ICICLE CREEK TARGET FLOW REPORT FOR LEAVENWORTH NATIONAL FISH HATCHERY

DECEMBER 2004

PREPARED FOR:
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BY:

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Water Resources Engineering

December 20, 2004

Rolf Wielick, P.E.
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Bellevue, WA 98007

RE: U.S. Fish and Wildlife Service - W.O. No. 11 - Leavenworth NFH Icicle Creek Target Flow Report

Dear Rolf:

Enclosed is the completed Icicle Creek Target Flow Report for the USFWS Leavenworth National Fish Hatchery. Three copies have also been sent to the LNFH for their use.

Please call if we can address further comments or requests for information.

Very truly yours,
MONTGOMERY WATER GROUP, INC.

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1.0 Introduction

The purpose of this technical report is to summarize the analyses of target flows for the reach of Icicle Creek downstream of the LNFH diversion, approximately river miles (RM) 3.9 to 4.5. The reach downstream of the diversion currently experiences low flow during late summer periods because water is diverted from Icicle Creek by LNFH and others, including the Icicle and Peshastin Irrigation District at RM 5.7, the City of Leavenworth at RM 5.5 and Cascade Orchards Irrigation Company. The LNFH and Cascade Orchards Irrigation Company share a diversion at RM 4.5. A target flow for the downstream reach is desired to allow migratory Bull Trout and Steelhead passage during the low flow time period to areas upstream of the LNFH diversion. In addition, consideration of rearing habitat is desired at various target flows.

2.0 Methods

Three approaches to evaluating target flows for Icicle Creek downstream of the hatchery diversion were evaluated; hydrologic assessment methods (Tennant and Hatfield & Bruce methods), a physical based method using measured stream properties incorporated into the PHABSIM model and a hydraulic analysis of the creek to estimate adult fish passage requirements. The hydrologic assessment and physical based methods are used to evaluate the potential habitat availability for different flows and life stages of fish while the hydraulic analysis focuses on fish passage alone. The fish expected to be found in the reach of interest are Rainbow Trout, Cutthroat Trout, Brook Trout, Bull Trout, Steelhead, Chinook, and Whitefish (*Instream Flow Study Report for Icicle Creek*, 1985).

2.1 Hydrologic Assessment using Tennant Method

The Tennant Method (Tennant 1976) recommends instream flows based on the annual average flow. This method was developed with the assumption that aquatic habitat in various sizes of streams is very similar when the available water is the same proportion of the annual average flow. The method relies on eight flow classifications established by Tennant after analyzing a series of field measurements and observations. Each classification is assigned a percentage or percentage range of the average annual flow (AAF) as shown in Table 2-1. The year is divided into two six-month periods, April through September and October through March, in order to apply the percentages.

The Tennant Method is termed a “hydrologic” or “desktop” method and does not use physical measurements of important flow conditions in a stream. They are typically used as a reconnaissance level analysis of environmental flows and are not typically used in complex cases requiring negotiation of instream flows. In this case they are presented to provide background to more detailed target flow analyses.

Table 2-1
Habitat Quality Expressed As A Percentage Of The Average Annual Flow (Tennant Method)

Description of Flows	Recommended Percent of Average Annual Flow	
	October-March	April-September
Flushing Flow	200%	200%
Optimal Range	60%-100%	60%-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	<10%	<10%

2.1.1 Analysis of Streamflow Statistics

The hydrologic data available to complete the Tennant method comes from a variety of sources. Table 2-2 summarizes the data available and the length of record for each station. Figure 1 shows the location of the various diversions, gages, and tributaries to Icicle Creek.

Table 2-2
Hydrologic Data Available

Station	Agency	Period of Record
Icicle Creek above Snow Creek	USGS (#12458000)	1936 – 1971 and 1993 - present
Snow Lakes/Snow Creek	USFWS	Periodic, 1994 - 2002
Icicle/Peshastin Irrigation Diversion	Irrigation District	1990-1991
LNFH and Cascade Orchards Diversion	USFWS	Periodic, 1991 - 2001
City of Leavenworth Diversion	City of Leavenworth	estimated based on water right

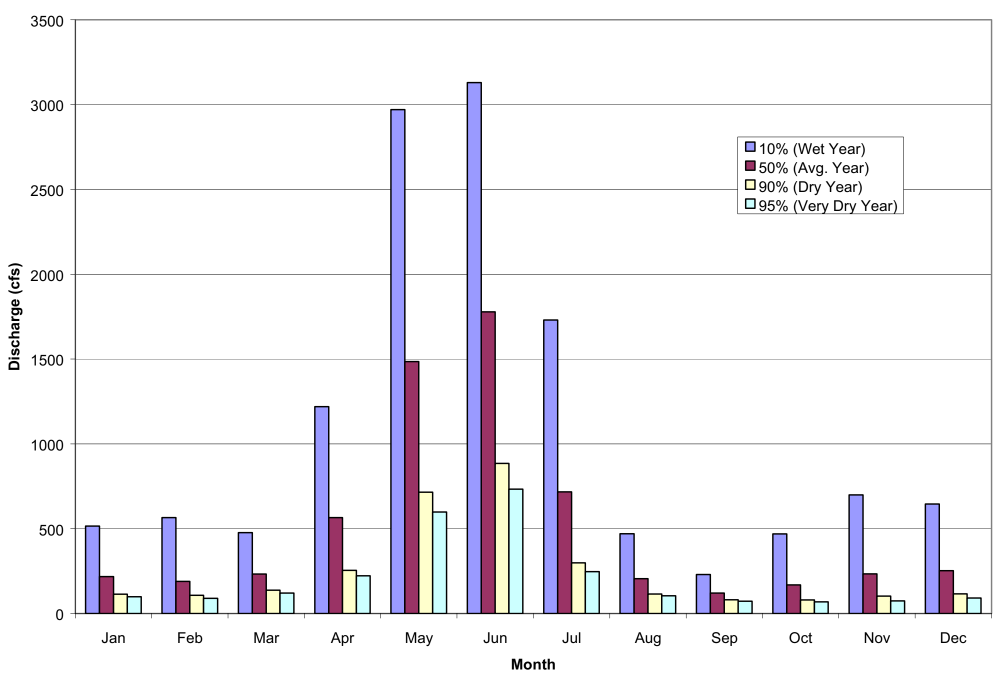
The available hydrologic data was compiled to estimate the flow regime at the USGS gage, which would be closely representative to the flow regime downstream of the LNFH diversion in natural conditions. Table 2-3 and Figure 1 present the results of that analysis, with the 10%, 50%, 90%, and 95% exceedance flows presented. These exceedance flows typically represent a high flow or wet year, median flow or average year, low flow or dry year and very low flow or very dry year, respectively. Note that the flow record at the USGS gage is affected by supplementation from high alpine lakes operated by the Icicle and Peshastin Irrigation Districts. The rate of supplementation is not available, but is believed to be about 15 cfs. Therefore the gage record was modified by subtracting 15 cfs in August and September to account for the supplementation.

