HABITAT ANALYSIS
FOR THE SANTA YNEZ RIVER

Prepared for:

SANTA YNEZ RIVER CONSENSUS COMMITTEE
Santa Barbara, California

Prepared by:

SANTA YNEZ RIVER TECHNICAL ADVISORY COMMITTEE
Santa Barbara, California

March 1999

Cachuma Member Units Exhibit No. 226(b)

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1.0
INTRODUCTION

The waters of the Santa Ynez River are put to a variety of uses, including the maintenance of public trust resources both within Lake Cachuma and downstream of Bradbury Dam, as well as consumptive urban and agricultural uses within the Santa Ynez Valley and along the coastal plain encompassing the City of Santa Barbara and its urban environs. Since 1993, the U.S. Bureau of Reclamation, California Department of Fish and Game (DFG), U.S. Fish and Wildlife Service (FWS), and various water project operators have been party to a "Memorandum of Understanding (MOU) for Cooperation in Research and Fish Maintenance" on the Santa Ynez River, downstream of Bradbury Dam ("lower river"). Parties to the MOU maintain a Technical Advisory Committee (TAC) whose ultimate goal is to "develop recommendations for long term fishery management, projects and operations" in the lower river.

The TAC was established in response to State Water Resources Control Board (SWRCB) actions dealing with Bradbury Dam and the lower Santa Ynez River that culminated in the SWRCB requesting flow recommendations for maintenance of public trust resources in the lower river. It was also established to broaden the scope of management options potentially available to protect public trust resources within the lower river, to attempt to accommodate the needs of all interested parties, and ultimately to develop mutually acceptable management actions. Since 1993, the TAC has worked from year to year to undertake a variety of studies of the lower river. These studies have included: (i) water temperature and dissolved oxygen (DO) monitoring in Lake Cachuma and in the lower river from the stilling basin below Bradbury Dam to the lagoon; (ii) habitat quality evaluations in both the lower river and its tributaries; (iii) flow requirements for fish passage in the lower river; and (iv) fish population surveys in both the lower river and its tributaries (SYRTAC 1994, 1995).

Over time, the parties and the SWRCB recognized a need for a longer-term study plan to provide additional technical information to policy makers. In March 1996, the Consensus Committee approved a long-term study plan developed by the TAC Biology Subcommittee (SYRTAC 1996). The plan provides the overall framework for the TAC studies, which are devoted to acquiring technical information regarding:

1. The diversity, abundance, and condition of existing public trust fishery resources within the lower river;

2. Conditions which may limit the diversity, abundance, or condition of public trust fishery resources within the lower river;

3. Non-flow measures which could be expected to improve the conditions that currently act to limit the diversity, abundance, or condition of public trust fishery resources within the lower river; and

4. Alternatives to the existing operational regime of the Cachuma Project which could be expected to improve the conditions that currently act to limit the diversity, abundance, or condition of public trust fishery resources within the lower river.

This report addresses the issue of how habitat availability and quality changes with respect to flow in the mainstem Santa Ynez River below Bradbury Dam. This is part of Item 2, above.

This study is identified as Job 3 in the 1997 revision of the Proposed Investigations Report (SYRTAC 1997). The specific objective of this report is to determine the relationship between streamflow and habitat quantity and quality for each fish species life-stage function, using modeling and empirical data. This document addresses the effects of flow on rearing habitat. Included are a description of the methods used, the results of these investigations and a discussion of the implications of these results for steelhead management in the mainstem Santa Ynez River. Fish passage, also part of Job 3, is addressed in a separate report.

In 1996, the SYRTAC implemented a study led by DFG to determine how stream habitat varies with flow in the Santa Ynez River. The study was designed to evaluate changes in the top width of the river (the wetted width of the channel) with changes in stream flow releases from Bradbury Dam. Additional parameters to be considered in this study included water depth at the deepest portion of the flowing channel (the thalweg) and the mean column velocity associated with this portion of the channel (the thalweg velocity). The study was set up to evaluate how these parameters changed in the primary habitat types of importance, these habitat types being riffles, runs, glides and deep pools.

2.0
METHODS

Two data sets were used to develop habitat-flow relationships in three reaches of the Santa Ynez River. These reaches are the Alisal reach, near the Alisal Road bridge, the Refugio reach, upstream of the Refugio Road bridge, and the Highway 154 reach which extends from Highway 154 to Bradbury Dam. In the first two reaches, empirical data was collected as described below. In the Highway 154 reach, it was not possible to obtain permission to access the river from the landowners, and therefore the IFG-4 models developed by the California Department of Water Resources (DWR, 1989) were used to generate the measurements collected in that reach.

A total of 23 individual habitat units (pool, riffle, run, glide) were selected for a habitat/flow relationship study in the Refugio and Alisal reaches of the Santa Ynez River. Each habitat unit was surveyed at flow levels of 50 cubic feet per second (cfs), 35 cfs, 20 cfs, and 10 cfs (release levels from Bradbury Dam), although the flows at the habitat units were generally less than this due to groundwater recharge of the released flows. Each habitat unit was measured for length, and between 3-10 transects were placed in each unit perpendicular to the flow. Transect endpoints were marked by driving 1/2-inch rebar into the substrate on each bank outside of the wetted channel at the highest flow measured. The distance between the two headpins was noted during the first set of data collected (at 50 cfs) and matched during subsequent measurements to facilitate precise collection of data. At this time, the distance of the thalweg from the left bank headpin was also determined, and at each subsequent release level the water surface elevation, depth, and velocity measurements were taken at the same location. During each measurement, top width (the width of the wetted channel) was determined from the tape. Water surface elevation and thalweg bed elevation were surveyed by using an automatic level and standard surveying techniques. Mean column velocity was taken to the nearest 0.05 feet per second (fps) at the thalweg using a Marsh McBirney model 2000 current meter and a top set wading rod. This measurement was taken as the water velocity at 60 percent of the total depth if water depth was less than 2.5 feet, or as the average of the water velocities at 20 and 80 percent of the total depth if the depth was greater than 2.5 feet. These velocity measurements are referred to as thalweg velocities in the remainder of this document. River flow was measured upstream of survey locations during each day data were collected.

During data reduction and analysis, pools were separated into deep and shallow pools. A pool was placed in the shallow pool category if no transect within that habitat unit had a thalweg depth of more than three feet at a flow of 10 cfs. The empirical data collected above were log transformed, and log-log linear regression equations were generated between stream flow release and top width, thalweg depth, and thalweg velocity for each transect. From this function, the top width, thalweg depth and thalweg velocity was determined at 1.5 and 3 cfs, and at 5-cfs intervals from 5 to 50 cfs. To be considered acceptable for further evaluation, the regression equations were required to have a positive slope and a r-squared value of 0.8 or greater. The values produced by these equations were checked against the field data for accuracy and only those regressions that reproduced velocity or depth values within 0.1 fps or 0.1 feet or wetted perimeter values within 2 feet were accepted. The individual predictions for each predicted value of a parameter were then averaged by reach and habitat type to produce the final functions for each parameter.

A similar habitat analysis in the area of the Santa Ynez River between Highway 154 and Bradbury Dam was conducted based on the IFIM models originally produced by DWR and re-calibrated by ENTRIX (1995). Output from the hydraulic models was used to determine the top widths, thalweg depths and thalweg velocities at simulated target flows described above. In this analysis, the target flows were the flows at the transect, not the flows being released from the dam.

The data collected were evaluated to determine how habitat changes with stream flow. This analysis is based primarily on changes in top width and width to depth ratio, with changes in depth and velocity considered secondarily. Top width is evaluated as a measure of habitat quantity, while width to depth ratio, depth and velocity are measures of habitat quality.

