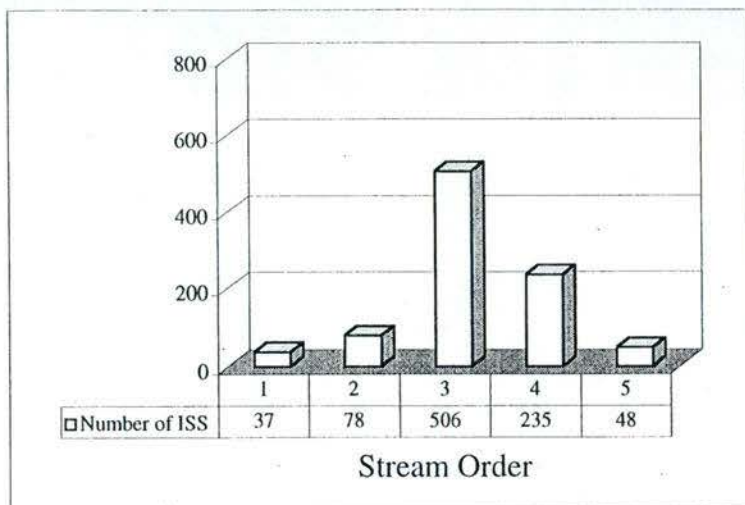


Figure 28. Distribution of ISS across watershed and reach characteristics in the Forest Service data set.

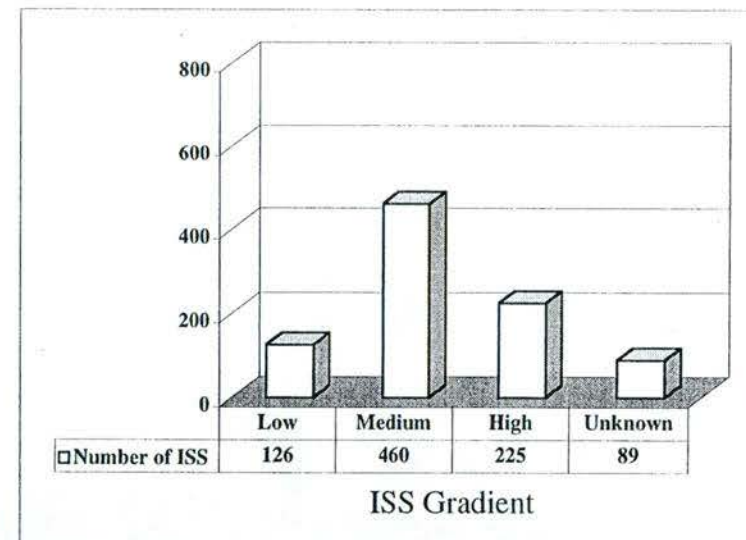
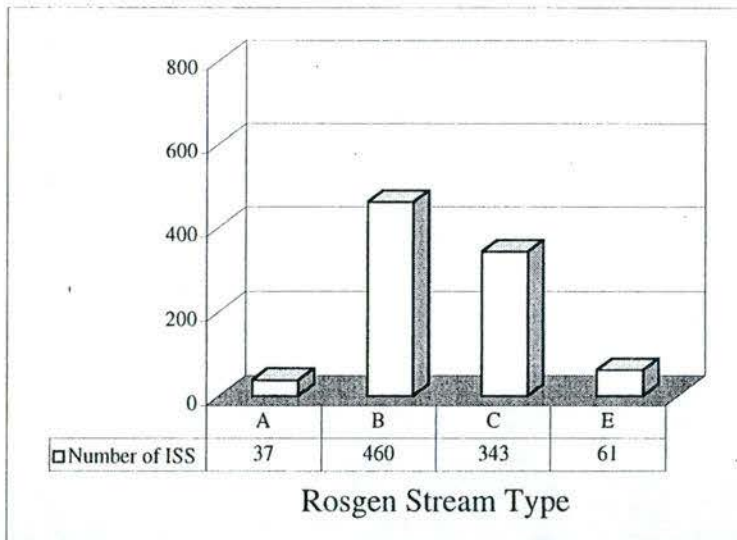
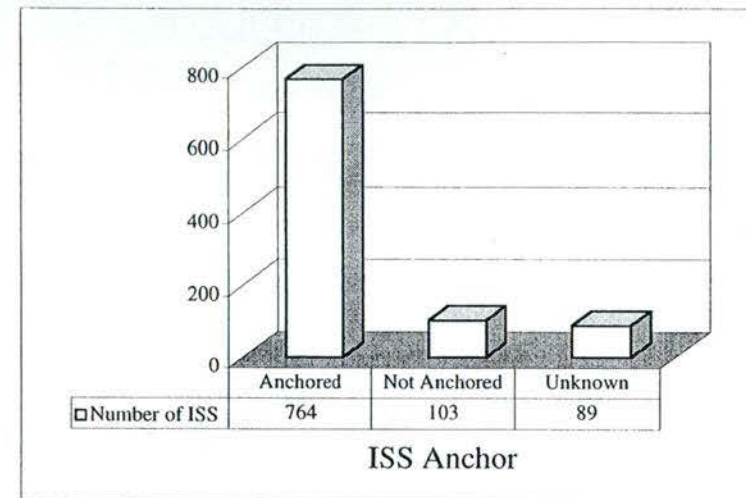
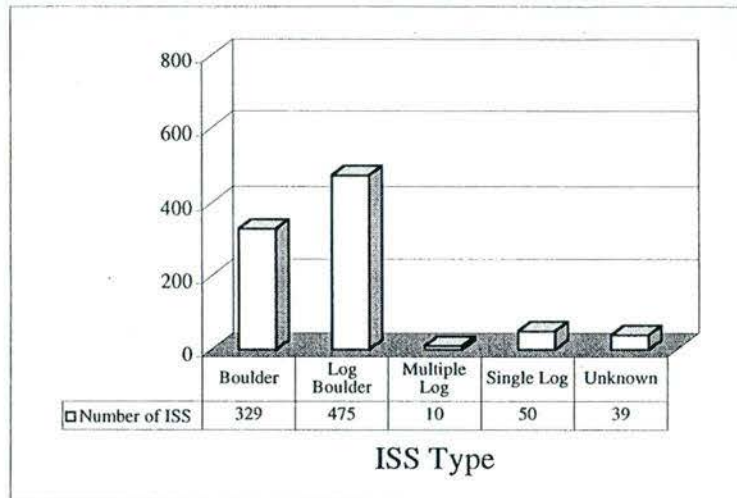


Figure 29. Distribution of ISS across stream type and ISS characteristics in the Forest Service data set.

ISS Control Variables

ISS control variables include ISS type, ISS gradient and ISS anchor. These were used in the analysis to assess whether ISS type, gradient or anchor influenced ISS survival or performance.

ISS Type

Four types of ISSs were recorded in the study area (Table 51) (Figure 3, chapter I). Each type of ISS is likely to be affected differently by watershed, channel and stream-type characteristics, and to affect ISS survival and performance differently.

TABLE 51. ISS Control Variables Recorded
During Field Surveys in 1996 and 1997

Variable	Type	Category
ISS Type	nominal	SL = Log, single piece LM = Log, multiple piece B = Boulder, multiple piece LB = Log Boulder, multiple piece
ISS Gradient	ordinal	L = 0 - 2% M = > 2 - 4% H = > 4%
ISS. Anchor	nominal	A = Anchor N = Not Anchored

ISS Gradient

The gradient of each ISS was measured from the pool tail crest just downstream of the structure pool to just above the upstream side of the weir. Gradient percent was recorded in one of three categories (Table 51).

ISS Anchor

ISSs were categorized as either “anchored” or “not anchored” (Table 51). Most log-boulder and multiple-boulder ISSs were cabled together with half-inch steel cable intended to hold the ISS in place. Holes were drilled into the logs and boulders, and the cable was inserted and secured with epoxy resin. These were categorized as “anchored.” They were considered “not anchored” when the ISSs components were not cabled together. Most single-log ISSs were anchored into the bank and these were categorized as “not anchored.”

Additional Control Variables for Taylor Data set

The control variables (Table 48) used for analysis of ISS survival and performance of the Taylor data set were obtained during field surveys described in chapter V.

Variables from Aerial Photo and Map Analysis

Watershed and Channel Control Variables

Several variables were obtained from maps (Table 52). Drainage area was measured on USGS 1:100,000-scale maps. Drainage area was measured using a planimeter. The perimeter of the drainage area was located at the drainage divide. The drainage areas at both the upstream and downstream ends of each reach were measured and averaged to provide the drainage area for each reach. Valley constraint, stream order, valley length, reach length, and the change in reach elevation from the beginning to the end of the reach were measured from USGS 1:24,000-scale maps. Valleys were defined as constrained if valley width

measured on USGS 1:24,000-scale quadrangles was less than 100 feet (31 m). Geology was obtained from the 1:500,000-scale Geologic Map of Oregon (Walker and McLeod, 1991).

TABLE 52. Morphological Attributes Derived from Maps

Drainage Area	watershed control variable
Valley Constraint	watershed control variable
Stream Order	watershed control variable
Valley Length	to calculate sinuosity
Reach Length	to calculate sinuosity
Change in Reach Elevation	to calculate gradient
Geology	watershed control variable

Stream order, a watershed control variable, was determined using the Horton method as modified by Strahler (Knighton, 1998) using the blue line stream network as shown on USGS 1:24,000-scale quadrangle maps. Valley and reach lengths were measured from the upstream to the downstream ends of the reach on USGS topographic maps.

Sinuosity was calculated from reach length and valley length and was verified using 1:12,000 scale aerial photographs and through field reconnaissance. The change in reach elevation between upstream and downstream ends of the reach was measured. Reach gradient was calculated from reach length and the change in reach elevation. Geology for each reach was represented by a categorical control variable. Geology was classified into one of two categories (A or B). Geology A is a group of "hard" rocks that includes igneous and metamorphic rocks, Columbia River Basalts, intrusive ultramafics and older metamorphosed volcanics (Lamb, 1996). Geology B is a group of "soft" rock types that includes sedimentary and volcanoclastic, fluvial and lacustrine deposits, siltstones and sandstones (Lamb, 1996).

Stream-Type Control Variables

Each reach was categorized using Rosgen level I and Montgomery-Buffington stream-type classification systems (Montgomery and Buffington, 1993; Rosgen, 1996). Reaches were classified into Rosgen stream-type categories using the criteria outlined in Table 93 (appendix B) using data values derived from USGS 1:24,000-scale maps. Montgomery-Buffington stream-type classification (Table 94, appendix B) was also based on values derived from USGS 1:24,000-scale maps and from field observations of bed material, bedform pattern and dominant roughness elements.

Summary of Reach Characteristics

Reaches in the Forest Service data set had drainage areas $< 200 \text{ km}^2$, and stream order ranged from 1 to 5. Most reaches were in unconstrained valleys, but several were in constrained valleys. Reaches were in both types A and B geology. Sinuosity ranged from 1.10, slightly sinuous, to 1.65, moderately sinuous. Gradient ranged from 1.2% to 7%. Rosgen stream-types were A, B, C, and E.

Reaches in the Taylor data set had gradients ranging from 1.6% to 3.8%. Sinuosity ranged from 1.10, slightly sinuous to 1.65, moderately sinuous. Median bed material ranged in size from silt ($< 2 \text{ mm}$) to small cobble (64 - 96 mm).

Data Analysis

Contingency table analysis and logistic regression analysis were used to evaluate relationships between control variables and ISS survival and performance response variables. The Forest Service data set was used for the contingency table analysis. Contingency table analyses were used to examine relationships between a single control variable and a single response variable (survival or performance) before doing multivariate

analysis. Logistic regression analysis, using several control variables as predictors, was used to construct models to predict ISS response. Analyses of ISS survival and performance using logistic regression were done using both the Forest Service data set and the Taylor data set. While the Taylor data set had fewer ISSs, additional control variables were collected for these reaches during field surveys, and were used in the multivariate analyses to evaluate ISS survival and performance. In the remainder of the chapter, contingency table analysis methods, results and discussion are addressed first, followed by a presentation of logistic regression analysis methods and results. This is followed by a discussion section that integrates the results of contingency table analysis and logistic regression analysis. Conclusions about the factors that affected ISS survival and performance are then presented.

Contingency Table Analysis: Methods, Results and Discussion

Contingency table analysis is a method that can be used to evaluate associations between categorical or qualitative variables. This method is also referred to as an analysis of cross-classified data (Rodgers, 1995). Variables used in contingency table analysis need not be control (independent, predictor or explanatory) and response (dependent) variables (Fienberg, 1977; Rodgers, 1995). However, in this study, control and response variables were distinguished.

Contingency Table Analysis: Methods

In contingency analysis, the categories chosen for the variables must be mutually exclusive, each observation can belong in only one category. Several categorical variables form a multidimensional contingency table (Fienberg, 1977). Each variable forms one dimension of the table. Contingency table analysis compares the expected and observed frequencies of characteristics within a group of observations. If variables are independent

of each other, the expected frequency would be the same as the observed frequency. The number of observations in each category can also be compared. A chi-square test for association is the test for significance. The chi-square statistic can be compared to a theoretical probability distribution, and can be used to assess whether the cross-classifying variables are independent of each other or whether they are associated. A p-value indicates whether there is significant evidence for an association between the variables. A p-value ≤ 0.05 was used as an indication that there was an association between the variables greater than expected due to chance alone.

In this study, contingency table analysis was used to evaluate the relationship between several categorical watershed, channel, stream-type and ISS control variables (Table 53) and ISS response variables (survival and performance) (Table 54). It was also used to summarize the relationships between the continuous variables for reach gradient and stream order and the ISS response variables. Reach gradients were grouped into six categories for contingency table analysis.

TABLE 53. Categorical Variables for Contingency Table Analysis

ISS Type
ISS Gradient
ISS Anchor
Geology
Valley Constraint
Rosgen Stream-Type
Reach Gradient
Stream Order

TABLE 54. ISS Survival and Performance
Variables for Contingency Table Analysis

ISS Survival
I = In place
S = Shift on site
L = Left Site
ISS Performance
F = Functioning
P = Partially Functioning
N = Not Functioning

For 93 of the 904 ISSs in the Forest Service data set, one or more ISS variable (ISS gradient, ISS type, or ISS anchor) was recorded as “unknown.” These characteristics were not recorded during the field surveys, either because the ISS was gone and these variables could not be recorded, or because the observation was not recorded. These 93 ISSs were removed from the data set for the contingency table analysis in order to provide more representative results. In addition, in some of the analyses, some observations were removed because there were too few observations in one or more dimensions in the tables and the results would have been invalid if they were included.

Contingency Table Analysis: Results and Discussion

The contingency table analyses indicated that there were significant associations between ISS survival and the control variables ISS type, ISS gradient, ISS anchor, geology, Rosgen stream-type, stream order and reach gradient ($p < 0.05$). The analyses also indicate that there were significant associations between ISS performance and the control variables ISS type, ISS anchor, geology, Rosgen stream-type ($p < 0.05$).

Summary of Survival and Performance

ISS survival and performance for the Forest Service data set and the Taylor data set are summarized in Tables 55 and 56. In both data sets, a majority of ISSs remained in place while only about half of the ISSs were functioning. In both data sets, it is likely that the rate of survival was overestimated, while the rate at which ISSs left the site was underestimated. This is because the total number of ISSs that had originally been installed was not known in some reaches, so if an ISS had left the site and no part of it remained, it would not have been recorded at all during the surveys.

TABLE 55. Summary of ISS Survival

Data Sets	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
Forest Service Data Set (n = 904)	747	82.7%	68	7.5%	89	9.8%
Taylor Data Set (n = 150)	138	92.0%	11	7.3%	1	0.7%

TABLE 56. Summary of ISS Performance

Data Sets	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
Forest Service Data Set (n = 904)	470	52.0%	245	27.0%	189	20.9%
Taylor Data Set (n = 150)	72	48.0%	47	31.3%	31	20.7%

ISS Type and ISS Survival and Performance

The results of contingency table analysis for ISS type and ISS survival and performance are summarized in Tables 57 and 58. Of the 904 ISSs evaluated, ISS type was not recorded for many ISSs because they had left the site and no record was available to identify ISS type, so these were not included in the analysis. In addition, multiple-log ISSs were not included because there were too few cases and when included, the chi-square statistic was invalid (Minitab, 1998).

The association between ISS type and ISS survival was not significant (chi-square = 7.668, $p = 0.105$) (Table 57). The association between ISS type and ISS performance was significant (chi-square = 57.553, $p = 0.0005$) (Table 58). Log-boulder ISSs were functioning (F) slightly more often than multiple-boulder ISSs, and both were functioning (F) more often than single-log ISSs. Very few (3 of 50) single-log ISSs were functioning.

The results indicated that log-boulder and multiple-log ISSs functioned more often than single-log ISSs. This may be explained by local hydraulics. At log-boulder and multiple-boulder ISSs with boulders along the banks, bed scour downstream of the ISSs might be greater than bank scour. This would contribute to pool maintenance and pools that are deeper than at single-log ISSs. At single-log ISSs without boulders along the banks, streamflow may be directed toward the banks and contribute to lateral scour and bank erosion rather than bed scour and deeper pools. The response associated with ISS type may also be related to reach characteristics, such as reach gradient, sinuosity, bed material, and bank material. In several of the reaches surveyed for the Taylor data set, log-boulder and multiple-boulder ISSs tended to be located in reaches with higher gradients, lower sinuosity and larger bed and bank material while single-log ISSs tended to be in reaches with lower gradient, higher sinuosity, and smaller bed and bank material. The combination

of local hydraulics and reach scale characteristics may have a significant effect on the ISS performance results that are associated with ISS type.

TABLE 57. Contingency Table Results for ISS Type and ISS Survival

ISS Type	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>Boulder</u> (n = 329)						
Observed (o)	283.0	86.0%	24.0	7.3%	22.0	6.7%
Expected (e)	284.3	86.4%	24.3	7.4%	20.4	6.2%
Difference (o - e)	-1.3	-0.4%	-0.3	-0.1%	1.6	0.5%
<u>Log Boulder</u> (n = 475)						
Observed (o)	411.0	86.5%	39.0	8.2%	25.0	5.3%
Expected (e)	410.5	86.4%	35.0	7.4%	29.5	6.2%
Difference (o - e)	0.5	0.1%	4.0	0.8%	-4.5	-0.9%
<u>Single-log</u> (n = 50)						
Observed (o)	44.0	88.0%	0.0	0%	6.0	12.0%
Expected (e)	43.2	86.4%	3.7	7.4%	3.1	6.2%
Difference (o - e)	0.8	1.6%	-3.7	-7.4%	2.9	5.8%
Total (n = 854)	738.0	86.4%	63.0	7.4%	53.0	6.2%

(Chi-Square = 7.668, DF = 4, p = 0.105)

TABLE 58. Contingency Table Results for ISS Type and ISS Performance

ISS Type	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>Boulder</u> (n = 329)						
Observed (o)	174.0	52.9%	95.0	28.9%	60.0	18.2%
Expected (e)	178.4	54.2%	93.2	28.3%	57.4	17.5%
Difference (o - e)	-4.4	-1.3%	1.8	0.6%	2.6	0.7%
<u>Log Boulder</u> (n = 475)						
Observed (o)	286.0	60.2%	122.0	25.7%	67.0	14.1%
Expected (e)	257.5	54.2%	134.6	28.3%	82.9	17.5%
Difference (o - e)	28.5	6.0%	-12.6	-2.6%	-15.9	-3.4%
<u>Single-log</u> (n = 50)						
Observed (o)	3.0	6.0%	25.0	50.0%	22.0	44.0%
Expected (e)	27.1	54.2%	14.2	28.3%	8.7	17.5%
Difference (o - e)	-24.1	-48.2%	10.8	21.7%	13.3	26.5%
Total (n = 854)	463.0	54.2%	242.0	28.3%	179.0	17.5%

(Chi-Square = 57.553, DF = 4, p = 0.0005)

ISS Gradient and ISS Survival and Performance

The results of contingency table analysis of ISS gradient and ISS survival and performance are summarized in Tables 59 and 60. Of the 904 ISSs evaluated, ISS gradient was not recorded for 89 ISS because they had left the site or no ISS gradient was recorded in the field. There was a significant association between ISS gradient and ISS survival (chi-square = 23.040, $p = 0.0005$) (Table 59). ISSs with high gradient remained in place (I) more often than ISSs with low gradient, and both remained in place (I) more often than ISSs with medium gradient. ISSs with medium gradient shifted on site (S) more often and left the site (L) more often than ISSs with either low or high gradient. The association between ISS gradient and ISS performance was not significant (chi-square = 5.129, $p = 0.274$) (Table 60). These results are difficult to interpret, because reaches at opposite ends of the gradient spectrum survived at higher than expected rates. The strongest point is that ISSs in higher gradient reaches tend to survive and perform the best.

TABLE 59. Contingency Table Results for ISS Gradient and ISS Survival

ISS Gradient	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>Low</u> (n = 130)						
Observed (o)	120.0	92.3%	6.0	4.6%	4.0	3.1%
Expected (e)	117.4	90.3%	9.3	7.1%	3.4	2.6%
Difference (o - e)	2.6	2.0%	-3.3	-2.9%	0.6	0.5%
<u>Medium</u> (n = 460)						
Observed (o)	397.0	86.3%	46.0	10.0%	17.0	3.7%
Expected (e)	415.4	90.3%	32.7	7.1%	11.9	2.6%
Difference (o - e)	-18.4	-4.0%	13.3	2.9%	5.1	0.5%
<u>High</u> (n = 225)						
Observed (o)	219.0	97.3%	6.0	2.7%	0.0	0.0%
Expected (e)	203.2	90.3%	16.0	7.1%	5.8	2.6%
Difference (o - e)	15.8	7.0%	-10.0	-4.4%	-5.8	-2.6%
Total (n = 815)	736.0	90.3%	58.0	7.1%	21	2.6%

(Chi-Square = 23.040, DF = 4, $p = 0.0005$)

TABLE 60. Contingency Table Results for ISS Gradient and ISS Performance

ISS Gradient	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>Low</u>						
Observed (o)	76.0	58.5%	35.0	27.0%	19.0	14.6%
Expected (e)	74.3	57.2%	38.4	29.6%	17.2	13.3%
Difference (o - e)	1.7	1.3%	3.4	-2.6%	1.8	1.3%
<u>Medium</u>						
Observed (o)	249.0	54.1%	147.0	32.0%	64.0	13.9%
Expected (e)	263.0	57.2%	136.0	29.6%	61.0	13.3%
Difference (o - e)	-14.0	-3.1%	11.0	2.4%	3.0	0.6%
<u>High</u>						
Observed (o)	141.0	62.7%	59.0	26.2%	25.0	11.1%
Expected (e)	128.7	57.2%	66.5	29.6%	29.8	13.3%
Difference (o - e)	12.3	5.5%	-7.5	-3.4%	-4.8	-2.2%
Total (n = 901)	466.0	57.2%	241.0	29.6%	108.0	13.3%

(Chi-Square = 5.129, DF = 4, p = 0.274)

ISS Anchor and ISS Survival and Performance

It was expected that ISSs that were anchored would have a better rate of survival and would perform better than those that were not anchored, and the analysis indicates that this was the case. This is consistent with previous the results of previous studies (Fitzgerald, 1997; Roper et al., 1998). The results of contingency table analysis of ISS anchor and ISS survival and performance are summarized in Tables 61 and 62. Of the 904 ISSs evaluated, ISS anchor was not known for 37 ISSs because they had left the site, or ISS anchor data were not recorded in the field. The analysis indicated that there was a significant association between ISS anchor and ISS survival (chi-square = 175.724, p = 0.0005 (Table 61). Anchored ISSs remained in place (I) more often and shifted on site (S) or left the site less often than ISSs that were not anchored.

There was also a significant association between ISS anchor and ISS performance as (chi-square = 96.694, p = 0.0005 (Table 62). ISSs that were anchored were functioning (F)

more often and were partially functioning (P) or not functioning (N) less often than ISSs that were not anchored. The result indicating that more ISSs were functioning when they were anchored was expected, simply because, as the results showed, when ISSs were not anchored, they shifted on site or left the site more often and were therefore less likely to be functioning.

TABLE 61. Contingency Table Results for ISS Anchor and ISS Survival

ISS Anchor	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>Anchor</u> (n = 764)						
Observed (o)	688.0	90.1%	56.0	7.3%	20.0	2.6%
Expected (e)	653.4	85.6%	59.1	7.7%	51.1	6.7%
Difference (o - e)	34.6	4.5%	-3.1	-0.4%	-31.1	4.1%
<u>Not Anchored</u> (n = 103)						
Observed (o)	54.0	52.5%	11.0	10.7%	38.0	36.9%
Expected (e)	88.2	85.6%	8.0	7.7%	6.9	6.7%
Difference (o - e)	-34.2	-33.1%	3.0	3.0%	31.1	30.2%
Total (n = 867)	742.0	85.6%	67.0	7.33%	58.0	6.7%

(Chi-Square = 175.724, DF = 2, p = 0.0005)

TABLE 62. Contingency Table Results for ISS Anchor and ISS Performance

ISS Anchor	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>Anchor</u> (n = 764)						
Observed (o)	442.0	57.9%	221.0	28.9%	101.0	13.2%
Expected (e)	413.3	54.1%	214.1	28.0%	136.6	17.9%
Difference (o - e)	28.7	3.8%	6.9	0.9%	-35.6	-4.7%
<u>Not Anchored</u> (n = 103)						
Observed (o)	27.0	26.2%	22.0	21.4%	54.0	52.4%
Expected (e)	55.7	54.1%	28.9	28.0%	18.4	17.9%
Difference (o - e)	-28.7	-27.9%	-6.9	-6.6%	35.6	34.5%
Total (n = 867)	469.0	54.1%	243.0	28.0%	155.0	17.9%

(Chi-Square = 96.694, DF = 2, p = 0.0005)

Geology and ISS Survival and Performance

The results of contingency table analysis for geology and ISS survival and performance are summarized in Tables 63 and 64. I expected that geology type might have had an important influence on ISS survival and performance because of differences in the erodability of geology A and geology B. Geology A rock types tend to produce more coarse alluvium (gravel to boulder size) than geology B rock types, which tend to produce fine alluvium (smaller than gravel size). Channel beds and banks derived from geology A rock types are probably harder to erode. These differences in erodability would affect bank stability and erosion, and that might have an effect on ISS survival and performance.

I would have expected ISSs in reaches with geology A rock types to have remained in place more often than ISSs in reaches with geology B rock types. I also expected that ISSs would have shifted on site or left the site more often in reaches with geology B than reaches with geology A. The analysis indicated that there was a significant association between geology type and ISS survival (chi-square = 11.561, $p = 0.003$) (Table 63). However, the results were opposite of what I expected. ISSs in reaches with geology B (soft-rock types) were in place (I) more often and shifted on site (S) or left the site (L) less often than ISSs in reaches with geology A.

I expected that ISSs would be functioning more often in reaches with geology B because it is more erodible, making it easier for pools to form and to be maintained in erodible material, and this was the result. The analysis indicated that there was a significant association between geology type and ISS performance (chi-square = 9.373, $p = 0.009$) (Table 64), and this was the expected result. ISSs in reaches with geology B were functioning (F) more often and were not functioning (N) less often than in reaches with geology A. ISSs in reaches with geology B were partially functioning slightly more often than ISSs in reaches with geology A. ISSs may have been functioning less in reaches with

geology A than in reaches with geology B because alluvium derived from geology A rock types is more mobile in these reaches. More bank erosion and mass movements in the uplands may occur in reaches with geology A, supplying sediment to fill the ISS pools, and contributing to an ISS functioning less often.

TABLE 63. Contingency Table Results for Geology and ISS Survival

Geology	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>Geology A (n = 830)</u>						
Observed (o)	678.0	81.7%	64.0	7.7%	88.0	10.6%
Expected (e)	688.1	82.9%	60.8	7.3%	81.1	9.8%
Difference (o - e)	-10.1	-1.2%	3.2	0.4%	6.9	0.8%
<u>Geology B (n = 71)</u>						
Observed (o)	69.0	97.2%	2.0	2.8%	0.0	0.0%
Expected (e)	58.9	82.9%	5.2	7.3%	6.9	9.8%
Difference (o - e)	10.1	14.3%	-3.2	-4.5%	-6.9	-9.8%
Total (n = 901)	747.0	82.9%	66.0	7.3%	88.0	9.8%

(Chi-Square = 11.561, DF = 2, p = 0.003)

TABLE 64. Contingency Table Results for Geology and ISS Performance

Geology	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>Geology A (n = 830)</u>						
Observed (o)	422.0	50.8%	228.0	27.5%	180.0	21.7%
Expected (e)	433.0	52.2%	225.7	27.2%	171.3	20.6%
Difference (o - e)	-11.0	-1.3%	2.3	0.3%	8.7	1.1%
<u>Geology B (n = 71)</u>						
Observed (o)	48.0	67.6%	17.0	23.9%	6.0	8.5%
Expected (e)	37.0	52.2%	19.3	27.2%	14.7	20.6%
Difference (o - e)	11.0	15.4%	-2.3	-3.3%	-8.7	-12.1%
Total (n = 901)	470.0	52.2%	245.0	27.2%	186.0	20.6%

(Chi-Square = 9.373, DF = 2, p = 0.009)

Valley Constraint and ISS Survival and Performance

The results of contingency table analysis for valley constraint and ISS survival and performance are summarized in Tables 65 and 66. I expected that valley constraint would affect ISS survival and performance. However, results indicated that valley constraint, as it was defined in this study, was not a significant control variable.

ISSs in constrained valleys remained in place (I) slightly more often and left the site (L) slightly less often than ISSs in unconstrained valleys, though this relationship was not significant (chi-square = 4.357, $p = 0.113$ (Table 65).

ISSs in constrained valleys were functioning (F) slightly more often and were not functioning (N) slightly less often than ISSs in unconstrained valleys. However, this was not a significant relationship (chi-square = 4.796, $p = 0.091$) (Table 66).

TABLE 65. Contingency Table Results for Valley Constraint and ISS Survival

Valley Constraint	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>Constrained</u> (n = 86)						
Observed (o)	77.0	89.5%	6.0	7.0%	3.0	3.5%
Expected (e)	71.3	82.9%	6.3	7.3%	8.4	9.8%
Difference (o - e)	5.7	6.6%	-0.3	-0.3%	-5.4	-6.3%
<u>Unconstrained</u> (n = 815)						
Observed (o)	670.0	82.2%	60.0	7.4%	85.0	10.4%
Expected (e)	675.7	82.9%	59.7	7.3%	79.6	9.8%
Difference (o - e)	-5.7	0.7%	0.3	0.1%	5.4	0.6%
Total (n = 901)	747.0	82.9%	66.0	7.3%	88.0	9.8%

(Chi-Square = 4.357, DF = 2, $p = 0.113$)

TABLE 66. Contingency Table Results for Valley Constraint and ISS Performance

Valley Constraint	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>Constrained</u> (n = 86)						
Observed (o)	51.0	59.3%	25.0	29.1%	10.0	11.6%
Expected (e)	44.9	52.2%	23.4	27.2%	17.8	20.6%
Difference (o - e)	6.1	7.1%	1.6	1.9%	-7.8	-9.0%
<u>Unconstrained</u> (n = 815)						
Observed (o)	419.0	51.4%	220.0	27.0%	176.0	21.6%
Expected (e)	425.1	52.2%	221.6	27.2%	168.2	20.6%
Difference (o - e)	-6.1	-0.8%	-1.6	-0.2%	7.8	1.0%
Total (n = 901)	470.0	52.2%	245.0	27.2%	186.0	20.6%

(Chi-Square = 4.796, DF = 2, p = 0.091)

Rosgen Stream-Type and ISS Survival and Performance

The results of contingency table analysis for Rosgen stream-type and ISS survival and performance are summarized in Tables 67 and 68. There was a significant association between Rosgen stream-type and ISS survival (chi-square = 17.182, p = 0.009) (Table 67). ISSs in reaches that were Rosgen type A and type E remained in place (I) more often and left the site (L) less often than ISSs in Rosgen type B or C reaches. ISSs in type B reaches shifted on site (S) more often in other reach types.

There was also a significant association between Rosgen stream-type and ISS performance (chi-square = 20.859, p = 0.002 (Table 68). ISSs in Rosgen type A reaches were functioning (F) more often and were not functioning (N) less often than in other reach types followed by ISSs in Rosgen type B reaches, then type C and finally, by type E reaches, where ISSs were functioning least often.

ISSs were functioning more often when they were in Rosgen type A and type B reaches than in type C or type E. This may be explained by the fact that reach gradients are higher

in Rosgen type A and B reaches, and they tend to have larger bed and bank material, than type C or E reaches. This interpretation is consistent with the results for residual pool depth presented in chapter V which indicated that residual pool depth in ISS pools was significantly greater than non-ISS pools in reaches with higher gradients and with larger bed and bank material. Deeper pools at ISSs indicate better performance.

TABLE 67. Contingency Table Results for Rosgen Stream-Type and ISS Survival

Rosgen Stream-Type	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>Type A</u> (n = 37)						
Observed (o)	36.0	97.3%	1.0	2.7%	0.0	0.0%
Expected (e)	30.7	82.9%	2.7	7.3%	3.6	9.8%
Difference (o - e)	5.3	14.4%	-1.7	-4.6%	-3.6	-9.8%
<u>Type B</u> (n = 460)						
Observed (o)	371.0	80.7%	41.0	8.9%	48.0	10.4%
Expected (e)	381.3	82.9%	33.7	7.3%	44.9	9.8%
Difference (o - e)	-10.3	-2.2%	7.3	1.6%	3.1	0.6%
<u>Type C</u> (n = 343)						
Observed (o)	282.0	82.2%	21.0	6.1%	40.0	11.7%
Expected (e)	284.4	82.9%	25.1	7.3%	33.5	9.8%
Difference (o - e)	-2.4	-0.7%	-4.1	-1.2%	6.5	1.9%
<u>Type E</u> (n = 61)						
Observed (o)	58.0	95.1%	3.0	4.9%	0.0	0.0%
Expected (e)	50.6	82.9%	4.5	7.3%	6.0	9.8%
Difference (o - e)	7.4	12.2%	-1.5	-2.4%	-6.0	-9.8%
Total (n = 901)	747.0	82.9%	66.0	7.3%	88.0	9.8%

(Chi-Square = 17.182, DF = 6, p = 0.009)

TABLE 68. Contingency Table Results for Rosgen Stream-Type and ISS Performance

Rosgen Stream-Type	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>Type A</u> (n = 37)						
Observed (o)	22.0	59.5%	12.0	32.4%	3.0	8.1%
Expected (e)	19.3	52.2%	10.0	27.2%	7.6	20.6%
Difference (o - e)	2.7	7.3%	2.0	5.2%	-4.6	-12.5%
<u>Type B</u> (n = 460)						
Observed (o)	252.0	54.8%	121.0	26.3%	87.0	18.9%
Expected (e)	240.0	52.2%	125.0	27.2%	95.0	20.6%
Difference (o - e)	12.0	2.6%	-4.0	-0.9%	-8.0	-1.7%
<u>Type C</u> (n = 343)						
Observed (o)	177.0	51.6%	84.0	24.5%	82.0	23.9%
Expected (e)	179.0	52.2%	93.4	27.2%	70.8	20.6%
Difference (o - e)	-2.0	-0.6%	-9.4	-2.7%	11.2	3.3%
<u>Type E</u> (n = 61)						
Observed (o)	19.0	31.2%	28.0	45.9%	14.0	22.9%
Expected (e)	31.7	52.2%	16.6	27.2%	12.6	20.6%
Difference (o - e)	-12.7	-21.0%	11.4	18.7%	1.4	2.3%
Total (n = 901)	470.0	52.16%	245.0	27.19%	186.0	20.64%

(Chi-Square = 20.859, DF = 6, p = 0.002)

Stream Order, Reach Gradient and ISS Survival and Performance

Stream order and reach gradient were recorded as continuous variables but were used in contingency table analysis as categorical variables to evaluate the relationships between these control variables and ISS response. Reach gradient values were divided into six categories and no category was greater than 1%. Stream order is an ordinal variable and was easily evaluated using contingency table analysis. The contingency table analysis of stream order and ISS survival also allows for comparisons with the results of previous studies (Fitzgerald, 1997; Roper et al., 1998).

The results of contingency table analysis for stream order and ISS survival and performance are summarized in Tables 69 and 70. I expected that ISS survival would be

highest in reaches with low gradient, but the results show that survival was greatest in reaches with high gradient. In addition, I expected that ISSs would be functioning most often in high order reaches, and least often in low order reaches. There was a significant association between stream order and ISS survival (chi-square = 32.195, $p = 0.005$) (Table 69). ISS survival was greatest (more ISSs were in place) in streams with lower stream order (1st and 2nd) than in higher order reaches (3rd, 4th and 5th). ISSs shifted on site (S) or left the site (L) more often in the higher order reaches. The association between ISS survival and higher reach gradient was not strong. In addition, the uneven distribution of the ISSs among reaches of different gradients may have skewed the results (Figures 28 and 29). There were fewer reaches with higher gradients ($\geq 4\%$) ($n = 134$) in this study than reaches with lower gradients. 85% ($n = 770$) of the ISSs were in reaches with gradients $< 4\%$ and over half of the ISSs ($n = 498$) were in reaches with gradients between 1.9% and 2.8%. Therefore the results may not be definitive.

The results of this analysis are consistent with the previous study of ISS survival in the Pacific Northwest (Roper et al., 1998), but not with the previous study in the Umatilla NF (Fitzgerald, 1997) that indicated that ISS survival was greatest in reaches with high stream order. However, the previous study (Fitzgerald, 1997) did not include reaches of 1st or 2nd order, while reaches of these orders were included in this thesis. The results of the analysis in this thesis, and from the Roper et al. (1998) study, suggest that ISS survival is likely to be higher in low order reaches than in high order reaches.

There was also a significant association between stream order and ISS performance (chi-square = 74.333, $p = 0.0005$) (Table 70). While relatively more ISSs survived in 1st order reaches, ISS performance was lowest in 1st order reaches where only about 5% of ISSs were functioning (3 out of 50). There was not a consistent pattern in ISS performance across stream orders 2 through 5.

ISSs were functioning less often in 1st order reaches even though they were in place more often in 1st order reaches. It may be important to consider other factors in the interpretation of this result. Landslides, debris flows and sediment aggradation associated with the floods that occurred in the Blue Mountains in 1995, 1996 and 1997 were especially influential in small watersheds in the Umatilla NF (Fitzgerald and Clifton, 1998). These factors could have had a significant effect of ISS performance in 1st order reaches by contributing to bedload which may have been deposited in ISS pools and reduced their effectiveness as pool habitat.

TABLE 69. Contingency Table Results for Stream Order and ISS Survival

Stream Order	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>1st Order</u> (37)						
Observed (o)	37	100.0%	0	0.0%	0	0.0%
Expected (e)	31	82.7%	3	7.5%	4	9.8%
Difference (o - e)	6	17.3%	-3	-7.5%	-4	-9.8%
<u>2nd Order</u> (78)						
Observed (o)	72	92.3%	3	3.8%	3	3.8%
Expected (e)	64	82.7%	6	7.5%	8	9.8%
Difference (o - e)	-8	9.6%	-3	-3.7%	-5	6.0%
<u>3rd Order</u> (506)						
Observed (o)	406	80.2%	31	6.1%	69	13.6%
Expected (e)	418	82.7%	38	7.5%	50	9.8%
Difference (o - e)	-12	-2.5%	-7	-1.4%	19	3.8%
<u>4th Order</u> (235)						
Observed (o)	194	82.6%	29	12.3%	12	5.1%
Expected (e)	194	82.7%	18	7.5%	23	9.8%
Difference (o - e)	0	-0.1%	-9	4.8%	-11	-4.7%
<u>5th Order</u> (48)						
Observed (o)	38	79.2%	5	10.4%	5	10.4%
Expected (e)	40	82.7%	4	7.5%	5	9.8%
Difference (o - e)	2	-3.5%	1	2.9%	0	0.6%
Total (n = 904)	747	82.7%	68	7.5%	89	9.8%

(Chi-Square = 32.195, DF = 8, p = 0.0005)

TABLE 70. Contingency Table Results for Stream Order and ISS Performance

Stream Order	ISS Survival					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>1st Order (37)</u>						
Observed (o)	2	5.4%	21	56.8%	14	37.8%
Expected (e)	19	52.0%	10	27.0%	8	20.9%
Difference (o - e)	-17	-46.6%	11	29.8%	6	16.9%
<u>2nd Order (78)</u>						
Observed (o)	42	55.1%	27	34.6%	8	10.3%
Expected (e)	41	52.0%	21	27.0%	16	20.9%
Difference (o - e)	1	3.1%	6	7.6%	-8	-10.6%
<u>3rd Order (506)</u>						
Observed (o)	244	48.2%	128	25.3%	134	26.5%
Expected (e)	263	52.0%	137	27.0%	106	20.9%
Difference (o - e)	-19	-3.8%	-9	-1.7%	28	5.6%
<u>4th Order (235)</u>						
Observed (o)	157	67.2%	52	22.1%	25	10.6%
Expected (e)	122	52.0%	64	27.0%	49	20.9%
Difference (o - e)	35	15.2%	-12	-4.9%	-24	-10.3%
<u>5th Order (48)</u>						
Observed (o)	23	47.9%	17	35.4%	8	16.7%
Expected (e)	25	52.0%	13	27.0%	10	20.9%
Difference (o - e)	-2	-4.1%	4	8.4%	-2	-4.2%
Total (n = 904)	470	52.0%	245	27.0%	189	20.9%

(Chi-Square = 74.333, DF = 8, p = 0.0005)

ISS survival and performance are summarized by reach gradient in Tables 71 and 72. There was a significant association between reach gradient and ISS survival (chi-square = 295.974, p = 0.0005) (Table 71). The overall pattern in ISS survival was greater survival in reaches with higher gradients. The differences in survival rates between groups were small. In reaches with gradients greater than 5.0%, ISSs remained in place (I) more and left the site (L) less than in reaches with lower gradients. ISS left the site (L) most often in reaches with gradients between 3.1 and 3.8%. These results were counter to what was expected and to the results in the previous study in the Umatilla NF (Fitzgerald, 1997) where ISS survival was greater in reaches with low (0 to 2%) and medium (> 2 to 4%) gradients than in reaches

with high (> 4 to 6%) gradients. In this thesis, the ISS responses were grouped by reach gradient. The grouping of reach gradients in the previous study (Fitzgerald, 1997) may conceal differences in responses within groups that were revealed in this thesis.

