TROUT HABITAT FLOW ANALYSIS

Reach Selection

The relationships between available trout habitat and streamflow were investigated during the 2007 field season in 11 of the 27 Grand County stream reaches using the PHABSIM (Physical Habitat Simulation) system (Bovee 1997; USGS 2001). The 11 reaches were selected for study based on several criteria, including streamflow magnitude, history of hydrologic alteration, location within the county's river drainage network, relative importance for recreational and other water uses and, in most cases, the lack of previous detailed instream flow studies. These reaches and the study sites sampled are described in Table A1. Eight additional PHABSIM sites were selected and sampled in 2008 and in 2009 as described in Table A2 and A3.

Table A1. Site Details for the 10 Reaches Selected for PHABSIM Surveys and Modeling in 2007

Location	Site	Number of Transects	Streamflow (cfs)			Dates Sampled		
			High	Medium	Low			
Vasquez Ck	F-VC	9	102	63	8	Jun 24	Jul 5	Jul 30
St Louis Ck	F-StL	11	58	30	12	Jun 22	Jun 24	Aug 2
Fraser River @ WWTP	F6	10	233	45	18	Jul 5	Jul 30	Oct 25
Fraser River @ Granby Ranch	F9	11	219	75	52	Jul 2	Jul 31	Oct 25
Colorado R. @ Miller Ranch	CR3	9	109	52	36	Jul 4	Aug 1	Oct 27
Colorado R. u/s K-B ditch	CR5	7	547	269	217	Jul 4	Aug 1	Oct 27
Colorado R. d/s K-B ditch	CR6	8	518	267	191	Jul 3	Aug 1	Oct 27
Colorado R. below Gore Canyon	CR7	3	958	535	509	Oct 10	Oct 31	Oct 31
Blue River	BR	10	530	345	NC	Jul 20	Aug 3	Oct 24
Williams Fork	WR	10	236	60	62	Jul 6	Jul 31	Oct 26
Muddy Ck	MC2	8	94	38	18	Jun 16	Jun 23	Oct 24

Table A2. Site Details for the 5 Reaches Selected for PHABSIM Surveys and Modeling in 2008

Location	Site	Number of Transects	Streamflow (cfs)			Dates Sampled		
			High	Medium	Low			
Fraser River at Idlewild Campground	F3	8	56	27	4.7	Jun 23	Jul 9	Oct 12
Ranch Creek, upper	F-RC1	7	35	11	3.1	Jun 24	Jul 8	Oct 13
Ranch Creek, lower	F-RC2	7	125	27	13	Jun 24	Jul 18	Oct 13
Colorado River at Chimney Rock	CR4	7	304	89	54	Jul 17	Sept 3	Oct 15
Blue River below Trough Rd	BR-Spawning	2	-	479	208	-	Jun 27	Jun 25

Table A3. Site Details for the 3 PHABSIM Survey Sites Modeled in 2009

Location	Site	Number of Transects	Streamflow (cfs)			Dates Sampled		
			High	Medium	Low			
Blue River at BVR-Upper	BVR-U	6	402	201	96	Nov 20	Nov 18	Nov 17
Blue River at BVR-Middle	BVR-M	6	380	192	97	Nov 19	Nov 18	Nov 16
Blue River at BVR-Lower	BVR-L	5	386	204	94	Nov 20	Nov 18	Nov 16

Site Selection

Within the constraints of access and ability to wade, the study sites were selected based upon their representation of the flow and habitat characteristics present within the reach. Stream reaches throughout Grand County were selected for PHABSIM modeling according to county priorities and availability and quality of prior surveys. Site scoping trips were conducted in May 2007 and again in 2008 and 2009 to select representative sites for each reach (Bovee 1997). Final selections were made by the study team following review of recent aerial photography, examination of streamflow and other available hydraulic and geomorphic data, and discussions with knowledgeable citizens and officials. Photographs and site descriptions are presented in Appendix E.

Field Data Collection

Field data collection was conducted at PHABSIM sites following the guidance of Bovee (1997). At each study site, a clearly defined hydraulic control was present and operational at the downstream end. Each site was divided into six to ten contiguous units of relatively homogenous habitat (such as riffles and runs) and microhabitat elements (woody debris, boulders). A cross-sectional transect was then placed to bisect each habitat unit. Transects were permanently established with head/tail pins, which were placed well above bankfull water elevations. Across each transect, 15 to 25 cells were established at uniform intervals ranging from 0.5 to 10 feet (depending on channel width). Photographs were taken of each site and each transect.

Longitudinal Channel Survey – Each study site was surveyed longitudinally, with distances recorded from each transect to the upstream and downstream boundaries of the channel unit or cell. Each site was also sketched in a field book to represent channel geometry and site features.

Elevational Channel Survey – At each site, primary and secondary benchmarks were installed that could be used to reference relative elevations. (Primary benchmarks were given the arbitrary elevation of 100 feet.) A rod and level survey recorded elevations of each headpin and tailpin, each pair of which was leveled, and all transects were linked within a level loop to determine longitudinal slopes. A steel tagline was then installed across each transect, and vertical distances were measured from tape-to-streambed at each cell, allowing cell elevations to be derived. Channel substrate material and size (sand, fine gravel, coarse gravel, cobble, boulder) was visually estimated at each cell, and the presence or absence of fish cover (such as wood and boulders) was noted.