Table 2-3
Estimated Flows in Icicle Creek above Snow Creek
USGS Gage 12458000

Month	Icicle Creek Flow Statistics (cfs)			
	10% (high flow)	50% (mean monthly flow)	90% (low flow)	95% (very low flow)
Jan	516	217	114	99
Feb	565	190	108	90
Mar	477	232	138	121
Apr	1220	565	255	223
May	2,970	1,485	715	598
Jun	3,130	1,778	885	733
Jul	1,730	718	299	247
Aug	470	206	115	104
Sep	230	121	81	72
Oct	469	168	80	69
Nov	699	233	102	75
Dec	646	253	116	92

Note: Flow in Icicle Creek is augmented in August and September by Icicle and Peshastin Irrigation District; flows listed in table are adjusted to account for supplementation.

Figure 1
Graph of Estimated Flows in Icicle Creek above Snow Creek
USGS Gage 12458000



An estimate of Icicle Creek flow downstream of the LNFH diversion was made using the hydrologic data available. The analysis was performed by subtracting from the USGS gage record the Icicle and Peshastin Irrigation District diversion, the City of Leavenworth diversion and the LNFH/Cascade Orchards diversion and adding contributions from Snow Lakes. The analysis was performed on a monthly basis. Limited data is available for the Icicle and Peshastin Irrigation District diversion and an average of 1990-1991 diversion data was used. It was reported in the *Wenatchee River Basin Watershed Assessment* (MWG, 2003) that data is still representative of their diversions. Limited data is also available for the LNFH diversion and Snow Lakes contributions so available data was averaged. No data was available for the month of January for Snow Creek therefore the values for December were used for January.

Years that are representative of average, dry and wet years were used. For an average year, data from 1998 was used. For a dry year, data from 2001 was used and for a wet year, data from 1997 was used.

Table 2-4 presents an analysis of estimated flows in Icicle Creek downstream of the LNFH diversion for an average flow year. Tables 2-5 and 2-6 present an analysis of estimated flows in Icicle Creek downstream of the LNFH diversion for a wet and dry year, respectively. For Tables 2-4 through 2-6, the values for Icicle Creek at the USGS gage are actual monthly averages for the given year while the diversion and Snow Creek values are averages of the available data. The instream flows downstream of the LNFH diversion for each of the years are also presented graphically in Figure 2.

Table 2-4
Results of Hydrologic Analyses – Average Flow Year - 1998

Month	Inflow and Outflow (cfs)					Instream Flow downstream of LNFH diversion (cfs) (=)
	Icicle Creek at USGS gage	IPID (-)	City (-)	Snow Creek (+)	LNFH & CO (-)	
Jan	227.6	-	2	*9.0*	38.2	196.4
Feb	188.8	-	2	32.3	44.6	174.6
Mar	296.9	-	2	21.6	46.0	270.5
Apr	571.9	68.6	2	23.7	40.1	485.0
May	1,929.7	88.2	2	56.0	28.4	1,867.1
Jun	1,331.8	96.1	2	29.6	42.4	1,220.9
Jul	486.5	99.3	2	43.5	48.2	380.4
Aug	180.1	98.3	2	36.6	47.2	69.3
Sep	98.5	78.5	2	43.3	44.0	17.3
Oct	94.8	-	2	33.5	41.1	85.2
Nov	259.6	-	2	3.9	41.6	219.9
Dec	291.8	-	2	9.0	38.0	260.8

Note: Icicle Creek at USGS gage flows are for 1998, IPID diversions are averaged from 1990-1991, City of Leavenworth diversion is assumed to be 2 cfs, Snow Creek flows are averaged from 1994-2002, LNFH & CO diversions are averaged from 1991-2001.

Table 2-5
Results of Hydrologic Analyses – High Flow Year -1997

Month	Inflow and Outflow(cfs)					Instream Flow downstream of LNFH diversion (cfs) (=)
	Icicle Creek at USGS gage	IPID (-)	City (-)	Snow Creek (+)	LNFH & CO (-)	
Jan	313.1	-	2	*9.0*	38.2	281.9
Feb	369.2	-	2	32.3	44.6	355.0
Mar	668.6	-	2	21.6	46.0	642.2
Apr	834.3	68.6	2	23.7	40.1	747.4
May	2,401.2	88.2	2	56.0	28.4	2,338.6
Jun	2,409.3	96.1	2	29.6	42.4	2,298.4
Jul	1,179.4	99.3	2	43.5	48.2	1,073.3
Aug	341.0	98.3	2	36.6	47.2	230.2
Sep	239.8	78.5	2	43.3	44.0	158.6
Oct	576.5	-	2	33.5	41.1	566.9
Nov	510.9	-	2	3.9	41.6	471.2
Dec	244.5	-	2	9.0	38.0	213.5

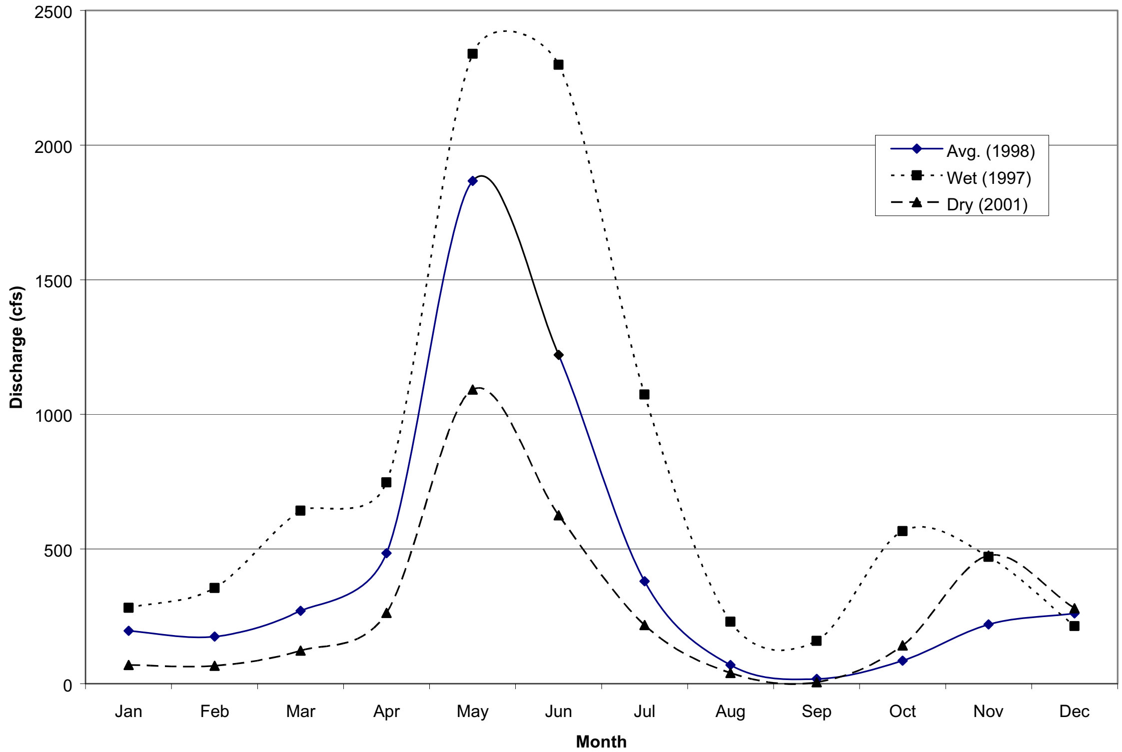
Note: Icicle Creek at USGS gage flows are for 1997, IPID diversions are average from 1990-1991, City of Leavenworth diversion is assumed to be 2 cfs, Snow Creek flows are averaged from 1994-2002, LNFH & CO diversions are averaged from 1991-2001.

