APPENDIX H: WOODLAND CREEK FISH HABITAT ANALYSIS

ANALYSIS OF EXISTING FISH HABITAT IN A PORTION OF WOODLAND CREEK, THURSTON COUNTY, WASHINGTON

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INTRODUCTION:

Stormwater management plans generally have limited analysis of the positive or negative effects of various management options on fisheries resources of urban streams. In particular, there have been few estimates of available fish habitat before or after implementation of the management option. As such, managers have had little information to evaluate the cost/benefits of various management options.

To provide this information, we integrated fisheries and engineering methods to examine existing fish habitat and review proposed stormwater management options. In particular, we are interested in the implications of various design flows and detention standards on protecting existing fish habitat. For our analysis, we selected a reach of Woodland Creek to:

1. identify the quality and quantity of existing fish habitat.
2. quantify specific fish habitats at different flows.
3. review the effectiveness of three proposed storm water management options in maintaining existing fish habitat.

The selected study reach was from Pleasant Glade Road upstream to Draham Road (approximately River Mile 1.5 to 3.0), a reach with mixed residential and open space land use. The reach was chosen because it is in a zone where residential development is likely (the currently-designated Urban Growth Boundary), it is downstream of currently developed areas, and corresponds to a discrete sub-basin used in the hydrologic modeling for the Woodland Creek basin plan.

METHODS:

The instream habitat of the study reach was inventoried by walking the entire reach on October 31, 1991. Fish habitat was inventoried using classifications described in the U.S. Forest Service Fish Habitat Relationships Program (U.S.F.S. 1990). Lineal distance, average width and depth were measured in each habitat unit.

The quantity of fish refuge habitat available during storm flows was estimated using the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM) (Bovee 1982), with computer programs from the Physical Habitat Simulation System (PHABSIM) (Milhous et. al. 1989). Refuge habitat was estimated through a two step process: a hydraulic model and a habitat model.

The IFG4 hydraulic model estimates the range of stream depths and velocities across a set of cross-sections for a range of flows. From the summary of habitat inventory, eight transects representing the major habitat types present in the study reach were selected for modeling. The transects were weighted proportionally to reflect the amount of that habitat type in the study reach. In addition, the transects were divided evenly (four each) between the rural and residential reaches to compare differences in habitat between these reaches.

The hydraulic model was calibrated using standard procedures (Bovee 1982; Milhous et al. 1989). A stage-discharge relationship was developed using a combination of available observations from the USGS gage, measured water surface slopes and Manning's equation. The range of flows modeled, 5 to 400 cfs, represents the present and future flows of interest (less than the 1-year storm to approximately the 100-year recurrence interval). Estimates of future flows were predicted by the Hydrological Simulation Program - Fortran (HSPF) hydrologic simulation model (M. Fisher, Thurston Co., pers. comm. 1991).

A weighted index of available storm refuge habitat was estimated using the HABTAE habitat model. For each modeled flow, the HABTAE model compares the array of depths and velocities predicted by the IFG4 hydraulic model with defined habitat criteria. The weighted index is the portion of total stream volume having particular combinations of depth and velocity, multiplied by the habitat preference weighing factor for each combination. This procedure calculates the volume of suitable habitat within the total water volume of the simulated reach. Bovee and Cochnauer (1977) discuss the idea of a weighted habitat index.

Storm refuge habitat was defined as channel areas with depths of 0.5 ft or more with various mean column velocities (up to a maximum of four feet per second). These criteria were obtained from literature information on swimming abilities and habitat preferences of small salmonids (less than 6 in. in length) (Ottaway and Clarke 1981; Hickman and Raleigh 1982; Powers and Orsborn 1985; Bell 1986; Belford and Gould 1989; Washington Dept. of Fisheries 1990; Bjornn and Reiser 1991). These smaller fish were chosen because we believe that they would be most affected by the high velocities present during storm flows. The habitat criteria were refined using professional judgement following methods outlined by Bovee (1986).

Depths and velocity preferences were defined for three different refuge habitat types in Woodland Creek. These are: cover associated with instream log debris (debris refuge); cover in and among streambank vegetation with bankfull and overbank flows (bank refuge); and simple instream cover not associated with debris complexes or other cover (instream refuge). Preferred velocities were defined as those against which small salmonids could swim for extended periods of time. Preferred velocities were set higher in the debris complex units because we assumed that the hydraulic complexity created by the debris provides refuge within the habitat unit even at higher mean-column velocities.

Preferred velocities for streambank refuge were set at values intermediate to the other two cases. Bank cover in Woodland Creek was primarily grasses, small bushes, and in the residential section, ivy plantings over riprap. We believe that while bank cover provides velocity shelter as streamflows increase, the vegetation was not large enough to provide shelter similar to that provided by debris complexes. Other types of refuge cover such as large boulders or cobble substrates were not present in this reach of Woodland Creek.

Analysis of the model output focused on:

1. estimating the quantity of existing refuge habitat in this reach of Woodland Creek.

2. determining what type of cover provided the most refuge habitat at a given flow.

3. investigating differences in refuge habitats between the rural and residential section.

4. estimating the quantity of future refuge habitat with three stormwater management options.

SITE DESCRIPTION:

The land use in the study reach consists of rural and residential land use (approximately a 60/40 ratio by length). The rural section extends from Pleasant Glade Road upstream to 21st Court N.E. Residential development exists from 21st Court N.E. upstream to Draham Road.

From Long Lake (approximately 165 feet in elevation), Woodland Creek flows for 5.1 miles before entering Henderson Inlet of lower Puget Sound. The average slope over this length is 0.5 percent. The stream gradient in the study reach ranged from 1 to 3 percent.

The stream substrate consists mostly of sand and small gravels (0.5 - 1.5 inch gravels). The substrate downstream of 21st Court NE was mostly sand with patches of gravel. Upstream of 21st Court NE, the stream gradient increases slightly (1-2 percent to as much as 3+ percent). In this reach, the substrate contains more gravel. Both the patch gravels of the rural reach and the areas with gravel substrate in the residential reach appear suitable for salmonid spawning.

The soils of the stream banks were primarily sand and silty soil with few cobbles or boulders evident. The soils are silt and silt clay loams with slopes of 15-30 percent (Pringle, 1990). In several locations, small areas with slumping or eroding streambanks with cuts up to two feet high were observed.

Coho (*Oncorhynchus kisutch*), chum (*O. keta*) and chinook salmon (*O. tshawytscha*) are known to utilize this stream system (Williams et. al., 1975). It is likely that steelhead (*O. mykiss*) and cutthroat trout (*O. clarkii*) also utilize this system. Adult chum and coho salmon were observed during the October habitat survey.

The riparian corridor consists primarily of native vegetation that varies from a few feet to over 100 feet in width. Dominant riparian vegetation is red alder (*Alnus rubra*), willows (*Salix sp.*) and Himalayan blackberries (*Rubus discolor*). Other vegetation includes Douglas fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), salmonberry (*Rubus spectabilis*), red-osier dogwood (*Cornus stolonifera*), cottonwood (*Populus trichocarpa*), big-leaf maple (*Acer macrophyllum*), and sword fern (*Polystichum munitum*).

RESULTS OF THE HABITAT SURVEY:

Approximately 7200 feet of stream was inventoried. Over this length, the stream averages 21 feet in width and 1.0 foot in depth (Table 1). The channel is generally U-shaped with stream banks that vary from less than two feet to more than six feet in height.

Table 1. Summary statistics of 109 habitat units identified in Woodland Creek from Pleasant Glade Road upstream to Draham Road. Total distance surveyed approximately 7200 feet. All distances are in feet.

	Length	Width	Depth
Average	46*	21	1.0
Minimum	9	8	0.5
Maximum	348	50	4.0

*Median value: average length of all habitat units was 68 feet.