Hydraulic Survey – Hydraulic characteristics were measured at each site at three streamflows, which were chosen to represent the widest possible flow range. Hydraulic characteristics consisted of both water surface elevations and current velocities. Using a level loop, water surface elevations were measured against both banks at each transect. Water surface elevations at hydraulic controls within each site were also surveyed. Current velocities were measured at each cell across each transect at 6/10 depth using a Marsh-McBirney electromagnetic velocity meter (velocities measured as 15-second averages). Short-term changes in discharge were monitored with an on-site staff gage, and gage height was noted for each transect's measurements.

Temperature – Temperature loggers were installed at selected sites to continuously monitor temperature changes through the summer and early fall of 2007 and 2008. Table A4 summarizes recovered temperature logger locations and monitoring periods.

Table A4. Temperature Logger Locations and Monitoring Periods

Stream Reach	GPS Coordinates		Date installed	Date removed
St Louis Ck	N39^{o} 55’ 602”	W105^{o} 51’102”	6/22/07	10/22/07
William Fork	N40^{o} 03’312”	W106^{o} 10’980”	7/01/07	10/26/07
Fraser R.	N40^{o} 04’754”	W105^{o} 54’221”	7/02/07	10/25/07
Vasquez Ck	N39^{o} 53’384”	W105^{o} 48’821”	6/24/07	10/23/07
Colorado R. above K-B ditch	N40^{o} 03’420”	W106^{o} 16’690”	7/04/07	10/27/07
Colorado R. at Miller Ranch	N40^{o} 06’644”	W105^{o} 56’455”	6/18/07	10/26/07
Colorado R. at Chimney Rock	N40^{o} 06’089”	W106^{o} 01’496”	7/01/08	10/15/08
Fraser River nr Idlewild CG	N39^{o} 54’024”	W105^{o} 46’597”	6/24/08	10/13/08
Upper Ranch Creek	N39^{o} 56’975”	W105^{o} 46’014”	6/24/08	10/14/08

Colorado River Reach 7 - Field methods varied somewhat for Reach CR7, Colorado River below Gore Canyon, because of the high flows and often unwadeable conditions encountered. Here, seven independent river cross-sections surveyed during 2007 were used as the basis for the PHABSIM analysis. Three cross-sections, surveyed in October 2007 at flows ranging from 509 to 958 cubic feet per second (cfs), were located at the Pumphouse Boat Launch, the Northern Properties, and the Radium Boat Launch, near the downstream end of Grand County. These cross-sections were selected during an August 13, 2007, float trip based on their habitat characteristics, accessibility, and likelihood of being wadeable at lower flow levels. Water depth and velocity were measured (using an Aquacalc 5000 with a Price AA current meter and wading rod) and substrate was observed at more than 20 locations along each cross-section. Elevations were measured with a robotic total station. The remaining four cross-sections were located in Eagle County at the Colorado River Road Bridge 8 miles upstream of Dotsero, Colorado, and were surveyed on March 28, 2007, at 1,054 cfs. Water velocities for these cross-sections were generated using the U.S. Army Corps of Engineer’s HEC-RAS hydraulic model, while general substrate observations were made on the day of the survey. Elevations were measured with a robotic total station.

Data Analysis and Modeling

Flow-habitat relations were developed for each of the sites using the PHABSIM for Windows modeling approach (USGS 2001). Verified habitat suitability curves for the target species brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and brook trout (*Salvelinus fontinalis*) and target life stages adult and juvenile were provided by the Colorado Division of Wildlife (pers. comm., Mark Uppendahl, CDOW Instream Flow Program Coordinator, 2007). Spawning habitat availability was also evaluated using water depth and velocity suitability curves for brown and rainbow trout, assuming a substrate preference for gravel (less than 3.0-inch diameter). Based on the similarity of these spawning curves and the lack of site-specific information to differentiate between species use patterns, these habitat data were grouped into a generic set of suitability curves for “trout spawning”. These spawning curves were then verified by comparing them to curves developed from the 2008 trout spawning survey described later in this appendix. The habitat suitability curve data used are presented in Table A5. PHABSIM modeling was conducted for each study site over a range of streamflows and weighted usable habitat area (expressed as square feet per 1,000 feet of channel length, WUA) was determined for each target species and life stage. Plots and tables describing these flow-habitat relations were generated to allow identification of environmental flow ranges.

Table A5. Habitat Suitability Curve Data used for PHABSIM Analysis

	Brown Trout						Rainbow Trout					
	Vel	SI	Depth	SI	Substrate	SI	Vel	SI	Depth	SI	Substrate	SI
Juvenile	0	0.6	0	0	0	0	0	0.72	0	0	0	0
	0.5	0.82	0.4	0.11	(1) No Cover	0.13	0.52	0.93	0.3	0.08	(1) No Cover	0.15
	0.8	0.92	0.6	0.18	(2) Visual Isolation	0.13	0.8	1	0.47	0.16	(2) Visual Isolation	0.15
	1.13	1	0.75	0.29	(3) Velocity Shelter	1	1.18	1	0.65	0.29	(3) Velocity Shelter	1
	1.57	1	1.05	0.55	(4) Combination	1	1.5	0.92	1.11	0.77	(4) Combination	1
	1.97	0.91	1.3	0.8	100	1	2.02	0.71	1.34	0.9	100	1
	2.31	0.8	1.5	0.92			2.67	0.39	1.63	1		
	3.3	0.42	1.66	1			3.04	0.24	1.85	1		
	3.37	0.28	1.83	1			3.42	0.14	2.09	0.93		
	4.3	0.15	2.05	0.89			3.74	0.08	2.55	0.66		
	5.06	0	2.35	0.62			4.12	0.04	3.01	0.36		
	100	0	2.65	0.35			4.28	0	3.36	0.19		
			2.87	0.2			100	0	3.65	0.1		
			3.13	0.09					4	0.04		
			3.22	0.06					4.63	0		
			3.8	0					100	0		
			100	0								