Generally, the greater the top width, the greater the amount of habitat. Changes in top width were considered from the standpoint of the absolute and relative change in top width from one flow to the next. Large changes in top width would indicate a large change in the amount of potential living space available to steelhead. While top width is not the same as suitable habitat, it has been used as an index of the amount of habitat available in the past (Swift 1976, Annear and Condor 1983, Nelson 1984). While top width can be used as an index of habitat quantity, it does not address habitat quality. For instance, a section of stream that is 100 feet wide and two inches deep provides less habitat for fish than a channel that is 20 feet wide and two feet deep.

To address the issue of habitat quality, this analysis incorporates an evaluation of width to depth ratios, which were calculated by habitat type for each reach. Generally speaking, a higher width to depth ratio indicates better habitat, as this indicates a generally narrower and deeper channel which provides fish with more cover. At flows where there is an inflection in the width to depth ratio vs. flow function, one would expect to find morphological changes in the river that might result in substantial changes in the habitat flow relationship and thus might result in substantial changes in habitat over a relatively small change in flow.

Different habitat typing systems were used between the DWR IFIM data for the Highway 154 reach and the empirical data gathered at the Refugio and Alisal reaches. While riffles, runs and pools were similar, the IFIM transects included shallow pools (less than 3 feet deep) and the empirical transects included glides. Comparison of velocities and depths and their response to changes in flows indicates that glide and shallow pool habitats are hydrologically similar, although the shallow pools modeled by DWR were substantially wider than the glides evaluated in the current study. The similarities in their hydrologic response indicates that they may represent the same habitat type, however the difference in width suggests otherwise. The river has experienced several high flow years between the two studies (1986 and 1996) and may have become more incised as a result of these events.

The following sections describe top width, width to depth ratios, maximum depth, and velocity at the thalweg. The data show that riffles tended to be broad and shallow, as were glides and shallow pools. Runs and deep pools were narrower and deeper than riffles, glides, and shallow pools. Riffle habitats had the highest velocities, runs had somewhat lower velocities, and glide/shallow pools and deep pools had relatively low velocities which were of similar magnitude at any given flow.

3.1 TOP WIDTH

Top width increased most rapidly with flow between 1.5 and 5 cfs for all habitat types and in all reaches. The top width of riffles tended to increase the most as flow increased. Pools had the least change in top width with flow. Generally speaking, once flow increased beyond 10 cfs, there were only minor changes in top width for all habitat types at each sequential simulated flow. This was true in terms of both the absolute magnitude of the change and the percent increase.

In the Highway 154 reach, the greatest change in top width occurred when flow increased from 1.5 to 5 cfs (Figure 1). This change in flow resulted in a change in top width of 10 and 9 feet in run and riffle habitats, respectively (Table 2a), or a relative change of nearly 20 and 15 percent, respectively (Table 2b). The top width of shallow pools changed the most as flows went from 5 to 10 cfs (5 feet, 3 percent), while the top width of deep pools changed the most as flows went from 1.5 to 3 cfs (5 feet, 7 percent). As flows increased beyond 15 cfs, the relative change in the top width of all habitats was generally less than 3 feet (3 percent) between subsequent flow intervals. Top width increased by between 8 and 25 feet (11 and 45 percent), as flow was increased from 3 to 50 cfs, a sixteen-fold increase in flow. This increase was least in deep pools, which likely provide the best habitat for steelhead. Riffles and runs had the greatest cumulative increase in habitat, as indicated by greater top width values.

In the Refugio reach, the absolute change in top width from one flow value to the next exceed 4 feet only for riffle habitats as flow changed from 5 to 10 cfs (Figure 2, Table 2c). This flow interval had the greatest change in top width for all sampled habitats (Table 2c). These changes ranged from 1.3 to 4.3 feet (Table 2c) or 2 to 9 percent (Table 2d). As flow increased above 15 cfs, the relative increase in top width between subsequent flow intervals was generally less than 2 feet (4 percent) for all habitat types, with the relative change diminishing with increasing flow (Table 2d). The cumulative percent change in top width as flow increased from 3 to 50 cfs ranged from 5 feet (8 percent) in deep pools to 19 feet (43 percent) in riffles (Figure 2).

In the Alisal reach, top widths were less than in the Refugio reach for all habitat types except runs (Figure 3). The absolute magnitude of change in top width from one flow to the next is very similar to that for the Refugio reach, with the greatest changes occurring between 5 and 10 cfs for all habitat types (Table 2e). At this flow, top widths changed by between 2 and 5 feet depending on habitat. Because the top widths were generally less than in the Refugio reach, however, the relative change in top width was somewhat higher, with all habitat types except runs having relative changes in top width of 7 to 12 percent (Table 2f) as flow increased from 5 to 10 cfs. As in the other two reaches, the relative change in top width decreases with increasing flow, generally increasing less than 3 feet (5 percent) between simulation flows as flow increased beyond 15 cfs. The cumulative change in top width ranged from 9 to 22 feet (34 to 58 percent) as flow increased from 3 to 50 cfs (Figure 3). Unlike the other two reaches, deep pools in the Alisal reach had the second highest proportional increase in top width, rather than the lowest increase.

In general, deep pools had the least change in top width in response to changing flows, while riffles had the most change. In the Alisal reach, however, deep pools changed more than did glides or runs. In all three reaches, the amount of increased flow needed to obtain a given increase in top width is proportionately much greater than the amount of habitat gained. For example, to increase glide top widths by 10 percent in the Refugio reach requires more than a 300 percent increase in flow. To attain a similar increase in deep pool habitats in the Highway 154 reach requires an increase in flow of nearly 1,300 percent. The habitats in the Alisal reach are more responsive than in the other reaches, requiring about a 200 to 250 percent change in flow to obtain a 10 percent change in top width for all habitat types.

3.2 WIDTH TO DEPTH RATIOS

The width to depth ratios were fairly uniform across the range of flows modeled in all habitat types except riffles (Figure 4). The width to depth ratio in riffles was generally much higher than that of the other habitat types and decreased as flow increased. The rate of change in the width to depth ratios in riffles at the Refugio and Alisal reaches changed substantially at about 5 cfs. Glides in the Refugio reach and shallow pools in the other two reaches also had higher width to depth ratios than runs and deep pools. In the Highway 154 reach, the width to depth ratios of shallow pools was greater than that of riffles at all flows and generally declined as flow increased. The declining width to depth ratio here and in the riffle habitats in all reaches indicates that the proportional increase in width is less than the proportional increase in depth as flow increases. This indicates that in these shallow habitat types, habitat is generally improved as flow is increased, and that this improvement is greatest as flows increase between 1.5 and 5 cfs in the Refugio and Alisal reaches. In the Highway 154 reach, the inflection in the width to depth ratio is not as pronounced for the riffle or the shallow pool habitats, but appears to lie between 10 and 15 cfs.

The relatively constant width to depth ratios in the other habitat types indicates that there is not a substantial change in habitat as flow increases. Based on this, it is reasonable to use the results of the top width analysis to assess changes in habitat with flow in these habitats.

3.3 MAXIMUM DEPTH

As would be expected, the values of maximum depth increased with flow in all reaches and in all habitat types (Table 3, Figure 5). Unexpectedly, deep pools showed an initially greater response to changes in flow in the Refugio (Figure 5) and Alisal reaches (Figure 5) than did the other habitat types. This greater change in maximum depth is attributed to the narrower channel widths of deep pools and their inability to increase velocities as rapidly as other habitat types, because of their downstream controls. However, over the entire range of flows simulated, deep pools had the lowest response of any habitat type. Across all sampled habitats, the Refugio reach had the greatest average change in depth (0.8 feet), and the Highway 154 reach had the least (0.6 feet). Generally, depths increased relatively slowly over the range of simulated flows in all reaches and in all habitats. The changes in depth at flows of 1.5 vs. 50 cfs ranged from 0.4 to 1.1 feet for all three reaches and habitats. This 3200 percent increase in flow resulted in an increase of depth ranging from 15 to 250 percent.