Table 2-6
Results of Hydrologic Analyses – Low Flow Year - 2001

Month	Inflow and Outflow(cfs)					Instream Flow downstream of LNFH diversion (cfs) (=)
	Icicle Creek at USGS gage	IPID (-)	City (-)	Snow Creek (+)	LNFH & CO (-)	
Jan	100.9	-	2	*9.0*	38.2	69.7
Feb	81.0	-	2	32.3	44.6	66.8
Mar	149.1	-	2	21.6	46.0	122.7
Apr	349.8	68.6	2	23.7	40.1	262.9
May	1,154.4	88.2	2	56.0	28.4	1,091.8
Jun	735.9	96.1	2	29.6	42.4	625.0
Jul	324.0	99.3	2	43.5	48.2	217.9
Aug	150.2	98.3	2	36.6	47.2	39.4
Sep	86.3	78.5	2	43.3	44.0	5.1
Oct	151.7	-	2	33.5	41.1	142.1
Nov	515.6	-	2	3.9	41.6	475.9
Dec	311.0	-	2	9.0	38.0	280.0

Note: Icicle Creek at USGS gage flows are for 2001, IPID diversions are average from 1990-1991, City of Leavenworth diversion is assumed to be 2 cfs, Snow Creek flows are averaged from 1994-2002, LNFH & CO diversions are averaged from 1991-2001.

Figure 2
Instream Flows Downstream of the LNFH Diversion



Additionally, a worst-case scenario was completed for a very dry year with all water users taking the full amount of their water right in order of priority (earliest date of water right certificate or permit). The water right for each of the water users is provided in Table 2-7. The results of the analysis are shown in Table 2-8. The results show that in a very dry year on Icicle Creek with average inflow from Snow Creek, the channel downstream of the LNFH diversion will be dry in August and September if all users upstream of the LNFH could take their full water right. The LNFH would have a reduced water supply in August and no water available for diversion in September.

Table 2-7
Water Rights on Icicle Creek

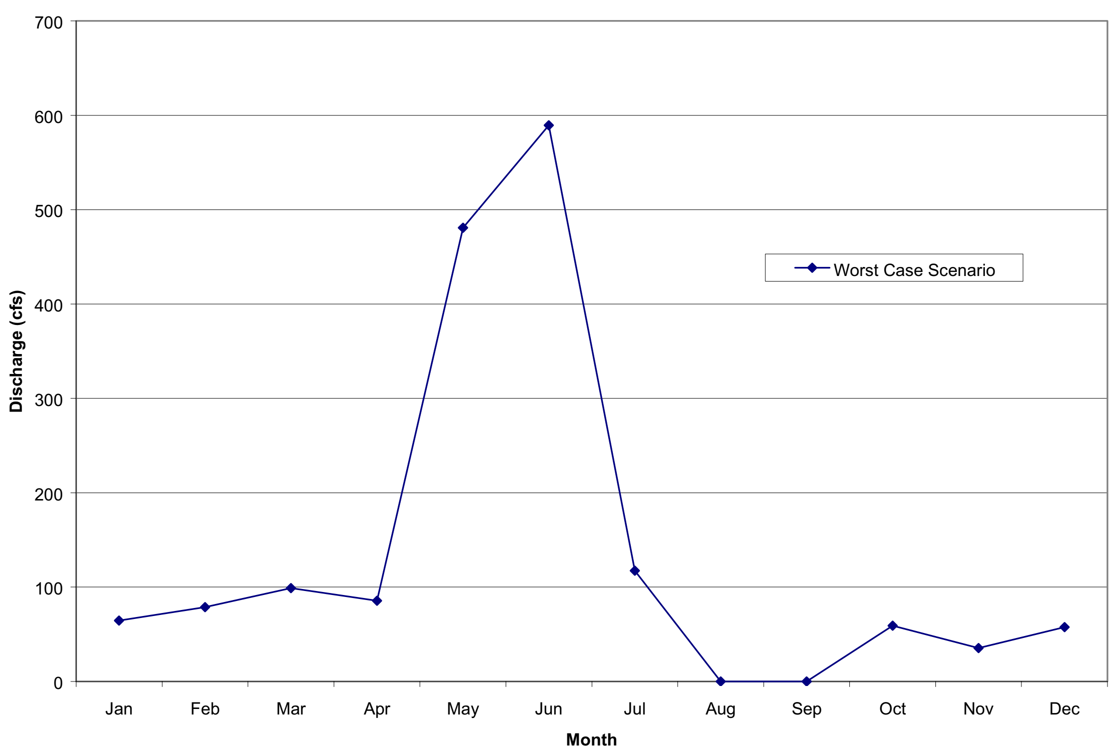
Water User	Water Right Amount	Priority Date
Icicle and Peshastin Irrigation District	83.3 cfs and 34.4 cfs (117.7 cfs total)	1910 and 1926
City of Leavenworth	1.5 cfs	1912
Cascade Orchards	12 cfs	1905
Leavenworth National Fish Hatchery	42 cfs	1942

Table 2-8
Results of Hydrologic Analyses – Very Low Flow – 95% Exceedance

Month	Inflow and Maximum Outflow(cfs)						Instream Flow downstream of LNFH diversion (cfs) (=)
	Icicle Creek at USGS gage	IPID (-)	City (-)	Snow Creek (+)	CO (-)	LNFH (-)	
Jan	99		1.5	*9.0*		42	64.5
Feb	90		1.5	32.3		42	78.8
Mar	121		1.5	21.6		42	99.1
Apr	223	117.7	1.5	23.7		42	85.5
May	598	117.7	1.5	56.0	12	42	480.8
Jun	733	117.7	1.5	29.6	12	42	589.4
Jul	247	117.7	1.5	43.5	12	42	117.3
Aug	119	117.7	1.5	36.6	12	24	0.0
Sep	87	117.7	1.5	43.3	12	0	0.0
Oct	69		1.5	33.5		42	59.0
Nov	75		1.5	3.9		42	35.4
Dec	92		1.5	9.0		42	57.5

Note: Icicle Creek at USGS gage flows are the 95% exceedance flows, IPID diversions are the full water right for April through September, Snow Creek flows are averaged from 1994-2002, City of Leavenworth and CO diversions are the full water right, LNFH diversions are the full water right except for August and September when the flows are reduced to the water remaining in the creek.