	Brown Trout Vel	SI	Depth	SI	Substrate	SI	Rainbow Trout Vel	SI	Depth	SI	Substrate	SI
Adult	0	0.33	0	0	0	0	0	0.31	0	0	0	0
	0.82	0.81	0.23	0.1	(1) No Cover	0.36	0.6	0.55	0.78	0.07	(1) No Cover	1
	1.07	0.92	0.88	0.25	(2) Visual Isolation	0.36	1.2	0.86	1.29	0.19	(2) Visual Isolation	1
	1.32	1	1.31	0.4	(3) Velocity Shelter	1	1.4	0.95	1.93	0.44	(3) Velocity Shelter	1
	1.63	1	2.25	0.8	(4) Combination	1	1.6	1	2.69	0.81	(4) Combination	1
	1.94	0.92	2.68	0.94	100	1	1.9	1	3.33	1	100	1
	3	0.44	2.97	1			2.15	0.94	3.72	1		
	3.49	0.26	3.4	1			2.45	0.81	4.1	0.93		
	3.74	0.19	3.77	0.92			3.2	0.37	5.1	0.59		
	4.18	0.11	4.63	0.58			3.5	0.22	5.8	0.38		
	4.68	0.06	5.21	0.34			3.9	0.09	6.4	0.23		
	5.55	0.02	5.59	0.22			4.3	0.03	7.3	0.11		
	5.8	0	6	0.12			4.9	0	8.3	0.05		
	100	0	6.9	0			100	0	9.3	0.03		
			100	0					10	0		
									100	0		

	Vel	SI	Depth	SI	Substrate	SI	Substrate codes	
Trout Spawning - adjusted CDOW curves	0	0	0	0	0	0	1	grass, wood, bare ground
	0.3	0	0.2	0	1	0	2	clay
	0.7	1	0.8	1	2	0	3	silt
	1.7	1	6	1	3	0	4	sand
	3.9	0	10	0	4	0	5	gravel
	100	0	100	0	5	1	6	cobble
					6	0.1	7	boulder
					7	0		decimal number
					100	0	5.5 = 50% gravel, 50% cobble	

In the case of Reach CR7, the PHABSIM modeling was conducted independently for each of the seven cross-sections over a range of flows extending from 200 to 1,600 cfs. The mean WUA for the seven cross-sections for each species, life stage, and flow was then calculated to estimate the flow-habitat relations for the reach.

Determination of Environmental Flow Ranges

The flow-habitat relations for each study site, target species, and life stage were inspected to determine the recommended environmental target flow ranges for two seasons of the year. Summer was defined as April 1 through September 30, while winter was considered to be October 1 through March 31. As adult WUA was consistently less than juvenile WUA across study sites and flows, summer flow ranges were based primarily on the availability of adult habitat. Winter flow ranges were based primarily on spawning and incubation habitat availability. Brown trout spawn in the fall to early winter period and the eggs incubate in the stream gravels over the winter before hatching in the spring, while rainbow trout may begin spawning in the late winter to early spring period. The recommended environmental target flow ranges, for each season at each site were bounded on the upper end by the flow that provided the maximum or near maximum WUA for the target species and life stage and on the lower end by the flow below which habitat was lost at the greatest rate. The low end of the winter recommended environmental target flows were also reviewed for water availability in the winter months as reflected in long term stream gage records. This resulted in slight modifications to the low end of winter flow recommendations for several reaches.

Single Transect Sites and Analysis

Single transect sites were established in August 2008 on Troublesome Creek and Reeder Creek to perform instream flow analyses similar to the R2Cross procedure of the Colorado Water Conservation Board (CWCB) (Espegren 1996). The Troublesome Creek site was located 60 ft upstream of the Highway 40 bridge near the stream's confluence with the Colorado River in Reach CR6, while the Reeder Creek site was immediately downstream of the footbridge at the BLM access area just upstream from the confluence with the Colorado River in Reach CR5. At each site a single surveyed cross-section transect was established across a shallow riffle along which water depth and velocity were measured using a Marsh-McBirney Model 2000 current meter and top-setting rod and substrate type was observed following the guidance of Bovee (1997). Water surface slope was determined using an engineer's transit and survey rod. Hydraulic conditions at each transect across a range of flows were estimated using the USDA's WinXSPRO software program for analyzing channel cross sections (Hardy et al 2005). Summer and winter instream flow recommendations for each site were then developed following the CWCB criteria for water depth, water velocity and wetted perimeter (Espegren 1996). Flushing flow recommendations were also developed following the procedures described below.

FLUSHING FLOW ANALYSIS

Flushing flow analysis was conducted for each of the PHABSIM study sites described above and also for several other of the 27 Grand County river reaches where suitable channel cross-section and hydraulic data were available. Flushing flows can be an important management tool for maintaining trout habitat quality by periodically removing ("flushing") accumulated fine sediments (such as silts and sands) from the streambed surface as well as the inter-gravel environment (Wesche and Rechard 1980; Reiser and others 1990). Removal of such "fines" can enhance the survival of incubating trout eggs, improve macroinvertebrate production for trout food, and maintain pool quality for trout shelter. The flushing flow recommendations presented for Grand County river reaches include guidance regarding the flow magnitude, duration and frequency.