3.4 VELOCITY AT THE THALWEG

Velocity at the thalweg increased as a function of flow in all habitat types and in all reaches. Riffles had the greatest increase in velocity with increased flow, followed by runs, and then by shallow pools and glides (Table 4, Figure 6). Deep pools had the lowest increase in velocity with increased flow levels. The velocity in riffles at 5 cfs was 0.4 to 0.5 fps and increased to 1.3 to 1.8 fps at 50 cfs. In deep pools, velocities were 0.0 to 0.1 fps at 5 cfs and 0.3 to 0.7 fps at 50 cfs, depending on the reach.

Habitat availability and quality changes with respect to flow were analyzed in the mainstem Santa Ynez River below Bradbury Dam. Four types of analyses were utilized to accomplish this: 1) top width, 2) width to depth ratio, 3) maximum depth, and 4) velocity at the thalweg.

Generally, top width increased most rapidly with flow between 1.5 and 5 cfs for all habitat types and in all three reaches studied. The top width of riffles tended to increase the most as flow increased, while deep pools had the least change in top width with flow, with the exception of deep pools in the Alisal reach (which changed more than glides or runs). Top width increased between 5 and 12 feet (equating to top widths of 33 to 66 feet) as flow increased from 1.5 and 5 cfs in riffle habitats of all sampled reaches. As flow increased from 1.5 and 5 cfs in deep pools of all sampled reaches, top width increased between 2 and 5 feet (equating to top widths of 29 to 69 feet). In all three reaches studied, the amount of flow required to obtain a given increase in top width was proportionately much greater than the amount of habitat gained. This is illustrated by the minor changes in top width observed in all habitat types once flow increased beyond 10 cfs.

Analysis of width to depth ratios revealed that in most habitat types, there was not a substantial change in habitat improvement as flow increased, as indicated by relatively constant width to depth ratios. However, in shallow habitat types, it was deduced that habitat generally improves as flow increases, as illustrated by declining width to depth ratios with the increase in flow. This improvement was greatest as flows increased between 1.5 and 5 cfs in the Refugio and Alisal reaches. In the Highway 154 reach, the inflection in the width to depth ratio was not as pronounced for the riffle or the shallow pool habitats, but appeared to be between 10 and 15 cfs (Figure 4).

Maximum depth increased with flow in all reaches and habitat types, although depths generally increased relatively slowly over the range of simulated flows. At flows of 1.5 cfs and 50 cfs, the changes in depth ranged from 0.4 to 1.1 feet. Deep pools in the Refugio and Alisal reaches showed an initially greater response to changes in flow than did the other habitat types. This greater response is attributed to the narrower channel widths of deep pools and the inability to increase velocities as rapidly as other habitat types due to downstream controls. However, over the entire range of flows simulated, deep pools had the lowest response of any habitat type.

In all habitat types and reaches, velocity at the thalweg increased as a function of flow, as anticipated. The largest increase in velocity with increased flow (from 1.5 to 50 cfs) was observed in riffles (0.3 to 1.8 fps), followed by runs (0.0 to 1.3 fps), and then by shallow pools (0.0 to 0.9 fps) and glides (0.1 to 0.8 fps) of all three reaches studied. Deep pools had the lowest increase in velocity with increased flow levels (0.0 to 0.7 fps) in all three reaches. Velocities in the Refugio reach were generally the greatest among all three reaches studied.

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APPENDIX A

TABLES

Table 1. Top width by habitat type in the three study reaches.

Highway 154

Discharge (cfs)	Top Width (ft) Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	54	49	Not	145	64
3	58	58	Sampled	147	68
5	66	69		150	69
10	69	70		155	71
15	71	75		159	73
20	74	77		162	74
25	76	78		164	75
30	78	79		166	75
35	79	80		167	75
40	80	80		169	76
45	82	81		170	76
50	83	81		171	76

Refugio Reach

Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	41	25	51	29	52
3	44	27	54	30	53
5	46	28	56	32	54
10	51	30	59	34	55
15	53	32	61	36	56
20	56	33	62	37	57
25	57	33	64	37	57
30	59	34	65	38	57
35	60	35	65	39	58
40	61	36	66	39	58
45	62	36	67	40	58
50	63	37	68	40	58

Alisal Reach

Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	33	25	42	Not	29
3	37	26	45	Sampled	31
5	40	28	47		33
10	45	30	52		37
15	48	31	54		39
20	50	32	56		41
25	52	32	58		42
30	54	33	59		44
35	55	33	61		45
40	57	34	62		46
45	58	34	63		48
50	59	35	64		49

Table 2. Change on top width in each reach.

Change in Top Width (in ft) from Previous Simulated Flow

HWY 154

a)

Discharge	Riffles	Runs	Glides	Sh. Pools	Dp. Pools
1.5	-	-	not	-	-
3	3.4	9.6	sampled	2.9	4.7
5	8.7	10.3		2.7	1.0
10	2.9	1.8		5.2	1.8
15	2.1	4.6		3.9	1.3
20	2.4	1.5		3.1	1.3
25	2.3	1.1		2.0	0.9
30	1.8	1.5		1.6	0.3
35	1.3	0.5		1.4	0.3
40	1.2	0.5		1.2	0.4
45	2.1	0.4		1.2	0.3
50	1.1	0.4		1.1	0.2

Percent Change in Top Width from Previous Simulated Flow

b)

Discharge	Riffles	Runs	Glides	Sh. Pools	Dp. Pools
1.5	-	-	not	-	-
3	6.3	19.6	sampled	2.0	7.4
5	15.1	17.6		1.8	1.5
10	4.4	2.6		3.5	2.5
15	3.0	6.6		2.5	1.9
20	3.4	2.0		1.9	1.7
25	3.1	1.4		1.2	1.2
30	2.4	2.0		1.0	0.5
35	1.7	0.6		0.8	0.4
40	1.5	0.6		0.7	0.5
45	2.6	0.5		0.7	0.4
50	1.3	0.5		0.6	0.3

Table 2. Change on top width in each reach (continued).

Change in Top Width (in ft) from Previous Simulated Flow

Refugio

c)

Discharge	Riffles	Runs	Glides	Sh. Pools	Dp. Pools
1.5	-	-	-	-	-
3	3.0	2.0	3.0	1.9	1.2
5	2.5	1.0	1.9	1.5	0.9
10	4.3	2.1	3.0	2.2	1.3
15	2.8	1.4	1.9	1.4	0.8
20	2.1	1.1	1.5	1.0	0.6
25	1.7	0.9	1.2	0.8	0.5
30	1.4	0.8	1.0	0.7	0.4
35	1.3	0.7	0.9	0.6	0.3
40	1.1	0.6	0.8	0.5	0.3
45	1.0	0.5	0.7	0.5	0.2
50	0.9	0.5	0.6	0.4	0.2

Percent Change in Top Width from Previous Simulated Flow

d)

Discharge	Riffles	Runs	Glides	Sh. Pools	Dp. Pools
1.5	-	-	-	-	-
3	7.3	8.0	5.9	6.6	2.3
5	5.6	3.6	3.5	4.9	1.7
10	9.2	7.6	5.4	6.9	2.4
15	5.4	4.7	3.3	4.1	1.4
20	3.9	3.4	2.4	2.9	1.0
25	3.0	2.7	1.9	2.3	0.8
30	2.5	2.3	1.6	1.9	0.7
35	2.1	2.0	1.3	1.6	0.6
40	1.9	1.7	1.2	1.4	0.5
45	1.7	1.5	1.1	1.2	0.4
50	1.5	1.4	0.9	1.1	0.4

Table 2. Change on top width in each reach (continued).