Figure 3
Worst Case Scenario Instream Flows Downstream of the LNFH Diversion



2.1.2 Results of Tennant Method

An assessment of existing instream flow downstream of the LNFH diversion was made using the Tennant method. Table 2-9 shows the results of the assessment for representative average, wet and dry years. The average annual flow for Icicle Creek based on the USGS data is 621 cfs.

In Table 2-9, the ratio of each monthly flow value to the average annual flow is computed and compared to the Tennant habitat quality rating for each month contained in Table 2-1. The flow for which the criteria are applied to is the estimated flow downstream of the LNFH diversion, which is listed in Tables 2-4 through 2-6. During the majority of the year, the reach downstream of the LNFH diversion has a habitat quality rating of “fair” or better, even during dry years.

In August and September, the flows fall below “minimum” ratings in most years. In average water years, the percentage of average annual flow is 3% to 11% during those months, which correspond to a “minimum” rating in August to a “severe degradation” rating in September. In dry years, the ratings for both months are in the “severe degradation” category. Although natural streamflow can be very low in October, the percentage of instream flow increases as diversions by the Icicle and Peshastin Irrigation District typically end in September. The habitat quality ratings for October were “fair” or better for the three years listed in Table 2-9.

Observations by Mid-Columbia River Fishery Resource Office (MCRFRO) staff of low flow in September 2001 indicated that a flow of 12.6 cfs (measured on September 5, 2001 and approximately 2% of the AAF) caused redd mounds to be partially dewatered, reduced the amount of wetted channel width and depth, greatly reduced the number of live fish observed, and eliminated spawning activity. Surveys were also conducted on July 31, 2001 and August 31, 2001 by MCRFRO staff to count the number of live and dead adult spring Chinook salmon, assess spawning areas, and look for redds. No flow measurement was available for July 31, 2001. Observations of potentially viable redd mounds and active spawning made on August 31, 2001 at a measured flow of 23.1 cfs (4% of the AAF) indicate that this discharge did not inhibit fish use and may be in the range of a more appropriate target or minimum flow value for the low-flow month of September.

From this analysis, it appears flows are in “minimum” range for August but fall below that in September for most years. In dry years the flows experienced in August and September correspond to the “severe degradation” range. As described earlier, this method is typically used as a reconnaissance level analysis of environmental flows. It does not provide site-specific detail on habitat that may or may not be present in the study reach at various flows. It is presented to provide background to more detailed instream flow analyses.

Table 2-9
Results of Tennant Method

Month	1998 (Average Flow Year)			1997 (High Flow Year)			2001 (Low Flow Year)		
	Flow (cfs)	% of AAF	Rating	Flow (cfs)	% of AAF	Rating	Flow (cfs)	% of AAF	Rating
Jan	196.4	32%	Excellent	281.9	45%	Outstanding	69.7	11%	Fair
Feb	174.6	28%	Good	355	57%	Outstanding	66.8	11%	Fair
Mar	270.5	44%	Outstanding	642.2	103%	Optimal	122.7	20%	Good
Apr	485	78%	Optimal	747.4	120%	Optimal	262.9	42%	Good
May	1867.1	301%	Flushing	2338.6	377%	Flushing	1091.8	176%	Flushing
Jun	1220.9	197%	Flushing	2298.4	370%	Flushing	625	101%	Optimal
Jul	380.5	61%	Outstanding	1073.4	173%	Flushing	218	35%	Fair
Aug	69.2	11%	Minimum	230.1	37%	Fair	39.3	6%	Severe Degradation
Sep	17.3	3%	Severe Degradation	158.6	26%	Fair	5.1	1%	Severe Degradation
Oct	85.1	14%	Fair	566.8	91%	Optimal	142	23%	Good
Nov	219.9	35%	Excellent	471.2	76%	Optimal	475.9	77%	Optimal
Dec	260.8	42%	Outstanding	213.5	34%	Excellent	280	45%	Good

2.2 Hydrologic Assessment Using Hatfield and Bruce Method

Another method that has been used in the review of instream flows is the Hatfield and Bruce method (AFS, 2000). This method uses regression equations developed from a study of 127 PHABSIM studies from western North America to predict the flow needs for four life stages of four different salmonids (Chinook salmon, steelhead, rainbow trout and brown trout) plus an aggregate salmonid prediction. The equations predict the "optimal" flow that would be determined with a PHABSIM analysis. The optimal flow is defined as the flow that maximizes an index of habitat availability, the Weighted Usable Area (WUA) index. The optimal flow is related to channel configuration, velocity, depth, substrate, cover and other factors related to fish preference. It does not consider the availability of flow, which needs to be considered during dry summer months. The optimal flow is different than a "minimum" flow or "target" flows that are negotiated flows based upon water availability and water needs for both fish habitat and water users. The optimal flows estimated in this section can be compared to the results of the Tennant Method and the preliminary PHABSIM modeling performed for this study to help compare various target flows to optimal flows.

The optimal flow regression equations generally take the form:

$$Ln\ (optimal\ flow) = A \times Ln\ (MAD),$$

where "MAD" is the mean annual discharge and "A" a coefficient that is less than 1. Some improvements to the optimal flow predictions were found when latitude and longitude coordinates were added to the regression.

2.2.1 Hydrology Data Available

The hydrologic data used previously to complete the Tennant method is suitable for use with the Hatfield and Bruce regressions. The MAD (equal to Average Annual Flow) was determined to be 621 cfs (see Section 2.1.2). The latitude and longitude for the project area were also used to refine the regressions.

2.2.2 Results of Optimal Flow Estimates

Table 2-10 lists the optimal flows determined using the Hatfield and Bruce regressions. Generally, the optimal habitat for adults is estimated to occur with flows between 30 and 55 percent of the MAD (182 to 341 cfs), with the larger fish preferring larger flows. As shown previously, these flows occur infrequently during August, September, and October when fish are assumed to be migrating upstream to suitable spawning habitat. Optimal flows for fry and juvenile life stages are less, estimated to be 60-193 cfs for the species listed in Table 2-10 (Chinook Salmon, Rainbow Trout and Steelhead Trout).

Table 2-10
Results of Hatfield and Bruce Method - Optimal Flow for Salmonid Life Stages

Species	Life Stage	Optimal Flow (cfs)	Percent of MAD (%)
Chinook Salmon	Fry	68	11%
	Juvenile	156	26%
	Adult	NA	NA
	Spawning	271	44%
Rainbow Trout	Fry	60	10%
	Juvenile	193	32%
	Adult	275	45%
	Spawning	330	54%
Steelhead Trout	Fry	82	13%
	Juvenile	181	30%
	Adult	345	57%
	Spawning	302	49%

NA: Not applicable since adult salmon do not reside in rivers, they are only there for spawning.

