STATE OF COLORADO
Roy Romer, Governor
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WILDLIFE
John W. Mumma, Director

For Wildlife–
For People

From the desk of... **Jay W. Skinner**
Instream Flow Program Coordinator

TO: Interested Parties - Snowmass Creek Modification

DATE: 29 February 1996

SUBJ: Review of Data and Summary of Opinions regarding Snowmass Creek Modification

80

Snowmass water-flows fight settled

Heather McGregor
Daily Sentinel

OLD SNOWMASS — Environmental groups, Aspen Skiing Co. and the Colorado Water Conservation Board have settled a dispute between using water for snowmaking and maintaining instream flows in Snowmass Creek.

In 1992, the state water board decided to reduce its instream-flow water right in the creek from 12 cubic feet per second to 7 cfs. The move would have allowed Aspen Skiing Co. to divert water from the creek for early-season snowmaking at the Snowmass ski area.

Environmentalists appealed the decision, arguing that the state water board should go through water court to make such a change. The Colorado Supreme Court upheld their argument, and the issue became the subject of new legislation this year.

Meanwhile, ski company and water board officials have been negotiating with the Sierra Club Legal Defense Fund, the Aspen Wilderness Workshop and the Snowmass/Capitol Creek Caucus to resolve the issue.

Under the Friday agreement, Aspen Skiing Co. may divert water for snowmaking, but it may reduce the flows in the creek to 7 cfs only once every 10 years.

"The days when instream flow protection comes last are over," Sierra Club Legal Defense Fund attorney Lori Potter said. "What we have here is a recognition that preserving Colorado's environment is just as important as skiing at Thanksgiving, if not more so."

The settlement awaits the approval of the full Colorado Water Conservation Board, which will take up the issue in meetings July 8 and 9 in Glenwood Springs.

ROCKY MOUNTAIN NEWS
Denver, CO
(Denver County)
AM, 355,644; Sun, 411,924

Colorado Press Clipping Service
1336 Glenarm Place · Denver, CO 80204
303-571-5117 · FAX 303-571-1803

80

Court upholds water decree

The Colorado Supreme Court on Monday upheld a conditional water decree granted to Hines Highlands Limited after it bought the Aspen Highlands Ski Area and adjacent property in Pitkin County in 1993.

The water would come from Maroon Creek, a tributary of the Roaring Fork River.

INTRODUCTION

The Colorado Water Conservation Board currently holds an instream flow water right for Snowmass Creek for 12 cfs year round with an appropriation date of January 14, 1976 (Case No. W-2943, Water Division 5). This water right covers 17 miles of stream from the outlet of Snowmass Lake (in the Maroon Bells - Snowmass Wilderness) to the confluence with the Roaring Fork River. The basis for this instream flow appropriation was a R2CROSS cross section that was collected by the Division of Wildlife in September, 1975. This cross section was collected at a point that is approximately 5 miles from the upper terminus of this segment (200 yards upstream of the confluence with West Snowmass Creek).

In late August or early September of 1991 The Division was contacted by the CWCB staff regarding the existing instream flow filing on Snowmass Creek in Pitkin County. The CWCB had been contacted by the Pitkin County Planning Office regarding the Board's instream flow water right on Snowmass Creek. The county's questions involved a 4 cfs "survival flow" for Snowmass Creek that was referenced in a 1978 letter from the CWCB to Loyal Leavenworth. CWCB staff referred the county to me for a biological explanation of the term "survival flow".

On October 23, 1991, Greg Espegren of the CWCB staff and I conducted field investigations on Snowmass Creek in order to obtain information to address the county's concerns relative to the effect of additional snowmaking withdrawals at the Snowmass Water and Sanitation District's (SW&SD) pumphouse diversion on the Snowmass Creek instream flow. We conducted a qualitative fishery survey of the creek by electrofishing approximately 300 feet of stream where we collected 13 fish; 6 brown trout, 6 brook trout, and 1 mottled sculpin (see field data). In addition to the fish sampling, we conducted an R2CROSS cross section that was to be used to address the county's concerns relative to additional snowmaking withdrawals at the SW&SD diversion on Snowmass Creek.

The October, 1991 field data was analyzed using the R2CROSS model immediately after its collection. The results of this analysis were communicated to the CWCB staff in a letter dated February 21, 1992. In the intervening months, the Division was contacted by James Chadwick of Chadwick and Associates, a biological consultant under contract with the Aspen Ski Company. Chadwick informed the

Division that they were interested in reviewing all of the data that the Division had on Snowmass Creek. CDOW provided Chadwick with copies of the cross section data that was collected in 1975, the 1991 cross section data, and three 1977 fisheries surveys that we had on file for Snowmass Creek. On February 27, 1992 the Division received a copy of a draft report from Chadwick and Associates entitled, "Evaluation of the Fishery and Minimum Streamflow Issues of Snowmass Creek" which evaluated the two R2CROSS transects using the Instream Flow Incremental Methodology (IFIM) and evaluated the fishery by comparing it to other western slope streams. This information (both the DOW's data analysis and the Chadwick evaluation) was presented to the CWCB at their March, 1992 meeting in Denver.

At the March, 1992 CWCB meeting, the staff recommended to the Board that the Snowmass Creek basin be analyzed as if it was a new appropriation applying the appropriate segmentation and seasonal split flow criteria to the entire reach. The staff recommendation to the Board was to notice the Board's intent in the exact same manner as it would if Snowmass Creek did not have an existing instream flow water right. The CWCB instructed the Division to collect any additional data that was needed to address the entire segment of Snowmass Creek.

On March 23, 1992 Greg Espegren and I collected an additional R2CROSS cross section approximately half way between the confluence of Castle Creek and Snowmass Creek and the existing lower terminus (the confluence with the Roaring Fork River). The results of the R2CROSS analysis for this cross section was transmitted to the CWCB in an April 1, 1992 letter. This letter was presented to the CWCB at the May, 1992 meeting.

At both the May and July, 1992 CWCB meetings the Board heard from the CWCB staff, the DOW staff, and from the public regarding the Snowmass Creek instream flow modification. On both of these occasions the Board delayed final action and instructed staff and the Division to continue to work with the public on the issue. During the time period between May and September of 1992 several studies were conducted by individuals other than the CDOW. Chadwick and Associates conducted additional instream flow studies using the IFIM model and produced a final report on June 25, 1992; this report built upon the above referenced draft report with additional transect work and hydrology studies. Pitkin County retained the services of W. J. Miller and Associates to review the Division's data as well as Chadwick's data. Miller produced a final report July 7, 1992. The Snowmass-Capitol Creek Caucus retained the services of Mark Hill of Don Chapman Consultants. Hill recommended that additional cross section work be done to verify the previous studies. Hill directed the collection of four additional R2CROSS cross sections on August 11th and 12th of 1992 with the assistance of the Division. Hill produced a final report that was presented to the Board at the September, 1992 meeting; the Division analyzed the cross sections collected with Mr. Hill and presented those findings to the Board by a August 26, 1992 letter.

Since the September, 1992 CWCB meeting in Grand Junction four additional reports have been generated. The U. S. Forest Service has produced a Final Environmental Impact Statement and Record of Decision (FEIS), Chadwick and Associates has produced a Supplemental Addendum to their 1992 final report (June 9, 1993), W. J. Miller and Associates produced a draft of "PHABSIM Data Analysis for Snowmass Creek Downstream of Snowmass Water & Sanitation District Weir" on June 14, 1993, and the Snowmass-Capitol Creek Caucus has produced a draft report, "The Winter Ecology of Trout in Snowmass Creek, Colorado" by Walsh Aquatic Consultants (December, 1995).

This report analyzes all of the prior studies as a part of the process for making a recommendation to the CWCB regarding the winter stream flow needs for the entire segment of Snowmass Creek.

R2CROSS CROSS SECTIONS

In total, there are seven R2CROSS cross sections on Snowmass Creek from the outlet of Snowmass Lake to the confluence with the Roaring Fork River. Three of these were collected by the Division of Wildlife and four were collected at the direction of Mark Hill of Don Chapman Consultants. The location of these cross sections are displayed on the map in Figure 1. All of the cross sections were on either critical riffles or hydraulic controls consistent with the procedures described in Espegren (1996). The six "new" cross sections were run through the R2CROSS Lotus 123(R) spreadsheet and analyzed independently. The original data, the 1975 cross section, was also re-run through the R2CROSS model. In 1975, R2CROSS was a FORTRAN program that had to be run on a mainframe computer; the Lotus 123 (R) version of R2CROSS is operationally the same as the

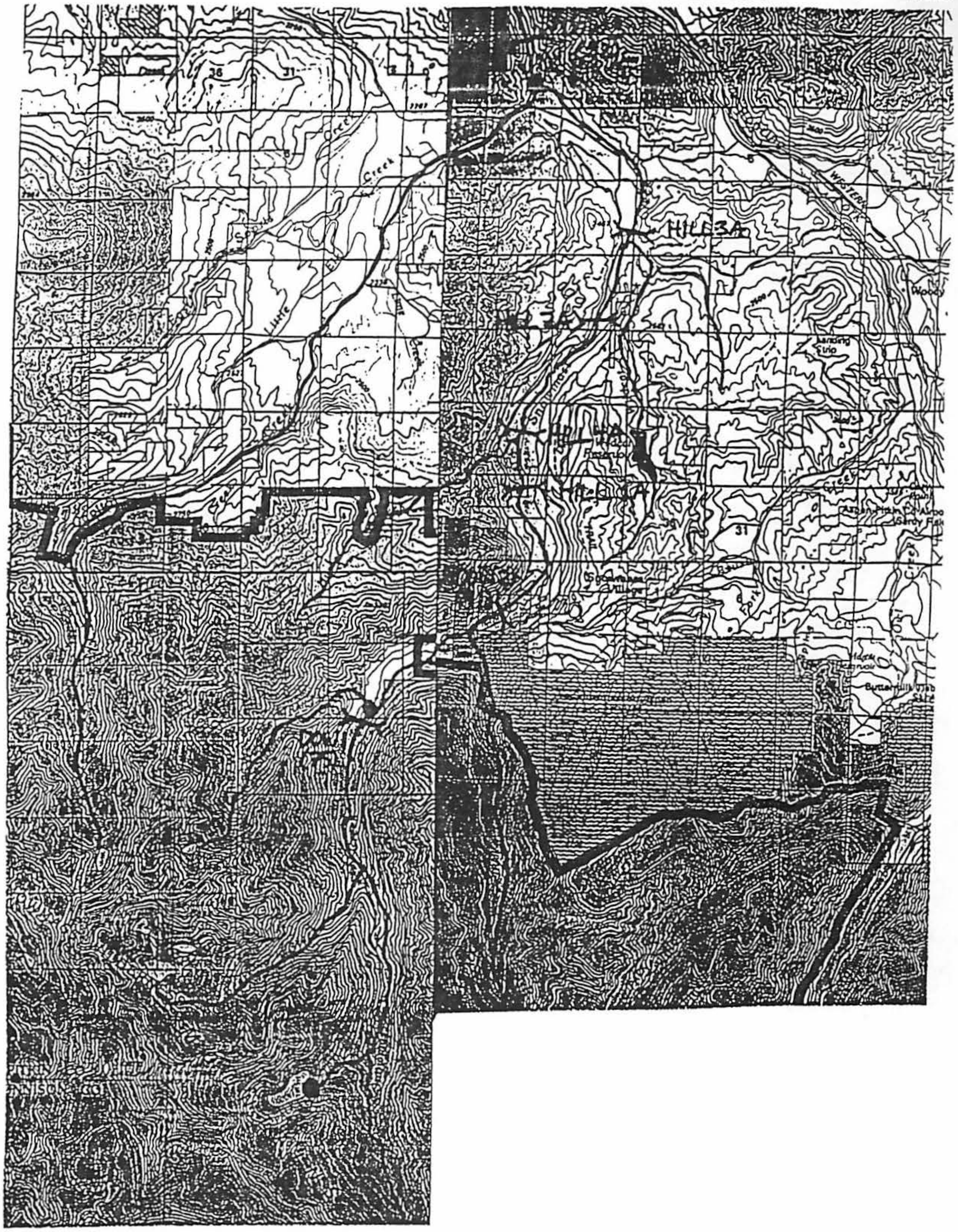


Figure 1. Map of Snowmass Creek basin

FORTRAN version but the input and the output are more user friendly in developing instream flow recommendations. Espegren (1996) describes the mechanics of the Lotus 123 (R) R2CROSS model in detail.

Nehring (1979) describes the hydraulic criteria that are used to develop instream flow recommendations to protect cold water fisheries using the R2CROSS model. The criteria used to develop instream flow recommendations are average water depth, percent of bankfull wetted perimeter, and average water velocity. More specifically, the criteria as they apply to streams the size of Snowmass Creek are as follows:

- seek to maintain an average water depth of 1% of the bankfull top width of the stream or 0.20 feet, whichever is greater,
- seek to maintain an average water velocity of 1 foot per second, and
- seek to maintain 50% of the bankfull wetted perimeter for streams up to 60 feet wide (at bankfull discharge).

The lowest flow that meets two of these three criteria is considered to be sufficient to maintain salmonids during the winter low flow months. A summer flow recommendation is developed by selecting a flow between the winter flow (two of three criteria) and that flow which meets all three of the above hydraulic criteria. The flow recommendation sometimes requires some professional biologic judgement taking into consideration the size of the stream, hydraulic conditions, and species composition. In other words, the flows that meet these hydraulic criteria can be modified based on biologic considerations such as stream conditions, species composition, fishery quality, or aquatic habitat quality. These three hydraulic parameters are good indices for flow related stream habitat maintenance; they will maintain adequate habitat conditions in pool, riffle and run habitats for most life stages of fish and macroinvertebrates, and will protect spawning and incubation habitats and fish passage during low flow periods, as well as protect macroinvertebrate production (Nehring, 1974).

Table 1 displays the flows at which the hydraulic criteria are met for the seven R2CROSS cross sections on Snowmass Creek. The field data and R2CROSS output for all seven cross sections is attached. The cross sections are displayed in an upstream to downstream manner (top to bottom); refer to the map (Figure 1) for cross section locations.

Table 1. Flows at which the R2CROSS hydraulic criteria are met for all cross sections on Snowmass Creek.

Cross Section	Flow at which ave vel = 1.00 ft/s	Flow at which WP = 50%	Flow at which ave depth = (x) ft	2 of 3 criteria met (driven by)	3 of 3 criteria met (driven by)
DOW1(75)*	0.95	16.22	4.08 (0.31)	4.08 (d)	16.22 (WP)
DOW2(91)+	3.28	4.99	16.38 (0.42)	4.99 (WP)	16.38 (d)
HILL1A (92)+	5.34	1.78	17.89 (0.40)	5.34 (v)	17.89 (d)
HILL4A (92)+	5.05	8.19	3.90 (0.38)	5.05 (v)	8.19 (WP)
HILL2A (92)+	10.72	3.51	16.84 (0.42)	10.72 (v)	16.84 (d)
HILL3A (92)+	9.19	5.36	6.68 (0.38)	6.68 (d)	9.19 (v)
DOW3(92)#	23.35	1.44	11.33 (0.42)	11.33 (d)	23.35 (v)

Notes:
* denotes upper segment cross section
+ denotes middle segment cross sections
# denotes lower segment cross section
(x) is the depth criterion in feet
v refers to the average velocity criterion
WP refers to the wetted perimeter criterion
d refers to the average depth criterion

Present day guidelines for stream segmentation and cross section placement are different than they were in the early years of the instream flow program. The guidelines used today take into account factors such as tributary inflow, watershed area, existing diversion structures, lakes, reservoirs, and access considerations. Segmentation is now considered before any field measurements are collected. Using topographic maps and land status maps (from either the Forest Service or the Bureau of Land Management) and information from the Division of Water Resources, stream segments are delineated to address all of the above listed factors. Since R2CROSS utilizes hydraulic geometry and hydraulic geometry is dictated by the flows that form the channel, segments are described in such a manner to be responsive to the changes in hydrology that come with the addition of tributary flows. In other words, cross sections are added to a segment where tributaries (or other hydrologic or physical features) might impact the hydraulic geometry of a given representative stream cross section. Following this line of logic, the actual stream cross section is placed in the lower one-half to one-third of the segment so it is representative of the hydraulic conditions in the segment. R2CROSS is a model that describes the retention of hydraulic characteristics as a function of slope and the hydraulic geometry of a cross section. Since hydraulic geometry is a product of the ranges of flows that have occurred over time, the effect of tributary inflow must be considered when determining the number of cross sections that might be needed to describe the changes in hydraulic geometry that might occur along a stream's course.

Under present standards, a 17 mile long headwaters segment is too long to be considered in a single segment described by only one cross section. Several minor and major tributaries contribute flow to Snowmass Creek along its course from the headwaters at Snowmass Lake to the confluence with the Roaring Fork River. The 1975 R2CROSS cross section was taken in the upper one-third of the stream segment not the lower one-half to one-third as we would do today. These two factors are contrary to the present segmentation guidelines described above. Under present standards, a minimum of three R2CROSS cross sections would be needed to account for the tributary inflow, the changes in slope, and the changes in elevation that occur over the 17 mile course. The three cross sections would be placed to describe three segments; a headwaters segment down to West Snowmass Creek, a middle segment from West

Snowmass Creek to Capitol Creek, and a lower segment from Capitol Creek to the Roaring Fork confluence. The cross sections would be located in the lower one-half to one-third of each stream segment. The three Snowmass Creek segments have R2CROSS cross sections that meet the guidelines described above.

The additional cross sections in the middle segment were a direct result of the controversy and public's interest in this case.

ANALYSIS AND RECOMMENDATIONS

The upper segment of Snowmass Creek is best described by the original 1975 field data. This cross section yields a winter flow recommendation of 4 cfs; at 4 cfs both the average velocity and average depth criteria are met with the average depth criterion of 0.31 feet driving this flow recommendation. This flow should protect the over wintering fish population. As for the summer months, a flow of 9 cfs will maintain adequate summer habitat conditions for the existing trout population. While this flow does not meet all three criteria, it falls between winter flow recommendation and the flow which meets all three criteria. This flow maintains more than adequate levels of water depth and velocity to protect the fishery during the summer months.

In the middle segment, the five R2CROSS cross sections when viewed in aggregate support a flow recommendation of 7 cfs during the winter months and 15 cfs during the summer months. Table 1 shows that in all but one of the cross sections, two of three criteria are exceeded at 7 cfs. As previously stated, I am of the opinion that it is appropriate to exceed the second criteria because in three of the five cross sections the average depth criterion is not met. It is my opinion that the over wintering life stages of trout (particularly the incubating fry in the gravel) are vulnerable if adequate water depths are not maintained. As for the summer months, Table 1 shows that two of the five cross sections have the third criterion met at approximately 8 and 9 cfs while the other three cross sections have the third criterion met at flows between 16.4 cfs and 17.9 cfs. It is my opinion that all five cross sections support a summer flow of 15 cfs. 15 cfs will adequately protect the fishery during the summer months.

In the lower segment there is only one cross section that was collected in 1992 by the Division of Wildlife. The cross section supports flow recommendation of 11 cfs during the winter months and 22.5 cfs during the summer months. At approximately 11 cfs two of three criteria are met with the average depth criterion of 0.42 feet driving this flow recommendation. The Division's opinion on this segment is that the over wintering fish population will be protected with this flow. While 22.5 cfs does not mathematically meet all three criteria, the R2CROSS output shows that the average velocity at 22.5 cfs is approximately 0.99 feet per second and the Division is of the opinion that this flow will protect the fishery during the summer months.

Other than proposing several additional studies, Mark Hill (of Don Chapman Consultants) agreed with the Division of Wildlife's interpretation of the four HILL cross sections (see Hill's letter report that was submitted to the Board at the September, 1992 CWCB meeting in Grand Junction).

IFIM STUDIES BY CHADWICK AND MILLER

Since the last Snowmass Creek hearing before the CWCB, both Chadwick and Associates and W. J. Miller and Associates have conducted studies utilizing the IFIM and Physical Habitat Simulation Models (PHABSIM) to look at the relationship between discharge and trout habitat with particular attention to the lower flows. At the time of the last hearing before the CWCB in September, 1992 Chadwick's study was lacking what is termed a "low flow data deck". A low flow data deck allows one to use the IFIM model to predict how the habitat changes at very low flows. In 1993, Chadwick collected the necessary low flow information to re-run the model and examine the habitat versus flow relationships for the species of fish found in Snowmass Creek.

At the request of Pitkin County, the Aspen Wilderness Workshop, and the Forest Service, W. J. Miller and Associates conducted their own independent IFIM study in the middle reach of Snowmass Creek. They also mapped the pool, winter and spawning habitat in the middle and lower segment of Snowmass Creek. Miller also examined the hydrologic data that has been generated by all of the parties involved with this case.

Both of the above referenced studies support and corroborate the results that have been generated by the R2CROSS studies that were conducted by both CDOW and Don Chapman Consultants. The effect of the low flow data deck on the previous Chadwick study was minimal; in fact it showed that habitat conditions at the lower flows were slightly higher than was reported in the original final report. The Miller studies did not include any analysis of the results nor did they report any findings or recommendations. However, the Division's interpretation of the data is similar to Chadwick's IFIM study in that adequate levels of trout habitat are maintained at 7 cfs for nearly all life stages of all three species that occur in Snowmass Creek. The results of the habitat mapping also corroborate the Division's opinion regarding the habitat of Snowmass Creek. Previous reports by the DOW indicate that Snowmass Creek has poor habitat for trout. Miller reported that Snowmass Creek is predominantly riffle and run habitat (83 to 93%) and has very poor pool development (less than 7% pools). Generally speaking, it is desirable to have a balanced proportion of pool, riffle, and run habitats to support thriving trout populations. Nonetheless, Snowmass Creek does support naturally reproducing populations of brook trout and brown trout. There is nothing in the data reported by either Chadwick or Miller that suggests that the fishery will not continue to maintain itself as a result of these recommendations.

Miller's earlier work for Pitkin County, the "Critique of Snowmass Creek Minimum Flow Studies" (July 7, 1992) also supported the Division's winter flow recommendation for the middle reach of Snowmass Creek. The objectives of that evaluation were to review the available study results; critique the appropriateness of the methods, the adequacy and accuracy of the data, and the reasonableness of the findings; and to analyze impacts to the Snowmass Creek fishery. Miller's conclusions were that the methodologies that were used were appropriately applied, that the data was sufficient to formulate the winter flow recommendations, and that the 7 cfs winter flow recommendations would protect the existing fishery, and that the riparian areas would not be adversely impacted by the flow recommendations as long as the high spring and flows remain at their current level.

WALSH'S WINTER ECOLOGY STUDY

Walsh Aquatic Consultants was hired by the Snowmass-Capitol Creek Caucus to conduct winter studies of the trout population in Snowmass Creek. In December, 1995, a draft report ("The Winter

Ecology of Trout in Snowmass Creek, Colorado") was released to the Division of Wildlife for review. The Division has reviewed the report in light of the request to examine the winter streamflow needs to preserve the natural environment to a reasonable degree in Snowmass Creek.

In general, the Walsh report provides some interesting information regarding the wild trout populations in Snowmass Creek. Walsh evaluates stream discharge, water and air temperature between November, 1994 and March 1995. Walsh also analyzed water depths and velocities relative to identified spawning sites in Snowmass Creek. The report describes the physical characteristics of 36 trout redds in Snowmass Creek and the water depths and velocities upstream, directly over, and downstream (the tailspill)of a redd pit. Measurements were taken in November, 1994 to describe the conditions present at the time of egg deposition and at intervals during the winter to evaluate conditions as streamflows fall during the winter months. Walsh reported that statistically significant reductions in water depth and velocity occurred between November, 1994 and February, 1995. Walsh concluded that water depths and velocities fall to unacceptable levels during the winter months but he offers little evidence of this since trout abundance and density were not affected during the study; in fact, abundant trout fry were observed following the winter in which the measurements were taken in spite of the near record runoff year of 1995. Walsh does not propose any alternative flow recommendations in his report nor does he state that the proposed 7 cfs winter flow recommendation will be not maintain the existing trout population.

Given the nature of rocky mountain streams and their unique hydrology in the fall and winter, many of Walsh's findings are not surprising; however it must be noted that many of the findings are not controllable either. In the rocky mountains, streamflows naturally decline through the fall and early winter months and as streamflows fall, water depth and velocity fall in a corresponding manner. The instream flow program cannot maintain streamflows at a constant "optimum" level throughout the fall and winter nor can it protect streams against the formation of anchor ice; anchor ice forms under certain conditions that are not directly related to flow, namely air and water temperature and degree of snow coverage.

Trout are opportunistic in their selection of spawning habitats and in their selection of winter habitats. Trout survive and reproduce in streams all over the rocky mountains under hydrologic conditions similar to those that occur in Snowmass Creek. The instream flow program is not equipped to prevent all adverse conditions from occurring, it can only seek to protect the water dependant natural environment to a reasonable degree.

There is nothing in the Walsh report that suggests that spawning and incubation habitat will be adversely effected by setting a winter instream flow for the middle section of Snowmass Creek based on the R2CROSS and IFIM studies conducted by other investigator. In my opinion, based on the R2CROSS and IFIM results, adequate depths and velocities will be maintained at most if not all spawning sites investigated by Walsh. With the natural variability in fall and winter stream flows that occur in Snowmass Creek and the gaining nature of the stream segment, there is nothing that suggests that flows in Snowmass Creek will be at 7 cfs year in and year out. 7 cfs is however the threshold below which the natural environment will not be preserved to a reasonable degree.

CONCLUSIONS AND SUMMARY RECOMMENDATIONS

The goal of the Colorado instream flow program is to protect the natural environment to a reasonable degree; the Division of Wildlife's interpretation of this goal is to recommend instream flows that will, over the long term, maintain the existing fisheries in streams. The instream flow program is not authorized to protect optimum levels of habitat nor is it a program that protects the survival of the natural environment - it is somewhere in the middle of these two extremes.

Based on all of the information summarized in the above referenced studies and reports, the Division of Wildlife's recommendation to the Colorado Water Conservation Board is as follows.

1) Based on a review of the corrected (see Computational Error report dated 29 February 1996) R2CROSS run for the original 1975 cross section 200 yds upstream of the confluence of Snowmass Creek and West Snowmass Creek using current standards for summer and winter flow recommendations, the instream flow for the upper segment of Snowmass Creek (from Snowmass Lake to the confluence with West Snowmass Creek) should be 9 cfs summer (April 1 through October 15) and 4 cfs winter (October 16

through March 31)

2) Based on a review of the five R2CROSS cross sections in the middle reach of Snowmass Creek (from the confluence with West Snowmass Creek to the confluence with Capitol Creek) using current standards for summer and winter flow recommendations, the instream flow for this segment of Snowmass Creek should be 15 cfs summer and 7 cfs winter (same time periods as above). All of the additional studies conducted by other investigators in this segment of the stream support this recommendation. Over wintering adult fish as well as spawning and incubating fish will be maintained at these flow levels.

3) Based on a review of the 1992 R2CROSS cross section in the lower reach of Snowmass Creek (from the confluence with Capitol Creek to the confluence with the Roaring Fork River) using current standards for summer and winter flow recommendations, the instream flow should be 22.5 cfs during the summer months and 11 cfs during the winter months (same time periods as above). None of the additional studies refute this instream flow recommendation for this stream segment. This flow will, in the opinion of the Division of Wildlife, protect all life stages of all species of trout found in this stream segment.

The above recommendations will, in the opinion of the Division of Wildlife, preserve the natural environment to a reasonable degree.

REFERENCES

Espegren, Gregory D. 1996. Development of Instream Flow Recommendations In Colorado Using R2CROSS. Colorado Water Conservation Board, Denver, Colorado.

Nehring, R. B. 1979. Evaluation of Instream Flow Methods and Determination of Water Quantity Needs for Streams in the State of Colorado. Colorado Division of Wildlife. Fort Collins, Colorado.

COPIES OF FIELD DATA AND R2CROSS OUTPUT

CRO[illegible] PLOT

Location (Card One-Title Card) Cols. 3-80 as needed

Watershed Name: Snowmass Creek (3.... ...22)(Col. 23 Blank)

Date: 9-19-75 (45... ...53) Mil. Time: 1200 (55 58)

General Transect Location: 200 yds upstream from confluence with West Snowmass Cr. (24... ...43)(Col. 44 Blank)

DIVISION OF WILDLIFE

Observers: Whitaker, Byrne, Voeltker (60.. ...75)

Location: State: Colorado (24... ....33) County: Pitkin (35... ...44) Township: ____ (45.. 48) Range: ____ (50...53) Section: __ 55 56 Qtr. __ 58 59

Remarks: ____

Sag Tape Data: Card three-Data Cards Cross Sect. No: 001 (1 2 3) Tape Wt. 0107 (4..7) Tape Tens: 025 lbs. (8 9 10)

11 14 Distance	15 17 Depth	18 21 Dist.	22 24 Depth	25 28 Dist.	29 31 Depth	32 35 Dist.	36 38 Depth	39 42 Dist.	43 45 Depth	46 49 Dist.	50 52 Depth	53 56 Dist.	57 59 Depth	60 63 Dist.	64 66 Depth	67 70 Dist.	71 73 Depth
3000	0	001.0	01.0	002.0	01.7	003.0	01.7	004.0	02.9	W 005.0	03.0	006.0	03.4	007.0	03.4	008.0	03.3
009.0	02.9	010.0	03.3	011.0	03.3	012.0	02.9	013.0	02.8	014.0	03.3	015.0	03.4	016.0	03.8	017.0	03.7
018.0	04.1	019.0	04.2	020.0	04.1	021.0	03.7	022.0	03.9	023.0	04.0	024.0	03.8	025.0	03.1	026.0	03.1
027.0	03.0	028.0	02.8	029.0	02.7	030.0	02.0	031.0	01.6	W 032.0	01.0	999	999				

Note: Use following letter designation for Water line: W, and Grassline: G, inserted above distance data in appropriate block.
Enter 999 in Dist. Col. and 999 in Depth Col. to denote end of cross section.