Change in Top Width (in ft) from Previous Simulated Flow

Alisal

e)

Discharge	Riffles	Runs	Glides	Sh. Pools	Dp. Pools
1.5	-	-	-	not	-
3	4.0	1.0	3.0	sampled	2.0
5	3.2	1.7	2.5		2.4
10	4.8	1.9	4.1		3.2
15	3.1	1.2	2.7		2.3
20	2.4	0.9	2.0		1.9
25	1.9	0.7	1.7		1.6
30	1.6	0.6	1.4		1.5
35	1.4	0.5	1.2		1.3
40	1.3	0.4	1.1		1.2
45	1.2	0.4	1.0		1.2
50	1.1	0.4	0.9		1.1

Percent Change in Top Width from Previous Simulated Flow

f)

Discharge	Riffles	Runs	Glides	Sh. Pools	Dp. Pools
1.5	-	-	-	not	-
3	12.1	4.0	7.1	sampled	6.9
5	8.6	6.7	5.5		7.6
10	11.9	6.8	8.7		9.7
15	6.9	4.0	5.2		6.3
20	4.9	2.8	3.8		4.8
25	3.8	2.2	3.0		4.0
30	3.1	1.8	2.5		3.4
35	2.6	1.5	2.1		3.0
40	2.3	1.3	1.8		2.7
45	2.0	1.2	1.6		2.5
50	1.8	1.1	1.5		2.3

Table 3. Thalweg depth by habitat type in the three study reaches.

	Maximum Depth (ft)				
Highway 154					
Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	0.4	2.1	Not	0.7	4.0
3	0.5	2.1	Sampled	0.7	4.1
5	0.6	2.5		0.8	4.1
10	0.7	2.7		0.8	4.2
15	0.7	2.7		0.9	4.3
20	0.8	2.8		0.9	4.4
25	0.8	2.9		1.0	4.4
30	0.9	2.9		1.0	4.5
35	0.9	2.9		1.0	4.5
40	0.9	3.0		1.1	4.6
45	1.0	3.0		1.1	4.6
50	1.0	3.0		1.1	4.6
Refugio Reach					
Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	0.5	1.5	1.5	1.3	2.6
3	0.6	1.6	1.6	1.4	2.7
5	0.7	1.7	1.7	1.5	2.8
10	0.8	1.9	1.9	1.7	3.0
15	0.9	2.0	2.0	1.8	3.1
20	1.0	2.0	2.1	1.9	3.2
25	1.0	2.1	2.1	1.9	3.3
30	1.1	2.1	2.2	2.0	3.3
35	1.1	2.1	2.2	2.0	3.4
40	1.1	2.2	2.2	2.1	3.4
45	1.2	2.2	2.3	2.1	3.4
50	1.2	2.2	2.3	2.2	3.5
Alisal Reach					
Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	0.5	2.3	1.5	Not	2.8
3	0.6	2.4	1.6	Sampled	3.0
5	0.7	2.5	1.7		3.1
10	0.8	2.6	1.8		3.3
15	0.9	2.7	1.8		3.5
20	1.0	2.8	1.9		3.6
25	1.0	2.9	1.9		3.7
30	1.1	2.9	2.0		3.7
35	1.1	2.9	2.0		3.8
40	1.2	3.0	2.0		3.8
45	1.2	3.0	2.0		3.9
50	1.2	3.0	2.1		3.9

Table 4. Thalweg velocity by habitat type in the three study reaches.

Thalweg Velocity (fps)

Highway 154

Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	0.3	0.1	Not	0.0	0.0
3	0.4	0.1	Sampled	0.1	0.0
5	0.4	0.2		0.1	0.0
10	0.6	0.3		0.2	0.1
15	0.8	0.4		0.2	0.1
20	0.9	0.5		0.3	0.1
25	1.1	0.5		0.3	0.2
30	1.2	0.6		0.4	0.2
35	1.3	0.7		0.4	0.2
40	1.4	0.7		0.5	0.2
45	1.5	0.8		0.5	0.3
50	1.6	0.9		0.5	0.3

Table 4. Thalweg velocity by habitat type in the three study reaches (continued).

	Thalweg Velocity (fps)				
Refugio Reach					
Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	0.3	0.1	0.1	0.1	0.0
3	0.4	0.2	0.1	0.1	0.1
5	0.5	0.3	0.1	0.2	0.1
10	0.6	0.4	0.2	0.3	0.1
15	0.9	0.5	0.3	0.4	0.2
20	1.0	0.6	0.3	0.5	0.3
25	1.2	0.8	0.4	0.5	0.3
30	1.3	0.9	0.4	0.6	0.4
35	1.4	1.0	0.5	0.7	0.5
40	1.5	1.1	0.6	0.7	0.5
45	1.6	1.2	0.6	0.8	0.6
50	1.8	1.3	0.7	0.9	0.7

Table 4. Thalweg velocity by habitat type in the three study reaches (continued).

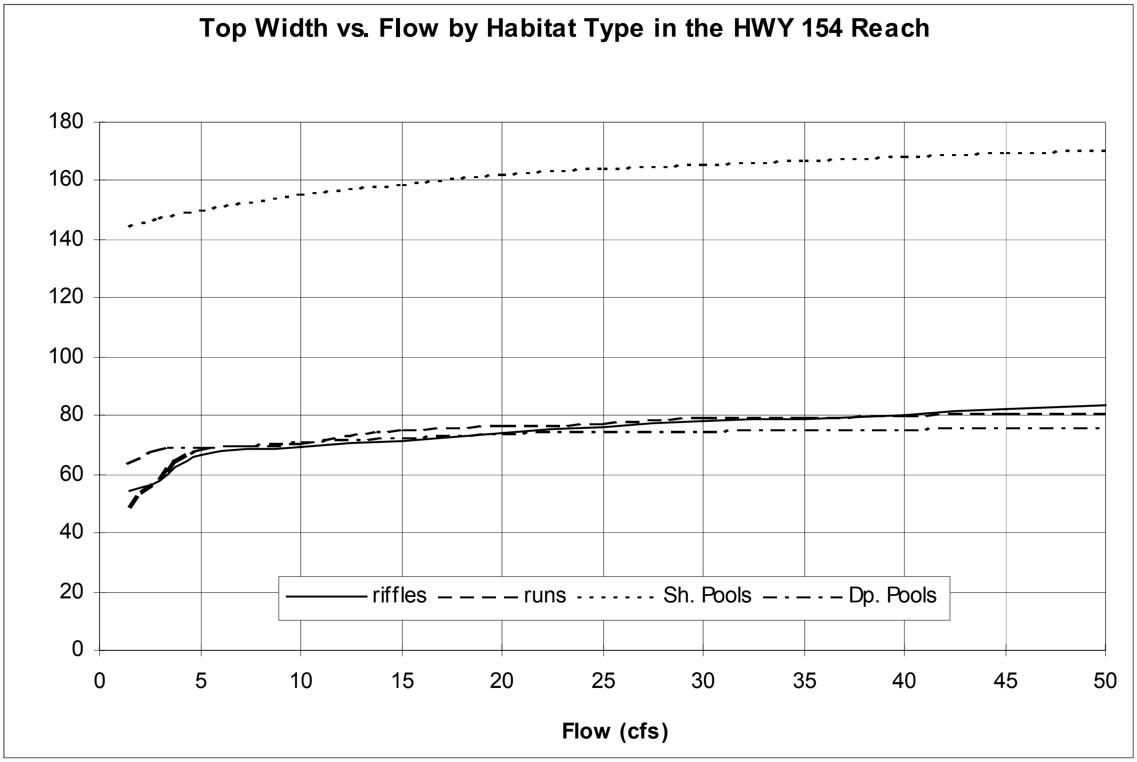
Thalweg Velocity (fps)