There was a significant association between reach gradient and ISS performance (chi-square = 218.378, $p = 0.0005$) (Table 72). However, there was no overall trend observed in ISS performance related to reach gradient. In the analyses of reach gradient and ISS response, there were few ISSs in reaches with gradients greater than 5%, perhaps not providing a large enough sample size to make inferences about ISS survival or performance.

TABLE 71. Contingency Table Results for Reach Gradient and ISS Survival

Reach Gradient	ISS Survival					
	I (in place)		S (shifted)		L (left site)	
	#	%	#	%	#	%
<u>1.2% to 1.7%</u> (n = 149)						
Observed (o)	124	83.2%	9	5.0%	16	12.4%
Expected (e)	123	82.7%	11	7.5%	15	9.8%
Difference (o - e)	1	0.5%	-2	-2.5%	1	2.6%
<u>1.9% to 2.8%</u> (n = 498)						
Observed (o)	407	81.7%	47	9.4%	44	8.8%
Expected (e)	412	82.7%	37	7.5%	49	9.8%
Difference (o - e)	-5	-1.0%	10	1.9%	-5	1.0%
<u>3.1% to 3.8%</u> (n = 123)						
Observed (o)	100	81.3%	4	3.2%	19	15.4%
Expected (e)	102	82.7%	9	7.5%	12	9.8%
Difference (o - e)	-2	-1.4%	-5	-4.3%	7	5.6%
<u>4.0% to 4.7%</u> (n = 73)						
Observed (o)	60	82.2%	4	5.5%	9	12.3%
Expected (e)	60	82.7%	5	7.5%	7	9.8%
Difference (o - e)	0	-0.5%	-1	-2.0%	2	2.5%
<u>5.0% to 5.5%</u> (n = 23)						
Observed (o)	20	87.0%	2	8.7%	1	4.3%
Expected (e)	19	82.7%	1.7	7.5%	2	9.8%
Difference (o - e)	1	4.3%	-0.3	1.2%	-1	-5.5%
<u>6.1% to 7.0%</u> (n = 38)						
Observed (o)	36	94.7%	2	5.3%	0	0.0%
Expected (e)	31	82.7%	3	7.5%	4	9.8%
Difference (o - e)	5	12.0%	-1	-2.2%	-4	-9.8%
Total (n = 904)	747	82.7%	68	7.5%	89	9.8%

(Chi-Square = 296.974, DF = 52, $p = 0.0005$)

TABLE 72. Contingency Table Results for Reach Gradient and ISS Performance

Reach Gradient	ISS Performance					
	F (functioning)		P (partially functioning)		N (not functioning)	
	#	%	#	%	#	%
<u>1.2% to 1.7% (n = 149)</u>						
Observed (o)	60	40.3%	54	36.4%	35	23.5%
Expected (e)	77	52.0%	40	27.0%	31	20.9%
Difference (o - e)	-17	-11.7%	14	9.4%	4	2.6%
<u>1.9% to 2.8% (n = 498)</u>						
Observed (o)	292	58.6%	113	22.7%	93	18.7%
Expected (e)	258	52.0%	134	27.0%	104	20.9%
Difference (o - e)	34	6.6%	-21	-4.3%	-11	-2.2%
<u>3.1% to 3.8% (n = 123)</u>						
Observed (o)	59	48.0%	37	30.0%	27	22.0%
Expected (e)	64	52.0%	33	27.0%	26	20.9%
Difference (o - e)	-5	-4.0%	4	3.0%	0	1.1%
<u>4.0% to 4.7% (n = 73)</u>						
Observed (o)	28	38.6%	25	34.0%	20	27.4%
Expected (e)	38	52.0%	20	27.0%	15	20.9%
Difference (o - e)	-10	-13.2%	5	7.0%	5	6.5%
<u>5.0% to 5.5% (n = 23)</u>						
Observed (o)	9	39.1%	4	17.4%	10	43.5%
Expected (e)	12	52.0%	6	27.0%	5	20.9%
Difference (o - e)	-3	-12.9%	-2	-9.6%	5	22.6%
<u>6.1% to 7.0% (n = 38)</u>						
Observed (o)	22	58.0%	12	31.5%	4	10.5%
Expected (e)	20	52.0%	10	27.0%	10	20.9%
Difference (o - e)	2	6.0%	2	4.5%	-6	-10.4%
Total (n = 904)	470	52.0%	245	27.0%	189	20.9%

(Chi-Square = 218.378, DF = 52, p = 0.0005)

Contingency Table Analysis: Summary

Contingency table analysis was used to assess relationships between categorical variables and ISS survival and performance. It was also used to summarize the relationships between the continuous variables for reach gradient and stream order and ISS survival and performance, and to examine relationships between one response (survival or performance) and one control variable at a time before doing multivariate analysis.

ISS Survival

The results of contingency table analysis indicate that there were significant relationships between ISS survival response and the control variables ISS gradient, ISS anchor, geology, Rosgen stream-type, stream order and reach gradient. ISS survival was greatest when geology was type B, when ISSs were anchored, when ISS gradient was low ($\leq 2\%$) or high ($> 4\%$), and in reaches with lower stream order and higher gradient. ISS survival was higher in reaches that were Rosgen type A or Rosgen type E. ISS type and valley constraint were not significantly associated with ISS survival.

The associations between ISS survival and ISS gradient, and between ISS survival and Rosgen stream-type are not clear. In both cases, ISS survival was lower when associated with medium gradient, and higher when associated with low and high gradient (Rosgen type A reaches have higher gradients, while Rosgen type E reaches have lower gradients). Other factors, such as bank material size or bank stability may have important influences on these results. This is evaluated in the next section using logistic regression analysis.

Fitzgerald (1997) and Roper and others (1998) suggested that ISS survived less often in watersheds with high landslide frequency. Fitzgerald and Clifton (1998) found that the flood events in 1995, 1996 and 1997 in the northern Blue Mountains triggered landslides and debris flows in the Umatilla NF, especially in small watersheds, in loam-clay-ash soils and on moderate to steep slopes. The high flood flows and mass wasting resulted in bed and bank scouring, sediment aggradation, accumulation of large woody debris and lateral channel migration which had effects on stream channels (Fitzgerald and Clifton, 1998) and ISSs. Frissell and Nawa (1992) found that bedload deposition and stream bank erosion was the most common type of damage in reaches with greater sediment yield and channel instability, especially in wide, low gradient alluvial valley and alluvial fan-influenced segments. In these reaches, ISSs were buried and channels shifted laterally due to high

rates of bedload transport and deposition. These factors were not evaluated in this thesis, but are likely to be important factors that affected ISS response.

ISS Performance

There were significant relationships between ISS performance response and the control variables ISS anchor, ISS type, geology, and Rosgen stream-type. ISSs were functioning less often in 1st order reaches than in other stream orders, though the trends were not consistent among other stream orders. ISSs were also functioning more often in Rosgen type A and B reaches than in Rosgen type C and E reaches, when geology was type B, and when ISSs were log-boulder or multiple-boulder. Very few single-log ISSs were functioning. Several control variables were not significantly associated with ISS performance. These include ISS gradient, valley constraint and reach gradient.

The results summarized here provide useful information about the factors that influence ISS survival and performance. As suggested in this discussion, multiple factors in combination may provide better explanations about which control variables have the greatest effect on ISS survival and performance. The results and explanations discussed here are explored further using logistic regression analysis, a multivariate analysis technique. Analyses using this method are presented in the next section, followed by an integrated discussion of the results of contingency table analysis and logistic regression analysis and by additional conclusions about ISS survival and performance.

Logistic Regression Analysis: Methods and Results

Logistic Regression Analysis: Methods

Logistic regression analysis was used in this study to evaluate the relationship between a number of control variables and ISS response. Logistic regression, like simple linear

regression and multiple regression, provides a numerical model for predicting a response. In simple and multiple regression, the response variable is continuous (Shaw and Wheeler, 1994). In logistic regression, the response variable is dichotomous; it has only two values which are expressed numerically as 1 and 0 (Wright, 1995). Logistic regression is often used as a method for predicting the probability that an observation belongs to one of the two groups (Wright, 1995) or the probability that the event of interest will occur. Once the probability of an event occurring is known, the probability of that event not occurring can also be known. If the probability that an event or response will occur is P , then the probability that it will not occur is $P - 1$. Logistic regression was appropriate for this study since the ISS response variables were not continuous, but were categorical.

Response Variables for the Logistic Regression Analysis

The responses for ISS survival and ISS performance in this study each had three possible values or categories. For the analyses using logistic regression, the nominal response variables were transformed into dichotomous variables (Table 73). Logistic regression equations were then fit to the data to estimate the probabilities that an ISS survived or failed and the probabilities that an ISS was functioning or not functioning, given particular values of the control variables.

TABLE 73. Dichotomous Response Variables for ISS Survival and Performance

ISS Survival
1 = Sv = Survived (includes I = In place)
0 = Fd = Failed (includes S = Shift on site and L = Left Site)
ISS Performance
1 = Fc = Functioning (includes F = Functioning and P = Partially functioning)
0 = Fn = Not functioning

Control Variables for the Logistic Regression Analysis

Control (dependent or predictor) variables used in regression equations can be either continuous or categorical. The continuous variables used in this study to evaluate the survival and performance in the Forest Service data set included drainage area, stream order, sinuosity, and gradient. For better interpretation, drainage area was log transformed to provide a data set that was linear and more normally distributed.

Several of the control variables used in this study were categorical, including ISS type, ISS gradient, ISS anchor, geology, valley constraint and Rosgen stream-type. ISS anchor, and valley constraint were used in the logistic regression analysis as nominal (dichotomous) variables. ISS type, ISS gradient, and Rosgen stream-type were transformed into ordinal variables and assigned numeric values. Ordinal variables are preferable to nominal variables because they provide a model which is more interpretable and useful. ISS types were ordered by ISS "strength" (Table 74). The value assigned to each ISS type to represent its relative "strength" was influenced by the results of the contingency table analysis. In that analysis, log-boulder type ISSs survived and were functioning more often than other ISS types so were considered to be the "strongest" ISS type and given the highest ordinal value. Single-log ISSs were considered to be the least strong and given the lowest ordinal value.

TABLE 74. ISS Type Ordinal Values

8 = Log-Boulder
6 = Multiple-Boulder
4 = Multiple-Log
2 = Single-Log

ISS gradient categories and Rosgen stream-type categories were also transformed into ordinal variables of increasing numeric value which corresponded to increasing gradient percent (Table 75).

TABLE 75. Ordinal Variables Assigned to ISS Gradient and Rosgen Stream-Type

ISS Gradient
6 = High ($< 4\%$)
4 = Medium ($> 2\%$ to $\leq 4\%$)
2 = Low (0 to $\geq 2\%$)
Rosgen Stream-Type
4 = A
3 = B
2 = C
1 = D

Geology and ISS anchor control variables were transformed into dummy variables, dichotomous variables indicating membership in one of two groups (Mather, 1976; Tatsuka, 1988) (Table 76). Additional variables that represent the interaction between the dummy variable and each continuous variable are also considered as predictors by incorporating them into the regression equation. For example, the variable anchor was multiplied by log drainage area to provide an additional control variable. When the value for anchor was 0, the anchor x log drainage area was equal to 0, but it was equal to log drainage area when anchor equaled 1. This results in two different regression curves, one with all the observations where anchor equals 0, and another where anchor is equal to 1.

TABLE 76. Dummy Variables used for Geology and ISS Anchor Categories

Geology
1 = Geology A
0 = Geology B
ISS Anchor
1 = Anchored
0 = Not Anchored

Several additional continuous and categorical control variables were used to evaluate ISS survival and performance in the 12 reaches in the Taylor data set. The continuous variables included entrenchment (bankfull width/floodprone width), D-50 bed material size, dominant bank material size, subdominant bank material size, bankfull width-to-depth ratio, bank stability percent and bank vegetation percent. Categorical variables included Montgomery-Buffington stream-type and fire occurrence (Table 77). Montgomery-Buffington stream-type was transformed into an ordinal variable such that an increased ordinal value corresponded to an increase in reach gradient. Reach gradient was one attribute used to categorize reaches into Montgomery-Buffington stream-type. Variables representing the interaction of fire occurrence and each continuous variable were also used in each model.

TABLE 77. Categorical Control Variables for ISS Survival and Performance

Montgomery-Buffington stream-type
2 = Plane Bed
1 = Pool Riffle
Fire Occurrence
1 = Fire
0 = No Fire

“Unknown” Observations

As discussed previously, for as many as 93 of the ISSs in the Forest Service data set, one or more ISSs variable (ISS gradient, ISS type, or ISS anchor) was recorded as “unknown.” Because of these “unknowns” in the data set, two sets of logistic regression analyses were performed. In one set of analyses, all of the ISSs with “unknown” characteristics were removed from the data set. In this new data set, all of the control variables were used in the logistic regression analysis. In the second set of analyses to identify logistic regression models for ISS survival and ISS performance, the “unknowns” were retained in the data set and the ISS control variables were not used for analysis.

Interpreting the Results of Logistic Regression Analysis

The logistic regression model provides regression coefficients for each of the predictor or control variables as do other regression models. However, the relationship between control and response variables is not linear. The plot of the predicted values for the logistic regression is the logistic curve which is S-shaped or sigmoidal (Figures 30 and 31) and has limits of 0 and 1 (Wright, 1995). The coefficients of the predictors control the steepness and shape of the curve, and consequently the estimated probability of membership in the target group. The coefficient of each predictor variable also estimates the change in the probability of success for each change of one unit in the predictor variable. A larger coefficient associated with the predictor makes the curve steeper, and indicates a stronger association between the predictor and the probability of membership in the target group. When the coefficient is positive, the probability of membership in the group increases as the predictor variable increases. When the coefficient is negative, the probability of membership in the group increases as the predictor variable decreases (Wright, 1995). A p-value is associated with the coefficient for each predictor variable in the logistic regression

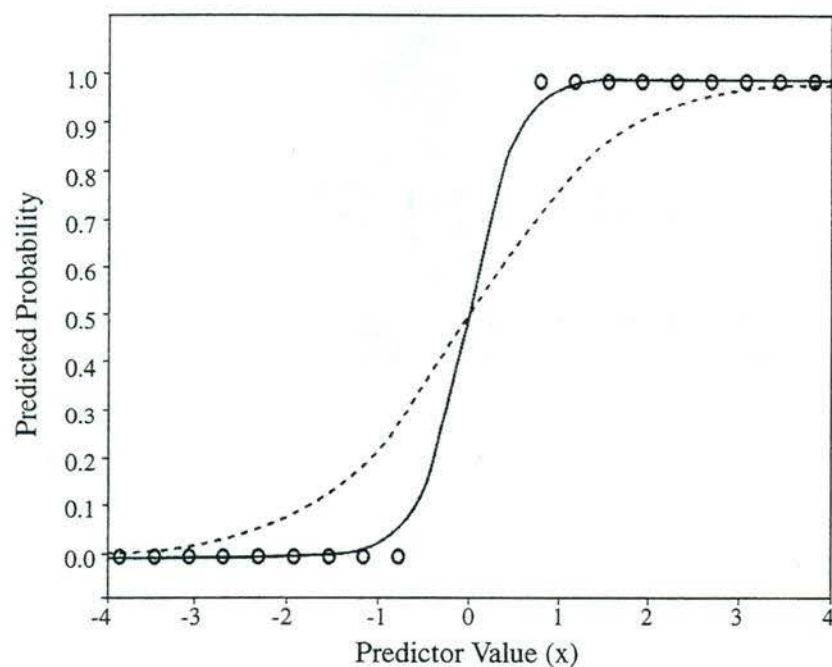


Figure 30. Logistic regression curve with positive constant (Wright, 1995). The steepness of the curve is reduced with smaller values of the coefficients (dotted line).

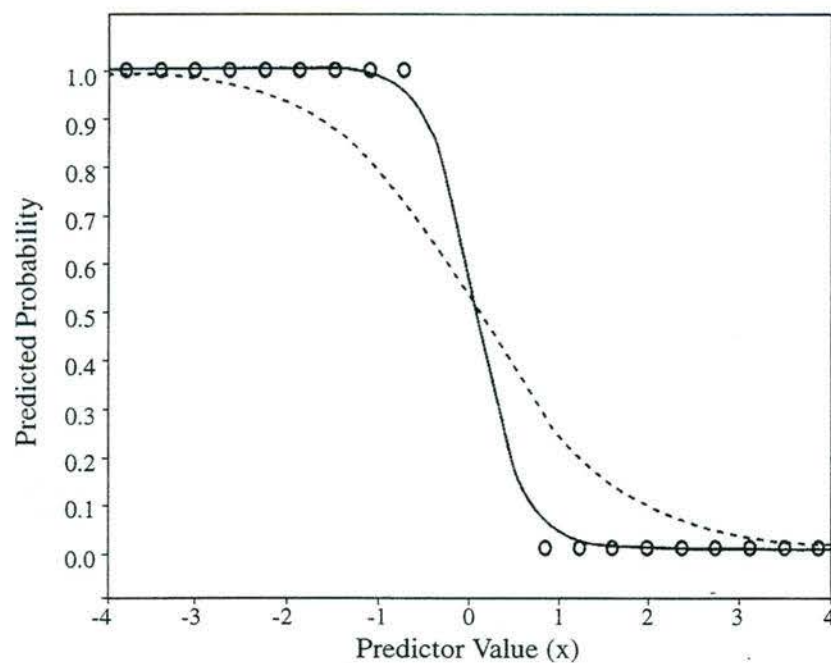


Figure 31. Logistic regression curve with negative constant (Wright, 1995). The steepness of the curve is reduced with smaller values of the coefficients (dotted line).

equation. A p-value less than 0.05 indicates that the variable is a statistically significant predictor.

The odds ratio is the regression coefficient (b) of the predictor variable expressed as an exponent of e. The odds ratio associated with each predictor estimates the change in the probability of membership in the target group for a one unit increase in the predictor. An odds ratio greater than 1 indicates that as the predictor increases by one unit, the probability of membership in the target group increases. When the odds ratio is less than 1, the probability of membership in the target group decreases with a one unit increase in the value of the predictor. When the odds ratio is equal to 1, the probability of membership in the target group is the same as for membership in the non-target group (Wright, 1995).

The constant in the logistic regression equation estimates the value of the response variable when the predictor variable is 0. It also controls the location of the curve along the X-axis. When the constant is positive, the probability of an event occurring is greatest when the co-efficients are positive (Figure 30). When the constant is negative, the probability of an event occurring is greatest when the co-efficients are negative (Figure 31). As the constant increases, the curve shifts left. When the constant is larger, smaller values of the predictors are needed to achieve the same predicted probability. For example, when the constant is large, if drainage area is a significant predictor and is small, the probability of ISS failure is not high. As drainage area increases, the probability of ISS survival does not get much higher. The probability of group membership can be calculated by adding the constant to the products of the regression coefficients and the predictors to obtain "g." Then "g" is used in the equation, $e^g/(1+(e^g))$ to calculate the probability of an event occurring, i.e. "success" or membership in the group (Wright, 1995).

Minitab statistical software (Minitab, 1998) was used to perform the logistic regression analyses. Along with reporting the coefficient, standard error, z-value and p-value associated with each predictor variable, several test statistics indicate the whether there is

sufficient evidence that the model fits the data well. One of these, the log-likelihood, estimates the likelihood that the model predicts group membership of the observations in the sample. The log-likelihood is usually negative and a larger negative value indicates that the coefficients maximized the probability of predicting group membership. In Minitab, a G statistic is used to evaluate the overall model (Wright, 1995). A large G statistic with an associated p-value less than 0.05 indicates that the coefficients in the logistic regression equation differ from 0 and that the predictors had a significant effect on the likelihood of an event occurring. If the G statistic is positive, this means that higher predictor values indicate an increased probability of an event occurring. In this study, the events or responses are ISS survival and ISS performance.

Minitab performs a number of statistical tests to evaluate whether the model fits the data. The Pearson, Deviance and Hosmer-Lemeshow goodness-of-fit tests evaluate whether the model fits the data. A chi-square statistic is reported for each of these, and an associated p-value of less than 0.05 indicates that the model is not an adequate fit for the data.

A Table of Observed and Expected Frequencies also indicates how well the model fits the data. The Hosmer-Lemeshow statistic is also associated with this table. The table groups the data into ten groups, arranged from lowest to highest estimated probabilities. Group 1 is the group with the lowest estimated probabilities and Group 10 has the highest estimated probabilities. If the p-value associated with the Hosmer-Lemeshow test statistic has a p-value less than 0.05, it indicates that the Table of Observed and Expected Frequencies does not provide sufficient evidence that the model fits the data well (Minitab, 1998).

A table listing the Measures of Association displays the number and percentage of concordant, discordant and tied pairs which are summarized by Somer's D, Goodman-Kruskal Gamma, and Kendall's Tau-a. These measures are usually between 0 and 1. Higher values indicate a better predictive ability of the model (Minitab, 1998).

Building the Logistic Regression Models

In this study, I attempted to develop logistic regression models to predict ISS survival and ISS performance using data from the 43 reaches surveyed for the Flood Assessment (Forest Service data set). I also attempted to develop logistic regression models using data from 12 reaches surveyed for the ISS effectiveness analysis (the Taylor data set).

I used an iterative model building strategy to find a subset of control variables that included only statistically significant predictors. The iterative model building approach is similar to a stepwise regression approach and combines forward and backward model building (Wright, 1995). Unfortunately, this iterative approach may increase the Type I error rate, the probability of rejecting the null hypothesis when it is actually true (Wright, 1995). In this study, the null hypothesis is that the control variables have no effect on ISS survival or performance.

In every model, I included the log of drainage area as a control or predictor variable in each model because drainage area is known to be an important variable in controlling many aspects of stream behavior and it was thought to be important in controlling ISS survival and performance. It is also a confounding variable, and thus it is difficult to separate the effects of drainage area from the effects of other variables (Berenson et al., 1983). In many studies, stream order is used as a surrogate for drainage area (Naiman et al., 1992) and both are used as surrogates for discharge (Chin, 1999). In this study, stream order was included only if it was a significant control variable. Drainage area is a more appropriate variable because it better represents the relative differences in drainage area and discharge than stream order. Drainage area is also a confounding variable and was included because results are very likely to be attributed to drainage area when in fact they are function of the other variables in the model. Including it shows that it does not have an effect on the performance of the other variables.

I examined logistic regression models that included only one continuous variable at a time in order to test the significance of each as a control or predictor variable. Variables were considered to be significant if the p-value associated with each coefficient and its odds ratio was less than 0.05. I then developed a model using the log of drainage area as one predictor and all other continuous variables that were found to be significant. The continuous variables were kept in the model if the p-value was less than 0.05. I added each categorical variable, one at a time, to the model. For use in the logistic model, each categorical variable was transformed into a dummy variable (Licht, 1995). Variables that were the cross products of the dummy variable and each continuous variable were also added to the model to see if they were significant (Mather, 1976). These cross product variables account for the interaction of each continuous variable and each categorical variable. All of the predictors that were found to be significant were included in a logistic regression model. With the exception of log drainage area, any predictors that were not significant when included in this model were removed until only variables that were significant remained.

Logistic Regression Analysis: Results

The logistic regression models developed in this can be used to predict ISS survival and ISS performance based on several control variables. I was able to develop statistically significant models for ISS survival using the Forest Service data set but not for the Taylor data set. I was able to develop logistic regression models for ISS performance using both the Forest Service data set and the Taylor data set.

ISS Survival using Forest Service Data Set

Two logistic regression analyses for ISS survival were done for the Forest Service data set in order to address the problems in data set. For the first analysis, all the ISSs with “unknown” ISS characteristics (type, gradient or anchor) were included in the data set but the ISS control variables were not used. Two logistic regression equations (Model 1 and Model 2) were generated from this analysis. In the second analysis, the ISSs with “unknown” ISS characteristics were removed from the data set and ISS control variables were used. One logistic model (Model 3) was generated by this analysis.

The ISS survival response variable used for this analysis had two possible outcomes: survival ($S_v = 1$) or failure ($F_d = 0$). ISSs were considered to survive if they remained in place (I) and were considered to have failed if they shifted on site (S) or left the site (L).

First Analysis of ISS Survival: Model 1 and Model 2

This analysis included all the ISSs with “unknown” ISS characteristics in the data set but did not include the ISS control variables. Two models, Model 1 and Model 2 are included here because they are nearly identical except that stream order was a significant predictor in Model 1, and sinuosity was a significant predictor in Model 2, and each of these predictor are useful in explaining ISS response. The first logistic regression model to predict ISS survival (Model 1) is summarized in Table 78. Model 2 is summarized in Table 79. In both models, log drainage area and geology were shown to be significant predictors, and the coefficients for the predictors were similar in magnitude and direction. In addition, the statistical test results were very similar, indicating that both models fit the data equally well. Only the test statistics for Model 1 are presented here.

TABLE 78. Logistic Regression Results for ISS Survival using Forest Service Data Set: Model 1 (without ISS Control Variables)

Predictor	Coefficient	StDev	p	Odds Ratio
Constant	5.0966	0.8620	0.0005	
Log Drainage Area	-0.1773	0.2823	0.530	0.84
Stream Order	-0.3383	0.1230	0.006	0.71
Geology (A = 1)	-2.2269	0.7312	0.002	0.11

(n = 903; 747 survived, 156 failed)

TABLE 79. Logistic Regression Results for ISS Survival using Forest Service Data Set: Model 2 (without ISS Control Variables)

Predictor	Coefficient	StDev	p	Odds Ratio
Constant	1.804	1.417	0.203	
Log Drainage Area	-0.4125	0.2730	0.131	0.66
Sinuosity	1.8819	0.8837	0.033	6.57
Geology (A = 1)	-1.9606	0.7255	0.007	0.14

(n = 903; 747 survived, 156 failed)

Model 1 included two control variables, stream order and geology, that were statistically significant as indicated by the p-values ($p < 0.05$) for each coefficient (Table 78). The log of drainage area was included as a control variable in the model, even though it was not significant ($p < 0.05$), because it is a confounding variable. Model 1 indicates that the probability of ISS survival increased with decreasing drainage area and stream order, and when geology was type B ("soft" rocks). The constant in the logistic regression equation controls the location of the logistic curve on the x-axis. When the constant is large as it is for this logistic regression equation, the curve shifts to the left and smaller values of the predictors are needed to predict the same probability.

The coefficients for log drainage area and stream order are negative, indicating that as drainage area or stream order decreased, the probability that an ISS survived increased. The odds ratio of 0.84 for the log of drainage area indicates that as this predictor increased by one unit, it less likely that an ISS survived. The odds ratio of 0.71 for stream order

indicates that when stream order increased by one unit, it was less likely that an ISS survived. Geology was represented by a dummy variable where a value of 1 was geology A ("hard" rocks) and a value of 0 was geology B ("soft" rocks). A negative coefficient indicates that when geology was type B, the probability that an ISS survived increased. As indicated by the odds ratio of 0.11, when geology was type A it was less likely that an ISS was functioning.

A couple of test statistics indicate that Model 1 fits the data and predicts ISS survival while others indicate that it has less predictive ability. The G statistic and the log-likelihood statistic suggest that the model has value in predicting ISS survival. The goodness-of-fit tests and the summary measures of association indicate that the model does not provide a very good fit for the data (Table 80).

TABLE 80. Test Statistics for Logistic Regression for ISS Survival: Model 1 (without ISS Control Variables)

Test Statistic		p
Log-Likelihood	-401.648	
G	27.882	0.0005
Goodness-of-Fit Tests		Chi-Square
Pearson	198.745	0.0005
Deviance	191.113	0.0005
Hosmer-Lemeshow	22.693	0.002
Measures of Association		
Concordant		56.0%
Discordant		35.8%
Ties		8.2%
Measures of Association – Summary Measures		
Somers' D		0.20
Goodman-Kruskal Gamma		0.22
Kendall's Tau-a		0.06

The p-value associated with the G statistic for this model is 0.0005, indicating that the coefficients of the predictor (control) variables in the logistic equation are not zero and that the predictors had a significant effect on ISS survival. A large, negative log-likelihood

indicates that the coefficients maximized the probability of predicting whether an ISS survived. The goodness-of-fit tests for this model have p-values < 0.05 which indicate that there is sufficient evidence that this model is not a good fit for the data. The Hosmer-Lemeshow test statistic is also associated with a Table of Observed and Expected Frequencies. For this model, the Hosmer-Lemeshow statistic is < 0.05 and indicates that the Table of Observed and Expected Frequencies does not provide sufficient evidence that the model fits the data well. The summary measures of association (Somers' D, Goodman-Kruskal Gamma and Kendall's Tau-a) are associated with the percentages of concordant, discordant and tied pairs and also indicate the predictive ability of the model. These measure the association between observed responses and predicted probabilities. The values of these summary measures are always between 0 and 1, and values closer to 1 indicate better predictive ability of the model. For this model, none of the three summary measures are close to 1, suggesting that the model is limited in predicting ISS survival.

Model 2 (Table 79) indicates that the probability of ISS survival increased with decreasing drainage area and sinuosity, and when geology was type B ("soft" rocks). The constant is small for this logistic regression equation indicating that larger values of the predictors are needed to predict the same probability. Drainage area and geology varied in the same direction as in Model 1, discussed above. Sinuosity is a significant predictor in Model 2. The positive coefficient and the odds ratio of 6.57 associated with sinuosity indicate that as sinuosity increased by one unit, it was 6.57 times more likely that an ISS survived.

Second Analysis of ISS Survival: Model 3

In this second analysis of ISS survival using the Forest Service Data set, the ISSs with "unknown" ISS characteristics were removed from the data set and the ISS control

variables were used. The resulting logistic regression model to predict ISS survival is summarized in Tables 81.

TABLE 81. Logistic Regression Results for ISS Survival using Forest Service Data Set: Model 3 (without Unknowns)

Predictor	Coefficient	StDev	p	Odds Ratio
Constant	-1.632	2.203	0.459	
Log Drainage Area	1.0918	0.41580	0.017	2.98
Stream Order	-0.8822	0.1897	0.0005	0.41
Sinuosity	4.826	1.348	0.0005	124.74
Geology (A = 1)	-2.1709	0.7615	0.004	0.11
ISS Anchor	1.4522	0.4089	0.0005	4.27

(n = 811; 733 survived, 78 failed)

The logistic model included several control variables, log drainage area, stream order sinuosity, geology and ISS anchor, that were statistically significant as indicated by the p-value ($p < 0.05$) for each coefficient (Table 81). Of the three logistic regression models for ISS survival, log drainage area was significant only in this model. The model indicates that the probability of ISS survival increased with increasing drainage area and sinuosity, decreasing stream order, when geology was type B ("soft" rocks) and when the ISS was anchored. The constant is small and negative for this logistic regression equation indicating that larger values of the predictors are needed to predict the same probability.

The coefficient for stream order is negative, indicating that as stream order decreased, the probability that an ISS survived increased. The odds ratio for stream order indicates that when stream order increased by one unit, an ISS was less likely to survive. The positive coefficient indicates that as drainage area increased, the probability that an ISS survived increased. The odds ratio of 2.98 for the log of drainage area indicates that as this predictor increased by one unit, it was 2.98 times more likely that an ISS survived. The odds ratio associated with sinuosity indicates that as sinuosity increased by one unit, it was 124.74

times more likely that an ISS survived. A negative coefficient for geology indicates that when geology was type B ("soft" rocks), the probability of an ISS surviving increased. The odds ratio of 0.11 indicates that when geology was type A ("hard" rocks), it was less likely that that an ISS was functioning. The positive coefficient and odds ratio of 4.27 associated with ISS anchor indicates that if an ISS was anchored it was 4.27 times more likely that it survived.

In this model, a couple of the test statistics indicate that there is some evidence that the model fits the data moderately well but most of the test statistics indicate that the model is not a good fit for the data. The G statistic, the log-likelihood statistic and one of the goodness-of-fit tests suggest that the model has value in predicting ISS survival. Two of the goodness-of-fit tests and the summary measures of association indicate that the model does not provide a very good fit for the data (Table 82).

TABLE 82. Test Statistics for Logistic Regression for
ISS Survival: Model 3 (without Unknowns)

Test Statistic	p	
Log-Likelihood	-224.909	
G	63.711	0.0005
Goodness-of-Fit Tests	Chi-Square	p
Pearson	99.191	0.0005
Deviance	96.485	0.0005
Hosmer-Lemeshow	10.605	0.157
Measures of Association		
Concordant		71.7%
Discordant		22.1%
Ties		6.2%
Measures of Association – Summary Measures		
Somers' D		0.50
Goodman-Kruskal Gamma		0.53
Kendall's Tau-a		0.09

The p-value associated with the G statistic for this model is 0.0005, indicating that the coefficients of the predictor (control) variables in the logistic equation are not zero and that

the predictors had a significant effect on ISS survival. A large, negative log-likelihood indicates that the coefficients maximized the probability of predicting whether an ISS survived. One of the goodness-of-fit tests for this model has a p-value > 0.05 indicating that there is sufficient evidence that the model does fit the data. The other two goodness-of-fit tests have p-values < 0.05 which indicate that there is sufficient evidence that this model is not a good fit for the data. The Hosmer-Lemeshow statistic is > 0.05 indicating that the Table of Observed and Expected Frequencies does provide sufficient evidence that the model fits the data well. Two of the three summary measures of association are midway between 1 and 0, suggesting that the model has some ability to predict ISS survival.

ISS Survival for Taylor Data Set

I was not able to build a logistic regression model for ISS survival using the Taylor data set. In each iteration of the model, there were no predictor variables that were significant. The data set may not have been large enough to fit a model to the data. This data set included 159 ISSs compared with a minimum of 811 ISSs in the Forest Service Data set. In addition, there were very few ISSs included in the data set that did not survive. The most likely reason that there was no significant model is that there were too few cases of ISS failure to fit a model to the data.

ISS Performance using Forest Service Data Set

Two logistic regression analyses for ISS performance were done for the Forest Service data set. For the first analysis, all the ISSs with "unknown" ISS characteristics were included in the data set but the ISS control variables were not used. In the second analysis, the ISSs with "unknown" ISS characteristics were removed from the data set and the ISS control variables were used. The ISS performance response variable used for this model had two possible outcomes: functioning ($F_c = 1$) or not functioning ($F_n = 0$). ISSs were

considered to be functioning if they functioned (F) and were considered to be not functioning if they were partially functioning (P) or were not functioning (N).

First analysis of ISS performance: Model 4

In this analysis of ISS performance, all the ISSs with “unknown” ISS characteristics were included in the data set but the ISS control variables were not used. The logistic equation to predict whether an ISS was functioning is summarized in Table 83.

TABLE 83. Logistic Regression Results for ISS Performance using Forest Service Data Set: Model 4 (without ISS Control Variables)

Predictor	Coefficient	StDev	p	Odds Ratio
Constant	1.0595	0.6033	0.079	
Log Drainage Area	-0.2471	0.2490	0.321	0.78
Stream Order	0.2790	0.1153	0.015	1.32
Rosgen Stream-Type	-1.1458	0.4594	0.013	0.32
Geology (A = 1)	0.3536	0.1245	0.005	1.42

(n = 903; 715 functioning, 188 not functioning)

The logistic model included several control variables, stream order, Rosgen stream-type and geology, that were statistically significant as indicated by the p-values ($p < 0.05$) associated with the coefficient for each variable (Table 83). The log of drainage area was included as a control variable in the model even though it was not significant ($p < 0.05$) because it is a confounding variable. The model indicates that the probability of ISS functioning increased with decreasing drainage area, increasing stream order, when Rosgen stream-type was type C or E and when geology was type A (“hard” rocks).

The negative coefficient for log drainage area indicates that as drainage area decreased, the probability that an ISS was functioning increased. The odds ratio of 0.78 indicates that as log drainage area increased by one unit, it was less likely that an ISS was functioning. The positive coefficient and odds ratio for stream order indicates that as stream order

increased by one unit, it was 1.32 times more likely that an ISS was functioning. The coefficient for geology was positive. A positive coefficient and odds ratio for geology indicate that when geology was type A, it was 1.42 times more likely that an ISS was functioning.

This analysis suggests that Rosgen stream-type is a significant control of ISS performance. For logistic regression analysis, Rosgen stream-type categories were transformed into ordinal variables of increasing numeric value which corresponded to increasing gradient percent. A negative coefficient indicates that as Rosgen stream-type "decreased," the probability of an ISS functioning increased. Using the scheme where Rosgen type C reaches were assigned a value of 2 and Rosgen type E reaches were assigned a value of 1, an ISS was more likely to function if it were in a Rosgen type C or E reach but less likely to function in type A (value = 4) or B (value = 3) reaches.

Several test statistics indicate that there is some evidence that the model fits the data moderately well while others indicate that the model is not a good fit for the data (Table 84). The G statistic and the log-likelihood statistic suggest that the model has value in predicting ISS performance. The goodness-of-fit tests and the summary measures of association indicate that the model does not provide a very good fit for the data.

TABLE 84. Test Statistics for Logistic Regression for ISS Survival: Model 4 (without ISS Control Variables)

Test Statistic		p
Log-Likelihood	-449.983	
G	23.903	0.0005
Goodness-of-Fit Tests	Chi-Square	p
Pearson	225.598	0.0005
Deviance	224.756	0.0005
Hosmer-Lemeshow	15.757	0.015
Measures of Association		
Concordant		57.3%
Discordant		37.2%
Ties		5.5%
Measures of Association – Summary Measures		
Somers' D		0.20
Goodman-Kruskal Gamma		0.21
Kendall's Tau-a		0.07

The p-value associated with the G statistic for this model is 0.0005, indicating that the coefficients of the predictor (control) variables in the logistic equation are not zero and that the predictors had a significant effect on ISS performance. A large, negative log-likelihood indicates that the coefficients maximized the probability of predicting whether an ISS functioned. All of the goodness-of-fit tests for this model have p-values < 0.05 which indicate that there is sufficient evidence that this model is not a good fit for the data. The Hosmer-Lemeshow statistic is < 0.05 and suggests that the Table of Observed and Expected Frequencies provides some evidence that the model fits the data well. None of the summary measures of association are close to 1 and this indicates that the model has limited ability to predict ISS performance.

Second Analysis of ISS Performance: Model 5

For this analysis, all the ISSs with “unknown” ISS characteristics were removed from the data set and the ISS control variables were used. The logistic regression equation to predict whether an ISS was functioning is summarized in Table 85.

TABLE 85. Logistic Regression Results for ISS Performance using Forest Service Data Set: Model 5 (without Unknowns)

Predictor	Coefficient	StDev	p	Odds Ratio
Constant	-5.894	1.631	0.0005	
Log Drainage Area	0.4568	0.3270	0.162	1.58
Sinuosity	3.457	1.047	0.001	31.72
Rosgen Stream-Type	0.4688	0.1750	0.007	1.60
ISS Anchor	0.9317	0.3220	0.004	2.54
ISS Type	0.13481	0.06768	0.046	1.14

(n = 811; 712 functioning, 99 not functioning)

The logistic model for ISS performance, model 5 included several control variables, sinuosity, Rosgen Stream-type, ISS anchor and ISS type, that were statistically significant as indicated by the p-values ($p < 0.05$) associated with the coefficient for each variable (Table 85). The log of drainage area was included as a control variable in the model even though it was not significant ($p < 0.05$). The model indicates that the probability of ISS functioning increased with increasing drainage area and sinuosity, when Rosgen stream-type was type A or B rather than types C or E, when ISSs were anchored and when ISS type was of greater strength (log-boulder or multiple-boulder).

The positive coefficients for log drainage area and sinuosity indicate that as the value of these variables increased, the probability that an ISS was functioning increased. The odds ratio of 1.58 for the log of drainage area indicate that as this predictor increased by one unit, it was 0 1.58 times more likely that an ISS was functioning. The odds ratio of for sinuosity indicates that when sinuosity increased by one unit it was 31.72 times more likely that an

ISS was functioning. The positive coefficient and odds ratio for ISS anchor indicates that when an ISS was anchored, it was 2.54 times more likely to be functioning.