Fish Collected:

Species	Length

DISCHARGE MEASUREMENT NOTES

Dist. From Initial Point	B Width	C Depth	D Observation Depth	F Revolution	G Time in seconds	H At Point	I Mean in vertical	J Area	K Discharge
2	1	0.4	0.6	11	10		1.1	.6	.66
3	1	1.4	0.6	6	10		.6	.6	.36
4	1	0.6	0.6	11			1.1	.6	.66
5		✓	0.6						
6	2	1.4	0.6	7	10		.7	1.2	.84
7	1	1.4	0.6	13	10		1.3	.6	.78
8		✓	0.6						
9		✓	0.6						
10	3	0.4	0.6	13	10		1.3	1.8	2.34

	Dist. From Initial Point	Width	Depth	Observation Depth	Revolution	Time in seconds	At Point	Mean in vertical	Area	Discharge
A	11	1	1.5	0.6	28	10		2.8	.6	1.68
E	12	1	0.9	0.6	22	10		2.2	.6	1.32
	13	1	0.9	0.6	23	10		2.3	.6	1.38
	14	1	1.3	0.6	25	10		2.5	.6	1.5
	15	1	1.4	0.6	28	10		2.8	.6	1.69
	16	1	1.2	0.6	20	10		2.0	.6	1.2
	17	1	0.9	0.6	33	10		3.3	.6	1.98
	18	1	1.1	0.6	46	10		4.6	.6	2.76
	19	1	1.2	0.6	22	10		2.2	.6	1.32
	20	1	1.0	0.6	19	10		1.9	.6	1.14
										21.6

Gradient Ex. 6% = .060 .020

No. photographs taken ____

Air ____ °F Water ____ °F

Type Meter: ____

Recorder: Byrne

Flow cfs: ____

E.R.S., 7/75

```
################################################
*      COLORADO WATER CONSERVATION BOARD       *
*   INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM  *
*    STREAM CROSS-SECTION AND FLOW ANALYSIS    *
################################################
```

LOCATION INFORMATION

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 200 YDS U/S W SNOWMASS CREEK
XS NUMBER: 1

DATE: 9/19/75
OBSERVERS: WHITAKER BYRNE VOELKER

1/4 SEC:
SECTION:
TWP:
RANGE:
PM:

COUNTY: PITKIN
WATERSHED: ROARING FORK
DIVISION: 5
DOW CODE:

USGS MAP:
USFS MAP: WHITE RIVER NF

SUPPLEMENTAL DATA

NOTE
Leave TAPE WT and TENSION at defaults for data collected with a survey level and rod

TAPE WT: 0.0107
TENSION: 25

CHANNEL PROFILE DATA

SLOPE: 0.02

INPUT DATA CHECKED BY: ______________DATE________

ASSIGNED TO: ______________DATE________

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 200 YDS U/S W SNOWMASS CREEK
XS NUMBER: 1

INPUT DATA # DATA POINT 33 | VALUES COMPUTED FROM RAW FIELD DATA

FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
1 S,GL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	2.00	1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	3.00	1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	4.00	2.90	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
WL	5.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	6.00	3.40	0.40	1.10	1.08	0.40	0.40	0.44	1.4%
	7.00	3.40	0.40	0.60	1.00	0.40	0.40	0.24	0.8%
	8.00	3.30	0.60	1.10	1.00	0.60	0.60	0.66	2.1%
R	9.00	2.90	0.00	0.00	1.08	0.00	0.00	0.00	0.0%
	10.00	3.30	0.40	0.70	1.08	0.40	0.40	0.28	0.9%
	11.00	3.30	0.40	1.30	1.00	0.40	0.40	0.52	1.6%
R	12.00	2.90	0.00	0.00	1.08	0.00	0.00	0.00	0.0%
R	13.00	2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	14.00	3.30	0.40	1.30	1.12	0.40	0.40	0.52	1.6%
	15.00	3.40	0.90	2.80	1.00	0.90	0.90	2.52	8.0%
	16.00	3.80	0.90	2.20	1.08	0.90	0.90	1.98	6.3%
	17.00	3.70	1.30	2.30	1.00	1.30	1.30	2.99	9.4%
	18.00	4.10	1.40	2.50	1.08	1.40	1.40	3.50	11.0%
	19.00	4.20	1.20	2.80	1.00	1.20	1.20	3.36	10.6%
	20.00	4.10	0.90	2.00	1.00	0.90	0.90	1.80	5.7%
	21.00	3.70	1.10	3.30	1.08	1.10	1.10	3.63	11.5%
	22.00	3.90	1.20	4.60	1.02	1.20	1.20	5.52	17.4%
	23.00	4.00	1.00	2.20	1.00	1.00	1.00	2.20	6.9%
	24.00	3.80	0.80	1.90	1.02	0.80	0.80	1.52	4.8%
	25.00	3.10	0.10	0.00	1.22	0.10	0.10	0.00	0.0%
	26.00	3.10	0.10	0.00	1.00	0.10	0.10	0.00	0.0%
WL	27.00	3.00	0.00	0.00	1.00	0.00	0.00	0.00	0.0%
	28.00	2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	29.00	2.70	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	30.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	31.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
1 S,GL	32.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
TOTALS					21.95	1.4 (Max.)	13.50	31.68	100.0%

Mannings' N = 0.0648

STREAM NAME: SNOWMASS CR
XS LOCATION: 200 YDS U/S
XS NUMBER: 1

WATER LINE COMPARISON TAB

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
2.78	13.50	16.74	24.0%
2.80	13.50	16.25	20.4%
2.82	13.50	15.77	16.8%
2.84	13.50	15.29	13.2%
2.86	13.50	14.81	9.7%
2.88	13.50	14.34	6.2%
2.90	13.50	13.87	2.7%
2.92	13.50	13.41	-0.6%
2.94	13.50	12.96	-4.0%
2.96	13.50	12.52	-7.2%
2.98	13.50	12.09	-10.4%
2.99	13.50	11.88	-12.0%
3.00	13.50	11.67	-13.5%
3.01	13.50	11.47	-15.1%
3.02	13.50	11.26	-16.6%
3.03	13.50	11.06	-18.1%
3.04	13.50	10.86	-19.5%
3.05	13.50	10.67	-21.0%
3.06	13.50	10.47	-22.4%
3.07	13.50	10.28	-23.9%
3.08	13.50	10.09	-25.3%
3.10	13.50	9.71	-28.1%
3.12	13.50	9.35	-30.8%
3.14	13.50	8.99	-33.4%
3.16	13.50	8.66	-35.8%
3.18	13.50	8.33	-38.3%
3.20	13.50	8.01	-40.6%
3.22	13.50	7.70	-43.0%
3.24	13.50	7.39	-45.3%
3.26	13.50	7.08	-47.5%
3.28	13.50	6.78	-49.7%

WATERLINE AT MINIM
AREA ERROR = 2.92

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 200 YDS U/S W SNOWMASS CREEK
XS NUMBER: 1

GL = lowest Grassline elevation corrected for sag

STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST T WATE (FT)	TOP WIDT (FT)	AVG DEPT (FT)	MAX DEPT (FT)	AREA (SQ FT	WETT PERIM (FT)	PERCE WET P (%)	HYDR RADIU (FT)	FLOW (CFS	AVG. VELOCITY (FT/SEC)	
*GL	1.00	31.01	2.13	3.25	66.06	33.27	100.0%	1.99	338.72	5.13	
	1.92	27.07	1.44	2.33	39.09	28.77	86.5%	1.36	155.62	3.98	
	1.97	26.90	1.40	2.28	37.74	28.57	85.9%	1.32	147.45	3.91	
	2.02	26.74	1.36	2.23	36.40	28.38	85.3%	1.28	139.45	3.83	
	2.07	26.63	1.32	2.18	35.07	28.23	84.9%	1.24	131.51	3.75	
	2.12	26.52	1.27	2.13	33.74	28.08	84.4%	1.20	123.75	3.67	
	2.17	26.41	1.23	2.08	32.42	27.93	84.0%	1.16	116.19	3.58	
	2.22	26.29	1.18	2.03	31.10	27.78	83.5%	1.12	108.82	3.50	
	2.27	26.18	1.14	1.98	29.79	27.62	83.0%	1.08	101.65	3.41	
	2.32	26.07	1.09	1.93	28.48	27.47	82.6%	1.04	94.67	3.32	
	2.37	25.96	1.05	1.88	27.18	27.32	82.1%	0.99	87.90	3.23	
	2.42	25.84	1.00	1.83	25.89	27.17	81.7%	0.95	81.34	3.14	
	2.47	25.73	0.96	1.78	24.60	27.02	81.2%	0.91	74.97	3.05	
	2.52	25.62	0.91	1.73	23.31	26.87	80.8%	0.87	68.82	2.95	
	2.57	25.51	0.86	1.68	22.03	26.71	80.3%	0.82	62.89	2.85	
	2.62	25.39	0.82	1.63	20.76	26.56	79.8%	0.78	57.17	2.75	
	2.67	25.28	0.77	1.58	19.50	26.41	79.4%	0.74	51.67	2.65	
	2.72	25.17	0.72	1.53	18.23	26.26	78.9%	0.69	46.40	2.54	
	2.77	24.65	0.69	1.48	16.99	25.71	77.3%	0.66	41.82	2.46	
	2.82	24.14	0.65	1.43	15.77	25.17	75.7%	0.63	37.46	2.38	
	2.87	23.63	0.62	1.38	14.57	24.64	74.1%	0.59	33.32	2.29	
*WL	2.92	22.74	0.59	1.33	13.41	23.70	71.2%	0.57	29.78	2.22	
	2.97	21.47	0.57	1.28	12.31	22.39	67.3%	0.55	26.80	2.18	
	3.02	20.27	0.56	1.23	11.26	21.15	63.6%	0.53	24.02	2.13	
	3.07	19.17	0.54	1.18	10.28	19.99	60.1%	0.51	21.40	2.08	
	3.12	18.09	0.52	1.13	9.35	18.86	56.7%	0.50	18.99	2.03	
	3.17	16.31	0.52	1.08	8.50	17.02	51.2%	0.50	17.35	2.04	
	3.22	15.64	0.49	1.03	7.70	16.28	48.9%	0.47	15.16	1.97	
	3.27	14.97	0.46	0.98	6.93	15.55	46.7%	0.45	13.13	1.89	
	3.32	14.30	0.43	0.93	6.20	14.81	44.5%	0.42	11.26	1.82	
	3.37	12.39	0.45	0.88	5.53	12.85	38.6%	0.43	10.22	1.85	
	3.42	11.18	0.44	0.83	4.94	11.61	34.9%	0.43	9.06	1.83	← 9 cfs = Summ
	3.47	9.49	0.47	0.78	4.43	9.90	29.8%	0.45	8.43	1.90	
	3.52	9.30	0.43	0.73	3.97	9.68	29.1%	0.41	7.10	1.79	
	3.57	9.10	0.39	0.68	3.51	9.46	28.4%	0.37	5.87	1.67	
	3.62	8.91	0.34	0.63	3.05	9.24	27.8%	0.33	4.74	1.55	← 4cfs = Winter
	3.67	8.71	0.30	0.58	2.61	9.01	27.1%	0.29	3.72	1.42	
	3.72	8.51	0.26	0.53	2.18	8.79	26.4%	0.25	2.80	1.28	
	3.77	7.99	0.22	0.48	1.77	8.24	24.8%	0.21	2.05	1.16	
	3.82	6.79	0.21	0.43	1.40	6.99	21.0%	0.20	1.55	1.11	
	3.87	5.68	0.19	0.38	1.09	5.82	17.5%	0.19	1.15	1.06	
	3.92	4.93	0.17	0.33	0.82	5.05	15.2%	0.16	0.79	0.97	
	3.97	4.06	0.15	0.28	0.60	4.16	12.5%	0.14	0.53	0.89	
	4.02	3.05	0.14	0.23	0.42	3.12	9.4%	0.13	0.35	0.85	

4.07	2.42	0.12	0.18	0.29	2.46	7.4%	0.12	0.22	0.77
4.12	2.17	0.08	0.13	0.17	2.19	6.6%	0.08	0.10	0.59
4.17	1.68	0.04	0.08	0.07	1.68	5.1%	0.04	0.03	0.39
4.22	0.68	0.02	0.03	0.01	0.68	2.0%	0.02	0.00	0.21

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 200 YDS U/S W SNOWMASS CREEK
XS NUMBER: 1

SUMMARY SHEET

MEASURED FLOW (Qm)=	31.68 cfs	
CALCULATED FLOW (Qc)=	29.78 cfs	
(Qm-Qc)/Qm * 100 =	6.0 %	
MEASURED AREA (Am)=	13.50 sq ft	
CALCULATED AREA (Ac)=	13.41 sq ft	
(Am-Ac)/Am * 100 =	0.6 %	
MAX MEASURED DEPTH (Dm)=	1.40 ft	
MAX CALCULATED DEPTH (Dc)	1.33 ft	
(Dm-Dc)/Dm * 100	4.7 %	
MEAN VELOCITY=	2.22 ft/sec	
MANNING'S N=	0.065	
SLOPE=	0.02 ft/ft	
.4 * Qm =	12.67 cfs	
2.5 * Qm=	79.20 cfs	

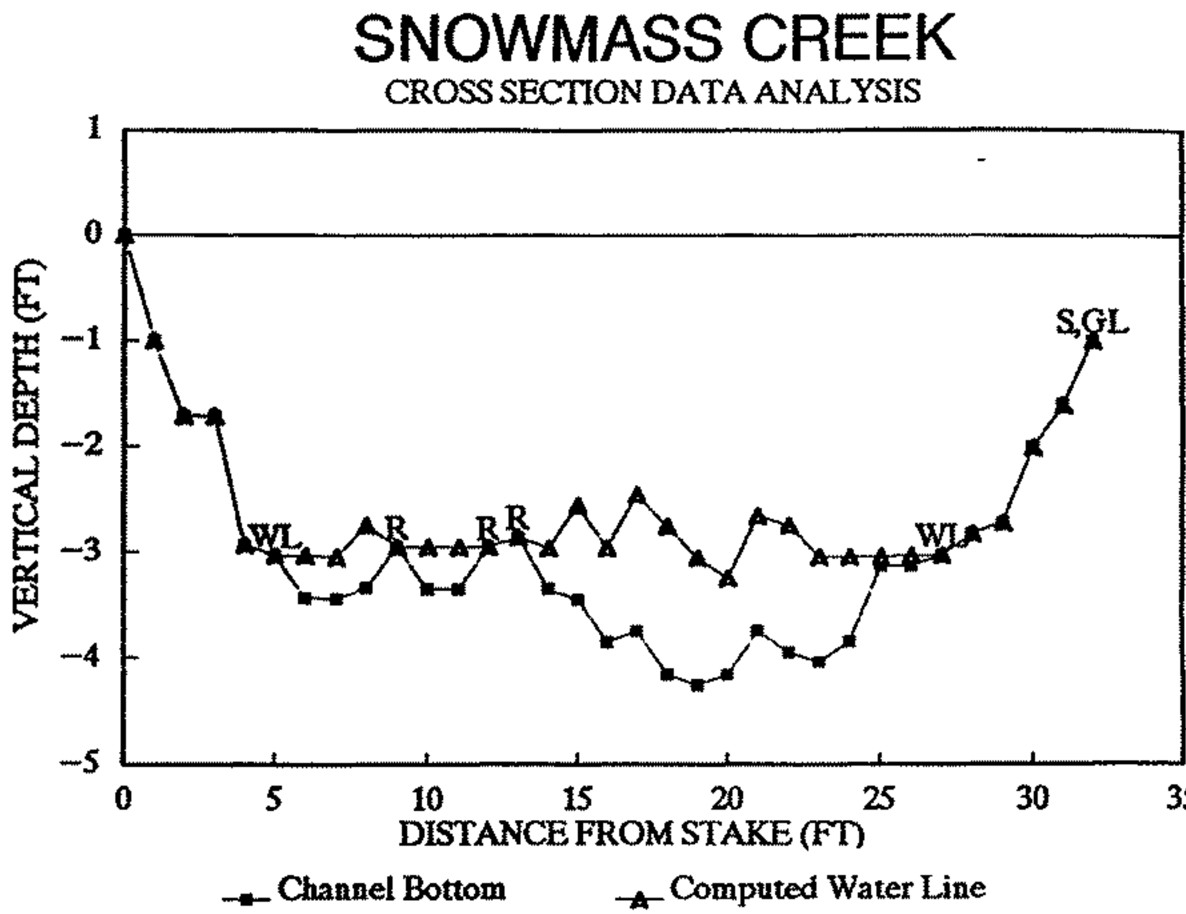
RECOMMENDED INSTREAM FLOW:

FLOW (CFS)	PERIOD

RATIONALE FOR RECOMMENDATION:

DOW RECOMMENDATION BY: ....DATE:..............

CWCB REVIEW BY: ....DATE:..............


SNOWMASS CREEK
CROSS SECTION DATA ANALYSIS
VERTICAL DEPTH (FT)
DISTANCE FROM STAKE (FT)
WL
R
R
R
WL
S,GL
Channel Bottom
Computed Water Line

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO WATER CONSERVATION BOARD

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME: SNOWMASS CREEK					CROSS-SECTION NO.: 1
CROSS-SECTION LOCATION: 130 YDS [illegible]					
DATE: [illegible]	OBSERVERS: SKINNER [illegible]				
LEGAL DESCRIPTION	¼ SECTION:	SECTION:	TOWNSHIP: N/S	RANGE: E/W	PM:
COUNTY: PITKIN	WATERSHED: ROARING FORK	WATER DIVISION: 5	DOW WATER CODE:		
MAP(S):	USGS:				
	USFS: WHITE RIVER N.F.				

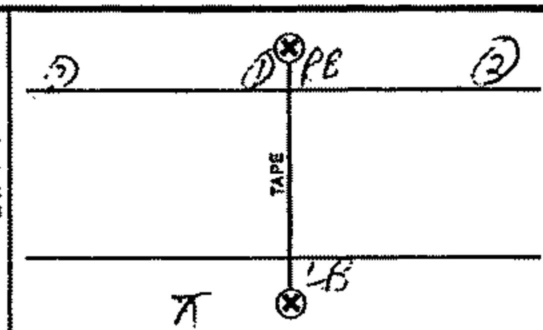
SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: (YES) NO	METER TYPE: MARSH McBIRNEY 2000			
METER NUMBER: —	DATE RATED: —	CALIB/SPIN: 10.22 sec	TAPE WEIGHT: N/A lbs/foot	TAPE TENSION: N/A lbs
CHANNEL BED MATERIAL SIZE RANGE:		PHOTOGRAPHS TAKEN: YES/NO	NUMBER OF PHOTOGRAPHS:	

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
Tape @ Stake LB	0.0	—
⊗ Tape @ Stake RB	0.0	—
① WS @ Tape LB/RB	0.0	7.09 / 7.13
② WS Upstream	35.0	6.66
③ WS Downstream	25.5	7.83
SLOPE	1.17 / 60.5 = 0.019	

SKETCH



LEGEND: Stake ⊗ Station ① Photo ◇→ Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED: (YES) NO	DISTANCE ELECTROFISHED: 300 ft	FISH CAUGHT: (YES) NO	WATER CHEMISTRY SAMPLED: YES (NO)

LENGTH-FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL
L (7400−5800=1600g)										11	1	1	1	1			6
B (5900−4900=1000g)								11	11	1	1						6
Sculpin				1													1
80% Efficiency / Poor Effort																	

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME:

COMMENTS

Cloudy + Breezy, Stream blown out + steep, all glide
Brown ♂ in spawning condition
Brooks also in spawning condition — both sexes
Large stream for good effort with BP-6

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: SNOWMASS CREEK	CROSS-SECTION NO.: 1	DATE: 23 Oct 91	SHEET 1 OF 2
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) LEFT / RIGHT (circled: RIGHT)	Gage Reading: 0.10 ft	TIME: 1225

Feature: Stake (S) Grassline (G) Waterline (W) Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical	Area (ft²)	Discharge (cfs)
S	0		2.33								
	1		3.85								
	2		4.30								
GL	3		4.62								
	4		4.98								
	5		5.08								
	6		5.02								
	7		5.25								
	8		5.32								
	9		5.66								
	10		6.04								
	11		6.10								
	12		6.37								
	13		6.56								
	14		6.83								
	15		6.65								
	16		6.95								
	17		6.98								
WL	18.9	0.55	7.09	0							
	19	1.05	7.18	0.10					0.10	0.11	0.011
	20	1.0	7.39	0.20					1.55	0.20	0.310
	21	↓	7.49	0.35					2.02	0.35	0.707
R	22		7.43	0.30					0.59	0.30	0.177
R	23		7.66	0.45					0.19	0.45	0.08[illegible]
	24		7.53	0.35					3.11	0.35	1.089
	25		7.53	0.40					1.90	0.40	0.760
	26		7.48	0.35					0.69	0.35	0.24[illegible]
R	27		7.45	0.30					0	0.30	0
	28		7.53	0.30					0.65	0.30	0.195
	29		7.63	0.35					1.24	0.35	0.434
	30		7.75	0.40					2.62	0.40	1.04[illegible]
	31		8.07	0.85					1.60	0.85	1.36[illegible]
	32		8.08	0.90					1.95	0.90	1.755
	33		8.11	1.00					2.48	1.00	2.48
	34		7.80	0.65					3.67	0.65	2.386
	35		7.80	0.90					3.54	0.90	3.186
R	36		7.61	0.60					0.24	0.60	0.1[illegible]
R	37		7.70	0.65					0.31	0.65	0.20[illegible]
R	38		7.89	0.70					0.59	0.70	0.41[illegible]
	39		7.71	0.40					1.88	0.40	0.75[illegible]
	40		7.82	0.60					1.92	0.60	1.152
	41		7.45	0.30					1.84	0.30	0.552
TOTALS:											

End of Measurement	Time:	Gage Reading: ft	CALCULATIONS PERFORMED BY:	CALCULATIONS CHECKED BY:

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO WATER CONSERVATION BOARD

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME: SNOWMASS CK			CROSS-SECTION NO.: 3A
CROSS-SECTION LOCATION: 1/2 MI AB WATSON DIVIDE RD			
DATE: 12 Aug 92	OBSERVERS: SKINNER HILL CONKLIN		
LEGAL DESCRIPTION: ¼ SECTION: SE	SECTION: 2	TOWNSHIP: T 9 N/(S)	RANGE: R86 E/(W) PM: 6th
COUNTY: Pitkin	WATERSHED: Roaring Fk	WATER DIVISION: 5	DOW WATER CODE:
MAP(S): USGS: Woody Creek			
MAP(S): USFS: White River N.F.			

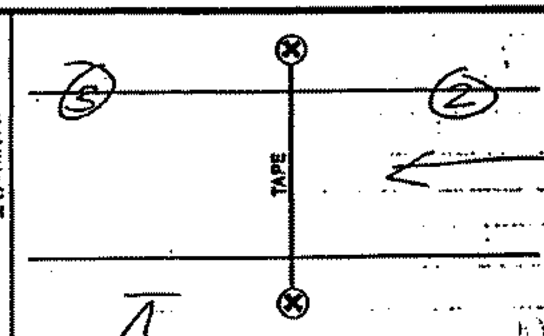
SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: (YES)/NO	METER TYPE: Marsh McB 2000			
METER NUMBER: —	DATE RATED: —	CALIB/SPIN: ✓ sec	TAPE WEIGHT: NA lbs/foot	TAPE TENSION: 99 lbs
CHANNEL BED MATERIAL SIZE RANGE: Sand – Lg Cobble		PHOTOGRAPHS TAKEN: (YES)/NO	NUMBER OF PHOTOGRAPHS: 3	

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
⊗ Tape @ Stake LB	0.0	—
⊗ Tape @ Stake RB	0.0	—
① WS @ Tape LB/RB	0.0	5.59 / 5.63
② WS Upstream	15.0	5.39
③ WS Downstream	8.0	5.60
SLOPE	0.21 / 23.0 = 0.00913	

SKETCH



LEGEND: Stake ⊗ Station ① Photo Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED: YES/(NO)	DISTANCE ELECTROFISHED: ____ ft	FISH CAUGHT: YES/NO	WATER CHEMISTRY SAMPLED: YES/(NO)

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME:

COMMENTS

Clear + Warm, Clear Water, no recent precip

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: SNOWMASS CK **CROSS-SECTION NO.:** 3A **DATE:** 12 Aug 92 **SHEET** 1 **OF** 1

BEGINNING OF MEASUREMENT | EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) LEFT / (RIGHT) | Gage Reading: ____ ft | TIME: 1004

Feature: Stake (S), Grassline (G), Waterline (W), Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical	Area (ft²)	Discharge (cfs)
S	0		4.11								
GL	0.5		4.41	~~0.10~~					~~0~~		
	1		5.32								
	2		5.36								
	3		5.49								
WL	4	0.50	5.51								
	5	1.00	5.67	0.10					0	0.100	0
	6	↓	5.67	0.10					0.65	0.100	0.065
	7		5.78	0.30					1.20	0.300	0.360
	8		5.71	0.20					1.30	0.200	0.260
	9		5.84	0.20					1.05	0.200	0.210
R	10		6.13	0.60					0.65	0.600	0.390
	11		6.26	0.70					2.85	0.700	1.995
	12		6.30	0.70					2.50	0.700	1.750
	13		6.70	1.10					0.95	1.100	1.045
	14		6.84	1.20					3.05	1.200	3.660
	15		6.71	1.20					2.35	1.200	2.820
	16		6.55	1.10					1.95	1.100	2.145
R	17		6.65	1.10					0.10	1.100	0.110
R	18		6.73	1.20					0.75	1.200	0.900
	19		6.63	1.20					2.40	1.200	2.880
	20		6.28	0.60					1.85	0.600	1.110
	21		6.76	1.10					2.95	1.100	3.245
	22		6.21	0.90					4.00	0.900	3.600
	23		5.94	0.40					3.10	0.400	1.240
	24		6.04	0.45					1.90	0.450	0.855
	25		6.18	0.50					0	0.500	0 .429
	26		6.91	1.30					3.30	1.300	~~3.900~~
	27		6.70	1.20					1.75	1.200	2.100
	28		6.51	1.00					1.30	1.000	1.300
	29		6.39	0.80					1.10	0.800	0.880
	30		6.95	1.30					1.15	1.300	1.495
	31		7.04	1.40					0.90	1.400	1.260
	32		7.22	1.50					0.40	1.500	0.600
	33		7.11	1.40					0.05	1.400	0.070
R	34		6.78	1.00					0	1.000	0
	35		6.72	1.00					0	1.000	0
R	36		5.44	0					0	0	0
	37	1.00	5.81	0.20					0	0.200	0
WL	38	0.50	5.53	0							
GL	39		5.34								V= ~~1.493~~ 1.508
	40		4.50								
TOTALS:	34.0	34.0								26.95	~~40.245~~ 40.63

End of Measurement | Time: 1032 | Gage Reading: ____ ft | CALCULATIONS PERFORMED BY: | CALCULATIONS CHECKED BY:

```
##################################################
*        COLORADO WATER CONSERVATION BOARD        *
*    INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM    *
*      STREAM CROSS-SECTION AND FLOW ANALYSIS      *
##################################################
```

LOCATION INFORMATION

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 0.5 MI AB WATSON DIVIDE ROAD
XS NUMBER: 3A

DATE: 8/12/92
OBSERVERS: SKINNER HILL CONKLIN

1/4 SEC: SE
SECTION: 2
TWP: 9S
RANGE: 86W
PM: 6TH

COUNTY: PITKIN
WATERSHED: ROARING FORK
DIVISION: 5
DOW CODE:

USGS MAP: WOODY CREEK
USFS MAP: WHITE RIVER NF

SUPPLEMENTAL DATA   ### NOTE ###
Leave TAPE WT and TENSION
at defaults for data collected
TAPE WT: 0.0001 with a survey level and rod
TENSION: 99999

CHANNEL PROFILE DATA

SLOPE: 0.0091

INPUT DATA CHECKED BY: ____________ DATE ________

ASSIGNED TO: ____________ DATE ________

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 0.5 MI AB WATSON DIVIDE ROAD
XS NUMBER: 3A

INPUT DATA # DATA POINT 42 | VALUES COMPUTED FROM RAW FIELD DATA

FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL.	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
S	0.00	4.11	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
1 GL	0.50	4.41	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	1.00	5.32	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	2.00	5.36	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	3.00	5.49	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
WL	4.00	5.51	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	5.00	5.67	0.10	0.00	1.01	0.10	0.10	0.00	0.0%
	6.00	5.67	0.10	0.65	1.00	0.10	0.10	0.07	0.2%
	7.00	5.78	0.30	1.20	1.01	0.30	0.30	0.36	0.9%
	8.00	5.71	0.20	1.30	1.00	0.20	0.20	0.26	0.6%
	9.00	5.84	0.20	1.05	1.01	0.20	0.20	0.21	0.5%
R	10.00	6.13	0.60	0.65	1.04	0.60	0.60	0.39	1.0%
	11.00	6.26	0.70	2.85	1.01	0.70	0.70	2.00	4.9%
	12.00	6.30	0.70	2.50	1.00	0.70	0.70	1.75	4.3%
	13.00	6.70	1.10	0.95	1.08	1.10	1.10	1.05	2.6%
	14.00	6.84	1.20	3.05	1.01	1.20	1.20	3.66	9.0%
	15.00	6.71	1.20	2.35	1.01	1.20	1.20	2.82	6.9%
	16.00	6.55	1.10	1.95	1.01	1.10	1.10	2.15	5.3%
R	17.00	6.65	1.10	0.10	1.00	1.10	1.10	0.11	0.3%
R	18.00	6.73	1.20	0.75	1.00	1.20	1.20	0.90	2.2%
	19.00	6.63	1.20	2.40	1.00	1.20	1.20	2.88	7.1%
	20.00	6.28	0.60	1.85	1.06	0.60	0.60	1.11	2.7%
	21.00	6.76	1.10	2.95	1.11	1.10	1.10	3.25	8.0%
	22.00	6.21	0.90	4.00	1.14	0.90	0.90	3.60	8.9%
	23.00	5.94	0.40	3.10	1.04	0.40	0.40	1.24	3.1%
	24.00	6.04	0.45	1.90	1.00	0.45	0.45	0.86	2.1%
	25.00	6.18	0.50	0.00	1.01	0.50	0.50	0.00	0.0%
	26.00	6.91	1.30	3.30	1.24	1.30	1.30	4.29	10.6%
	27.00	6.70	1.20	1.75	1.02	1.20	1.20	2.10	5.2%
	28.00	6.51	1.00	1.30	1.02	1.00	1.00	1.30	3.2%
	29.00	6.39	0.80	1.10	1.01	0.80	0.80	0.88	2.2%
	30.00	6.95	1.30	1.15	1.15	1.30	1.30	1.50	3.7%
	31.00	7.04	1.40	0.90	1.00	1.40	1.40	1.26	3.1%
	32.00	7.22	1.50	0.40	1.02	1.50	1.50	0.60	1.5%
	33.00	7.11	1.40	0.05	1.01	1.40	1.40	0.07	0.2%
R	34.00	6.98	1.00	0.00	1.05	1.00	1.00	0.00	0.0%
	35.00	6.72	1.00	0.00	1.00	1.00	1.00	0.00	0.0%
R	36.00	5.44	0.00	0.00	1.62	0.00	0.00	0.00	0.0%
	37.00	5.81	0.20	0.00	1.07	0.20	0.20	0.00	0.0%
WL	38.00	5.53	0.00	0.00	1.04	0.00	0.00	0.00	0.0%
1 GL	39.00	5.34	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	40.00	4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
TOTALS					35.80	1.5 (Max.)	27.05	40.63	100.0%