Alisal Reach

Discharge (cfs)	Riffle	Run	Glide	Sh. Pools	Dp. Pools
1.5	0.3	0.0	0.1	Not	0.1
3	0.3	0.1	0.2	Sampled	0.1
5	0.4	0.1	0.2		0.1
10	0.6	0.2	0.3		0.2
15	0.7	0.3	0.4		0.3
20	0.8	0.4	0.5		0.3
25	0.9	0.5	0.5		0.4
30	1.0	0.6	0.6		0.4
35	1.1	0.7	0.6		0.5
40	1.2	0.8	0.7		0.5
45	1.2	0.9	0.7		0.6
50	1.3	1.0	0.8		0.6

APPENDIX B

FIGURES



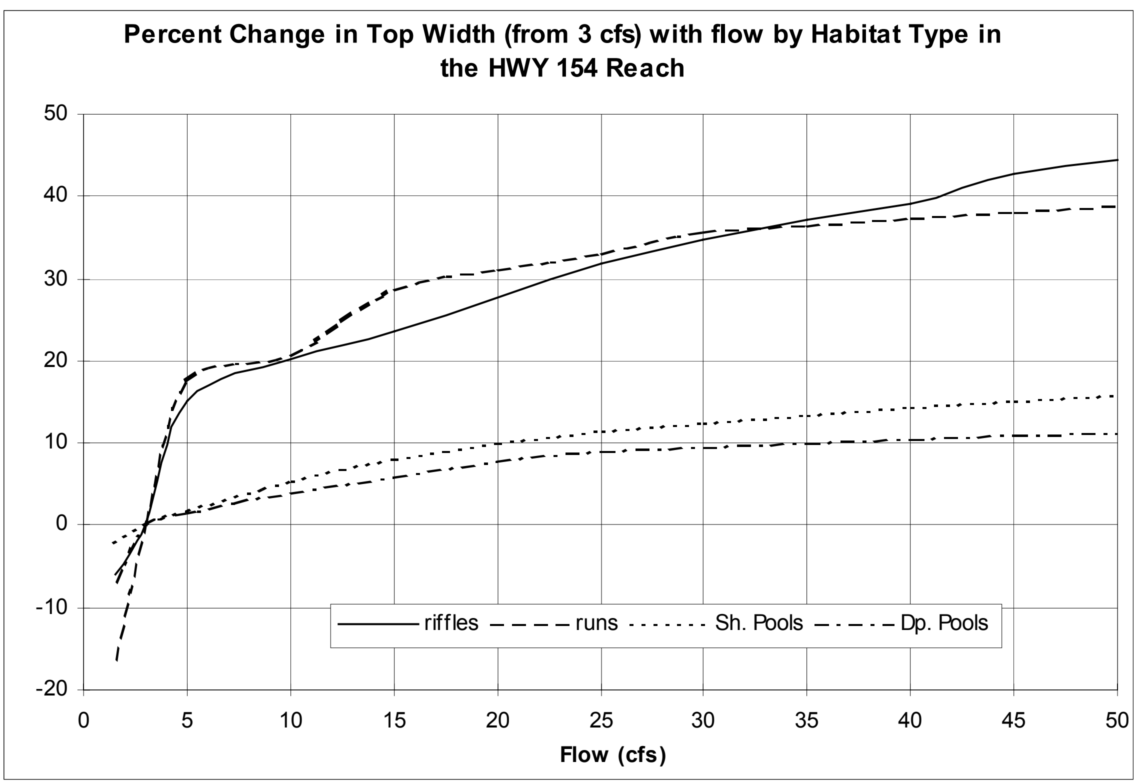
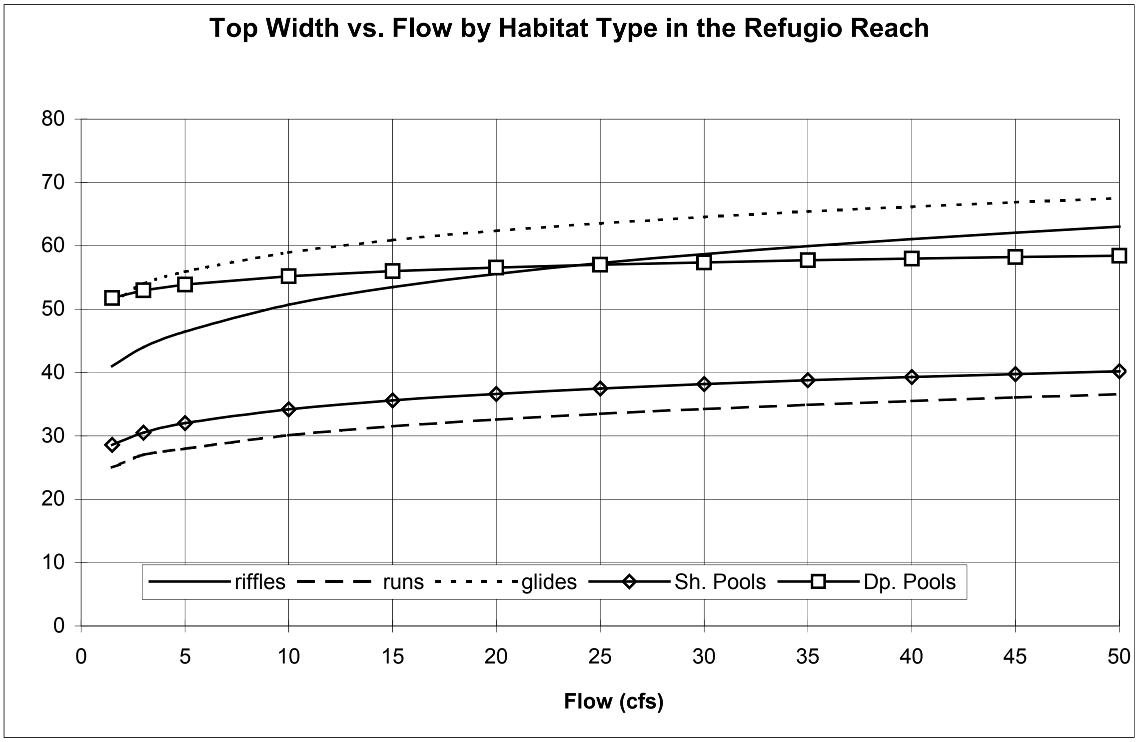


Figure 1. Top width vs. flow relationship in the Highway 154 reach.