The various habitat types identified in Woodland Creek are described in Appendix A. While nine different habitat types were identified, the existing habitat is mostly run-riffle complex (Table 2; Figure 1; Appendix B). This habitat type accounts for 39 percent of the total length, 40 percent of the total area, and 32 percent of the volume of this reach. Fourteen of the 19 longest habitat units (each more than 100 feet in length) are runs or riffles. At low to moderate flows, these areas contain a meandering thalweg (flow path) that provides a fair amount of hydraulic diversity as deeper and shallower areas alternate. Additional habitat is provided in these areas by overhanging vegetation.

Figure 1. Summary of existing habitat in Woodland Creek between Pleasant Glade Rd. and Draham Rd. Length of survey reach: 7230 feet.

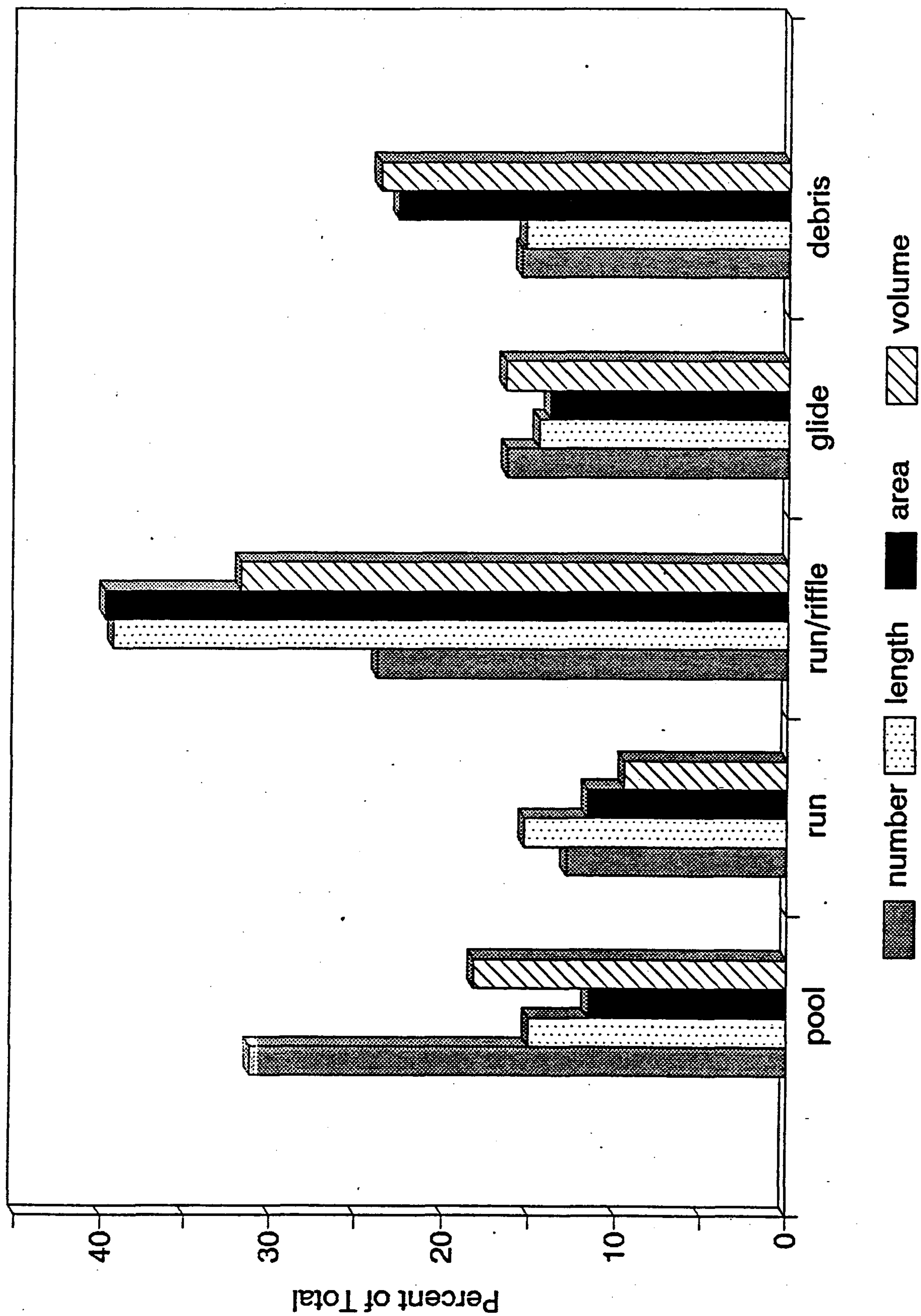


Table 2. Summary of the 109 habitat units identified in Woodland Creek between Pleasant Glade Road (RM 1.5) and Draham Road (RM 3.0). Inventory date: October 31, 1991.

Habitat Type	No. of Units	% of Total	Total Length (ft.)	% of Total	Total Area (ft^2)	% of Total	Total Volume (ft^3)	% of Total
Run-riffle Complex	26	24	2913	39	60550	40	55704	32
Debris Complex	17	16	1141	15	34495	23	41603	24
Pools	34	31	1114	15	17562	12	31891	18
Glides	18	17	1077	15	21170	14	28938	17
Run	14	13	1133	15	17679	12	16564	9
Total	109		7378		151456		174699	

Thirty-four pools of four different types were identified. Lateral scour and mid-channel pools account for nearly 80 percent (27 of 34) of the pools. Of the various pool types, scour pools generally have the fastest water velocity, and as such, provide limited refuge areas during higher flows.

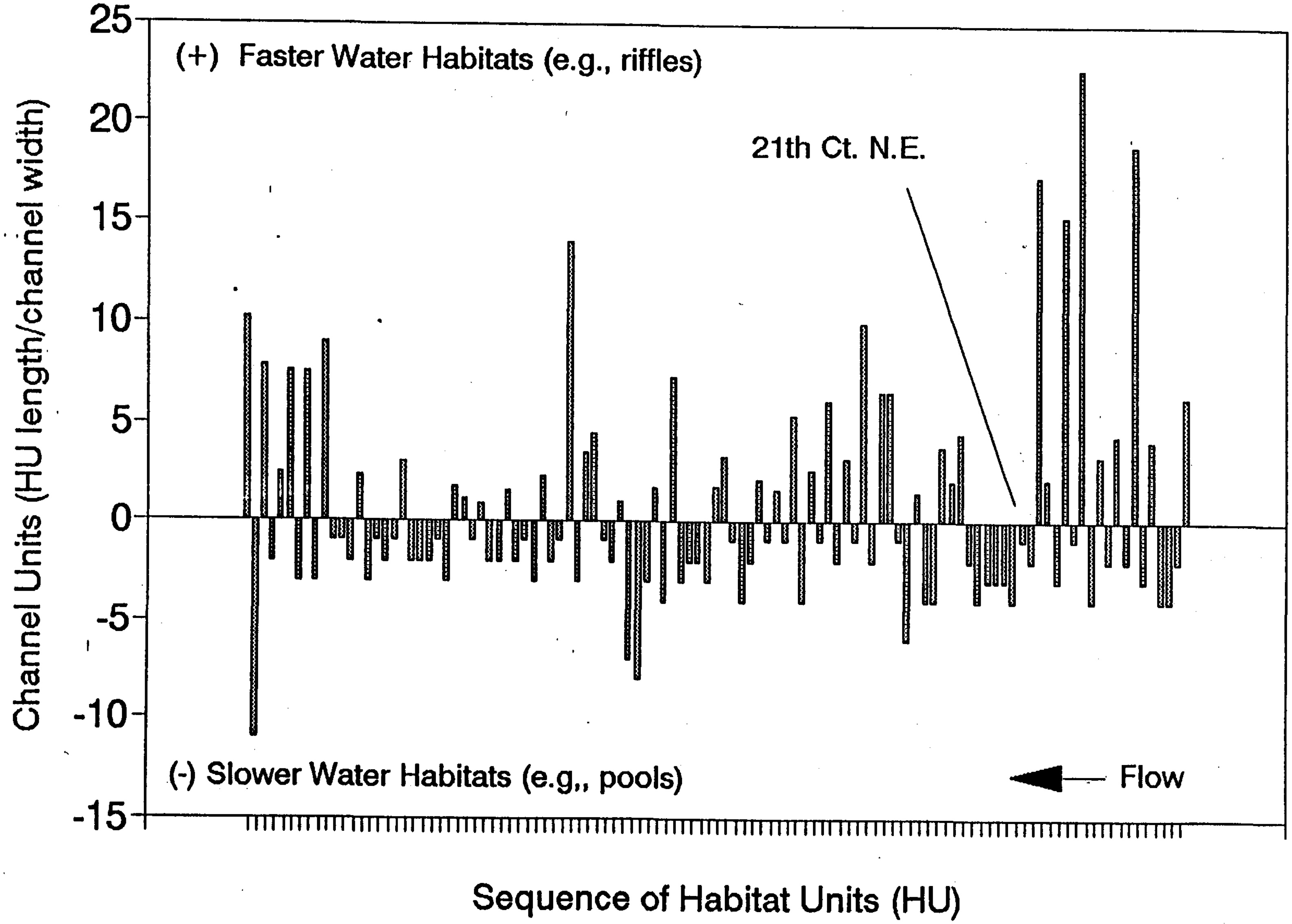
Nearly 80 percent of the habitat units (86 of 109) had an average depth of one foot or more; nearly 60 percent (64) had a maximum depth of two feet or more. The maximum water depth found during this survey was four feet.