The magnitude for the flushing flow recommendations was determined as follows:

1. Transect data for each PHABSIM site were reviewed and the transect with the highest proportion of spawning gravel was selected for analysis.
2. Cross-section and other pertinent data for the selected transect were entered into the WinXSPRO hydraulic model (Hardy and others 2005) and a suite of hydraulic parameters (including depth, velocity, wetted perimeter, hydraulic radius, and shear) were estimated over a range of conditions from low flow up to bank full.
3. Bedload transport was analyzed for the particle size distribution of spawning gravels measured during the October 2008 trout spawning survey at 78 redds using the Parker (1990) bedload function for gravel bed streams in the western United States.
4. Transport plots were then inspected to identify the flow threshold at which gravel mobilization was initiated (see Figure A-1 for example plot).
5. The threshold flow identified in step 4 then became the low end of the recommended flushing flow range.

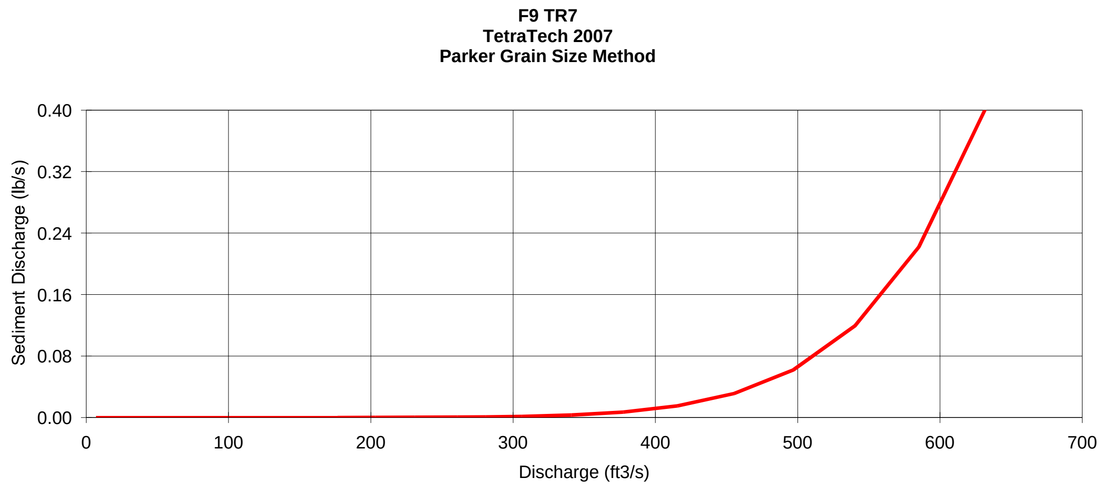

Figure A1. Example of Bedload Discharge Relationship used to determine the minimum flushing flow. In this example, the recommended flow is 400cfs.

The determination of flushing frequency and duration was based primarily on a hydrologic events approach as described by Reiser and others (1990). Collection of detailed empirical data regarding sedimentation processes within the study sites (for example, inter-gravel grain size distributions and sediment storage volumes) and time-of-travel information for the river reaches was beyond the scope of the Phase 2 and 3 effort, so a sediment transport mechanics and sediment budget approach was not possible. The hydrologic events approach has been commonly used in the development of flushing frequency and duration information and is typically based on characteristics of the bank full and channel-forming discharges (Reiser and others 1990). The bank full discharge for alluvial streams is often similar in magnitude to the flood flow having a 2-year return period (Wolman and Leopold 1957), while for gravel-cobble bed streams in Colorado and Wyoming, the channel-forming discharge is often considered to be in the range of the 1.18- to 3.26-year event (Andrews 1980). The duration of bank full discharge in Colorado streams was found to range from 0.44 to 22 days per year (Andrews 1984), while several flushing and channel maintenance flow methodologies based on discharges in the bank full range have recommended a 3-day duration (Reiser and others 1990; Wesche and others 1977; Rosgen 1982; Water and Environment Consultants 1980). Based on these studies, a flushing frequency of 1 in 2 years was recommended for a duration of 3-days at the Grand County sites. The availability of the recommended flushing flows was evaluated using results of the Indicators of Hydrologic Alteration (IHA) analysis wherever possible.

TROUT SPAWNING SURVEYS

Brown trout spawning surveys were conducted on foot from October 27 to 31, 2008 at and in the vicinity of PHABSIM sites located in the following reaches: Colorado River 3, 4, 5, 6, and 7, Fraser River 4, 5, 6, and 9, Blue River, Muddy Creek, William's Fork, St. Louis Creek, and Ranch Creek. Trout redds (egg nests) were identified by their distinctive stream bed morphology consisting of both pit and tailspill, and by the presence of adult fish exhibiting spawning behavior. At each identified redd, water depth (ft) and mean water velocity (ft/s) were measured immediately upstream of the disturbed area and the diameter (mm) of ten substrate particles randomly selected from the tailspill were measured along their intermediate ("b") axis. In total, 78 redds were measured and the data used to verify the spawning habitat suitability curves used for PHABSIM modeling. The particle size distribution plot was also used in the bedload transport modeling for flushing flow determination.