2.3 Physical Habitat Evaluation Method

A preferred method of analyzing instream or target flows is through direct measurements of hydraulic properties of the channel and observation of fish behavior if present. The most common method entails data collection and analysis using the PHABSIM model (a component of a detailed Instream Flow Incremental Methodology [IFIM] study). This method involves assessing the available habitat in a stream reach at various flows through the use of channel geometry. Channel cross-sections are surveyed and channel properties measured (water depth, velocity, substrate size, cover). The sections are measured at representative features such as pools and riffles. A preliminary PHABSIM analysis was completed for this study. The analysis is considered to be preliminary because additional field data is needed to more completely describe the Icicle Creek channel downstream of the LNFH diversion and site-specific fish habitat preference data should be obtained to better describe fish use in Icicle Creek.

2.3.1 Summary of Channel Data Used in PHABSIM

The reach downstream of the LNFH diversion structure is primarily step/pool with large boulders and a steep slope. About 500 feet downstream of the diversion structure is a long pool. Again there are large boulders in the channel, but the water surface slope is flat for about 500 feet. Approximately 1,500 feet downstream from the diversion structure, along the RV Park property, the channel acts like a long riffle. Here the bed material is slightly smaller with the majority of the boulders ranging in size from 1 ft to 3 ft. At the downstream end of RV Park property, the channel splits around two small islands.

An area that is a possible barrier to adult fish passage due to shallow depth is the broad riffle at the downstream end of the RV Park property. In this area, the channel is very wide as the water spreads out to flow around an island.

Downstream of these islands, approximately 2,500 feet downstream of the diversion structure, the water is again pooled for about 500 feet. In this area, sand and gravel have collected along the left bank in a small point bar. The material in the channel is primarily cobble ranging in size from 0.3 ft to 1.0 ft. The LNFH headgate structure is approximately another 1,000 feet downstream.

In this reach three representative channel cross-sections were surveyed and channel properties measured. The sections were measured at representative runs and riffles. The most downstream riffle is located behind the Sleeping Lady Resort and upstream from the LNFH headgate structure (diversion into the historic channel). The middle cross-section was measured a few hundred feet upstream at a run. The upstream cross-section was measured at the RV Park in the broad riffle described above. The location of those measurements is shown in Map 1. The fieldwork was performed at three flow conditions (55, 147, and 291 cfs). It was hoped that lower flows in the 20 to 30 cfs range would occur during the past year, but these flows were not observed because of a wet August. Although the flows measured are higher than those typically recorded during the driest time of year they are much less than the Average Annual Flow (621 cfs) and the flows typically experienced in spring (mean monthly flow = 1,778 cfs in June). The shape of the Icicle Creek channel has been formed by flows much greater than experienced in late summer, which is an important consideration in evaluating instream flow.

Fish habitat preference data is not available for the reach of Icicle Creek studied so generalized habitat preference curves (WDFW and Ecology April 2004) were used. The generalized, or fallback, curves were prepared by WDFW and Ecology using data from a number of instream flow studies conducted by those two agencies. The use of these generalized habitat preference curves is probably suitable for this application, which reviews the relative increase in habitat with flow. If a detailed PHABSIM and IFIM study is performed in the future, we would recommend field data be collected to revise the curves to meet site-specific conditions.

The data collected was input into PHABSIM as well as preference curves for Bull Trout and Steelhead. Based on the substrate present in the reach of interest, the habitat is primarily suitable for juvenile and adult bull trout and steelhead habitat and over wintering steelhead. Boulders and large cobbles dominate the substrate. In the reconnaissance survey of the channel no significant deposits of gravels, suitable for spawning, were observed.

2.3.2 PHABSIM Results

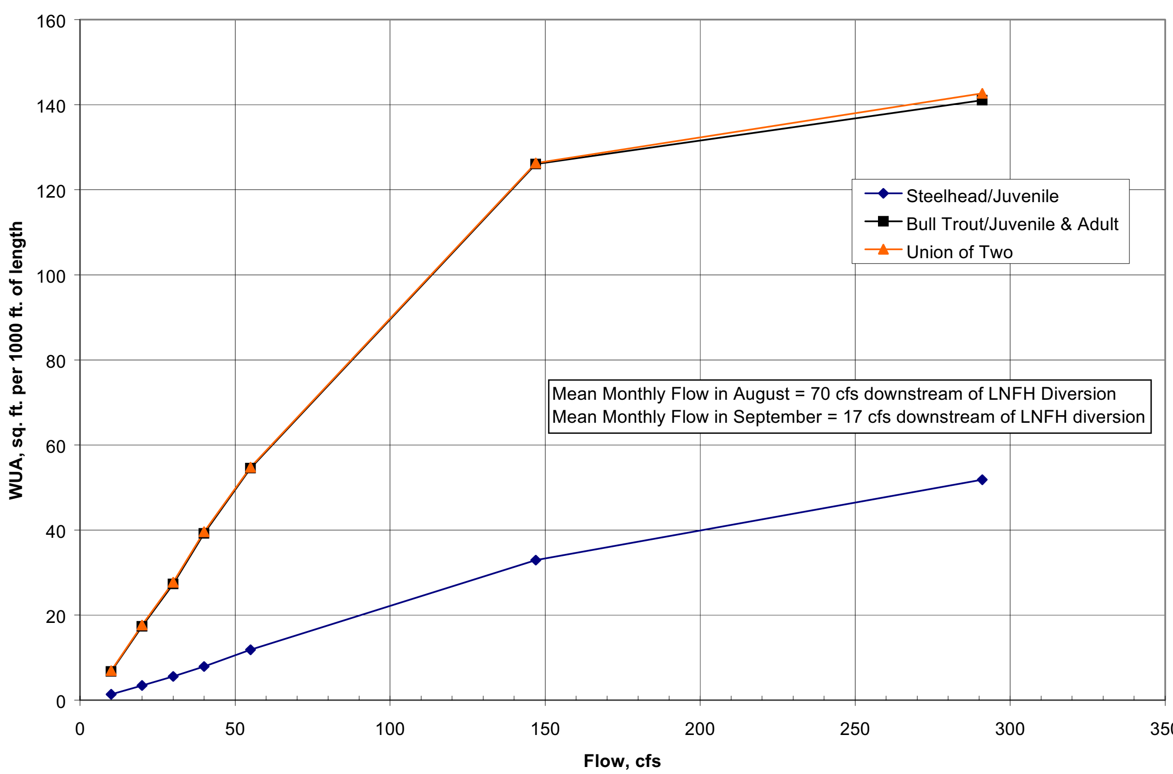
Table 2-11 provides a listing of the WUA at the various flows measured for Steelhead and Bull Trout. Habitat is measured as weighted usable area (WUA) in square feet per 1000 ft of channel length. For this application, data was not provided to characterize the entire length of the study reach but only at the cross sections measured. The WUA would need to be multiplied by the lengths of riffle and runs to obtain total WUA. However these results are useful to compare the relative amounts of habitat at various target flows.

Table 2-11
PHABSIM Results

Flow (cfs)	Juvenile and Adult Bull Trout (WUA)	Juvenile Steelhead (WUA)
291	51.8	141.0
147	32.9	126.0
55	11.8	54.5

Figure 4 illustrates the results of the PHABSIM analysis.