Much of the fish habitat, especially in the rural section, is formed by large organic debris (LOD). In Woodland Creek, instream LOD occurred not as single trees, but often as debris complexes that were 10 to 80 feet in length. These complexes consisted of both large and small debris; the largest debris observed was estimated to be over three feet in diameter. The hydraulic complexity of this habitat is valuable both as refuge and rearing areas.

It is generally assumed that alternating slower and faster water habitats (pool to riffle ratios of 50/50 to 40/60) provides the most complete habitat for stream dwelling fish. In gravel-bedded streams, pools and riffles are regularly spaced at distances equal to 5 to 7 channel widths (Leopold et. al., 1964; Brookes, 1988). Overall, the study reach is evenly balanced between slower and faster water habitats; the ratio of slower water to faster water for the entire survey reach is 41/59 (Fig. 2). While the ratio for the entire reach is balanced, the habitat ratios of rural and residential reaches are very different. The habitat of the residential reach is mostly fast water habitat (slow water/fast water habitat ratio of 33/77). Conversely, the habitat of the rural reach has a balanced ratio (47/53). Only eight of 109 habitat units in the survey reach are more than 10 channel widths in length (approximately 200 feet). Of these, only four units are more than 15 channel widths.

No potential fish passage problems were identified in the study reach. Overall, the quality of the habitat in this reach of Woodland Creek appears very good.

Figure 2. Sequencing of habitat units in Woodland Creek between Pleasant Glade Rd. and Draham Rd. Lenght of survey reach: 7230 feet. Average width of survey reach: 21 feet. See text for discussion.



RESULTS OF HYDRAULIC & HABITAT MODELING:

The existing refuge habitat in this reach of Woodland Creek varies from over 60 percent of the total stream volume at low flows to 10 percent at 100-year storm flows (Fig. 3). The volume of refuge habitat gradually declines from 50 percent at the 1-year storm to approximately 20 percent at the 10- year storm flow. At flows greater than the 25 year storm, refuge habitat continues to gradually decline to less than 10 percent at extreme flows.

The refuge habitat in Woodland Creek consists of debris, instream and bank refuge habitat. When the contribution of these three habitat types are separated, the relative importance of instream LOD and log debris complexes is clearly demonstrated (Fig. 4). Debris refuge provides the most habitat over the range of flows modeled. This is because of the complex hydraulics within debris complexes provide shelter even at relatively high velocities. Instream cover, present mostly at very low flows, tapers off quickly and remains low at flows greater than the present 2-year storm. Bank refuge cover, which by definition becomes available at higher flows, is present only at moderate volumes at flows greater than the 2-year storm.

There are significant differences in the volume of refuge habitat between the residential and rural reaches (Fig. 5). In the residential reach, less than 10 percent of the total stream volume is suitable refuge at storms greater than the 1-year event. As noted above, the habitat in the residential reach was run and glide habitats (i.e., faster water habitats); debris complexes were uncommon.

The rural reach, with more debris complexes and the hydraulically complex run-riffle habitat, provides substantially more refuge habitat than the residential reach. Over 60 percent of the total stream volume in the rural reach is suitable habitat at the 1-year storm. While refuge habitat gradually declines with increasing storm events, the percentage remains near 20 percent even at the 100-year event.

It should be noted that while the estimates of refuge habitat in Figures 3 and 5 have similar patterns, the estimates of refuge habitat in the two figures are not additive. While refuge habitat in both graphs is expressed as the percent of total stream habitat, the reaches are slightly different in length.

The quantitiy of refuge habitat at future 2-, 10- 25- and 100-year flows with three stormwater management options was also examined. All three options are for maximum build-out conditions within the drainage basin. The three options examined were:

1. Service Level 1: Future flows with provisions as specified by provisions in the Thurston County design manual.

2. Service Level 2: Future flows with 804 acre-feet of detention (approximate existing storm flows).

3. Service Level 3: Future flows with 1459 acre-feet of detention storage.

With Service level 1, future storm flows are predicted to increase 38 to 66 percent over existing storm flows (Table 3). Compared with existing flows, future storm flows with Service level 2 would be 1 to 16 percent less than existing flows. Finally, Service level 3 would reduce future storm flows by 40 percent or more at all storm flows.

Figure 3. Estimated total refuge habitat in Woodland Creek between Pleasant Glade Rd. and Draham Rd.