This analysis suggests that Rosgen stream-type was a significant control of ISS performance. A positive coefficient indicates that as Rosgen stream-type “increased,” it was 1.14 time more likely that an ISS was functioning, as indicated by the odds ratio. An ISS was more likely to function if it were in a Rosgen type A (value = 4) or B (value = 3) reach but less likely to function in type C (value = 2) or E (value = 1) reaches.

This analysis also indicates that ISS type was a significant control of ISS performance. ISS type was transformed into an ordinal variable reflecting ISS strength. Log-boulder ISSs were defined as the “strongest” type of ISS, (value = 8) followed by multiple-boulder (value = 6), multiple-log (value = 4) and single-log (value = 2). The positive value for the coefficient and odds ratio of 1.14 for ISS type indicate that as ISS “strength” increased, the likelihood that an ISS was functioning increased by a factor of 1.14. ISSs were more likely to be functioning if they were log-boulder or multiple-boulder instead of multiple-log or single-log.

Several test statistics indicate that there is some evidence that the model fits the data moderately well (Table 86). The G statistic and the log-likelihood statistic suggest that the model has value in predicting ISS performance. The goodness-of-fit tests and the summary measures of association indicate that the model does not provide a very good fit for the data.

TABLE 86. Test Statistics for Logistic Regression for
ISS Survival: Model 5 (without Unknowns)

Test Statistic		p
Log-Likelihood	-281.915	
G	37.984	0.0005
Goodness-of-Fit Tests	Chi-Square	p
Pearson	225.933	0.0005
Deviance	192.043	0.0005
Hosmer-Lemeshow	17.233	0.028
Measures of Association		
Concordant		63.5%
Discordant		33.8%
Ties		2.7%
Measures of Association – Summary Measures		
Somers' D		0.30
Goodman-Kruskal Gamma		0.31
Kendall's Tau-a		0.06

The p-value associated with the G statistic for this model is 0.0005, indicating that the coefficients of the predictor (control) variables in the logistic equation are not zero and that the predictors had a significant effect on ISS performance. A large, negative log-likelihood indicates that the coefficients maximized the probability of predicting whether an ISS functioned. The goodness-of-fit tests for this model have p-values < 0.05 which indicate that there is sufficient evidence that this model is not a good fit for the data. The Hosmer-Lemeshow test statistic has a p-value < 0.05 and suggests that the Table of Observed and Expected Frequencies provides some evidence that the model fits the data well. None of the summary measures of association for this model are close to 1 suggesting that the model is limited in its ability to predict ISS survival.

ISS Performance using Taylor Data Set: Model 6

All of the ISS characteristics in the Taylor data set were known, so this analysis included all ISS surveyed and all control variables. More control variables were used to analyze ISS performance in this data set than in the previous analyses using the Forest Service data set. The logistic regression equation to predict whether an ISS was functioning is summarized in Table 87.

TABLE 87. Logistic Regression Results for ISS Performance using Taylor Data Set: Model 6

Predictor	Coefficient	StDev	p	Odds Ratio
Constant	-15.918	3.059	0.0005	
Log Drainage Area	2.8284	0.7250	0.0005	18.70
Sinuosity	5.739	2.052	0.005	310.60
Bankfull Width-to-Depth Ratio	-0.08859	0.04339	0.041	0.92
Bank Stability Percent	8.556	2.638	0.001	5196.18
Dominant Bank Material Size	0.4597	0.2167	0.034	1.58

(n = 159; 126 functioning; 33 not functioning)

Model 6 for ISS performance included several control variables, log drainage area, sinuosity, bankfull width-to-depth ratio, bank stability percent and dominant bank material size, that were statistically significant as indicated by the p-values ($p < 0.05$) associated with the coefficient for each variable (Table 87). The model indicates that the probability of ISS functioning increased with increasing drainage area, sinuosity, bank stability percent and dominant bank material size. Decreased bankfull width-to-depth ratio increased the probability that an ISS was functioning.

Drainage area, sinuosity and bank stability had the greatest effect on the probability that an ISS was functioning. The positive coefficient and odds ratio for the log of drainage area indicate that as this predictor increased by one unit, the probability of an ISS functioning increased 18.70 times. When sinuosity increased by one unit, the probability that an ISS

was functioning increased by 310.60, and when bank stability percent increased by one unit, an ISS was 5196.18 times more likely to be functioning.

Though shown to be significant predictors, dominant bank material size and bankfull width-to-depth ratio were less influential in affecting the probability that an ISS was functioning. The probability that an ISS was functioning increased by 1.58 times when dominant bank material size increased by one unit. The negative co-efficient and odds ratio for bankfull width-to-depth ratio indicate that when this variable increased by one unit it was less likely that an ISS was functioning.

Several test statistics indicate that there is evidence that the model fits the data well (Table 88). The G statistic and the summary measures of association indicate that the model has value in predicting ISS performance and fits the data well. The goodness of fit test, however, indicates that there is sufficient evidence that the model fits the data well.

TABLE 88. Test Statistics for Logistic Regression for ISS Survival using Taylor Data Set: Model 6

Test Statistic		p
Log-Likelihood	-51.653	
G	59.093	0.0005
Goodness-of-Fit Tests		Chi-Square
Pearson	51.504	0.0005
Deviance	32.190	0.0005
Hosmer-Lemeshow	47.484	0.0005
Measures of Association		
Concordant		80.6%
Discordant		15.3%
Ties		4.0%
Measures of Association – Summary Measures		
Somers' D		0.65
Goodman-Kruskal Gamma		0.68
Kendall's Tau-a		0.22

The p-value associated with the G statistic for this model is 0.0005, indicating that the coefficients of the predictor (control) variables in the logistic equation are not zero and that

the predictors had a significant effect on ISS performance. The log-likelihood and associated p-value of 0.0005 indicate that the model does fit the data. All of the goodness-of-fit tests for this model have p-values < 0.05 which indicate that there is sufficient evidence that the model does not fit the data well. The Hosmer-Lemeshow test statistic has a p-value < 0.05 and suggests that the Table of Observed and Expected Frequencies provides sufficient evidence that the model fits the data well. Two of the summary measures of association are fairly close to 1 indicating that the model can predict ISS performance.

ISS Survival and ISS Performance: Summary and Discussion

This analyses in this chapter addressed the fourth research question: “What are the watershed, channel, stream-type and ISS characteristics that affect the survival and performance of ISSs?” I used contingency table and logistic regression analyses to identify the variables that had significant influences on ISS survival and performance.

Summary of ISS Survival and Performance Results

Summary of ISS Survival Results

The results of the analysis of ISS survival are summarized in Table 89. The results were generally consistent among the logistic regression models. However, some of the variables in the contingency table analysis did not appear in the logistic regression models. Model 3 was the best model based on the test statistics, but the results from Model 3 may not be as reliable as Model 1 and Model 2 in identifying the influential watershed, channel and stream-type variables than that influenced ISS survival and failure. Model 1 and Model 2 included all the ISS observations, but did not include the ISS control variables. Model 3 did not include the ISSs that had “unknown” ISS characteristics, which comprised about half of the ISSs that failed, so it did not provide a complete picture of ISS failure. However,

Model 3 does provide information about the influence of ISS characteristics, and some of the influential control variables are consistent with Model 1 and Model 2, and/or with the results from contingency table analysis.

TABLE 89. Summary of Analysis of ISS Survival: Factors that Contributed to Increased ISS Survival

Contingency Table Analysis	Logistic Regression Analysis		
	Analysis 1: Model 1 (without ISS control variables, n = 903)	Analysis 1: Model 2 (without ISS control variables, n = 903)	Analysis 2: Model 3 (without "unknowns," n = 811)
	Survived: n = 747 (82.7%) Failed: n = 156 (17.3%)	Survived: n = 747 (82.7%) Failed: n = 156 (17.3%)	Survived: n = 733 (90.4%) Failed: n = 78 (9.6%)
	-Log Drainage Area *	-Log Drainage Area	+Log Drainage Area
-Stream order	-Stream Order		-Stream Order
+Reach gradient (weak trend)			
		+Sinuosity	+Sinuosity
Rosgen stream-type: +A and E -B and C			
+Geology B	+Geology B	+Geology B	+Geology B
+ISS Anchor			+ISS Anchor
ISS gradient: +High and low -Medium			

* A minus sign indicates that as a control variable increased, the probability that an ISS survived increased. A plus sign indicates that as a control variable increased, the probability that an ISS survived decreased.

Summary of ISS Performance Results

The results of the analysis of ISS performance are summarized in Table 90. The results were not consistent for all the variables among the logistic regression models, and some of the variables in the contingency table analysis did not appear in the logistic regression models. Model 6 was the best model based on the test statistics. Model 6 included a

smaller number of observations, but also included additional control variables, and is the only to provide information about the influence of these additional variables. Model 5 provides the best information about the influence of ISS characteristics, and some of the influential control variables are consistent with Model 6, or with the results from contingency table analysis.

TABLE 90. Summary of Analysis of ISS Performance: Factors that Contributed to Increased ISS Performance

Contingency Table Analysis	Logistic Regression Analysis		
	Analysis 1: Model 4 (without ISS control variables, n = 903)	Analysis 2: Model 5 (without "unknowns," n = 811)	Taylor: Model 6 (n = 159)
	Survived: n = 715 (79.2%) Failed: n = 188 (20.8%)	Survived: n = 712 (87.8%) Failed: n = 99 (12.2%)	Survived: n = 126 (79.2%) Failed: n = 33 (20.8%)
	-Log Drainage Area *	+Log Drainage Area	+Log Drainage Area
+Stream order (very low in 1 st order even though they were in place; trend not clear in 2 nd - 5 th order)	+Stream Order		
		+Sinuosity	+Sinuosity
+Rosgen Stream-Type	-Rosgen Stream-Type	+Rosgen Stream-Type	
+Geology B	-Geology B		
+ISS Anchor		+ISS Anchor	
+ISS Type		+ISS Type	
			-Bankfull width-to-depth ratio
			+Bank Stability
			+Dominant Bank Material Size

* A minus sign indicates that as a control variable increased, the probability that an ISS survived increased. A plus sign indicates that as a control variable increased, the probability that an ISS survived decreased.

Based on the statistical tests for significance and the relative strength of the predictors identified in the logistic regression equations, some of these control variables appeared to have a greater influence on ISS survival and performance than others. In order to evaluate the implications for predicting ISS survival and performance, based on the control variables identified, the results will be discussed in greater detail in the following section.

Discussion of ISS Survival and Performance Results

Relationship between ISS Survival and ISS Performance

In the study presented in this thesis, 90.2% of ISSs either were in place or shifted on site in the Forest Service data set, and 99% were in place in the Taylor data set. In the evaluation of ISS survival throughout Region 6, Roper and others (1998) found that 80% of ISSs were in place or shifted on site. Roper and others (1998) did not evaluate ISS performance due to the large number and variability of observers. The results of the study presented in this thesis indicate that fewer ISSs were functioning than remained in place (Tables 55 and 56). These results suggest that just because an ISS remained in place, it did not always guarantee that the ISS was functioning to meet project the objective of pool development and maintenance.

Influential Watershed Control Variables for ISS Survival and Performance

Drainage Area, Stream Order and ISS Survival and Performance

In this study, drainage area was included in all of the logistic regression models for ISS survival and performance, even when it was not significant because it is a confounding variable. Stream order was included only if it was a significant control variable. Both drainage area and stream order are often used as surrogates for discharge (Chin, 1999) which is an important control on channel form.

The relationship between drainage area (evaluated as log drainage area) and ISS survival and performance was not consistent among the logistic regression analyses. Logistic regression Models 1, 2 and 4 provided the best indication of the relationship between log drainage area and both ISS survival and performance because they included all ISS observations, and all the ISSs that failed or were not functioning. These models indicated that as log drainage area decreased, it was more likely that an ISS survived or was functioning. However, since log drainage area was not significant in any of them, this relationship may not be a strong relationship. Log drainage area was significant in model 6, and indicated that ISSs were more likely to be functioning when drainage area increased. An analysis of ISS survival of the 3,946 ISSs throughout region 6 (Pacific Northwest Region) using drainage area as a control variable could provide additional information on the relationship between drainage area and ISS survival.

The results of contingency table analysis and logistic regression analysis indicated that as stream order decreased, ISS were more likely to survive. This is consistent with the interpretation of the relationship between drainage area and ISS survival in Models 1, 2 and 4. The relationship between stream order and ISS survival reported in this thesis was consistent with the results reported by Roper and others (1998) in an analysis of ISS survival throughout Region 6 (Pacific Northwest Region). Roper and others (1998) evaluated 3,946 ISSs in reaches throughout the Pacific Northwest, and found that ISS survival was greater in low order reaches. The results for stream order and ISS survival in this thesis were not consistent with the results reported by Fitzgerald (1997) in an evaluation of ISS survival in the Umatilla NF. The results of the Fitzgerald (1997) study in the Umatilla NF indicated that ISS survival was greater in higher order reaches than in lower order reaches. Only 217 ISSs were evaluated in the Fitzgerald (1997) study and they were located only in 3rd, 4th and 5th order reaches. 904 ISSs were evaluated in the study presented in this thesis, and included the 217 ISSs from the Fitzgerald (1997) study. The reaches

with ISSs in this thesis were in streams with a wider range of stream orders (1st through 5th order) than the Fitzgerald (1997) study and it is likely that the results of this thesis better portray the relationship between stream order and ISS survival than the previous study (Fitzgerald, 1997).

The negative relationship between stream order and ISS survival, and between drainage area and ISS survival might be explained by the increased discharge that is found in higher order streams. Discharge is greater in stream with high stream order and large drainage area than in stream with low stream order and small drainage area. Erosive effectiveness also increases as discharge increases. With increasing discharge and erosive effectiveness, ISSs might be more easily dislodged in reaches with higher stream order and larger drainage area, potentially contributing to an increased occurrence of ISSs that did not survive.

While the relationship between stream order and ISS survival is very clear, the relationship between stream order and ISS performance is less clear. The logistic regression model developed using the full Forest Service data set (Model 4) showed a positive relationship between stream order and ISS performance. As stream order increased, it was more likely that an ISS was functioning. Drainage area was not significant in this model, but it was significant in Model 6 using the Taylor data set. Model 6 showed a positive relationship between drainage area and ISS performance, consistent with the results for stream order. Contingency table analysis showed that ISSs were functioning less often in 1st order reaches, but there is not a consistent relationship between stream order and ISS performance in 2nd through 4th order reaches. This suggests that stream order alone may not be enough to explain ISS function. In both contingency table analysis and logistic regression analysis, other factors or combinations of factors are likely to have affected ISS performance. The reaches in this study having the same stream order have widely varied characteristics, including gradient, sinuosity and drainage area. The relationship between

stream order and performance observed in the logistic regression analysis may reflect controls other than stream order.

Valley Constraint and ISS Survival and Performance

Valley constraint was evaluated using contingency table analysis, and this analysis indicated that there was not a significant relationship between valley constraint and ISS survival or ISS performance. Valley constraint was not found to be a significant predictor in the logistic regression analysis. The contingency table results do show that ISSs were in place slightly more often in constrained valleys and left the site slightly more often in unconstrained valleys. The results also suggest that ISSs were functioning slightly more often in constrained valleys and slightly less often in unconstrained valleys. If ISSs survive and are functioning less often in unconstrained reaches, this may be the result of the greater lateral mobility of these channels.

Frissell and Nawa (1992) found that ISSs failed more often in constrained reaches and in wider streams, and they attributed this to more erodible bank material. Beschta and others (1991) noted that reaches with ISSs in unconstrained valleys were wider and shallower than similar reaches without ISSs. Beschta and others (1991; 1996) also suggested that ISSs shifted the geomorphic potential in unconstrained reaches to that of streams in constrained, high gradient environments, and that ISSs restricted channel adjustment that occurs through lateral migration. However, the results in this thesis suggest that some lateral migration in streams with ISSs in unconstrained reaches did occur. Lateral migration around the outside ends of ISSs, especially at meander bends, was noted in several reaches (Camas, Hidaway, Phillips, Thomas, and Wilson). Channel width was increased when the channel migrated around the outside of the ISSs, and the ISSs seemed to prevent deposition on the inside of meander bends. In some reaches where lateral migration had occurred, the ISS was no longer in the active channel and the stream was not

flowing over the weir, but was flowing around the ISS. At several ISS locations in Phillips, channel width was nearly doubled when lateral migration around the ISS occurred. This suggests that ISSs do migrate laterally and contribute to channel widening.

Geology and ISS Survival and Performance

The contingency table and logistic regression analyses indicated a positive relationship between geology B ("soft" sedimentary and volcanoclastic rocks, fluvial and lacustrine deposits, and siltstones and sandstones) and ISS survival. In both the contingency table and logistic regression analyses, there was a positive relationship between geology B and ISS survival. Contingency table analysis showed that ISSs were in place more often in reaches with geology B, and logistic regression analysis indicated that the probability that an ISS survived increased in reaches with geology B. I would have expected that ISSs would have survived more often in reaches of geology A ("hard" rocks, igneous and metamorphic rocks, Columbia River Basalts, intrusive ultramafics, and older metamorphosed volcanics), because the alluvium from these rock types would be less erodible than alluvium in geology B. However, in reaches with geology A, it might have been more difficult to anchor the ISSs because the banks were less cohesive, and therefore ISSs were more easily shifted or removed from their original location.

The relationship between geology and ISS performance was not consistent among the contingency table analysis and logistic regression analyses. Contingency table analysis indicated that ISSs were functioning more often in reaches that were in geology B. This could be because the alluvium derived from these rock types is "soft," more erodible, and perhaps pool bedforms are more easily scoured and maintained by hydraulic action in reaches in geology B. Model 4 indicated that the probability that an ISS was functioning increased when geology was type A, though the relationship was weak. The relationship between geology and ISS performance could be explored in future research.

Influential Channel Control Variables and ISS Survival and Performance

Reach Gradient and ISS Survival Performance

Contingency table analysis indicated a significant positive relationship between ISS survival and reach gradient. For this analysis, reach gradient was used as a categorical variable rather than a continuous variable. The analysis showed greater ISS survival in reaches with high gradient than in reaches with low gradient, though the trend was not strong. None of the logistic regression analyses identified reach gradient as a significant predictor of ISS survival. In the previous studies conducted in the Umatilla NF and throughout the Pacific Northwest Region, ISS survival was greater in low and medium gradient reaches (Fitzgerald, 1997; Roper et al., 1998). In the study presented in this thesis, there was a small number of ISSs in reaches with gradients $\geq 4\%$ compared to the relatively large number of ISSs in reaches with gradients $< 4\%$. The small sample size in reaches with high gradients may have skewed the data and affected the results of this study. If only the reaches with gradients $\geq 4\%$ are considered, more ISSs survived in low gradient reaches than in the higher gradient reaches (3-3.8%), and more ISSs left the site in the higher gradient reaches, consistent with the results of Fitzgerald (1997) and Roper and others (1998). However, even among reaches with gradients less than 4%, the differences in ISS survival were relatively small.

The analysis of the relationship between ISS performance and reach gradient using contingency table analysis does not show consistent results across categories of increasing gradient, and none of the logistic regression analyses indicated that reach gradient was a significant predictor. Again, the relatively small number of ISSs in reaches with higher gradients ($> 4\%$) compared with the large number of ISSs in reaches with lower gradients ($< 4\%$) skewed the data set and this affected the results.

Frissell and Nawa (1992) found that ISSs in low gradient reaches were not functioning because they were buried, and a similar effect was observed in some of the reaches with the lowest gradients in this study. In some low gradient reaches in this study, sediment was deposited just upstream from the ISSs, and the pools below the ISSs were filled in with cobble and gravel. However, none of the analyses show this effect.

Reach gradient co-varies with drainage area and stream order, so these variables may be representative of reach gradient and may shed some light on the relationship between reach gradient and ISS response. As discussed in a previous section Models 1, 2 and 4 indicated that as log drainage area decreased, it was more likely that an ISS survived or was functioning. Analyses previously discussed indicate that ISS survival increased as stream order decreased. In the Forest Service data set the trend in the relationship between stream order and reach gradient shows that reach gradient increased as stream order decreased. The relationship between stream order and reach gradient, between drainage area and reach gradient, and the results for ISS survival based on stream order suggest that ISS survival also increased as reach gradient decreased. These results are consistent with the findings of Frissell and Nawa (1992).

Sinuosity and ISS Survival and Performance

Logistic regression analysis indicated that there was a positive relationship between sinuosity and both ISS survival and ISS performance. Models 2 and 3 for ISS survival showed that as sinuosity increased, the probability that an ISS survived increased. Lower gradient and less erosive energy might be the important factors associated with an increased probability of ISS survival in reaches with higher sinuosity.

Other Channel Control Variables and ISS Survival and Performance

Logistic regression analysis using the Taylor data set (Model 6) indicated that bankfull width-to-depth ratio, bank stability and dominant bank material were significant predictors of ISS performance. As bankfull width-to-depth ratio decreased, the probability that an ISS was functioning increased. This suggests that when a reach was narrower and deeper, it was more likely that there was a pool associated with the ISS. Also, as bank stability increased, and dominant bank material size increased, the probability that an ISS was functioning increased. These results are consistent with the results of the analysis of the effects of ISSs on channel morphology, discussed in chapter V. The analysis showed that residual pool depth in ISS pools was greater in reaches with coarse bed and bank material.

Influential Stream-Type Control Variables for ISS Survival and Performance

Contingency table analysis indicated that there was a significant association between Rosgen stream-type and ISS survival. ISS survived in reaches that were type A and type E more than in type B and type C. However, Rosgen stream-type was not found to be a significant variable in any of the logistic regression analyses for ISS survival.

Contingency table analysis and logistic regression analysis indicated a significant association between Rosgen stream-type and ISS performance. The analyses indicated that ISS were functioning more often in type A and B reaches than in type C or E reaches. ISSs were not often functioning in type E reaches even though they often survived.

Rosgen stream-type is related to reach gradient and sinuosity, and these factors could have affected ISS survival and performance. Type A reaches have the highest gradient followed by type B, C and then E. Based on the results showing that there was a positive relationship between Rosgen stream-type and ISS performance, this suggests that as reach gradient increased and sinuosity decreased, the probability of an ISS functioning increased.

This interpretation is consistent with the results for ISS performance and reach gradient, but not for sinuosity. For the relationship between Rosgen stream-type and ISS performance, gradient may be an important factor. In reaches with higher gradient, the hydraulic drop at the ISS may facilitate scour below the ISS and maintain a pool better than in reaches with lower gradient. This is consistent with the results of residual pool depth in ISS pools discussed in chapter V. In that analysis, residual pool depth in ISS pools was significantly greater in reaches with higher gradient.

The data for ISSs in streams in specific Rosgen stream-types were skewed and this is likely to have affected the results. Most of the ISSs were in Rosgen type B (460) and C (343) reaches, while there were fewer ISSs in type A (37) and E (61) reaches. A larger number of ISSs in type A and E reaches would provide a better data set for analysis. It is quite likely that other factors that are not included in the Rosgen level I classification (besides gradient and sinuosity) are important in explaining the relationships between Rosgen stream-type and ISS survival.

Influential ISS Control Variables for ISS Survival and Performance

ISS Gradient and ISS Survival and Performance

ISS gradient was used as a categorical variable in contingency table analysis. The results related to ISS gradient are not comparable to the results for reach gradient and ISS survival, because ISS gradient was a very localized measurement.

Contingency table analysis indicated that there was a significant but complex relationship between ISS gradient and ISS survival. ISSs with high ISS gradient survived most often, followed by ISSs with low ISS gradient. In the study reported in this thesis, very few ISSs with high ISS gradient failed. These results are not consistent with those in a previous study of ISS survival where ISSs with medium ISS gradient survived more often

than ISSs with either low or high ISS gradient (Roper et al., 1998). A majority of the ISSs in this thesis had medium ISS gradient, and this may be a factor influencing the results of the contingency table analysis.

Contingency table analysis indicated that there was not a significant relationship between ISS gradient and ISS performance, and none of the logistic regression analyses showed that ISS gradient was a significant predictor of ISS performance.

ISS Anchor and ISS Survival and Performance

This analysis indicated that there was a positive relationship between ISS anchor and both ISS survival and performance. ISSs survived more often and were functioning more often when they were anchored. These were the expected results, especially for ISS survival, and were consistent with a previous study (Roper et al., 1998).

None of the logistic regression models identified ISS anchor as a significant predictor of ISS performance, even though over half of the ISSs that were not anchored were not functioning. For ISS performance, other factors are likely to be more important in predicting the probability that an ISS was functioning.

ISS Type and ISS Survival and Performance

Contingency table analysis and logistic regression analysis indicated that there was not a significant association between ISS type and ISS survival.

Contingency table analysis indicated that there was a significant association between ISS type and ISS performance. The logistic regression analysis in Model 3 also indicated that ISS type was a significant predictor of ISS performance. These analyses of ISS performance indicated that log-boulder and multiple-boulder ISSs were more likely to be functioning than multiple-log and single-log ISSs. This may be the result of the hydraulic effects of specific ISS types. Log-boulder and multiple-boulder ISSs usually included

boulders that lined the banks both upstream and downstream from the weir. Streamflow over the weir may be deflected by the boulders and directed towards the bed, resulting in bed scour and pool maintenance. Single-log ISSs may direct streamflow toward the banks, and the hydraulics associated with single-log ISSs may not be as effective in maintaining pools downstream from the weir.

While this analysis does provide some useful information, it may also be the case that reach characteristics were more important than ISS type in influencing ISS performance. Some types of ISSs were used more often in some types of streams than in other types of reaches. For example, most single-log ISSs were in reaches with low gradient, high sinuosity, and fine bed and bank material. Log-boulder and multiple-boulder ISSs were most often located in reaches with low sinuosity and that had larger bed and bank material sizes. These reach characteristics may have had a greater affect on ISS performance than did ISS type. The combination of low reach gradient and single-log ISSs type appears to be important factor for ISS performance. Other factors, such as bed and bank material size or stream power in low gradient settings, may also be important in influencing ISS performance.

Problems with the Data Set

One of the major problems with the data set used for evaluating ISS survival and performance was the number of ISSs where ISS type, ISS gradient or ISS anchor were not known. Since a majority of the “unknown” ISSs did not survive and were not functioning, the analyses of ISS survival and performance were greatly affected by the exclusion of these observations from the Forest Service data set. If these observations had been included, influential predictor variables could have been better identified.

Another problem with the data set was that several watershed, reach, stream-type and ISS characteristics were not evenly distributed among the ISSs (Figures 28 and 29). For

example, a majority of ISSs were in reaches with low gradients (under 3%), most were in reaches with gradients between 1.9% and 2.8%, and very few were in reaches with high gradients (between 4 and 7%). The uneven distribution of ISSs across a number of control variable values would have a significant effect on the analyses of ISS survival and performance. Other characteristics that had this uneven distribution of ISSs include stream order, geology, valley constraint, Rosgen stream-type, ISS type, ISS anchor and ISS gradient. Additional observations in underrepresented categories would provide a more normally distributed data set and better results.

Another reason why the results of contingency table analysis and the logistic regression analyses may not be consistent is because ISS survival and performance categories were slightly different in each type of analysis. Contingency table analysis used three categories of ISS survival (in place, shifted on site, left the site) and three categories of ISS performance (functioning, partially functioning, and not functioning). For logistic regression analysis of ISS survival, the category “failed” included both ISSs that had shifted on site and that had left the site. For the logistic regression analysis of ISS performance, the category “functioning” included both ISSs that were functioning and ISSs that were partially functioning. Because of this, contingency table analysis provided more detailed information about ISS survival or performance than logistic regression analysis for some control variables.

Conclusions

This study showed that 90% of ISSs survived (either remained in place or shifted on site), and that fewer ISSs were functioning than survived. About half of the ISSs were fully functional, and 25% were partially functioning. This is an important result indicating that just because an ISS survives, it may not be functioning to meet the project objective of providing a pool for fish habitat. Researchers who conduct surveys to assess ISS survival

must be cautious in claiming “success” if their assessments have not considered whether ISSs are actually creating pools and providing habitat.

The results presented and discussed in this chapter indicated that the probability of ISS survival increased with decreasing drainage area, increasing sinuosity, when geology was type B, and when ISS were anchored. More ISS survived when ISS gradient was high or low, and when stream-type was Rosgen type A or type E. ISS survival was also greater in reaches with low stream order. The results for stream order and ISS survival are consistent with results of one previous study in the region (Roper et al., 1998), but not with a previous study of ISS survival in the Umatilla NF (Fitzgerald, 1997).

Results from the analyses of ISS performance using the Forest Service data set indicated that the probability that an ISS was functioning increased when ISSs were anchored, when ISSs were log-boulder or multiple-boulder, when bankfull width-to-depth ratio was low, when bank stability was high and when the dominant bank material size was large. This analysis also showed that ISSs were more likely to be functioning in streams with higher stream order. Contingency table analysis indicated that ISSs were functioning least often in 1st order reaches, but in this analysis, there was not a consistent relationship between ISS performance and stream order in 2nd through 5th order reaches. The reaches in this study having the same stream order have widely varied characteristics, including gradient, sinuosity and drainage area, and this suggests that other factors or combinations of factors are likely to have affected ISS performance.

The results of logistic regression analysis for Rosgen stream-type could be related to reach gradient or sinuosity. Since Rosgen type A and B reaches have higher gradients than Rosgen type C or E reaches, this result could indicate that ISSs were functioning more often in reaches with high gradients or with low sinuosity. The results for the influence of Rosgen stream-type and ISS performance could also be related to other channel characteristics. For example, scatter plots using the Taylor data set indicated that as reach

gradient increased, bank stability, dominant bank material size, and Rosgen stream-type increased. Scatter plots also indicate that as Rosgen stream-type “increases” (from E to A), bankfull width-to-depth ratio, dominant bank material size and bed material size increased. The results for Rosgen stream-type could be related to these channel characteristics.

The results indicate that installation methods, such as ISS anchoring, were important in influencing whether or not an ISS survives, and therefore whether an ISS was functioning.

ISS type was important as a predictor of ISS performance. Log-boulder and multiple-boulder ISSs performed better than single-log or multiple-log ISSs, and it is likely that this is because of the hydraulics associated with specific types of ISSs. The results related to ISS type may also be strongly related to watershed, channel and stream-type characteristics.

Missing observations may have had a significant influence on the results of a number of analyses. Contingency table and logistic regression analyses using the Forest Service data set were affected by the 10% of the ISSs that were removed from the data set because their characteristics were “unknown,” and most of the ISSs that were “unknown” failed. In future habitat enhancement projects, documentation that includes detailed descriptions of projects, along with maps showing the locations of specific enhancement treatments, are recommended, so that project monitoring can be conducted.

Other factors that were not considered in this thesis may have significant effects on ISS. Several studies have found that ISS survival was related to landslide frequencies, logging and road building (Fitzgerald, 1997) (Frissell and Nawa, 1992). Fitzgerald (1997), and Roper and others (1998) suggested that ISSs survived less often in watersheds with high landslide frequency. In reaches with high sediment yield and channel instability, bedload deposition and stream bank erosion was the most common type of damage to ISSs (Frissell and Nawa, 1992). ISSs were buried, and channels shifted laterally due to high rates of bedload transport and deposition (Frissell and Nawa, 1992). In the Umatilla NF, flood

events in 1995, 1996 and 1997 triggered landslides and debris flows, especially in small watersheds, and resulted in bed and bank scouring, sediment aggradation and channel migration (Fitzgerald and Clifton, 1998). Recent fires, which removed vegetation, also contributed to mass movement. The effects of land-use and mass movements were not evaluated in this thesis, but are likely to be important factors that affected ISS response and could be evaluated in future studies.

CHAPTER VII

CONCLUSIONS

In this thesis, I have evaluated the stream habitat enhancement projects that used ISSs to create additional pool habitat for steelhead salmon. I evaluated the effectiveness of ISSs in creating appropriate habitat conditions, the effects of ISSs on channel morphology and vegetation, and the survival and performance of ISSs following large magnitude floods.

ISS Effectiveness

The ISSs in this study did create pool habitat in most of the reaches, and these created pools were usually deeper than other pools in the reach. It is likely that these deeper pools have been important for the fish in these streams. However, when other characteristics of these reaches were compared with target values for a variety of channel and riparian characteristics, the results indicated that the stream enhancement projects have not been highly effective in contributing to improvements in other channel and habitat conditions. Based on the number of target values met by each reach, a few of the reaches evaluated were in good condition, and most were in only fair or poor condition.

Channel complexity was as great as in healthy streams in the region as indicated by the fact that every reach met the target value for habitat unit frequency (Lamb, 1996). However, this measure of channel condition should be used with caution, since it is often over- or underestimated during stream inventories.

The stream temperatures recorded in this study did not indicate that high temperatures were a serious problem in these reaches. Most of the reaches met the target values for stream temperature in these measurements, but the temperature measurements were made on

only one or two days in each reach. However, since stream temperature is affected by highly variable ambient conditions, these measurements may not be representative. Monitoring of stream temperature will continue to be important.

Vegetation conditions in the reaches in this study could be improved. Few of the vegetation target values, such as the amount of large woody debris, canopy cover or overhanging bank vegetation target values, were met by most of the reaches. Continued improvement in riparian vegetation will be important in order to provide supplies of large wood, and to improve vegetation conditions in the reaches. Vegetation conditions may also have affected bank stability

There were some problems in bank stability and channel form characteristics in many of the reaches. Few of the bank stability or channel form target values were met by most of the reaches. Some current land use activities, such as grazing, contributed to low amounts of overhanging bank vegetation in two reaches. Low amounts of vegetation is likely to have contributed to low bank stability and high width-to-depth ratios. Improved vegetation conditions in these and other reaches could have a positive effect on bank stability and width-to-depth ratios. Greater amounts of bank vegetation could facilitate sediment deposition, and lead to channel narrowing and reduced width-to-depth ratios. Since some of these characteristics might improve over time, monitoring and evaluation will be important in the future.

The results of this study suggest that the mechanisms which operate to provide and deliver large wood to streams should be investigated further. Results indicated that two of the three reaches that met the target values for large woody debris were in watersheds where disturbance processes are outside the range of natural variability. In these watersheds, fuels accumulated on the forest floor as a result of fire suppression during the last century (USDA Forest Service, 1997). Because of fire suppression, insect infestation and high tree mortality have been widespread. As a result of the accumulation of fuels on the forest floor,

the fires that occurred in these watersheds in 1996 were intense and catastrophic. These fires were followed by large magnitude floods. Flooding contributed to the delivery of large wood to the channels, and to geomorphic changes in the stream channels. While it is known that fire has been an important landscape process in forests in the Blue Mountains (Heyerdahl, and Agee, 1996; Heyerdahl, 1997), the specific role that fire and other disturbance processes play in the forests and streams in the Blue Mountains is not well known, and could be the subject of future research.

In this analysis of ISS effectiveness, preliminary analyses to identify the variables that were important in explaining why some target values were met by some reaches but not by other reaches did not provide any conclusive results. The Lamb (1996) target values are likely to be the best target values to use in this region because they were development from streams in the region. However, some of the target values from other sources were more stringent and may be appropriate target values to use to evaluate channel condition. In addition, observations suggest that different reaches in this study have different potentials to meet specific target values. For example, the target values for large woody debris, overhanging bank vegetation, bank stability, or width-to-depth ratio used in this study may not be appropriate for every reach because of the variety of vegetation types, bed material sizes, and bank material sizes among the reaches. Because of differing ecological or geomorphic settings and potentials, it may be appropriate to devise target values for specific settings.

ISSs and Channel Morphology

In most reaches, ISS pools were deeper than other pools in the reach, and significantly deeper in three reaches. These reaches had higher reach gradients, larger bed and bank material and were Rosgen type B streams. It is likely that once the pool associated with the ISS was constructed, it was maintained because the scour associated with water flowing over

the weir helped prevent deposition of bedload in the pool, facilitated the maintenance of a deep pool, and contributed to increased pool habitat. However, in some reaches, even when ISSs survived, they limited improvements in channel conditions by contributing to local bank erosion, channel widening and decreased bank vegetation. Flowing water at ISSs may also have been directed toward the stream banks downstream of the ISSs, contributed to greater wetted widths through bank erosion, and prevented bank vegetation from becoming established. This limited channel narrowing which normally occurs through vegetation establishment and sediment deposition. Reaches where bank erosion, channel width and bank vegetation were affected the most by the presence of ISSs had finer bed and bank material, smaller drainage areas and lower gradients.

In some reaches, the active stream channel had migrated around some of the ISSs, and some water continued to flow through the portion of the channel containing the ISSs, especially during higher flows. This has resulted in a very wide channel where, typically, the abandoned channel would be filled in by sediment. Where the channel has migrated around the ISSs and caused channel widening, the ISSs should be removed to facilitate channel narrowing (Phillips, Thomas, Wilson). In addition, ISSs could be removed from channels that are typically dry in late summer, such as Dry Camas or Phillips. Dry Camas was completely dry during surveys, none of the ISSs were functioning, and the width of the channel was much wider in habitat units with ISSs than in habitat units without ISSs. In this reach, ISSs were not providing habitat and only prevented channel narrowing, so they should be removed. Another channel enhancement technique, such as riparian corridor fencing, might be a better technique to use at this site. This could limit vegetation removal from grazing ungulates, facilitate vegetation establishment, and contribute to channel narrowing in Dry Camas. In Phillips, most of the channel was dry, but there were deep pools at many of the ISSs. Fish surveys in these pools would provide valuable information

as to whether fish were under stress by being isolated in these pools in summer. If this were the case, then ISSs should also be removed from this reach.

In some reaches, ISSs seemed to be serving another function; they were behaving like grade control structures. In many of the reaches, ISSs created a stepped longitudinal profile. In some reaches, especially low gradient reaches with fine bed and bank material, the ISSs were trapping sediment just upstream from the ISSs and preventing head cuts from progressing upstream. While there was greater bank erosion downstream from ISSs, much of the sediment eroded from the banks was likely deposited behind ISSs located further downstream. In reaches where this was occurring, the ISSs may eventually be buried and will have helped to stabilize the channel from further degradation.

ISS Survival and Performance

Over 90% of ISSs evaluated in this study survived, half of the ISSs were functioning, and almost 30% were partially functioning to create pools. These results suggest that when an ISS remains in place, it does not always guarantee that it will be functioning to meet project objectives or to create habitat. Researchers who assess ISS survival must be cautious in claiming “success” if their assessments considered only survival but not performance.

ISSs that survived tended to be in reaches with smaller drainage area, lower stream order, higher sinuosity, in geology type B, and when they were anchored. More ISSs survived when ISS gradient was high or low, and when stream-type was Rosgen type A or type E. The negative relationship between stream order and ISS survival, and between drainage area and ISS survival, might be explained by the increased discharge that is found in higher order streams. Stream order is often used as a surrogate for drainage area and discharge, which increases as drainage area and stream order increase. With increasing

discharge, ISSs might be more easily dislodged in higher order reaches, potentially contributing to an increased occurrence of ISSs that failed, either shifting or leaving the site.

ISSs were more likely to be functioning when they were in reaches with higher stream order, smaller bankfull width-to-depth ratio, larger bank material size, higher bank stability and when the ISSs were anchored. Log-boulder and multiple-boulder ISSs were more likely to be functioning than multiple-log or single-log. This could be attributed to the greater strength or immobility of log-boulder and multiple-boulder ISSs. It could also be the result of the hydraulics associated with these log-boulder and multiple-boulder ISSs, which may have better facilitated the maintenance of pool depth. Log-boulder and multiple-boulder ISSs usually included boulders that lined the banks, upstream and downstream from the weir. Downstream of the weir, the banks were partially protected by boulders, and the force of the flow is diverted more toward the bed, resulting in bed scour and pool maintenance. Single-log ISSs may direct streamflow toward the banks, and the hydraulics associated with single-log ISSs may not be as effective in maintaining pools downstream from the weir. While this analysis does provide some useful information, it may also be the case that reach characteristics were more important than ISS type in influencing ISS performance. The various ISS types were not equally represented in all of the reaches. For example, most single-log ISSs were in reaches with low gradient, higher sinuosity and finer bed and bank material, while log-boulder and multiple-boulder ISSs were in reaches with lower sinuosity and larger bed and bank material size. Bank and bed material size, or stream power in low gradient settings may also be important in influencing whether an ISS was functioning or not. The better performance of log-boulder and multiple-boulder ISSs might also be related to reach characteristics such as bank material size and bank stability rather than to ISS type. Control variables associated with better ISS performance are similar to those contributing to significantly deeper pools at ISSs. In both analyses, ISS

pools were significantly deeper and were functioning more often in reaches with higher gradients, and larger bed and bank material size than in other reaches.