Mannings' N = 0.0784

STREAM NAME: SNOWMASS CR
XS LOCATION: 0.5 MI AB WAT
XS NUMBER: 3A

WATER LINE COMPARISON TAB

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
5.26	27.05	38.50	42.3%
5.28	27.05	37.74	39.5%
5.30	27.05	36.98	36.7%
5.32	27.05	36.22	33.9%
5.34	27.05	35.47	31.1%
5.36	27.05	34.72	28.4%
5.38	27.05	33.99	25.6%
5.40	27.05	33.26	22.9%
5.42	27.05	32.53	20.3%
5.44	27.05	31.81	17.6%
5.46	27.05	31.10	15.0%
5.47	27.05	30.74	13.7%
5.48	27.05	30.39	12.3%
5.49	27.05	30.04	11.0%
5.50	27.05	29.69	9.8%
5.51	27.05	29.35	8.5%
5.52	27.05	29.01	7.3%
5.53	27.05	28.68	6.0%
5.54	27.05	28.34	4.8%
5.55	27.05	28.01	3.5%
5.56	27.05	27.67	2.3%
5.58	27.05	27.01	-0.1%
5.60	27.05	26.36	-2.6%
5.62	27.05	25.71	-5.0%
5.64	27.05	25.06	-7.3%
5.66	27.05	24.42	-9.7%
5.68	27.05	23.80	-12.0%
5.70	27.05	23.19	-14.3%
5.72	27.05	22.59	-16.5%
5.74	27.05	22.01	-18.6%
5.76	27.05	21.44	-20.7%

WATERLINE AT MINIM
AREA ERROR = 5.58

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 0.5 MI AB WATSON DIVIDE ROAD
XS NUMBER: 3A

STAGING TABLE

GL = lowest Grassline elevation corrected for sag
WL = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETT. PERIM. (FT)	PERCENT WET PERIM (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
*GL	5.34	37.50	0.95	1.88	35.47	39.33	100.0%	0.90	59.95	1.69
	5.38	36.64	0.93	1.84	33.99	38.46	97.8%	0.88	56.67	1.67
	5.43	35.99	0.89	1.79	32.17	37.80	96.1%	0.85	52.32	1.63
	5.48	35.20	0.86	1.74	30.39	36.98	94.0%	0.82	48.28	1.59
	5.53	33.56	0.85	1.69	28.68	35.30	89.8%	0.81	45.21	1.58
*WL	5.58	32.90	0.82	1.64	27.01	34.59	88.0%	0.78	41.48	1.54
	5.63	32.23	0.79	1.59	25.39	33.88	86.2%	0.75	37.92	1.49
	5.68	30.54	0.78	1.54	23.80	32.15	81.7%	0.74	35.28	1.48
	5.73	29.29	0.76	1.49	22.30	30.85	78.5%	0.72	32.52	1.46
	5.78	27.38	0.76	1.44	20.88	28.90	73.5%	0.72	30.45	1.46
	5.83	26.77	0.73	1.39	19.53	28.25	71.8%	0.69	27.65	1.42
	5.88	26.52	0.69	1.34	18.20	27.97	71.1%	0.65	24.75	1.36
	5.93	26.31	0.64	1.29	16.88	27.72	70.5%	0.61	21.95	1.30
	5.98	25.55	0.61	1.24	15.58	26.93	68.5%	0.58	19.59	1.26
	6.03	24.65	0.58	1.19	14.32	25.99	66.1%	0.55	17.44	1.22
	6.08	23.87	0.55	1.14	13.11	25.16	64.0%	0.52	15.37	1.17
	6.13	23.11	0.52	1.09	11.94	24.37	62.0%	0.49	13.43	1.13
	6.18	22.15	0.49	1.04	10.81	23.36	59.4%	0.46	11.70	1.08
	6.23	21.51	0.45	0.99	9.71	22.67	57.6%	0.43	10.00	1.03
	6.28	20.58	0.42	0.94	8.66	21.69	55.1%	0.40	8.50	0.98
	6.33	19.56	0.39	0.89	7.66	20.59	52.3%	0.37	7.18	0.94
	6.38	18.99	0.35	0.84	6.70	19.93	50.7%	0.34	5.86	0.88
	6.43	18.01	0.32	0.79	5.77	18.86	48.0%	0.31	4.74	0.82
	6.48	16.94	0.29	0.74	4.90	17.69	45.0%	0.28	3.77	0.77
	6.53	15.92	0.26	0.69	4.08	16.57	42.1%	0.25	2.90	0.71
	6.58	14.51	0.23	0.64	3.31	15.06	38.3%	0.22	2.18	0.66
	6.63	12.78	0.21	0.59	2.63	13.21	33.6%	0.20	1.62	0.62
	6.68	10.61	0.19	0.54	2.04	10.95	27.8%	0.19	1.21	0.59
	6.73	8.08	0.19	0.49	1.57	8.32	21.2%	0.19	0.93	0.60
	6.78	5.99	0.20	0.44	1.22	6.18	15.7%	0.20	0.75	0.61
	6.83	4.70	0.20	0.39	0.95	4.84	12.3%	0.20	0.58	0.61
	6.88	4.01	0.18	0.34	0.74	4.10	10.4%	0.18	0.43	0.58
	6.93	3.58	0.15	0.29	0.55	3.64	9.3%	0.15	0.28	0.51
	6.98	3.06	0.12	0.24	0.38	3.11	7.9%	0.12	0.17	0.45
	7.03	2.35	0.10	0.19	0.25	2.39	6.1%	0.10	0.10	0.40
	7.08	1.87	0.08	0.14	0.14	1.89	4.8%	0.07	0.05	0.32
	7.13	1.32	0.05	0.09	0.06	1.33	3.4%	0.04	0.01	0.23
	7.18	0.59	0.02	0.04	0.01	0.59	1.5%	0.02	0.00	0.13

STREAM NAME: SNOWMASS CREEK
XS LOCATION: 0.5 MI AB WATSON DIVIDE ROAD
XS NUMBER: 3A

SUMMARY SHEET

MEASURED FLOW (Qm)=	40.63 cfs	RECOMMENDED INSTREAM FLOW:	
CALCULATED FLOW (Qc)=	41.48 cfs		
(Qm-Qc)/Qm * 100 =	-2.1 %		
		FLOW (CFS)	PERIOD
MEASURED AREA (Am)=	27.05 sq ft		
CALCULATED AREA (Ac)=	27.01 sq ft		
(Am-Ac)/Am * 100 =	0.1 %		
MAX MEASURED DEPTH (Dm)=	1.50 ft		
MAX CALCULATED DEPTH (Dc)	1.64 ft		
(Dm-Dc)/Dm * 100	-9.3 %		
MEAN VELOCITY=	1.54 ft/sec		
MANNING'S N=	0.078		
SLOPE=	0.0091 ft/ft		
.4 * Qm =	16.25 cfs		
2.5 * Qm=	101.59 cfs		

RATIONALE FOR RECOMMENDATION:

DOW RECOMMENDATION BY: .... DATE: ....

CWCB REVIEW BY: .... DATE: ....

STATE OF COLORADO

Colorado Water Conservation Board
Department of Natural Resources
721 State Centennial Building
1313 Sherman Street
Denver, Colorado 80203
Phone (303) 866-3441
FAX (303) 866-4474

MEMORANDUM

TO: Steven O. Sims
Harris Sherman/David Neslin
Jay Skinner
Gregory Kuyumjian
Grady McNure/Mike Claffey
Jay Cope
Jim Chadwick
Steven Connor
Lori Potter
Dottie Fox
William Walsh
Don Chapman/Tracy Hillman
Sue Helm

FROM: Dan Merriman

DATE: March 5, 1996

SUBJECT: March 15, 1996, Meeting Notice
Snowmass Creek ISF Modification Issue

The Colorado Water Conservation Board (CWCB) staff will hold a meeting on March 15, 1996, to discuss the biologic and hydrologic data that has been collected with regard to the proposed modification of the Board's instream flow water right in Snowmass Creek. The meeting will begin at 9:00 a.m. in Room 721 of the Centennial Building, 1313 Sherman Street, Denver, CO. The purpose of this meeting is to allow biologists and hydrologists to openly share their data, analyses, and conclusions on the proposed modification of the instream flow water right. Legal counsel and interested persons are welcome to attend the meeting, however, discussions outside the technical group will be strongly discouraged.

Additional written reports describing the biologic instream flow requirements of Snowmass Creek are to be distributed today by the respective parties. The CWCB staff expects to receive, or has received, reports from the Colorado Division of Wildlife, Don Chapman Consultants, Chadwick & Associates, and Walsh Aquatic Consultants. The CWCB staffs' report is attached. These reports, along with any previous reports or information, will provide the framework for discussions at the meeting.

If you have questions or comments prior to the meeting date, please contact Greg Espegren, of my staff, or me at your earliest convenience.

attachment
DCM/GDE

Steven O. Sims
Colorado State Attorney Generals Office
1525 Sherman Street
Denver, CO 80203

Harris Sherman/David Neslin
Arnold and Porter
One United Bank Center
1700 Lincoln Street
Denver, CO 80203

Jay Skinner
Colorado Division of Wildlife
6060 Broadway
Denver, CO 80216

Gregory Kuyumjian
White River National Forest
P.O. Box 948
Glenwood Springs, CO 81602

Grady McNure/Mike Claffey
COE
402 Rood Avenue
Grand Junction, CO 81501

Jay Cope
Frascona, Joiner and Goodman
4750 Table Mesa Drive
Boulder, CO 80303-5575

Jim Chadwick
Chadwick & Associates, Inc.
5575 S. Sycamore Street, Suite 101
Littleton, CO 80120

Steven Connor
P.O. Box 6240
Snowmass Village, CO 81615

Lori Potter
Sierra Club Legal Defense Fund
1631 Glenarm Street, Suite 300
Denver, CO 80202

Dottie Fox
Box 545
Snowmass, CO 81654

William Walsh
Walsh Aquatic Consultants
9560 Carr Street
Westminster, CO 80021

Don Chapman/Tracy Hillman
3653 Rickenbacker, Suite 200
Boise, ID 83705

Sue Helm
11000 Snowmass Creek Road
Snowmass, CO 81654

Summary of Biologic Reports

CDOW Studies

The CWCB's original Snowmass Creek instream flow appropriation was based on a cross section collected by CDOW personnel 200 yards upstream of West Snowmass Creek on September 19, 1975. This hydraulic field data was used to develop a staging table using a hand calculator to iteratively solve Manning's equation. The staging table provides a summary of predicted hydraulic streamflow parameters at various unobserved stream discharges. CDOW biologic experts analyzed this staging table and used it as the biologic basis for the CWCB's 12 cfs Snowmass Creek instream flow appropriation. The CWCB appropriated this 12 cfs instream flow water right on the 17-mile long stream reach of Snowmass Creek from Snowmass Lake downstream to its confluence with the Roaring Fork River on January 14, 1976. Unfortunately, the staging table CDOW used to develop the 12 cfs biological recommendation was based on an erroneous discharge calculation.

CDOW's first biologic report addressing the proposed modification of the CWCB's Snowmass Creek instream flow was issued on March 3, 1992, in the form of a letter from Jay Skinner to Dan Merriman. The recommendation was based upon the original cross section data for the segment of Snowmass Creek upstream of West Snowmass Creek and on additional cross information collected in October 1991 immediately below the SWSD' s Snowmass Creek pipeline. The report concluded that a winter flow recommendation would be appropriate for Snowmass Creek and that an increase in the summer flow within the middle segment of Snowmass Creek would also be appropriate. The report found that:

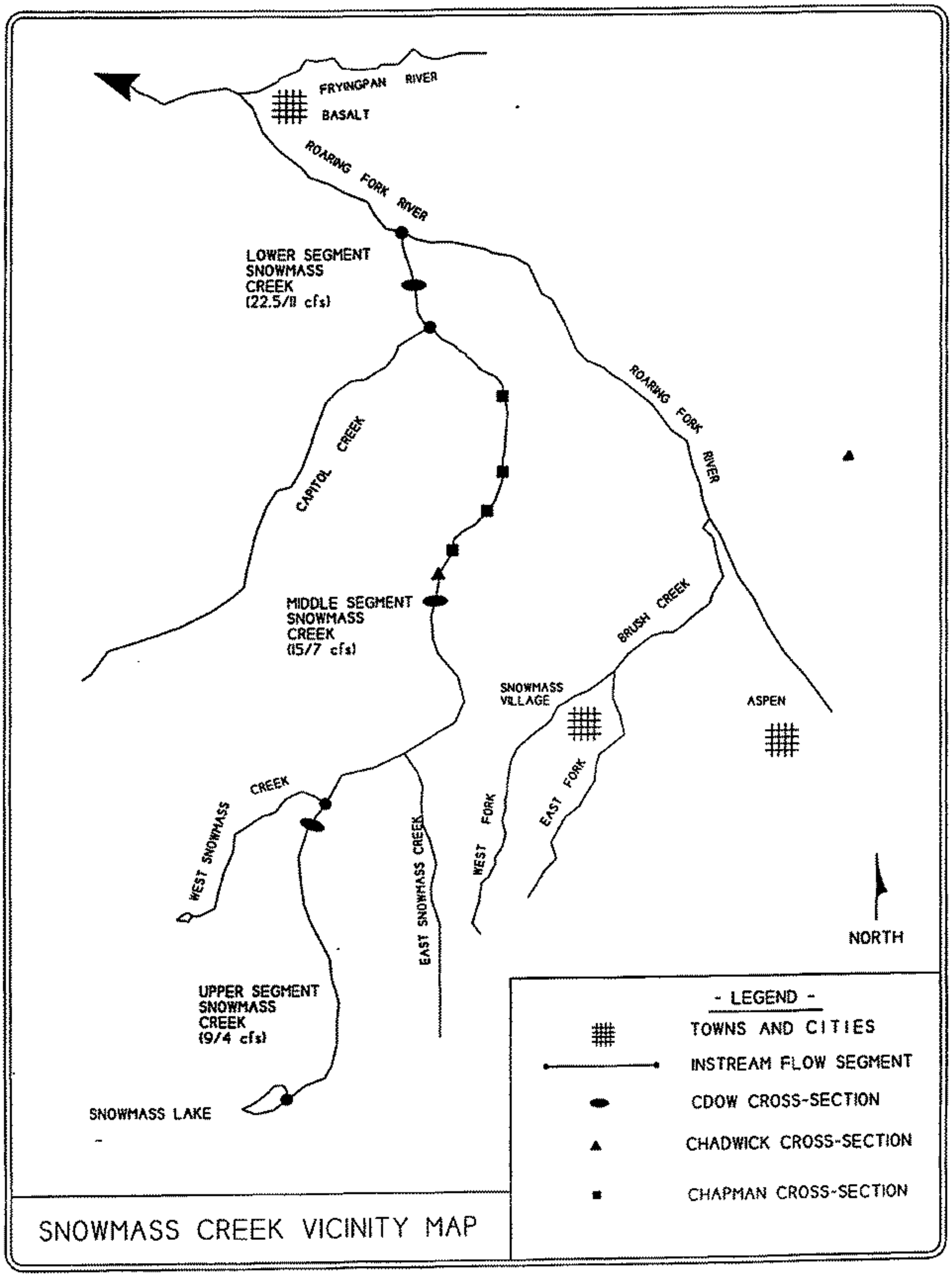
(1) A natural environment was present in the form of a wild brook and brown trout fishery,
(2) A summer flow of 15 cfs would maintain adequate average velocities and wetted perimeters to protect the fishery,
(3) A winter flow of 7 cfs would be adequate to maintain the fishery in its current condition, and
(4) These recommendations were supported by and were consistent with an independent IFIM/PHABSIM analysis provided by Chadwick and Associates on behalf of the Aspen Skiing Company.

An April 1, 1992, follow-up letter from Mr. Skinner to Mr. Merriman further clarified CDOW's recommendation for an instream flow modification on Snowmass Creek. It indicated that:

(1) Using up-to-date criteria on the corrected 1975 cross section resulted in a flow recommendation of 9 cfs, summer, and 4 cfs, winter, in the segment of Snowmass Creek upstream of West Snowmass Creek,
(2) The previous recommendation of 15 cfs, summer, and 7 cfs, winter should be used between West Snowmass Creek and Capitol Creek, and
(3) Flows of 22.5 cfs, summer, and 11 cfs, winter, from Capital Creek downstream to the Roaring Fork River should be adequate to protect the natural environment to a reasonable degree.

The recommendation on the lower segment was based upon additional cross section information collected on March 23, 1992. The attached map depicts these three segments and the associated flow recommendations. It also shows the relative location of the three CDOW R2CROSS cross sections. Copies of the Recommendation Summary Reports which were provided to the Board at the time of the final notice of modification are attached at the end of the report.

The CDOW recommendations were based upon a standard R2CROSS analysis. This analysis consists of evaluating a staging table generated by the CWCB's R2CROSS macro and determining the streamflow that meets certain hydraulic criteria (Nehring 1979). The CDOW and CWCB have used this type of R2CROSS analysis on the majority of instream flow appropriations on coldwater streams throughout the state. The modifications were intended to bring the streamflows up to today's standards by (1) segmenting the 17 mile long, gaining stream reach into three shorter stream segments with more uniform habitat characteristics and (2) presenting separate flow recommendations for summer and winter within each of the new stream segments to more appropriately address the natural hydrologic characteristics of the stream and the seasonal biologic requirements of the fish. The proposed modification also corrected the original 12 cfs recommendation which was based upon a calculation error.



SNOWMASS CREEK VICINITY MAP

Chadwick and Associates, Inc. Report

On June 25, 1992, Chadwick and Associates, Inc. issued a report entitled "Evaluation of the Fishery and Minimum Streamflow Issues of Snowmass Creek. The Chadwick Report focused on trout population data, trout habitat data and the hydrology of the middle (West Snowmass Creek to Capitol Creek) and lower (Capitol Creek to the Roaring Fork River) segments of Snowmass Creek.

Chadwick utilized CDOW electrofishing samples collected in 1977 and 1991 and CDOW stocking records to evaluate the present and historic recreational fishery in Snowmass Creek. Chadwick reports that fish populations in Snowmass Creek are comprised of brook trout, rainbow trout, brown trout, and mottled sculpin. Snowmass Creek was stocked with rainbow trout from 1987 through 1989.

Chadwick states that trout biomass in streams of similar size, elevation, and channel morphology to Snowmass Creek averages 60 lbs/acre. Biomass estimates from Snowmass Creek ranged from 4.3 lbs/acre in the headwaters segment to 35.5 lbs/acre in the lower instream flow segment. Based upon this analysis, Chadwick concludes that the recreational potential of Snowmass Creek is poor, biomass is less than average, and access to the stream downstream of the SWSD diversion is limited.

With regard to the hydrology of Snowmass Creek, Chadwick references a Wright Water Engineers' (WWE) hydrologic study which estimated mean monthly flows over a 20-year period from 1970 to 1989 at a point just upstream of the SWSD diversion structure on Snowmass Creek. The WWE study indicates that Snowmass Creek follows the typical pattern of runoff for a stream in the Rocky Mountain region. Peak mean monthly flow was reported to be 243 cfs on average, low mean monthly flow was reported to be 13 cfs during the month of March. During dry years (1 in 10 frequency) flows may drop to 8.5 cfs.

Chadwick's "visual" evaluation of trout habitat in Snowmass Creek indicates that "the stream appeared to have poor trout habitat ... due to the wide, shallow nature of the stream. There appeared to be few areas of the stream with deep pools, runs, or boulders to provide holding water for larger trout. Also, the wide nature of the stream results in a channel that is exposed and has limited riparian cover available for fish."

Chadwick modeled trout habitat using the Instream Flow Incremental Methodology (IFIM) and the Physical Habitat Simulation (PHABSIM) models. Field data for Chadwick's IFIM analysis was collected at a flow of 60 cfs in early May 1992 and at a flow of 150 cfs in late May 1992. The IFIM model was run to evaluate flows from 3 cfs to 400 cfs. Chadwick acknowledges that the modeling accuracy of IFIM is best when modeled flows range between 0.4 and 2.5 times the field measured calibration flows. Based on the 60 cfs and 150 cfs calibration flows measured by Chadwick, the IFIM model would be most accurate down to a flow near 24 cfs and up to a flow of 375 cfs. However, Chadwick suggests the that the IFIM modeling results are accurate for flows between 3 cfs and 24 cfs because "given the slope of the weighted usable area versus discharge curves and our general observation on channel configuration in this reach, it appears that the model is performing well."

Concerns over the accuracy of Chadwick's IFIM modeling at flows below 24 cfs prompted the collection of additional cross section data at lower flows (7.5 cfs to 10 cfs) during the spring of 1993. On June 9, 1993, Chadwick issued a supplemental report which addressed these low flow modeling concerns.

The PHABSIM model simulates a relationship between stream discharge and fish habitat. Habitat suitability curves form the link between stream discharge and fish habitat in the PHABSIM model. Chadwick used generally accepted habitat suitability curves reported by Bovee (1978) for brook trout, Raleigh et al. (1984) for rainbow trout, and Raleigh et al. (1986) for brown trout in the IFIM/PHABSIM modeling effort.

Chadwick combined the hydrologic information provided in the WWE study with the IFIM/PHABSIM model to evaluate the relative amounts of habitat available over different seasons in Snowmass Creek. According to Chadwick "the representations of habitat over the course of the year clearly indicate that the high flow periods are the critical low habitat period for trout in Snowmass Creek." Chadwick's modeling also indicates that "habitat levels during the winter low flow period are high relative to habitat levels during peak flows" and he demonstrates that winter flows between 3 cfs and 5 cfs would be required to reduce habitat levels to the amounts typically experienced at high springtime peak flows.

Chadwick also evaluates CDOW's R2CROSS recommendations. He indicates that under CDOW's general policy of meeting two of three hydraulic criteria, the resultant winter flow recommendation in the middle and lower segments of Snowmass Creek should be 5.1 and 11.6 cfs, respectively.

Chadwick's IFIM modeling indicates that there is more trout habitat available during the winter months at a flow of 7 cfs than there is during the spring runoff. Based on that finding, Chadwick suggests that high peak flows in the spring are more of a "bottleneck" to trout populations than a 7 cfs winter flow. Chadwick concludes that "the winter minimum flow(s) .... proposed by CDOW would be more than adequate to provide habitat levels necessary to maintain trout populations" in both the middle and lower segments of Snowmass Creek.

W.J. Miller & Associates Report

W. J. Miller and Associates issued a report entitled "Critique of Snowmass Creek Minimum Flow Studies" on June 24, 1992. The Miller Report begins with a review of the existing CDOW and Chadwick reports and a general description of the aquatic habitat, riparian habitat, and hydrology of Snowmass Creek. It goes on to critique the appropriateness of the study methods, adequacy and accuracy of the data, and the comprehensiveness and reasonableness of the findings of the CDOW and Chadwick studies. It also analyzes CDOW's recommendations as to the impact that their implementation would have on Snowmass Creek.

Miller conducted a site visit to Snowmass Creek on June 12, 1992, and found that the predominant aquatic habitat type in the lower stream segment was high gradient riffles dominated by large cobble and small boulders. Miller also stated that the lower segment had very little pool habitat and limited potential spawning areas.

Miller found that the aquatic habitat within the middle segment of Snowmass Creek was predominantly high gradient riffles interspersed with riffles and runs. There were few areas with pools and deep runs. The substrate was predominantly cobble and large gravel with very few areas containing both the hydraulic characteristics and substrate sizes that could be used by spawning trout.

As an additional check on CDOW's field data, Miller evaluated changes in stream width and available habitat at several selected flows. Miller found that stream width was reduced by less than 4% as flows drop from 12 cfs to 7 cfs but it was reduced by over 23% as flows drop from 7 cfs down to 4 cfs. Miller concluded that the decrease in stream width from 12 cfs to 7 cfs was not significant but that more dramatic decreases in stream width below 7 cfs could dewater fall-spawned egg nests of brook and brown trout and reduce available habitat for other life stages of trout.

Based upon the evidence collected during his June 12 site visit, Miller agreed with Chadwick's conclusion that the lowest habitat for all life stages, except spawning, occurs during the spring peak flow periods. His conclusions were based on the observation that the aquatic habitat of Snowmass Creek is dominated by high gradient riffles, riffles, and runs which provide little refuge habitat from high velocities during the spring runoff. Miller states that "these high flows can have a significant impact on the younger life stages present in the stream" and that "the lack of deeper habitats also limits the winter holding habitat available to those fish remaining in the stream."

With regard to spawning habitat, Miller states that it is "the most limited habitat for all species." Miller concludes that any "reduction of available spawning habitat could further reduce the already low population levels".

Miller also investigated flow recommendations resulting from the Tennant Method (Tennant 1976). The resulting Tennant Method recommendations were 5.2 cfs to 6.6 cfs for "short term survival", 15.6 cfs to 19.8 cfs for "good habitat", and 31.2 cfs to 39.6 cfs for "low optimum flow." Miller concludes that these flows are "close to those selected by the CDOW" and that "since the CDOW method uses actual channel shape, those [*the CDOW*] flows should more accurately reflect the minimum flow needed to maintain the fishery."

Don Chapman Consultants, Inc. Report

On July 22, 1992. Don Chapman Consultants, Inc. provided input regarding the Snowmass Creek modification in the form of a letter from Mark Hill to Sue Helm. The letter was a cursory review of the CWCB and Chadwick Reports. The letter indicated that:

(1) Mean monthly flows on Snowmass Creek from the WWE study used by Chadwick were "estimated using Maroon Creek and basin characteristics" and that "the estimated hydrograph could be inaccurate by several cfs in the winter months which would be a very critical error",

(2) "The results of IFIM are probably quite unreliable" and "only confuse the issue" because:

 (a) Chadwick used curves which were synthesized by Raleigh on streams that may not have habitat conditions applicable to the habitat conditions on Snowmass Creek, and

 (b) Raleigh's curves were derived from observations of trout in summer habitat conditions and may not reflect winter habitat requirements of trout,

(3) "The fisheries conclusions presented in the Chadwick report are irrelevant" because a number of sampling and statistical assumptions were violated, and

(4) "There has been no analysis or perhaps thought given to winter habitat conditions and the effects of reduced flows" specifically, the potential detrimental impacts of increased anchor ice at reduced flows.

The Chapman letter concludes that additional R2CROSS cross section data should be gathered and that CDOW should "pause and re-evaluate" winter conditions on Snowmass Creek.

Don Chapman Consultants, Inc. released a "Report On and Recommendations For Establishing a Minimum Winter Flow in the Middle Reach of Snowmass Creek". The findings of the report were based upon a review of the existing CDOW and Chadwick data as well as four additional R2CROSS datasets. Chapman selected the four additional cross section locations to "incorporate as much stream channel diversity and different fish habitats as possible in the R2CROSS analysis." Based upon this additional modeling, Chapman found that "the results of the analysis showed somewhat different flows in each of the sites but that a 7 cfs minimum flow in winter meets the physical criteria set by the CDOW."

Chapman concludes that "the additional R2CROSS analysis mathematically corroborated a 7 cfs minimum flow" but that " no change in the water right should be made at this time" because " the R2CROSS results (and IFIM results) simply do not square with the biological facts." Prior to changing the instream flow right, Chapman suggests that:

(1) Our limited understanding of winter fish habitat should be increased,
(2) The factor which is limiting the trout population should be identified,
(3) Impacts of reduced streamflows on fall spawning salmonids should be quantified, and
(4) Additional hydrologic data should be gathered and analyzed.

Chapman suggests that detailed mapping and inventory of Snowmass Creek habitat, an over-winter mortality study, an anchor ice study, a spawning habitat survey, and the development of site-specific winter habitat suitability curves would be necessary to answer these questions.

USFS Snowmass Ski Area EIS and ROD

On March 8, 1994, the USFS issued its Record Of Decision (ROD) and Final Environmental Impact Statement (EIS) addressing the potential impacts of a proposed expansion of the Snowmass Ski Area by Aspen Skiing Company (ASC). Increased withdrawals of water from Snowmass Creek for snowmaking purposes at the ski area was one of the impacts evaluated in the FEIS. The USFS ROD permitted an additional 220 acres of new snowmaking on USFS lands, bringing the total snowmaking acreage on USFS lands at Snowmass Ski Area to 235 acres at full build out. Snowmaking on up to 125 acres of private land was not considered to be within USFS jurisdiction and therefore, was not addressed in the ROD (Table II-16, Page II-46 of FEIS).

In making its determination, the USFS evaluated the hydrology and aquatic biology of Snowmass Creek and determined that "Water withdrawals have the potential to adversely affect the stream ecosystem." While the ROD recognized that "diversion activity is entirely outside of Forest Service jurisdiction" (Page 35), the use of Snowmass Creek water for snowmaking purposes on USFS lands was conditioned on the following:

1. A gaging system at the SWSD diversion will be maintained to track the amount of water pumped for snowmaking and gage records will be made available for inspection by the CDOW, CWCB, and USFS,
2. General snowmaking operations will cease on December 31; recovering or patching

will be limited to that which can be done by water in storage,

3. Pumping for snowmaking and/or refilling water storage facilities will cease when continued pumping would reduce flows in Snowmass Creek below 7 cfs,
4. A 3 million gallon (9 acre-foot) storage facility will be constructed to buffer instantaneous diversion requirements from Snowmass Creek.

Under these constraints, the FEIS indicates that "adequate water will be available to meet municipal and snowmaking needs". However, it also predicts that "snowmaking withdrawals could reduce brown trout overwintering habitat by greater than 25 percent", "brown trout riffle and spawning habitat (used for a surrogate for egg incubation habitat) will not be significantly affected", and "brook trout spawning habitat reductions are predicted to reach the significant threshold for two weeks during a one-in-ten dry year."

The ROD goes on to suggest that "flow reductions during a single year may not show measurable effects on the aquatic ecosystem, but recurring annual impacts may have cumulative adverse effects." Consequently, the ROD recommended "ongoing monitoring by the permittee and agencies with jurisdiction" and that additional mitigation measures (i.e., additional storage or limiting snowmaking diversions from Snowmass Creek) be adopted should such monitored impacts differ from the impacts predicted in the FEIS.

Pursuant to 36 CFR 251, ASC opposed several decision elements of the ROD. At issue were several tables regarding changes in brown trout winter, riffle, and pool habitat, alternatives to reducing diversion requirements in lieu of constructing more than 9 acre-feet of storage capacity, and participation in the "ongoing monitoring" provisions.

The USFS and ASC were able to clarify these disputed decisions elements with the release of an errata to the FEIS and ROD on November 7, 1994. The errata included revisions to the disputed tables and recognition that construction of a storage facility greater than 9 acre-feet may not be feasible but that other alternative, i.e., water conservation measures, may help reduce ASC diversion requirements.