Figure 4
PHABSIM Results
Icicle Creek below LNFH Diversion



This PHABSIM analysis shows the maximum habitat for adult and juvenile bull trout and steelhead was available at the maximum flow in the simulation (291 cfs). The optimal flow was not estimated for this reach of Icicle Creek, as the simulation was not performed above the highest measured flow of 291 cfs. That flow is well below the Average Annual Flow (621 cfs). For this reach of Icicle Creek, it appears the optimum habitat would occur at flows greater than 291 cfs as the shape of the channel is formed by flows much greater than 291 cfs. At higher flows the creek fills its channel and floods additional area that would have more suitable substrate, velocity and cover, especially for juvenile fish.

Tables 2-12 and 2-13 present a comparison of WUA for Bull Trout at different flow levels experienced in Icicle Creek in August and September (obtained from Tables 2-4 through 2-6).

Table 2-12
Existing Flow vs. WUA, August

Flow, cfs	Existing Flow Level	WUA, sq. ft/1000 ft. for Bull Trout Juveniles & Adults
10		7
20		17
30		27
40	Low flow (i.e. 2001)	39
50		49
60		58
70	Average Flow (i.e. 1998)	65
80		73
90		81
100		89
230	High flow (i.e. 1997)	133

Table 2-13
Existing Flow vs. WUA, September

Flow, cfs	Existing Flow Level	WUA, sq. ft/1000 ft. for Bull Trout Juveniles & Adults
5	Low flow (i.e. 2001)	4
10		7
17	Average Flow (i.e. 1998)	12
20		17
30		27
50		49
60		58
159	High flow (i.e. 1997)	126

These estimates of WUA at various flow levels can be used to determine the relative benefit of providing various target flows. For example, a target flow of 20 cfs provided downstream of the LNFH diversion in September would result in an increase in WUA of 41% (17/12) over the average flow present (17 cfs). A target flow of 20 cfs provided during a low flow year would provide a much greater increase in WUA, 425% (17/4). Larger target flows would provide larger percentage increases in habitat. Note that the WUA calculation is only providing a relationship between flow and available habitat and does not describe the presence or absence of fish in that habitat nor does it predict fish production.

2.4 Fish Passage Criteria

There are different criteria used in analyzing depths and velocities for fish passage. One method was established by Thompson (1972). This method involves identifying areas that may be barriers to adult fish passage due to shallow depth such as shallow runs, riffles, bars, or bedrock outcrops. Measurements are made at these locations determine the percentage of the channel width with adequate depth for passage. Thompson's minimum depth criteria are 0.8 feet for Chinook Salmon and 0.6 feet for steelhead. A channel is considered adequate for adult passage if 25% of the channel width meets or exceeds Thompson's minimum depth criteria. Within that 25%, a width of at least 10% of the entire wetted channel width must be contiguous. In addition, it is common to look at the length of the barrier as fish can navigate the water below the minimum depth specified by Thompson for short distances (e.g. it is common during floods to see salmon crossing over roads in only a few inches of water). As a rule of thumb, barriers that appear greater than 10 feet in length should be investigated. In the study reach, the only area identified as a possible barrier to adult fish passage due to shallow depth is a broad riffle at the downstream end of the RV Park property (cross-section 300). In this area the channel is wide (approximately 130 feet) as the water spreads out to flow around an island

2.4.1 Results of Hydraulic Model

The hydraulic modeling routines within the PHABSIM model were used at the three cross-sections to review the fish passage criteria. Figures 5-7 provide an illustration of the hydraulic modeling results from PHABSIM for the three cross-sections measured. Flow depths and velocities are shown in the figures.