Although the results of this analysis did not show that valley constraint was important in influencing ISS survival or ISS performance, other studies indicate that it might be. The results in this thesis, though not statistically significant, suggest that ISSs survived more often and were functioning slightly more often in constrained valleys, and slightly less often in unconstrained valleys. In other studies, researchers have reported that valley constraint was an important factor in ISS survival, and in stream response to the presence of ISSs. Their studies have shown that ISSs failed more often in constrained reaches and in wider streams, and attributed this to more erodible bank material (Beschta et al., 1991; Frissell and Nawa, 1992; Beschta et al., 1996). Beschta and others (1991; 1996) suggested that ISSs shifted the geomorphic potential in unconstrained reaches to that of streams in a constrained, high gradient environment (Beschta et al., 1991; Beschta et al., 1996), and that ISSs restrict channel adjustment that occurs through lateral migration. Beschta and others (1991) also noted that reaches with ISSs in unconstrained valleys were wider and shallower than similar reaches without ISSs. However, the results in this thesis, if indicative of the possible response of stream reaches to the presence of ISSs, suggest that some lateral migration in streams with ISSs in unconstrained reaches did occur. Lateral migration around the outside ends of ISSs, especially at meander bends, was noted in several reaches. It contributed to greater channel width and poor ISS performance. Valley constraint was a categorical variable in this thesis, but might have provided more information if actual valley width measurements were used. Additional analysis of the influence of valley constraint may provide more definitive results.

Mass movement and landslide frequency were not evaluated in this thesis, but may be important factors influencing ISS survival and performance. The floods of 1995, 1996 and 1997 in the Blue Mountains triggered landslides and debris flows, especially in small

watersheds, in loam-clay-ash soils, and on moderate to steep slopes (Fitzgerald and Clifton, 1998). Other studies have reported that ISS survival was related to landslide frequencies, logging and road building (Frissell and Nawa, 1992; Fitzgerald, 1997). Fitzgerald (1997), and Roper and others (1998) suggested that ISSs survived less often in watersheds with high landslide frequency.

Both contingency table analysis and logistic regression analysis were useful in identifying the variables that had the greatest influence on ISS survival and performance. A limitation of each of the analyses in this study is the use of categorical variables rather than continuous variables as control variables. In some of the analyses performed, the use of categorical variables does provide useful information. However, continuous variables should be used as often as possible, and are likely to provide results which are easier to explain and more useful for land managers to apply. In addition, the influence of categorical variables that encompass a number of continuous variables, such as those for stream-type, is difficult to explain since the results may indicate the influence on a specific parameter rather than the combination of parameters represented by the stream-type variable. Evaluation using the specific, individual continuous variables provides results which are easier to interpret, explain and apply to watershed management and channel enhancement projects.

One of the major problems in the analysis to evaluate ISS survival and performance was the potential effect of the removal of the ISS observations from the data set when ISS type, ISS gradient or ISS anchor were not known. Since a majority of the ISSs with "unknown" characteristics did not survive and were not functioning, the analyses of ISS survival and performance were greatly affected by the exclusion of these observations from the Forest Service data set. If these observations had been included, influential predictor variables could have been better identified. In future habitat enhancement projects, documentation that includes detailed descriptions of projects, along with maps showing the

locations of specific enhancement treatments, are recommended, so that project monitoring can be conducted.

Another problem with the data set was that several watershed, reach, stream-type and ISS characteristics were not evenly distributed among the ISSs. The uneven distribution of ISSs across a number of control variable values had a significant effect on the results of the analyses of ISS survival and performance. Additional observations in underrepresented categories would have provided a more normally distributed data set and better results. An analysis of ISS survival and performance of the 3,946 ISSs throughout region 6 (Pacific Northwest Region) using a larger number of control variables could provide additional information. However, due to the limited number of streams where ISSs were installed, an ideal data set may never be available.

Future Research

The results of this thesis suggest several topics for further research. As previously mentioned, the role of hydrological, ecological and geomorphic disturbance in watersheds in the Blue Mountains is not well known or understood. Disturbance appears to be important in influencing the availability and delivery of large wood to streams, and is also important in influencing channel morphology. In addition, it has been suggested that mass movement frequency and valley constraint are important factors influencing ISS survival and performance. Future research is needed to better understand the importance of these factors in influencing channel morphology in watersheds in the Blue Mountains.

As this study indicates, ISSs have been important in providing additional pools in streams, but as a method to enhance in-stream habitat, they are not enough. To date, there has been little monitoring of stream habitat enhancement projects to evaluate their effects, to determine the time frames within which channels adjust or riparian conditions improve to the desired parameters, or to understand which kinds of techniques are most effective in

particular ecological and geomorphic settings. One approach that could be undertaken in future research would be to monitor, from their inception, a variety of enhancement projects in a variety of settings to evaluate changes that occur over time. Many enhancement projects have been implemented without recording channel or riparian parameters before installation of the project. By measuring channel morphology and riparian conditions before and after project installation, researchers would be better able to evaluate changes in the riparian area and in channel morphology, and the time that it takes for these changes to occur. Monitoring and implementing several kinds of habitat enhancements in a variety of ecological and geomorphic settings would provide additional information about which types of enhancement techniques are most appropriate in specific landscape settings.

APPENDIX A

BED AND BANK MATERIAL CATEGORIES

TABLE 91. Bed Material Categories
(after USDA Forest Service,
1996; Wolman, 1954)

Particle	Size (mm)
Silt/Clay/Sand	
≤ sand	< 2
Gravels	
Very Fine	2 - 4
Fine	4 - 6
Fine	6 - 8
Medium	8 - 12
Medium	12 - 16
Coarse	16 - 24
Coarse	24 - 32
Very Coarse	32 - 48
Very Coarse	48 - 64
Cobbles	
Small	64 - 96
Small	96 - 128
Large	128 - 192
Large	192 - 256
Boulders	
Small	256 - 384
Small	384 - 512
Medium	512 - 1024
Large	1024 - 2048
Very Large	2048 - 4096
Bedrock	

TABLE 92. Soil Texture Test Characteristics

	DRY PRESSURE	DRY FEEL	DRY BREAKING STRENGTH	MOIST PRESSURE	MOIST FEEL	1/2" - 1" WIDE, 1/8" THICK, MOIST PLASTIC RIBBON	2" LONG, 1/8" THICK, MOIST PLASTIC WIRE	MOIST SHAKING	MOIST SHINE
SAND	Falls apart with release of pressure	Individual grains seen and felt	Collapse on touch	Holds shape, crumbles when touched	Individual grains seen and felt	Will not ribbon	Will not wire	Rapid reaction	No shine
SANDY LOAM	Falls apart with release pressure	Individual grains appear dirty	Crumbles with slight finger pressure	Weak cast with careful handling	Individual grains appear dirty	Will not ribbon	Will not wire	Moderately rapid reaction	No shine
LOAM	Forms weak cast with careful handling	Gritty, floury feel	Crumbles with moderate finger pressure	Cast freely handled and thrown a short distance	Gritty, smooth, slick	Very weak ribbon with broken appearance	Very weak wire in broken segments	Moderate reaction	Faint dull shine
SILTY LOAM	Cast withstands handling	Soft and floury	Crumbles with considerable finger pressure	Cast holds shape when thrown, none sticks to target	Smooth, slick with some stickiness	Ribbon is broken in appearance	Weak wire, easily broken	Moderately slow reaction	Dull shine
CLAY LOAM	Cast can be dropped	Slightly hard, little grittiness	Crumbles with considerable finger pressure, can be powdered	Cast withstands handling, some sticks to target	Smooth, slightly sticky with some grittiness	Ribbon barely sustains weight	Wire sustains weight	Slow reaction	Prominent dull shine
SILTY CLAY LOAM	Cast can be thrown with moderate speed	Moderately hard, no grittiness	Crumbles with high finger pressure, powdered with difficulty	Cast resists breaking, sticks to target but can be removed	Smooth, sticky feel, some plasticity	Ribbon sustains weight and careful handling	Wire sustains weight and withstands gentle shaking	Very slow reaction	Paint shine
SILTY CLAY	Cast can be thrown with fast speed	Hard, no grittiness	Can be broken, difficult to powder	Cast is difficult to remove from target	Smooth, sticky plastic, faint fingerprints visible	Ribbon withstands some movement and deformation	Wire withstands considerable shaking and rolling	No reaction	Shine
CLAY	Cast can only be broken with hammer	Very hard, no grittiness	Broken w/ difficulty, cannot be powdered	Cast must be scraped off target	Smooth, very sticky, plastic, fingerprints visible	Very long, thin ribbon, withstands considerable movement and deformation	1/16" wire withstands shaking, rolling, bending	No reaction	Bright shine

APPENDIX B

ROSGEN AND MONTGOMERY-BUFFINGTON STREAM TYPE CLASSIFICATION CRITERIA

Table 93. Rosgen Classification; Entrenchment, Sinuosity and Width-to-Depth Ratios can vary by +/- 0.2 units (Rosgen, 1994)

	SINGLE-THREAD CHANNELS						MULTIPLE CHANNELS	
Entrenchment Ratio	Entrenched (Ratio: < 1.4)		Moderate (1.4 - 2.2) Entrenchment		Slightly Entrenched (Ratio: > 2.2)			
Width-to-Depth Ratio	Low Width-to-Depth Ratio (Ratio: < 1.4)		Moderate to High W/D (> 12)		Moderate Width-to-Depth (> 12)		Very Low W/D (< 12)	Moderate to High W/D (> 12)
Sinuosity	Low Sinuosity (< 1.2)		Moderate Sinuosity (> 1.2)		Moderate Sinuosity (> 1.2)		Very High Sinuosity (> 1.5)	High Sinuosity (> 1.2)
STREAM TYPE	A		G		F		B	
Slope	Slope		Slope		Slope		Slope	
Channel Material	> 0.10	0.04-0.099	0.02-0.039	< 0.02	0.02-0.039	< 0.02	0.04-0.099	0.02-0.039
Bedrock	A1a+	A1	G1	G1c	F1b	F1	B1a	B1
Boulders	A2a+	A2	G2	G2c	F2b	F2	B2a	B2
Cobbles	A3a+	A3	G3	G3c	F3b	F3	B3a	B3
Gravel	A4a+	A4	G4	G4c	F4b	F4	B4a	B4
Sand	A5a+	A5	G5	G5c	F5b	F5	B5a	B5
Silt / Clay	A6a+	A6	G6	G6c	F6b	F6	B6a	B6

TABLE 94. Montgomery-Buffington Reach Types (after Montgomery and Buffington, 1993; Bisson and Montgomery, 1996; Montgomery and Buffington, 1997)

	COLLUVIAL	BEDROCK	CASCADE	STEP POOL	PLANE BED	POOL RIFFLE	DUNE RIPPLE (OR REGIME)	BRAIDED
TYPICAL BED MATERIAL	Variable	Rock	Boulder	Cobble-boulder	Gravel-cobble	Gravel	Sand	Variable
BEDFORM PATTERN	Variable	Irregular	Random	Vertically oscillatory	Featureless	Laterally oscillatory	Multilayered	Laterally oscillatory
DOMINANT ROUGHNESS ELEMENTS	Grains	Boundaries (bed and banks)	Grains, banks	Bedforms (steps, pools), grains, banks	Grains, banks	Bedforms (bars, pools, grains, sinuosity, banks)	Sinuosity, bedforms (dunes, ripples, bars) grains, banks	Bedforms (bars, pools)
DOMINANT SEDIMENT SOURCES	Hillslope, debris flows	Fluvial, hillslope	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, bank failure, debris flows	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank erosion, debris flows
SEDIMENT STORAGE ELEMENTS	Bed	Pockets	Lee and stoss sides of flow obstructions	Bedforms	Overbank	Overbank, bedforms	Overbank, bedforms	
TYPICAL CONFINEMENT	Confined	Confined	Confined	Confined	Variable	Unconfined	Unconfined	Unconfined
TYPICAL POOL SPACING (channel widths)	Unknown	Variable	< 1	1 to 4	None	5 to 7	5 to 7	Variable
TYPICAL SLOPE	>20	Variable	8-30	4-8	1-4	0.1-2	<.01	<3

APPENDIX C

FOREST SERVICE FORM FOR 1996 AND 1997 SURVEYS
OF ISS SURVIVAL AND PERFORMANCE

DIRECTIONS FOR INSTREAM STRUCTURE DURABILITY ASSESSMENT:

General direction and funding for selected Post Flood Assessment activities has been included in the initial FY96 Emergency Flood Repair Allocation (letter to Forest Supervisors, 26 June, 1996). The activities include completing field reconnaissance of habitat structure condition and durability, and selected re-inventory of streams (Phase II- Flood Assessment in draft). Habitat structure condition and durability information needs were developed in conjunction with BLM, PNW Research, and the Regional flood assessment team. This information will help forests refine flood effects assessment, contribute to continued Regional assessment of flood effects and document effectiveness and durability of established habitat structures. The information about the effectiveness and durability of instream restoration treatments. This direction specifically addresses the reconnaissance of structure condition and durability. The primary objective of this assessment is to: Document the durability of instream habitat structures during flood events of FY96.

General: Complete this assessment as part of field reconnaissance to identify/characterize flood effects on stream channels and aquatic habitat. Priorities for site selection should include: a focus on areas with moderate to high levels of past restoration treatment and evaluation of all structures (old and new ones) that went through at least a 25 year flood event.

Steps: Review project plans/interview or involve people who designed or implemented the projects to determine objectives of the restoration treatment. 2) Gather durability information (fill out the data sheet). Included with this document are the Regional core set of information items (data form and definitions) needed for the R.O. flood assessment. You are encouraged to add to the items as needed by your forest. 3) Return Regional core data to R.O. on a 3.5 inch diskette in a ASCII file. Enclosed is the ASCII file structure needed to report the Regional core set of data back to R.O.

INSTREAM STRUCTURE EVALUATION FORM INSTRUCTIONS

Structure Number: Begin at downstream end of project and number all original structure locations consecutively. A "structure" is considered to be any number of logs, rootwads, and /or boulders which were designed to function as a unit.

If new logs are found in the project area from upstream structures or projects, begin the structure number with "N" and evaluate the same as original structures.

Structure Description:

Channel Location:	E = Edge IN = In-channel OC = Off Channel	CC = Cross Channel SC = Side Channel
Description: S = Single	M = Multiple piece	
Material:	L = Log B = Boulder O = Other	LB = Log/boulder RW = Root Wad
Special Treatment:	SC = Side Channel PD = Pond	OC = Off Channel Alcoves

Gradient: Low = 0-2% Med = 2-4% High = > 4%

Channel Type: C = Constrained UC = Unconstrained

Performance Category:

A	B
I = In-Place	F = Fully meeting objectives
S = Shift on Site	P = Partially meeting objectives
L = Left Installed Site	N = Not meeting objectives
N = New structure recruited from upstream	
U = Unknown	

Anchored: Y = Yes N = No

Flood Return Frequency: Record Interval or U = Unknown

Comments: Describe changes to structure, if any. If logs/rootwads are gone, how many and how far did the material travel? Describe additional wood accumulations and maintenance needs.

APPENDIX D

LOCATIONS AND MAPS OF REACHES
IN TAYLOR DATA SET

TABLE 95. Reach Names and Locations for Taylor Data Set

Stream Name	USGS Quad	Location
Bear Wallow - lower (BWL)	Lehman Springs, OR	T4S R33E sec 29
Bear Wallow - upper (BWU)	Lehman Springs, OR	T4S R33E sec 9
Big Wall (BW)	Turner Mountain, OR	T7S R26E sec 26
Camas Creek (CC)	Owens Butte, OR	T4S R27E sec 30 to sec 32
Desolation (DS)	Desolation Butte, OR	T8S R33E sec 27
Dry Camas (DC)	Sullivan Gulch, OR	T5S R33 1/2 E sec 6
Hidaway (HD)	Pearson's Ridge, OR	T5S R33E sec 25
Kelsay (KL)	Kelsay Butte, OR	T7S R33E sec 26
Lane (LN)	Owens Butte, OR	T4S R33E sec 30
N. Fork Cable (NFC)	Pearson, OR	T62, R33E sec 13
Phillips (PH)	Sanderson Spring, OR	T1N R38E sec 3 and sec 2
Thomas (TH)	Bingham Spring, OR	T2N R37E sec 4 and sec 23
Wilson (WL)	Turner Butte, OR	T3N R37E sec 25

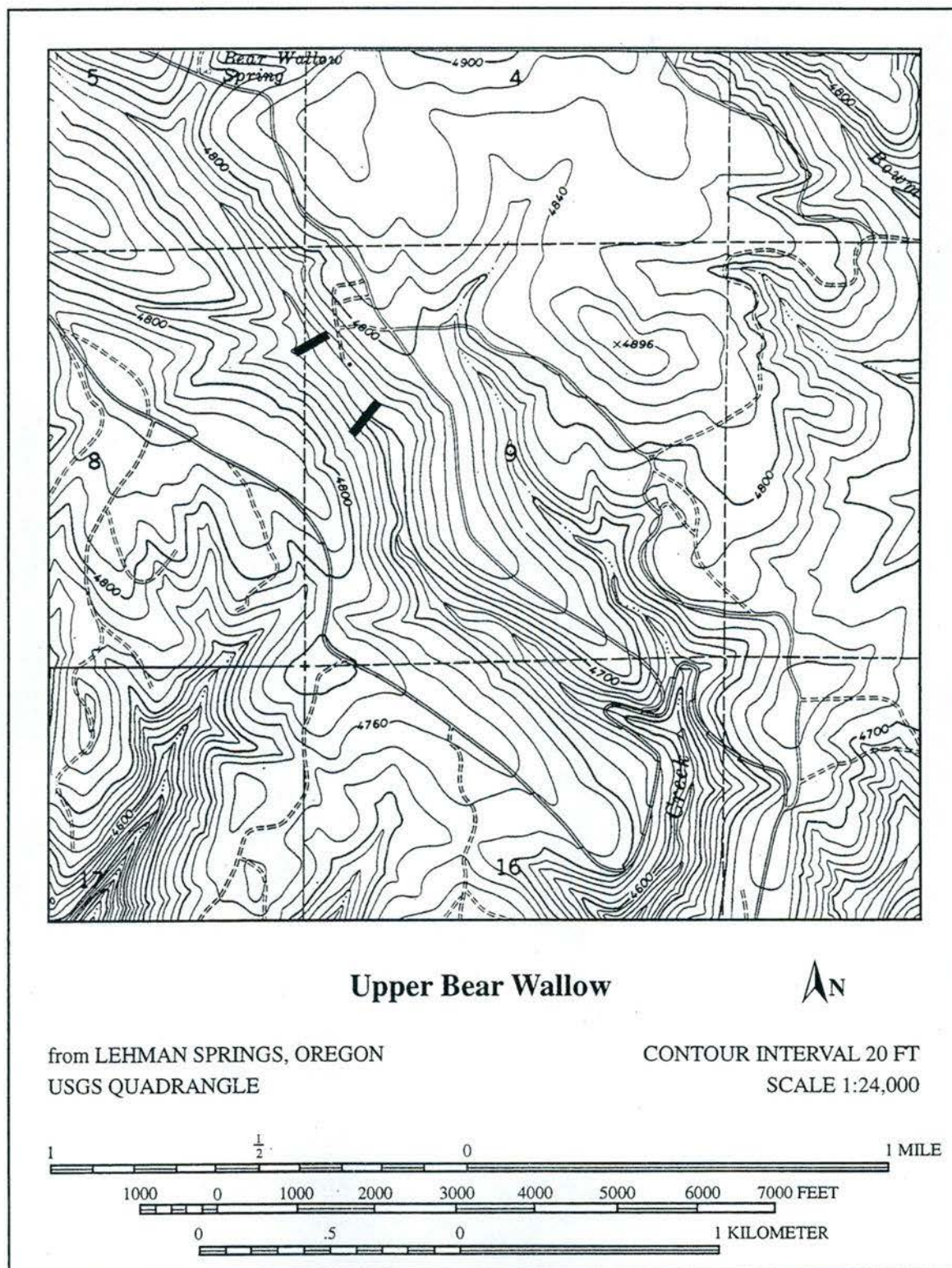


Figure 32. Map Showing Location of Upper Bear Wallow.

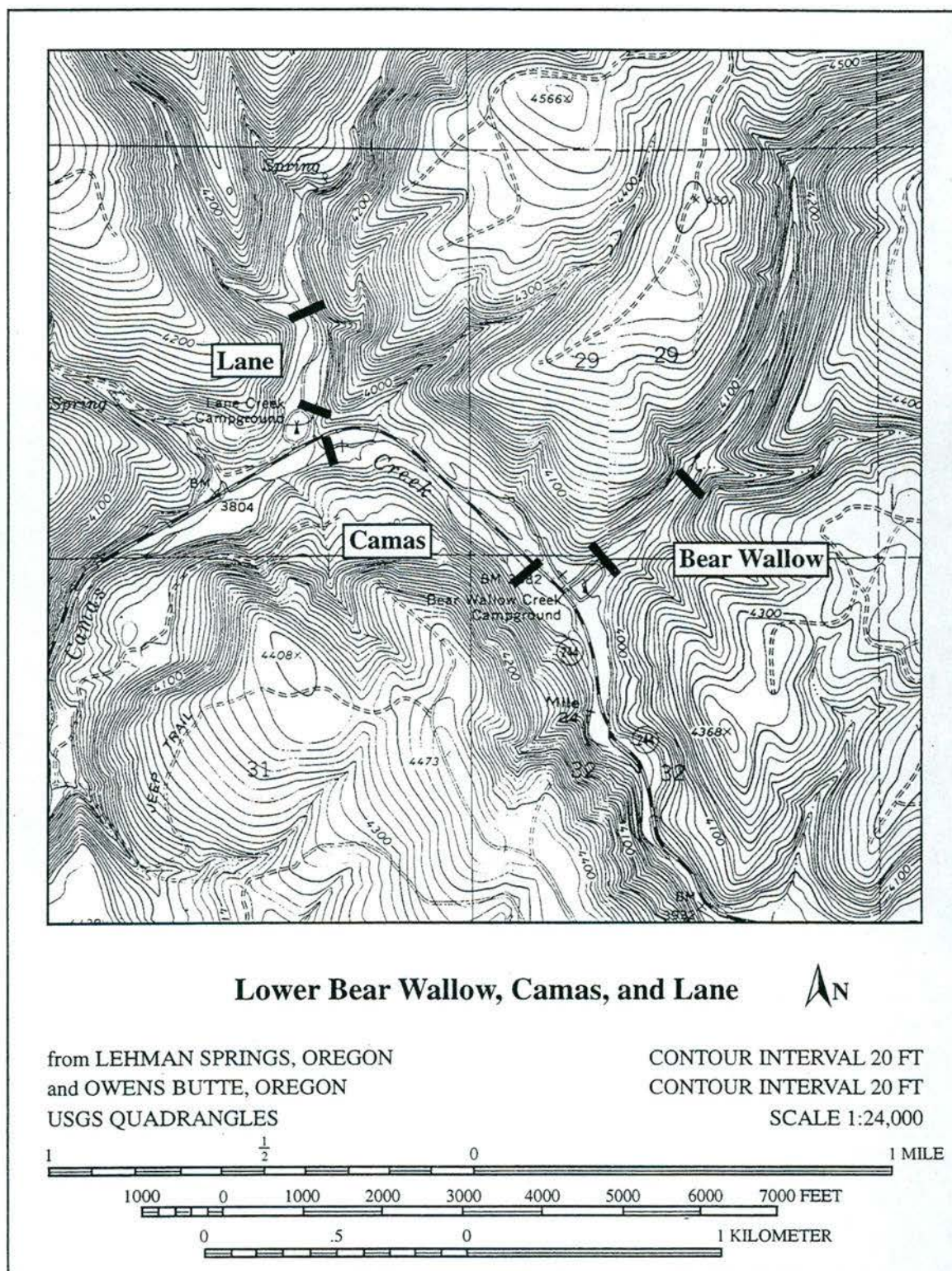


Figure 33. Map Showing Location of Lower Bear Wallow, Camas, and Lane.

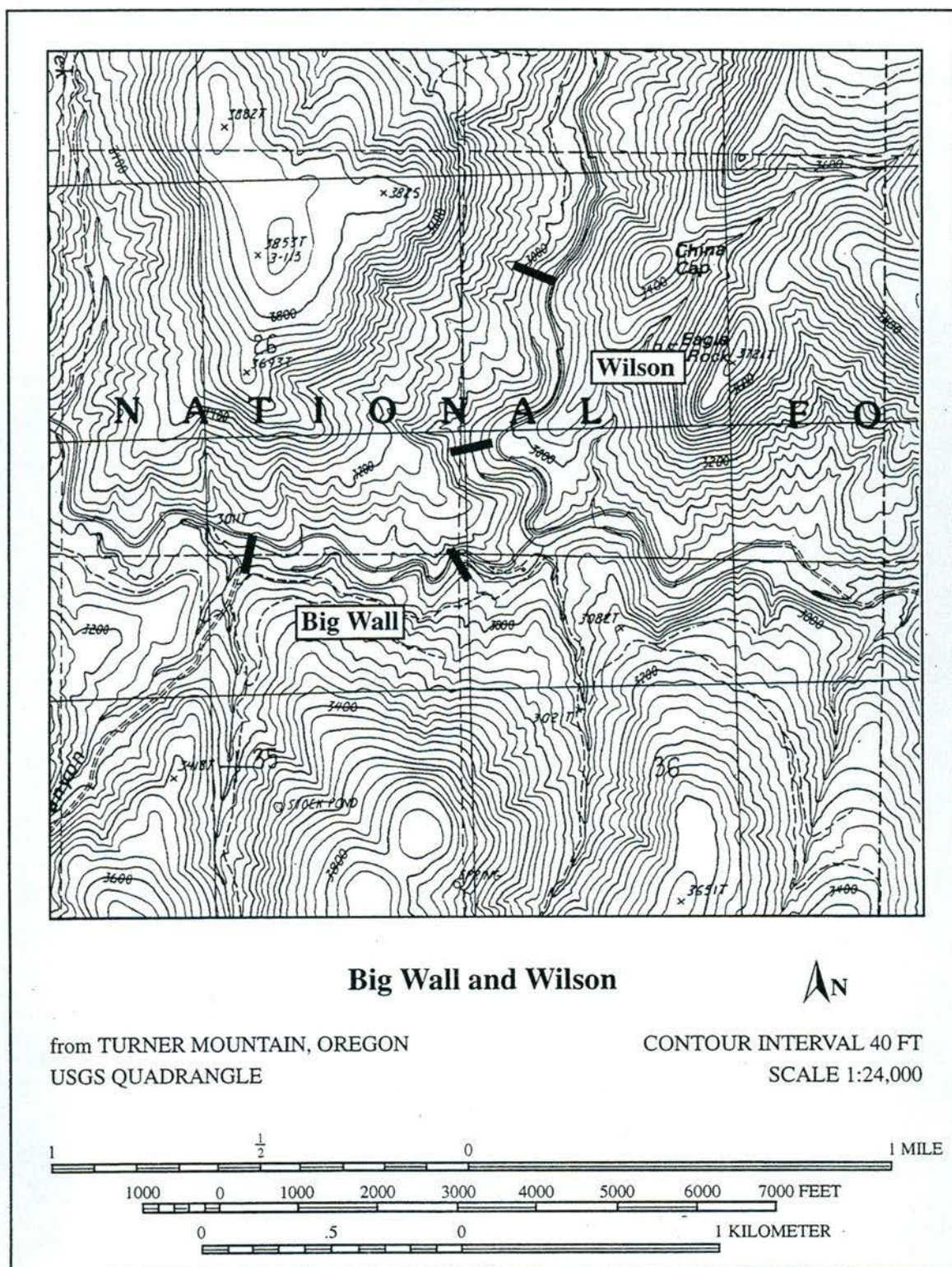


Figure 34. Map Showing Location Big Wall and Wilson (Taylor Data Set).

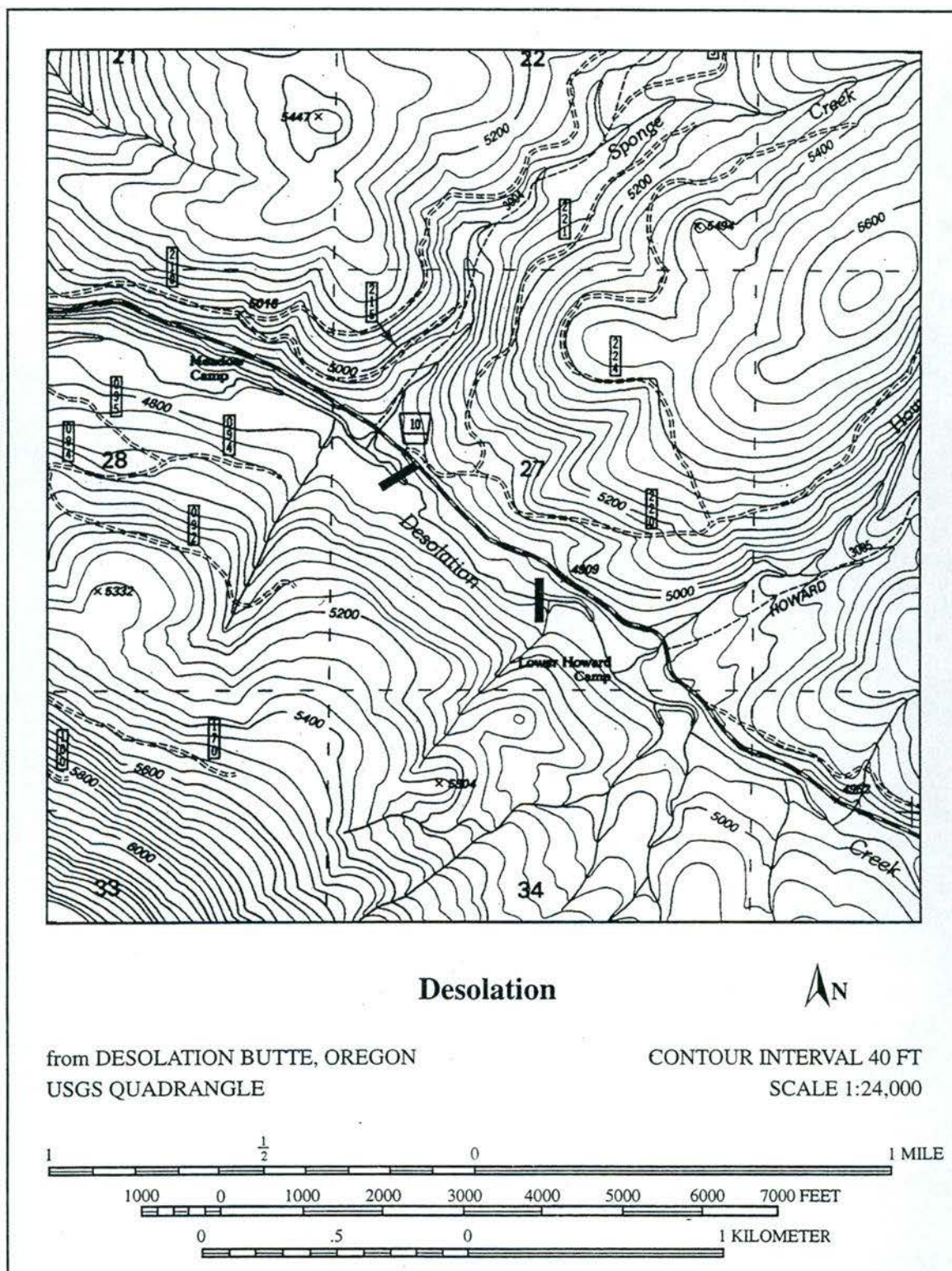


Figure 35. Map Showing Location of Desolation.

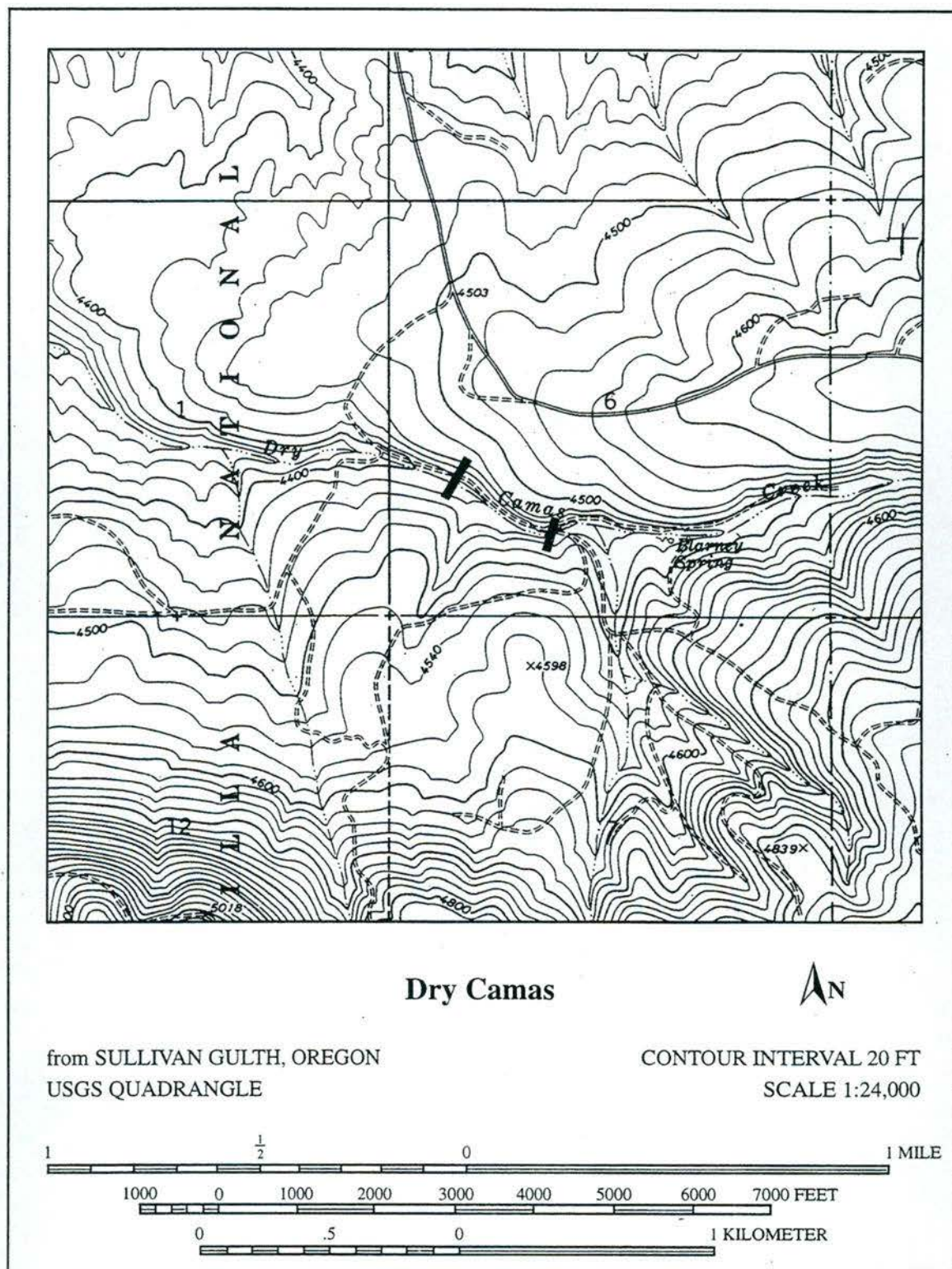


Figure 36. Map Showing Location of Dry Camas.

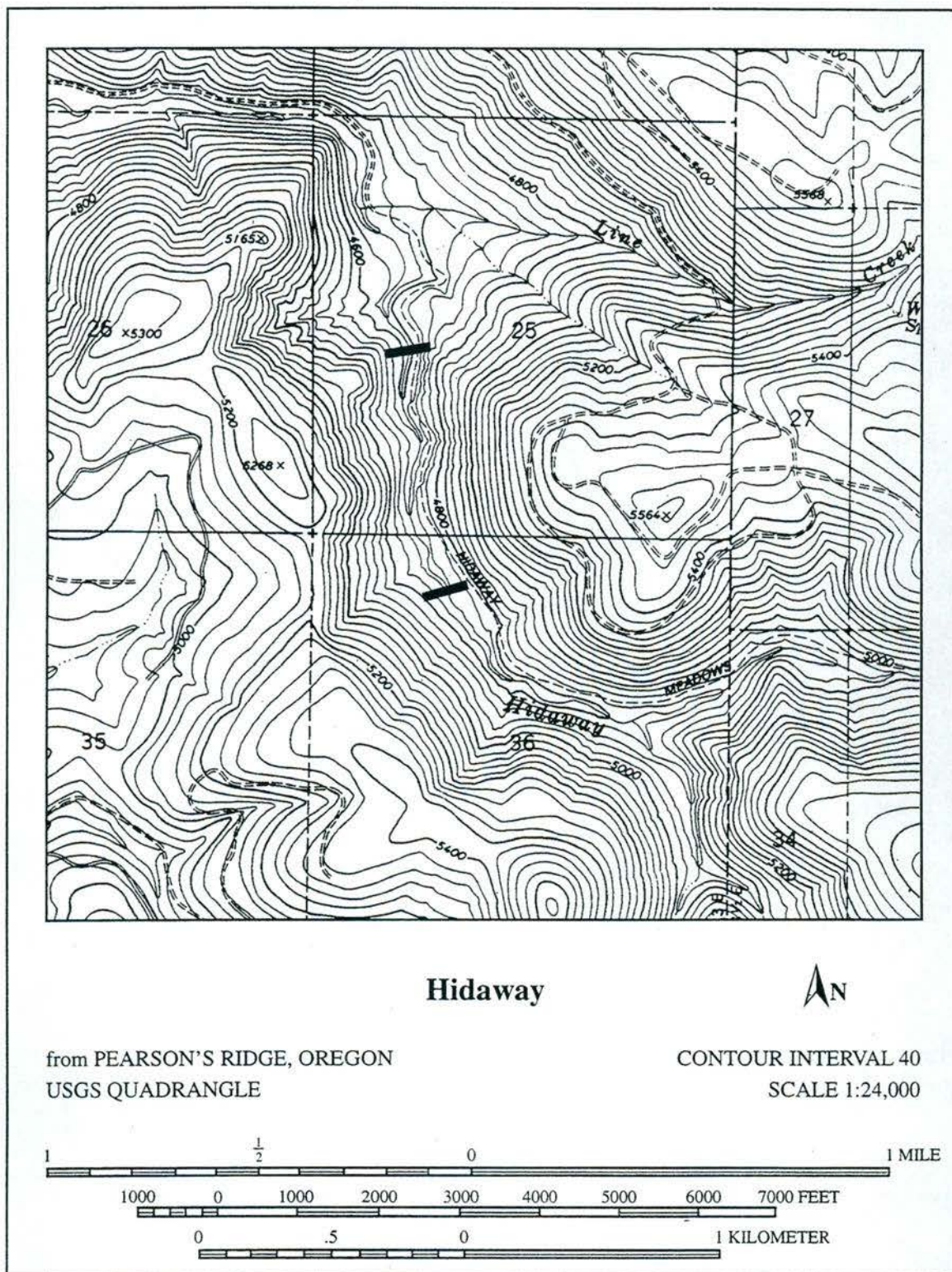


Figure 37. Map Showing Location of Hidaway.

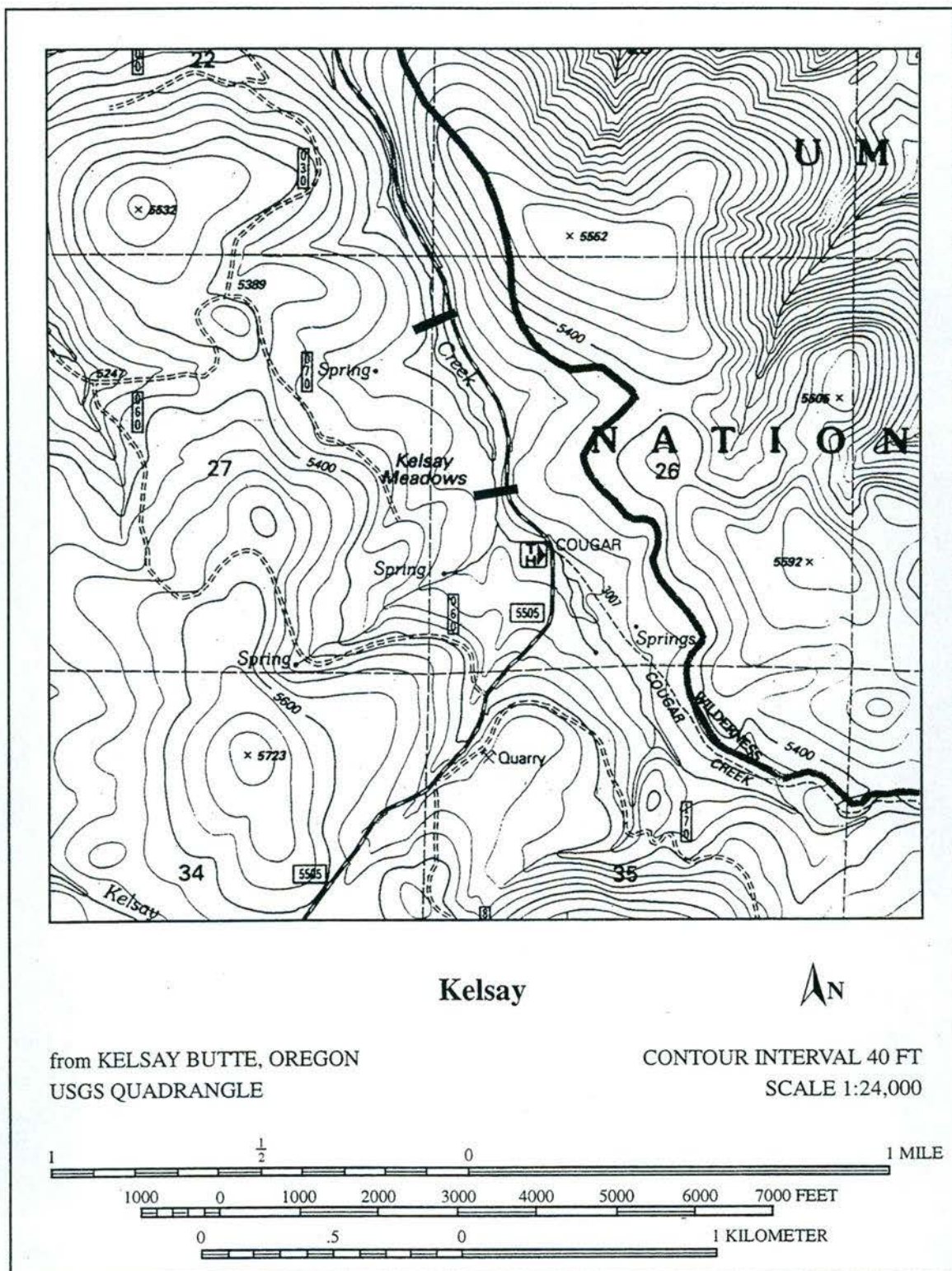


Figure 38. Map Showing Location of Kelsay.