HYDROLOGIC ANALYSIS

An important objective of Phases 2 and 3 was to acquire, analyze, and evaluate hydrologic data describing the present streamflow regime throughout Grand County and, where possible, how that regime has been altered from historic conditions. The IHA procedure developed by The Nature Conservancy (TNC) was the primary tool used to address this objective. The IHA procedure and its application is described below:

Description of the IHA Approach

The IHA approach first defines a series of biologically relevant hydrologic attributes that characterize intra-annual variation in water flow conditions and then uses an analysis of the inter-annual variation in these attributes as the basis for comparing hydrologic regimes before versus after a river has been altered by significant human activities (Richter and others, 1996). The method is statistically based, software driven, and for river applications, the basic data unit is mean daily discharge. Streamflow data are typically obtained from U. S. Geological Survey (USGS) (or other appropriate sources) gage records. Application of the method includes four general steps:

1. The data series is defined for pre- and post-impact periods in the river system of interest, with the period-of-record for each series recommended to be at least 20 years, thereby accounting for natural climatic variability.

2. Values for each of 33 ecologically-relevant hydrologic attributes are calculated for each year in each data series.

3. Inter-annual statistics are computed by calculating measures of central tendency and dispersion for the 33 attributes in each data series, based on the values obtained in Step 2.

4. Values of the Indicators of Hydrologic Alteration are calculated by comparing the 66 inter-annual statistics between the pre-and post- impact data series, and each result is presented as a deviation of one time period relative to the other. The method can be used to compare the state of one river system with itself over time (such as temporal comparisons or pre- versus post-impact); or it can be used to compare the state of one system to another (for example, spatial comparisons, a highly altered system to a less altered, reference system).

The 33 attributes evaluated by the IHA are based on five fundamental characteristics of hydrologic regimes:

1. ***Flow Magnitude:*** The magnitude of the flow at any given time is a measure of the availability or suitability of the habitat.

2. ***Flow Timing:*** The timing of particular flow conditions can determine whether certain life cycle requirements are met, or influence the degree of stress or mortality associated with extreme events such as floods or droughts.

3. ***Flow Frequency:*** The frequency of occurrence of specific flow conditions such as floods or droughts may be tied to reproduction or mortality events, thereby influencing population dynamics.

4. ***Flow Duration:*** The length of time over which a specific flow condition exists may determine whether a particular life cycle phase can be completed or the degree to which stressful effects such as inundation or desiccation can accumulate.

5. ***Flow Rate of Change:*** The rate of change in flow conditions may be tied to the stranding of certain organisms in ponded depressions or along the water's edge.

The 33 biologically relevant hydrologic attributes comprising the IHA method are divided into five major groups for analysis. These groups are:

IHA Group #1; Magnitude of Monthly Flow Conditions: This group includes 12 attributes, the mean or median flow value for each calendar month.

IHA Group #2; Magnitude and Duration of Annual Extreme Water Conditions: This group is composed of 12 attributes, including the 1-, 3-, 7-, 30-, and 90-day annual flow minima and maxima, the number of zero flow days, and base flow (7-day minimum flow divided by the mean flow for the year).

IHA Group #3; Timing of Annual Extreme Water Conditions: This group includes 2 attributes, the Julian date of the 1-day annual minimum flow condition and the Julian date of the 1-day annual maximum flow condition.

IHA Group #4; Frequency and Duration of High and Low Flow Pulses: The four attributes in this group include two which measure the number of annual occurrences during which the flow magnitude exceeds an upper threshold or remains below a lower threshold, and two that measure the mean duration of such high and low flow pulses. Pulses are defined as those periods within a year in which the mean daily flow rises above the 75^{th} percentile (high pulse) or drops below the 25^{th} percentile (low pulse) of all daily values for the pre-impact time period.

IHA Group #5; Rate and Frequency of Flow Change: The four attributes in this group measure the number and mean rate of both positive and negative flow changes from one day to the next.

Range of Variability Analysis (RVA) builds on the IHA analysis described above by using the range of historic (pre-development) variability in the 33 different hydrologic attributes as the basis for setting water management targets (Richter and others, 1997). The RVA target range for each attribute is normally based on selected percentile levels or a simple multiple of the parameter standard deviations for the more natural, or pre-development streamflow regime. The management objective is not to have the river attain the targeted range every year, but instead to attain the targeted range at the same frequency as occurred in the more natural or pre-development flow regime. For example, attainment of an RVA target range defined by the 75^{th} and 25^{th} percentile values of a particular attribute would be expected in only 50 percent of years, while a range defined by (+) or (-) one standard deviation would be expected to be attained in about 68 percent of years, assuming normally distributed data. The degree to which the RVA target range is not attained is a measure of "hydrologic alteration," calculated as:

$$(\text{Observed - Expected})/\text{Expected}) * 100$$

when expressed as a percentage, where "observed" is the count of years in which the observed value of the hydrologic parameter fell within the targeted range and "expected" is the count of years for which the value is expected to fall within the targeted range. Hydrologic alteration is equal to zero when the observed frequency of post-development annual values falling within the RVA target range equals the expected frequency. A positive deviation indicates the target range is being attained more often than expected, while a negative value indicates attainment less frequently than expected.

The version of IHA used, Version 7.0.2 (Copyright 2006, The Nature Conservancy), has expanded capability to analyze what are termed "Environmental Flow Components" (EFC) of the streamflow regime. The EFC parameters characterize portions of the regime as extreme low flows, low flows, high flow pulses, small floods, and large floods and describe the magnitude, timing, frequency, duration, and rates of change for each of these categories. The EFC analysis is presented for each gage station where IHA was applied. However, EFC output was not extensively relied on to establish preferred flow ranges because the field-based, more substantive PHABSIM approach was used for this purpose.