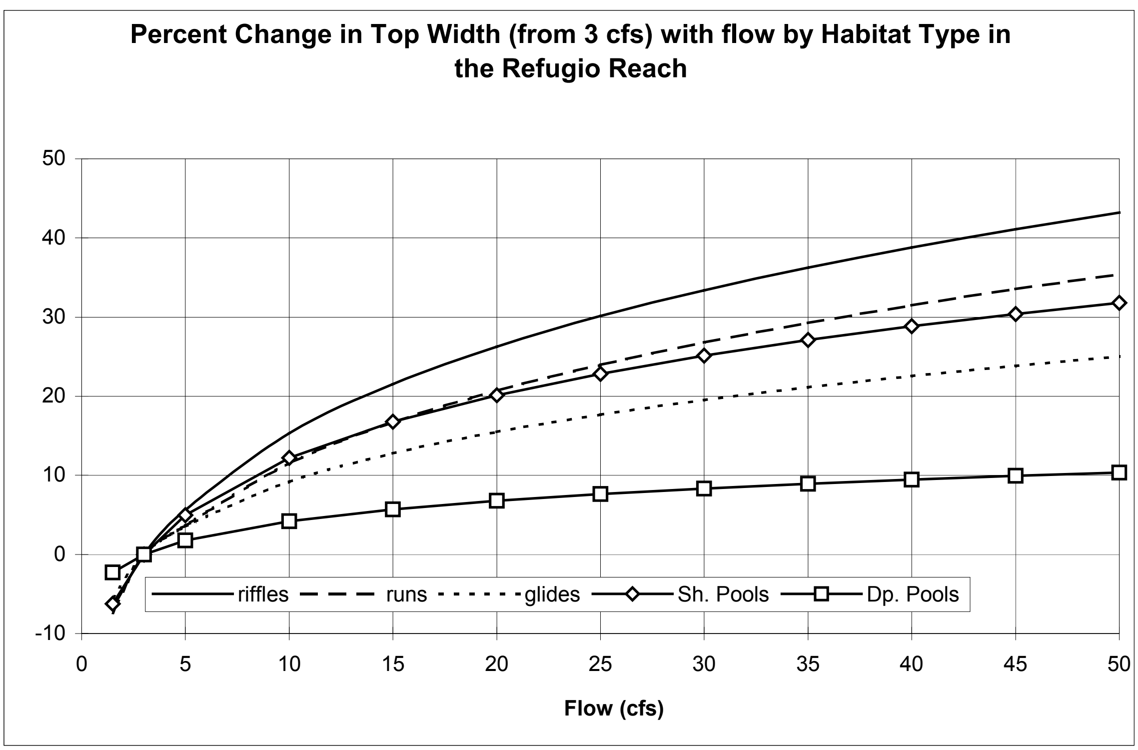
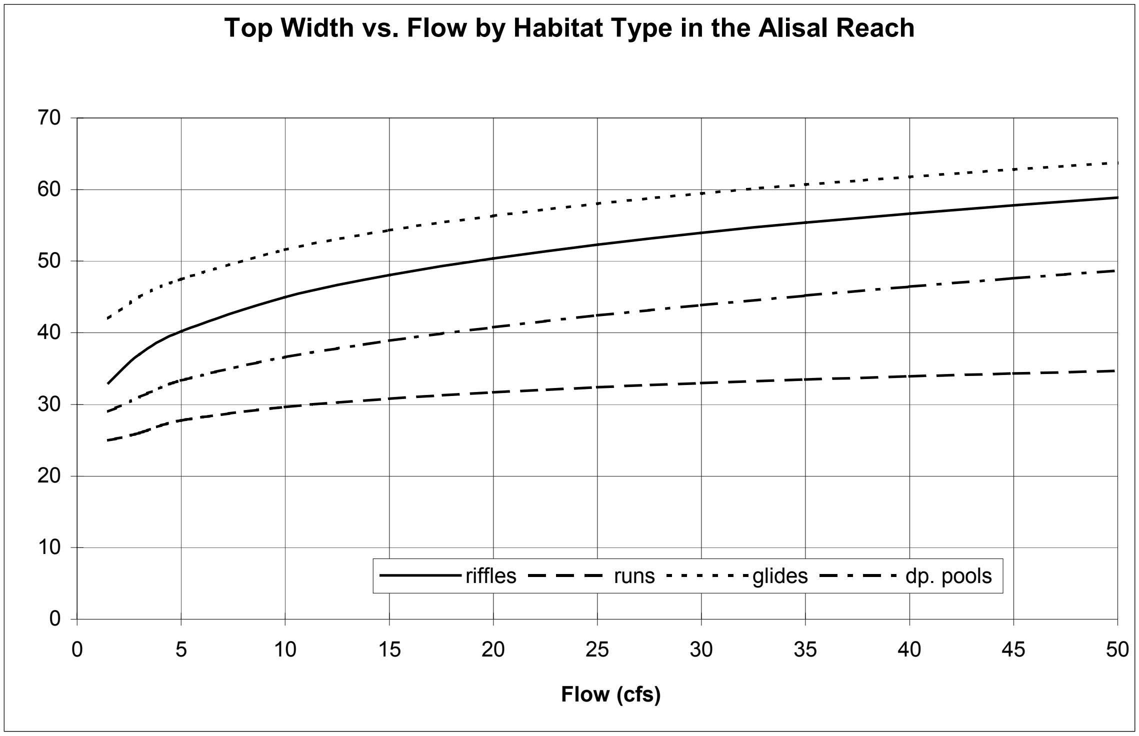


Figure 2. Top width vs. flow relationship in the Refugio reach.



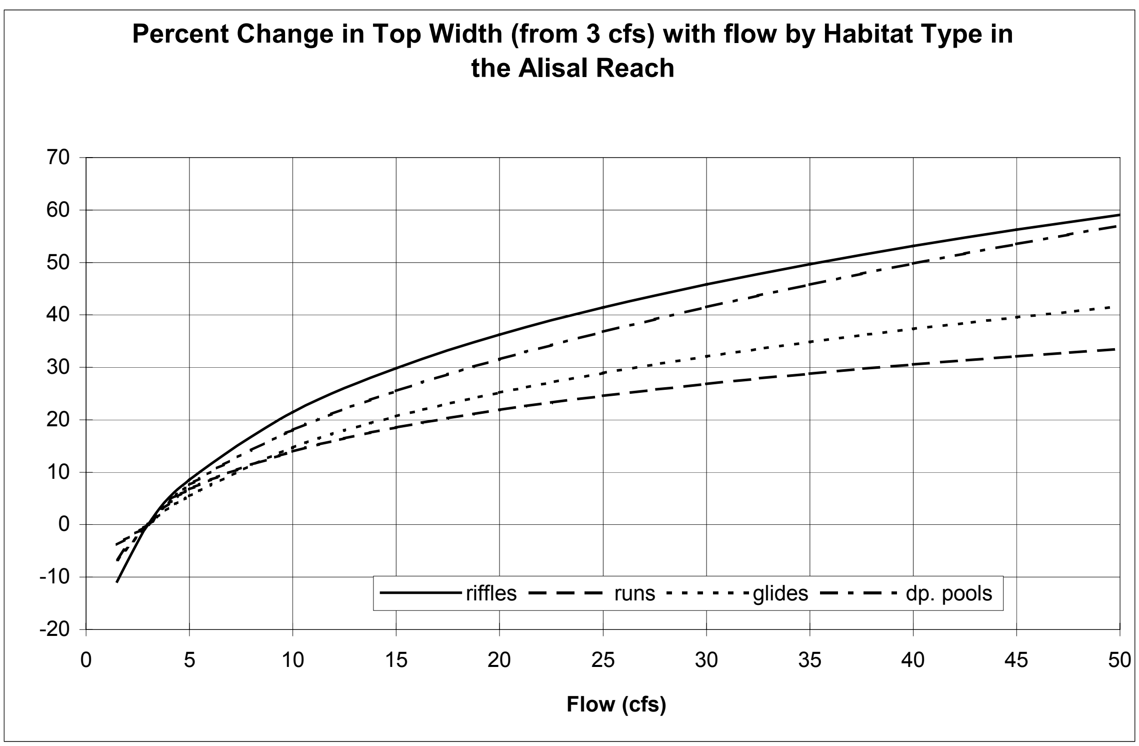
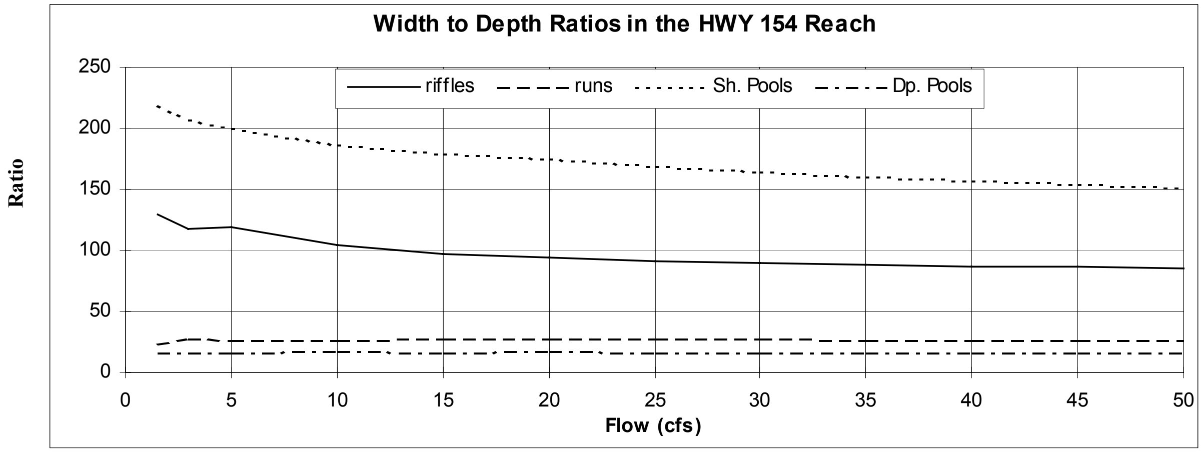
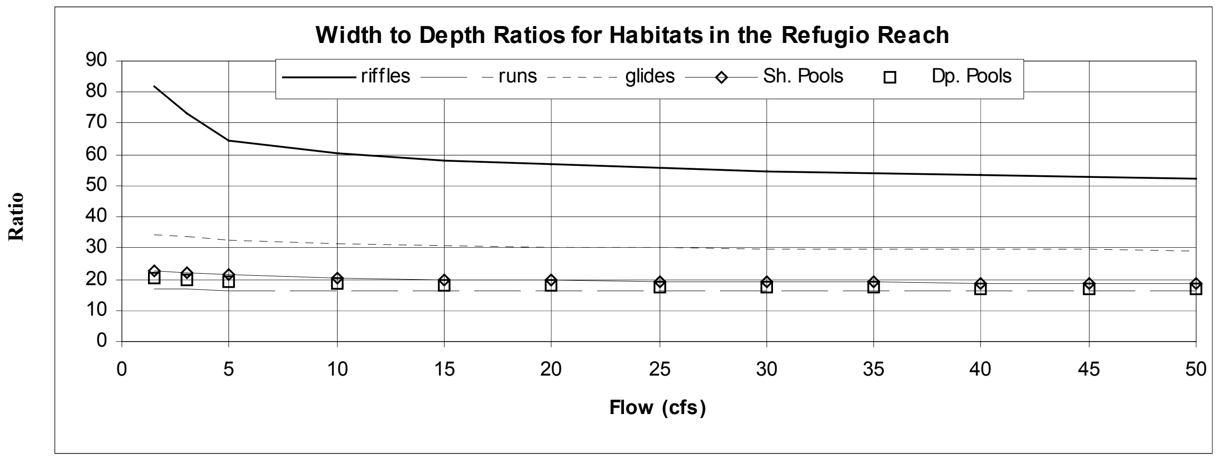