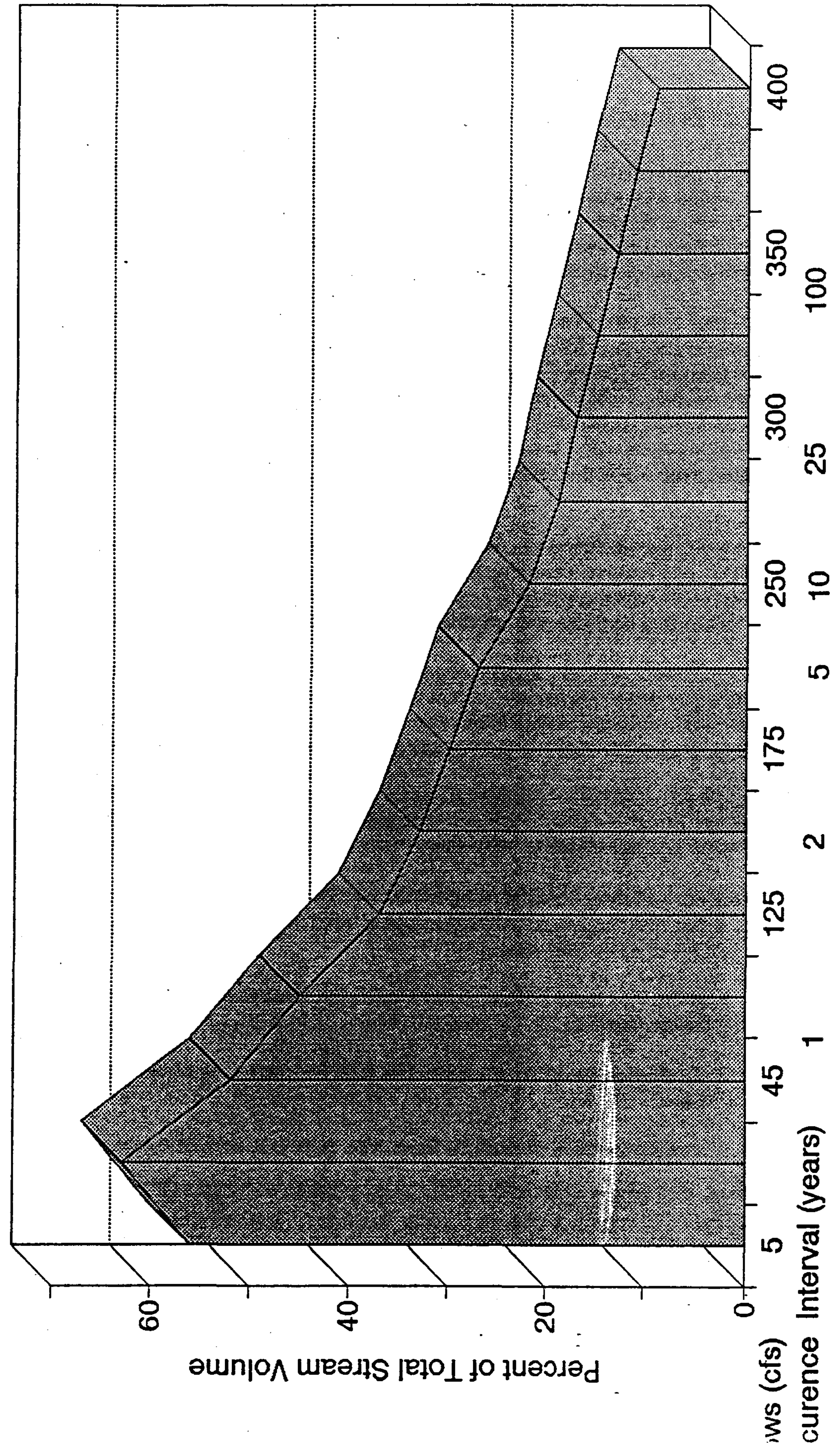


Figure 4. Estimated total refuge habitat provided by three different habitat types in Woodland Creek between Pleasant Glade Rd. and Draham Rd.

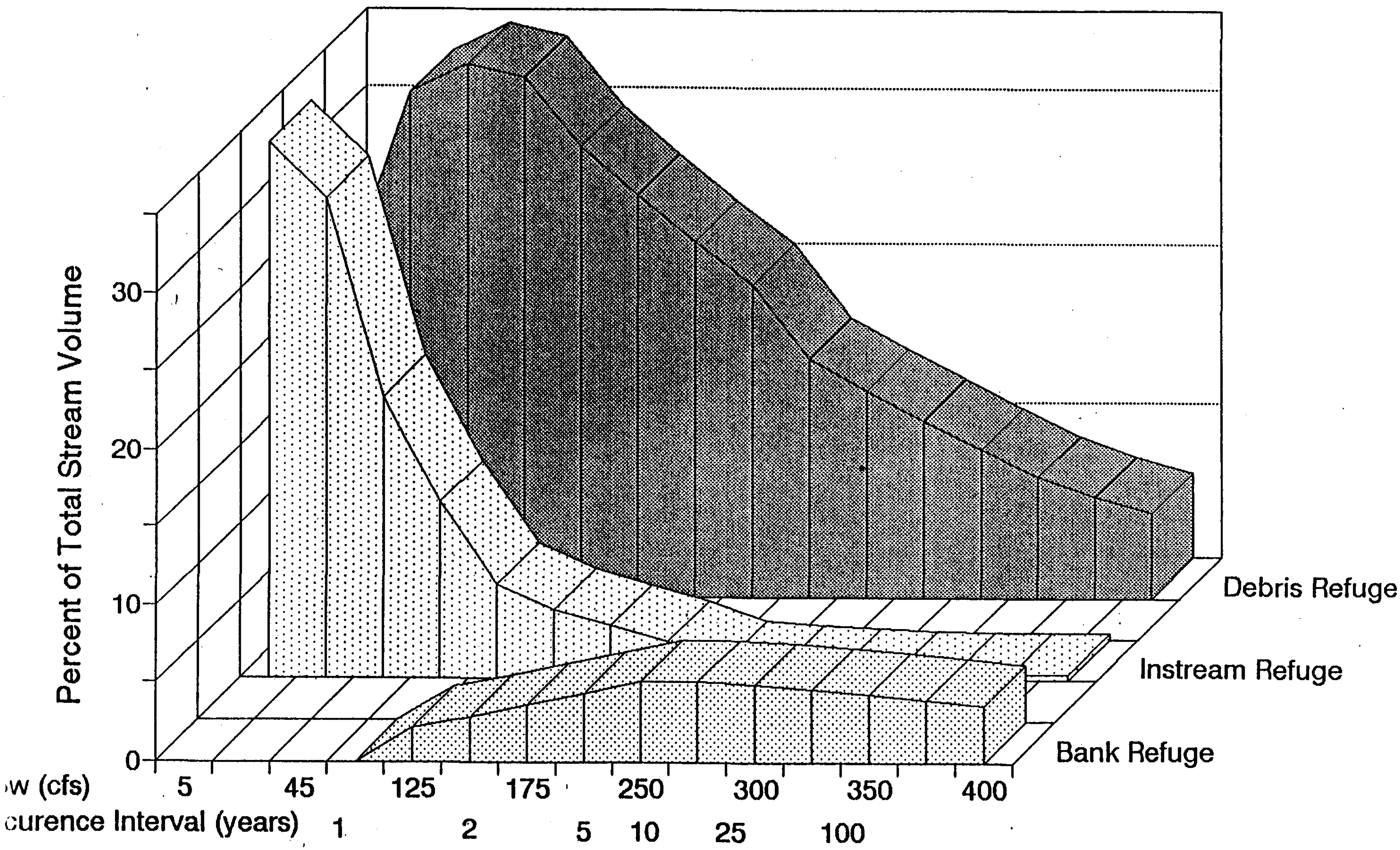


Figure 5. Estimated total refuge habitat in two sections of Woodland Creek between Pleasant Glade Rd. and Draham Rd. Stream sections divided by landuse in riparian coridor. See text for discussion.