Application of IHA to Grand County

IHA analyses were conducted on USGS and Northern Colorado Water Conservation District stream gage records the 30 stream reaches investigated within Grand County. In total, records from over 20 gage stations were analyzed, with 12 stations having sufficient period of record to allow temporal comparisons of flow alteration to be made. At the remaining stations, IHA was used solely to describe the hydrologic regime. The temporal comparisons, by reach, were:

Reach F3: USGS Gage 09024000, 1911-35 (Pre-Denver Water) compared with 1936-70, 1971-2007, and 1936-2007.
Reach F9: USGS Gage 09034000, 1938-55 compared with 1988-2007.
Reach F-VC: USGS Gage 09025000, 1936-70 compared with 1971-2007.
Reach F-RC1: USGS Gage 0903200; 1935-70 compared with 1971-2008.
Reach F-StL: USGS Gage 09026500, 1936-70 compared with 1971-2007.
Reach CR1: USGS Gage 09011000, 1905-18 (Pre-CBT) compared with 1957-86.
Reach CR3: USGS Gage 09019500, 1908-53 (Pre-CBT) compared with 1961-2007.
Reach CR 4: USGS Gage 09034500, 1905-84 (Pre-Windy Gap) compared with 1986-94.
Reach CR7: USGS Gage 09058000, 1962-84 compared with 1985-2007 (Post-Green Mt Res operations change)
Reach WR: USGS Gage 09038500, 1949-87 compared with 1988-2007.
Reach BR: USGS Gage 09057500, 1950-84 compared with 1985-2007 (Post-Green Mt Res operations change)
Reach MC2: USGS Gage 09041500, 1982-95 (pre-Wolford) compared with 1996-2007.

The flow values needed for the IHA analysis were obtained from the USGS Daily Streamflow for Colorado database (http://waterdata.usgs.gov/co/nwis/discharge) and from the Northern database (http://www.ncwcd.org/datareports/westflow.asp). Recent records for Willow Creek were provided by the State of Colorado, Division of Water Resources. Following review, the data were input into Version 7.0.2 of the IHA computer software program developed and maintained by TNC. Following the recommendation of TNC, non-parametric statistics were used for computing IHA parameters. The coefficient of dispersion (CD) was defined as equal to (75th percentile - 25th percentile)/50th percentile, while the high and low pulse thresholds were set as the median plus or minus 17 percent (between the 33rd and 67th percentiles). HA values were classified as low (-0.33 to +0.33), moderate (-0.34 to -0.67 and +0.34 to +0.67), and high (< -0.67 and > +0.67) following the guidance of Richter and others (1998) based on their analysis of the Colorado River farther downstream in the system.

Other Hydrologic Analyses

Daily streamflow exceedence plots were generated directly from data available at the above USGS website. Flood frequency analysis was performed using the Log Pearson Type III method for peak flow data from the USGS. The on-line calculator developed by Dr. Victor Ponce, San Diego State University, was used (http://ponce.sdsu.edu/onlinepearson.php).

STREAM ASSESSMENTS

In 2008 and 2009 three evaluations were conducted at 29 locations within 22 of the project reaches. Priority was given to segments of rivers that were 1) physically accessible and 2) representative of the project reach. Several of the reaches were evaluated in multiple locations including CR-3, CR-4, and BR. Reaches not evaluated in 2008 include F1, CR1, CR2 and TC. The stream assessment was generally limited to 100 feet from each side of the banks. The goal of the stream assessment was to qualitatively evaluate the general, existing morphological and biological conditions of the project study reach. Procedures used for these assessments included 1) the Stream Reach Inventory and Channel Stability Evaluation (SRI/CSE; Pfankuch 1975 and Rosgen 1996), 2) the Riffle Stability Index (RSI, Kappesser 2002), and 3) the EPA's Rapid Stream Habitat Assessment protocol (EPA 1999). These procedures are briefly described below. Copies of the field forms are included as Figures A2-A4.

1. The SRI/CSE procedure was developed by the USDA Forest Service to provide a systematic measurement and evaluation of the resistive capacity of stream channels to the detachment of bed and bank materials and to provide information about the capacity of streams to adjust and recover from potential changes in flow and/or increases in sediment production. This ocular system involves the numerical evaluation of 15 hydraulic indicators found within three major stream zones: upper banks, lower banks, and channel bottom. Scoring is based on four stability categories, excellent, good, fair and poor, with a numerical value assigned to each of the 15 indicators within each category. The total reach score is derived by summing the values recorded under each category. The reach score is then compared to a series of numerical intervals, thereby determining the reach to either be excellent, good, fair or poor in terms of hydraulic stability and condition as follows:

Excellent	< 38
Good	39 to 76
Fair	77 to 114
Poor	115 and greater

   All SRI/CSE scoring was conducted by Dr. Wesche, who has been using this method to evaluate streams across the Rocky Mountain region for more than 30 years.

2. The RSI was developed to evaluate stream bed stability and particle mobility in riffle habitats of cobble/gravel bed rivers. To conduct an RSI evaluation, a riffle and adjacent point bar was selected within or near each PHABSIM study site. Measurement and analysis then included 1) measuring the diameter along the intermediate axis of 200 bed particles in the riffle, 2) measuring the diameter along the intermediate axis of the 30 largest recently deposited particles comprising the adjacent point bar, and 3) locating the mean size of the point bar samples on the particle size distribution plot developed for the riffle, thereby determining the RSI value, the percentage of riffle particles smaller than the mean point bar particle size. Since the largest particles on the point bar represent the largest bed particles moved by the stream during a recent channel altering event, the RSI provides an assessment of the percentage of stream bed materials mobilized by the event and a measure of relative stream bed stability. The higher the RSI value, the less stable the stream bed. Values between 40 and 70 have been considered indicative of stable channel and watershed conditions, values between 70 and 85 signify moderate instability, and values greater than 85 are indicative of high instability (Kappesser 2002). A riffle stability index evaluation was conducted once at each of the PHABSIM sites.