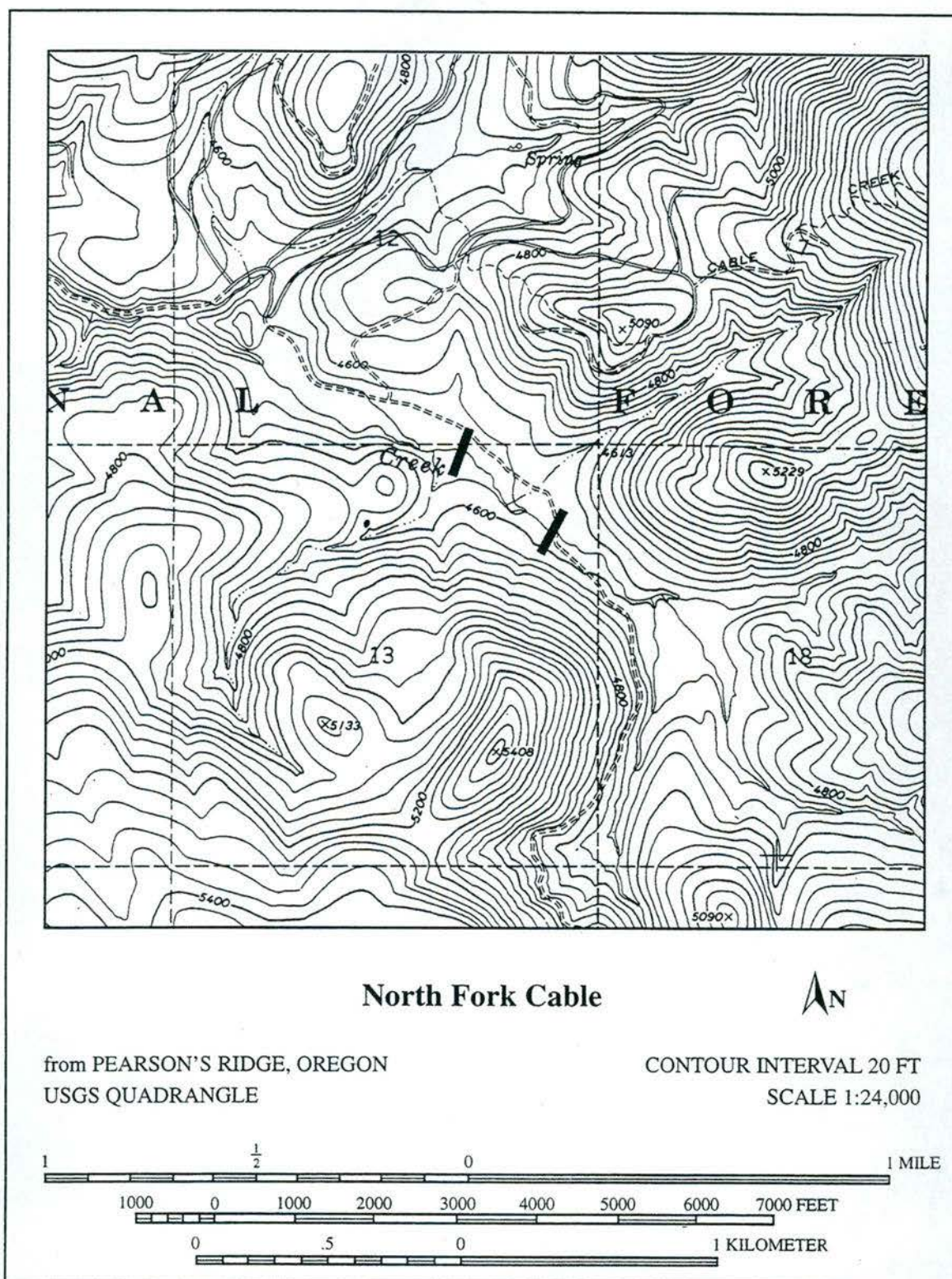


Figure 39. Map Showing Location of North Fork Cable.

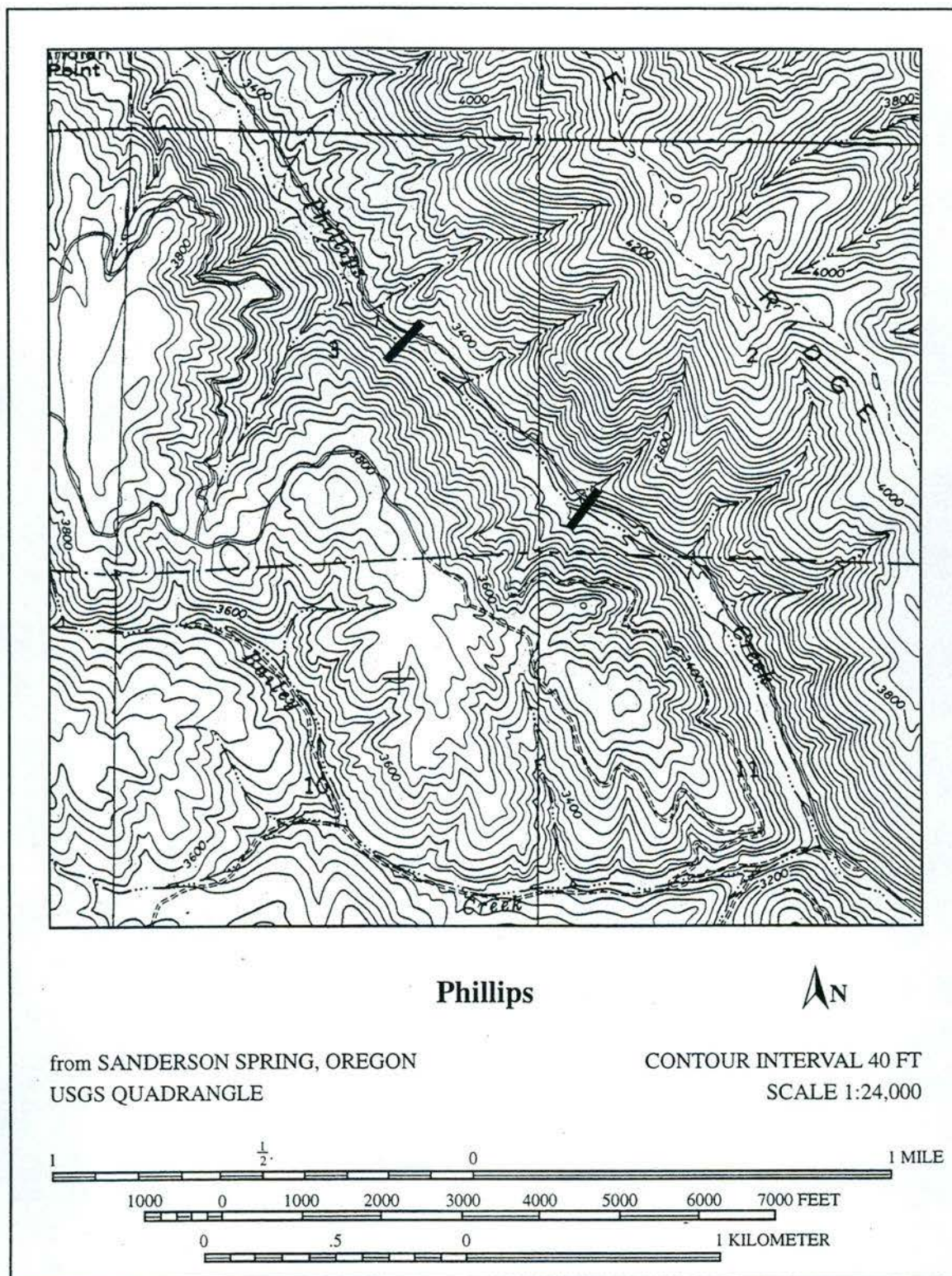


Figure 40. Map Showing Location of Phillips.

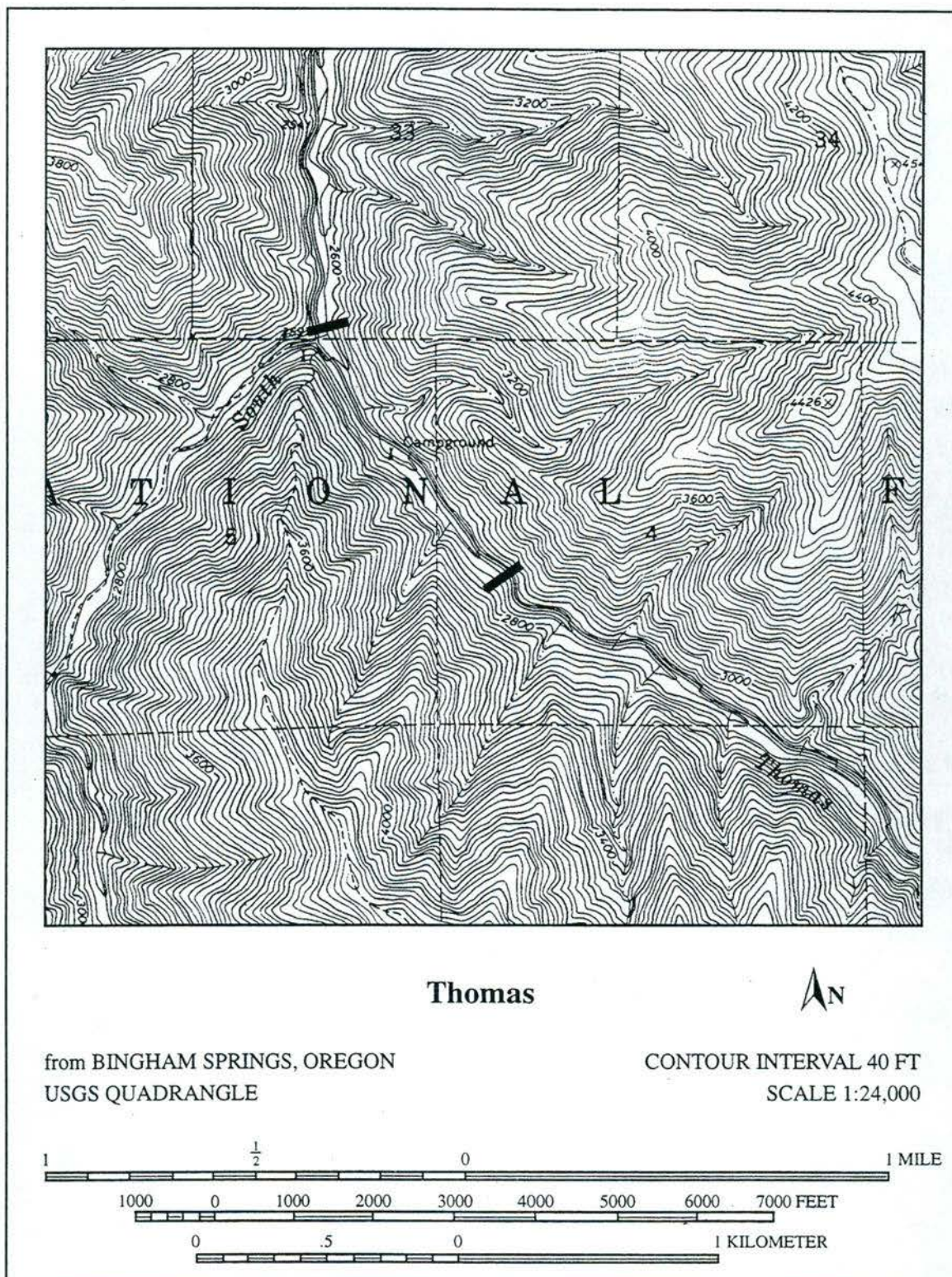


Figure 41. Map Showing Location of Thomas.

APPENDIX E

CHARACTERISTICS OF REACHES, ROSEN AND MONTGOMERY- BUFFINGTON STREAM-TYPES, AND MAPPED GEOLOGY UNITS OF REACHES IN THE TAYLOR DATA SET

TABLE 96. Summary 1 of Reach Characteristics (Taylor Data Set)

Stream Name	Drainage Area (km ²)	Stream Order	Sinuosity	Gradient	Reach Length (mi)	Reach Length (m)	Valley Length (m)
Bear Wallow - lower (BWL)	18.25	2	1.15	3.5%	0.296	477.0	415
Bear Wallow - upper (BWU)	8.76	1	1.20	1.0%	0.242	389.5	325
Big Wall (BW)	28.25	4	1.15	3.0%	0.559	900.3	780
Camas Creek (CC)	173.80	3	1.10	2.5%	0.611	984.0	895
Desolation (DS)	85.40	3	1.15	2.5%	0.465	748.4	650
Dry Camas (DC)	9.37	1	1.10	1.5%	0.222	357.3	325
Hidaway (HD)	34.00	4	1.20	4.0%	0.555	893.9	745
Kelsay (KL)	3.78	3	1.65	1.5%	0.665	1069.5	650
Lane (LN)	38.18	2	1.10	3.5%	0.275	443.0	403
North Fork Cable (NFC)	16.14	3	1.50	1.5%	0.372	899.4	600
Phillips (PH)	25.77	3	1.10	2.0%	0.667	1074.2	980
Thomas (TH)	47.37	4	1.10	3.0%	0.588	946.5	860
Wilson (WL)	103.24	3	1.30	3.0%	0.670	1078.8	830

TABLE 97. Summary 2 of Reach Characteristics (Taylor Data Set)

Stream Name	Wetted Width (ww)	Reach Length (ww)	Bankfull Width, m	Bankfull Depth, m	Bankfull Width- to-Depth Ratio	Width-to-Depth Ratio (PACFISH)
Bear Wallow - lower (BWL)	2.04	233.82	4.22	0.23	18.4	10.2
Bear Wallow - upper (BWU)	1.91	203.93	3.59	0.45	7.9	5.2
Big Wall (BW)	4.46	201.86	8.01	0.29	27.4	14.9
Camas Creek (CC)	6.89	142.82	13.32	0.32	41.4	20.9
Desolation (DS)	8.50	88.05	14.47	0.43	34.0	20.7
Dry Camas (DC)	1.66	215.24	3.58	0.37	9.8	6.2
Hidaway (HD)	4.24	210.83	9.00	0.38	23.4	12.5
Kelsay (KL)	1.99	537.44	5.34	0.28	19.3	7.1
Lane (LN)	4.44	99.77	7.14	0.31	23.1	17.1
North Fork Cable (NFC)	3.07	292.96	7.59	0.27	28.5	11.2
Phillips (PH)	2.88	372.99	10.22	0.30	34.1	12.5
Thomas (TH)	4.93	191.99	9.67	0.43	22.4	13.3
Wilson (WL)	6.44	167.52	12.48	0.43	29.4	18.4

TABLE 98. Summary 3 of Reach Characteristics (Taylor Data Set)

Stream Name	Bed Material Size		Dominant Bank Material Category	Subdominant Bank Material Category	Bank Stability	Bank Erosion	Bank Undercut
	D50	D84					
Bear Wallow - lower (BWL)	64-96	128-192	7.41	5.12	87%	13%	5.4%
Bear Wallow - upper (BWU)	<2	<2	2.00	2.00	78%	22%	0.5%
Big Wall (BW)	48-64	96-128	8.12	6.95	79%	21%	0.0%
Camas Creek (CC)	48-64	128-192	7.80	5.65	76%	24%	3.0%
Desolation (DS)	64-96	128-192	6.05	6.83	82%	18%	2.9%
Dry Camas (DC)	12-16	96-128	4.07	6.98	40%	60%	0.0%
Hidaway (HD)	48-64	128-192	5.71	6.32	63%	37%	1.2%
Kelsay (KL)	2-4	8-12	2.56	3.34	83%	17%	6.8%
Lane (LN)	64-96	128-192	7.70	5.76	91%	9%	2.6%
North Fork Cable (NFC)	2-4	24-36	4.10	4.95	81%	19%	3.1%
Phillips (PH)	64-96	96-128	5.37	6.68	59%	41%	0.0%
Thomas (TH)	32-48	96-128	6.62	6.55	70%	30%	0.7%
Wilson (WL)	48-64	96-128	7.71	6.60	71%	29%	1.5%

TABLE 99. Summary 4 of Reach Characteristics (Taylor Data Set)

Stream Name	Bank Vegetation	Overhanging Bank Vegetation	Shrubs on Bank	Shrubs on Bank > 8 ft high	Reach Canopy Density % (PACFISH)	Reach Canopy Density Category (Lamb)	Inner Riparian Vegetation Seral Stage
Bear Wallow - lower (BWL)	83%	5%	10%	6%	34%	2.69	5.46
Bear Wallow - upper (BWU)	81%	45%	3%	3%	9%	1.27	3.52
Big Wall (BW)	38%	0%	52%	28%	67%	3.71	5.93
Camas Creek (CC)	74%	3%	42%	28%	28%	2.32	6.74
Desolation (DS)	59%	1%	21%	12%	36%	2.46	6.93
Dry Camas (DC)	69%	3%	3%	3%	24%	1.77	5.67
Hidaway (HD)	68%	2%	11%	5%	25%	1.95	5.12
Kelsay (KL)	88%	71%	16%	1%	5%	1.16	2.38
Lane (LN)	68%	14%	31%	17%	NA	NA	5.93
North Fork Cable (NFC)	46%	24%	1%	1%	NA	NA	4.67
Phillips (PH)	70%	0%	37%	22%	37%	2.73	5.97
Thomas (TH)	80%	4%	72%	41%	33%	2.44	5.83
Wilson (WL)	30%	NA	NA	NA	58%	3.37	5.27

TABLE 100. Summary 5 of Reach Characteristics (Taylor Data Set)

Stream Name	Average Maximum Pool Depth (ft)	Minimum maximum Pool Depth (ft)	Maximum Pool Depth (ft)	Residual Pool Depth	Number of Pools	Number of Habitat Units
Bear Wallow - lower (BWL)	1.64	0.49	1.36	1.36	15	43
Bear Wallow - upper (BWU)	1.94	0.82	2.95	1.30	14	39
Big Wall (BW)	1.76	0.72	3.61	1.30	25	64
Camas Creek (CC)	2.79	1.12	5.25	1.92	9	36
Desolation (DS)	2.46	0.85	3.44	1.65	20	43
Dry Camas (DC)	0.29	0.00	1.31	0.28	15	35
Hidaway (HD)	1.85	0.72	3.74	1.46	30	58
Kelsay (KL)	1.89	0.82	2.79	1.23	25	92
Lane (LN)	1.70	0.75	2.95	1.10	11	29
North Fork Cable (NFC)	1.74	0.85	2.56	1.27	27	59
Phillips (PH)	0.89	0.00	3.28	0.85	28	58
Thomas (TH)	2.39	0.98	4.92	1.83	23	63
Wilson (WL)	1.63	0.66	3.12	0.94	19	66

TABLE 101. Summary 6 of Reach Characteristics (Taylor Data Set)

Stream Name	Average Water Temperature		Median Pool Temperature °C	Large Large Woody Debris per mile	Small Large Woody Debris per mile	Total Large Woody Debris per mile	Large Woody Debris Complexity
	°C	°F					
Bear Wallow - lower (BWL)	17.4	63.4	16.0	3.4	20.2	23.6	1.70
Bear Wallow - upper (BWU)	15.1	59.3	15.0	8.3	12.4	20.7	1.60
Big Wall (BW)	13.5	56.2	17.5	19.7	30.4	50.1	1.34
Camas Creek (CC)	16.8	62.2	16.8	1.6	16.4	18.0	1.90
Desolation (DS)	14.5	58.2	14.9	17.2	219.3	236.6	1.60
Dry Camas (DC)	18.6	65.4	18.8	4.5	18.0	22.5	1.33
Hidaway (HD)	15.1	59.2	14.0	25.2	169.4	194.6	1.94
Kelsay (KL)	14.2	57.6	15.0	4.5	15.0	19.5	1.00
Lane (LN)	16.3	61.3	17.5	0	50.9	50.9	1.17
North Fork Cable (NFC)	13.8	56.9	13.0	13.4	255.4	268.8	1.30
Phillips (PH)	13.2	54.2	13.0	15.0	67.5	82.5	1.00
Thomas (TH)	12.3	54.2	12.5	1.7	22.1	23.8	1.27
Wilson (WL)	22.4	72.3	22.0	4.5	4.5	9.0	1.00

TABLE 102. Summary 7 of Reach Characteristics (Taylor Data Set)

Stream Name	Geology	Valley Constraint	Fire	Bankfull Width, m	Flood-prone width	Entrenchment	Rosgen Stream Type	Montgomery/ Buffington Stream Type
Bear Wallow - lower (BWL)	A	U	N	4.22	12.5	3.0	C	Plane Bed
Bear Wallow - upper (BWU)	A	U	N	3.59	14.1	3.6	E	Pool Riffle
Big Wall (BW)	A	U	N	8.01	12.7	1.6	B	Plane Bed
Camas Creek (CC)	A	U	N	13.32	74.7	5.3	C	Plane Bed
Desolation (DS)	A	U	N	14.47	48.5	3.5	C	Plane Bed
Dry Camas (DC)	A	U	N	3.58	19.0	5.1	E	Pool Riffle
Hidaway (HD)	B	U	Y	9.00	86.7	9.6	C	Plane Bed
Kelsay (KL)	A	U	N	5.34	62.5	11.7	C	Pool Riffle
Lane (LN)	A	U	N	7.14	13.8	1.9	B	Plane Bed
North Fork Cable (NFC)	A	U	Y	7.59	34.0	4.5	C	Pool Riffle
Phillips (PH)	A	U	N	10.22	65.0	6.4	C	Plane Bed
Thomas (TH)	A	U	N	9.67	50.0	5.2	C	Plane Bed
Wilson (WL)	A	U	N	12.48	20.1	1.6	B	Plane Bed

TABLE 103. Mapped Geology Units and Geologic Classification

Stream Reach	Mapped Geologic Unit	Classification
Bear Wallow, Lower	Tcg	A
Bear Wallow, Upper	Tcg	A
Big Wall	Tcp	A
Camas Creek	Tcg	A
Desolation	TRPv	A
Dry Camas	Tcg	A
Hidaway	Tsfj	B
Kelsay	TRPv	A
Lane	Tcg	A
North Fork Cable	Tsfj	B
Phillips	Tcg	A
Thomas	Tcg	A
Wilson	Tcg	A

TABLE 104. Variables used to Determine Rosgen Stream Type

Stream Name	Single or Multiple Thread Channel	Rosgen Stream Type	Entrenchment	Rosgen Stream Type	Bankfull to-Depth Ratio (Lamb)	Width- Rosgen Stream Type
Bear Wallow, lower (BWL)	Single	A, G, F, B, E, or C	3.0	E or C	18.4	C
Bear Wallow, upper (BWU)	Single	A, G, F, B, E, or C	3.6	E or C	7.9	E
Big Wall (BW)	Single	A, G, F, B, E, or C	1.6	B	27.4	B
Camas Creek (CC)	Single	A, G, F, B, E, or C	5.3	E or C	41.4	C
Desolation (DS)	Single	A, G, F, B, E, or C	3.5	E or C	34.0	C
Dry Camas (DC)	Single	A, G, F, B, E, or C	5.1	E or C	9.8	E
Hidaway (HD)	Single	A, G, F, B, E, or C	9.6	E or C	23.4	C
Kelsay (KL)	Single	A, G, F, B, E, or C	11.7	E or C	19.3	C
Lane (LN)	Single	A, G, F, B, E, or C	1.9	B	23.1	B
N. Fork Cable (NFC)	Single	A, G, F, B, E, or C	4.5	E or C	28.5	C
Phillips (PH)	Single	A, G, F, B, E, or C	6.4	E or C	34.1	C
Thomas (TH)	Single	A, G, F, B, E, or C	5.2	E or C	22.4	C
Wilson (WL)	Single	A, G, F, B, E, or C	1.6	B	29.4	B

TABLE 104 (continued). Variables used to Determine Rosgen Stream Type (Stream Type Used for Analysis in Gray Column)

Stream Name	Sinuosity	Rosgen Stream Type	Gradient	Rosgen Stream Type	D50 Sediment Size	Rosgen Stream Type	Rosgen Stream Type
Bear Wallow, lower (BWL)	1.15	A or D	3.5%	Cb	64-96 (Cobble)	C3b	C
Bear Wallow, upper (BWU)	1.20	E	1.0%	E	< 2 (Silt-Clay)	E4	E
Big Wall (BW)	1.15	A or D	3.0%	B	48-64 (Gravel)	B4	B
Camas Creek (CC)	1.10	A or D	2.5%	Cb	48-64 (Gravel)	C4b	C
Desolation (DS)	1.15	A or D	2.5%	Cb	64-96 (Cobble)	C3b	C
Dry Camas (DC)	1.10	A or D	1.5%	E	12-16 (Gravel)	E4	E
Hidaway (HD)	1.20	A or D	4.0%	Cb	48-64 (Gravel)	C4b	C
Kelsay (KL)	1.65	C	1.5%	C	2-4 (Gravel)	C4	C
Lane (LN)	1.10	A or D	3.5%	B	64-96 (Cobble)	B3	B
N. Fork Cable (NFC)	1.50	C	1.5%	C	2-4 (Gravel)	C5	C
Phillips (PH)	1.10	A or D	2.0%	C	64-96 (Cobble)	C3	C
Thomas (TH)	1.10	A or D	3.0%	Cb	32-48 (Gravel)	C4b	C
Wilson (WL)	1.30	B	3.0%	B	48-64 (Gravel)	B4	B

TABLE 105. Variables used to Determine Montgomery-Buffington Reach Type

Stream Name	D50 Sediment Size	D84 Sediment size	Typical Bed material	Bedform Plan	Dominant Roughness Elements	Dominant Sediment Sources
Bear Wallow, lower (BWL)	64-96	128-192	Cobble	Featureless	Grains, Banks	Bank Failure, Debris Flow, Fluvial
Bear Wallow, upper (BWU)	< 2	< 2	Silty Clay Loam	Laterally oscillatory	Bedforms	Bank Failure, Fluvial
Big Wall (BW)	48-64	96-128	Gravel, Cobble	Featureless	Grains, Banks	Bank Failure, Hillslope, Debris Flow, Fluvial
Camas Creek (CC)	48-64	128-192	Gravel, Cobble	Featureless	Grains, Banks	Bank Failure, Hillslope, Debris Flow, Fluvial
Desolation (DS)	64-96	128-192	Cobble	Featureless	Grains, Banks	Bank Failure, Debris Flow, Fluvial
Dry Camas (DC)	12-16	96-128	Gravel	Laterally oscillatory	Bedforms	Bank Failure, Fluvial
Hidaway (HD)	48-64	128-192	Gravel, Cobble	Featureless	Grains, Banks	Bank Failure, Debris Flow, Fluvial
Kelsay (KL)	2-4	8-12	Sand, Gravel	Laterally oscillatory	Bedforms	Bank Failure, Fluvial
Lane (LN)	64-96	128-192	Gravel, Cobble, Boulder	Featureless	Grains, Banks	Bank Failure, Hillslope, Debris Flow, Fluvial
N. Fork Cable (NFC)	2-4	24-36	Gravel	Laterally oscillatory	Bedforms	Bank Failure, Fluvial
Phillips (PH)	64-96	96-128	Gravel, Cobble	Featureless	Grains, Banks	Bank Failure, Debris Flow, Fluvial
Thomas (TH)	32-48	96-128	Gravel, Cobble	Featureless	Grains, Banks	Bank Failure, Debris Flow, Fluvial
Wilson (WL)	48-64	96-128	Gravel, Cobble Boulder	Featureless	Grains, Banks	Bank Failure, Hillslope, Debris Flow, Fluvial

TABLE 105 (continued). Variables used to Determine Montgomery-Buffington Reach Type (Stream Type Used for Analysis in Gray Column).

Stream Name	Sediment Storage Elements	Typical Confinement	Typical Slope	Montgomery-Buffington Stream Type	Stream Type with Structures
Bear Wallow, lower (BWL)	Overbank	unconfined	3.5%	Plane Bed	Step Pool
Bear Wallow, upper (BWU)	Overbank, Bedforms	unconfined	1.0%	Pool Riffle	Plane Bed
Big Wall (BW)	Overbank	unconfined	3.0%	Plane Bed (Step Pool-like in sections)	Step Pool
Camas Creek (CC)	Overbank	unconfined	2.5%	Plane Bed (Step Pool-like in sections)	Plane Bed with Step Pools
Desolation (DS)	Overbank	unconfined	2.5%	Plane Bed	Plane Bed
Dry Camas (DC)	Overbank, Bedforms	unconfined	1.5%	Pool Riffle	Pool Riffle
Hidaway (HD)	Overbank	unconfined	4.0%	Plane Bed (Step Pool)	Step Pool
Kelsay (KL)	Overbank, Bedforms	unconfined	1.5%	Pool Riffle	Pool Riffle / Plane Bed
Lane (LN)	Overbank	unconfined	3.5%	Plane Bed (Step Pool)	Step Pool
N. Fork Cable (NFC)	Overbank, Bedforms	unconfined	1.5%	Pool Riffle (Plane Bed)	Plane Bed with Step Pool
Phillips (PH)	Overbank	unconfined	2.0%	Plane Bed	Plane Bed with Step Pools
Thomas (TH)	Overbank	unconfined	3.0%	Plane Bed	Plane Bed with Step Pools
Wilson (WL)	Overbank	unconfined	3.0%	Plane Bed	Plane Bed

APPENDIX F

TARGET VALUES TABLES

Stream Name	Pools per Wetted Width (Lamb, 1996)				Average Maximum Pool Depth (ft) (Lamb, 1996)				Residual Pool Depth (Lamb, 1996)			
	Actual	Target	TVI		Actual	Target	TVI		Actual	Target	TVI	
BWL	0.064	0.00357	16.93	*	1.64	1.63	0.01	*	1.36	1.31	0.04	*
BWU	0.069	0.00357	18.33	*	1.94	1.63	0.14	*	1.34	1.31	0.02	*
BW	0.124	0.0075	15.53	*	1.76	2.23	-0.21		1.30	1.70	-0.24	
CC	0.063	0.0075	7.40	*	2.79	2.23	0.25	*	1.92	1.70	0.13	*
DS	0.227	0.0075	29.27	*	2.46	2.23	0.10	*	1.65	1.70	-0.03	
DC	0.070	0.00357	18.61	*	0.29	1.63	-0.98		0.28	1.31	-0.72	
HD	0.142	0.0075	17.93	*	1.85	2.23	-0.17		1.46	1.70	-0.14	
KL	0.047	0.00357	12.17	*	1.89	2.23	-0.24		1.23	1.31	-0.06	
LN	0.110	0.0075	13.67	*	1.70	1.63	0.16	*	1.10	1.70	-0.35	
NFC	0.092	0.00357	24.77	*	1.74	1.63	0.06	*	1.27	1.31	-0.03	
PH	0.075	0.0075	9.00	*	0.89	2.23	-0.60		0.85	1.70	-0.50	
TH	0.120	0.0075	15.00	*	2.39	2.23	0.06		1.83	1.70	0.08	*
WL	0.113	0.0075	14.07	*	1.63	2.23	-0.27		0.94	1.70	-0.45	

* indicates that the reach value met the target value

Stream Name	Habitat Units per Wetted Width (Lamb, 1996)				Width-to-Depth Ratio (Lamb, 1996)				Canopy Cover (Category) (Lamb, 1996)			
	Actual	Target	TVI		Actual	Target	TVI		Actual	Target	TVI	
BWL	0.18	0.079	1.33	*	18.4	9.22	-1.00		20.2	3.06	-0.12	
BWU	0.19	0.079	1.42	*	7.9	9.22	0.14	*	12.4	3.06	-0.58	
BW	0.335	0.133	1.52	*	27.4	12.279	-1.23		30.4	2.83	0.31	*
CC	0.252	0.133	0.89	*	41.4	12.279	-2.37		16.4	2.83	-0.18	
DS	0.488	0.133	2.67	*	34.0	12.279	-1.77		219.4	2.83	-0.13	
DC	0.16	0.079	1.06	*	9.8	9.22	-0.06		18.0	3.06	-0.42	
HD	0.280	0.133	1.11	*	23.4	12.279	-0.91		169.4	2.83	-0.31	
KL	0.17	0.079	1.14	*	19.3	9.22	-1.09		15.0	3.06	-0.62	
LN	0.291	0.133	1.19	*	23.1	12.279	-0.88		50.9	2.83	NA	
NFC	0.30	0.079	2.75	*	28.5	9.22	-2.09		255.4	3.06	NA	
PH	0.158	0.133	0.19	*	34.1	12.279	-1.78		67.5	2.83	-0.04	
TH	0.328	0.133	1.47	*	22.4	12.279	-0.82		22.1	2.83	-0.14	
WL	0.394	0.133	1.96	*	29.4	12.279	-1.39		4.5	2.83	0.19	*

* indicates that the reach value met the target value

Stream Name	Small LWD / mile (Lamb, 1996)			Large LWD / mile (Lamb, 1996)			Total LWD /mile (Lamb, 1996)		
	Actual	Target	TVI	Actual	Target	TVI	Actual	Target	TVI
BWL	20.2	64.67	-0.69	3.4	30.59	-0.89	23.6	222.15	-0.89
BWU	12.4	64.67	-0.81	8.3	30.59	-0.73	20.7	222.15	-0.91
BW	30.4	33.12	-0.08	19.7	30.59	-0.36	50.1	127.09	-0.61
CC	16.4	33.12	-0.50	1.6	30.59	-0.95	18.0	127.09	-0.86
DS	219.4	33.12	5.62 *	17.2	30.59	-0.44	236.6	127.09	0.86 *
DC	18.0	64.67	-0.72	4.5	30.59	-0.85	22.5	222.15	-0.90
HD	169.4	33.12	4.11 *	25.2	30.59	-0.18	194.6	127.09	0.53 *
KL	15.0	64.67	-0.77	4.5	30.59	-0.85	19.5	222.15	-0.91
LN	50.9	33.12	0.54 *	0.0	30.59	-1.00	50.9	127.09	-0.60
NFC	255.4	64.67	2.95 *	13.4	30.59	-0.71	268.8	222.15	0.21 *
PH	67.5	33.12	1.04 *	15.0	30.59	-0.51	82.5	127.09	-0.35
TH	22.1	33.12	-0.33	1.7	30.59	-0.94	23.8	127.09	-0.81
WL	4.5	33.12	-0.86	4.5	30.59	-0.85	9.0	127.09	-0.93

* indicates that the reach value met the target value

Stream Name	Eroding Banks (Ebersole, 1994)			Overhanging Vegetation (Ebersole, 1994)			Average Maximum Pool Depth, m (Ebersole, 1994)		
	Actual	Target	TVI	Actual	Target	TVI	Actual	Target	TVI
BWL	13%	< 3.75%	-2.47	5%	26.25%	-0.81	0.50	0.27	0.87 *
BWU	22%	< 3.75%	-4.87	45%	26.25%	0.71 *	0.60	0.27	1.21 *
BW	21%	< 3.75%	-4.60	0%	26.25%	-1.00	0.54	0.27	1.01 *
CC	24%	< 3.75%	-5.40	3%	26.25%	-0.89	0.86	0.27	2.18 *
DS	18%	< 3.75%	-3.80	1%	26.25%	-0.96	0.76	0.27	1.80 *
DC	60%	< 3.75%	-15.00	3%	26.25%	-0.89	0.09	0.27	-0.67
HD	37%	< 3.75%	-8.87	2%	26.25%	-0.92	0.57	0.27	1.11 *
KL	17%	< 3.75%	-3.53	71%	26.25%	1.70 *	0.58	0.27	1.15 *
LN	9%	< 3.75%	-1.40	14%	26.25%	-0.47	0.52	0.27	0.94 *
NFC	19%	< 3.75%	-4.07	24%	26.25%	-0.09	0.54	0.27	0.98 *
PH	41%	< 3.75%	-9.93	0%	26.25%	-1.00	0.27	0.27	0.01 *
TH	30%	< 3.75%	-7.00	4%	26.25%	-0.85	0.74	0.27	1.72 *
WL	29%	< 3.75%	-6.73	NA	26.25%	NA	0.50	0.27	0.86 *

* indicates that the reach value met the target value

Stream Name	Canopy Cover (Ebersole, 1994)			Median Pool Temperature °C (Ebersole, 1994)		
	Actual	Target	TVI	Actual	Target	TVI
BWL	34%	43.67%	-0.22	16.0	14.73 °C	-0.09
BWU	9%	43.67%	-0.79	15.0	14.73 °C	-0.02
BW	67%	43.67%	0.53 *	17.5	14.73 °C	-0.19
CC	28%	43.67%	-0.36	16.8	14.73 °C	-0.14
DS	36%	43.67%	-0.18	14.9	14.73 °C	-0.01
DC	24%	43.67%	-0.45	18.8	14.73 °C	-0.27
HD	25%	43.67%	-0.43	14.0	14.73 °C	0.05 *
KL	5%	43.67%	-0.89	15.0	14.73 °C	-0.02
LN	NA	43.67%	NA	17.5	14.73 °C	-0.19
NFC	NA	43.67%	NA	13.0	14.73 °C	0.12 *
PH	37%	43.67%	-0.15	13.0	14.73 °C	0.12 *
TH	33%	43.67%	-0.24	12.5	14.73 °C	0.15 *
WL	58%	43.67%	0.33 *	22.0	14.73 °C	-0.49

* indicates that the reach value met the target value

Stream Name	Pools per Km (PACFISH, 1995)			Water Temperature, °F (Rearing) (PACFISH, 1995)			Water Temperature, °F (Spawning) (PACFISH, 1995)		
	Actual	Target	TVI	Actual	Target	TVI	Actual	Target	TVI
BWL	31.45	154	-0.80	63.4	< 64 °F	0.01 *	63.4	< 61.8 °F	-0.03
BWU	35.94	154	-0.77	59.3	< 64 °F	0.07 *	59.3	< 61.8 °F	0.04 *
BW	27.77	90	-0.69	56.2	< 64 °F	0.12 *	56.2	< 61.8 °F	0.09 *
CC	9.15	76	-0.88	62.2	< 64 °F	0.03 *	62.2	< 61.8 °F	-0.01
DS	29.40	76	-0.61	58.2	< 64 °F	0.09 *	58.2	< 61.8 °F	0.06 *
DC	41.98	154	-0.73	65.4	< 64 °F	-0.02	65.4	< 61.8 °F	-0.06
HD	33.56	90	-0.63	59.2	< 64 °F	0.08 *	59.2	< 61.8 °F	0.04 *
KL	23.38	154	-0.85	57.6	< 64 °F	0.10 *	57.6	< 61.8 °F	0.07 *
LN	24.83	90	-0.72	61.3	< 64 °F	0.04 *	61.3	< 61.8 °F	0.01 *
NFC	46.71	154	-0.70	56.9	< 64 °F	0.11 *	56.9	< 61.8 °F	0.08 *
PH	27.00	154	-0.82	54.2	< 64 °F	0.15 *	55.7	< 61.8 °F	0.10 *
TH	26.41	90	-0.71	54.2	< 64 °F	0.15 *	54.2	< 61.8 °F	0.12 *
WL	17.61	90	-0.80	72.3	< 64 °F	-0.13	72.3	< 61.8 °F	-0.17