With regard to the "ongoing monitoring" provisions, an additional paragraph was added to the ROD as follows:

> "If additional monitoring is undertaken, it should be directed by the Colorado Division of Wildlife, which has responsibility for recommending instream flows in Colorado. Further, it should incorporate additional and appropriate controls to minimize the possibility that changes in habitat or populations caused by other factors are attributed to snowmaking. Any additional off-site mitigation directly related to instream flow levels will be generated through governing procedures of the Colorado Water Conservation Board. While ASC will participate in the recommended monitoring, the level of such participation will be at the discretion of ASC. Such participation is intended to ensure efficient and effective use of ASC's previous studies, and ASC's financial contribution, if any, will be at the level it deems appropriate."

Walsh Aquatic Consultants Report

"The Winter Ecology of Trout in Snowmass Creek, Colorado" was prepared by Walsh Aquatic Consultants for the Snowmass/Capitol Creek Caucus. The report was released in December 1995 and it focuses on over-winter stream conditions in Snowmass Creek between November 1994 and March 1995. Stream discharge, water temperature, and ambient air temperature data were collected over this time period. The authors also report on changes in water velocities and water depths at brown and brook trout redds between spawning (November 1994) and incubation (December 1994 through March 1995) and on underwater visual observations of adult brown and brook trout from six winter habitats.

Walsh found that mean monthly, maximum daily, and minimum daily streamflows in Snowmass Creek between November 1994 and March 1995, as recorded at the SWSD diversion, were as follows:

Mean, Maximum, and Minimum Daily Streamflows in Snowmass Creek at SWSD Diversion.

Month	Mean Daily Flow (cfs)	Max. Daily Flow (cfs)	Min. Daily Flow (cfs)
November 1994	16.20	20.00	8.20
December 1994	13.60	20.90	9.80
January 1995	10.70	23.60	5.40
February 1995	8.90	17.70	5.10
March 1995	12.40	20.80	6.70

Between November 1994 and February 1995, mean daily water temperature in Snowmass Creek immediately below the SWSD diversion fluctuated between 0° C (32°F) and 2.5°C (36.5°F). The minimum daily water temperature, -0.3°C (31.6°F), occurred on January 22, 1995.

To evaluate trout spawning, Walsh divided Snowmass Creek into two stream reaches based upon differences in valley bottom, stream gradient, substrate, and riparian corridor. The upper 1.8 mile stream segment, located immediately downstream of the SWSD diversion, was characterized as a narrow U-shaped valley with a conifer riparian zone, large to medium cobble/intermittent gravel substrate, and stable stream banks with some pool habitats. The lower 3.4 mile reach was characterized by a wide U-shaped depositional valley with a cottonwood/willow riparian corridor, unstable/eroded streambanks, and fast riffle habitats. Walsh located 23 trout redds within the upper stream segment and 13 redds within the lower stream segment. Thirteen of the redds located within the upper stream segment were situate just downstream of the SWSD diversion.

Walsh quantified the physical characteristics of trout redds observed in Snowmass Creek during November 1994. Most redds were constructed near cover and were typically located in side channels, backwaters, or braided stream sections. With the exception of redd width, Walsh found no significant differences between trout redds in the upper and lower stream segments. Walsh suggests that water depth and water velocity measurements that were taken to characterize "preferred" spawning characteristics are conservative estimates because the trout had actually spawned earlier in the season when streamflows were probably greater and, therefore, velocities and depths would have most likely been greater.

Water depth and water velocity measurements were taken at "Upstream", "Redd Pit", and "Tailspill" locations for each of the redds quantified in the study. Measurements taken in November were used to characterize spawning characteristics. Average water depths and water velocities at the three measurement locations during spawning (November 1994) were as follows:

Water Depths and Water Velocities at Trout Redds in November 1994 (Spawning).

Location	Average Water Depth (inches)	Average Water Velocity (ft/sec)
Upstream	6.6	0.55
Redd Pit	6.6	0.72
Tailspill	4.1	0.92

Measurements were also taken throughout the remainder of the study period to characterize incubation conditions at the redds. In general, water depth and water velocity decreased at the redds as streamflow decreased over the winter baseflow period. The lowest streamflow occurred in February 1995 and resulted in the following average water depths and water velocities at the three measurement locations:

Water Depths and Water Velocities at Trout Redds in February 1995 (Incubation).

Location	Average Water Depth (inches)	Average Water Velocity (ft/sec)
Upstream	5.1	0.32
Redd Pit	5.3	0.32
Tailspill	2.9	0.47

Based upon a statistical analysis of the trout redd data, Walsh concluded that reductions in streamflow over the winter period caused significant reductions in water depth and water velocity near trout redds.

Measurements were also taken to quantify and compare substrate composition at the trout redds between spawning and incubation. The results of this analysis indicate that the percentage of fine substrate materials (≤0.18") increased significantly from 11.1% in November 1994 to 28.9% in February 1995.

Walsh did not identify significant changes in adult winter habitat attributes or in the abundance of adult trout between November 1994 and March 1995.

Walsh presents two analyses to develop the conclusion that water depths and velocities fall to unacceptable levels during the winter months in Snowmass Creek. The first analysis utilizes published spawning habitat suitability curves for brook trout and brown trout to estimate potential impacts of reducing streamflows. He states that optimum spawning velocities for brown trout and brook trout range from 0.68-1.67 ft/sec and 0.60-1.18 ft/sec, respectively. Walsh infers that optimum incubation velocities are identical to optimum spawning velocities and concludes that incubation velocities fell as much as 52%-92% below optimum during the month of February 1995.

Walsh also used a "binary criteria" analysis to support the contention that water depths and velocities fall to unacceptable levels over winter in Snowmass Creek. The binary criteria analysis compared 1994 incubation velocities against 1995 spawning velocities. Under this analysis, water velocity data collected on redds that were spawned during the fall of 1995 were ranked and divided into three categories; the central 50%, 75%, and 95%. The range that included the central 50% of these spawning velocities was labeled "optimum" spawning velocity. Likewise, the central 75% and 95% were labeled "suitable" and "usable" habitat, respectively. The resulting "optimum", "suitable", and "usable" velocity ranges for redd tailspills in 1995 were as follows:

Optimum, Suitable, and Usable Spawning Velocity Ranges from 1995 dataset.

	Lower Range (ft/sec)	Upper Range (ft/sec)
Optimum (Central 50%)	0.90	1.44
Suitable (Central 75%)	0.74	1.72
Usable (Central 95%)	0.60	2.30

By comparing the 1994-95 incubation velocities against these 1995 spawning velocity ranges, Walsh concluded that streamflows during the months of January 1995 (10.7 cfs) and February 1995 (8.9 cfs) were insufficient to maintain "usable" pit velocities.

Walsh states that survival of salmonid eggs during incubation may be limited by reductions in water velocity because (1) oxygen may not be delivered and metabolic wastes may not be carried out of the redds and (2) alevins may be trapped during emergence by increased sediment deposition. However, he goes on to suggest that reductions in oxygen and metabolic waste transport are not likely to be a problem in Snowmass Creek because low over-winter water temperatures reduce the metabolic requirements of the developing embryos.

With regard to changes in over-winter habitat for adult trout in Snowmass Creek, Walsh concludes that "the changes observed with decreasing velocities and flow during the winter period did not seem to affect the trout abundance or density during the study."

The general conclusions of "The Winter Ecology of Trout in Snowmass Creek, Colorado" are:

(1) Trout populations in Snowmass Creek are potentially limited by the quality of the incubation and emergence habitat conditions,

(2) Changes in water depth and or formation of anchor ice over the trout redds did not seem to be a problem for trout redds,

(3) Comparing incubation habitat utilization data with reported habitat suitability curves revealed highly significant decreases in velocity attributes,

(4) Comparing incubation velocity data from 1994-95 to spawning velocity data from fall 1995 indicated low winter streamflows in January and February did not maintain

"usable" pit velocities in trout redds.

(5) Spring runoff may limit fry survival and subsequent recruitment,

(6) Reductions to redd velocity habitat conditions from declining streamflows will proportionally increase the ecological risks to the Snowmass Creek trout population.

Summary of Hydrologic Studies

CWCB Staff's Hydrologic Analyses

On April 3, 1992, the CWCB staff used the equations provided in USGS Water Resources Investigations Report 85-4086 to develop synthetic hydrographs for the three proposed segments of Snowmass Creek. The USGS report uses average basin elevation, average annual precipitation, and basin area to predict mean monthly streamflows in the mountainous regions of Colorado. Based upon this analysis, the mean monthly flows from September through April for each of these segments were:

USGS WRIR 85-4086 Flow Estimates for Snowmass Creek

Month	Upper Segment (at West Snowmass Ck. confluence)	Middle Segment (at SWSD Weir)	Middle Segment (at Capitol Ck. confluence)	Lower Segment (at Roaring Fork River confluence) ▲
September	20.3	19.2	21.8	25.2
October	13.8	14.9	18.2	22.8
November	9.2	10.9	14.2	18.8
December	6.8	8.3	11.0	14.8
January	5.7	7.0	9.3	12.7
February	5.2	6.7	9.1	12.8
March	5.0	7.4	10.9	16.4
April	13.2	19.8	32.2	52.1

This synthetic hydrology indicates that 12 cfs may not be available in the upper and middle segments of Snowmass Creek. The CWCB's WRIR 85-4086 discharge estimates were the most conservative of all the hydrologic techniques considered.

The CWCB staff also evaluated the State Engineer's Water Rights Tabulation and met with Water Division 5 Assistant Engineer Alan Martellaro and District 38 Water Commissioner Joe Bergquist to determine the quantity of water legally available for the CWCB's instream flow appropriation. Based on these analyses and discussions, the CWCB staff determined that water was physically and legally available to satisfy the biologic recommendations being proposed by CDOW.

Wright Water Engineers' Hydrologic Study

On April 17, 1992, the CWCB staff received a copy of a WWE engineering report that was prepared for the SWSD. The report indicated that a gaging station had been operated on Snowmass Creek from October 1910 to November 1913 and that this three-year period of record was reflective of higher than average water years. The report also stated that SWSD had installed a concrete weir on Snowmass Creek prior to 1980 and that a staff gage on the weir was read three to four times per month over a three year period. The report suggested that these readings were not extremely accurate because of sediment accumulation and icing problems at the weir.

Due to the absence of reliable streamflow records on Snowmass Creek, WWE correlated unit runoff with several different hydrologic parameters. They found that tributary area provided the best correlation with stream discharge. Based on this finding, WWE apportioned gage records from Maroon Creek, over the period from 1970 to 1989, to estimate the streamflow in Snowmass Creek at the SWSD weir. Mean monthly flows from the WWE report were:

WWE Flow Estimates for Snowmass Creek

Month	Middle Segment (at SWSD Weir)
September	52
October	32
November	23
December	18
January	18
February	16
March	15
April	18

WWE also provided a summary of the winter staff gage readings at the SWSD weir. In general, WWE's Snowmass Creek streamflow estimates were more liberal than those derived by the CWCB staff using the USGS WRIR 85-4086 report.

USFS EIS Hydrologic Study

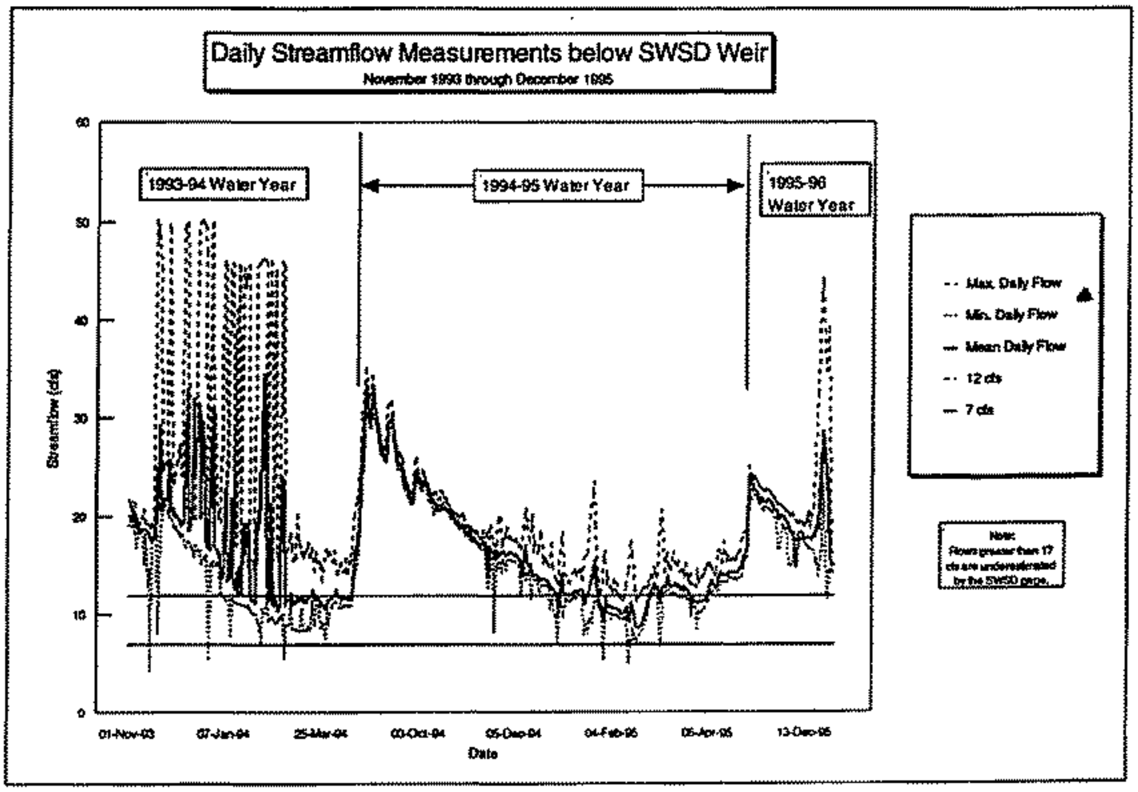
The USFS used a regression technique similar to that employed by WWE to develop a synthetic hydrograph for use in the Snowmass Ski Area EIS. The USFS EIS also evaluated the Snowmass Creek streamflow estimates generated by the CWCB and WWE within the EIS. The USFS estimates of mean monthly streamflow during the winter months were similar to those generated by WWE.

USFS EIS Flow Estimates for Snowmass Creek

Month	Middle Segment (at SWSD Weir)
September	46
October	34
November	25
December	20
January	16
February	15
March	14
April	17

Recent Stream Gaging Efforts On Snowmass Creek

The CWCB staff has recently received stream gaging records from November 1993 through December 1995 which were collected by SWSD at its Snowmass Pipeline diversion structure. Variability is high within and between daily flow readings.



In general, the mean monthly flow measurements at the SWSD diversion for these two winter periods fall between the conservative streamflow estimates generated by the CWCB's synthetic techniques and the more liberal streamflow estimates generated by the USFS and WWE regression analyses.

SWSD Mean Monthly Stream Gage Records for Snowmass Creek
(November 1993 through December 1995)

Month	Middle Segment (below SWSD Weir)
September	26.6
October	21.2
November	19.3
December	18.6
January	14.6
February	13.5
March	12.0
April	15.3

It is difficult to draw definitive conclusions from only two years of stream gaging records. In an attempt to put the SWSD flows in perspective, the CWCB staff evaluated monthly flow exceedances on the Maroon Creek gage from November 1993 through April 1994 and found that the mean monthly flows during this 6-month period were exceeded only 10% to 50% of the time over the 1969 to 1993 period of record on Maroon Creek. This analysis suggests that SWSD's flow measurements over the 1993-94 winter period reflect wetter than average winter flow conditions in Snowmass Creek. A similar analysis may be performed for the 1994-95 winter flow records as soon as USGS gage records on Maroon Creek become available.

The Walsh report also presents some new hydrologic data on Snowmass Creek. Walsh uses daily readings of a staff gage installed on the Ziegler Bridge, located approximately 0.75 miles downstream of the SWSD diversion structure, to identify changes in flow patterns and flow dynamics between the SWSD diversion and the Ziegler Bridge. His analysis affirms that Snowmass Creek is a gaining stream between these two points and that the amount of the gain varies between months. The greatest amount of gain occurs during the month of November and the least amount of gain occurs between February and March.

Discussion

On September 15, 1992, the CWCB used all of the biologic evidence presented within the CDOW, Chadwick, Miller, and Chapman reports and the hydrologic studies presented by the CWCB staff and WWE to make its determination to modify the Snowmass Creek instream flow water right. The Recommendation Summary Reports which were provided to the Board at that time are attached at the end of this memo.

The USFS EIS, the Walsh report, and the SWSD gaging records were developed subsequent to the 1992 decision to modify. These reports provide some additional biologic and hydrologic information regarding winter flow requirements and water availability within the middle and lower stream segments of Snowmass Creek.

CDOW's biologic recommendations for modification on Snowmass Creek were based on a standard application of the R2CROSS methodology. The CWCB has used the R2CROSS methodology as the basis for the vast majority of its instream flow appropriations on coldwater streams throughout the state. The R2CROSS methodology uses a standard setting approach that results in a distinct instream flow recommendation. Applying a uniform biologic standard to instream flow recommendations helps to maintain a statewide level of consistency in instream flow appropriations.

The Chadwick and Miller reports both supported CDOW's recommendations for modification. The Chapman report indicated that their additional cross section information "mathematically corroborated" CDOW's flow recommendations.

The USFS EIS and ROD did not develop an independent instream flow recommendation on Snowmass Creek. Rather, the ROD made reference to the CWCB's instream flow water right and required that ASC's withdrawals of water from Snowmass Creek for snowmaking purposes on USFS lands be limited to times when the streamflow in Snowmass Creek is at least 7 cfs. The ROD also required that diversions from Snowmass Creek for snowmaking purposes cease on December 31 of each year and that any water required for snowmaking after that time come from storage rather than directly out of Snowmass Creek.

The USFS EIS evaluated the potential impacts of reducing the streamflow from 12 cfs down to 7 cfs in Snowmass Creek immediately below the SWSD diversion structure. This analysis led to the conclusion that such a reduction would have an impact on certain life stages of trout in Snowmass Creek but it did not suggest that a winter flow of 7 cfs would be insufficient to "preserve the natural environment to a reasonable degree."

The ROD recommended ongoing monitoring to evaluate the future impacts of reducing the streamflow to 7 cfs on a regular basis in the winter months and it proposed several mitigation alternatives that could be implemented to ameliorate impacts to the winter ecology of Snowmass Creek if future impacts of reducing the streamflow are greater than those predicted. The November 7, 1994, errata to the ROD clearly left "additional monitoring" to the direction of CDOW and "additional off-site mitigation directly related to instream flow levels" to the "governing procedures of the CWCB."

The Walsh report provided some valuable, site-specific information regarding changes in salmonid habitat conditions over the course of the winter in Snowmass Creek but it did not recommend an alternative instream flow scenario. Walsh indicates that as streamflows diminish during the winter months, water depths and velocities at trout redds decrease significantly and fine substrate materials may accumulate over trout redds. Walsh's study design, data collection methods, and data analyses are reasonable.

Walsh found that as streamflows decline, water depths and water velocities are reduced in Snowmass Creek. This finding is not particularly surprising given that, mathematically, stream discharge (Q) is defined as the product of velocity (V), depth (D), and width (W); i.e., (Q=V*D*W). Therefore, as streamflow is reduced, at least one of the other variables must also be reduced.

Based on this finding, Walsh goes on to conclude that reductions in streamflow, velocity, and depth may compromise successful egg incubation for fall spawning trout species. However, this conclusion is based upon several simplifying assumptions that may not be entirely appropriate.

Walsh first assumes that "data collected on trout redds during November are assumed to be representative of the best combination of microhabitat conditions available for trout spawning and therefore are assumed to be the optimum conditions for incubation." Similarly, he assumes that "trout embryo optima for velocity is the same as that selected by trout for spawning." Finally, Walsh concludes that "trout select the optimum habitat available for spawning and subsequent egg/fry survival and emergence."

Walsh's conclusion that reductions in streamflow, depth, and velocity result in "significant" reductions in incubation velocity attributes is based upon acceptance of the assumption that streamflows should remain constant between spawning in November and incubation throughout the remainder of the winter. This assumption is not likely to be satisfied in most mountain streams in Colorado.

In fact, streamflows in the majority of Colorado's undepleted mountain streams decline significantly between November and the remaining winter months. Trout have evolved to survive highly variable streamflow conditions, including reductions in streamflows throughout the winter months. If Walsh's assumption that streamflows should remain constant from November through April is true, it could be argued that the natural hydrology of most Colorado streams provides less than desirable habitat for egg incubation of fall-spawning trout species.

Walsh's binary analysis led him to conclude that trout redds were "unusable" for incubation purposes during January and February 1995. First, it should also be noted that under the terms and conditions of the USFS ROD, snowmaking withdrawals from Snowmass Creek will cease on December 31 of each year and, therefore, the lowest flow months of January, February, and March will not be impacted by snowmaking withdrawals. More importantly, these "unusable" incubation conditions resulted during "natural" flow conditions that were not, and will not be, impacted by future snowmaking withdrawals.

Second, Walsh's conclusion that trout redds were unusable was based upon the observation that water velocities near redds spawned in 1993-94 were significantly lower than the velocities trout selected for spawning purposes in the fall of 1995. This conclusion may be inappropriate because it requires acceptance of the assumption that trout either (1) selected identical velocities and depths for spawning in 1994 and 1995 even though streamflows at the time of spawning in 1994 may not have been the same as streamflows during the 1995 spawn or (2) that trout spawned in exactly the same locations in 1994 and 1995 and that the channel configuration did not change between years.

Finally, Walsh's conclusion is once again based upon the questionable assumption that hydraulic parameters for spawning and incubation should remain constant throughout the winter months. Under this assumption, an equally persuasive conclusion might be that increased withdrawals of water during spawning (November) would benefit egg incubation simply because the potential for reductions in streamflow, water depth, and velocity between spawning and incubation would be lessened.

Walsh's study also indicated that deposition of fine substrate material increases at lower flows and he surmised that increases in sediment deposition may have detrimental effects on egg incubation and alevin emergence. However, his data did not suggest that the amount of fine sediment deposition was excessive or sufficient to inhibit embryo development or alevin emergence. In fact, Page 4-55 of the Walsh report indicates that "trout fry were frequently observed during September (1995) surveys". On Page 5-17, Walsh states that "the presence of trout fry in these side channels was a significant finding." Walsh uses this observation to refute Chadwick's suggestion that extreme spring flows are more limiting than low winter flows on trout the populations in Snowmass Creek. However, Walsh's observation of trout fry in September 1995 also provides conclusive evidence that the 1994-95 winter flows in Snowmass Creek were adequate for incubation, development, and emergence without the need to rely on the results of studies which may be based on untested assumptions.

The Walsh report concludes that "reductions to redd velocity habitat conditions as shown by habitat suitability as a consequence of declining streamflows, will proportionally increase the ecological risks to the Snowmass Creek trout population." This conclusion is generally applicable to almost any environmental disturbance.

The newly gathered hydrologic information collected at the SWSD diversion structure indicates that, with the exception of February 1995, average monthly streamflows in Snowmass Creek immediately downstream of the SWSD diversion exceeded 12 cfs between November 1993 and December 1995. The average monthly flow in February 1995 was 10.4 cfs. Wintertime diversions in the stream segment between the SWSD diversion structure and the confluence with the Roaring Fork River are minimal. Based on this newly collected data, it can be assumed that, on average, streamflows were greater than 12 cfs from November 1993 through December 1995 within the middle and lower instream flow segments of Snowmass Creek.

Hydrologic studies contained within the USFS EIS also indicate that mean monthly flows exceed 12 cfs during the winter months in the middle segment of Snowmass Creek.

Walsh's summary of stream gaging on Snowmass Creek at the SWSD diversion structure and the Ziegler Bridge indicate that between November 1994 and March 1995, average monthly flows in the middle segment of Snowmass Creek exceeded 12 cfs during the months of November, December, and March. Flows during January 1995 and February 1995 were 10.7 cfs and 8.9 cfs, respectively.

Conclusion

In summary, CDOW has recommended that the CWCB's 12 cfs Snowmass Creek instream flow water right be segmented into three stream reaches and that each stream reach should have separate summer and winter flow recommendations. CDOW's recommendations are based on the same R2CROSS methodology that has been employed by the CWCB since the Instream Flow Programs inception in 1973. By using the R2CROSS methodology, instream flow recommendations on coldwater streams throughout the state have remained relatively uniform and consistent.

The other reports either critique the CDOW's recommendations or present the results from independent studies that have been conducted on Snowmass Creek. Several of the reports support CDOW's recommendations. None of the other reports suggest alternative instream flow recommendations or prove that CDOW's proposed instream flow modifications will not be sufficient to "preserve the natural environment to a reasonable degree".

Hydrologic studies indicate that water is available to satisfy the modifications proposed by CDOW.

Literature Cited

Bovee, K.D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper No. 4. U.S. Fish and Wildlife Service FWS/OBS-78/07. 80 pp.

Nehring, R.B. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado. Colorado Division of Wildlife. Fort Collins, CO.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information. Rainbow trout. U.S. Fish and Wildlife Service FWS/OBS-82/10.60. 64 pp.

Raleigh, R.F., L.D. Zuckerman, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves. Brown trout, revised. U.S. Fish and Wildlife Service FWS/OBS-82(10.124). 65 pp.

Tennant, D.L. 1976. Instream flow regimes for fish, wildlife, recreation and related environmental resources. Fisheries, 1(4)6-10.

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW RECOMMENDATIONS

RECOMMENDATION SUMMARY REPORT

STREAM: Snowmass Creek — ID: 5-W2943-76A
WATERSHED: Roaring Fork — DIV: 5 , COUNTY: Pitkin

RECOMMENDATION
FLOW (cfs): 9 (4/1-10/15) — LENGTH (miles): 5.9
4 (10/16-3/31)

UPPER TERMINUS: Snowmass Lake at
lat 39 07 03N long 107 01 47W

LOWER TERMINUS: confl W Snowmass Creek at
lat 39 11 24N long 107 00 57W

USGS QUADS: Snowmass Mtn, Capitol Pk

FISH SURVEY — DATE: 07/15/77
DOW CODE: 23444 LOCATION: u/s confl Bear Ck.
SAMPLE SUMMARY: 200 ft electrofished.
Sample included: 2 brook trout (7").

FIELD SURVEY — DATE: 09/19/75
CROSS SECTION LOCATION: 200 yds u/s W Snowmass Creek.
MEASURED FLOW (cfs): 31.68 GRASSLINE WIDTH (ft): 31.0 PHOTOS: 3
REMARKS: None.

HYDRAULIC ANALYSIS
AT RECOMMENDED
FLOW (cfs): 9 (4/1-10/15)
AVE DEPTH (ft): 0.44-0.47
% WET PERIM.: 30%-35%
AVE VEL. (fps): 1.83-1.93
REMARKS: 9 cfs meets depth and velocity criteria and maintains 34% wetted perimeter. Lower winter flow (4 cfs) meets depth and velocity criteria. These flows are required to protect the fishery in this stream reach.

WATER AVAILABILITY
METHOD: Synthesized from USGS method WRIR 85-4086 for Snowmass Creek.

AVERAGE MONTHLY FLOWS (cfs)

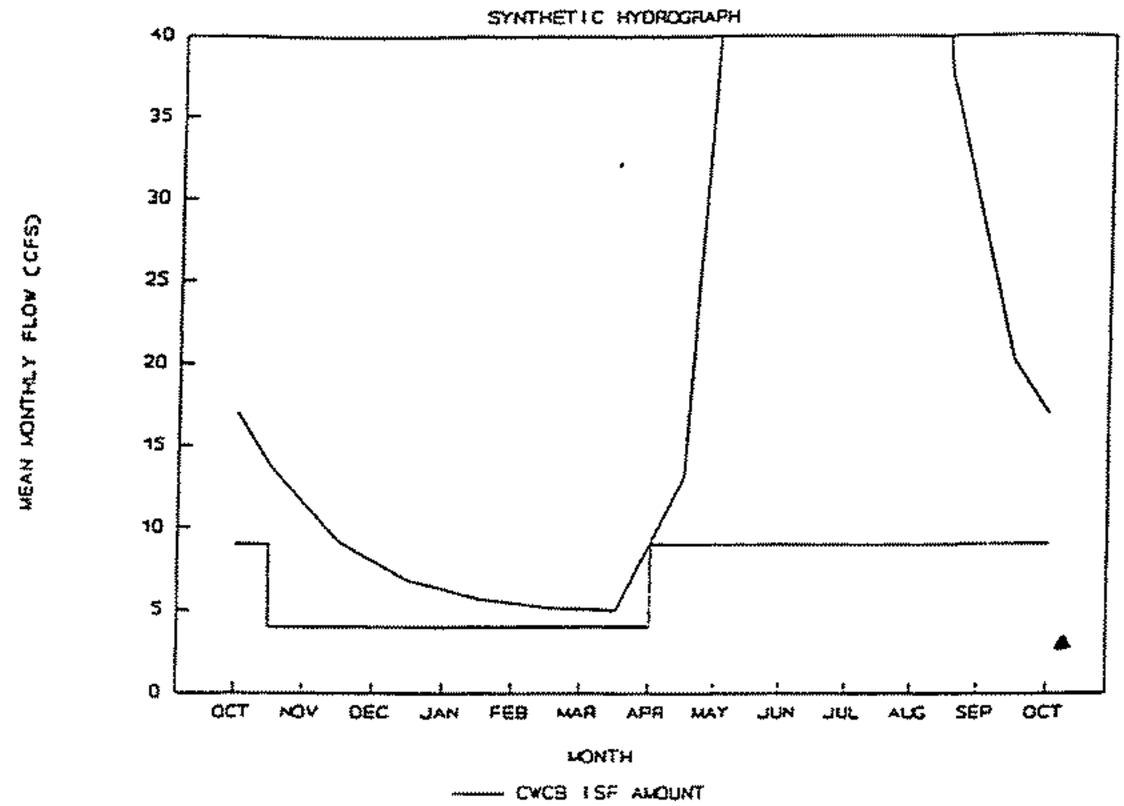
OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
13.83	9.16	6.81	5.70	5.21	4.98	13.65	72.87	186.9	90.89	37.86	20.32

IMPORTED WATER: None. TRANSBASIN DIVS: None.
INBASIN DIVERSIONS: Several senior rights within reach.
REMARKS: As per Assistant Division Engineer, senior rights do not present a water availability problem within this reach of Snowmass Creek.