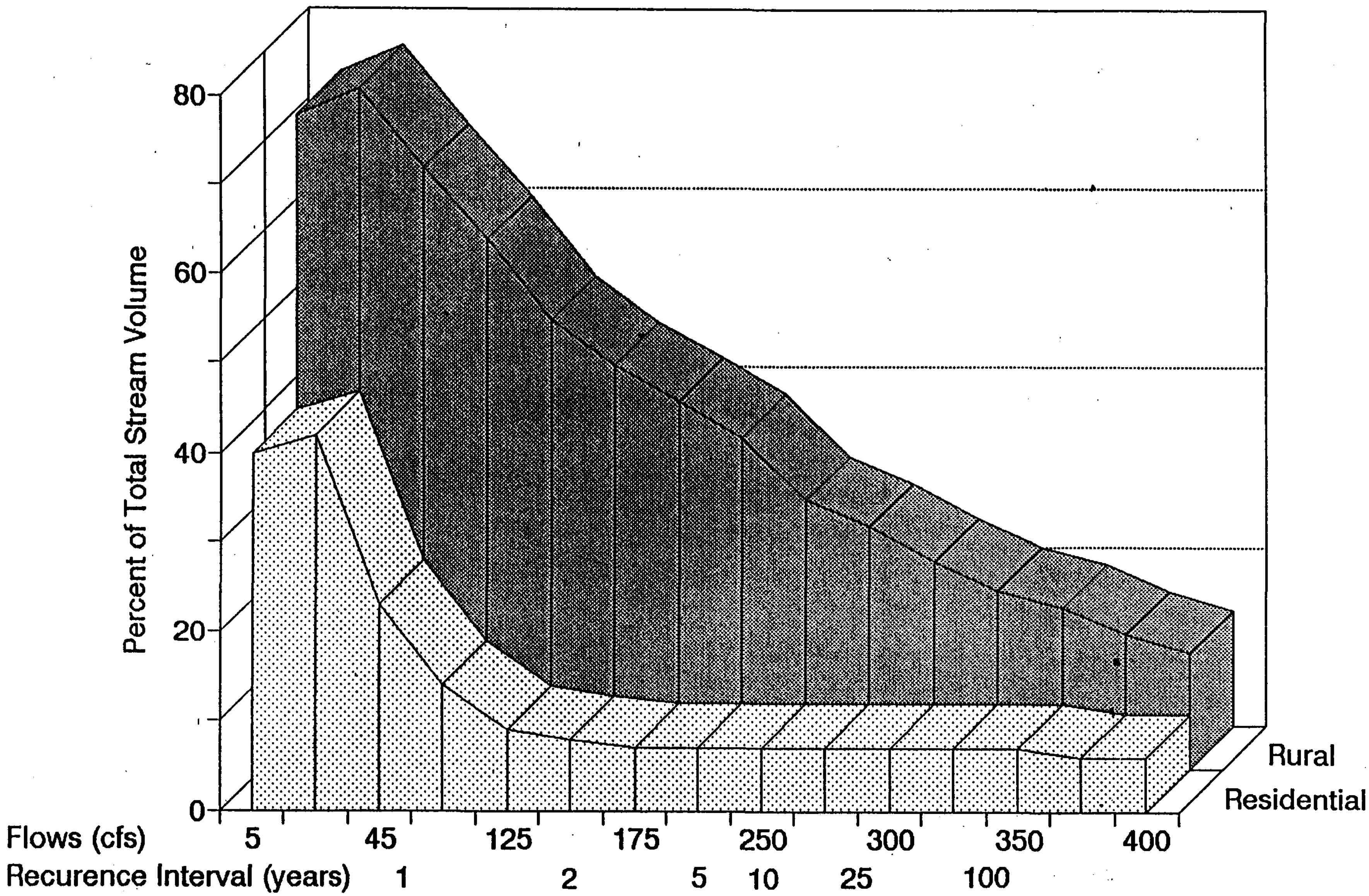


Figure 6. Estimated total refuge habitat in Woodland Creek at future flows with three levels of service. See text for discussion and description of levels of service.

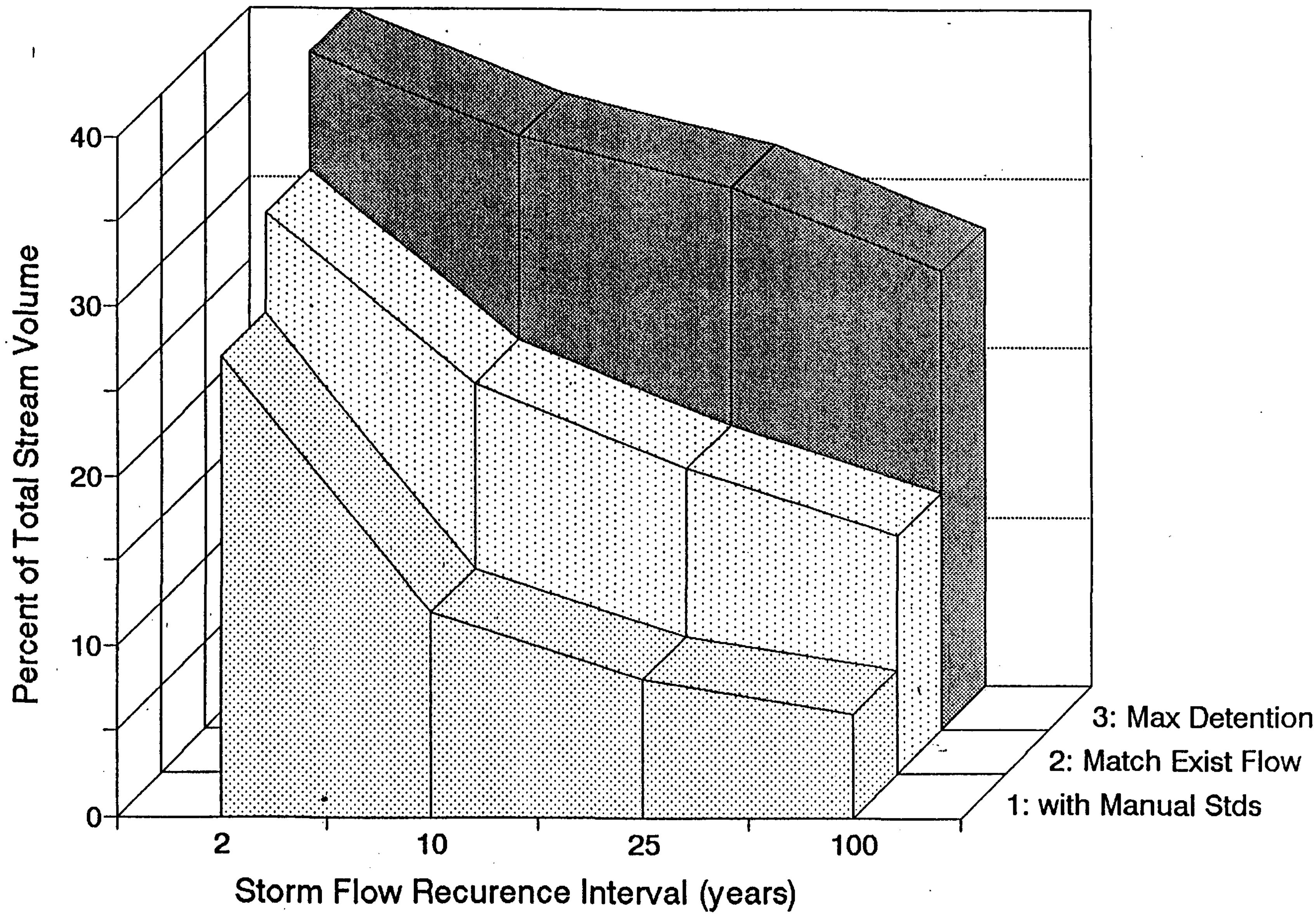


Table 3. Existing and future stream flow in Woodland Creek at Pleasant Glade Road. Predicted future flows at full build-out conditions with three stormwater management options. All flow values in cubic feet per second. (xx) indicates the percent change from existing flows.

Storm Return Interval (years)	Existing Flows	Service Level 1	Service Level 2	Service Level 3
2	155	214 (+38)	130 (-16)	92 (-41)
10	244	367 (+50)	210 (-14)	138 (-43)
25	284	444 (+56)	255 (-10)	162 (-43)
100	336	559 (+66)	333 (-1)	200 (-40)

Of the three stormwater options, Service Level 1 provides the least refuge habitat; less than 20 percent of the total stream volume is suitable refuge habitat at all flows greater than the two-year flow (Fig. 6). With Service Level 2, the refuge habitat gradually declines from 30 percent at the two-year flows to approximately 10 percent at the 100-year storm. This is slightly more refuge habitat than available under existing storm flows. Service Level 3 provides the most refuge habitat with over 25 percent of total stream volume available at all storm flows.