* indicates that the reach value met the target value

Stream Name	Large LWD / mile (PACFISH, 1995)			Bank Stability (PACFISH, 1995)			
	Actual	Target	TVI	Actual	Target	TVI	
BWL	3.4	> 20/mile	-0.89	87%	> 80%	0.09	*
BWU	8.3	> 20/mile	-0.73	78%	> 80%	-0.03	
BW	19.7	> 20/mile	-0.36	79%	> 80%	-0.01	
CC	1.6	> 20/mile	-0.95	76%	> 80%	-0.05	
DS	17.2	> 20/mile	-0.44	82%	> 80%	0.02	*
DC	4.5	> 20/mile	-0.85	40%	> 80%	-0.50	
HD	25.2	> 20/mile	-0.18	63%	> 80%	-0.21	
KL	4.5	> 20/mile	-0.85	83%	> 80%	0.04	*
LN	0.0	> 20/mile	-1.00	91%	> 80%	0.14	*
NFC	13.4	> 20/mile	-0.71	81%	> 80%	0.01	*
PH	15.0	> 20/mile	-0.51	59%	> 80%	-0.26	
TH	1.7	> 20/mile	-0.94	70%	> 80%	-0.13	
WL	4.5	> 20/mile	-0.85	71%	> 80%	-0.11	

* indicates that the reach value met the target value

Stream Name	Width-to-Depth Ratio (PACFISH, 1995)			Bank Undercut (PACFISH, 1995)			
	Actual	Target	TVI	Actual	Target	TVI	
BWL	10.20	< 10	-0.02	5.4%	< 75%	0.93	*
BWU	5.16	< 10	0.48	0.5%	< 75%	0.99	*
BW	14.87	< 10	-0.49	0.0%	< 75%	1.00	*
CC	20.91	< 10	-1.09	3.0%	< 75%	0.96	*
DS	20.73	< 10	-1.07	2.9%	< 75%	0.96	*
DC	6.15	< 10	0.39	0.0%	< 75%	1.00	*
HD	12.47	< 10	-0.25	1.2%	< 75%	0.98	*
KL	7.11	< 10	0.29	6.8%	< 75%	0.91	*
LN	17.08	< 10	-0.71	2.6%	< 75%	0.97	*
NFC	11.15	< 10	-0.12	3.1%	< 75%	0.96	*
PH	12.52	< 10	-0.25	0.0%	< 75%	1.00	*
TH	13.32	< 10	-0.33	0.7%	< 75%	0.99	*
WL	18.40	< 10	-0.84	1.5%	< 75%	0.98	*

* indicates that the reach value met the target value

Stream Name	Bank Shrub Cover (all shrubs) (Howell and McKinney, 1997)			Bank Shrub Cover (shrubs > 8 ft. tall) (Howell and McKinney, 1997)			Bank Stability (Howell and McKinney, 1997)		
	Actual	Target	TVI	Actual	Target	TVI	Actual	Target	TVI
BWL	10%	> 80%	-0.88	6%	> 50%	-0.88	87%	> 90%	-0.03
BWU	3%	> 80%	-0.96	3%	> 50%	-0.94	78%	> 90%	-0.13
BW	52%	> 80%	-0.35	28%	> 50%	-0.44	79%	> 90%	-0.12
CC	42%	> 80%	-0.48	28%	> 50%	-0.44	76%	> 90%	-0.16
DS	21%	> 80%	-0.74	12%	> 50%	-0.76	82%	> 90%	-0.09
DC	3%	> 80%	-0.96	3%	> 50%	-0.94	40%	> 90%	-0.56
HD	11%	> 80%	-0.86	5%	> 50%	-0.90	63%	> 90%	-0.30
KL	16%	> 80%	-0.80	1%	> 50%	-0.98	83%	> 90%	-0.08
LN	31%	> 80%	-0.61	17%	> 50%	-0.66	91%	> 90%	0.01 *
NFC	1%	> 80%	-0.99	1%	> 50%	-0.98	81%	> 90%	-0.10
PH	37%	> 80%	-0.54	22%	> 50%	-0.56	59%	> 90%	-0.34
TH	72%	> 80%	-0.10	41%	> 50%	-0.18	70%	> 90%	-0.22
WL	NA	> 80%	NA	NA	> 50%	NA	71%	> 90%	-0.21

* indicates that the reach value met the target value

APPENDIX G

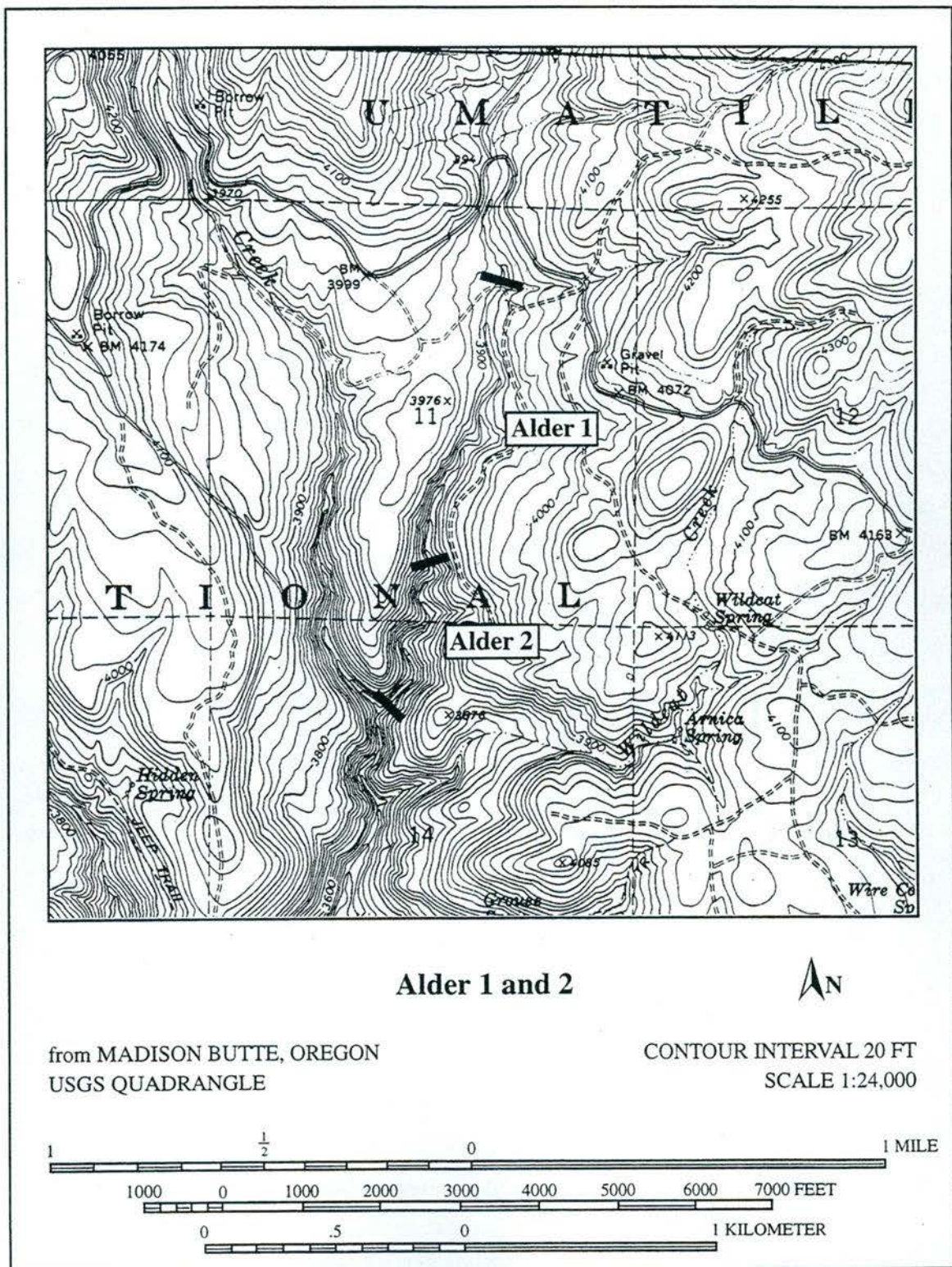
LOCATIONS AND MAPS OF REACHES IN FOREST SERVICE DATA SET

TABLE 106. Forest Service Data Set, Locations and Number of ISSs

Forest Service Data Set Stream Reach Name	1:24,000 USGS Quadrangle	Location	# of Structures
Alder 1	Madison Butte, OR	T6S R27E sec 11	19
Alder 2	Madison Butte, OR	T6S R27E sec 11	11
Bear Wallow Lower	Lehman Springs and Owens Butte, OR	T4S R33E sec 29	17
Bear Wallow Upper	Lehman Springs, OR	T4S R33E sec 9	12
Big Wall 1	Turner Mountain, OR	T7S R26E sec 27	35
Big Wall 2	Turner Mountain, OR	T7S R26E sec 27	18
Camas	Owens Butte, OR	T4S R27E sec 30 to sec 32	6
Charley	Peola, WA	T9N R43E sec 18	7
Cummins	Hopkins Ridge, WA	T9N R41E sec 1	16
Desolation	Desolation Butte, OR	T8S R33E sec 27	17
Ditch Upper 1	Lake Penland, OR	T5S R28E sec 28	8
Ditch Upper 2	Lake Penland, OR	T5S R28E sec 28	10
Ditch Lower 3	Lake Penland, OR	T6S R28E sec 21	15
Ditch Lower 4	Lake Penland, OR	T5S R28E sec 21 and sec 22	7
Dry Camas	Sullivan Gulch, OR	T5S R33 1/2 E sec 6	9
Ellis	Thompson Flat, OR	T6S R29E sec 34	6
Hidaway 1	Pearson's Ridge, OR	T5S R33E sec 25	20
Hidaway 2	Pearson's Ridge, OR	T5S R33E sec 36	37
Kelsay 1	Kelsay Butte, OR	T7S R33E sec 26	20
Kelsay 2	Kelsay Butte, OR	T7S R33E sec 26	7
Lane	Owens Butte, OR	T4S R33E sec 30	5
Little Wall 1	Big Rock Flat and Turner, OR	T6s R27E sec 29	14

TABLE 106 (continued). Forest Service Data Set, Locations and Number of ISSs

Forest Service Data Set Stream Reach Name	1:24,000 USGS Quadrangle	Location	# of Structures
Little Wall 2	Big Rock Flat and Turner, OR	T6S R27E sec 32	19
Little Wall 3	Big Rock Flat and Turner, OR	T6S R27E sec 32	45
Meacham	Huron, WA	T1S R36E sec 14 and sec 15	18
N. Fork Cable	Pearson's Ridge, OR	T6S R33E sec 13	14
Phillips	Sanderson Spring, OR	T1N R38E sec 3 and sec 2	12
Porter 1	Chapin Creek, OR	T6S R25E sec 36 and T7S R26E sec 6	10
Porter 2	Chapin Creek and White Tail Butte, OR	T6S R27E sec 32 and sec 36	9
Skookum 1	Madison Butte, OR	T6S R27E sec 11 and sec 14	27
Skookum 2	Madison Butte, OR	T6S R27E sec 14 and sec 23	17
Skookum 3	Madison Butte, OR	T6S R27E sec 23 and sec 22	10
Skookum 4	Madison Butte, OR	T6S R27E sec 23 and sec 25	23
Skookum 5	Madison Butte, OR	T6S R27E sec 25 and sec 31	14
S. Fork Umatilla 1	Bingham Springs, OR	T3N R37E sec 22	4
S. Fork Umatilla 2	Bingham Springs, OR	T3N R37E sec 22 and sec 28	9
S. Fork Umatilla 3	Bingham Springs, OR	T3N R37E sec 23 and sec 33	17
Stalder	Lake Penland, OR	T6S R28E sec 13	10
Swale	Lake Penland and Madison Butte, OR	T6S R28E sec 4	6
Thomas 1	Bingham Springs, OR	T2N R37E sec 10 and sec 33	125
Wilson 1	Turner Mountain, OR	T7S R26E sec 2	37
Wilson 2	Turner Mountain, OR	T3N R37E sec 8 and sec 13	75
Wilson 3	Turner Mountain, OR	T3N R37E sec 22 and sec 25	61



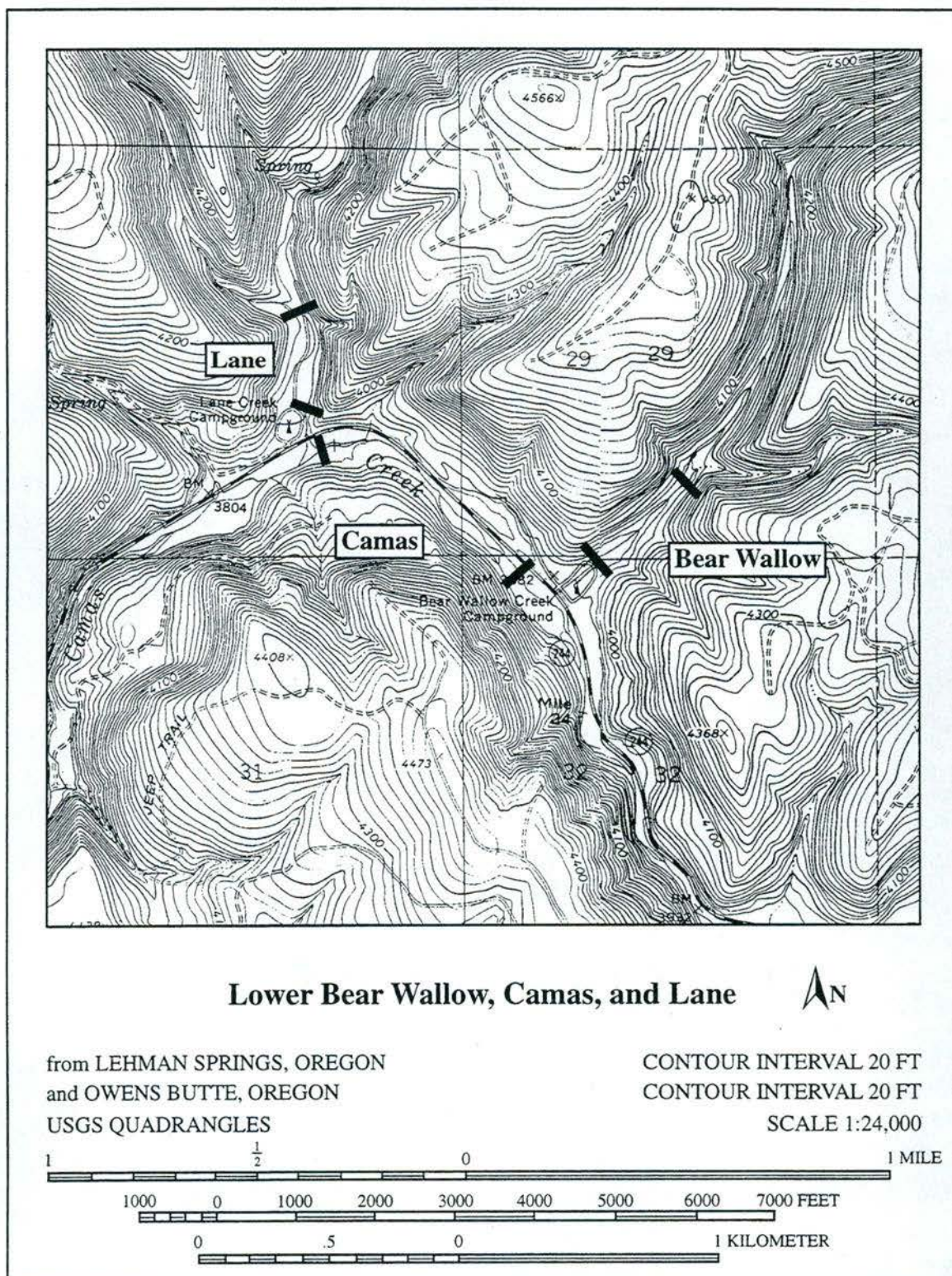


Figure 43. Map showing location of Lower Bear Wallow, Camas, and Lane.

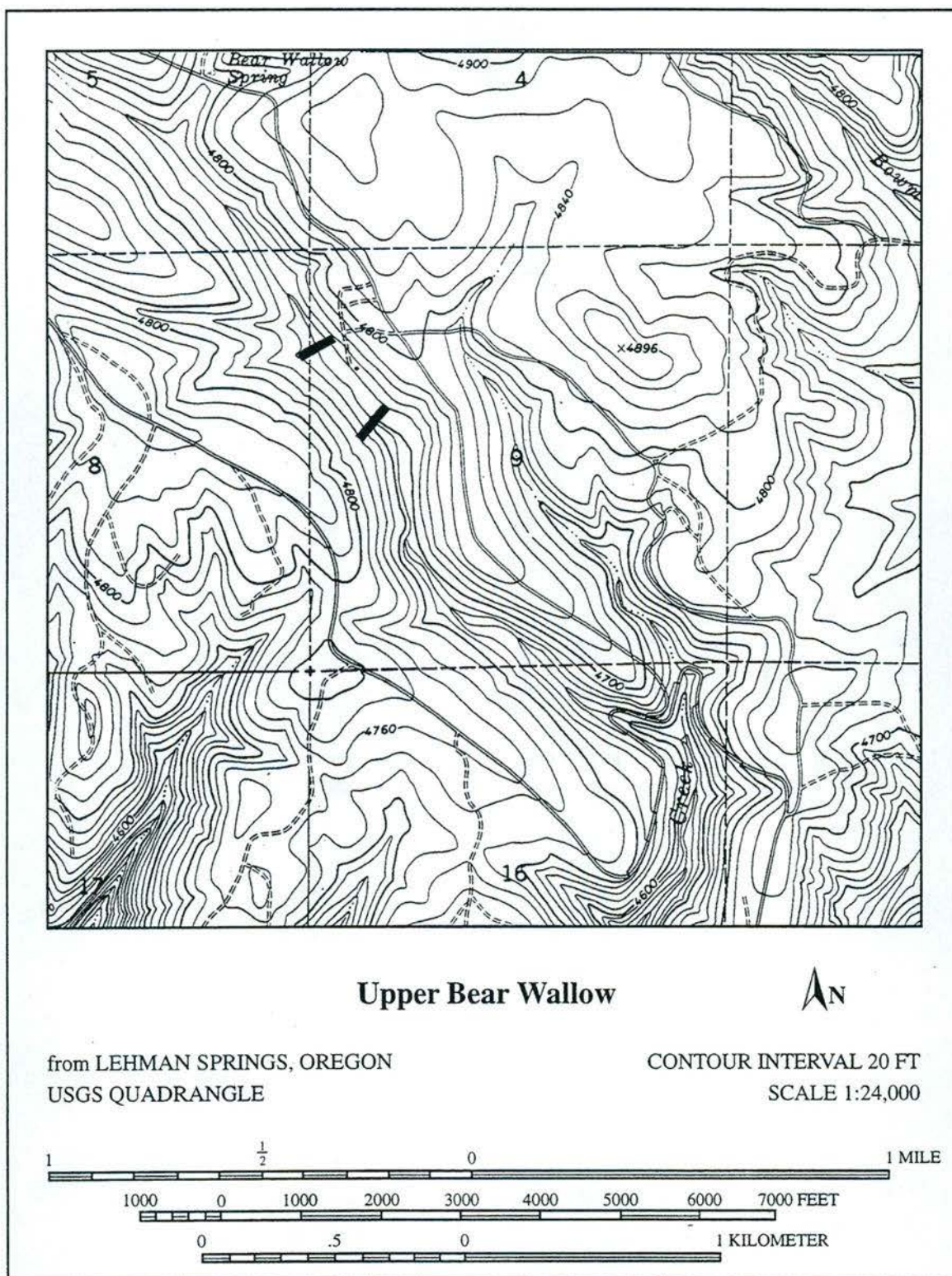


Figure 44. Map Showing Location of Upper Bear Wallow.

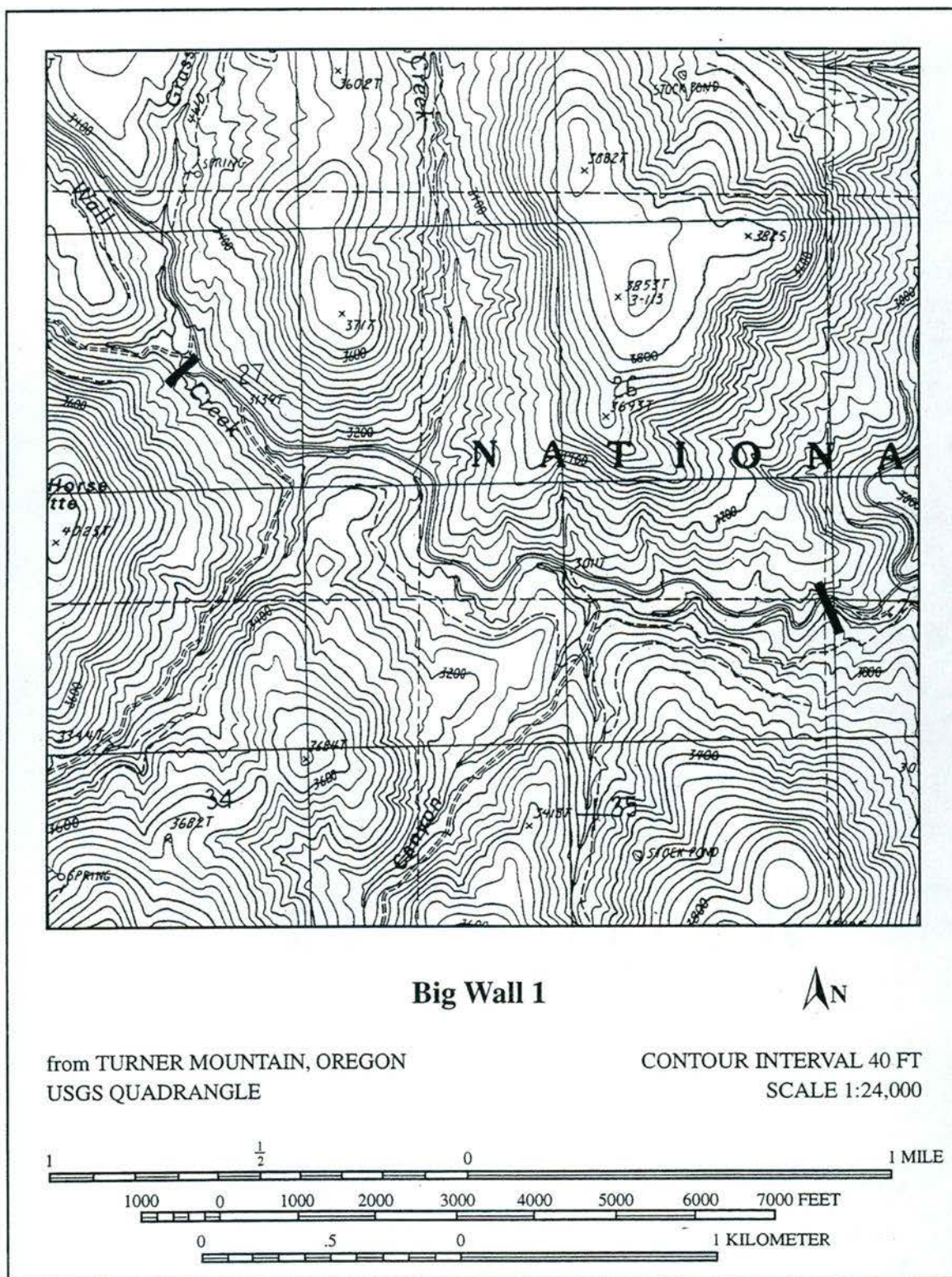


Figure 45. Map Showing Location of Big Wall 1.

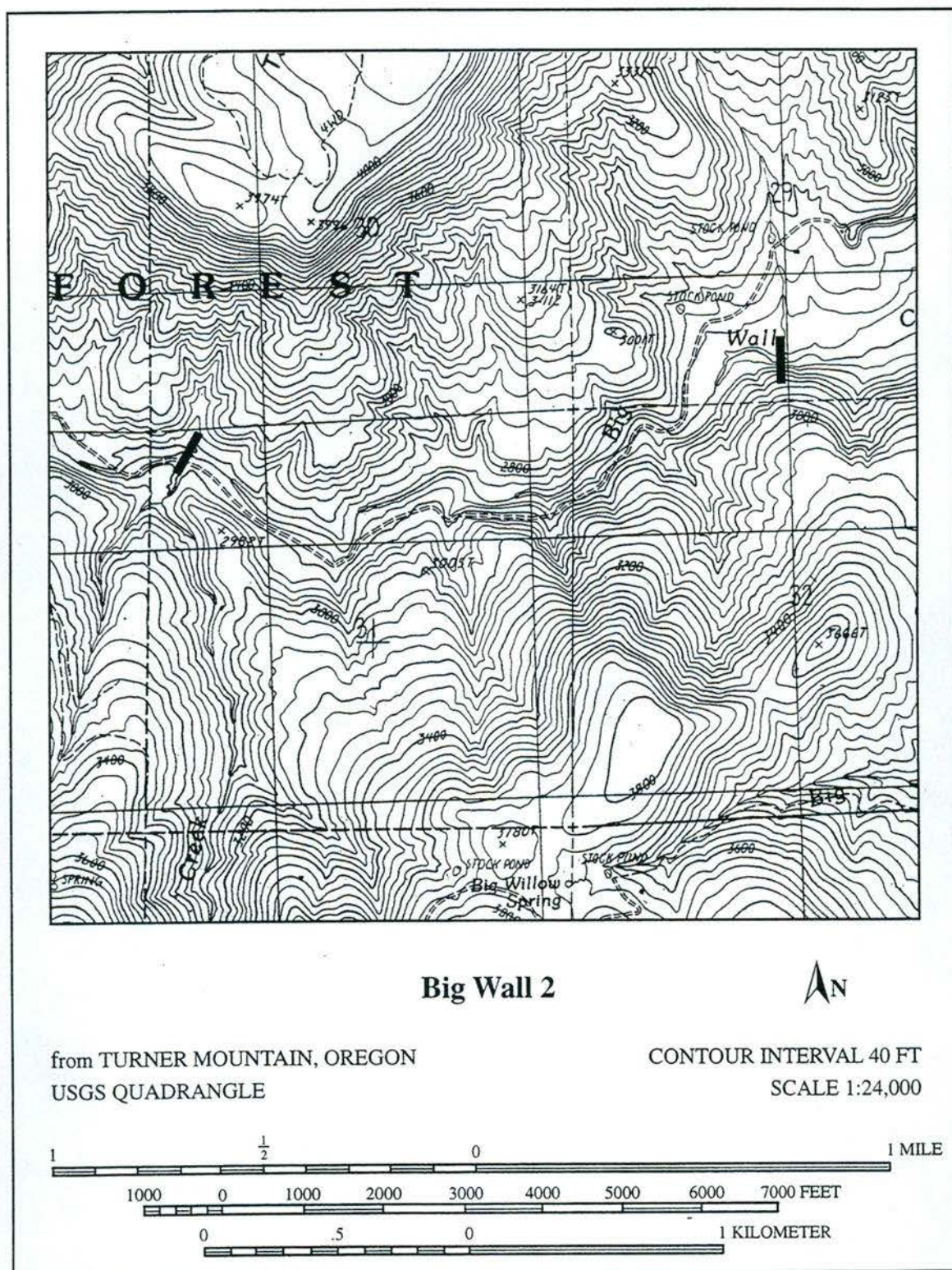


Figure 46. Map Showing Location of Big Wall 2.

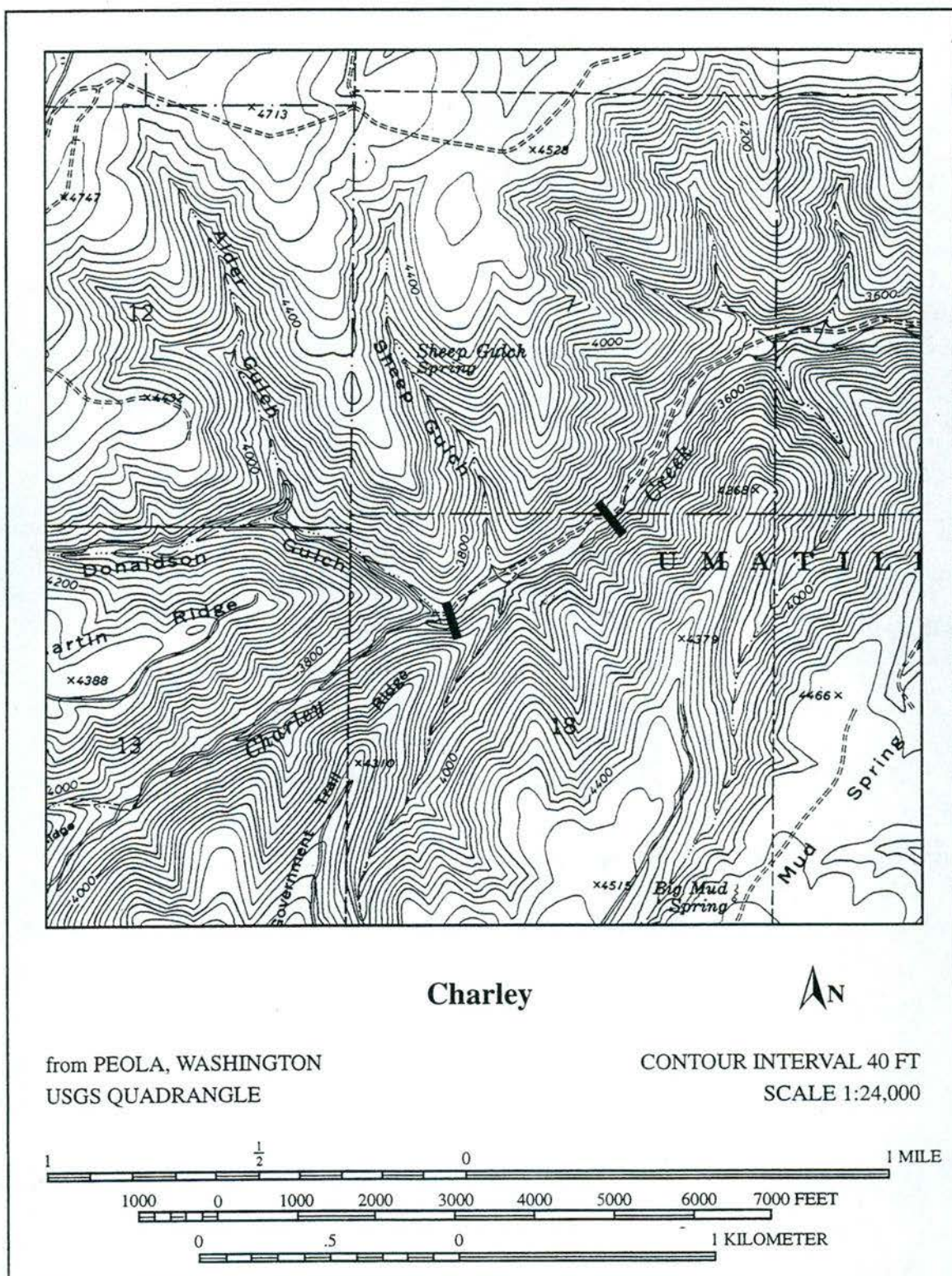


Figure 47. Map Showing Location of Charley.

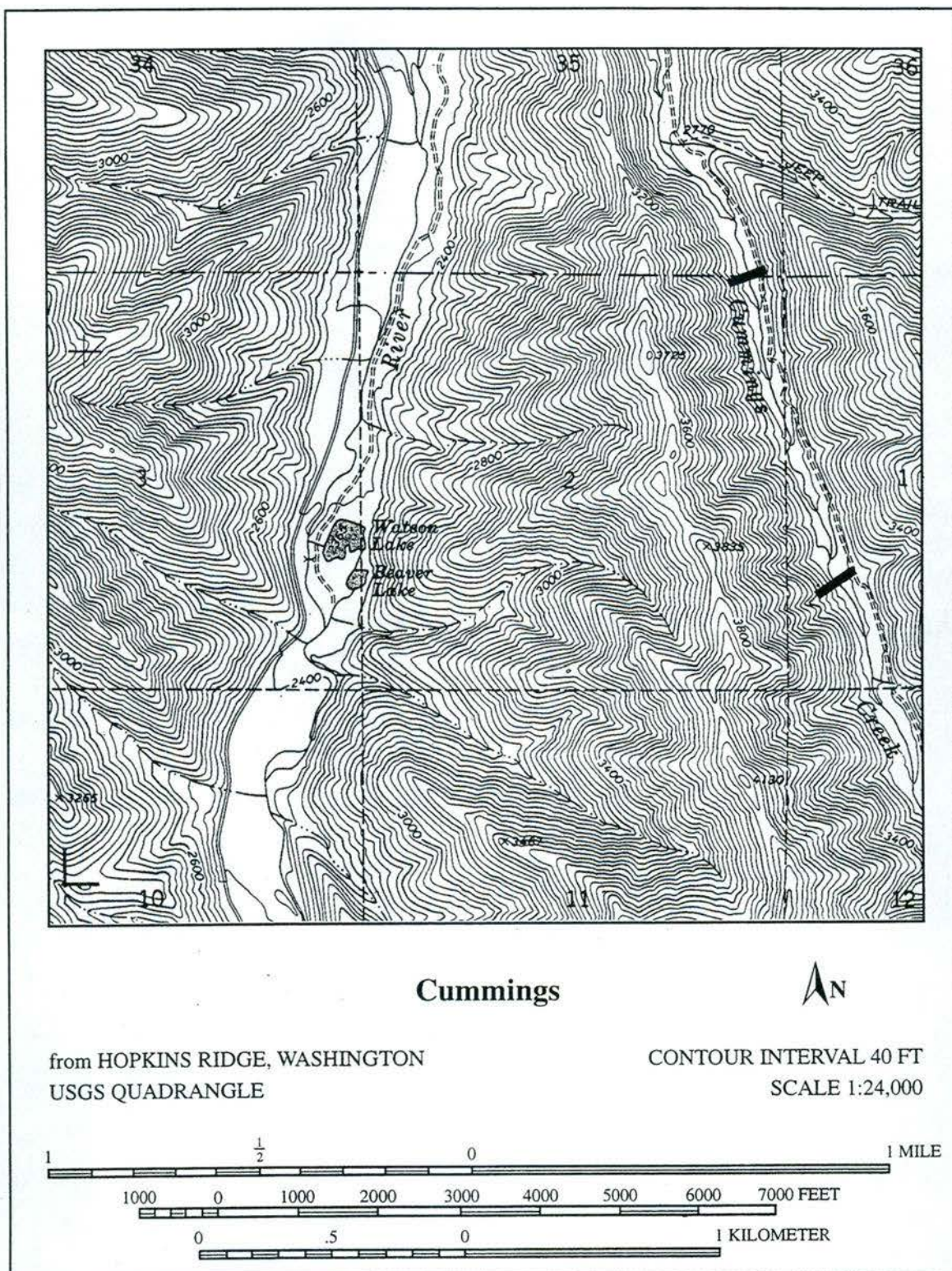


Figure 48. Map Showing Location of Cummings.

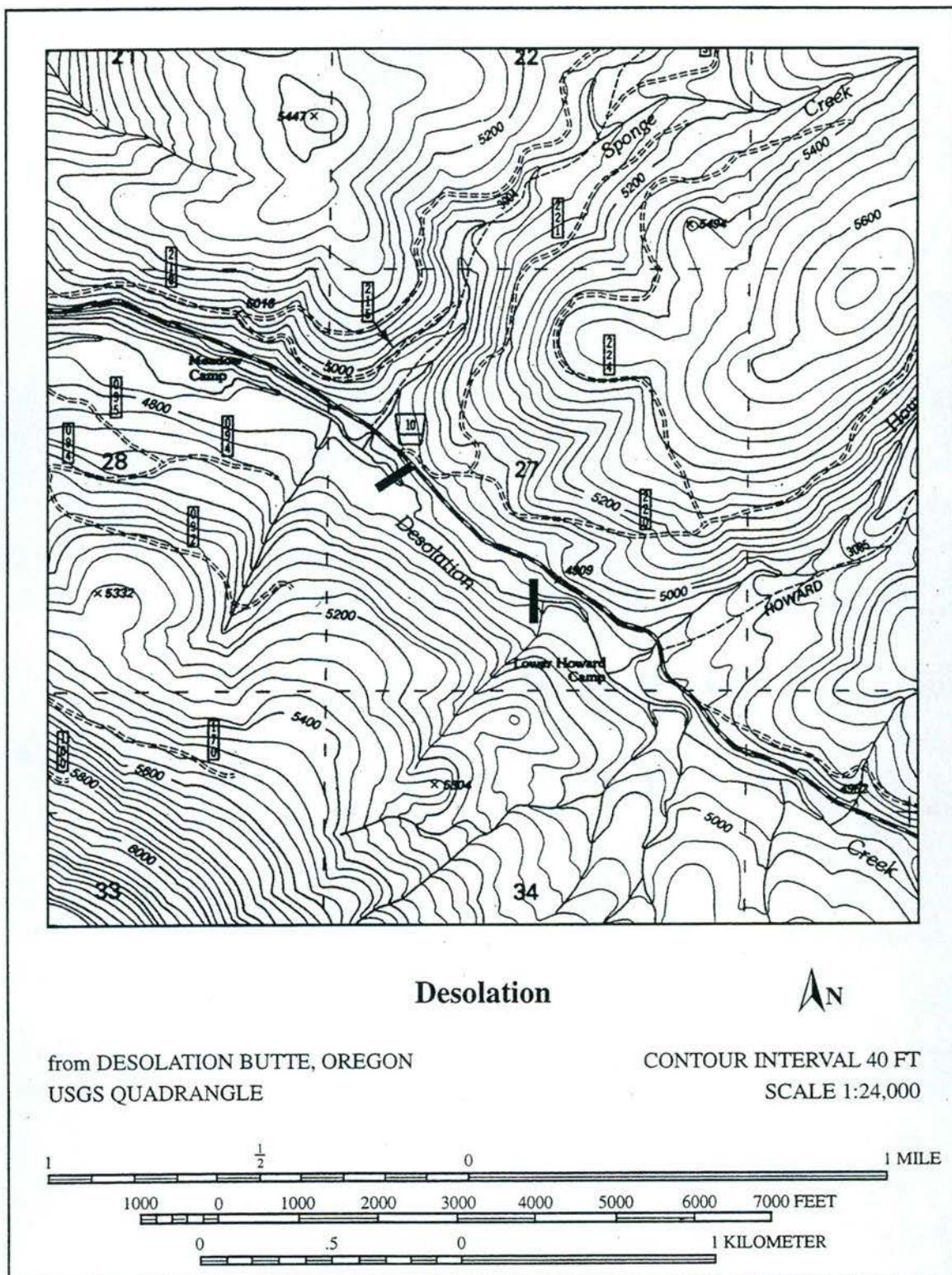


Figure 49. Map Showing Location of Desolation.

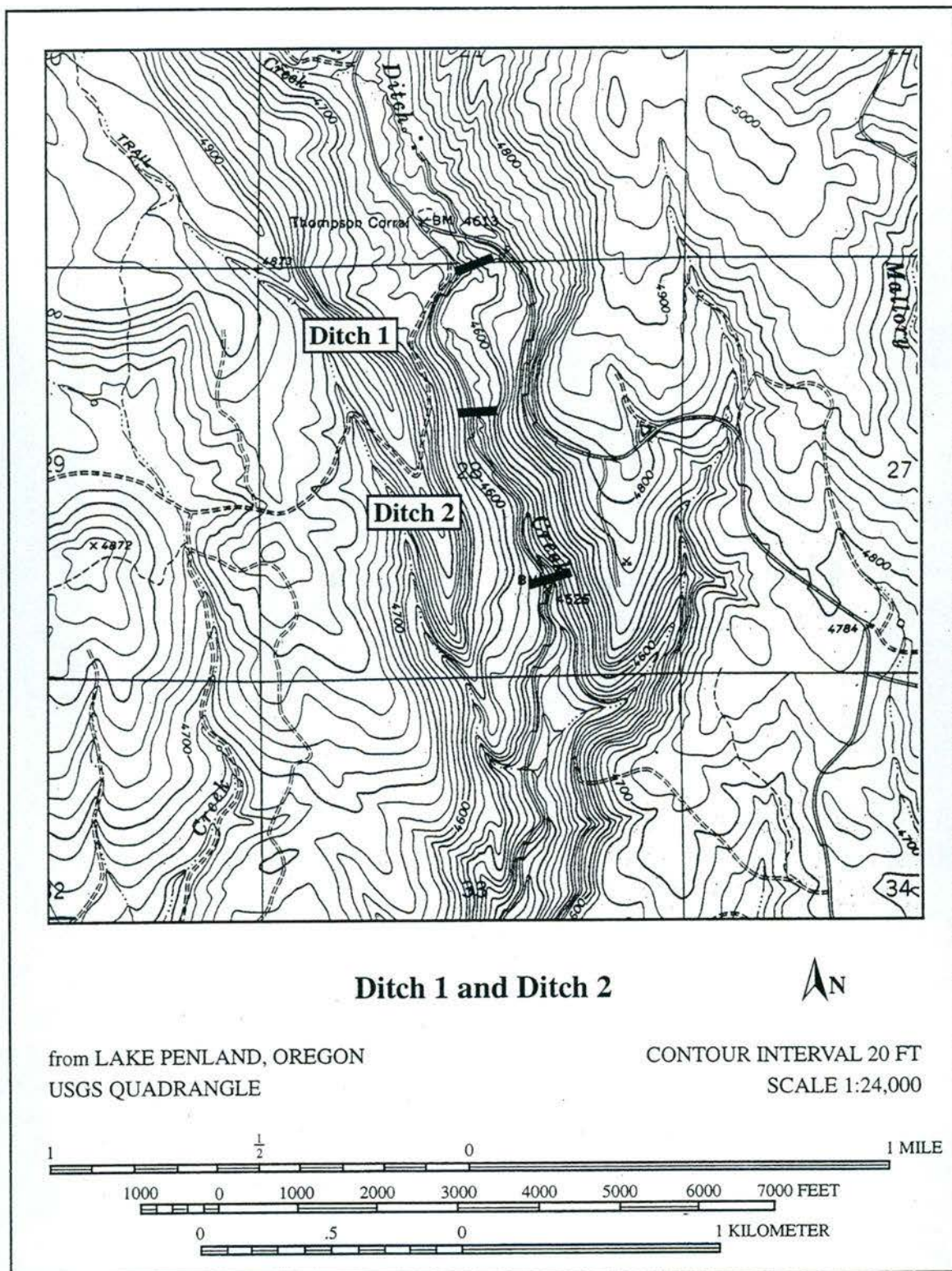


Figure 50. Map Showing Location of Ditch 1 and Ditch 2.