CONSULTATIONS
DOW: Jay Skinner 04/01/92
DWR: Alan Martellaro 06/04/92

PREPARED BY: Espegren APPROVED BY: [signature] DATE: 9/14/92

Snowmass Creek, headwaters to West Snowmass Creek



The Snowmass Creek hydrograph was synthetically derived utilizing the methods outlined in the USGS Water Resources Investigations Report 85-4086.

SUMMARY

* The DOW has documented that a natural environment is present in the form of a brook trout fishery.

* The DOW has recommended that a flow of 9 cfs in the summer together with a flow of 4 cfs in the winter is necessary to preserve the natural environment to a reasonable degree.

* The CWCB staff has conducted a water availability analysis and determined these amounts are available for the Board's appropriation.

* The CWCB staff has determined that adequate water supplies exist such that the natural environment may be preserved without limiting or foreclosing the exercise of valid existing water rights.

USGS QUADS:

FISH SURVEY

DOW CODE: 23444 LOCATION: 130 yds d/s

SAMPLE SUMMARY: 300 ft electrofished.

Sample included: 6 brown trout (10"-14")

1 sculpin (4").

DATE: 10/23/91

FIELD SURVEY

CROSS SECTION LOCATION: 130 yds d/s Snowmass WSD wier.

MEASURED FLOW (cfs): 20.10 GRASSLINE WIDTH (ft): 42.09 PHOTOS: 3

REMARKS: None.

HYDRAULIC ANALYSIS

AT RECOMMENDED

FLOW (cfs): 15 (4/1-10/15)

AVE DEPTH (ft): 0.40-0.44

% WET PERIM.: 59%-60%

AVE VEL. (fps): 1.48-1.59

REMARKS: 15 cfs meets 3 of 3 criteria. Lower winter flow (7 cfs) meets meets velocity and wetted perimeter criteria. These flows are required to protect the fishery in this stream reach.

WATER AVAILABILITY

METHOD: Synthesized from USGS method and Maroon Creek regression.

AVERAGE MONTHLY FLOWS (cfs)

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
18.24	14.15	10.96	9.32	9.13	10.85	32.21	136.9	214.4	71.51	35.00	21.78

IMPORTED WATER: None. TRANSBASIN DIVS: Snowmass WSD.

INBASIN DIVERSIONS: Several senior rights within reach.

REMARKS: As per Assistant Division Engineer, senior rights do not present a water availability problem within this reach of Snowmass Creek.

CONSULTATIONS

DOW: Jay Skinner 04/01/92

DWR: Alan Martellaro 06/04/92

DRAFT

PREPARED BY: Espegren APPROVED BY: [signature] DATE: 9/14/92

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW RECOMMENDATIONS

RECOMMENDATION SUMMARY REPORT

STREAM: Snowmass Creek — ID: 5-W2943-76B
WATERSHED: Roaring Fork — DIV: 5 , COUNTY: Pitkin

RECOMMENDATION
FLOW (cfs): 15 (4/1-10/15) — LENGTH (miles): 11.3
7 (10/16-3/31)

UPPER TERMINUS: confl W Snowmass Creek at lat 39 11 24N long 107 00 57W

LOWER TERMINUS: confl Capitol Creek in NW4 SE4 S34 T8S R86W 6PM

USGS QUADS: Capitol Pk, Highland Pk, Woody Ck

FISH SURVEY — DATE: 10/23/91
DOW CODE: 23444 LOCATION: 130 yds d/s Snowmass WSD weir.
SAMPLE SUMMARY: 300 ft electrofished.
Sample included: 6 brown trout (10"-14"); 6 brook trout (8"-11"); 1 sculpin (4").

FIELD SURVEY — DATE: 10/23/91
CROSS SECTION LOCATION: 130 yds d/s Snowmass WSD wier.
MEASURED FLOW (cfs): 20.10 GRASSLINE WIDTH (ft): 42.09 PHOTOS: 3
REMARKS: None.

HYDRAULIC ANALYSIS
AT RECOMMENDED
FLOW (cfs): 15 (4/1-10/15)
AVE DEPTH (ft): 0.40-0.44
% WET PERIM.: 59%-60%
AVE VEL. (fps): 1.48-1.59
REMARKS: 15 cfs meets 3 of 3 criteria. Lower winter flow (7 cfs) meets meets velocity and wetted perimeter criteria. These flows are required to protect the fishery in this stream reach.

WATER AVAILABILITY
METHOD: Synthesized from USGS method and Maroon Creek regression.

AVERAGE MONTHLY FLOWS (cfs)

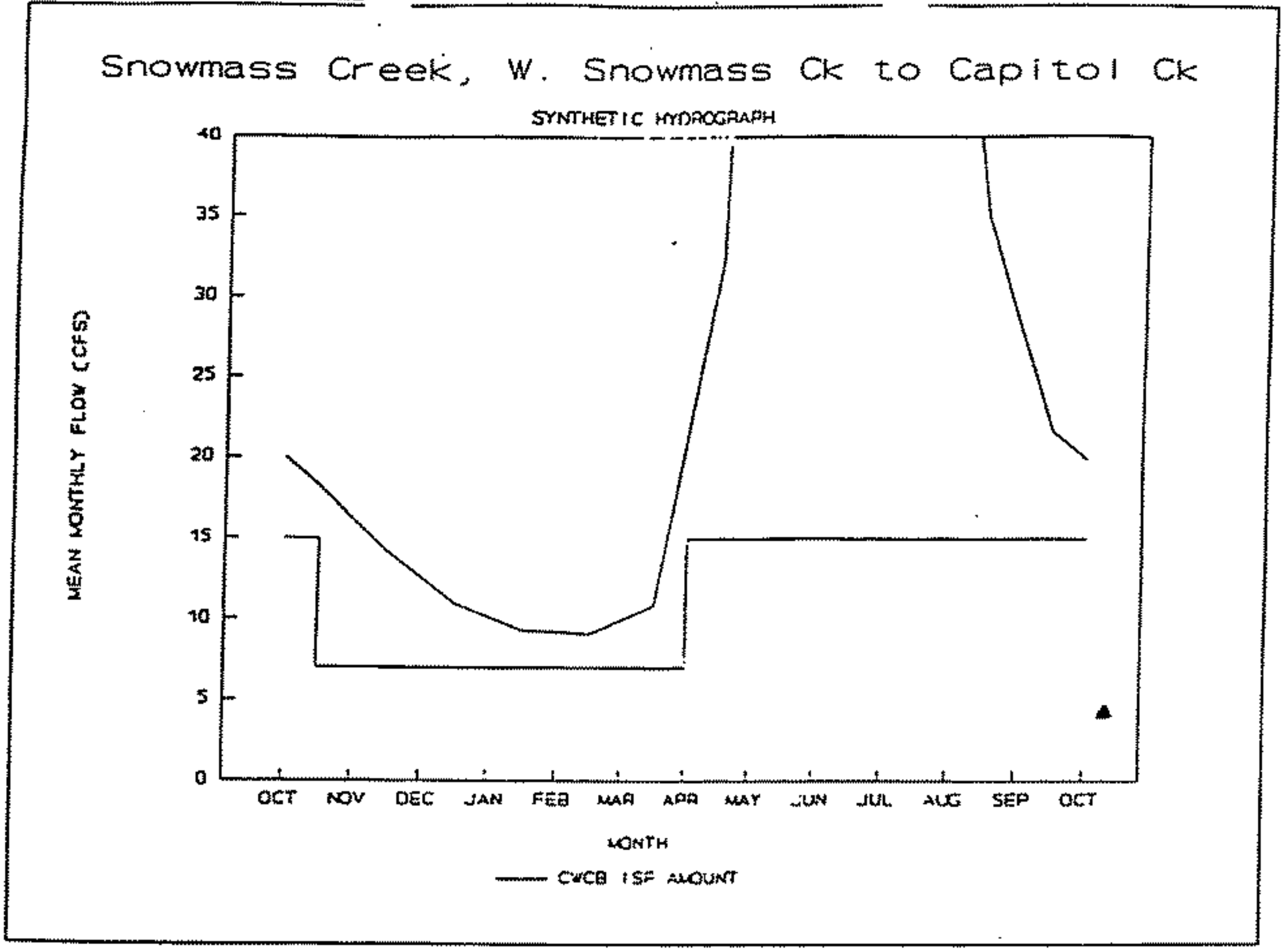
OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
18.24	14.15	10.96	9.32	9.13	10.85	32.21	136.9	214.4	71.51	35.00	21.78

IMPORTED WATER: None. TRANSBASIN DIVS: Snowmass WSD.
INBASIN DIVERSIONS: Several senior rights within reach.
REMARKS: As per Assistant Division Engineer, senior rights do not present a water availability problem within this reach of Snowmass Creek.

CONSULTATIONS
DOW: Jay Skinner 04/01/92
DWR: Alan Martellaro 06/04/92

DRAFT

PREPARED BY: Espegren APPROVED BY: [signature] DATE: 9/14/92



The Snowmass Creek hydrograph was synthetically derived utilizing the methods outlined in the USGS Water Resources Investigations Report 85-4086.

SUMMARY

* The DOW has documented that a natural environment is present in the form of naturally reproducing brook and brown trout fisheries.

* The DOW has recommended that a flow of 15 cfs in the summer together with a flow of 7 cfs in the winter is necessary to preserve the natural environment to a reasonable degree.

* The CWCB staff has conducted a water availability analysis and determined these amounts are available for the Board's appropriation.

* The CWCB staff has determined that adequate water supplies exist such that the natural environment may be preserved without limiting or foreclosing the exercise of valid existing water rights.

DRAFT

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW RECOMMENDATIONS

RECOMMENDATION SUMMARY REPORT

STREAM: Snowmass Creek — ID: 5-W2943-76C
WATERSHED: Roaring Fork — DIV: 5 , COUNTY: Pitkin

RECOMMENDATION
FLOW (cfs): 22.5 (4/1-10/15) — LENGTH (miles): 1.4
11 (10/16-3/31)

UPPER TERMINUS: confl Capitol Creek in
NW4 SE4 S34 T8S R86W 6PM

LOWER TERMINUS: confl Roaring Fork River in
SE4 NW4 S27 T8S R86W 6PM

USGS QUADS: Woody Ck

FISH SURVEY — DATE: 07/15/77
DOW CODE: 22056 LOCATION: 0.5 mi u/s Old Snowmass.
SAMPLE SUMMARY: 400 ft electrofished.
Sample included: 12 rainbow trout (8"-11"); 7 brown trout (4"-11"

FIELD SURVEY — DATE: 03/23/92
CROSS SECTION LOCATION: 0.7 mi u/s Roaring Fork River.
MEASURED FLOW (cfs): 21.99 GRASSLINE WIDTH (ft): 41.61 PHOTOS: 3
REMARKS: None.

HYDRAULIC ANALYSIS
AT RECOMMENDED
FLOW (cfs): 22.5 (4/1-10/15)
AVE DEPTH (ft): 0.60-0.64
% WET PERIM.: 88%-89%
AVE VEL. (fps): 0.99-1.04
REMARKS: 22.5 cfs meets 3 of 3 criteria. Lower winter flow (11 cfs) meets depth and wetted perimeter criteria. These flows are required to protect the fishery in this stream reach.

WATER AVAILABILITY
METHOD: Synthesized from USGS method WRIR 85-4086 for Snowmass Creek.

AVERAGE MONTHLY FLOWS (cfs)

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
22.76	18.80	14.81	12.69	12.76	16.39	52.09	200.1	249.1	73.11	38.40	25.21

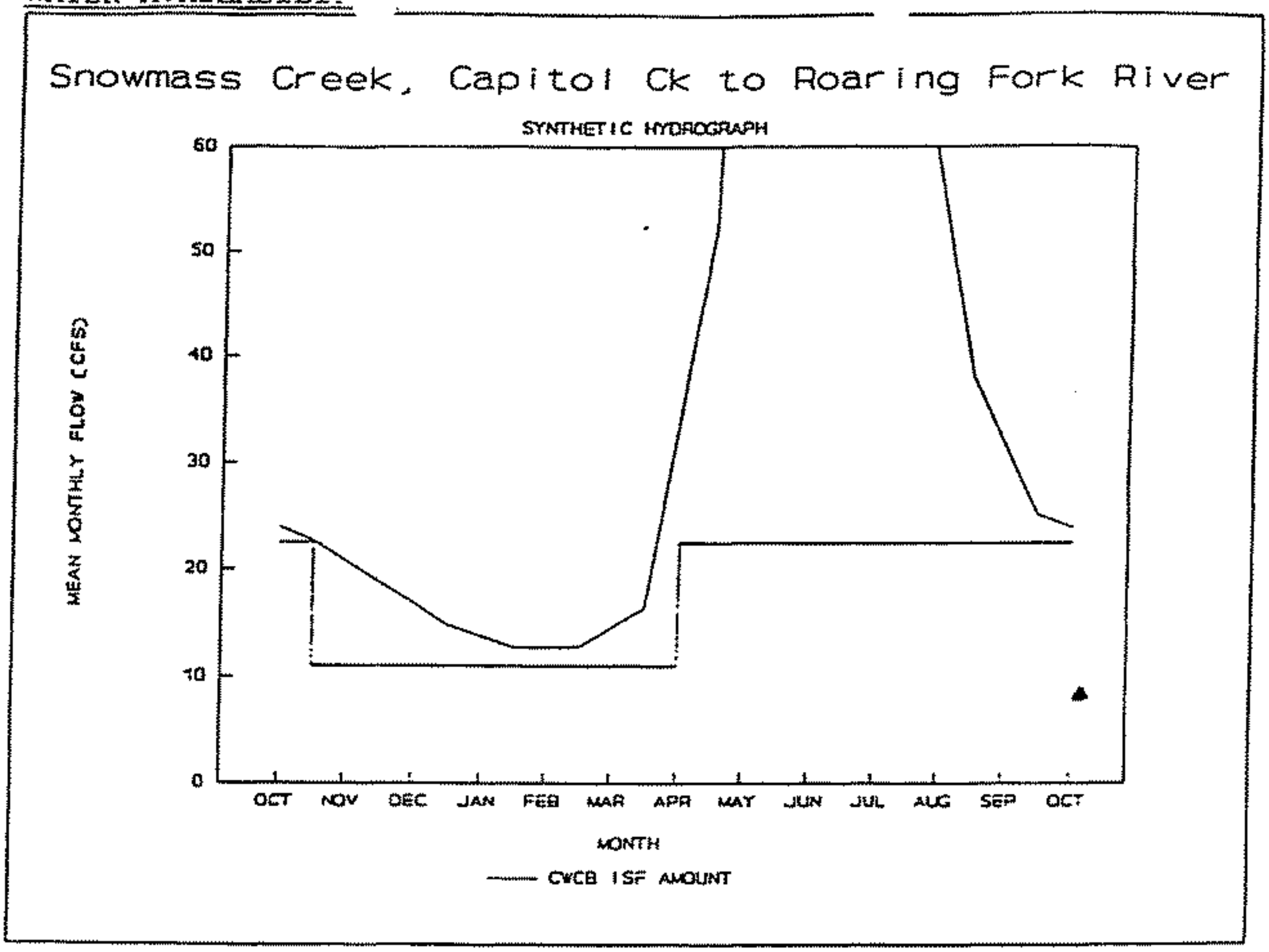
IMPORTED WATER: None. TRANSBASIN DIVS: None.
INBASIN DIVERSIONS: Several senior rights within reach.
REMARKS: As per Assistant Division Engineer, senior rights do not present a water availability problem within this reach of Snowmass Creek.

CONSULTATIONS
DOW: Jay Skinner 04/01/92
DWR: Alan Martellaro 06/04/92

DRAFT

PREPARED BY: Espegren APPROVED BY: [signature] DATE: 9/14/92

CCB 000148



The Snowmass Creek hydrograph was synthetically derived utilizing the methods outlined in the USGS Water Resources Investigations Report 85-4086.

SUMMARY

* The DOW has documented that a natural environment is present in the form of a naturally reproducing brown trout fishery and a rainbow trout fishery.

* The DOW has recommended that a flow of 22.5 cfs in the summer together with a flow of 11 cfs in the winter is necessary to preserve the natural environment to a reasonable degree.

* The CWCB staff has conducted a water availability analysis and determined these amounts are available for the Board's appropriation.

* The CWCB staff has determined that adequate water supplies exist such that the natural environment may be preserved without limiting or foreclosing the exercise of valid existing water rights.

DRAFT

GREG ESPEGREN

Senior Water Resource Specialist
Colorado Water Conservation Board
1313 Sherman Street, Room 721
Denver, CO 80203
(303) 866-3441

EXPERIENCE

COLORADO WATER CONSERVATION BOARD - Denver, CO. April 1990 to Present.
Senior Water Resource Specialist responsible for hydrologic, hydraulic, and water rights investigations relating to the administration of Colorado's Instream Flow Program. Also responsible for development, documentation, and technical support of CWCB's R2CROSS computer program.

COLORADO DIVISION OF WILDLIFE - Montrose, CO. January 1989 to April 1990.
Research Associate working with R. Barry Nehring to verify transferability of rainbow trout and brown trout habitat suitability curves between rivers. Became proficient in the use of the Instream Flow Incremental Methodology and the Physical Habitat Simulation System. Published CDOW Special Report Number 67.

COLORADO STATE UNIVERSITY - Fort Collins, CO. January 1987 to January 1989.
Graduate Research Assistant working on a CDOW-sponsored project to develop a new technique for quantitative sampling and numeric estimation of trout populations within the pelagic zone of high mountain lakes. Conducted an in-lake experiment to evaluate gear performance and estimator bias and precision. Met scholastic requirements for Masters degree and worked as a Graduate Teaching Assistant consulting with faculty and fellow graduate students on all computer-related questions and problems that arose within the Fish and Wildlife Department.

COLORADO DIVISION OF WILDLIFE - Montrose, CO. July 1986 to December 1986.
Field Assistant on CDOW research project designed to assess the effects of special angling regulations on trout populations in Colorado rivers.

LAND SURVEYING AND ENGINEERING - Grand Junction, CO. January 1977 to July 1986.
Registered Colorado Land Surveyor supervising several survey crews on land development and cadastral survey projects throughout western Colorado.

EDUCATION

M.S. Fishery Biology - 1989. Colorado State University.
B.S. Fishery Biology - 1976. Colorado State University.

PUBLICATIONS

- Espegren, G.D. 1996. Development of Instream Flow Recommendations in Colorado Using R2CROSS. CWCB Special Report.
- Espegren, G.D., D.D. Miller, and R.B. Nehring. 1990. Modeling the Effects of Various Angling Regulations on Trout Populations in Colorado Streams. CDOW Special Report Number 67.
- Espegren, G.D. and E.P. Bergersen. 1990. Quantitative Sampling of Fish Populations with a Mobile Rising Net. North American Journal of Fisheries Management. 10:469-478.

SHORT COURSES AND SEMINARS

University of Colorado at Denver - Western Water Rights and Water Engineering. 1991.
U.S. Fish and Wildlife Service - Instream Flow Incremental Methodology course work. 1988.

LICENSES AND CERTIFICATES

Professional Colorado Land Surveyor #18452.

DRAFT

MEMBERSHIPS

American Fisheries Society
Trout Unlimited

WINTER ECOLOGY OF TROUT: IMPLICATIONS FOR SNOWMASS CREEK

Prepared for

Snowmass/Capitol Creek Caucus
11000 Snowmass Creek Road
Snowmass, CO 81654

Prepared by

T. W. Hillman
D. W. Chapman

Don Chapman consultants inc.

3653 Rickenbacker, Ste 200 • Boise, Idaho 83705
(208) 383-3401 • FAX (208) 344-4861

FEBRUARY 1996

TABLE OF CONTENTS

WINTER ECOLOGY OF TROUT: IMPLICATIONS FOR SNOWMASS CREEK

The Aspen Ski Corporation has expressed a desire to purchase water at the Snowmass Water and Sanitation District (SWSD) diversion during October through March, thus reducing the winter minimum instream flow in some periods. Both the Colorado Division of Wildlife (CDOW) and the Aspen Ski Corporation (ASC) support a minimum flow of 7 cubic feet per second (cfs) during winter. The CDOW estimated minimum flow using the R-2 Cross method, while the ASC used the physical habitat simulation system (PHABSIM) component of the instream flow incremental methodology (IFIM). In this report we show that these methods should not be used to assess minimum streamflows for trout in "ice-covered streams"[1] such as Snowmass Creek during winter. In fact, at this time there are no hydraulic or habitat models available that can adequately assess minimum winter streamflows for trout in ice-covered streams (Prowse and Gridley 1993).

Because models should not be used to assess minimum winter flows for trout in ice-covered streams, a detailed understanding of the winter requirements of trout during winter is essential before one can assess minimum winter flows for trout. In addition, a thorough understanding of ice processes and how stream ice impacts suitable winter habitat of trout is also necessary. Therefore, in this report we review the winter habitat characteristics and the winter behavior and mortalities of selected stream fishes, particularly brown trout, rainbow trout, and brook trout because they live in Snowmass Creek during the winter. Our goal is to identify critical characteristics of winter habitat. In addition we discuss the impacts of stream ice on trout habitat. There has been some testimony that indicates that reduced streamflows will have no influence on icing conditions in Snowmass Creek. We will show that this is incorrect. We use this information to assess impacts of winter flow reductions on trout in Snowmass Creek. We do not

[1] "Ice-covered streams" are streams in which surface and/or subsurface ice form.

review in any detail winter feeding habits, winter metabolism and energetics, and winter habitat of pre-emergent fish (i.e., overwintering alevins[2] and eggs). The latter is reviewed in a separate document by Walsh and Walsh (1995).

We organized this report into five major components: (1) review of the winter ecology of trout in streams, (2) effects of stream ice on the winter habitat of trout, (3) effects of reduced winter streamflows on trout, (4) ability of models to predict winter conditions for trout in ice-covered streams, and (5) conclusions and recommendations. We believe that it is important first to describe the behavior, habitat use, and mortalities of trout during winter. We then describe ice processes, its effects on trout habitat, and effects of reduced flows on ice formation and trout habitat. This information is important for two reasons: (1) it will show that trout do not use the same microhabitat in winter as they do during warmer seasons and (2) that stream ice and reduced flows profoundly affect winter habitat used by trout in ice-covered streams like Snowmass Creek (an effect that cannot be simulated with models). Next we show that models such as R-2 Cross and PHABSIM should not be used to assess minimum streamflows for trout in Snowmass Creek during winter. To rely on such methods could seriously impact trout populations in ice-covered streams. Finally, we bring together all this information to establish a minimum winter flow that we believe will protect to a reasonable degree the natural environment of Snowmass Creek.

WINTER ECOLOGY OF TROUT

In this section we describe the winter behavior, habitat use, and mortalities of trout in ice-covered streams like Snowmass Creek. After reviewing this section, the reader will understand why the habitat curves used in PHABSIM and R-2 Cross are not appropriate for modeling changes during winter in Snowmass Creek. This section should also provide the background information necessary to establish

[2]Alevins or sac fry are newly hatched fish that still possess a yolk sac. They are known as fry after the yolk sac is absorbed and the alevins emerge from the gravel.

appropriate minimum flows for trout in Snowmass Creek.

Before we describe the winter ecology of trout, we need to define "winter." Winter is the period from egg deposition by autumn-spawning salmonids (and coincident with a decline in water temperature) to the loss of all surface ice (often accompanied by snowmelt), and before any reproductive activity by spring-spawning fish.[3] According to Cunjak (in press), this definition has more biological relevance than one that follows calendar dates. Because Snowmass Creek is subject to near-freezing temperatures (<1°C or <34°F) and ice-formation during the winter, we reviewed studies conducted in streams subject to those winter conditions.

Winter Behavior

When water temperatures decline below about 10°C (50°F), salmonids change behavior from mostly feeding and defending territories to hiding and schooling (Bjornn and Reiser 1991; Hillman et al. 1992). This involves movement to areas with low water velocities (<15-17 cm/s or <0.49-0.56 ft/s) and extensive cover (e.g., shallow, quiet areas along the streambanks, backwaters, pools, beaver ponds and side channels). Heggenes et al. (1993), who studied the winter ecology of brown trout in streams much like Snowmass Creek, describe this change in behavior and habitat selection as an "ecologically adaptive homeostatic response." That is, trout respond to adverse conditions (e.g., colder water temperatures and ice) by selecting habitats that minimize energy loss. This adaptation increases the overwinter survival of trout because at cold temperatures (<10°C or 50°F) trout cannot assimilate energy as quickly and efficiently as they do at warmer temperatures (Brett 1964; Brett and Glass 1973). The speed of digestive enzymatic action at low temperatures limits metabolism, especially the rate and efficiency of food digestion and assimilation. It follows, then, that even if the digestive tract were full, limited energy would be available for metabolism in

[3]In Snowmass Creek, brown trout and brook trout spawn in the autumn; rainbow trout spawn in the spring.

the winter. Contor (1989) notes that when temperatures drop below 4°C (39°F), trout that increase activity beyond "resting" must break down body tissue for supplemental energy even if they maintain a full digestive tract. This breakdown of tissue results in decreased condition (weight per unit length) and survival (Smith and Griffith 1994). Thus, during winter conditions, trout in Snowmass Creek will survive at higher rates in quiet areas, where little to no energy is spent in swimming against the stream current. These quiet areas differ significantly from those used during warmer months. Thus, the habitat curves used in PHABSIM and R-2 Cross, which were developed during warmer months or in streams without ice, should not be used to simulate winter habitat conditions in ice-covered streams like Snowmass Creek. Below we describe the habitats used by trout in ice-covered streams.

Winter Habitat Characteristics

Following the working hypothesis that trout choose winter habitat to minimize energy loss, Cunjak (in press) recently proposed a list of criteria that define the winter habitat selected by trout in streams like Snowmass Creek. He lists three criteria in order of relative importance:

(1) protection from adverse physico-chemical conditions (e.g., ice, low oxygen) and access to refugia,
(2) protection from predators, and
(3) access to food.

Cunjak (in press) described habitats that meet these criteria. For example, deep water, instream cover (cobble/boulder substrate, woody debris, and undercut banks), floodplain habitat and side-channels, and groundwater discharge zones are selected by trout during winter to avoid adverse physico-chemical conditions. Suitable depths and instream cover also protect trout from predators, while selection of low-velocity microhabitats and nighttime foraging provide access to food. Feeding at night also reduces predation risk. Below, we describe in more detail the winter habitat or microhabitat (focal positions) selected by trout during the day and night in ice-covered streams.

Daytime Winter Habitat.--Winter habitat selected by trout during the daytime in streams like Snowmass Creek is related to fish size and the availability of suitable habitat. Like many salmonids, brown trout, rainbow trout, and brook trout are photonegative (avoid light) during winter (Cunjak, in press). Small trout (<15-25 cm or <6-10 in) prefer to secrete themselves in interstitial spaces in the substrate during daylight where rock diameter is directly proportional to the size of the fish (Cunjak 1988; Heggenes et al. 1993). These trout may move 15-30 cm (6-12 in) below the substrate surface (Everest 1969; Cunjak, in press). In a small Idaho stream, Hillman et al. (1987) found that salmonids, if given a choice, prefer to conceal themselves in cobbles and small boulders along the stream edge during daytime in winter. Hillman et al. (1987) found few fish concealed in submerged vegetation or in clean substrate[4] near stream center if clean substrate was available near the stream edge. Contor (1989), Riehle and Griffith (1993), and Griffith and Smith (1993) also found that juvenile trout concentrated along shallow stream margins where they concealed themselves during the daytime among boulders with low embeddedness, in vegetation, and beneath undercut banks. In the Credit River, Ontario, however, brook and brown trout occupied stations beneath woody debris, undercut banks, and shelf ice, or within macrophyte beds during daytime (Cunjak, in press). Cunjak (in press) notes that other species of fish overwinter in the river substrate. Macrophyte beds, which are rare in Snowmass Creek during winter, may be less desirable daytime winter habitat than spaces in woody debris or substrate. For example, Griffith and Smith (1995) observed that the density of young trout in macrophyte beds declined steadily between November and January despite continued availability of the vegetation cover. Instead, most trout overwintered in any available cobble and boulder substrate.

Trout that are too large to hide in the substrate or woody debris tend to

[4]Clean substrate refers to the lack of fine sediments (silt and sand) that fill spaces between cobbles and boulders.

aggregate in large schools (up to 600 fish) in pools during the daytime (Bjornn and Reiser 1991). This is mostly true of larger trout (>15-25 cm or >6-10 in) because interstitial spaces large enough to conceal them are scarce in most streams; however, if spaces are available, they will use them (T. Hillman, personal observation). Water depths selected by these trout vary with availability. For example, Cunjak and Power (1986) observed that juvenile and adult brook trout and brown trout in an Ontario river selected water depths that ranged from 42.4-95.4 cm (16.7-37.6 in) and 50-75 cm (19.7-29.5 in), respectively. For both species, water velocities selected by the trout were usually less than 17 cm/s (0.56 ft/s). On the other hand, Griffith (1991) found that radio-tagged trout in an Idaho river selected stations in quiet water that ranged from 150-200 cm (59-79 in) deep. The presence of pools, however, does not necessarily imply suitable winter habitat. For example, Cunjak and Caissie (1994) found that the accumulation of ice in a pool in the Miramichi River filled more than 75% of the pool volume between December and March, and reached the pool bottom in the deepest part. The remaining pool space was considered to be of marginal suitability because of the consequent higher water velocities caused by the ice mass. W. Walsh (personal communication) indicates that extensive icing occurs in pools in Snowmass Creek. As we discuss later, reduced stream flows increase ice formation, which will reduce the suitability of pools in Snowmass Creek.

Backwater habitats and beaver ponds are frequently used by some trout during the winter, apparently because they contain deep water and low velocities. These habitats occur in Snowmass Creek and are probably used by trout during the winter. In a Wyoming stream much like Snowmass Creek, Chisholm et al. (1987) found that brook trout moved into a beaver pond in October and remained there all winter. In October, when water temperatures declined below 8°C (46°F), Cunjak (in press) observed more than 60 brook trout in a beaver pond in Catamaran Brook, more trout than he had observed in any other pool in the system during the previous three years. In Rocky Mountain streams in Montana, as water temperatures decline below about 7°C (45°F), numbers of bull trout and cutthroat trout declined in all habitat types except in beaver ponds, where large aggregations of both species overwintered (Jakober 1995). In shallow streams like Snowmass Creek, where ice cover is often in contact with the substrate, beaver ponds may represent the few suitable wintering sites available, so long as trout have adequate access to the ponds and water quality is not deleteriously affected (Komadina-Douthwright 1994).