The estimates of refuge habitat at future storm flows are from cross-sections in both the rural and the residential zones. If further simplification of the stream channel occurs (i.e., reduction in instream debris and riffle-run complexes), refuge habitat at Service Levels 2 and 3 will likely be lower than predicted.

CONCLUSIONS:

The most productive streams have a variety of habitat available which can accommodate different species and life stages of salmonids. In general, there appears to be a diverse habitat in this reach of Woodland Creek. This habitat appears appropriate for salmonid rearing habitat with suitable spawning in the upper reaches to seed the study reach.

While the overall habitat is generally good, there are differences between the rural and residential sections of this reach. The habitat of the rural reach is much more diverse and complex. The habitat of the residential reach is more simple and less complex.

The existing refuge habitat in this reach of Woodland Creek varies from over 60 percent of the total stream volume at low flows to 10 percent at 100-year storm flows. Most of the refuge habitat is provided by debris complexes in the rural reach. The little instream refuge cover that exists disappears as velocities increase. Bank cover provides some habitat at higher flows, especially in areas where small bars or benches were present above the current high-water mark.

Service level 3, the maximum storm flow detention, provides the most refuge habitat under future flows. For the most benefit to be realized from any capitol improvements, habitat complexity and variety, especially habitat provided by instream LOD, must be maintained in lower Woodland Creek. If instream LOD continues to be removed (a situation typical in many urban streams), the benefits provided with any of the proposed stormwater management options will be much less than those predicted.

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Appendix A. Description of various habitat types identified in Woodland Creek. The following habitat descriptions are adapted from the U.S. Forest Services' Stream Habitat Classification and Inventory Procedures for Northern California (1990). These descriptions define standardized habitat types used in inventorying fish habitat in streams in the Pacific Northwest. This system of naming habitat is derived from work of several investigators on stream channel morphology, pool-riffle and step-pool formation, and fish habitat utilization. See the reference cited above for further information.

LOW GRADIENT RIFFLES (LGR)

Shallow reaches with swiftly flowing, turbulent water with some partially exposed substrate. Gradient less than four percent; substrate usually cobble dominated.

PLUNGE POOL (PLP)

Found where stream passes over a complete or nearly complete channel obstruction and drops steeply into the streambed below, scouring out a depression. Depression often large and deep. Substrate size is highly variable.

LATERAL SCOUR POOL (LSP)

Formed by flow impinging against one streambank or against a partial channel obstruction. The associated scour is generally confined to less than 60 percent of the wetted channel width. Channel obstructions include rootwads, woody debris (logs), boulders and bedrock.

GLIDES (GLD)

A wide uniform channel bottom. Flow with low to moderate velocities, lacking pronounced turbulence. Substrate usually consists of cobble, gravel and sand.

RUN (RUN)

Swiftly flowing reaches with little surface agitation and no major flow obstructions. Often appears as flooded riffles. Typical substrates are gravel, cobble and boulders.

MID-CHANNEL POOL (MCP)

Large pools formed by mid-channel scour. The scour hole encompasses mort than 60 percent of the wetted channel. Water velocity is slow, and the substrate is highly variable.

CORNER POOLS (CRP)

Lateral scour pools formed at a bend in the channel. These pools are common in lowland valley bottoms where stream banks consist of alluvium and lack hard obstructions.

DEBRIS COMPLEX (DEB)

Complex habitat formed by debris jams. May consist of several habitat types (e.g. several pool types). Substrate highly variable.

RUN-RIFFLE COMPLEX (RRC)

A habitat of low-gradient sand-bed streams that is characterized by both shallow and somewhat deep water across a given cross-section, a thalweg meandering from one bank to another, and the presence of both fast and slow water in the habitat unit. A mixture of both run and riffle habitat.

Appendix B. Habitat survey data collected from Woodland Creek on October 31, 1991. Descriptions and abbreviations of the habitat units listed in Appendix A. See text for further discussion.

Habitat Type	Start Distance (ft)	Unit Length (ft)	Avg. Width (ft)	Avg. Depth (ft)	Max. Depth (ft)	Unit Area (ft^2)	Unit Volume (ft^3)
run	0	123	12	1.25	1.5	1476	1845
cpr	123	86	8	1.75	2	688	1204
run	209	109	14	0.75	1	1526	1145
lsp	318	32	14	1.5	1.75	448	672
run	350	51	20	1	1	1020	1020
gld	401	76	10	1.5	1.75	760	1140
mcp	477	43	15	2.75	3+	645	1774
rrc	520	149	20	0.5	1.5	2980	1490
crp	669	40	15	2	2	600	1200
rrc	709	179	20	1	1.5	3580	3580
lsp	888	26	20	1.5	2	520	780
mcp	914	21	20	1.5	2	420	630
crp	935	37	20	1.75	2.25	740	1295
run	972	48	20	1	1.5	960	960
deb	1020	131	40	0.75	1.5	5240	3930
lsp	1151	25	20	1.25	2	500	625
lsp	1176	21	12	2.25	4	252	567
deb	1197	28	25	0.75	2	700	525
rrc	1225	77	25	0.75	2	1925	1444
mcp	1302	37	20	2	2.5	740	1480
gld	1339	46	20	2	2.5	920	1840
lsp	1385	9	20	2	3	180	360
lsp	1394	18	15	1.5	2.25	270	405
lsp	1412	38	15	2	3	570	1140
rrc	1450	46	25	0.75	2	1150	863
split channel	1450	46	40	0.75		1840	1380
mcp	1496	28	20	1.5	2	560	840

Appendix B. cont'd.

Habitat Type	Start Distance (ft)	Unit Length (ft)	Avg. Width (ft)	Avg. Depth (ft)	Max. Depth (ft)	Unit Area (ft^2)	Unit Volume (ft^3)
deb	1562	47	30	1	2.5	1410	1410
mcp	1609	33	20	2.5	3.75	660	1650
rrc	1642	48	30	1	1.75	1440	1440
deb	1690	57	25	2	3	1425	2850
mcp	1747	25	25	1.5	2	625	938
gld	1772	42	15	1.75	1.75	630	1103
run	1814	35	15	1	1.5	525	525
deb	1849	73	40	1.5	2.75	2920	4380
lsp	1922	24	20	1.5	2.5	480	720
rrc	1946	348	25	1.5	2	8700	13050
mcp	2294	38	15	2	2.5	570	1140
split channel	2332	36	10	1.5	1	360	540
split channel	2332	36	8	1		288	288
deb	2368	27	30	1.5	2	810	1215
gld	2395	48	20	2	2.5	960	1920
rrc	2443	31	30	1	1.5	930	930
lsp	2474	98	15	2	4	1470	2940
rrc	2572	126	15	2	3	1890	3780
mcp	2698	50	15	1.5	2	750	1125
rrc	2748	36	20	1	2.5	720	720
deb	2784	105	25	1	2.5	2625	2625
run	2889	110	15	1.25	2	1650	2063
gld	2999	39	15	1.75	2	585	1024
gld	3038	38	20	1.25	2	760	950
deb	3076	57	30	1.25	2	1710	2138
gld	3133	64	20	1.5	2	1280	1920
gld	3197	37	20	1	2	740	740
rrc	3234	135	40	0.75	1.5	5400	4050

Appendix B. cont'd.