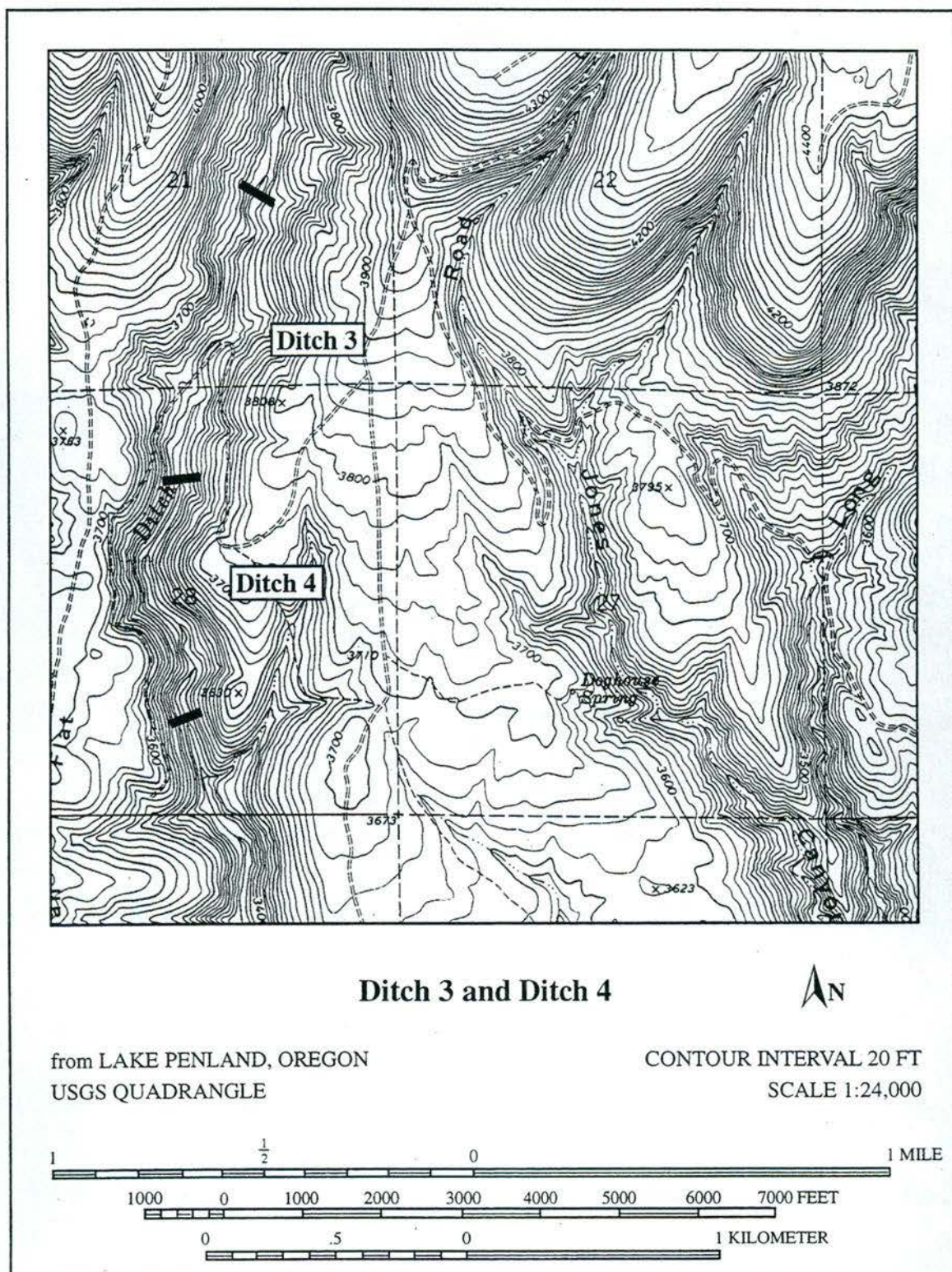


Figure 51. Map Showing Location of Ditch 3 and Ditch 4.

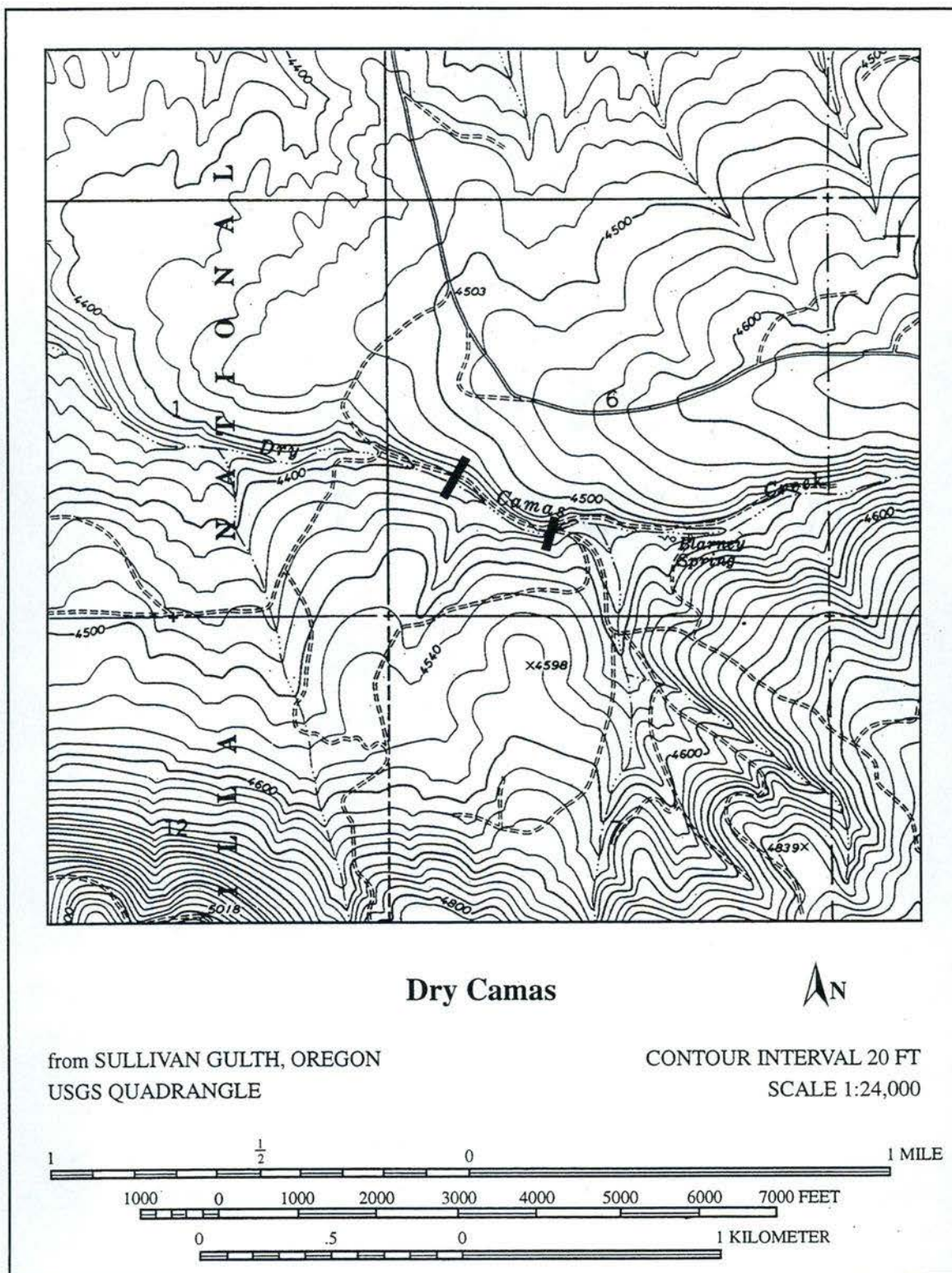


Figure 52. Map Showing Location of Dry Camas.

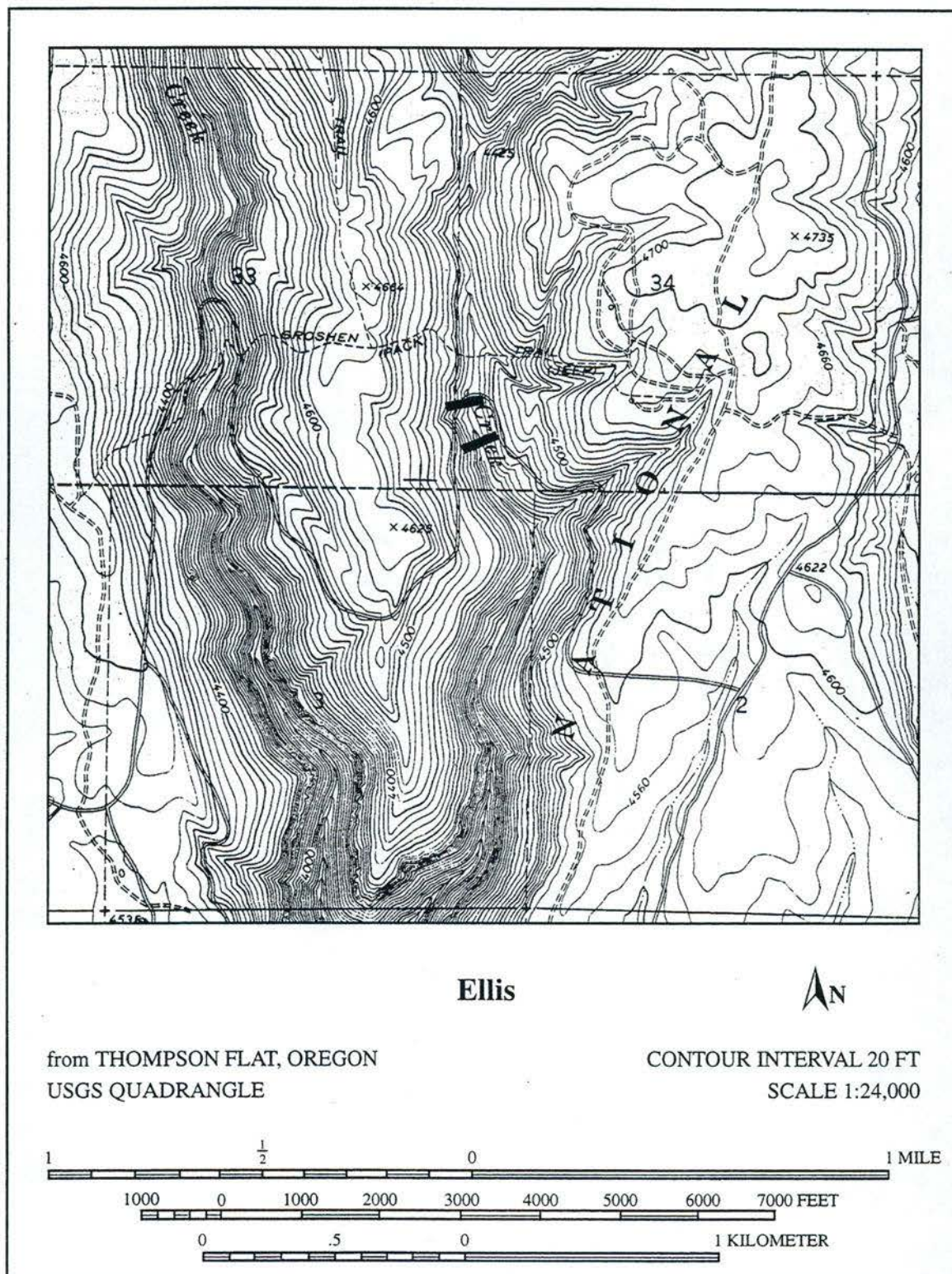


Figure 53. Map Showing Location of Ellis.

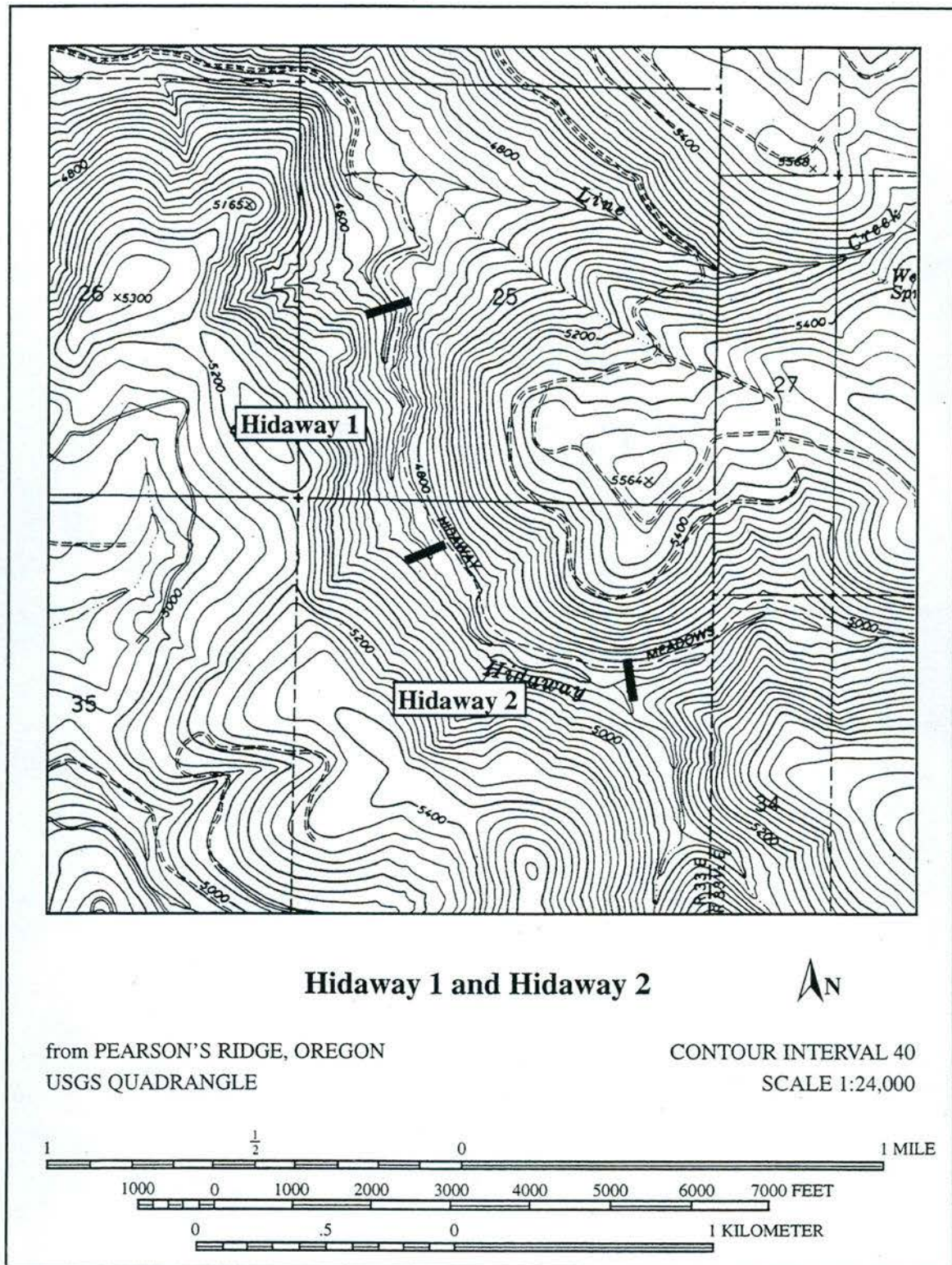


Figure 54. Map Showing Location of Hidaway 1 and Hidaway 2.



Figure 55. Map Showing Location of Kelsay 1 and Kelsay 2.

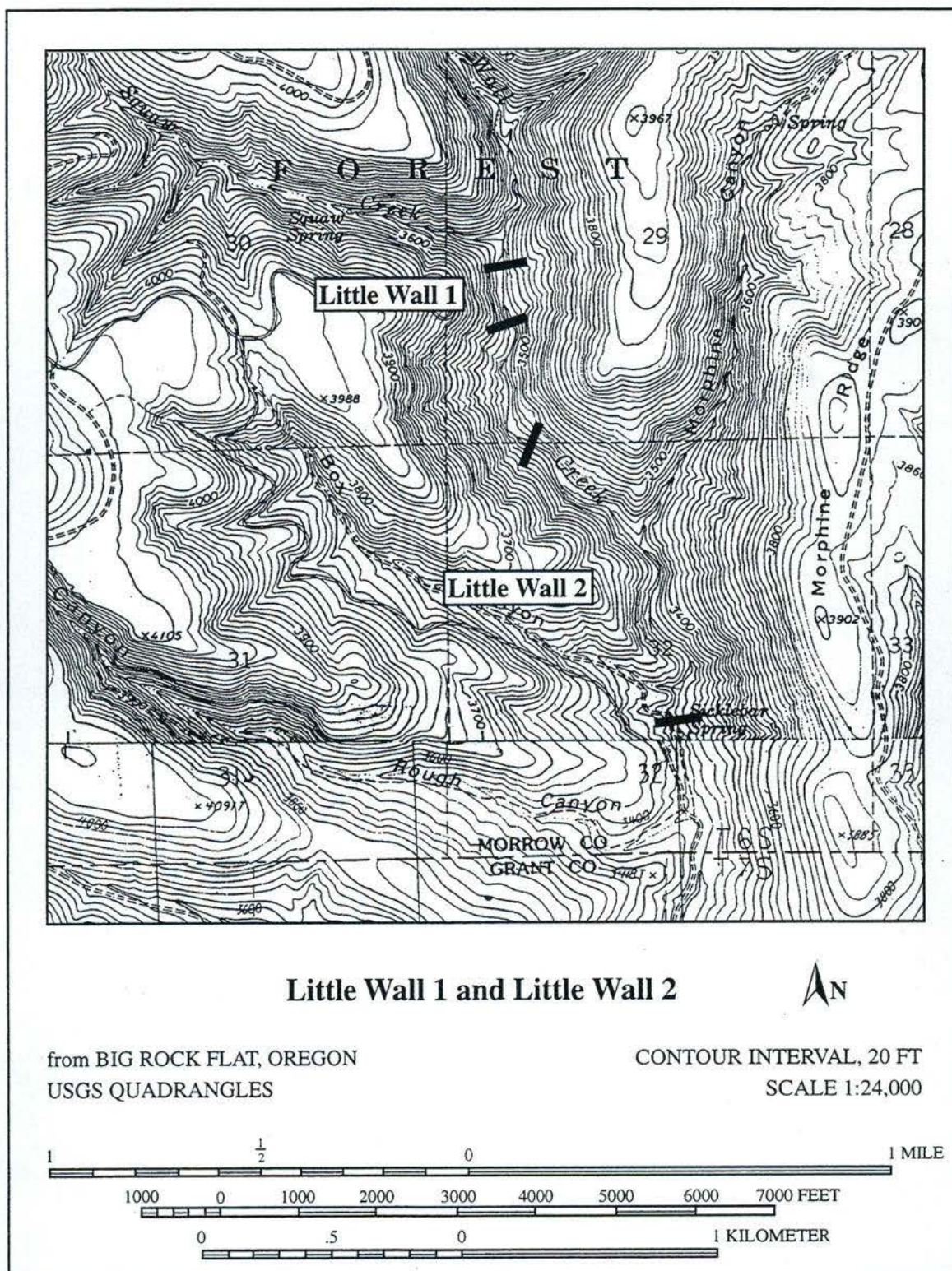


Figure 56. Map Showing Location of Little Wall 1 and Little Wall 2.

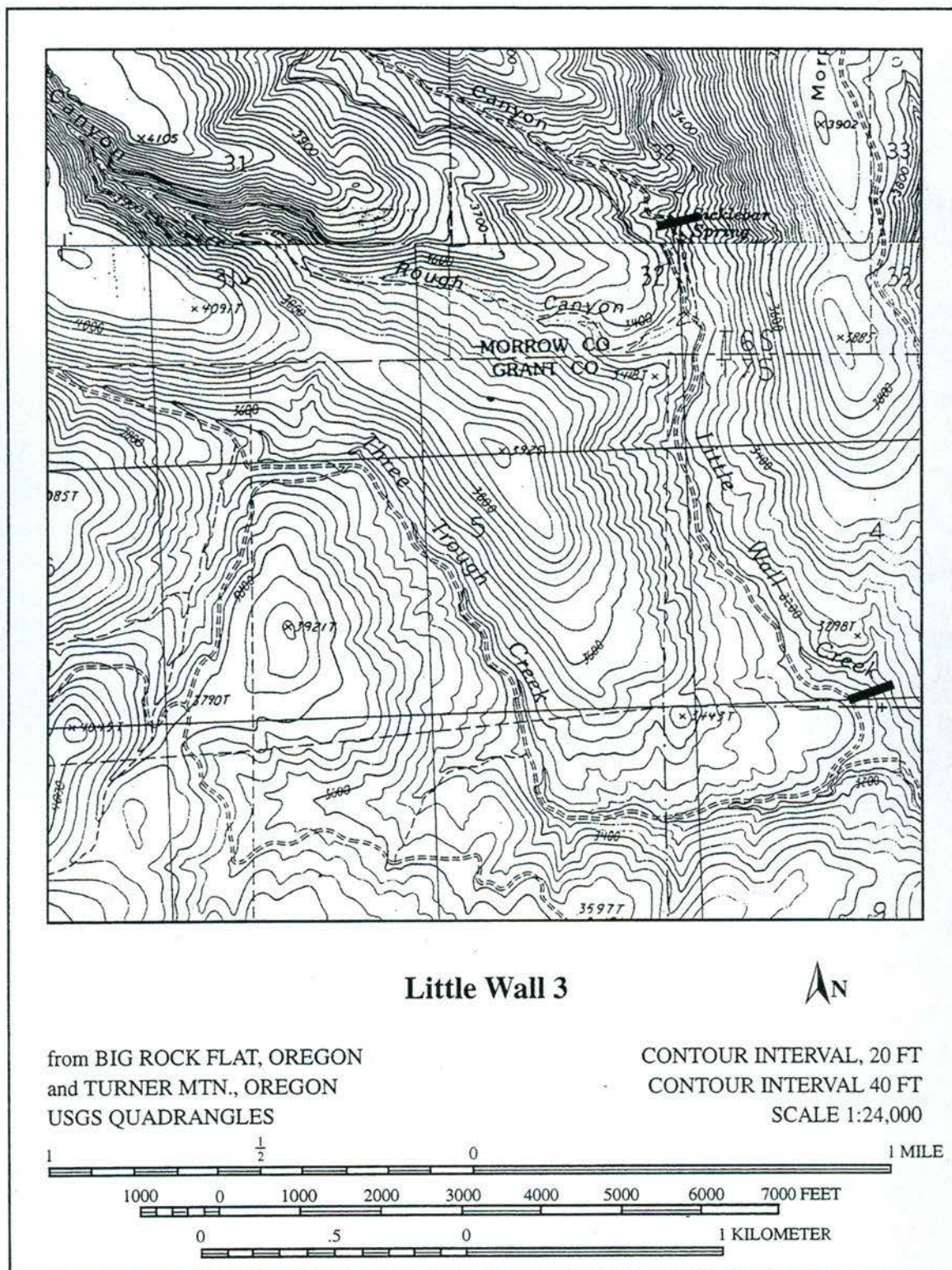


Figure 57. Map Showing Location of Little Wall 3.

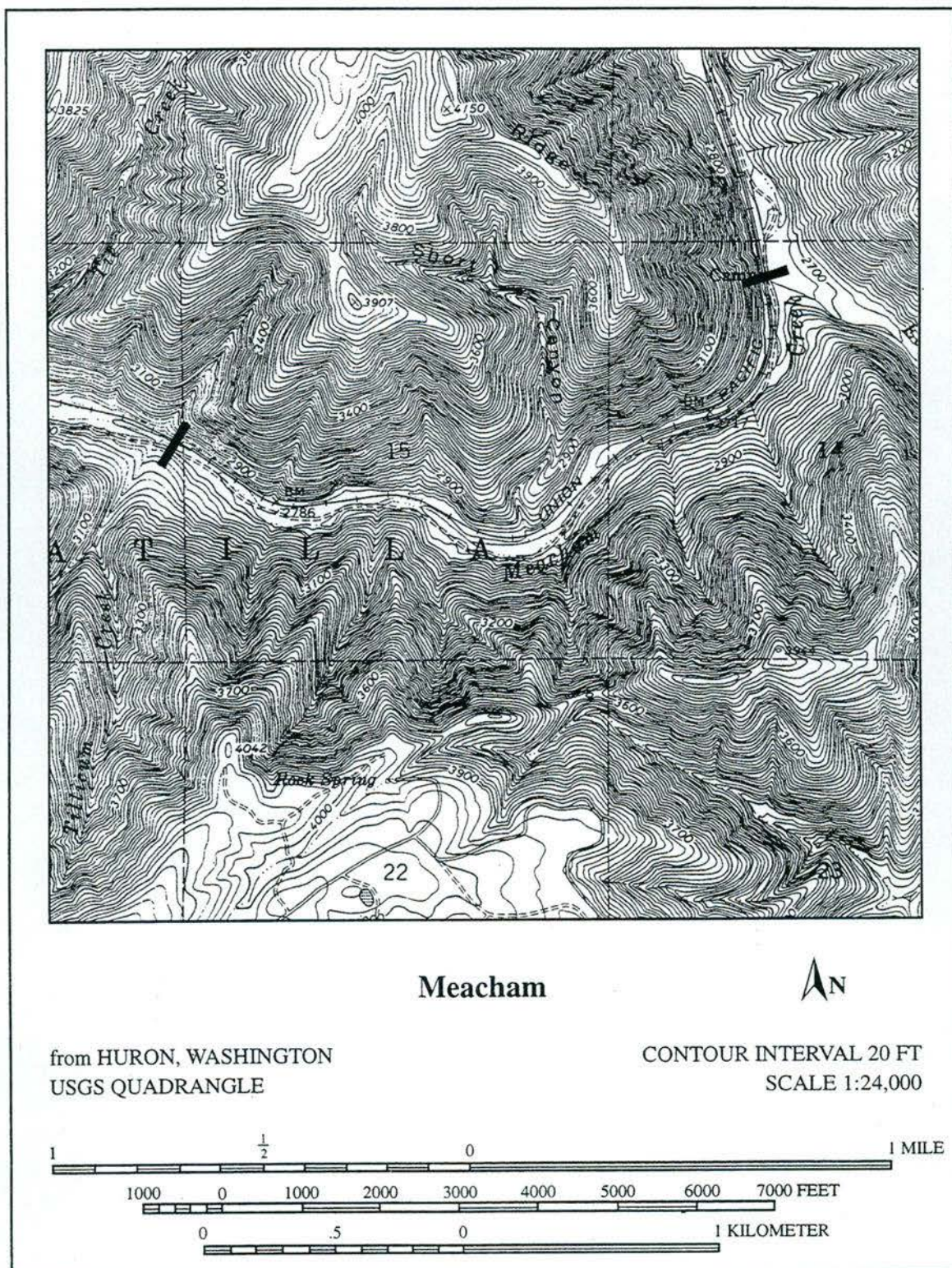


Figure 58. Map Showing Location of Meacham.

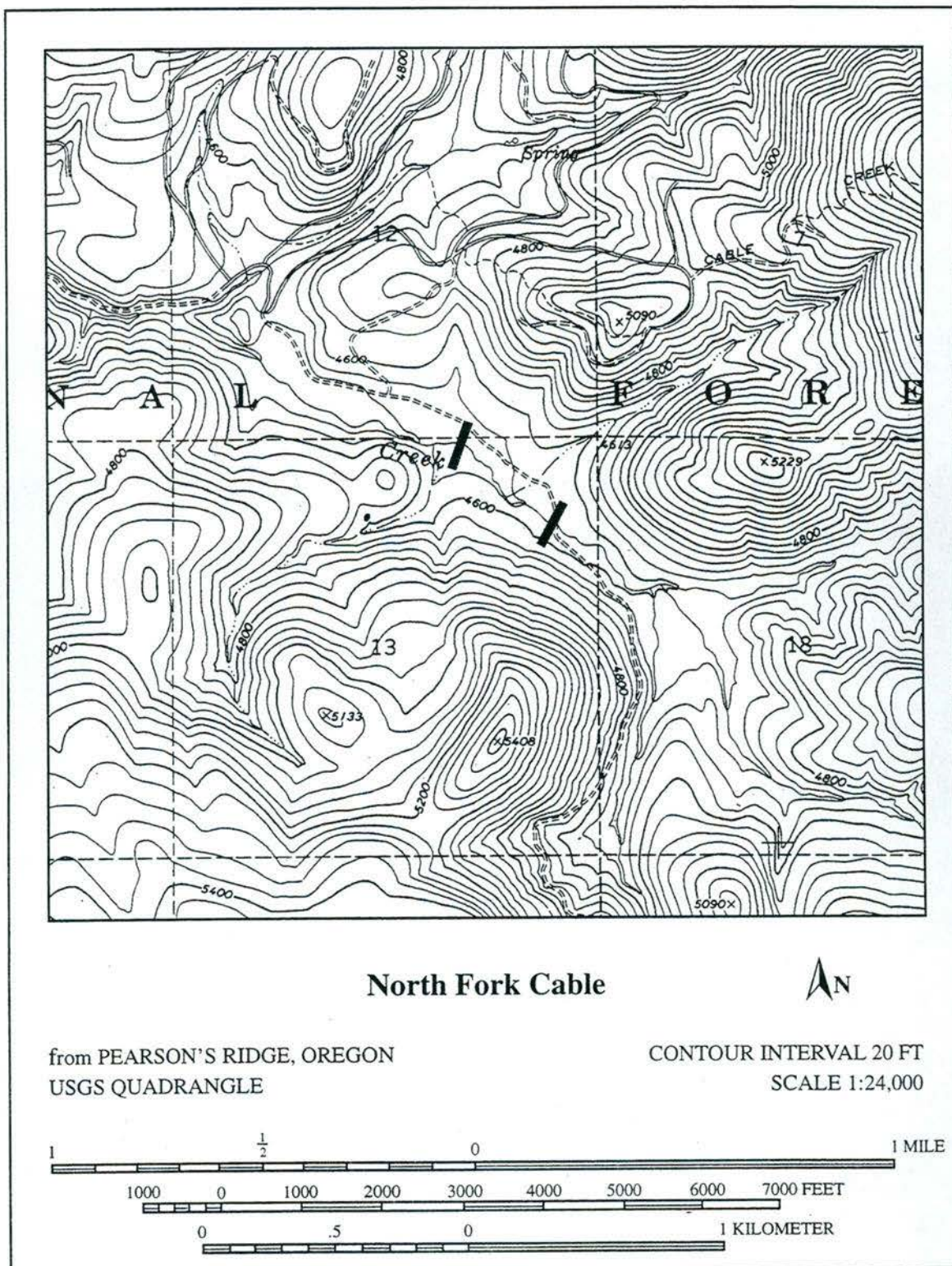


Figure 59. Map Showing Location of North Fork Cable.

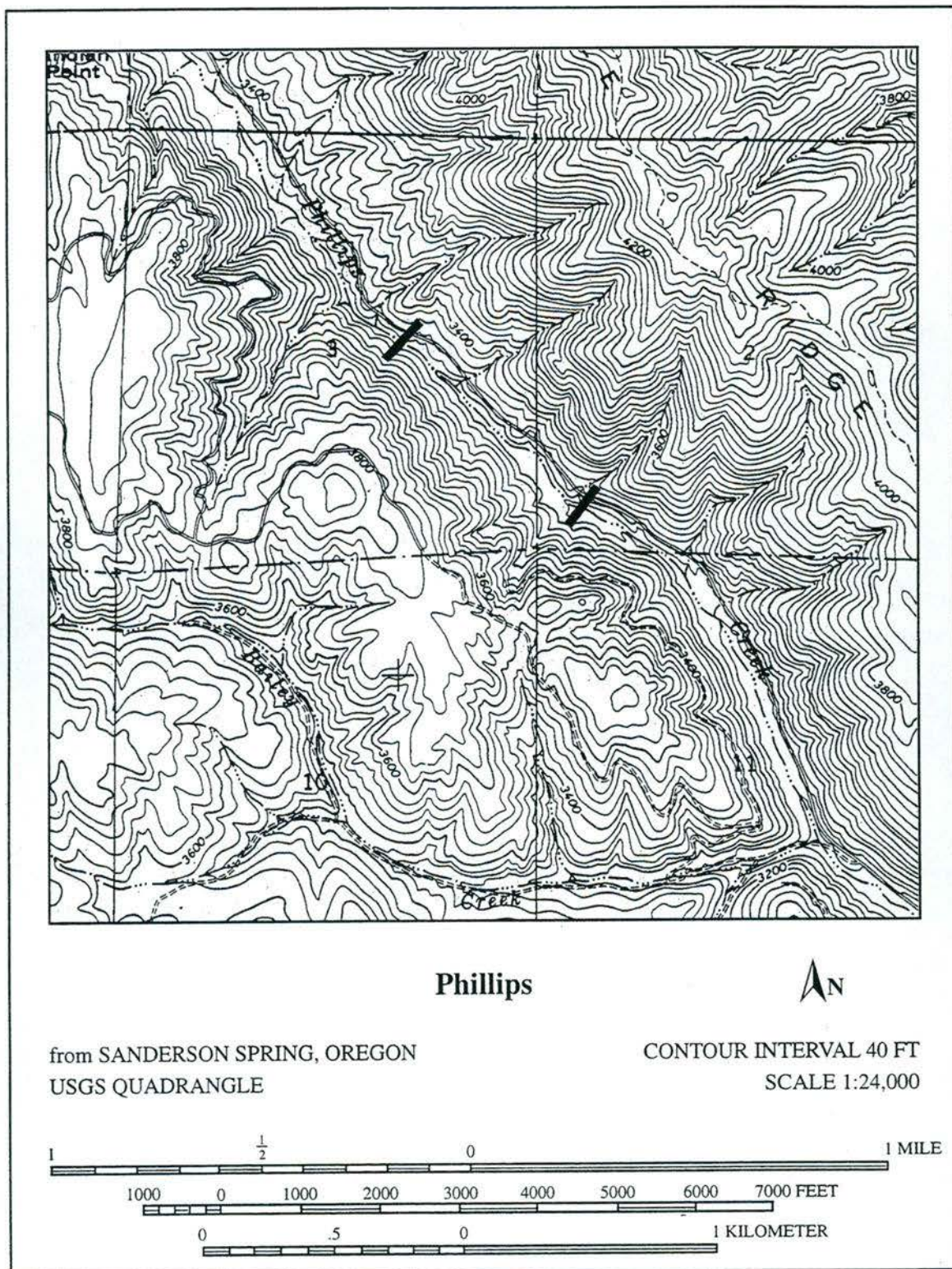


Figure 60. Map Showing Location of Phillips.

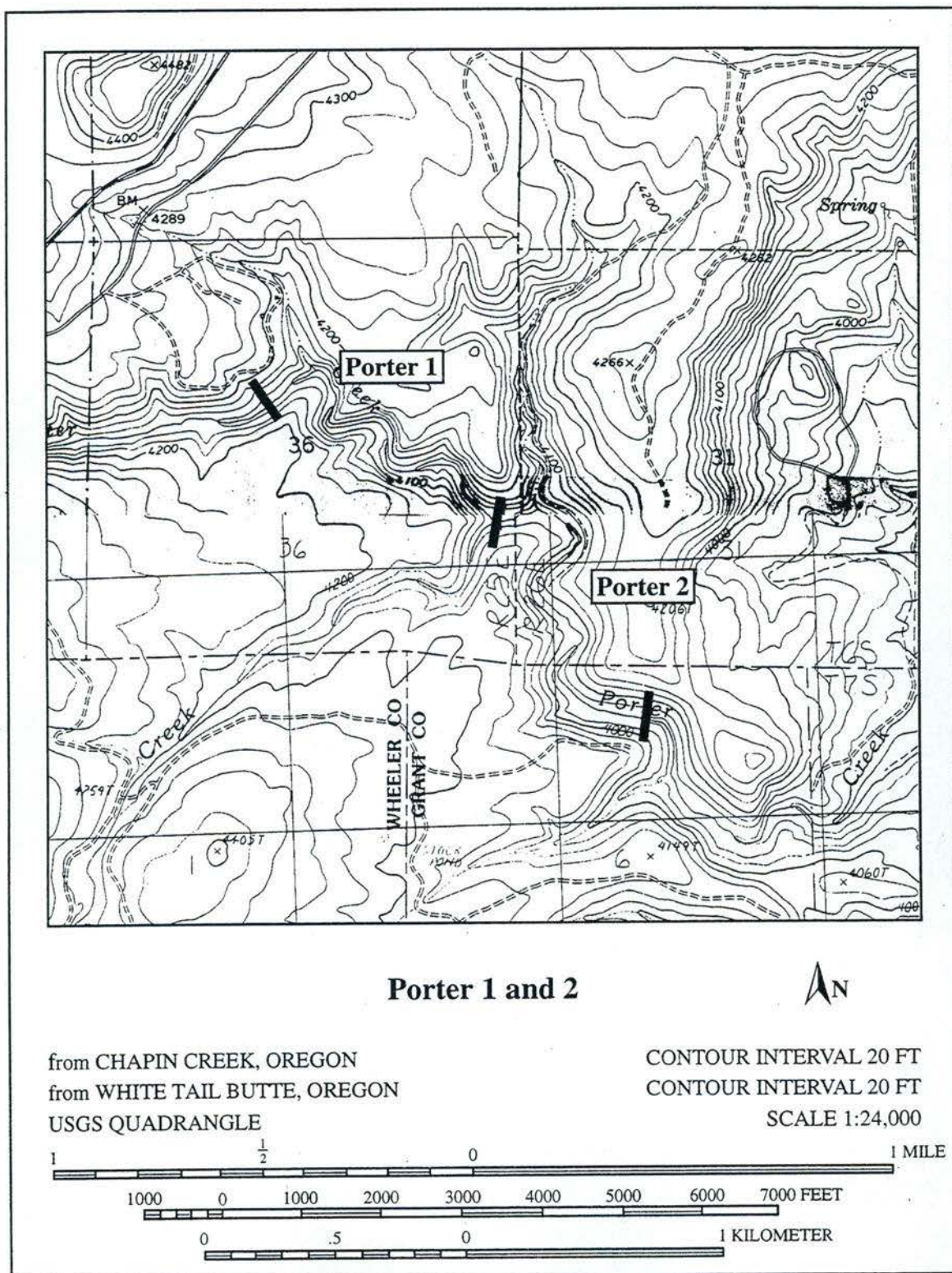


Figure 61. Map Showing Location of Porter 1 and Porter 2.