Nighttime Winter Habitat.--Although trout prefer to conceal themselves during the daytime in winter, many emerge from cover at night. For three consecutive winters, Hillman et al. (1989) studied the habitat and behavior of salmon and trout in the Wenatchee River, Washington. Although they observed no salmonids during the daytime in winter (fish concealed themselves in the substrate near the stream margin), they found relatively high numbers at night. These fish emerged about 30-60 minutes after dark and occupied stations on or near the substrate where water velocities were less than 5 cm/s (0.2 ft/s). The fish segregated based on size, with the largest fish in the deepest water at night. These observations comport with those of Campbell and Neuner (1985), who found that juvenile and adult rainbow trout were not visible during the day in winter, but occupied inshore areas in shallow, quiet water at night. Contor (1989) studied the nighttime winter habitat use by rainbow trout in an Idaho river and also found that they remained hidden during the daytime, but emerged at night. These fish occupied nighttime stations near the stream banks where water velocities and depths were <15 cm/s (<0.5 ft/s) and 20-45 cm (7.9-17.7 in), respectively. Contor and Griffith (1995) found that the number of trout emerging from cover at night was related to light intensity. Trout densities at night were lowest during moonlight phases or when artificial light illuminated the stream. In streams like Snowmass Creek, Heggenes et al. (1993) found that brown trout emerged from cover at night during the winter and held positions just above or on the substrate. They note that the trout preferred the lowest velocity areas (0-5 cm/s or 0-0.2 ft/s), such as pools, riffle edges close to stream banks, and backwaters. They also note that the trout were more active at night throughout the winter.

Not all trout emerge from concealment cover each night; some remain hidden throughout the night regardless of light intensity. For example, Griffith and Smith (1993) estimated that only 61-66% of the juvenile trout overwintering in an Idaho river emerged each night from substrate concealment. Those that emerge appear to feed throughout the night (Contor 1989; Heggenes et al. 1993). Griffith (1991) reports that food in the form of drifting aquatic insects (especially midges) is more abundant at night in winter. The trout he collected throughout the winter were actively feeding even at a water temperature of 1°C (34°F). Thus, it appears that trout emerge under the cover of darkness to feed on aquatic insects during winter. Contor (1989), Griffith (1991), Heggenes et al. (1993), and Cunjak (in press) speculate that because of reduced swimming performance at cold temperatures, trout are more vulnerable to warm-blooded predators. By emerging to feed at night, trout minimize the risk of predation and also acquire as much food as they can digest. Because the rate of digestion and assimilation is reduced at cold temperatures, feeding bouts may occur several days apart. Thus, trout that fed recently may remain concealed during the night. We have no reason to believe that trout would behave any differently during winter nights in Snowmass Creek.

Summary.--Compared with warmer seasons, trout during winter in ice-covered streams like Snowmass Creek select quiet water areas with more shelter where they can minimize energy loss. This energy-minimizing adaptation increases overwinter survival because fish cannot replace or store energy or evade predators as effectively during winter as during warmer seasons. Thus, in order to survive, trout must select winter habitats that protect them from adverse physico-chemical conditions and predators, yet remain near food sources. For example, smaller trout (<15-25 cm or <6-10 in) conceal themselves in the substrate or woody debris to avoid adverse physico-chemical conditions and predators during the daytime, but may venture out of concealment cover during the night to feed on aquatic insects. These smaller trout typically find suitable cover in side channels, along the margins of riffles, or under banks. Trout too large to conceal themselves in debris or the substrate tend to aggregate in pools or beaver ponds. Pool depth and surface ice probably serve as cover for these fish.

The fact that trout use significantly different habitat during the winter in ice-covered streams like Snowmass Creek is important because the habitat suitability information used in instream habitat models is compiled from information that describes the habitat (depths, velocities, cover, and substrate) used by trout during warmer seasons or in streams without ice. Therefore, the models are actually simulating the influence of streamflows on changes in habitat used by trout during warmer seasons rather than during winter.

Overwinter Mortality

Cunjak (in press) recently reviewed most of the literature on the winter habitat requirements of trout in ice-covered streams like Snowmass Creek and concluded that the occurrence of large aggregations of trout in quiet water areas (e.g., pools, backwater habitats, beaver ponds) strongly indicates that winter habitat limits trout production in ice-covered streams. It is not surprising, therefore, that the overwinter mortality of trout is high in many streams. For example, Smith and Griffith (1994) summarized population studies of wild salmonids in streams that remained near 0°C (32°F) for prolonged periods and were not affected by winter floods. In combination, these studies incorporated a total of 24 population estimates, and the overall average fish mortality rate during the first winter of life was about 50%. Needham et al. (1945) reported that on average 62% (range 16-85%) of age-0 and 80% (range 48-91%) of larger (>10 cm or >4 in) brown trout died during four winters in Convict Creek, California, a stream much like Snowmass Creek. Maciolek and Needham (1952) estimated that 50% of the trout they marked died over a mild winter in experimental channels in Convict Creek. Cerven (1973) reports that 97% of all ages of brown trout, 73% of all ages of cutthroat trout, and 45% of stocked rainbow trout died during winter in the Temple Fork of the Logan River, Utah. Winter mortalities of rainbow trout in South Willow Creek, Montana, averaged 32% during two winters (Schrader 1989). In studies of brook trout over 11 years in Lawrence Creek, Wisconsin, Hunt (1969) noted winter mortalities that averaged 46% (range 27-65%).

Lawrence Creek produces fish with better winter survival than streams like Snowmass Creek because it has warmer water temperatures and no anchor ice.

Physical damage from snow and ice, and fluctuating flows associated with ice formation and dispersal, appear to be the major causes of trout mortality in ice-covered streams with natural flow regimes (Needham and Slater 1944; Needham et al. 1945; Maciolek and Needham 1952; Reimers 1957; Needham and Jones 1959). Trout mortality in streams like Snowmass Creek has been observed because of:

(1) crushing or suffocation from collapsing snowbanks and ice (Needham and Slater 1944; Needham et al. 1945),

(2) stranding from flow fluctuations caused by anchor ice formation and dispersal (Maciolek and Needham 1952), and

(3) asphyxiation from ice crystals plugging gill lamellae (Tack 1938).

In Temple Fork, Cerven (1973) found that anchor ice was significantly and positively correlated with juvenile brown trout mortality. Smith and Griffith (1994) studied the relationship between juvenile trout mortality and suitable winter cover (cobble substrate) and water temperature. They found that mortality of juvenile rainbow trout in cages ranged from 0-37%. They noted that trout survival was 11-24% higher in cages with cover than in cages without cover. The highest mortalities occurred in cages where water temperatures were near 0°C (32°F). Virtually no mortality occurred in cages placed near springs where water temperatures remained near 7°C (11.7°F). Smith and Griffith (1994) state that mortalities of trout in cages were probably lower than those of free-living trout because the cages protected fish from shifting ice and predators.

It is apparent that winter is a very critical period for trout in ice-covered streams like Snowmass Creek. Even in streams with suitable winter cover and natural flow regimes, mortalities can be high because of icing conditions. As we discuss next, stream ice can rapidly change the hydraulics and habitat of streams like Snowmass Creek. These natural changes in streamflows affect the habitat use and survival of trout. If winter flows are further influenced by water withdrawals, the effects on trout habitat use and survival are exacerbated.

EFFECTS OF STREAM ICE ON TROUT HABITAT

In this section we describe the types of ice that form in Snowmass Creek, the impacts of ice on trout habitat, and the effects of reduced streamflows on ice formation in streams like Snowmass Creek. We present a detailed discussion on this topic because there has been some testimony that indicates that reduced streamflows during winter will have no influence on ice formation in Snowmass Creek. We will show that this testimony is wrong and that reduced winter flows do indeed increase ice formation in streams like Snowmass Creek. In addition, we will show that ice has profound and rapid effects on stream hydraulics (i.e., depths, velocities, and wetted perimeter). This is important because Chadwick and Associates (1992) assumed for modeling purposes that *"flows during the winter are less variable on a weekly or daily basis and probably do not differ substantially from those presented in the monthly analysis."*

Most of the information on ice formation comes from Ashton (1986), Hillman (1993), Prowse and Gridley (1993), and Prowse (1994).

Ice Formations

Ice is produced in streams like Snowmass Creek when water reaches the freezing point, provided the stream area has a quiet surface. Moving water (riffles) apparently does not crystallize at the freezing point, but will form frazil ice if it is slightly super-cooled (i.e., the temperature of the water drops below the freezing point). Whether a stream at a given location reaches the freezing point depends on its balance of heat input and loss. Heat is added by friction with the substrate, by conduction from warmer surfaces, by thermal (infrared) radiation, or by addition of warmer water. Heat is lost through conduction to colder masses, by thermal radiation, by evaporation from the surface, or by addition of colder water (including snow). Changes in ice, and consequently also hydraulic conditions, occur mostly during the night, while conditions are comparatively more stable during daytime. This periodicity in ice formation results from increased heat radiation loss during the night (Ashton 1986).

The type of ice that forms in a stream depends almost entirely on water velocity, although the nature of accumulations is a complex function of rates and durations of heat loss. Areas that are slow or lack turbulence (pools and ponds) develop surface ice; fast or turbulent areas (riffles) produce frazil ice (and consequently anchor ice) at first, then surface ice may form as ice dams reduce velocity and turbulence. Thus, there are two major types of ice that form in streams like Snowmass Creek: subsurface (frazil and anchor) and surface (surface, shelf, sheet, and contour) ice. Because the main channel of Snowmass Creek consists mostly of riffles (Hillman 1993; Chadwick and Associates 1993), subsurface ice will be the most common type that forms there. As we discuss later, subsurface ice is the most detrimental to trout.

Subsurface Ice:

Frazil Ice.--Frazil ice is created when nuclei form in moving water (riffles) that has been cooled to a few hundredths of a degree below the freezing point. Production of these small particles continues as long as heat loss is fast enough to maintain slight super-cooling. Once formed, frazil crystals grow into discs up to several hundredths of an inch in diameter, and are very adhesive to each other and to any rough objects in the channel (e.g., rocks, branches, debris, etc.). Even though heat released by formation of the first cloud of frazil crystals can stop crystal condensation, the nuclei already produced can enlarge if heat is removed at the freezing point.

Anchor Ice.--Anchor ice is composed of frazil discs that have been carried to the bottom by turbulence and have adhered to rough surfaces or other frazil crystals. As long as water temperature remains at freezing and heat is escaping, anchor ice accumulations can grow even in extremely high velocities. Consequently, anchor ice readily forms obstructions that can dam streams into a series of "stairstep" pools.

Surface Ice:

Surface Ice.--Surface ice can form either by growth of crystalline sheet ice in quiet water, or by accumulation of floating frazil discs or "flocs" (agglomerations of discs) laterally from the shore or other emergent objects. Frazil ice can float to the surface and wash into quiet pools or eddies. Both sheet and floating-frazil surface ice can become very thick, but the type formed from frazil can thicken more rapidly by accumulating ice freed from upstream areas. Drifting frazil ice or drowned snow crystals can also adhere to the undersurface of sheet ice, and rapidly create "underhanging dams" that constrict flow in pool areas.

Shelf Ice.--Shelf ice is surface ice that accumulates above normal water level as instream ice production increases water surface level by obstructing flow. When the ice obstructions melt, surface ice remains suspended over the lowered stream surface. Depending on the thickness of the ice and its physical support from banks or emergent objects, shelf ice consists of anything from narrow shelves along the shore to complete caps that persist for weeks or months. The longer and more severe a period of low temperature, the more ice accumulates at the surface and the thicker and more complete will be the shelf.

Sheet Ice.--Sheet ice forms when water is quiet (as along stream banks) or non-turbulent. The ice nuclei that form grow into networks. Sheet ice in streams is structurally the same as that forming in ponds and lakes, and can be recognized by its smooth surface and transparency. It is usually thin, so it often collapses to form "slides" along the banks.

Contour Ice.--Contour ice consists of slightly elevated shelves that follow surface contours of the most precipitously descending stream sections. It forms only when air temperatures are below freezing but water temperature remains above the freezing point. Contour ice can grow laterally from any emergent object, such as a bank, root, boulder, or even an ice-shelf remnant. If the water surface continually oscillates, as in a riffle, it wets emergent objects for a few milliseconds, then withdraws and allows the water to freeze and accrete. A plate of ice at the highest level of oscillation thereby grows from its support, and can eventually join with plates from other supports to cap a stream. Contour ice is dense and clear, and can suspend more weight for its thickness than other varieties of ice.

Now that we have some understanding of the types of ice that form in Snowmass Creek, we can proceed to examine how they influence habitat use and survival of trout.

Effects of Ice on Trout

Ice and stream-ice processes have profound effects on the winter habitat of trout and their overwinter survival in streams like Snowmass Creek (Power et al. 1993). Anchor and frazil ice (subsurface ice) are considered to be the most detrimental to fish (Hynes 1970). Brown et al. (1994) reports that frazil ice poses a serious threat to trout living in high gradient streams like Snowmass Creek both through direct physiological effects and by causing rapid and profound changes in habitat. They noted that as frazil crystals form, they directly affect the respiratory system of trout. When the ice crystals are small, they abrade the gills and cause hemorrhaging. As the crystals grow and aggregate, they plug the gill rakers and eventually suffocate the trout. Tack (1938) also found that frazil ice suffocated trout during cold winter nights. Brown et al. (1994) note that fry and juvenile trout are more vulnerable to suffocation by frazil ice because their mouths are smaller and more easily plugged with ice crystals than those of larger trout.

Not only does ice affect the physiology of trout, but it also has a profound affect on their habitat (Figure 1). Frazil ice has a negative effect on trout habitat by aggregating on woody debris and on substrate (forms of cover used by trout during winter) to form anchor ice (Brown et al. 1994). In fact, areas preferred by trout for spawning and winter rearing (shallow gravel-cobble reaches) actually promote anchor ice formation. This type of ice excludes trout from suitable winter habitat, and worse, traps them in the habitat where they later die from suffocation, freezing, or crushing. Chisholm et al. (1987) observed habitat exclusion by ice for brook trout overwintering in steam sites much like those in Snowmass Creek where abundant frazil and anchor ice occurred in the riffles. Brown et al. (1994) found that frazil and anchor ice actually excluded trout from overwintering habitat that had large amounts of cover in the form of woody debris. Trout mortality increased because they were forced to use sites with little or no cover. Cunjak and Caissie (1994) found that frazil ice accumulations precluded use of pools by overwintering salmon and trout. They noted that the accumulation of ice (underhanging ice dam) filled more than 75% of the volume of a pool, and was in contact with the pool bottom in the deepest part. This greatly reduced the suitability of the habitat because of the high water velocities deflected by the ice mass (Cunjak and Caissie 1994). Brown et al. (1994) found that the presence of woody debris in pools increased the buildup of underhanging dams. Thus, these pools, which are preferred winter habitat for trout, are quickly reduced to unsuitable habitat as frazil ice decreases rearing space and cover and increases velocities.

Power et al. (1993) note that substrate scouring, dewatering of stream sections, and freezing of redds are common causes of mortality that are attributed to anchor and frazil ice. Brown et al. (1994) report that incubating trout eggs and alevins of fall spawning species (brown and brook trout in Snowmass Creek) are damaged or displaced by anchor ice. During the formation of anchor ice, eggs and alevins in redds are destroyed or displaced when the ice freezes the stream bottom. As the anchor ice breaks up and lifts from the bottom, it detaches substrate materials and exposes eggs and alevins. The continued build up and break up of ice dams dewaters redds and scours the stream bed crushing eggs and alevins in the process (Calkins 1989). Walsh and Walsh (1995) observed several ice dams on Snowmass Creek in locations of greatest redd numbers. They even found dewatered and frozen redds in Snowmass Creek.

Not only do ice dams destroy eggs and alevins in redds, but they also dislodge or displace older trout from winter habitat when the dams break and scour the stream bottom (Power et al. 1993). Large fluctuations in water depths and velocities occur as ice dams form and break up. As ice dams build, the stream surface elevates (increased water depth and decreased velocities) upstream from the dam because the stream is forced out of its bed. Downstream from the dam water depths decrease resulting in dewatering of some trout habitat. Trout in these locations are trapped in dewatered areas and die from exposure to freezing air temperatures. Fish upstream from the ice dams move into the impoundments and conceal themselves in the substrate or debris along the margins of the impoundments. Larger fish that cannot conceal themselves in the substrate or debris may aggregate in the deep, quiet portions of the impoundments. If sufficient heat is absorbed during the day, the dams break and the stream quickly returns to its former bed (rapid increase in water velocity and decreased depth), displacing fish that aggregated in the pools and stranding and killing those concealed in the overflow areas. Maciolek and Needham (1952) and Needham and Jones (1959) reported on the mortalities of trout, by suffocation, after ice dams broke and dewatered stream side-channels and braids like those in Snowmass Creek. They note that trout moved into these areas as water depths increased behind ice dams and then became stranded and died when water levels subsequently receded after the ice detached from the substrate.

Effects of Reduced Flows on Ice Formation

Streamflows can influence ice formation in various ways (Prowse and Gridley 1993; Prowse 1994). For example, streamflows can influence ice formation by changing surface velocities. If changes in streamflow increase water turbulence, frazil and anchor ice tend to form. In contrast, if changes in flow increase quiet water areas (e.g., pools), then surface and shelf ice are likely to form. Lowering streamflows in Snowmass Creek will increase the formation of both surface and subsurface ice. There are several reasons why this is so:

(1) Because water has a high specific heat[5], larger volumes of water contain more heat than smaller volumes of water. Thus, a stream like Snowmass Creek at higher flows will take longer to cool to the freezing point than it will at lower flows. This is one reason why smaller streams develop relatively more ice sooner than larger streams under the same conditions.
(2) Reducing flows will favor the formation of sheet and shelf ice around emergent rocks. This will increase ice formation because emergent rocks increase the loss of heat from the stream. That is, Snowmass Creek will lose more heat as the boulders emerge at lower flows, so it will cool to the freezing point more rapidly.
(3) This cooling effect will be exacerbated because friction between the water and the substrate (a form of heat input) decreases as flows decrease.
(4) Finally, under similar conditions, a wide, shallow stream will develop more ice sooner than a narrow, deep stream with the same flow. This is because a larger proportion of the water volume in a wide, shallow channel will be exposed to the air (a point of major heat loss) than will be the volume of water in a narrow, deep channel. Because Snowmass Creek has a wide channel that is exposed, and has limited riparian cover (Chadwick and Associates 1992, 1993), a reduction of flows in Snowmass Creek will tend to decrease water depths and velocities more than surface area. Thus, in Snowmass Creek, a reduction in streamflows will increase the relative percentage of the volume of water that is exposed to cooling resulting in more ice.

Not only will reducing streamflows in Snowmass Creek increase ice formation, but the growth of ice will further reduce the streamflow below that set by the Colorado Water Conservation Board (CWCB). The reason is that some of the flow will be locked up (stored) as ice. The amount of flow that can be locked up as ice can be quite large. For example, Osterkamp et al. (1975) found that ice

[5]Specific heat is the quantity of heat needed to raise the temperature of one gram of the substance one degree Celsius.

production decreased discharge in a small stream by 0.38 and 0.42 m^3/s (13.4 and 14.8 cfs), which was 31% and 55% of the discharge, respectively. Therefore, reducing streamflows in Snowmass Creek will not only increase both surface and subsurface ice formation, but will further reduce flows as water is locked up as ice.

Summary

Two major types of ice form in Snowmass Creek: subsurface (frazil and anchor), and surface (surface, shelf, sheet, and contour) ice. Stream conditions largely determine which types form. For example, surface ice generally forms in non-turbulent water (pools), whereas frazil and anchor ice typically form in turbulent water (riffles). Because the main channel of Snowmass Creek consists of mostly riffles (Hillman 1993; Chadwick and Associates 1993), subsurface ice (frazil and anchor ice) will be the most common type that forms there. Not surprising, Walsh and Walsh (1995) observed extensive subsurface ice formation in Snowmass Creek. This type of ice is also the most detrimental to the survival and habitat use of trout. For example, frazil ice directly kills trout by causing hemorrhaging (gill abrasion) and suffocation (plugging the gills).

Subsurface ice also reduces winter habitat by excluding trout from suitable cover, or worse, trapping them in cover where they later die from suffocation, freezing, or crushing. Because frazil ice readily attaches to surface ice and woody debris in pools (forming underhanging dams), these habitats preferred by larger trout are quickly rendered unsuitable because of increased velocities and decreased pool volume. Furthermore, anchor ice will form ice dams. These dams, which are common in Snowmass Creek under extant conditions (Walsh and Walsh 1995), create rapid and unpredictable changes in stream hydraulics. Ice dams reduce water depths downstream from the dam resulting in dewatered habitat and stranded trout. Upstream they reduce water velocities and increase depths. Trout move into these impoundments (temporary pools created by the ice dams) and either aggregate in the deepest portion of the pool or conceal themselves in cover along the margins of the pool. When the dams break, which they do repeatedly throughout winter, trout are dislodged or displaced, crushed, and/or stranded in dewatered habitat. The formation and break up of anchor ice and ice dams also reduces survival of eggs and alevins by scouring the substrate, dewatering stream sections, and freezing the redds. Walsh and Walsh (1995) found dewatered and frozen redds in Snowmass Creek during a winter with natural flow conditions.

Lowering streamflows in Snowmass Creek will increase the formation of both surface and subsurface ice. Reduced streamflows accelerate ice formation by decreasing the storage of heat in the water, decreasing friction between water particles and the streambed (a source of heat input), increasing heat loss from rocks that emerge at lower flows, and increasing the relative proportion of the water volume that is exposed to air. This is one reason why small streams produce relatively more ice sooner than larger streams. In addition, the increased formation of ice at lower flows will further decrease flows because some of the water will be locked up as ice. Thus, reduced streamflows not only decrease habitat volume and increase ice formation (Peters 1982), but will further reduce winter flows as water is locked up as ice.

Next we describe in more detail the effects of reducing winter streamflows on trout and their habitat.

EFFECTS OF WINTER STREAMFLOW REDUCTIONS ON TROUT

Because reduced metabolic demands of trout at low water temperatures lessen or eliminate time spent defending territories and feeding (i.e., summer activities), suitable habitat is the primary factor that regulates trout populations in winter (Chapman 1966; Mason 1976). Therefore, any land-use activity that affects the amount of suitable winter habitat in a stream will also have some effect on the trout population. Recently, Cunjak (in press) reviewed the impacts of land-use activities on winter habitat of fish. He notes that water withdrawal and its direct influence on reducing available habitat probably affects fish populations more than any other winter alteration of streams. Power et al. (1993) note that habitat loss is most pronounced in shallow streams like Snowmass Creek (often the most productive rearing habitats for juvenile trout), and is exacerbated by ice conditions. Griffith and Smith (1995) found that when winter flow was kept low in a regulated stream, juvenile rainbow trout could not use near-bank concealment habitat, which was the preferred habitat, because it was dewatered. Contor (1989) also noted a reduction in numbers of juvenile trout in a stream section after a decrease in flow during the winter. He reports finding dead fish in and near the dewatered concealment cover along the banks.

Deinstadt and Wong (1989) studied the winter streamflow requirements of brown trout in the East Walker River, California. In many respects this stream is similar to Snowmass Creek. It consists of mostly riffles, both surface and subsurface ice form during the winter, and it has a mean monthly low flow of about 18 cfs in winter. They found that the mortality of juvenile brown trout during three winters averaged 46% (range 25-70%). The highest mortality (70%) occurred when winter streamflows declined below 10 cfs. Deinstadt and Wong (1989) concluded that these low flows were excessively detrimental to the overwinter survival of juvenile brown trout because flows less than 10 cfs substantially reduced preferred habitat (substrate concealment cover near the banks in riffles).

As we described earlier, a winter reduction in streamflow will increase ice formation. Cunjak (in press) notes that this can markedly reduce available habitat in ice-covered streams like Snowmass Creek. Maciolek and Needham (1952) reported on the mortality of brown and rainbow trout in Convict Creek, California, when subsurface ice accumulation precluded the flow of water into side-channels where trout were subsequently stranded. Chisholm et al. (1987) indicate that the impact of water withdrawal during winter may be more severe at elevations below 9,810 ft (Snowmass ranges from 8,240 ft at SWSD dam to 6,840 ft at its confluence) because of habitat exclusion by increased accumulations of surface and subsurface ice.

With this understanding of the winter ecology of trout and the effects of ice and reduced flows on trout habitat in ice-covered streams, we can evaluate the models used by ASC and CDOW to assess minimum winter flows for trout in Snowmass Creek.

INSTREAM HABITAT SIMULATION MODELS

In this section we discuss the instream habitat simulation methods used by ASC and CDOW to estimate minimum winter streamflows in Snowmass Creek. We first provide a general background of these methods and then describe why they should not be used to establish minimum winter streamflows in ice covered streams like Snowmass Creek.

Background

The primary purpose of instream habitat simulation methods is to develop relationships between the amount of suitable instream habitat (depth, velocity, cover, and substrate) and stream discharge (flow). These methods consider not only how these physical variables change with streamflow, but combine this information with the habitat preferences of given species to determine the amount of habitat available over a range of streamflows. Results are normally in the form of a curve showing the relationship between available habitat area and stream discharge. A manager can use these results as a guide for recommending instream flows, provided the assumptions of the methods are not violated. As we describe later, some of the assumptions prevent these methods from producing valid habitat-flow relationships in ice-covered streams like Snowmass Creek.

R-2 Cross.--This program is designed to calculate a series of hydraulic parameters from transect data and Manning's discharge formula (Stalnaker and Arnette 1976; Wesche and Rechard 1980). Transect data are collected in a "critical riffle reach," which is considered to be the shallowest cross section of the shallowest riffle in the reach. At each cross-channel transect a cross-section profile is constructed by measuring depths and velocities at regular intervals. These data are then applied to Manning's formula to synthesize the flow in the channel at various levels. The program produces a plot of the measured cross section and computes stream discharge, average flow velocity, wetted perimeter, cross-sectional area, maximum water depth, and hydraulic radius for the actual streamflow at the time of measurement as well as for various selected water stages. Based on these synthesized flow levels, a fisheries manager identifies the minimum flow at the critical riffle needed to meet minimum criteria for velocity, depth, and wetted perimeter. The criteria set by CDOW for fish in Snowmass Creek are: (1) average depth of 1% maximum stream width, (2) average velocity of 1 foot/second, and (3) wetted perimeter 50% of maximum. For recommending winter minimum flows the rule is to select the lowest flow that meets any two of the three criteria. For summer flows, the minimum flow is that meeting all three criteria.

PHABSIM.--PHABSIM (Physical HABitat SIMulation system) is a collection of computer programs that form a major component of IFIM. The main assumption of PHABSIM is that fish will react to changes in the hydraulic environment. Additionally, individual fish will tend to select the most favorable instream conditions, but will also use less favorable ones, with preference decreasing as conditions become less favorable (Stalnaker 1979). The model consists of two basic components: (1) hydraulic simulation and (2) habitat simulation. The hydraulic component calculates water-surface elevations and velocities, while the habitat component computes the quantity of physical habitat area in a reach for a given species and life stage (e.g., juvenile brown trout). Thus, PHABSIM estimates changes in water surface and velocity patterns with discharge and combines these relationships with habitat-suitability curves[6] to produce habitat-

[6]Habitat-suitability curves are graphs that are constructed with information on the effects of habitat variables (e.g., depth, velocity, cover, and substrate) on the growth, survival, or biomass of a fish species. Each curve provides an index of suitability over a range of values for each habitat variable.

discharge relationships. The final curve produced by PHABSIM displays the change in weighted usable area (WUA) with discharge. WUA is an indicator of the net suitability of use of a given reach by a certain life stage of a certain species. At a particular streamflow PHABSIM evaluates the distribution of physical habitat (depth, velocity, cover, and substrate; note that ASC did not include cover and assumed that substrate composition was constant across the channel) over the stream reach. This is combined with the habitat-suitability curves to determine the WUA for that discharge. The physical habitat is redefined at each discharge and the computations repeated to obtain WUA as a function of discharge.

Ability of Models to Predict Winter Conditions

Both PHABSIM and R-2 Cross have many positive benefits. These models are useful when applied to periods when fish are rearing (e.g., warmer seasons). They fall short, however, in predicting winter habitat changes caused by flow reductions. Hydraulic and habitat modeling, using either the R-2 Cross or PHABSIM approaches, fails to treat winter conditions appropriately and adequately. In fact, Petryk et al. (1994) concludes that these methods were not intended for use in ice-covered streams like Snowmass Creek as the hydraulic simulations and the species-specific habitat suitability curves do not account for the significant effects of ice and winter conditions.

R-2 Cross.--The cutoff levels for depth, velocity, and wetted perimeter used in R-2 Cross are based on instream flow characteristics without evaluation of on-site, short-term temporal and spatial variations caused by local ice formation and breakup. Osterkamp et al. (1975) found that ice formation in a small stream modified the stage, velocity profiles, and discharge. Frazil ice entrained in stream flow reduces velocity profiles and increases stage. After this increase, stage decreased in the short term, perhaps because of evolution of frazil ice into frazil flocs and because of transformation of water to anchor and border ice. Continued ice production in the stream constricted the channel, and stage increased until midday, when the anchor ice melted and was flushed downstream (Osterkamp et al. 1975). These hydraulic changes were not addressed in the methods used by modelers of habitat in Snowmass Creek.

"One size fits all" flow parameters (Nehring 1979) provide no quantitative on-site consideration of effects of discharge on winter habitat provided by side channels, overhead bank cover, or beaver ponds. Snowmass Creek has numerous side channels and beaver ponds. Those are important habitats for trout during winter. The criteria for the R-2 Cross flow selection simply cannot deal with that issue. An average depth criterion of 1% of maximum stream width or average velocity of 1 foot/second on critical riffles or average conditions on several riffles has no quantitative relationship to availability and connections of side channels and beaver ponds to the stream channel.

Nehring (1979) reviewed the relationship between R-2 Cross and biological conditions. He concluded that *"...R-2 Cross methods are only indirectly related to the biological conditions of the stream through the parameters average depth, average velocity and percent wetted perimeter. While some work has been done to summarize the average depth and velocity preferences for fish and aquatic invertebrates* [these preferences included warmer conditions, not winter conditions] *...in most instances the tolerance ranges are so wide that any attempt to correlate fish numbers and/or biomass with the R-2 Cross output would be futile. Cover factors* [which are critical for trout survival during winter] *at present cannot be incorporated into this method. In short, the R-2 Cross probably has the least applicability of any tested method of stream flow assessment..."*

The selection of a suitable winter minimum flow from the R-2 Cross output is inappropriate. There is no way to account for effects of icing on salmonid redds with the R-2 Cross method. The method does not account for use by trout of rubble or cobble for winter hiding, or use by larger trout of undercut banks and debris. In short, the R-2 Cross method does not help managers who need to know how various streamflows will affect Snowmass Creek during the winter. The CDOW uses the R-2 Cross method in the State of Colorado, but we know of no other western state that accepts data from the method as probative. The USFS has used it in California, but the California Department of Fish and Game does not. Reiser et al. (1989) show the R-2 Cross method as used or recognized in three states; the IFIM as used or recognized in 38 states or provinces.