Figure 3. Top width vs. flow relationship in the Alisal reach.





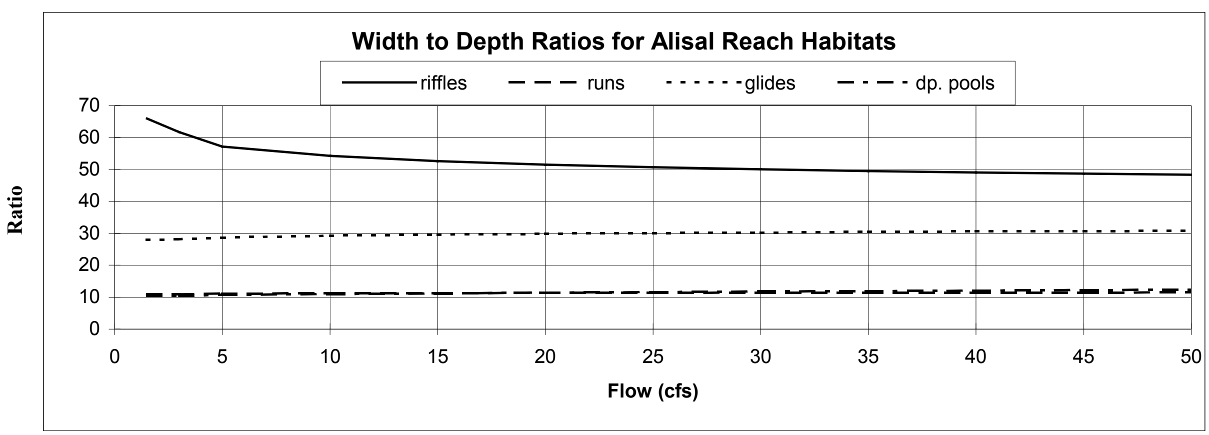
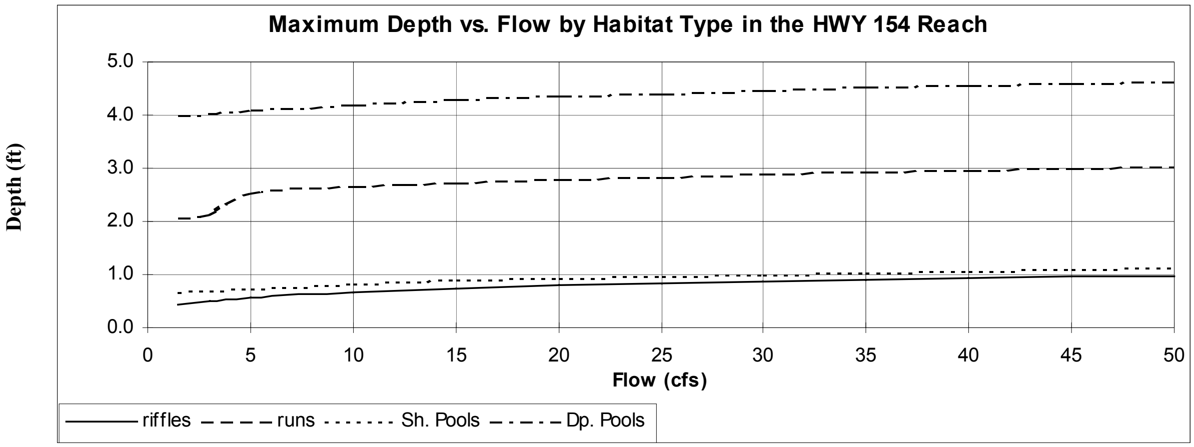
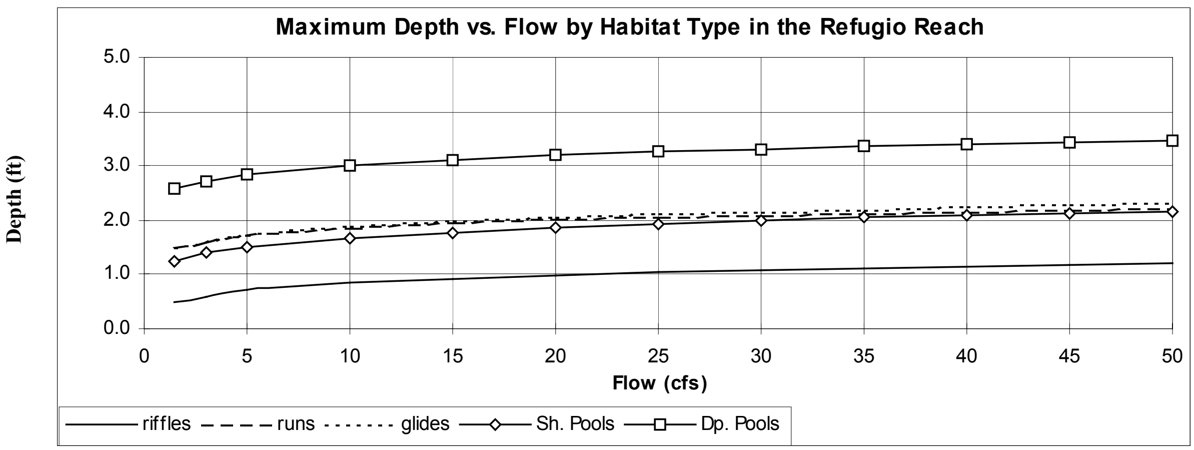


Figure 4. Width to depth ratio by reach and habitat type.