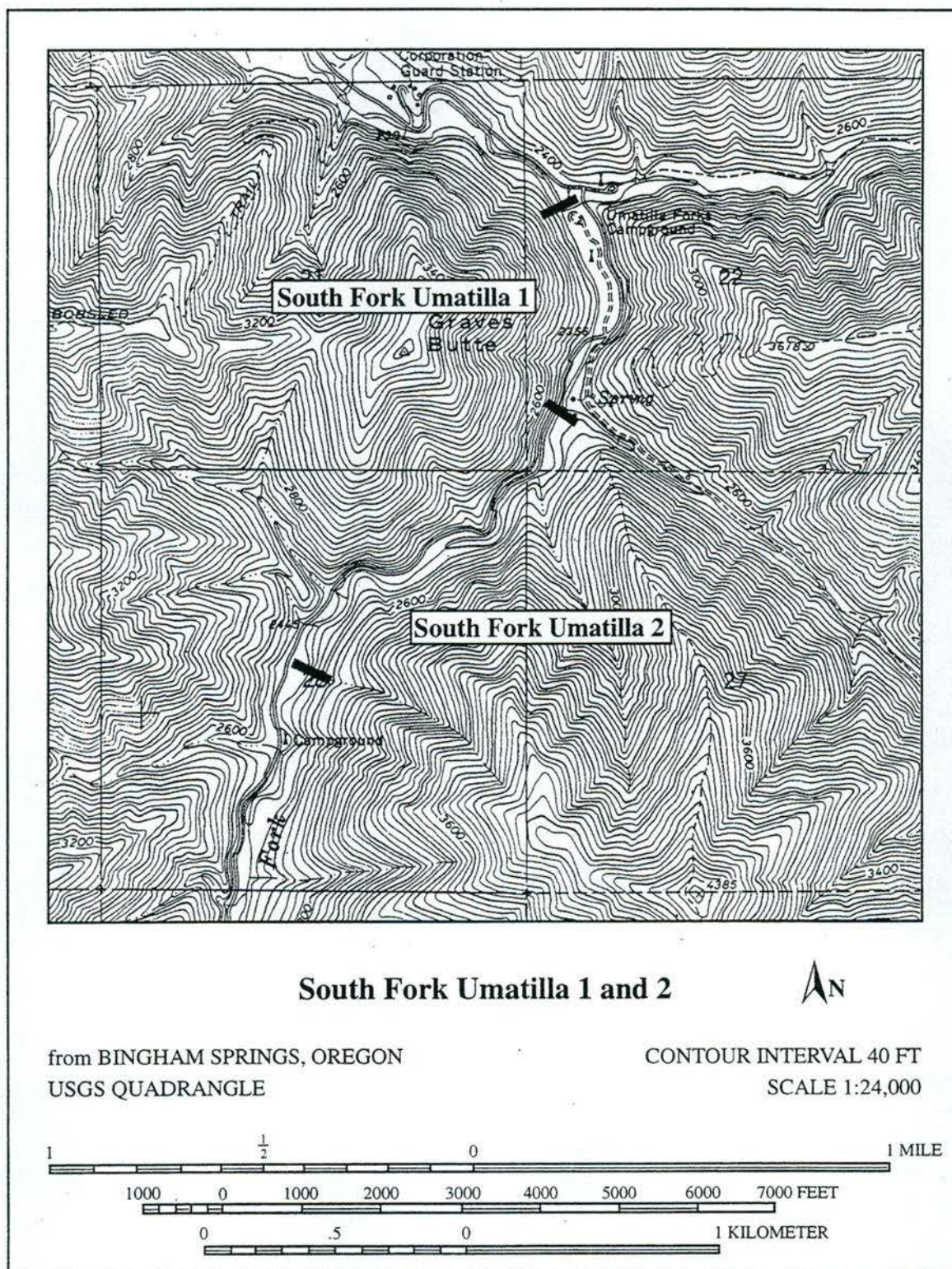


Figure 62. Map Showing Location of South Fork Umatilla 1 and 2.

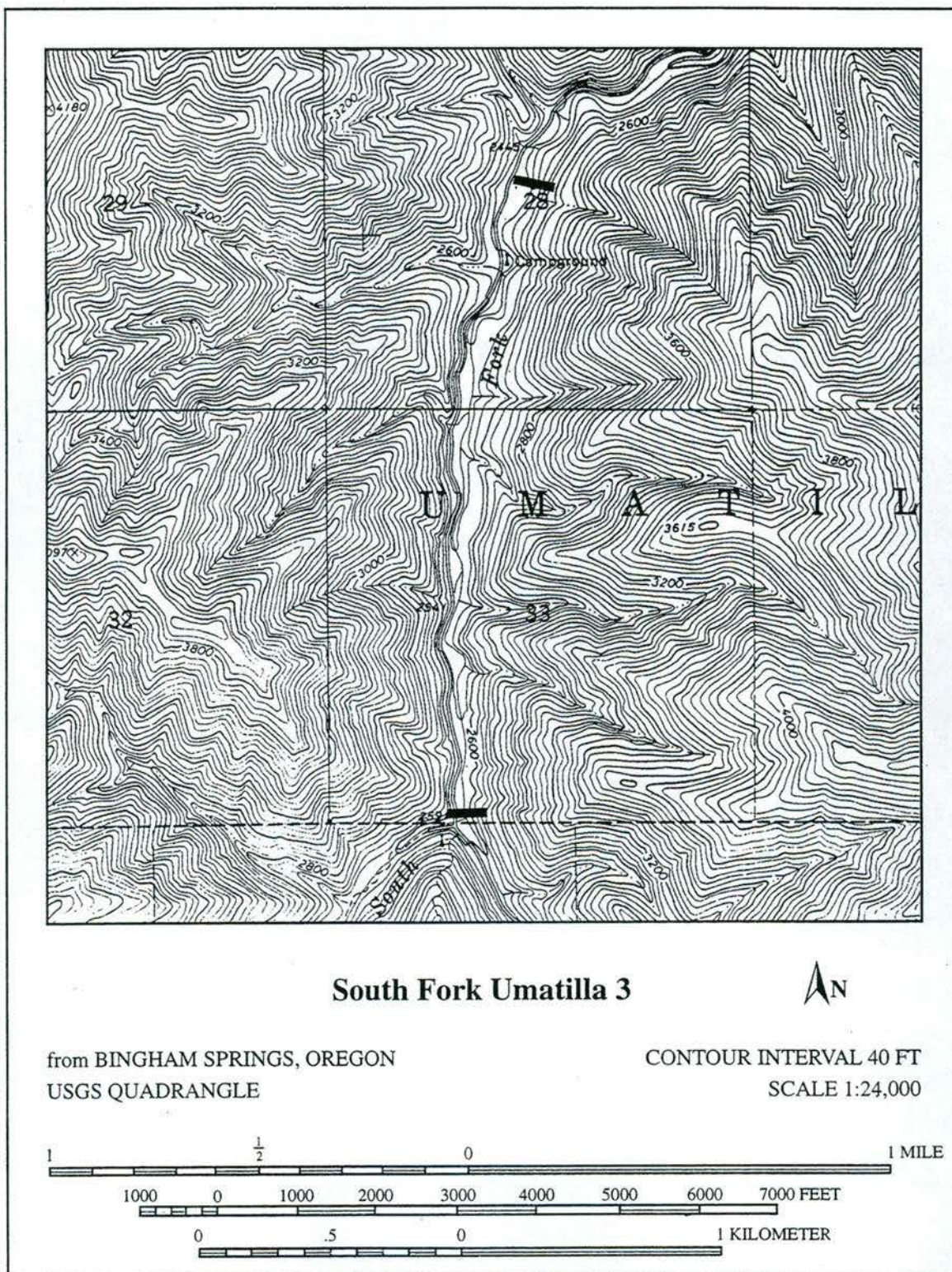


Figure 63. Map Showing Location of South Fork Umatilla 3.

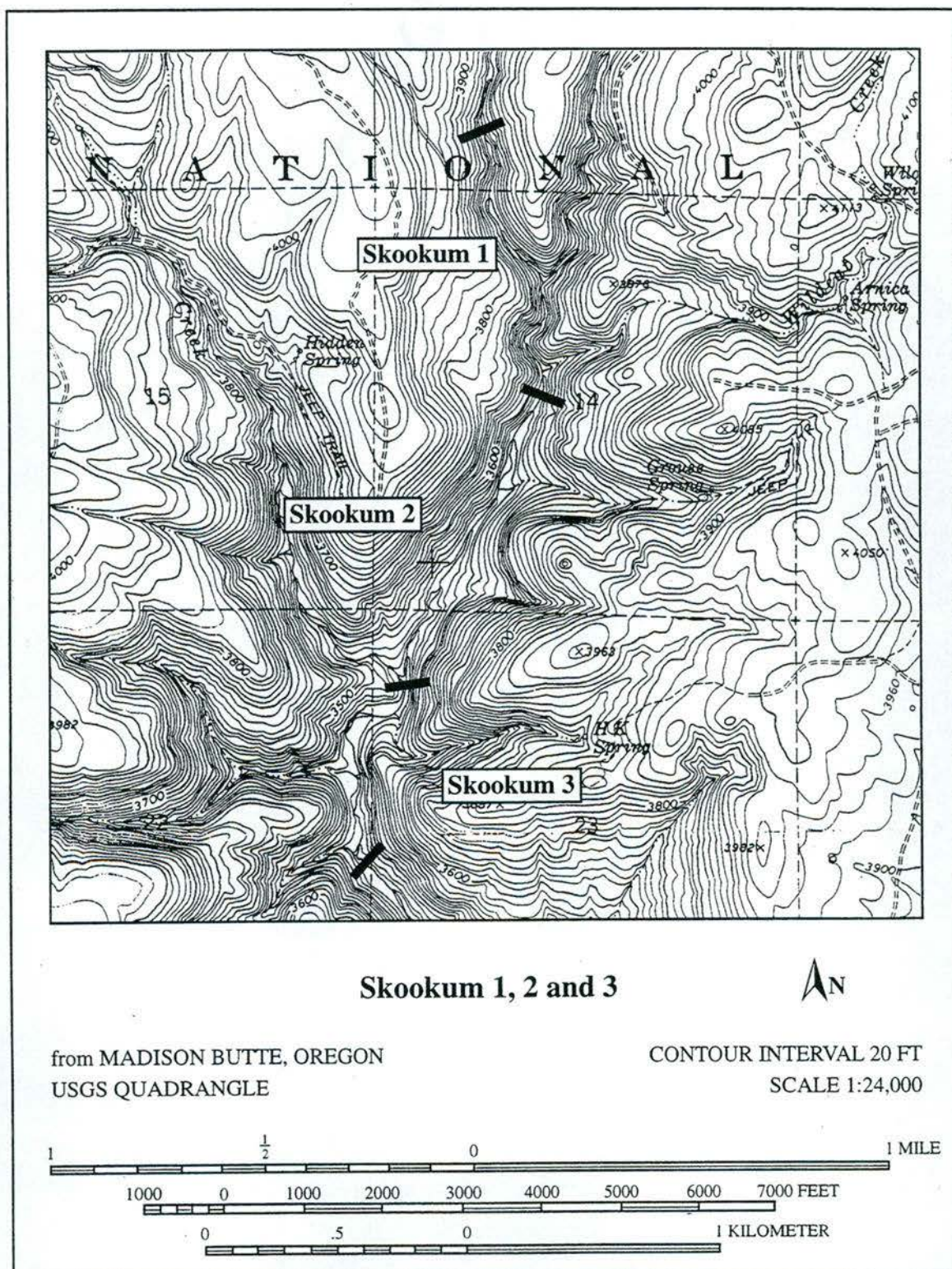
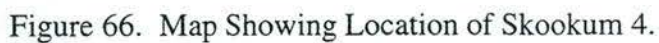


Figure 64. Map Showing Location of Skookum 1, Skookum 2 and Skookum 3.



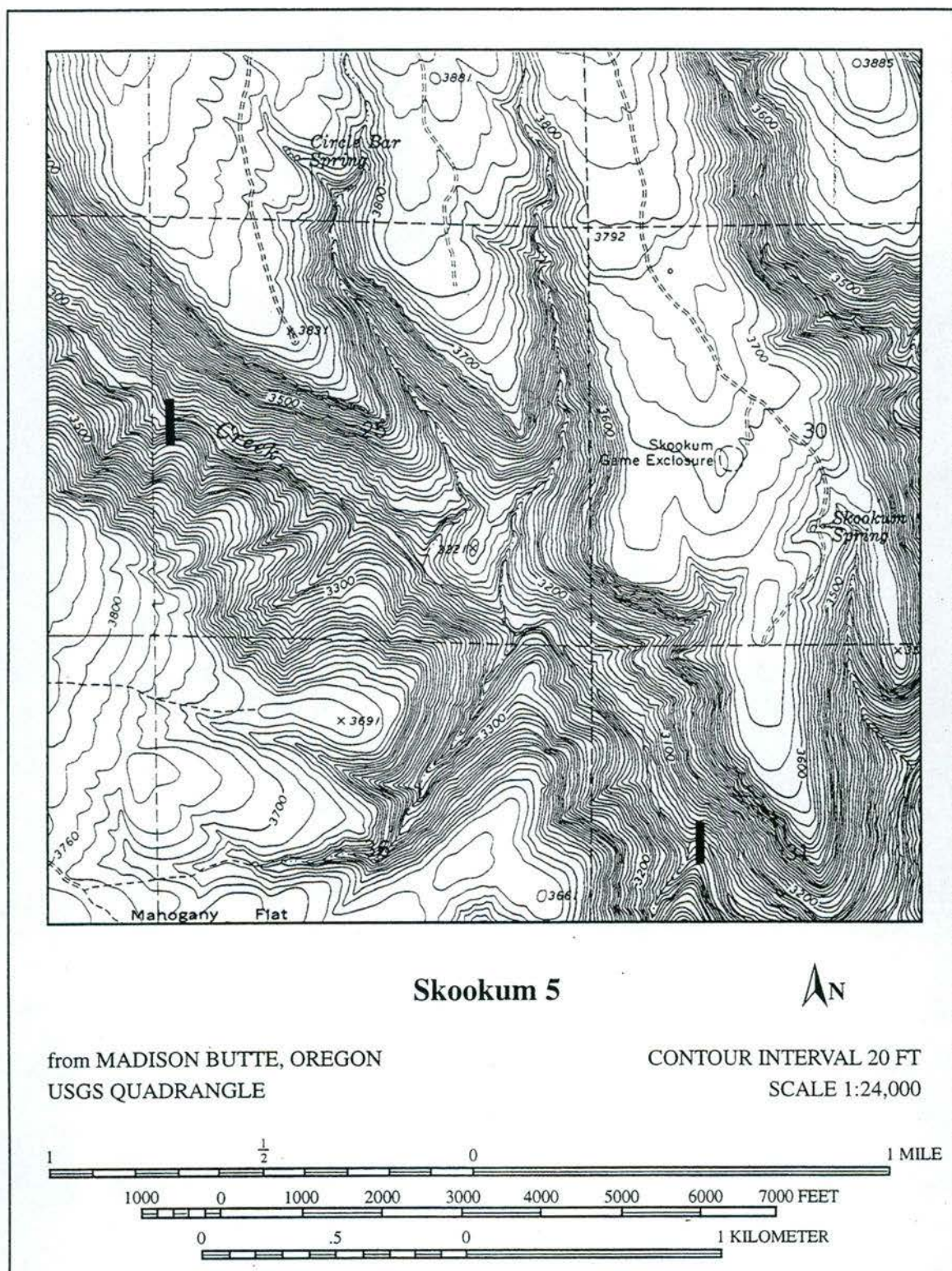


Figure 66. Map Showing Location of Skookum 5.

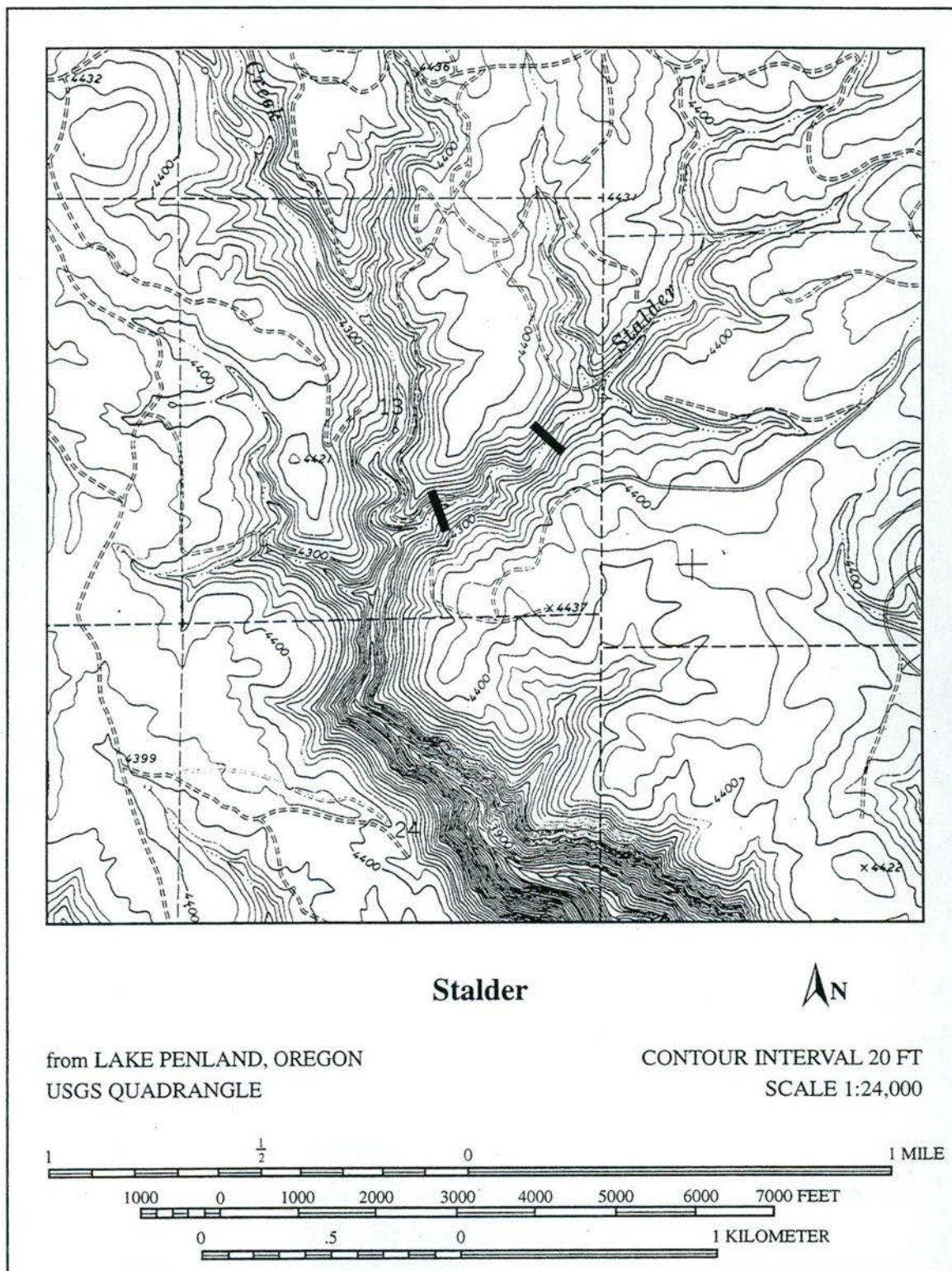


Figure 67. Map Showing Location of Stalder.

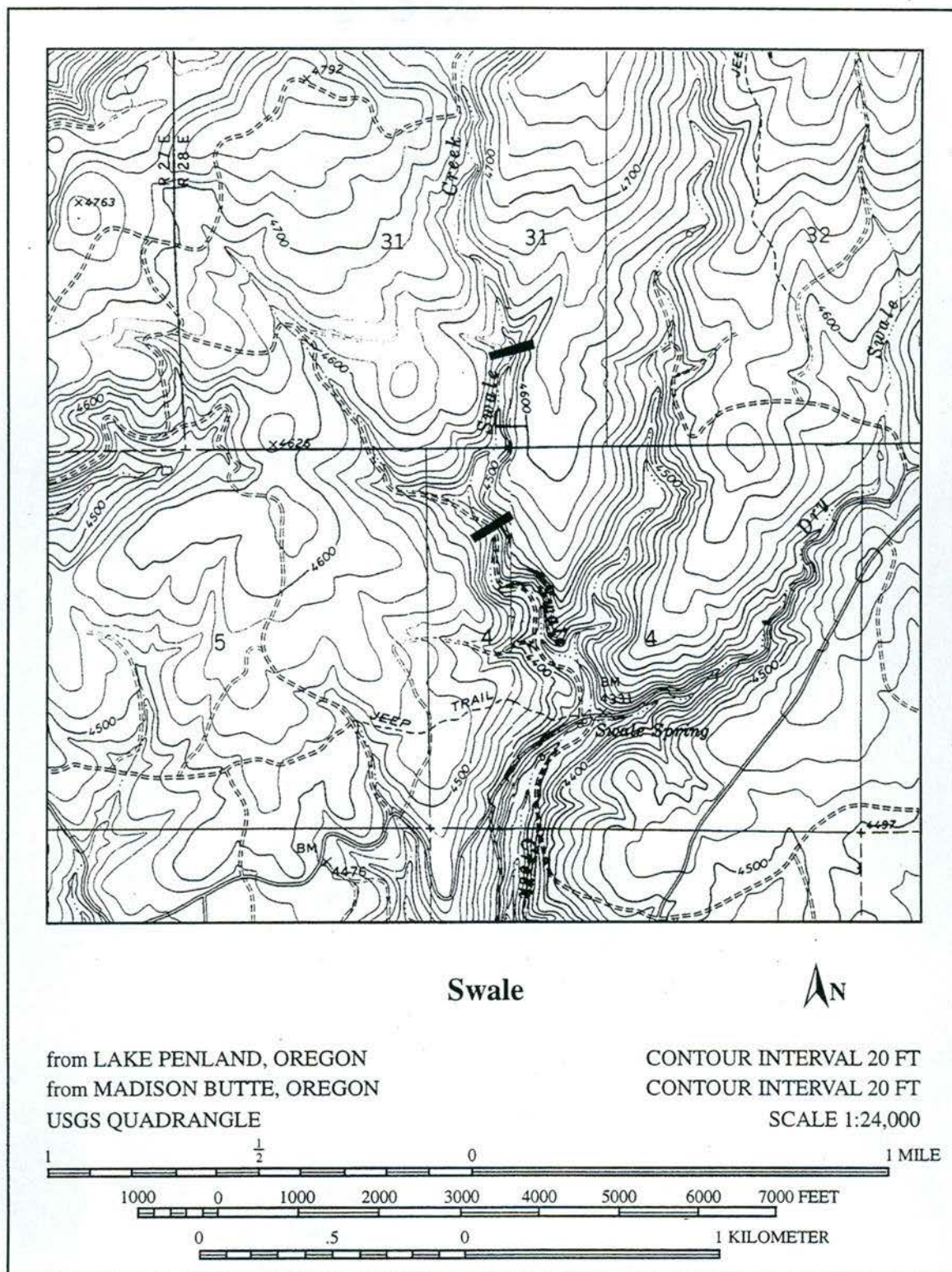


Figure 68. Map Showing Location of Swale.

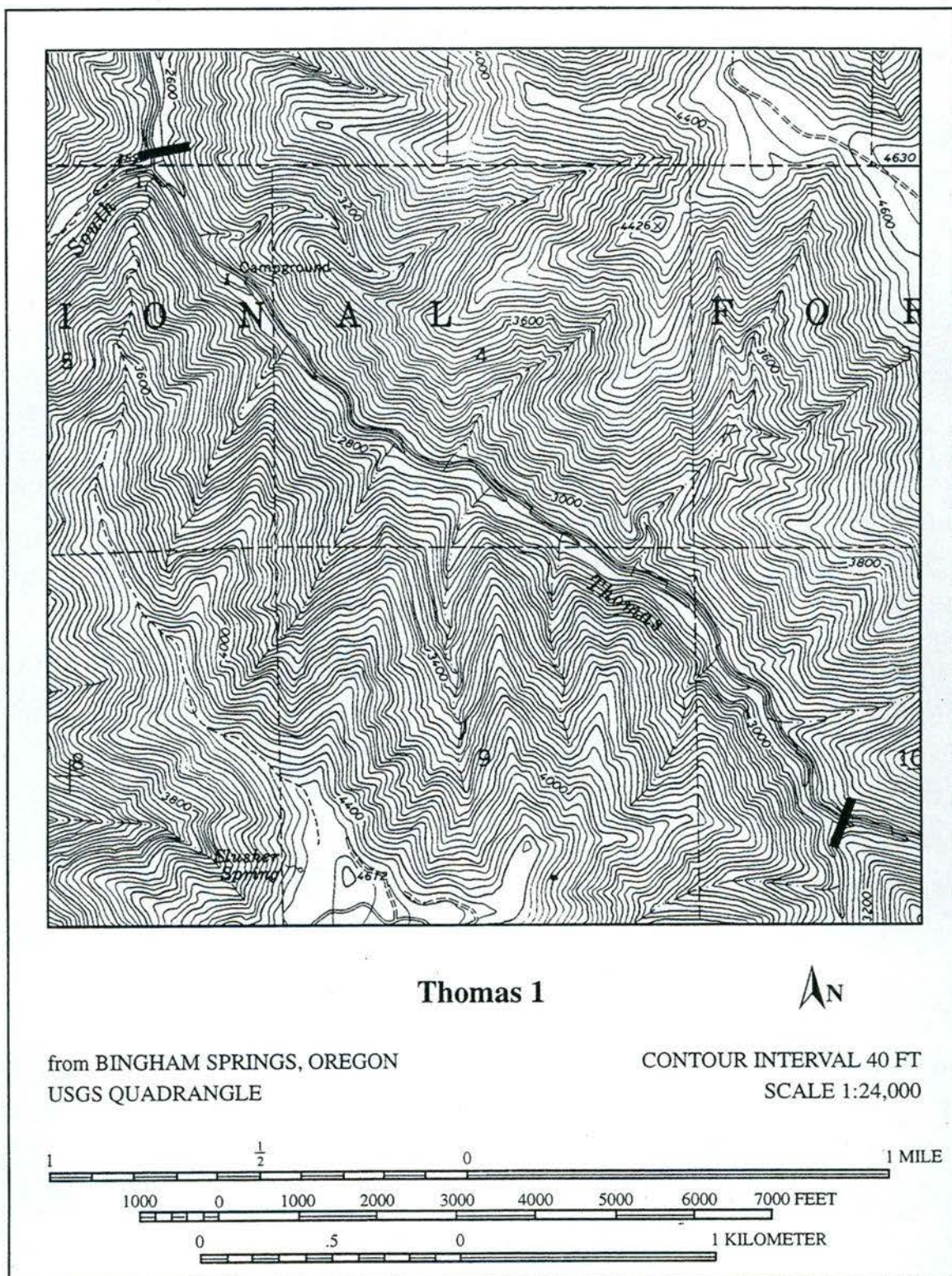


Figure 69. Map Showing Location of Thomas.

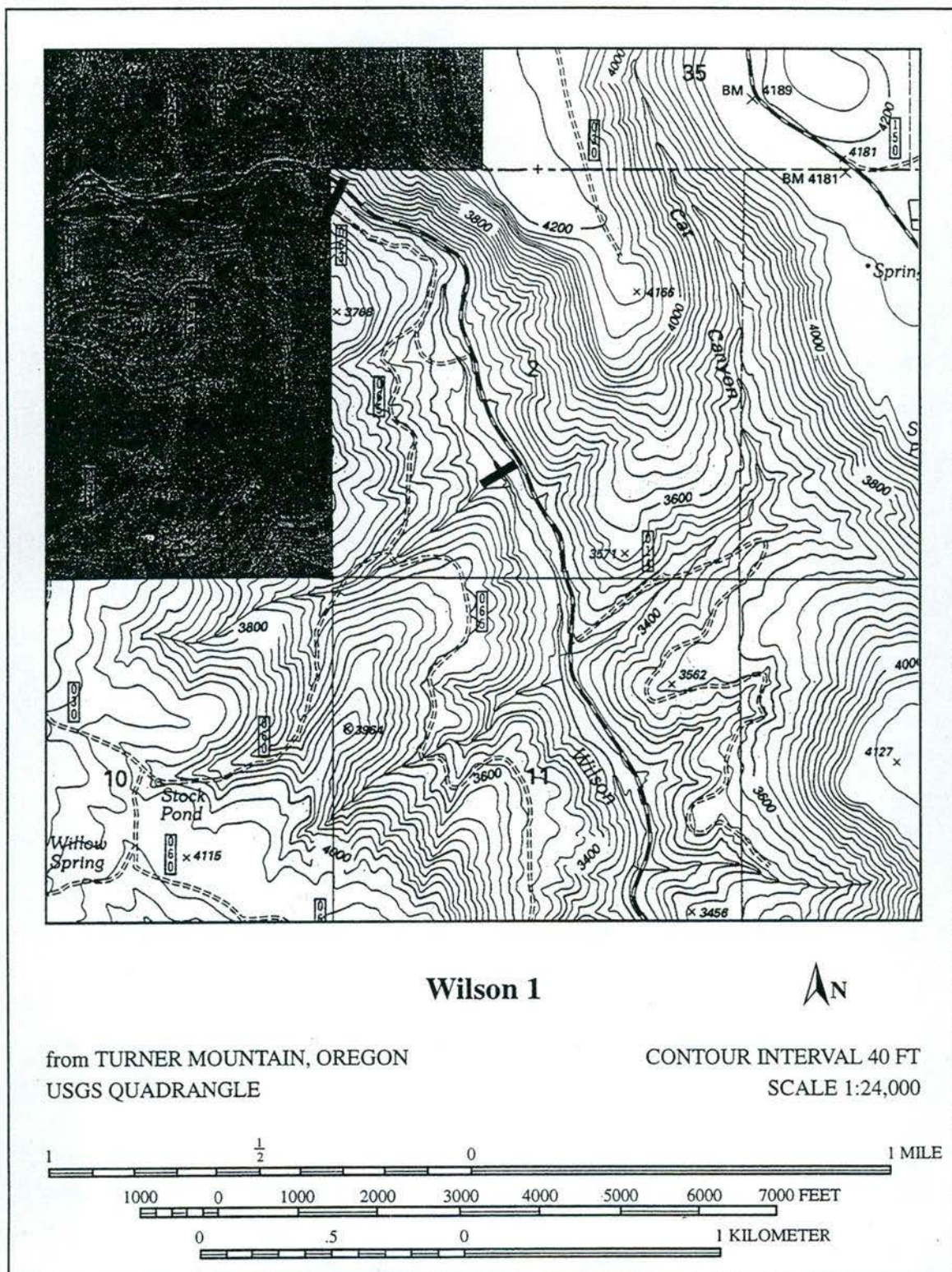


Figure 70. Map Showing Location of Wilson 1.

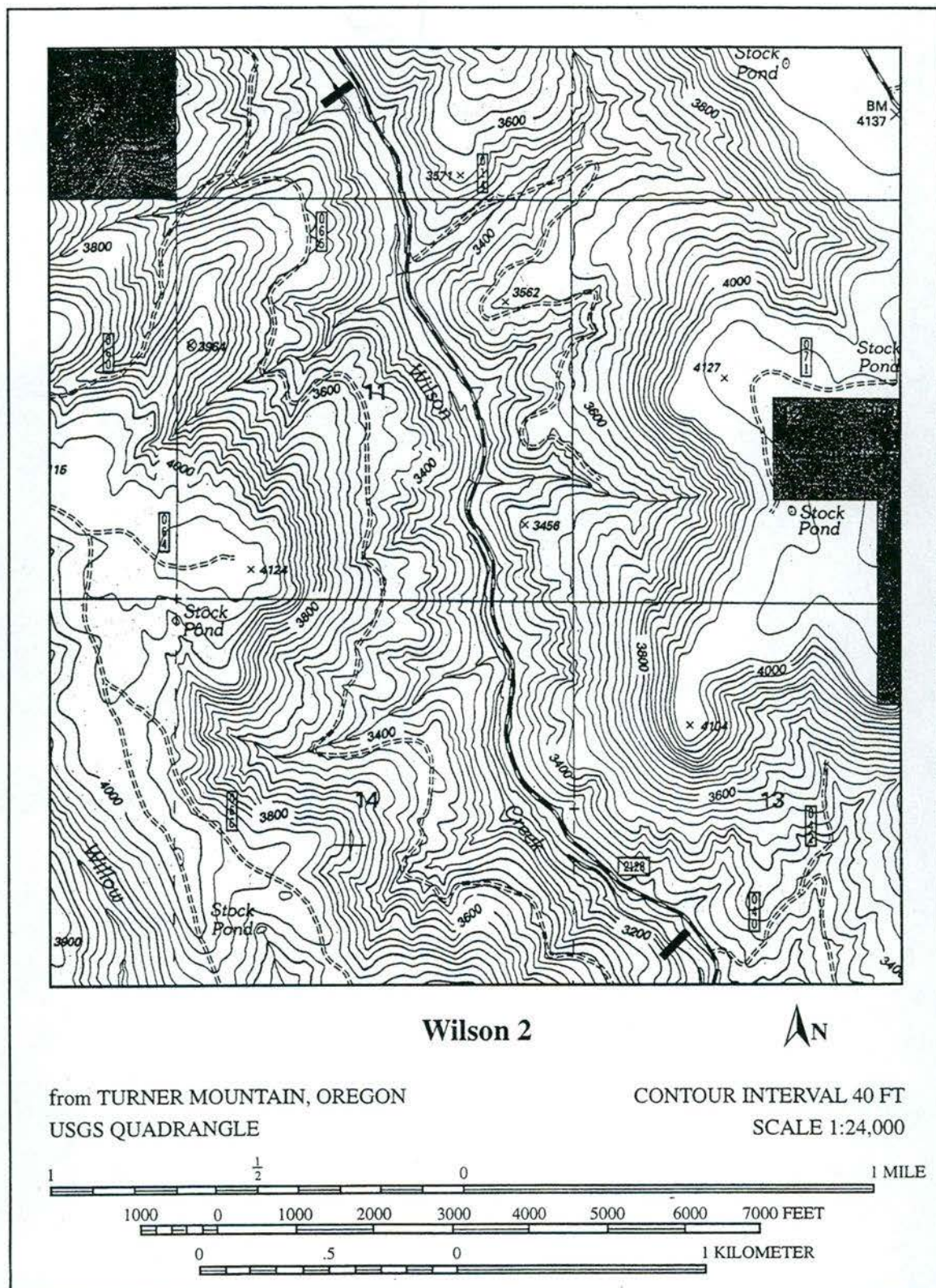


Figure 71. Map Showing Location of Wilson 2.

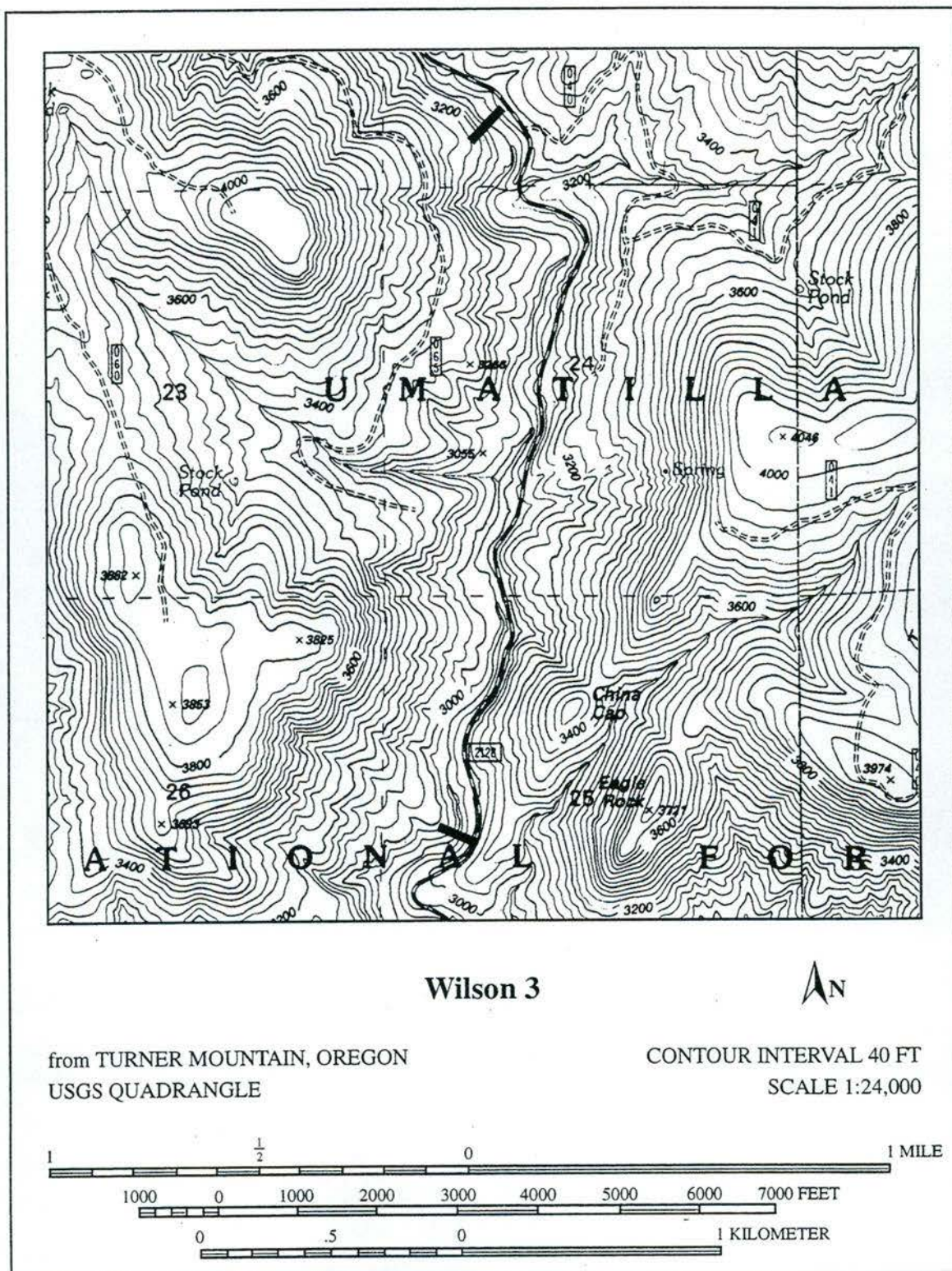


Figure 72. Map Showing Location of Wilson 3.

APPENDIX H

CHARACTERISTICS OF REACHES IN FOREST SERVICE DATA SET AND TAYLOR DATA SET FOR ANALYSIS OF ISS SURVIVAL AND ISS PERFORMANCE

Forest Service Data Set Stream Reach Name	Control Variables							
	Geology		Valley Constraint	Drainage Area (km ²)	Stream Order	Gradient	Sinuosity	Rosgen Stream Type
Alder 1	A	Tcp	U	27.08	2	3.8%	1.20	B
Alder 2	A	Tcp	C	25.64	2	7.0%	1.20	A
Bear Wallow Lower	A	Tcg	U	18.25	2	3.5%	1.15	B
Bear Wallow Upper	A	Tcg	U	8.76	1	1.6%	1.20	C
Big Wall 1	A	Tcg	U	176.08	4	2.8%	1.20	B
Big Wall 2	A	Tcg	U	49.16	4	1.9%	1.20	C
Camas	A	Tcg	U	173.80	3	2.6%	1.10	C
Charley	A	Tcg	U	9.97	3	5.0%	1.35	B
Cummins	A	Tcg	U	30.94	3	5.5%	1.35	B
Desolation	A	TRPv	U	85.40	3	2.8%	1.15	B
Ditch Upper 1	A	Tcg	U	31.63	3	1.7%	1.35	C
Ditch Upper 2	A	Tcg	C	32.87	3	2.7%	1.35	B
Ditch Lower 3	A	Tcg	U	48.50	3	2.5%	1.35	B
Ditch Lower 4	A	Tcg	C	50.37	3	2.8%	1.20	B
Dry Camas	A	Tcg	U	9.37	1	1.6%	1.10	C
Ellis	A	Tcg	U	18.00	2	4.4%	1.35	B
Hidaway 1	B	Tsfj	U	34.00	4	3.8%	1.20	B
Hidaway 2	B	Tsfj	U	32.44	4	2.5%	1.20	B
Kelsay 1	A	TRPv	U	3.78	3	1.6%	1.65	E
Kelsay 2	A	TRPv	U	1.37	3	2.3%	1.65	E
Lane	A	Tcg	U	38.18	2	3.6%	1.10	B
Little Wall 1	A	Tcp	U	20.95	3	3.3%	1.20	B

Forest Service Data Set Stream Reach Name	Control Variables							
	Geology		Valley Constraint	Drainage Area (km ²)	Stream Order	Gradient	Sinuosity	Rosgen Stream Type
Little Wall 2	A	Tcp	C	25.31	3	3.1%	1.20	B
Little Wall 3	A	Tcp	U	30.29	3	1.2%	1.20	C
Meacham	A	Tcg	U	58.92	5	1.6%	1.35	C
N. Fork Cable	A	Tsfj	U	16.14	3	2.0%	1.50	E
Phillips	A	Tcg	U	25.77	3	2.6%	1.10	B
Porter 1	A	Tcp	U	21.86	2	2.4%	1.35	B
Porter 2	A	Tcp	U	28.18	2	4.4%	1.35	B
Skookum 1	A	Tcp	C	26.55	3	6.1%	1.35	A
Skookum 2	A	Tcp	C	49.54	3	3.6%	1.35	B
Skookum 3	A	Tcp	U	58.78	3	1.9%	1.40	C
Skookum 4	A	Tcp	U	64.77	3	2.4%	1.20	B
Skookum 5	A	Tcp	C	73.33	3	3.7%	1.20	A
Stalder	A	Tcp	U	9.03	1	4.7%	1.35	B
Swale	A	Tcp	U	13.06	1	4.0%	1.35	B
S. Fork Umatilla 1	A	Tcg	U	138.77	5	1.7%	1.10	C
S. Fork Umatilla 2	A	Tcg	U	121.68	5	1.5%	1.10	C
S. Fork Umatilla 3	A	Tcg	U	115.88	5	1.9%	1.10	C
Thomas	A	Tcg	U	41.48	4	2.0%	1.10	B
Wilson 1	A	Tcp	U	77.33	3	4.6%	1.30	B
Wilson 2	A	Tcp	U	86.99	3	2.0%	1.30	C
Wilson 3	A	Tcp	U	99.37	3	1.9%	1.30	C

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