Figure 5
Cross-section 100 Hydraulic Data
Flow = 55 cfs

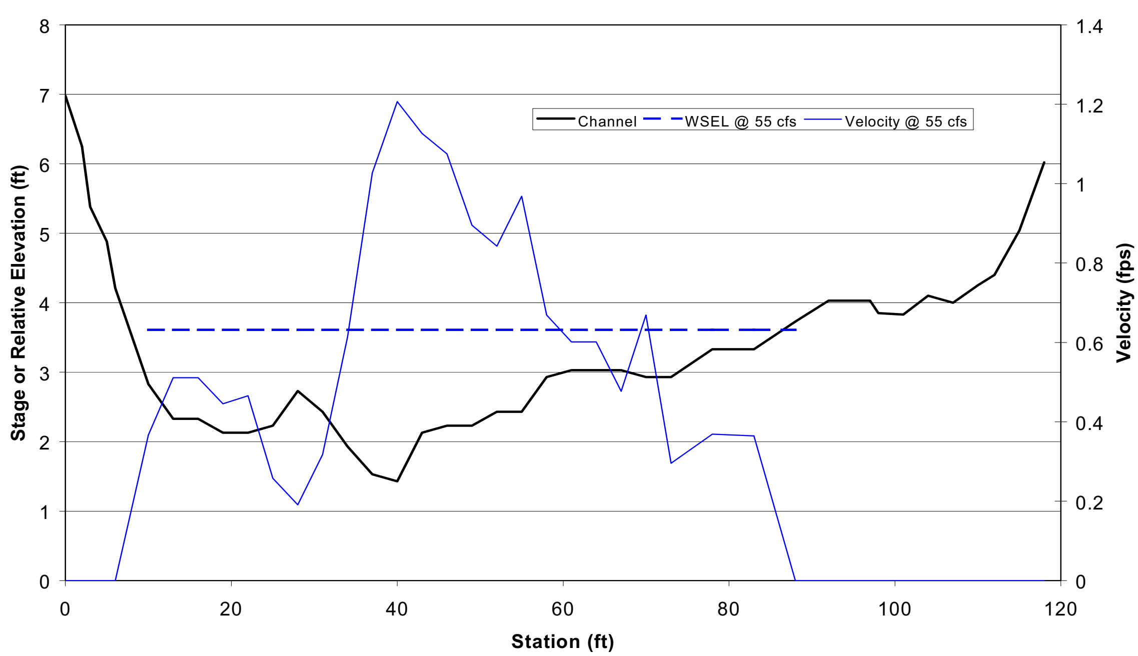


Figure 6
Cross-section 200 Hydraulic Data
Flow = 55 cfs

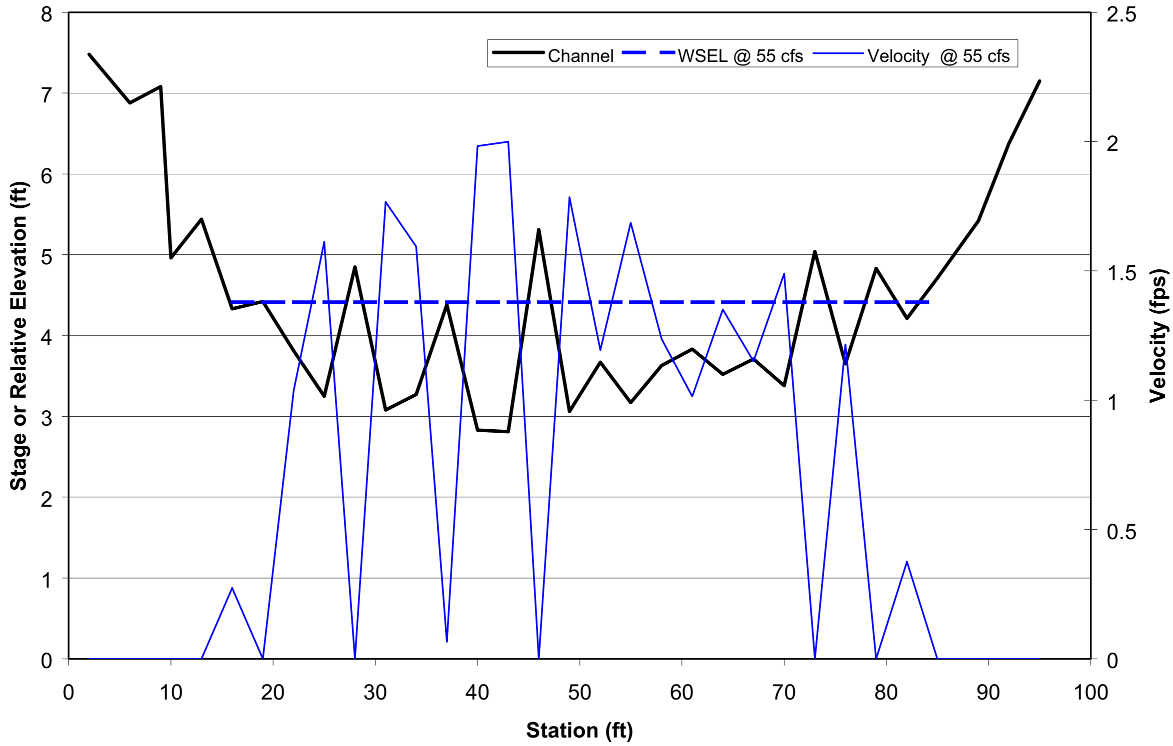
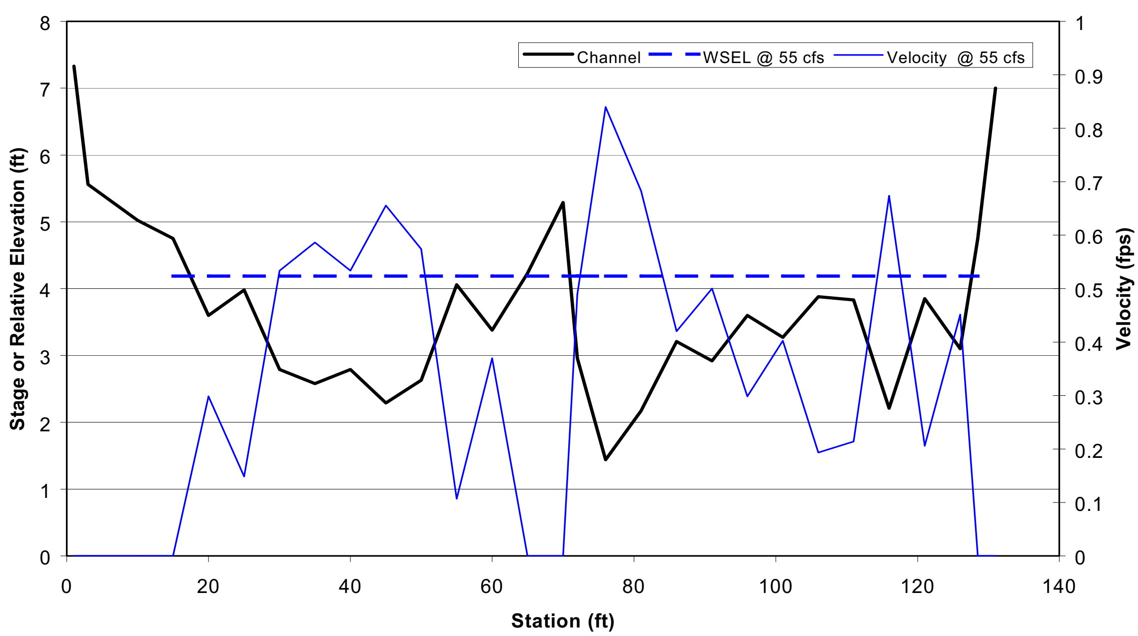


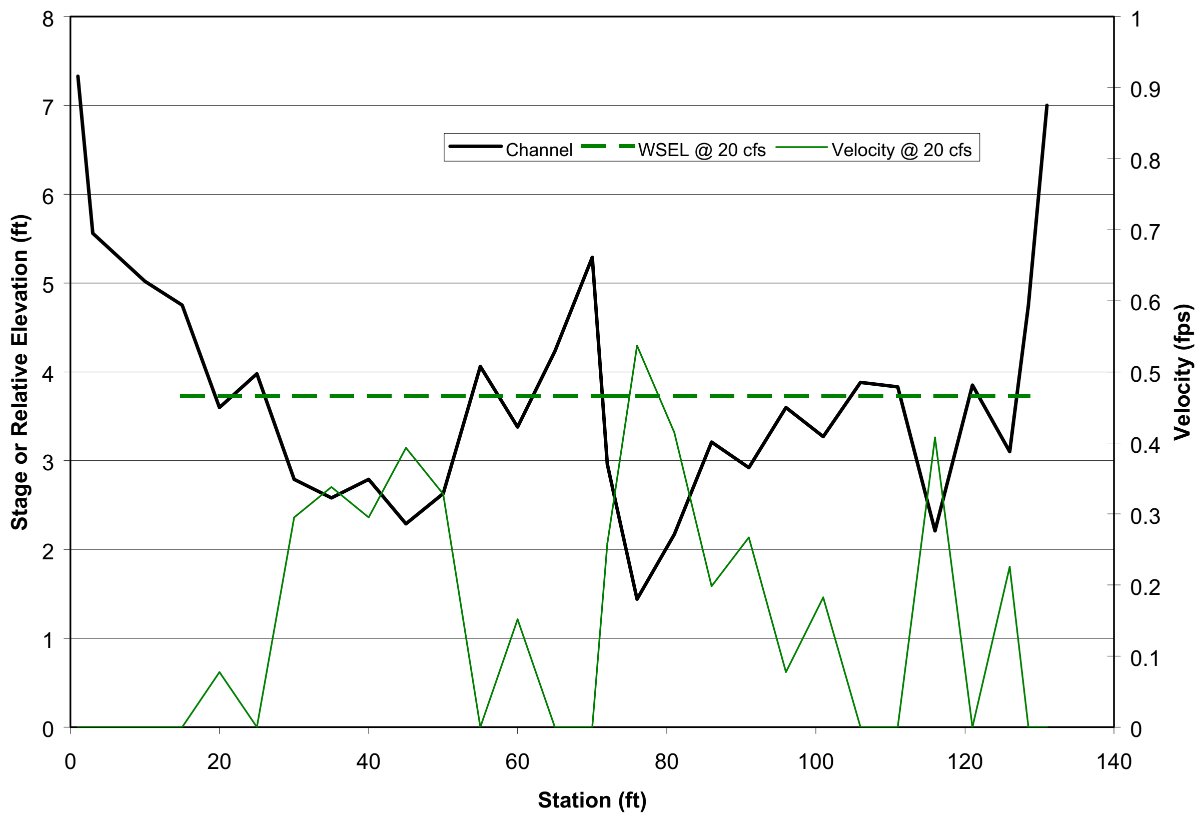
Figure 7
Cross-section 300 Hydraulic Data
Flow = 55 cfs



The velocities in the creek vary widely because of the varying depth across the channel. The large size of the bed material in the reach also influence the velocities at low, shallow flows. The bed material is often as large as the flow is deep and flow splits around large boulders as shown in Figures 6 and 7.