Habitat Type	Start Distance (ft)	Unit Length (ft)	Avg. Width (ft)	Avg. Depth (ft)	Max. Depth (ft)	Unit Area (ft^2)	Unit Volume (ft^3)
deb	3523	89	40	1.5	4	3560	5340
rrc	3612	55	25	0.75	1.25	1375	1031
gld	3667	43	30	1.5	2	1290	1935
rrc	3710	43	25	0.75	1.25	1075	806
deb	3753	36	30	1.5	3	1080	1620
run	3789	109	20	1	2	2180	2180
deb	3898	86	20	1	2.5	1720	1720
run	3984	53	20	0.75	1	1060	795
lsp	4037	16	15	1.25	2	240	300
run	4053	93	15	0.75	1	1395	1046
lsp	4146	18	10	1.5	2.25	180	270
rrc	4164	65	20	1	2	1300	1300
plp	4229	34	25	1.5	2	850	1275
rrc	4263	200	20	0.5	1	4000	2000
deb	4463	45	20	1.5	2	900	1350
rrc	4508	66	10	1	1.5	660	660
rrc	4508	66	10	1		660	660
lsp	4574	24	20	2	3	480	960
gld	4598	93	15	1	2	1395	1395
lgr	4691	23	15	0.5	0.75	345	173
lsp	4714	43	12	2.25	3	516	1161
deb	4757	108	25	0.75	1.5	2700	2025
run	4865	58	15	1	1.5	870	870
lgr	4923	32	15	0.5	0.75	480	240
run	4955	67	15	1	1.5	1005	1005
deb	5022	79	50	1	2	3950	3950
plp	5101	53	15	2.5	4	795	1988
gld	5154	20	8	1	1.5	160	160
gld	5174	52	15	1	1.25	780	780

Appendix B. cont'd.

Habitat Type	Start Distance (ft)	Unit Length (ft)	Avg. Width (ft)	Avg. Depth (ft)	Max. Depth (ft)	Unit Area (ft^2)	Unit Volume (ft^3)
mcp	5295	12	10	1.5	2	120	180
mcp	5307	18	10	1.5	2	180	270
run	5325	207	12	0.75	1.5	2484	1863
lgr	5532	54	25	0.5	0.75	1350	675
pool	5586	39	12	0.75	2.25	468	351
rrc	5625	229	15	1	2	3435	3435
lsp	5854	12	15	2	2.5	180	360
rrc	5866	341	15	1		5115	5115
deb	6207	89	20	1.5	3	1780	2670
rrc	6296	50	15	0.5	0.75	750	375
deb	6346	37	15	2.5	3	555	1388
rrc	6383	66	15	0.75	1.5	990	743
deb	6449	47	30	1.75	2.5	1410	2468
rrc	6496	282	15	0.75	1.5	4230	3173
gld	6778	45	15	2	2.5	675	1350
rrc	6823	62	15	2	2.5	930	1860
gld	6885	88	25	1	1.25	2200	2200
plp	6973	22	25	2	2.25	550	1100
gld	6995	45	25	1.75	2.25	1125	1969
rrc	7040	190	30	0.75	1.5	5700	4275
End of Survey	7230						

APPENDIX I: STORMWATER FACILITIES OVERVIEW

The following structures and management measures can be applied to drainage problems addressed in basin plans.

I.1 STORMWATER FACILITIES

CATCH BASINS

Catch basins are the concrete sumps set below the storm drain grates in streets and parking lots. Catch basins serve a vital role in removing sediments from stormwater runoff. The most important factor controlling catch basin effectiveness is the frequency of cleaning. Catch basins must be cleaned regularly to function properly. Depending on the location, catch basins should be cleaned from every six months to two years. Those installed with oil skimmers are very cost-effective, and trap a large quantity of oil and sediments. Catch basins address the quality of storm water, but do not help to handle the peak flows.

GRASSY SWALE

Grassy swales are broad, shallow, grass-lined channels. Grassy swales can be quite effective in capturing water pollutants (Horner, 1988). Grasses act as filters, and a number of physicochemical mechanisms operate at the soil surface to retain contaminants. Grassy swales can be used instead of pipes to convey stormwater. They are cheaper than pipes to install but require additional maintenance. Swales offer potential opportunities to equip existing developments retroactively with nonpoint source water pollution control facilities, because they often fit with landscaping and consume less land than other alternatives. This opportunity is particularly available when a developed area redevelops.

FRENCH DRAINS

The reverse French Drain system is a method that has been used very effectively to drain street runoff. The drainage water is collected from the street and then transported through perforated pipes. These pipes are set in an envelope of graded washed rock to aid in the percolation of water into the ground. Given proper soil conditions and assuming routine maintenance is performed, this system can be very effective until the voids between the envelope of graded rock fills up and the system must be replaced or abandoned.

RETENTION/DETENTION PONDS

A retention pond releases water only through infiltration or evaporation, while a detention pond discharges it as surface runoff. Pond frequently combine detention and retention functions, and the term retention/detention pond is often applied to both types of facilities.

A **dry pond** drains after a short water residence time (typically, a few hours) and operates principally in the detention mode. When designed according to local standards, a dry pond can offer good flood storage capacity. Dry ponds can easily be adapted to multiple-use purposes.

An **extended detention dry pond** also drains completely between storm events. It differs from a dry pond by having a restricted outlet that detains the water for more than 24 hours, which improves pollutant removal. The basic design is similar to the wet pond (covered below), except that it drains completely between storms. Water residence time depends on the outlet size, characteristics of the drainage area, and behavior of the storm. The Drainage Manual contains detailed requirements for designing extended-detention dry ponds.

A **wet pond** has "dead storage" volume, which remains full between storms, and "live storage," which fills with runoff from each storm, then drains. The permanent pool assists pollutant removal in several ways: 1) it provides a quiescent zone for gravity settling of small particles over an extended period; 2) it promotes bacterial action to decompose organic pollutants, as well as soluble pollutant uptake by rooted plants and algae; and 3) it prevents pond bottom scouring. Wet ponds are effective in areas of high groundwater tables.

A **sedimentation pond** is a pond installed on a construction site to collect and store sediment before it reaches a water body or adjacent property. Preventing erosion at the source using the methods described below is preferable to controlling it with a pond, but sedimentation ponds are frequently needed to supplement or replace source controls. They are usually temporary structures intended to serve until construction is complete or vegetation is fully established. They can be installed as permanent retention/detention ponds for the occupied development, but the construction sediment must be cleaned out to insure proper functioning.

VAULTS AND TRENCHES

Vaults and trenches are underground stormwater storage systems. Vaults are large chambers capable of storing stormwater and discharging it either to a surface outlet or an infiltration facility. Vaults are frequently used under streets and parking lots where there is no land available for ponds. Trenches are underground, gravel-filled infiltration systems. Vaults are sometimes installed in front of trenches to trap sediments. Trenches work best in soils of medium texture where solids loadings are low. Fine soils are subject to clogging, while coarse soils can pass pollutants to groundwater. The existence of glacial till in many locations in the Puget Sound area adds complication to using soil infiltration. A possible solution above the till would be an underdrain system.

SAND FILTERS

Sand Filters are used routinely in drinking water treatment, and are becoming common for industrial treatment and septic effluent treatment. Their use for treating stormwater is a fairly recent development. Stormwater sand filter systems have ben used successfully in Austin, Texas, Washington, D.C., and in the states of Maryland and Delaware. They require a fairly large land area, and frequent maintenance.

OIL/WATER SEPARATORS

Oil/Water separators are underground vaults designed remove oil and grease from runoff. Oil/water separators fall into two categories: API separators and coalescing plate separators. The API separator is an older design that uses three chambers to skim off the oil. Coalescing plate separators contain several thin, parallel plates that greatly improve the removal efficiency. Stormwater usually has concentrations of oil and grease below the levels that oil/water separators can treat, except in areas with heavy industrial traffic (e.g., trucking garages, gas stations) or in spill-prone areas. Large parking lots with in-and-out traffic can be significant sources, but usually not high-speed highways. There is evidence that grass swales can reduce the low concentrations of oil and grease prevalent in most runoff more effectively than separators can (Horner, 1988; Horner and Wonacott, 1985).