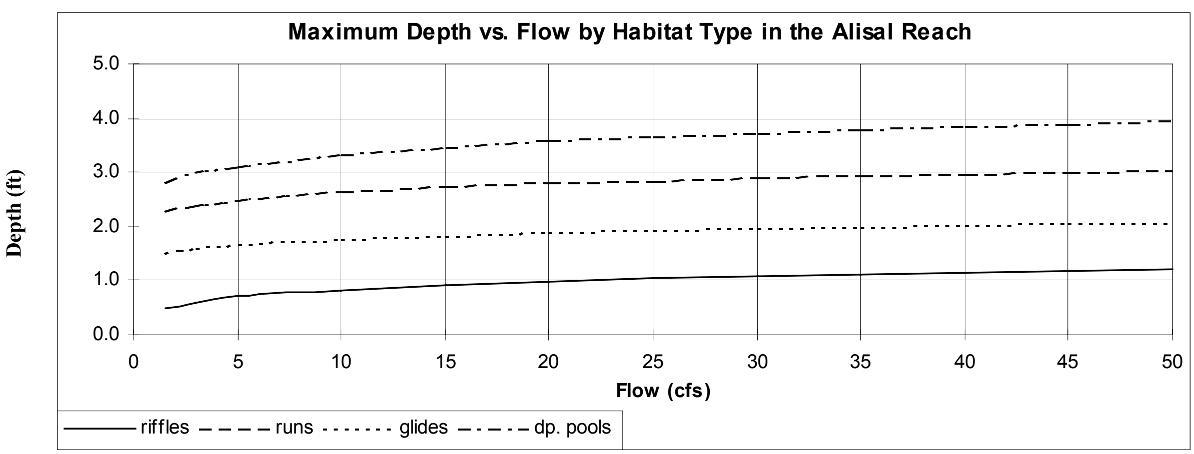
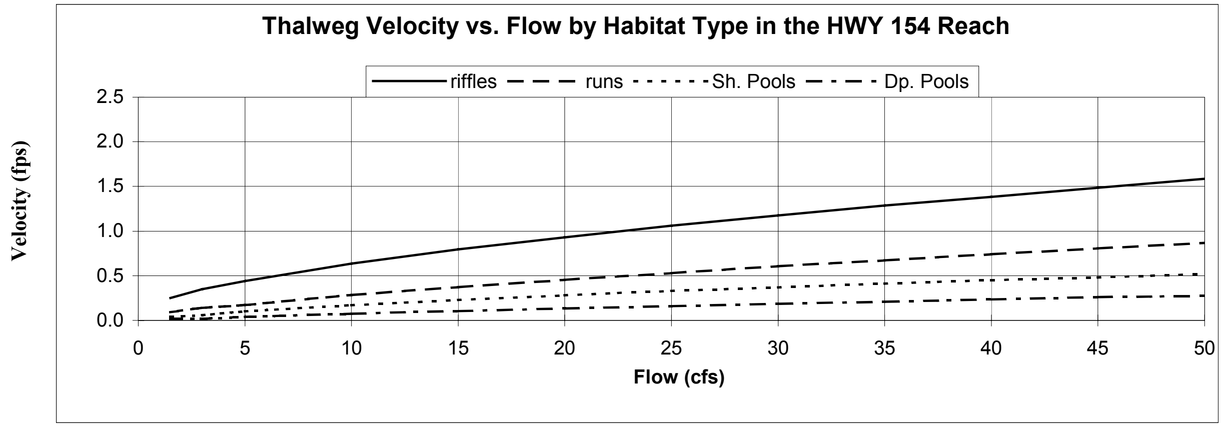
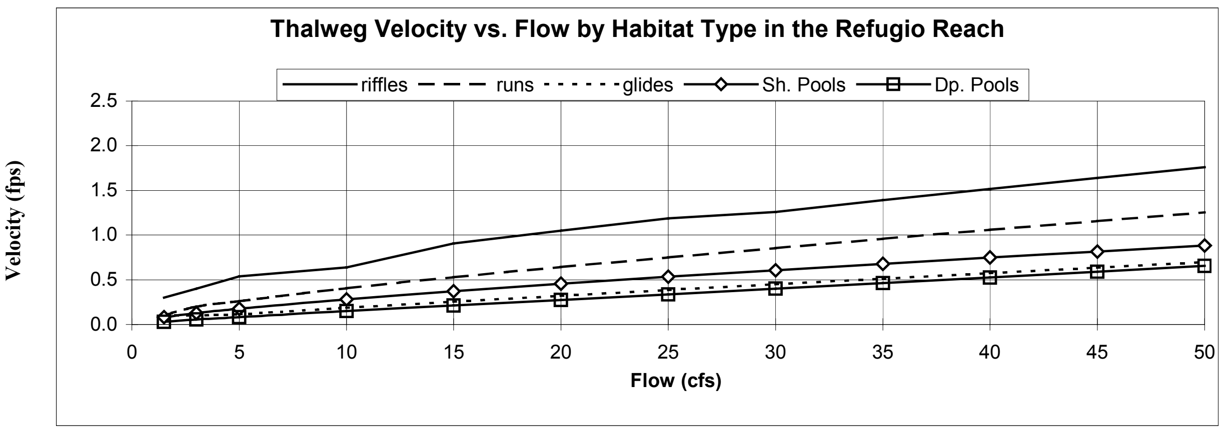


Figure 5. Depth vs. flow relationship by reach and habitat type.





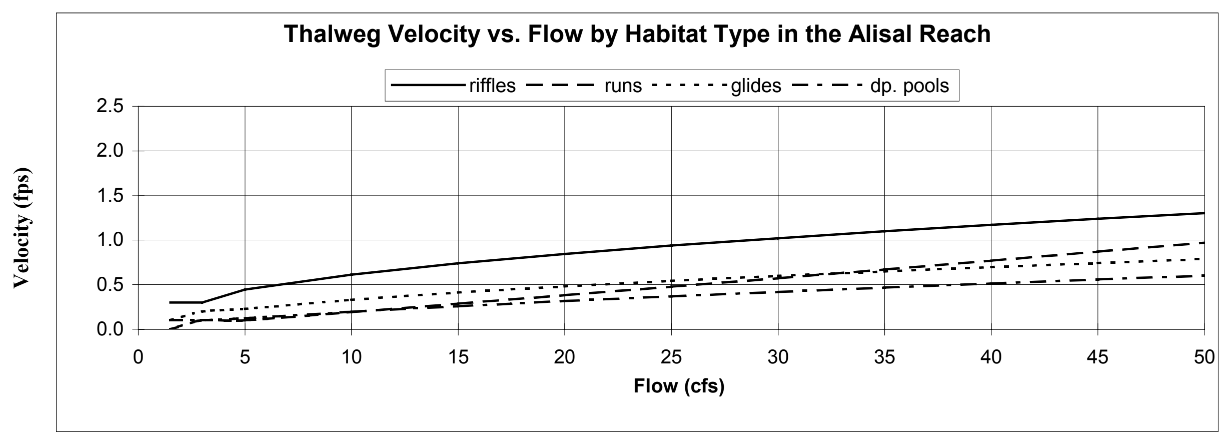


Figure 6. Velocity vs. flow relationship by reach and habitat type.