Hydraulic modeling was performed in the PHABSIM model to estimate water depths and velocities at flows lower than measured in the field. A flow rate of 20 cfs was selected for analysis. Figure 8 shows the results of the analysis at cross-section 300, which is the most critical cross-section for fish passage.

Figure 8
Results of Hydraulic Modeling at Cross-section 300
Flow = 20 cfs



According to the water surface elevation simulation in PHABSIM the depth in the channel through the riffle would exceed the minimum depth criteria established by Thompson at 20 cfs. The results of the modeling correspond to our observations that at lower flows, the larger boulders will tend to be exposed and the channel will be divided leaving passages between the boulders for fish to navigate. The results are also consistent with the observations by USFWS personnel in 2001 that recorded fish usage in the channel at 23 cfs, but a reduced level at 12.6 cfs.

The hydraulic modeling indicates Thompson's criteria could also be met at flows lower than 20 cfs. However additional fieldwork should be performed to verify those results as the modeling results can deviate from actual conditions because of the channel irregularity and the size of the substrate present in Icicle Creek.

3.0 Discussion

The purpose of this study is to review the flow needs for fish based upon fish passage requirements and habitat improvement with increased flow. We determined that passage can readily occur at 20 cfs and would likely be possible at lower flows also. Those conclusions are consistent with observations by USFWS in 2001 at a 23 cfs flow.

A preliminary PHABSIM model was prepared using field data and generalized fish habitat preference curves. The model provides estimates of the WUA for various flows. Because a complete PHABSIM model was not prepared (additional field work would be required to better define the extent of each type of habitat and site-specific habitat preference data) the results should be used as a means to compare the relative amount of habitat available at different flows. It was beyond the scope of this study to prepare recommendations for flow targets for the study reach.

Based on the substrate conditions and the lack of cover the study reach has greatest value for fish habitat during the low flow period (August through October) for only the adult and juvenile life stages of either bull trout or steelhead. For these life stages habitat increases with wetted area. Spawning habitat and rearing habitat for fry is limited because of the substrate and cover conditions.

Respectfully submitted,
MONTGOMERY WATER GROUP, INC.

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Principal Engineer

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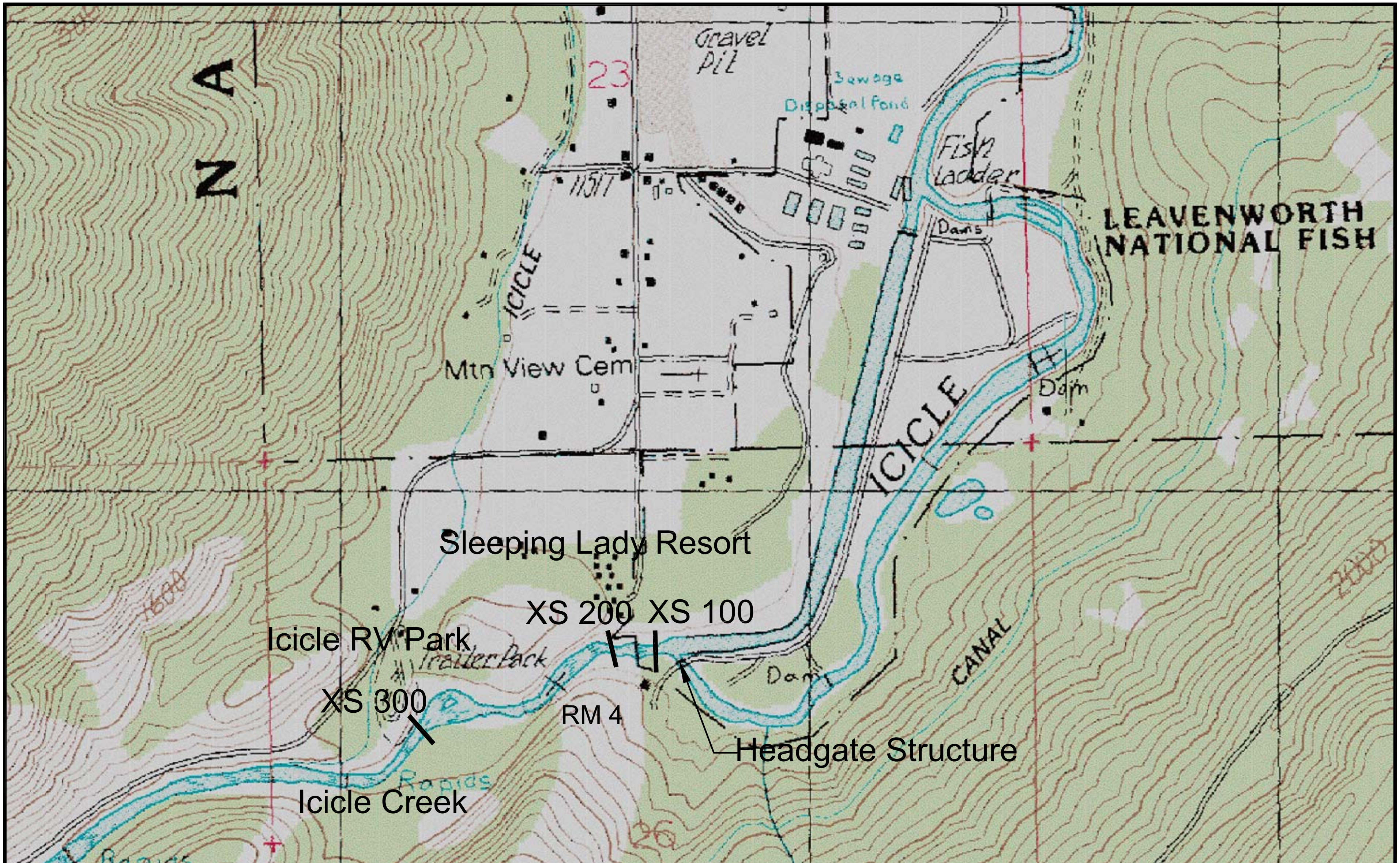

Map 1
Cross-Section Location Map
Target Flow Study

Leavenworth National Fish Hatchery

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10/20/04

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