3. The EPA Rapid Assessment protocol was applied at each site to evaluate general stream habitat quality for key characteristics and to supplement PHABSIM information. This ocular system involves the numerical rating of ten habitat parameters on a scale of 1 to 20 with the lowest rating indicating the poorest condition for a particular parameter. This assessment is based on the protocol designed and approved by EPA for use nationwide, and provides procedures for a simplified visual-based field procedure to measure habitat characteristics relevant to a broad range of stream-dependent life forms. The procedures developed for use in this Stream Management Plan was modified to include fish passage barriers. Other criteria evaluated included structural cover for fish, basic channel morphology, and riparian/overbank vegetation. Each of these habitat characteristics is scored in the field at each site with the exception of sinuosity, which is scored by plan view (aerial mapping) evaluation in the office. The larger scores are indicative of higher habitat quality. There are 10 attributes that are rated between 1 to 20 with a 20 being the highest quality and 1 or 0 being the lowest. Totals of all indices are grouped as follows:

Optimal	160 to 200
Suboptimal	107 to 159
Marginal	54 to 106
Poor	< 54

Pfankuch D.J. 1975. Stream Reach Inventory and Channel Stability Evaluation. USDA Forest Service Northern Region, Montana.

	Attribute	Excellent		Good		Fair		Poor	
	Upper Banks								
1	Landform slope	Bank slope gradient <30%	2	Bank slope gradient 30-40%	4	Bank slope gradient 40 - 60%	6	Bank slope gradient 60%+	8
2	Mass wasting hazard	No evidence of past or any potential for future mass wasting into channel	3	Infrequent and/or very small. Mostly healed over. Low future potential	6	Moderate frequency and size, with some raw spots eroded by water during high flows.	9	Frequent or large, causing sediment nearly yearlong or imminent danger of same	12
3	Debris jam potential	Essentially absent from immediate channel area	2	Present but mostly small twigs and limbs.	4	Present, volume and size are both increasing.	6	Moderate to heavy amounts, predominantly larger sizes.	8
4	Vegetation bank protection	90% + plant density. Vigor and variety suggests a deep, dense, soil binding, root mass	3	70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.	6	50-70%density. Lower vigor and still fewer species form a somewhat shallow and discontinuous root mass.	9	<50% density plus fewer species and less vigor indicate poor, discontinuous, and shallow root mass.	12
	Lower Banks								
5	Channel capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7	1	Adequate. Overbank flows rare. W/D ratio 8 to 15.	2	Barely contains present peaks. Occasional overbank floods. W/D ratio 15-25.	3	Inadequate. Overbank flows common. W/D ratio >25	4
6	Bank rock content	65% with large, angular boulders 12"+ numerous	2	40 to 65% , mostly small boulder to cobbles 6-12"	4	20 to 40% with most in the 3-6" diameter class.	6	<20% rock fragments of gravel sizes, 1-3" or less.	8
7	Obstructions - Flow deflectors, sediment traps	Rocks and old logs firmly embedded. Flow pattern without cutting or deposition. Pools and riffles stable	2	Some present, causing erosive cross currents and minor pool filling. Obstructions and deflectors newer and less firm.	4	Moderately frequent, moderately unstable obstructions and deflectors move with high water causing bank cutting and filling of pools.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
8	Cutting	Little or non-evident. Infrequent raw banks less than 6" high generally	4	Some, intermittently at outcurves and constrictions. Raw banks maybe up to 12".	8	Significant. Cuts 12 to 24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
9	Deposition	Little or no enlargement of channel or point bars	4	Some new increase in bar formation, mostly from coarse gravels.	8	Moderate deposition of new gravel and coarse sand on old and some new bars.	12	Extensive deposits of predominantly fine particles. Accelerated bar development.	16
	Channel Bottom								
10	Rock Angularity	Sharp edges and corners, plain surfaces roughened	1	Rounded corners and edges, surfaces smooth and flat.	2	Corners and edges well rounded in two dimensions.	3	Well rounded in all dimensions, surface smooth.	4
11	Brightness	Surface dull, darkened, or stained. Generally not "bright"	1	Mostly dull, but may have up to 35% bright surfaces.	2	Mixture, 50-50% dull and bright, range: 35 - 65%	3	Predominantly bright, 65% + exposed or scoured surfaces.	4
12	Consolidation or particle packing	Assorted sizes tightly packed and/or overlapping	2	Moderately packed with some overlapping.	4	Mostly a loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
13	Bottom size distribution and percent stable materials	No changes in sizes evident. Stable materials 80-100%	4	Distribution shift slight. Stable materials 50-80% .	8	Moderate change in sizes. Stable materials 20-50% .	12	Marked distribution change. Stable materials 0-20% .	16
14	Scouring and deposition	Less than 5% of the bottom affected by scouring and deposition	6	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30-50% affected. Deposits and scour at obstructions, constrictions, and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
15	Clinging aquatic vegetation (moss and algae)	Abundant. Growth largely moss-like, dark green, perennial. In swift water too.	1	Common. Algal forms in low velocity & pool areas. Moss here too and swifter waters.	2	Present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick.	3	Perennial types scarce or absent. Yellow-green, short term bloom maybe present.	4
	Overall rating								

Stream Name: **Observer:** **Date:** **Overall Score:**

Add each column, add column scores	<38 = Excellent; 39-76 = Good; 77-114 = Fair; 115+ = Poor