PHABSIM.--The IFIM can address such matters as effects of discharge on side channels, overhead bank cover, beaver pond access routes, and water surface elevations in beaver ponds. The IFIM is versatile in this regard. However, one must distinguish IFIM from PHABSIM. The latter, which was used by ASC, is a component of IFIM; a component that marries in-stream hydraulic modeling and fish habitat suitability curves. In other words, PHABSIM is only a microhabitat modeling routine that makes up part of IFIM. That component of IFIM, as used in Snowmass Creek, has not to date addressed certain key issues.

As with R-2 Cross, the hydraulic component of PHABSIM cannot adequately simulate the effects of stream ice on stage, velocity profiles, and discharge. As we stated above, the formation of ice can reduce streamflows because some of the flow is locked up as ice (Osterkamp et al. 1975). Hydraulic models cannot predict the magnitude or even the occurrence of such events. In addition, ice has profound effects on depths and velocity profiles. For example, as anchor ice and ice dams build, water depths increase and velocities decrease upstream from the dams. We have observed in Rocky Mountain streams smaller than Snowmass Creek that shallow riffles become deep pools (6 ft deep) within a few hours. Downstream from ice dams water depths and flows decrease. When the dams break, water depths decrease and velocities increase rapidly. Although these events occur frequently during the winter in ice-covered streams like Snowmass Creek, hydraulic models cannot predict or simulate them. Furthermore, hydraulic models cannot simulate the occurrence or effects of underhanging ice dams in pools. These formations reduce rearing space for trout and increase water velocities. These events are important because, as we noted earlier, they have profound effects on habitat use and survival of trout.

The habitat component of PHABSIM cannot adequately assess changes in winter trout habitat in ice-covered streams like Snowmass Creek. The habitat suitability curves used by Chadwick and Associates (1992, 1993) and Miller and Associates (1993) were developed by the USFWS and incorporate the results of many habitat studies in several different areas. However, none of the studies that the USFWS used to develop the curves included winter habitat selected by trout in ice-covered streams like Snowmass Creek.[7] As we described earlier, habitat selected by trout in ice-covered streams differs significantly from that selected by trout during warmer seasons or even during winter in streams that do not develop significant ice. Thus, PHABSIM, as used by ASC, is actually simulating the influence of streamflows on habitat used by trout during warmer seasons, not during winter in an ice-covered stream. EA Engineering (1986) evaluated various instream flow methods including PHABSIM and noted a lack of information on biological consequences of flow changes.

As a final note on the use of PHABSIM, the Special Master for the Environmental Defense Fund v. East Bay Municipal Utility District case in the American River in California put his finger on the problem that decision-makers face in many issues involving minimum flow: *"...too little is known about the basic biology even of chinook salmon to support reliable "methodologies" for setting flow standards..."* (Williams 1995).

Summary

If instream modeling does not embrace the right conditions (e.g., effects of

---

[7]We reviewed the reports that the USFWS used to develop suitability curves. Some of these studies did include winter habitat use. However, those that did cannot be compared with Snowmass Creek because they do not represent the winter (icing) conditions in Snowmass Creek. For example, Bustard and Narver (1975) studied winter habitat use of coho and steelhead in a coastal stream that has little to no ice during winter. Gosse (1981) studied winter habitat use of brown trout in the Logan River system and rainbow trout in the Green River downstream from Flaming Gorge Dam (Gosse 1982). These systems are much larger and deeper than Snowmass Creek and produced no ice during his observation periods. Many of the curves were developed from observations made by Moyle et al. (1983); however, their observations were made during the warmer seasons. Finally, the brook trout curves that were used by the ASC in PHABSIM indicate 0.0 suitability for fine substrates like silt and sand. This is certainly incorrect because we observed brook trout over sand and silt in Snowmass Creek.

ice on depths, velocities, cover, and wetted perimeter), or look in the right places (e.g., side-channel, cutbank, beaver ponds, beaver pond access), or if the suitability curves do not reflect needs of fish in winter, then these models can tell the manager very little about effects of winter discharge on fish. The PHABSIM and R-2 cross modeling methods, as applied in Snowmass Creek, did not specifically address the foregoing factors.

Chadwick and Associates (1992) state: *"...our analysis indicates that winter habitat conditions are not limiting trout populations. Low habitat levels during the spring runoff period are the limiting factor."* Unfortunately, the analysis to which they refer relies on PHABSIM modeling and assessments of WUA available at various discharges and seasons in the main stream channel. Off-channel habitat was not assessed. The habitat suitability curves used in the PHABSIM models for assessing habitat for rearing are rooted in data obtained during warmer seasons, not in winter in ice-covered streams when trout use microhabitat differently. Thus, even though Miller & Associates (1993) recognized that winter habitat requirements of trout are important, and mapped and physically placed transects in randomly selected components of such habitat, they lacked winter suitability curves to apply.

We could find no consideration in modeling of off-channel backwaters, side channels, beaver ponds, or trout redds. The transect data used by modelers, although including "spawning gravel," were not obtained on constructed trout redds, which (based on information in Walsh and Walsh (1995), who show serious declines in habitat suitability at redd sites with decreases in discharge) should be considered critical sites. Hydraulic conditions and effects of flows on those conditions over constructed redds will differ from hydraulics over undisturbed spawning gravels (Chapman 1988).

The IFIM is capable of dealing with issues such as flow effects on depth as winter cover, flow connections to beaver ponds, and backwater access in winter. But examination of flow needs to address those factors in winter depends upon adequate knowledge of ecological conditions and requirements in winter. Thus, when Chadwick and Associates (1993) discuss details of model performance, noting that the hydraulic model *"...performed well at the lower modelled flows,"* and *"... the habitat levels during the winter low flow period are relatively high compared to habitat levels during peak flows...,"* they are unduly optimistic, for winter ecological requirements of fish are not considered. They also note: *"Flows during winter are less subject to short-term events on a weekly or daily basis and probably do not differ substantially from those presented in the monthly analysis."* This observation does not comport with the field observations of Walsh and Walsh (1995), who found large short-term changes in hydraulic conditions in Snowmass Creek caused by ice buildup and breakup.

Chadwick and Associates (1992, 1993) appear to fixate on the effects of high flow as a limiting factor. To support this conclusion, they note that habitat modeling shows lowest habitat availability in spring runoff. However, as we noted above, they did not consider off-channel habitat in their analyses. This point is important not only because off-channel habitat provides winter habitat, but because it also provides habitat for trout during high flows. Since their work did not include these off-channel habitats, it is little wonder that they modeled a lack of high-flow habitat. Certainly they discount any effect of low flow on incubating embryos and alevins, stating: *The 7 cfs minimum flow* [which they support], *occurring during winter, would have no effect on spawning trout...Brook and brown trout fry occur in spring and summer, generally late April through August or September. As with spawning trout, this life stage is not present in Snowmass Creek during the winter low flow period and is not evaluated during the winter."* In light of results obtained by Walsh and Walsh (1995), this discounting appears excessively sanguine.

Chadwick and Associates (1992) further state: *"Extreme habitat conditions in Snowmass Creek appear to be occurring during the runoff period. This is apparently the critical period that limits the size of the resident trout population on a year to year basis...These high flow periods appear to be the determining factor for trout density and biomass in Snowmass Creek."* Also, Chadwick and Associates (1993) state that IFIM results indicate that *"... high flow periods are the critical low habitat period for trout in Snowmass Creek.....High flows result in* *low habitat levels by producing high velocity currents unsuitable for fish. This reduces their ability to move in the stream and may wash some fish, especially young fish, downstream..."* In early September, 1995, after a spring freshet in Snowmass Creek considered to represent a very high-flow event, we found many fish-of-the-year in slow-moving edge and side channels. Thus, we cannot support a hypothesis that Snowmass Creek is a "blowout" stream that washes juveniles out of the area.

In short, R-2 Cross and PHABSIM modeling, with attendant suitable flow parameters for depth and velocity, however suitable they may be for determining summer instream flows (see Nehring 1979), do not alone account for such factors as variable hydraulic conditions caused in winter by ice. They do not, as used in Snowmass Creek, account for side-channels, bank undercuts, or beaver pond maintenance or increased need in winter for cover provided by water depth. Finally, they do not consider the ecological requirements of trout in ice-covered streams.

Mundie (1991) cautioned, in recommending less reliance on model predictions, that *"....it is better to follow a guideline based on professional judgment than to engage in spurious quantification. The guidelines seem to be that the historic pattern of annual flow should be followed as much as possible, for this is what the life history strategy of the fish is related to, and that the flow should not be reduced by more than 25% to 30% of the mean monthly flows...., and, on common sense grounds, not at all in periods of very low flows."* Late winter is such a low-flow period. Following Mundy's advice, one would wisely recommend no reduction at all in January and February.

CONCLUSIONS

Trout require specific habitat during the winter in ice-covered streams like Snowmass Creek, and ice conditions and streamflows greatly affect these habitats. Certainly, any flow reduction during the winter in Snowmass Creek will affect suitable habitat available to trout. Not only does a flow reduction reduce the volume of habitat available, but it increases ice formation (see section on effects of stream ice on trout habitat). This increase in ice further reduces streamflows and hence habitat available for trout during winter. Although we do not know what fraction of the trout population in Snowmass Creek will be lost if streamflows are reduced in winter, the literature clearly demonstrates that any reduction in streamflows then will increase the risk of overwinter mortality; the greater the flow reduction, the higher the risk.

Except perhaps for the work by the ASC and CDOW, the information that we reviewed indicates that winter conditions can limit trout populations in Snowmass Creek. For example, Walsh and Walsh (1995) demonstrated that winter conditions affect the suitability of spawning and incubation habitats used by trout in Snowmass Creek. They noted a significant decrease in the suitability of incubation habitat during winter under natural flow conditions. Walsh and Walsh (1995) also observed high densities of adult trout in pools during the winter, which, according to Cunjak (in press), indicates that suitable winter habitat is limiting. Hillman (1993) noted that winter habitat (pool-like habitat with wood or rock concealment cover) in Snowmass Creek constituted only about 8% of the total habitat available between the SWSD diversion and Capital Creek. Hillman (1993) surveyed Snowmass Creek in mid-April when streamflows typically exceed those in January, February, and March. Thus, the percentage of winter habitat in Snowmass Creek would be lower than 8% during mid-winter when streamflows are lower and winter conditions are most severe.

Walsh and Walsh (1995) assessed changes in population numbers in Snowmass Creek and concluded that under natural streamflow conditions, trout numbers did not change significantly through the winter. Because Walsh and Walsh (1995) snorkeled during the daytime, however, they rarely observed juvenile trout, which conceal themselves in cover. Thus, as Walsh and Walsh (1995) noted, their counts probably underestimated actual populations. Furthermore, juvenile trout usually suffer higher overwinter mortalities than do larger fish. Therefore, significant changes, undetected by Walsh and Walsh

(1995), probably occurred in juvenile trout numbers during the winter.

Habitat simulation models and instream flow methodologies are commonly applied with the objective of providing managers information to protect habitat for aquatic resources subject to proposed streamflow alterations (Shirvell 1989). Habitat suitability curves used in these models derive from micro-habitat measurements during warmer seasons or in ice-free streams. Simulations based on these curves will not serve to describe winter habitat in ice-covered streams. Ice profoundly affects the hydrologic characteristics of streams during winter (e.g., Calkins 1989; Calkins and Brockett 1988; Prowse and Gridley 1993; Prowse 1994), yet no model presently can simulate those changes. For example, within a 24 hr period a given site can be transformed from a shallow, fast-water riffle to a deep impoundment behind an ice dam, then can return to a shallow riffle. A pool with ice cover can change within a short time from suitable winter habitat (deep, quiet water) to unsuitable fast water with limited volume. Thus, the previously-cited evidence of shifts in seasonal habitat preferences of trout, and the unique hydrologic characteristics of ice-covered streams in winter, which the hydraulic sub-model of PHABSIM cannot simulate, preclude the use of instream flow models to adequately predict conditions in Snowmass Creek in winter. Petryk et al. (1994) voiced similar concerns regarding the use of instream flow models for simulating conditions in ice-covered streams.

We believe, based on evidence described above and personal observations and experience, that high risk attends any further reduction in winter streamflows in Snowmass Creek. Any further reduction in natural winter flow conditions will make an already severe condition worse. The fact that Snowmass Creek has already been degraded does not justify further degradation; if anything, it justifies a greater degree of protection. As Power et al. (1993) state, *"Winter demands on water resources such as those posed by alpine ski operations in New England are ever increasing* (D. Calkins, personal communication). *Subsequent lower water levels and reduced discharge could exclude aquatic species from available overwintering habitats because of increased surface and subsurface ice formation."* Chisholm et al. (1987) indicate that the effect of winter water withdrawals at elevations below 9,810 ft (Snowmass Creek ranges from 8,240 ft at SWSD diversion dam to 6,840 ft at the confluence of the Roaring Fork River) will be most severe because of probable habitat exclusion by surface and subsurface ice and *"the lack of a suitable means for determining winter streamflow needs under these conditions."*

Next, we review scientific rules or methods recommended by various agencies for assessing minimum winter streamflows.

REVIEW OF RULES FOR RECOMMENDING WINTER FLOWS

As we described above, in terms of biotic integrity there is no "excess" water in a stream. All flow levels, including those above mean or median values, serve important functions in aquatic ecosystems. The functions include, but are not limited to, sediment transport, flushing of fine particles from sediments, temporary increased intergravel percolation, channel shaping and wetland recharge. Any extraction of water from extant winter flows reduces suitability of incubation conditions for embryos and redds in Snowmass Creek. Extraction of water also reduces depths that trout need for winter cover. It reduces flows in side channels and ultimately can reduce water surface elevations in beaver ponds. Risk of damage to the aquatic community in Snowmass Creek increases as flows are reduced from those that occur naturally. However, we recognize that authorities may accept increased risk to the aquatic community of Snowmass Creek to provide water of economic importance for snowmaking. Therefore, below we identify the methods currently recommended by different agencies for assessing minimum winter streamflows.

We applied these methods to Snowmass Creek and then, using the results of Walsh and Walsh (1995), assessed the "risk" of those methods to the aquatic community of Snowmass Creek as the percent reduction of suitable water velocities over trout redds. Although we use water velocities over redds to assess "risk," this does not minimize the importance of winter rearing habitat for juvenile and adult trout in Snowmass Creek. We used the former because we have quantitative data on conditions over redds in Snowmass Creek, and because eggs and alevins are quite sensitive to changes in flow regimes. To assess minimum flows in Snowmass Creek, we used the hydrograph prepared by the U.S. Forest Service in their Watershed Supplemental Analysis (see our Appendix A). We used the flow data of the Forest Service and not the CWCB because the former compares favorably with flows determined by Wright Water Engineers and by W. W. Wheeler and Associates (see our Appendix B). Our intent in the exercises below is not to estimate winter flows available for competing uses. Rather, it is to use the various methods to estimate minimum winter flows necessary to protect the natural environment of Snowmass Creek to a reasonable degree.

Montana Rule:

The winter instream flow approach of the Montana Department of Fish, Wildlife and Parks is to *"prohibit winter water depletions altogether"* (Flynn 1984). Their justification for protecting winter flows is based primarily on the fact that *"winter is the period most detrimental to trout survival in mountain streams that are subjected to icing and other severe weather conditions."* The harsh winter environment ultimately limits the numbers and biomass of trout that can be maintained indefinitely by the aquatic habitat. Flynn (1984) notes that winter flow depletions only serve to aggravate an already stressful situation, leading to even greater winter losses and the possible devastation of the fish populations.

Most other western states (e.g., Washington, Utah, Wyoming, Oregon, and Neveda) have no written protocol for establishing minimum flows during winter. The State of Idaho, however, follows the Montana Rule, even though Idaho has no formal rule written that addresses winter water withdrawals (W. Reid, Idaho Department of Fish and Game, personal communication).

Mundie Rule:

As we described earlier, Mundie (1991)[8] recommends that *"Although developers understandably maintain that before water can be allocated for fish some precise quantitative defense must be offered by biologists, it seems that such formulae will not be forthcoming. In view of this it is better to follow a guideline based on professional judgement than to engage in spurious quantification. The guidelines seem to be that the historic pattern of annual flow should be followed as much as possible, for this is what the life history strategy of the fish is related to, and that the flow should not be reduced by more than 25% to 30% of the mean monthly flows..., and, on common sense grounds, not at all in periods of very low flows."* Thus, minimum winter flows in Snowmass Creek should range from to **22.4 cfs** in October to **12.0 cfs** in March (Table 1). In this exercise we reduced the mean October through December flows by 30%. We consider the January through March flows as *"very low flows"* and therefore did not reduce them. These results indicate that suitable velocities would be reduced by 0-72% over brown trout redds and by 0-38% over brook trout redds in Snowmass Creek.

U.S. Fish and Wildlife Service (USFWS) Method:

For streams where inadequate flow records exist or for streams regulated by dams or upstream diversions, the USFWS (1981) method recommends that *"...the aquatic base flow (ABF) release be 0.5 cubic feet per second per square mile of drainage (cfsm), as derived from the average of the median August monthly records for representative New England streams. This 0.5 cfsm recommendation shall apply to all times of the year, unless superseded by spawning and incubation flow recommendations. The USFWS shall recommend flow releases of 1.0 cfsm in*

[8] J. H. Mundie is a retired fisheries research biologist for the Department of Fisheries and Oceans in Canada and worked at the Pacific Biological Station in Nanaimo, B.C. Much of his research focused on optimization and carrying capacity of Pacific Northwest streams.

the fall/winter and 4.0 cfsm in the spring for the entire applicable spawning and incubation periods." When we apply this method to Snowmass Creek we find that the flow limit to protect the spawning and incubation of brown and brook trout (fall spawners) in Snowmass Creek is **39.5 cfs** (1.0 cfsm x 39.5 square miles of drainage upstream from the SWSD diversion). As expected, this winter flow limit would not reduce suitable velocities over trout redds in Snowmass Creek (Table 2). If we ignore spawning and incubation flows for brown and brook trout, however, the flow limit according to the USFWS method would be **19.8 cfs** (0.5 cfsm x 39.5 square miles). This flow limit also would not reduce the suitability of velocities over brown and brook trout redds in Snowmass Creek (Table 2). We do not consider the USFWS method as appropriate for Snowmass Creek because the climate and hydrographs of New England streams differ from those at high altitude in the Rocky Mountains.

State of Vermont Agency of Natural Resources (ANR) Rule:

Median February Flow.--With regard to water withdrawals for snowmaking, section 16-3 (2) of the Vermont Agency of Natural Resources Environmental Protection Rules states that *"the general standard for the winter flow limit (October 1 through March 31) is the February Median Flow (FMF)"* (Clarke 1994; ANR 1995). The ANR uses the FMF to assure that fish are not subject to flow regimes much more severe (in terms of low flow) than the natural conditions to which they have adapted. February is typically the winter month with the lowest streamflow. Low flows in February may be the most stressful metabolically to aquatic organisms because of ice and the high physiological stress associated with overwintering. Because the physiological condition of fish decreases during winter and low flows increase stress and ice conditions (hence the reason why winter is the period of substantial mortality), the ANR recommends FMF since it does not deviate substantially from the low flow regimes that occur naturally. The FMF standard is intended to protect all life stages of fish, not just spawning and incubation. Applying this rule to Snowmass Creek, we find that the streamflow limit (October 1 through March 31) should be **12** cfs (Table 3). Depending on ice conditions, this flow limit would reduce suitable velocities over brown and brook trout redds by 72% and 38%, respectively.

Two-Thirds Median Flow.--The ANR will accept use of the IFIM as a basis for establishing conservation flows only if those flows provide a high level of aquatic habitat protection (ANR 1993). That is, the results of an IFIM evaluation may support a conclusion that acceptable minimum flows are less than the median monthly flow. The ANR accepts such flows only if the fall/winter minimum flow is not less than two-thirds the median monthly flow, unless a valid study demonstrates that ice formation would not be exacerbated. The latter restraint is included to assure that no undue damage to the fishery will result from increased ice conditions. Applying this protocol to Snowmass Creek results in minimum winter streamflows that range from **19.3** cfs in October to **7.3** cfs in March (Table 4). These flows would reduce suitable velocities over redds by 4-100% for brown trout and 0-58% for brook trout.

Summary

Clearly, a minimum winter flow of 7.0 cfs falls well below any limit recommended by the above rules. A minimum winter flow of 7.0 cfs would cause the greatest loss of suitable conditions over trout redds in Snowmass Creek (Table 5). This flow limit was supported with PHABSIM and R-2 Cross methods. However, because these methods used hydraulic simulations and species-specific habitat suitability curves that do not account for the significant effects of ice and winter conditions in Snowmass Creek, large impacts should be expected. For example, at a flow limit of 7.0 cfs, suitable velocities over brown trout redds would be reduced by nearly 100% (Table 5). Actually, velocities over redds would be completely unsuitable during periods of ice formation because the ice would reduce streamflows below the 7.0 cfs limit (see section on effects of stream ice on trout habitat). Walsh and Walsh (1995) observed the effects of ice on suitable conditions over trout redds in Snowmass Creek. They found that at streamflows of 13.5 cfs, suitable velocities declined by 65% over brown trout redds when no ice was present. At the same flow with ice, however, suitability declined 80% over brown trout redds.

RECOMMENDATIONS

The several results summarized above and in tables 1-5 offer alternatives for minimum-flow recommendations. Below we comment on each of the recommendations.

Mundie Rule:

The Mundie (1991) rule results in moderate losses of suitability in some months (Table 1). The December Mundie flow (12.6 cfs) appears inconsistent in that it is less than the January minimum flow. This occurs because we consider the "very low flow" months as January to March. We would expect less ice problem in December than in January, normally the coldest month of the year. Thus, the inconsistency may be acceptable. However, a Mundie flow of 12.6 cfs in December reduces brown and brook trout incubation suitability by a respective 66% and 34%. We suggest that the December minimum should, in common sense, be the average of the November and January minima, or 15.0 cfs.

Montana Rule:

The Montana Rule would result in no flow reductions in January to March, hence would result in the same minimum flows as the Mundie Rule. It would differ from the Mundie Rule by allowing no flow reductions of 25-30% in October, November, and December.

PHABSIM/R-2 methods:

We cannot recommend the 7.0 cfs flow limit supported by the PHABSIM/R-2 methods (Table 5). The methods did not and cannot incorporate effects of ice on winter habitat. The withdrawals that could result from adoption of the 7.0 cfs minimum would permit extreme reductions in incubation flows over redds, increase the propensity of Snowmass Creek to form ice masses, and thus reduce winter habitat available.

U.S. Fish and Wildlife Service:

The flows that the U.S. Fish and Wildlife Service method would set in Snowmass Creek exceed the mean and median flows of Snowmass Creek in January-March (Table 2). We consider them unrealistic for application in Snowmass Creek.

Vermont 2/3 Median Flow:

The minimum flows produced by the Vermont 2/3 median flow (Table 4) make some sense intuitively because they step down with time from 19.3 to 7.3 cfs from October to March. However, they very sharply reduce suitability of incubation flows over trout redds, and would exacerbate risk of ice-caused loss of winter habitat.

February Median Flow:

The use of a minimum flow based on the February median flow (FMF) results in 72% and 38% loss of suitability for incubation of brown and brook trout, respectively, and would likely exacerbate icing. We do not consider the FMF minimum as sufficient protection for instream resources. It does not provide for a step-down hydrograph through the winter.

Recommended Minimum Flows:

We recommend adoption of the minimum flows calculated with the Mundie rule (Table 1). They result in a step-down hydrograph generally similar in shape to that to which fall-spawning trout have adapted. They would reduce risk of accelerated ice formation, yet permit some water withdrawal in November and December.

REFERENCES

Agency of Natural Resources (ANR). 1993. Agency procedure for determining acceptable minimum stream flows. Vermont Agency of Natural Resources, July 14, 1993. 15 p.

Agency of Natural Resources (ANR). 1995. Agency of Natural Resources environmental protection rules; chapter 16, water withdrawals for snowmaking. Vermont Agency of Natural Resources proposed rule draft 7/3/95 for filing with the Interagency Committee on Administrative Rules.

Annear, T. C., and A. L. Conder. 1984. Relative bias of several fisheries instream flow methods. North American Journal of Fisheries Management 4:531-539.

Ashton, G. D. 1986. River and lake ice engineering. Water Resources Publications, Littleton, CO.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 *In*: W. R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19.

Brett, J. R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. Journal of Fisheries Research Board of Canada 21:1183-1226.

Brett, J. R., and P. Glass. 1973. Metabolic rates and critical swimming speeds of salmon (*Oncorhynchus nerka*) in relation to size and temperature. Journal of the Fisheries Research Board of Canada 30:379-387.

Brown, R. S., S. S. Stanislawski, and W. C. Mackay. 1994. Effects of frazil ice on fish. Pages 261-278 *In*: T. D. Prowse, ed. Proceedings of the workshop on environmental aspects of river ice. National Hydrology Research Institute Symposium Series No. 12. Saskatoon, Saskatchewan, Canada.

Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 32:681-687.

Calkins, D. J. 1989. Winter habitats of Atlantic salmon, brook trout, brown trout and rainbow trout-a literature review. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Special Report 89-34:9 p.

Calkins, D. J., and B. E. Brockett. 1988. Ice cover distribution in Vermont and New Hampshire Atlantic salmon rearing streams. Fifth Workshop on Hydraulics of river ice, Winnipeg, Manitoba.

Campbell, R. F., and J. H. Neuner. 1985. Seasonal and diurnal shifts in habitat utilized by resident rainbow trout in Western Washington Cascade mountain streams. Pages 39-48 *In*: F. W. Olson, R. G. White, and R. H. Hamre, eds. Proceedings of the symposium on small hydropower and fisheries. American Fisheries Society, Bethesda, MD.

Cerven, D. R. 1973. Overwinter mortality of trout in Temple Fork of the Logan River. Master's thesis. Utah State University, Logan, UT.

Chadwick and Associates, Inc. 1992. Evaluation of the fishery and minimum streamflow issues of Snowmass Creek. Prepared for Aspen Ski Corporation. Prepared by Chadwick and Associates, Inc., Littleton, CO. 27 p.

Chadwick and Associates, Inc. 1993. Supplemental report addendum to evaluation of the fishery and minimum streamflow issues of Snowmass Creek.

Prepared for Aspen Ski Corporation. Prepared by Chadwick and Associates, Inc., Littleton, CO. 11 p.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. American Naturalist 100:345-357.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117:1-21.

Chisholm, I. M., W. A. Hubert, and T. A. Wesche. 1987. Winter stream conditions and use of habitat by brook trout in high-elevation Wyoming steams. Transactions of the American Fisheries Society 116:176-184.

Clarke, C. 1994. Agency of Natural Resources procedure for determining conservation flows, specific application to snowmaking by ski areas. Agency of Natural Resources, Waterbury, Vermont. 5 p. plus appendix.

Contor, C. R. 1989. Diurnal and nocturnal winter habitat utilization by juvenile rainbow trout in the Henry's Fork of the Snake River, Idaho. Master's thesis. Idaho State University, Pocatello, ID.

Contor, C. R., and J. S. Griffith. 1995. Nocturnal emergence of juvenile rainbow trout from winter concealment relative to light intensity. Hydrobiologia 299:179-183.

Cunjak, R. A. 1988. Behaviour and microhabitat of young Atlantic salmon (*Salmo salar*) during winter. Canadian Journal of Fisheries and Aquatic Sciences 45:2156-2160.

Cunjak, R. A. In press. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences.

Cunjak, R. A., and D. Caissie. 1994. Frazil ice accumulation in a large salmon pool in the Miramichi River, New Brunswick: ecological implications for overwintering fishes. Pages 279-295 *In*: T. D. Prowse, ed. Proceedings of the workshop on environmental aspects of river ice. National Hydrology Research Institute, Saskatoon, Sask., NHRI Symposium Series No. 12:390 p.

Cunjak, R. A., and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 43:1970-1981.

Deinstadt, J. M., and D. M. Wong. 1989. Preliminary determination of the winter streamflow requirements of brown trout in the East Walker River, California. State of California Fish and Game Inland Fisheries Administrative Report No. 89-2.

EA Engineering, Science, and Technology, Inc. 1986. Instream flow methodologies. Research Project 2194-2. Final report to Electric Power Research Institute, Palo Alto, CA.

Everest, F. H. 1969. Habitat selection and spatial interaction of juvenile chinook salmon and steelhead trout in two Idaho streams. Doctoral dissertation. University of Idaho, Moscow, ID.

Flynn, J. W. 1984. Authority, background and guidelines for department recommendations on winter flows for small hydro development. Montana Department of Fish, Wildlife and Parks, Helena, MT. 26 p.

Gosse, J. C. 1981. Brown trout (*Salmo trutta*) responses to stream channel alterations, their microhabitat requirements, and a method for determination.

Doctoral dissertation. Utah State University, Logan, UT.

Gosse, J. C. 1982. Microhabitat of rainbow and cutthroat trout in the Green River below Flaming Gorge Dam, Volume I. Aqua-Tech Biological Consulting, Logan, UT. 114 p.

Griffith, J. 1991. Winter and trout in streams of the Rocky Mountains, USA. Freshwater Catch 46:911.

Griffith, J. S., and R. W. Smith. 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the South Fork of the Snake River, Idaho. North American Journal of Fisheries Management 13:823-830.

Griffith, J. S., and R. W. Smith. 1995. Failure of submersed macrophytes to provide cover for rainbow trout throughout their first winter in the Henry's Fork of the Snake River, Idaho. North American Journal of Fisheries Management 15:42-48.

Heggenes, J., O. M. W. Krog, O. R. Lindas, J. G. Dokk, and T. Bremnas. 1993. Homeostatic behavioural responses in a changing environment: brown trout (*Salmo trutta*) become nocturnal during winter. Journal of Animal Ecology 62:295-308.

Hillman, T. W. 1993. Revised stream habitat survey of Snowmass Creek, Colorado. Prepared for Snowmass Creek Caucus, Snowmass, CO. Don Chapman Consultants, Inc., Boise, ID.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116:185-195.

Doctoral dissertation. Utah State University, Logan, UT.

Gosse, J. C. 1982. Microhabitat of rainbow and cutthroat trout in the Green River below Flaming Gorge Dam, Volume I. Aqua-Tech Biological Consulting, Logan, UT. 114 p.

Griffith, J. 1991. Winter and trout in streams of the Rocky Mountains, USA. Freshwater Catch 46:911.

Griffith, J. S., and R. W. Smith. 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the South Fork of the Snake River, Idaho. North American Journal of Fisheries Management 13:823-830.

Griffith, J. S., and R. W. Smith. 1995. Failure of submersed macrophytes to provide cover for rainbow trout throughout their first winter in the Henry's Fork of the Snake River, Idaho. North American Journal of Fisheries Management 15:42-48.