I.2 STREAM ENHANCEMENT MEASURES

ANCHORING LOGS IN STREAM

Logs can be anchored into streams in order to protect the banks, redirect flows, or create in-stream fish habitat. Logs are usually anchored into the stream at an angle projecting downstream from the bank. They are held in place using cable connected to various anchoring devices placed in the banks.

DEFLECTOR STRUCTURES

Deflector structures are placed across a channel or may jut out from a channel bank to redirect the streamflow away from an eroding side slope or to maintain a minimum flow channel. Their height is generally set below the dry season mean water levels. The structures must be securely anchored and made of a material that can withstand the effects of continuous stream flow.

SPUR DIKES

Spur dikes or wing dams are built from the channel bank into the creek bed to direct the main channel flow away from the bank and to create a low velocity zone between the dikes to minimize erosion. The lengths and spacing of the dikes are based on hydraulic conditions of the stream. The dike lengths are limited by the channel width and by the effects on the opposite bank and downstream locations. The dikes usually exceed the normal stream water surface elevation and are overtopped in moderate and severe flooding conditions.

Flow Realignment

Flow realignment can be used over a short reach of the creek to: 1) alter localized channel velocities, 2) prevent erosion, 3) prevent backwater, and 4) increase channel conveyance capacity. This is a sensitive alternative with respect to fisheries habitat. It should be applied only when the measure is critical to stabilize a reach and no other feasible alternative is available. Construction must be performed when fish populations are least sensitive.

Channel Dredging

Channel dredging is an extreme measure that disrupts vegetation and fish habitat. A channel may need to be dredged occasionally if sedimentation fills the channel and causes flooding or fish blockages. Dredging is usually needed only for special situations, such as flat, slow-moving channels in highly erodible soils. Dredging may be required to realign the flow realignment or to maintain a low flow channel. The streambed is extremely sensitive, and special precautions would have to be taken to minimize the effects during construction.

Chevron Dams

Chevron dams are V-shaped, low water weirs built across a stream to redirect flow. The opening of the "V" faces upstream to move water toward the center of the main channel. The weirs are generally submerged and may be notched to allow extreme low flows to pass and prevent stranding fish.

Diversion to a Parallel Stream

The diversion of flow in a high water or flood condition to an adjacent stream channel with excess capacity can relieve flooding. A detailed analysis of this watershed interaction would be required to assure that the flood problem would not be transferred to another area.

Abandoned Channel Restoration

Additional channel conveyance through a particular reach may be acquired by restoring an abandoned channel or meander belt. Special protection at the inlet and outlet of this channel would have to be provided to prevent stranding fish in low flow conditions.

SPLIT CHANNEL

This alternative is similar to diverting a parallel stream or restoring an abandoned channel because the purpose is to increase stream conveyance. However, a split channel may require a flow control structure at its confluence with the main channel and/or a section of artificial channel where a natural channel is not available.

GRAVEL BAR SCALPING

Gravel bar scalping is performed occasionally as a maintenance measure to prevent build-up and loss of capacity in areas with a continual bedload deposition. Gravel bar scalping is not generally recommended because it requires constant attention and disrupts fish and habitat. Some bar scalping has been performed by private landowners following the guidelines established by the Washington Department of Fisheries.

SETBACK LEVEES

Setback levees are dikes installed with the toe "set back" a specific distance from the top of the stream bank. An optimum setback distance should: exceed the meander belt of the river; allow for recreational use of the area contained within the levees; avoid interfering with existing stands of vegetation; and, avoid interfering with particular wildlife habitat.

I.3 EROSION PREVENTION MEASURES

BIOENGINEERING

Bioengineering is the term given to the practice of using live vegetative material, consisting of bundles, stakes or layers of willows and other fast-rooting species, to stabilize channel side slopes and prevent erosion. Bioengineering usually combines plant materials with other structural materials including rock and erosion control fabrics. Bioengineering usually includes using plant materials in the structure of the engineered bank and planting live materials for surface coverage. Plantings can be selected which enhance fisheries habitat by providing canopy over the normal water surface of the creek with a resulting cooling effect. Other wildlife may also be attracted to this natural environment.

BANK SLOPE REDUCTION

Steep banks threatened by erosion can be "flattened" or have the slope reduced and then revegetated using other methods described in this section. The highest portion of the bank is cut away from the channel to reduce sloughing and slide potential during high water conditions. This may not be an appropriate measure if the top of bank is already heavily vegetated with trees and large shrubbery.

CRIB WALLS

Crib walls are stream bank reinforcements made of logs buried in the slope to achieve bank stability. Vegetation is then planted in the soil between the logs set side by side to provide canopy above the water surface. Live crib walls can be constructed by using live plant materials that will root into the bank when the crib walls are installed.

RIPRAP

Riprap consists of rock placed into a stream channel or against a bank to prevent erosion. Rip rap has been used for years to stabilize eroding stream channels, but it frequently causes the erosion to simply shift downstream. Riprap is often used below the high water mark to protect the toe of bioengineered slopes. Along stream reaches where areal constraints will not permit bank slope reduction or where there is the potential for a vegetated slope to be undermined, the use of riprap with mitigation may be acceptable. Riprap is placed in the critical erosive area and vegetation loss is mitigated by planting vegetation at or in the vicinity of the site.

VEGETATED BUFFERS

Vegetated buffers are areas of undisturbed vegetation adjacent to streams. Buffers prevent erosion caused by disturbance of streamside vegetation. They provide habitat and protect the riparian functions of the streamside area, and preserve flood capacity. Buffers can also capture pollutants in runoff, if the runoff sheet-flows across them. Close-growing, fine grasses provide the best pollutant removal action, but woody vegetation usually offers better habitat.

MISCELLANEOUS EROSION CONTROLS

Preventing erosion is always better than trying to control it. However, several erosion control measures are appropriate for construction sites where soil disturbance cannot be avoided.

A filter fence is a long wall made of commercially available filter fabric supported by a frame set into the ground. A filter fence is intended to dam-up runoff for long enough to settle out the sediment. Filter fences work best when they are placed along an area with sufficient capacity behind them to store significant quantities of runoff. They do not work well installed across narrow channels because they constrict the flow too much and cause flooding.

Straw bales can be placed across channels to strain out the sediments in the runoff. They allow runoff to pass through them faster than silt fences, so they are less prone to flooding but much less effective at removing sediment.

Mulches and seeding are methods of quickly stabilizing disturbed soils by covering them to prevent erosion. Mulches include straw, wood chips, plastic and various erosion control fabrics.

Construction entrances are driveways made quarried rock that help remove soil from the tires of trucks and equipment entering and leaving construction sites.

Water inlet protection consists of straw bales or filter fabric built up around storm drains to prevent sediments from entering the drainage system.

I.4 OTHER FLOOD CONTROL MEASURES

BERMS/LEVEES

Berms and levees protect a specific portion of the flood plain from flooding by placing a barrier between the flood waters and the protected lands. They are usually earthen structures with sloped sides, protected from erosion by riprap and/or vegetation. Levees should be located outside of the regulated floodway of the stream to avoid blocking or altering main channel conveyance. Levees may prevent overland runoff from flowing into a creek.

FLOODWALLS

Floodwalls perform much like levees except that they are vertical sided structures which require much less surface area. Because floodwalls are usually constructed of reinforced concrete, the expense of installation is often prohibitive and the structure provides no improvement to habitat value.

BRIDGE/CULVERT REPLACEMENT

If channel conveyance is restricted by an existing bridge, continual protection of the abutments against erosion and undermining may be more of a burden than complete replacement with a wider span section. The new bridge should be aligned considering channel morphology and the direction of bank-full flow as well as low flow.