Figure A2. Stream Reach Inventory and Channel Stability Evaluation (SRI/CSE; Pfankuch 1975 and Rosgen 1996)

Riffle Stability Index

Size Class (mm)		No.	Percent	Cumulative percent	
0 - 2					sand
2 - 4					v.fine gravel
4 - 8					fine gravel
8 - 16					med. gravel
16 - 32					crs. gravel
32 - 64					v. crs. gravel
64 - 128					sm. cobble
128 - 256					lrge cobble
256 - 512					sm. boulder
512 - 1024					med boulder
1024 - 2048					large bouldr
2048 - 4096					v lrge bouldr

TOTAL: ________

Enter the intermediate diameters of 10 - 30 bar samples (mm)

1_________	11__________	21__________
2_________	12__________	22__________
3_________	13__________	23__________
4_________	14__________	24__________
5_________	15__________	25__________
6_________	16__________	26__________
7_________	17__________	27__________
8_________	18__________	28__________
9_________	19__________	29__________
10_________	20__________	30__________

Arithmetic mean of the samples: ___________

Compare the average diameter of the common large particle on a fresh depositional area with the cumulative size distribution to determine the Riffle Stability Index.

Figure A3. Riffle Stability Index (RSI, Kappesser 2002)

EPA Rapid Bioassessment Site Habitat Quality Evaluation Form

Reach:____________ Weather Conditions:______________________________

Site:_____________ River Flow Notes (Qualitatively describe volume, turbidity, recent precipitation, human-caused flow alterations):

Date:_____________ ______________________________

Observer:

CHANNEL	Optimal	Suboptimal	Marginal	Poor
SCORING	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
1. Aquatic Habitat Barriers and Diversion Sinks **SCORE**	No physical barriers prevent or inhibit movement of fish or other aquatic organisms through the stream reach; diversion structures are absent or prevent movement of aquatic organisms into ditches or other population sinks.	Minimal physical barriers exist but mostly do not inhibit movement of fish or other aquatic organisms through the stream reach; diversion structures partially prevent movement of aquatic organisms into ditches or other population sinks.	Some physical barriers exist that partially inhibit movement of fish or other aquatic organisms through the stream reach; diversion structures may allow movement of aquatic organisms into ditches or other population sinks.	Substantial physical barriers exist that mostly or entirely prevent movement of fish or other aquatic organisms through the stream reach; diversion structures encourage movement of aquatic organisms into ditches or other population sinks.
2. Aquatic Structure as Cover **SCORE**	Greater than 70% of substrate provides fish cover; mix of snags, submerged logs, undercut banks, in-stream rocks larger than cobbles; structures stable (predicted to remain at least 5 years).	40-70% mix of stable habitat; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed, removed, or absent.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
3. Velocity/ Depth Regimes **SCORE**	All 4 velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (slow is <0.3 m/s, deep is >0.5 m).	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/ depth regime (usually slow-deep).
4. Channel Flow Status **SCORE**	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
5. Channel Alteration **SCORE**	Channelization absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
6. Frequency of Riffles **SCORE**	Occurrence of riffles relatively frequent; distance between riffles divided by width of the stream <7 (generally 5 to 7); variety of habitat is key.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is 7 to 15.	Occasional riffles; bottom contours provide some habitat; distance between riffles divided by the width of the stream is 15 to 25.	Generally all flat water or shallow runs; poor habitat; distance between riffles divided by the width of the stream is >25.
7. Channel Sinuosity NOTE—evaluate in office **SCORE**	Bends in the stream increase stream length 3 to 4 times longer than if it was straight.	Bends in the stream increase stream length 2 to 3 times longer than if it was straight.	Bends in the stream increase stream length 1 to 2 times longer than if it was straight.	Channel straight; waterway has been channelized for a long distance.
BANKS	**Optimal**	**Suboptimal**	**Marginal**	**Poor**
SCORING	10 9	8 7 6	5 4 3	2 1
8. Bank Stability (score each bank, left bank is on left facing downstream) **Left Bank SCORE** **Right Bank SCORE**	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
9. Riparian Vegetation Cover and Disturbance (score each bank) **Left Bank SCORE** **Right Bank SCORE**	More than 75% of the streambank and riparian zone to 50 ft boundary covered by riparian vegetation including trees, shrubs, herbaceous vegetation, or wetland emergents; vegetative disruption by grazing or cutting minimal or absent; almost all plants allowed to grow naturally.	50-75% of the streambank and riparian zone to 50 ft boundary covered by riparian vegetation; disruption by grazing or cutting may be evident but not seriously affecting riparian vegetation structure.	25-50% of the streambank and riparian zone to 50 ft boundary covered by riparian vegetation; extensive areas of bare cobble or patches of bare soil; disruption by grazing or cutting may be evident and seriously affecting riparian vegetation structure.	Less than 25% of the streambank and riparian zone to 50 ft boundary covered by riparian vegetation; mostly bare cobble or bare soil; disruption by grazing or cutting may be present and severely affecting riparian vegetation structure.
10. Riparian Vegetation zone width (score each bank) **Left Bank SCORE** **Right Bank SCORE**	Width of riparian zone > 50 ft; human activities (development, crops, parks, roads) have not impacted zone.	Width of riparian zone 35 to 50 ft; human activities have impacted zone only minimally.	Width of riparian zone 15 to 35 ft; human activities have impacted zone a great deal.	Width of riparian zone, 15 ft; little or no vegetation due to human activities. .

Figure A4. EPA's Rapid Stream Habitat Assessment protocol (EPA 1999)

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