Heggenes, J., O. M. W. Krog, O. R. Lindas, J. G. Dokk, and T. Bremnas. 1993. Homeostatic behavioural responses in a changing environment: brown trout (*Salmo trutta*) become nocturnal during winter. Journal of Animal Ecology 62:295-308.

Hillman, T. W. 1993. Revised stream habitat survey of Snowmass Creek, Colorado. Prepared for Snowmass Creek Caucus, Snowmass, CO. Don Chapman Consultants, Inc., Boise, ID.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116:185-195.

Hillman, T. W., D. W. Chapman, and J. S. Griffith. 1989. Seasonal habitat use and behavioral interaction of juvenile chinook salmon and steelhead: II. Nighttime habitat selection. Pages 84-108 *In*: Don Chapman Consultants, Inc., Boise, ID. Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final report to Chelan County Public Utility District, Wenatchee, WA.

Hillman, T. W., J. W. Mullan, and J. S. Griffith. 1992. Accuracy of underwater counts of juvenile chinook salmon, coho salmon, and steelhead. North American Journal of Fisheries Management 12:598-603.

Hunt, R. L. 1969. Overwinter survival of wild fingerling brook trout in Lawrence Creek, Wisconsin. Journal of the Fisheries Research Board of Canada 26:1473-1483.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press.

Jakober, M. J. 1995. Autumn and winter movement and habitat use of resident bull trout and westslope cutthroat trout in Montana. Master's thesis. Montana State University, Bozeman, MT.

Komadina-Douthwright, S. M. 1994. Effect of beaver (*Castor canadensis*) activity on stream water quality under conditions of prolonged snow and ice-cover (winter 1991-92). Canadian Technical Report of Fisheries and Aquatic Sciences 1986:34 p.

Maciolek, J. A., and P. R. Needham. 1952. Ecological effects of winter conditions on trout and trout foods in Convict Creek, California, 1951. Transactions of the American Fisheries Society 81:202-217.

Mason, J. C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. Journal of Wildlife Management 40:775-788.

Miller, J. W. and Associates. 1993. PHABSIM data analysis for Snowmass Creek downstream of Snowmass Water and Sanitation District weir. Draft report prepared for Pitkin County, Aspen, CO. Prepared by W. J. Miller and Associates, Fort Collins, CO.

Moyle, P. B., D. M. Baltz, and N. J. Knight. 1983. Instream flow requirements of native California stream fishes. Technical Completion Report B-210--CAL, University of California, Davis.

Mundie, J. H. 1991. Overview of effects of Pacific Coast river regulation on salmonids and the opportunities for mitigation. American Fisheries Society Symposium 10:1-11.

Nehring, R. B. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado. Report to the U.S. Department of the Interior, U.S. Fish and Wildlife Service, Cooperative Instream Flow Service Group. Colorado Division of Wildlife, Fort Collins, Colorado. 152 p.

Needham, P. R., and D. W. Slatter. 1944. Survival of hatchery-reared brown and rainbow trout as affected by wild trout populations. Journal of Wildlife Management 8:22-36.

Needham, P. R., J. W. Moffett, and D. W. Slatter. 1945. Fluctuations in wild brown trout populations in Convict Creek, California. Journal of Wildlife Management 9:9-25.

Needham, P. R., and A. C. Jones. 1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology 40:465-

474.

Osterkamp, T. E., R. E. Gilfilian, and C. S. Benson. 1975. Observations of stage, discharge, ph, and electrical conductivity during periods of ice formation in a small subarctic stream. Water Resources Research 11:268-272.

Peters, J. C. 1982. Effects of river and streamflow alteration on fishery resources. Fisheries 7(2):20-22.

Petryk, S., D. Calkins, R. A. Cunjak, K. Davar, G. Whiteley, and K. Wiebe. 1994. Research needs-results of panel discussion. *In*: T. D. Prowse, ed. Proceedings of the workshop on environmental aspects of river ice. National Hydrology Research Institute, Saskatoon, Sask., 1993. NHRI Symposium Series No. 12:390 p.

Power, G., R. A. Cunjak, J. F. Flannagan, and C. Katopodis. 1993. Biological effects of river ice. Pages 97-119 *In*: T. D. Prowse and N. C. Gridley, eds. Environmental aspects of river ice. National Hydrology Research Institute, Saskatoon, Sask., 1993. NHRI Science Report No. 5:155 p.

Prowse, T. D., ed. 1994. Proceedings of the workshop on environmental aspects of river ice. National Hydrology Research Institute Symposium Series No. 12. Saskatoon, Saskatchewan, Canada.

Prowse, T. D. 1994. Environmental significance of ice to streamflow in cold regions. Freshwater Biology 32:241-260.

Prowse, T. D., and N. C. Gridley, eds. 1993. Environmental aspects of river ice. National Hydrology Research Institute, Saskatoon, Sask., 1993. NHRI Science Report No. 5:155 p.

Reimers, N. 1957. Some aspects of the relation between stream foods and trout survival. California Fish and Game 43:43-69.

Reiser, D. W., T. A. Wesche, and C. Estes. 1989. Status of instream flow legislation and practices in North America. Fisheries 14:22-29.

Riehle, M. D., and J. S. Griffith. 1993. Changes in habitat use and feeding chronology of juvenile rainbow trout (*Oncorhynchus mykiss*) in fall and the onset of winter in Silver Creek, Idaho. Canadian Journal of Fisheries and Aquatic Sciences 50:2119-2128.

Schrader, W. C. 1989. Trout mortality, movements, and habitat selection during winter in South Willow Creek, Montana. Master's thesis. Montana State University, Bozeman, MT.

Shirvell, C. S. 1989. Habitat models and their predictive capability to infer habitat effects on stock size. Pages 173-179 *In*: C. D. Levings, L. B. Holtby, and M. A. Henderson, eds. Proceedings of the national workshop on effects of habitat alteration on salmonid stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105.

Smith, R. W., and J. S. Griffith. 1994. Survival of rainbow trout during their first winter in the Henrys Fork of the Snake River, Idaho. Transactions of the American Fisheries Society 123:747-756.

Stalnaker, C. B. 1979. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. Pages 321-337 *In*: J. V. Ward and J. A. Stanford, eds. The ecology of regulated streams. Plenum Press, New York, N.Y.

Stalnaker, C. B., and J. L. Arnette. 1976. Basic stream flow measurements and relationships. Pages 16-34 *In*: C. B. Stalnaker and J. L. Arnette, eds.

Methodologies for the determination of stream resourece flow requirements: an assessment. Prepared for U.S. Fish and Wildlife Service. Prepared by Utah State University, Logan.

Tack, E. 1938. Trout mortality from the formation of suspended ice crystals. Fischerei-Zeitung 41:42. (Cited in Brown et al. 1994)

U. S. Fish and Wildlife Service (USFWS). 1981. Interim regional policy for New England stream flow recommendations. Newton Corner, Massachusetts. 3 p.

Walsh, W. A., and M. C. Walsh. 1995. The winter ecology of trout in Snowmass Creek, Colorado. Final report to the Snowmass Creek/Capitol Creek Caucus, Snowmass, CO. Walsh Aquatic Consultants, Westminster, CO.

Wesche, T. A., and P. A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Water Resources Research Institute, University of Wyoming, Eisenhower Consortium Bulletin 9. 122 p.

Williams, J. G. 1995. Report of the special master, water years 1990-1993. Alameda County Superior Court No. 425955, Environmental Defense Fund, Inc., vs. East Bay Municipal Utility District, et al., County of Sacramento, et al.

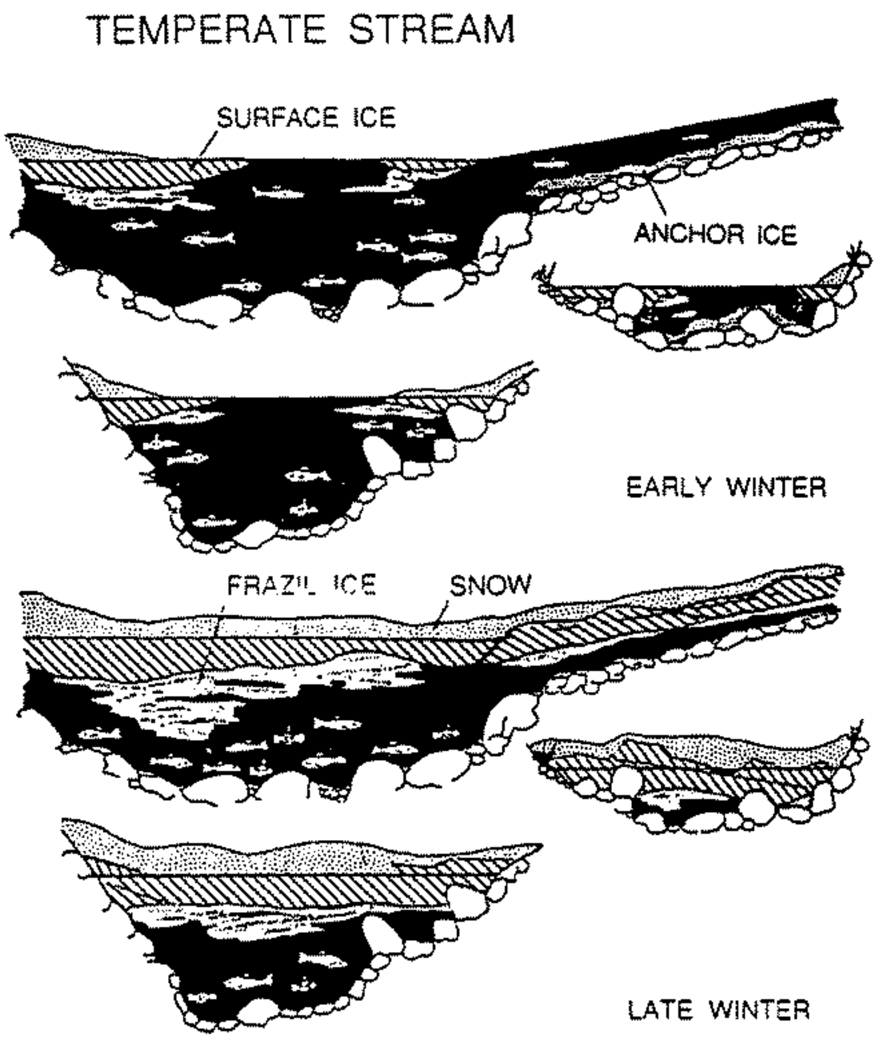


Figure 1. The change in available habitat in a temperate stream riffle and pool as winter progresses. The open sections in riffles may generate large amounts of frazil ice that restrict the habitat available to fish and may contribute to ice dam formation with subsequent effects on dischange. Figure reprinted from Prowse and Gridley (1993) with permission.

Table 1. Estimate of minimum winter streamflows for Snowmass Creek during October through March using the Mundie (1991) rule that flows should not be reduced by more than 25% to 30% of the mean monthly flows and not at all in periods of very low flows. "Loss" is estimated as the percent reduction in suitable velocities over brown and brook trout redds in Snowmass Creek (Walsh and Walsh 1995).

	Snowmass flows (cfs)[1]		Mundie	Loss (%)[2]	
Month	Mean	Median	flows	Brown	Brook
Oct	32.0	29.0	22.4	0	0
Nov	23.0	22.0	16.1	38	15
Dec	18.0	17.0	12.6[3]	66	34
Jan	14.0	14.0	14.0	56	26
Feb	13.0	12.0	13.0	64	32
Mar	12.0	11.0	12.0	72	38

[1]These estimates are USFS projections less 2.0 cfs for East Snowmass Creek diversions. The USFS estimated Snowmass Creek flows in their Watershed Supplemental Analysis (Appendix A).

[2]These percentages represent loss during ice-free conditions. Percent loss would be much higher during icing conditions (see text).

[3]We suggest that the Dec minimum should, in common sense, be the average of the Nov and Jan minima, or 15.0 cfs. This limit would reduce brown and brook trout incubation suitability by a respective 46% and 20%.

Table 2. Estimate of minimum winter streamflows for Snowmass Creek during October through March using the U.S. Fish and Wildlife Service rule of 0.5 cubic feet per second per square mile of drainage (cfsm) and 1.0 cfsm. The latter is used to protect spawning and incubation flows. "Loss" is estimated as the percent reduction in suitable velocities over brown and brook trout redds in Snowmass Creek (Walsh and Walsh 1995).

	Snowmass flows (cfs)[1]		USFWS minimum flows		Loss (%)	
Month	Mean	Median	0.5 cfsm	1.0 cfsm	Brown	Brook
Oct	32.0	29.0	19.8	39.5	0	0
Nov	23.0	22.0	19.8	39.5	0	0
Dec	18.0	17.0	19.8	39.5	0	0
Jan	14.0	14.0	19.8	39.5	0	0
Feb	13.0	12.0	19.8	39.5	0	0
Mar	12.0	11.0	19.8	39.5	0	0

[1]These estimates are USFS projections less 2.0 cfs for East Snowmass Creek diversions. The USFS estimated Snowmass Creek flows in their Watershed Supplemental Analysis (Appendix A).

Table 3. Estimate of minimum winter streamflows for Snowmass Creek during October through March using the Vermont Agency of Natural Resources rule of the February Median Flow (FMF) as the winter flow limit. "Loss" is estimated as the percent reduction in suitable velocities over brown and brook trout redds in Snowmass Creek (Walsh and Walsh 1995).

	Snowmass flows (cfs)[1]			Loss (%)[2]	
Month	Mean	Median	FMF	Brown	Brook
Oct	32.0	29.0	12.0	72	38
Nov	23.0	22.0	12.0	72	38
Dec	18.0	17.0	12.0	72	38
Jan	14.0	14.0	12.0	72	38
Feb	13.0	12.0	12.0	72	38
Mar	12.0	11.0	12.0	72	38

[1]These estimates are USFS projections less 2.0 cfs for East Snowmass Creek diversions. The USFS estimated Snowmass Creek flows in their Watershed Supplemental Analysis (Appendix A).

[2]These percentages represent loss during ice-free conditions. Percent loss would be much higher during icing conditions (see text).

Table 4. Estimate of minimum winter streamflows for Snowmass Creek during October through March using the Vermont 2/3 Median Flow for a Month limit. "Loss" is estimated as the percent reduction in suitable velocities over brown and brook trout redds in Snowmass Creek (Walsh and Walsh 1995).

	Snowmass flows (cfs)[1]			Loss (%)[2]	
Month	Mean	Median	2/3 Median	Brown	Brook
Oct	32.0	29.0	19.3	4	0
Nov	23.0	22.0	14.7	50	24
Dec	18.0	17.0	11.3	80	44
Jan	14.0	14.0	9.3	95	55
Feb	13.0	12.0	8.0	100	62
Mar	12.0	11.0	7.3	100	58

[1]These estimates are USFS projections less 2.0 cfs for East Snowmass Creek diversions. The USFS estimated Snowmass Creek flows in their Watershed Supplemental Analysis (Appendix A).

[2]These percentages represent loss during ice-free conditions. Percent loss would be much higher during icing conditions (see text).

Table 5. Estimate of minimum winter streamflows for Snowmass Creek during October through March using the PHABSIM and R-2 Cross results. "Loss" is estimated as the percent reduction in suitable velocities over brown and brook trout redds in Snowmass Creek (Walsh and Walsh 1995).

	Snowmass flows (cfs)[1]			Loss (%)[2]	
Month	Mean	Median	PHABSIM	Brown	Brook
Oct	32.0	29.0	7.0	100	68
Nov	23.0	22.0	7.0	100	68
Dec	18.0	17.0	7.0	100	68
Jan	14.0	14.0	7.0	100	68
Feb	13.0	12.0	7.0	100	68
Mar	12.0	11.0	7.0	100	68

[1]These estimates are USFS projections less 2.0 cfs for East Snowmass Creek diversions. The USFS estimated Snowmass Creek flows in their Watershed Supplemental Analysis (Appendix A).

[2]These percentages represent loss during ice-free conditions. Percent loss would be much higher during icing conditions.

APPENDIX A

Excerpts from the Snowmass Ski Area Expansion Watershed Supplemental Analysis by G. A. Kuyumjian, March 12, 1993.

Table 15: Peak daily supply (CFS) SWSD, December and January 1978 - 1992.

Year	December Date	December Peak Daily Supply	January Date	January Peak Daily Supply
1978	NA	NA	1	1.10
1979	27	2.52	12	1.97
1980	31	2.09	1	1.94
1981	31	1.82	6	1.36
1982	28	2.63	1	1.83
1983	30	2.96	4	2.31
1984	4	3.15	4	2.74
1985	28	2.60	1	2.39
1986	NA	NA	22	2.98
1987	30	3.19	NA	NA
1988	29	2.38	3	3.47
1989	28	2.51	27	2.35
1990	27	2.72	22	3.28
1991	15	3.95	2	2.43
1992	--	----	6	2.30

For comparative purposes, the increase in Peak Daily Use is displayed for 1978-1986 and 1987-1992.

	Peak Daily Use (cfs) 1978-1986	Peak Daily Use (cfs) 1987-1992	% Increase
December	2.54	2.95	16
January	2.07	2.77	34

The peak uses are somewhat less and may be influenced by the missing values but likely reflect a certain "saturation" at peak periods of skiers that can be associated with the growth of Snowmass Village and the Snowmass Ski Area. It is expected that these peak periods and demands can be buffered by the storage and delivery system of the SWSD.

SNOWMASS CREEK

Background - Snowmass Creek

Snowmass Creek, at the wier and diversion installed by the Snowmass Water and Sanitation District, has a watershed area of 39.5 square miles ranging in elevation from 8,250 feet to 14,092 feet at the summit of Snowmass Mountain. Most of the watershed above the wier is on National Forest lands, the wier is approximately 0.5 miles downstream of the Forest Boundary. The mean basin elevation is 10,800 feet with precipitation ranging from 20 - 45 inches, increasing with elevation, most of which falls as snow. Mean annual precipitation for the watershed is estimated to be 30 inches.

STREAMFLOW

A number of consulting firms have used a "synthetic hydrograph" of Snowmass Creek at the Snowmass Water and Sanitation District's (SWSD) wier that was developed by Wright Water Engineering and published by the Forest Service in previous documents on the expansion of Burnt Mountain. An evaluation of the hydrograph and the assumptions used has led to the development of a more refined version.

The following discussion is provided for an understanding of the background and assumptions used to develop the synthetic hydrograph, as Snowmass Creek does not currently have a recording gage. Recently, the wier was modified with the installation of a 5.5 foot rectangular sharp crested inner wier which can provide more accurate readings at lower flows. A recording level has also been installed to provide daily maximum, minimum and average flows. This data has been provided to the Forest Service by the SWSD. There are some icing problems that have resulted in days of questionable values. The diurnal variations are much higher than one would expect to see during baseflow conditions.

A reliable technique to use is the USGS WRIR Report #85-4086, "Estimation of Natural Streamflow Characteristics." This model was used by the Colorado Water Conservation Board (CWCB) as part of their evaluation to determine minimum streamflows for Snowmass Creek. The model is based upon the records of 123 gages in the mountainous region within the State of Colorado to provide estimates of flow. Relevant to this discussion are mean annual and mean monthly flows. Included in the model are the records of both Maroon and Castle Creeks, adjacent to Snowmass Creek. The estimated mean annual flow (using this model) for Snowmass Creek, at the weir, is 42.4 CFS. In comparison actual mean annual flows for Maroon Creek is 66.8 cfs and Castle Creek is 43.2 cfs. The Snowmass Creek watershed has geology similar to Maroon Creek but a lower mean basin elevation. Wright Water (1987) examined the basins in the area for comparative purposes and concluded basin size had the best correlation. Maroon Creek is adjacent with a common watershed boundary from the top of Baldy Mountain south to the Maroon Bells. Occasional discharge measurements have been made on Snowmass Creek and compared to flows on Maroon Creek; for the most part they were lower. The percentage differences were variable and a systematic procedure was not used.

In a report prepared for Pitkin County it was suggested that a "practical approach" be used (Miller 1992) and take the average of the flows computed by the CWCB using the USGS technical publication and those offered by Wright Water, which are an adjustment of Maroon Creek. While there is a lack of specific flow data for Snowmass Creek, there are two adjacent gauged watersheds with 22 years of continuous records. The maximum elevations are similar as is the geology, mapped by the USGS. It is realistic to assume that flows and yield would be similar. Aspects are both northeast, with a difference in area 39.5 vs 35.4 square miles. Mean basin elevation is 11,400 for Maroon Creek and 10,800 feet for Snowmass Creek. Primary factors for estimating flow are area and elevation. The USGS methodology referred to by Miller and used by the CWCB uses these two parameters to determine mean annual and mean monthly flows.

Using the computed mean annual flow for Maroon Creek and expressing it as a ratio of the actual flow, provides a mechanism to better estimate the mean annual flow of Snowmass Creek. This ratio adjusted the computed mean annual flow for Snowmass Creek from 42.4 cfs to 59 cfs. This falls into the range of confidence for the USGS model projection of 19 - 66 cfs for the 42.4 cfs value.
Another method one can use is the annual water yield in acre feet and calculate the mean annual flow based upon a unit area of yield. To determine this, the mean unit area yield of Castle and Maroon Creek was averaged, and the unit area was applied to Snowmass Creek, resulting in a mean annual flow of 63 cfs. The mean basin elevation of Snowmass Creek is lower than both these other gages, so the value could be adjusted downward, lending more support to the 59 cfs estimate (1090 ac ft/sq mi).

The only known diversion during the winter months is the SWSD's diversion from East Snowmass Creek. Until the fall of 1992 the maximum capacity of the pipeline was 2.1 cfs. Previous hydrographs have been reduced by 2 cfs from all values. At best, the reliability of the projected hydrograph would be the same plus or minus 25 percent of the data that was adjusted.

Table 16: Synthetic Monthly Flows Snowmass Creek at the SWSD's Diversion, adjusted Maroon Creek flows, Wright Water and CWCB projections.

	Mean	Median	25th%	10th%	Minimum	Wright Water Mean	CWCB Mean
October	34	31	29	25	16	32	14.9
November	25	24	20	19	13.0	23	10.9
December	20	19	16	14	11.0	18	8.3
January	16	16	14	11	9.2	18	7.0
February	15	14	12	11	9.5	16	6.7
March	14	13	12	10	9.7	15	7.4
April	17	15	12	11	10.0	18	19.8
May	65	54	38	29	25.0	72	91.3
June	219	218	192	147	81.0	245	187.9
July	181	183	118	71	33.0	196	71.2
August	78	76	57	40	24.0	87	32.6
September	46	44	35	30	20.0	52	19.2

All synthetic data for Forest Service projections based upon data published by the USGS for the adjacent gauged watershed, Maroon Creek - Water Years 1970 thru 1991 (22 years).

The mean projection is not radically different than those developed by Wright Water but are higher than those calculated by the CWCB using the USGS model, especially during the low flow months. Diversions from East Snowmass Creek are not subtracted from these projections.

PEAK FLOWS

Snowmass Creek has its highest flows during snowmelt runoff with peak flows occurring in June or early July. Wright Water estimated an average peak daily flow of 399 cfs for the period of 1970 - 1989. Again the Maroon Creek data was used and adjusted to reflect a synthetic peak estimate for Snowmass Creek. The Wright Water Estimates are displayed for comparative purposes. The results are similar, with the only major difference in the one in ten year flood flow (10 percent exceedence). While this estimate is high compared to the Wright Water figure, the peak flow recorded for the period of record for Maroon Creek is 836 cfs, which occurred on June 22, 1980.

Table 17. Estimated Peak Flows, Snowmass Creek at the SWSD diversion.

Recurrence Interval	Peak Flow (cfs)	Wright Water Estimate(cfs)
Bankfull (1.5)	372	364
Mean Annual Flood (2.3)	431	441
90 percent exceedence	200	217
25 percent exceedence	520	504
10 percent exceedence	780	520

On March 3 1992, a discharge measurement below the SWSD Weir was made by Mr. W. Goin of Minion Hydrology. He measured a flow of 7.6 cfs, with a "good" level of confidence, plus or minus 5 percent; the flow could be from 7.2 - 8.0 cfs at the time of measurement. With the 2 cfs from East Snowmass Creek, this would be 9.2 - 10.0 cfs, ranging from below the minimum estimate to above the 10th percentile. The USGS on the same day at approximately the same time made a discharge measurement on Maroon Creek of 13.1 cfs and later that day made a discharge measurement at Castle Creek and reported 10.9 cfs. One spot measurement is not adequate to build any correlation. The weather on that day was mostly cloudy with temperatures in the mid to high 30's during the day, which could increase flows later in the day. The readings are considered to be fair, plus or minus 8% of actual flow, so actual flows could be from 12.1 - 14.1 cfs for Maroon Creek and 10.0 - 11.8 cfs for Castle Creek.

Recently, other instantaneous flows have been measured on Snowmass Creek and provided to the Forest Service by William Johnson of Earth Resources Investigations, Inc. Immediately downstream of the SWSD diversion, the following discharge measurements were recorded at approximately 10:00 each day.

Date	Flow
January 16, 1993	11.20
February 11, 1993	9.08
March 3, 1993	14.16

The level of accuracy is considered to be "good", so the above values are plus or minus 5 percent. The recording measurements, supplied by the SWSD, at the wier on February 11 were a mean of 10.4 cfs, a maximum of 10.64 cfs, and a minimum of 10.22 cfs.

Downstream of the diversion (and possibly upstream), Snowmass Creek has some complex hydrology that is difficult to quantify with the information currently available to the Forest Service. Snowmass Creek appears to be a gaining stream downstream of the diversion. This was observed during a site visit to Snowmass Creek on November 20, 1992. Discharge measurements were not taken. Earth Resources investigations provided calculations of flow from a point approximately 0.8 miles downstream of the diversion that showed an average increase of 5.6 cfs. Further downstream at a point approximately 1.3 miles from the discharge measurements were taken and showed an average increase of 3.6 cfs above those at the weir. There is not enough site specific data available to draw conclusions other than the stream appears to gain flow downstream of the diversion and then start losing it farther down gradient. Inflows into the ponded area created by the diversion were not taken. It is possible that some of the increase could be attributed to recharging of the unconfined aquifer by the storage behind the weir that is "forced" back into the channel by some sub-surface nick point. Snowmass Creek has not been segmented out by gaining and losing reaches. Also, not available to the Forest Service is the duration and magnitude of increases during those periods when snowmaking would occur.

The data supplied by the SWSD for February 1993 showed some days with a diurnal variation greater than a value expected. There are days when the variation is less than 0.5 cfs and others in the range of 4 - 6 cfs. Through personal experience and evaluation of data, I would not expect to see baseflow variation any greater than 2 cfs during the winter low flow period for a watershed the size of Snowmass Creek, especially with the predominantly north aspect. Some of the variation can be attributed to ice formation within the weir pond which can artificially raise the level of the reading. The majority of snowmelt that would happen this time of year that would result in streamflow comes from within or directly adjacent to the channel in areas with a high energy exposure (ex: south facing slopes). More speculative in nature, could be a relationship with increases in temperature and barometric pressure that is resulting in increased streamflow. Another plausible explanation is the formation and dispersal of anchor ice. In a study of Convict Creek, California, typical daily flows varied by 4 cfs, with one day having a mean flow of 9.8 cfs with a peak flow of 16.4 cfs (Maciolek and Needham, 1952). They attributed these daily variations to the formation and dispersal to anchor ice.

In comparing the synthetic hydrograph with the available information, and accounting for upstream and pump station diversions, this water year is approximating the 25th percentile mean monthly flows. Assuming a one cfs diversion at East Snowmass Creek and using information provided by the SWSD, the mean monthly flow in February 1993 was 12 cfs.

STREAM DESCRIPTION

In a report for the Aspen Ski Company, Snowmass Creek is described as appearing to have relatively poor trout habitat (Chadwick 1992). The report goes on to state, "This was due to the wide, shallow nature of the stream. There appeared to be few areas of the stream with deep pools, runs or boulders to provide holding water for larger trout." The description from the field survey notes of Jay Skinner (CDOW) and Greg Espegren (CWCB) taken 130 yards downstream of the SWSD diversion on October 23, 1991, state "stream, blown out and steep, all glide." Chadwick and associates surveyed Snowmass Creek collecting Instream Flow Incremental Methodology (IFIM) habitat and hydraulic data were collected in a two-mile section of Snowmass Creek immediately downstream of the SWSD diversion. Their entire report is in the Appendix. The Forest Service has not made a similar survey as we have no jurisdiction on lands off National Forest other than to describe and disclose the best information available. In the examination of

APPENDIX B

Excerpts from a report prepared by W. W. Wheeler and Associates, Inc. for the Snowmass Water and Sanitation District.

WATER RESOURCES INVESTIGATION
FOR
PROPOSED SNOWMAKING DIVERSION
CASE NO. 92CW307

FOR
SNOWMASS WATER AND SANITATION DISTRICT

BY
W. W. WHEELER AND ASSOCIATES, INC.
WATER RESOURCES ENGINEERS
ENGLEWOOD, COLORADO

JUNE 1995

1257\SNOWRIT.RPT

PART 1 INTRODUCTION

In December, 1992, the Snowmass Water & Sanitation District (SWSD) filed application with the Division 5 Water Court for surface water rights from Snowmass Creek and from East Snowmass Creek in Case No. 92CW307. The intent of the application was to obtain additional direct flow rights for municipal purposes by the SWSD, including snowmaking at the Snowmass Ski Area. The application requests an appropriation date of May 28, 1992 and two points of diversion; one at an existing diversion structure on East Snowmass Creek (*the East Snowmass and Brush Creek Pipeline*)and another at an existing diversion on Snowmass Creek (*the Snowmass Creek Pipeline*). The amounts claimed were 5.1 cfs and 6.0 cfs, at the two locations, respectively. On May 24, 1993, the Water Referee for Division 5 entered a ruling approving the application as filed. A number of parties protested the ruling and the case was re-referred to the Water Judge.

In the interest of narrowing the disputed issues and attempting to address concerns by the protesting parties, the SWSD voluntarily offered to limit the new appropriation to only snowmaking purposes. The SWSD has also offered to limit the maximum diversion rate at the two points of diversion to a cumulative total of no more than six cfs. The primary season of use for the water right would be during the late fall and winter months, October through December, with small amounts diverted during the later winter months for patching in the heavily used trails at the Ski Area. Throughout this report, the primary snowmaking season will be defined as the period from October 18 through December 31.

W. W. Wheeler and Associates, Inc. (Wheeler) was retained by the SWSD to analyze the availability of water in the Snowmass Creek drainage to support the appropriation claimed in Case No. 92CW307 and to evaluate the reliability of the snowmaking diversions in wet, average and dry runoff years, after consideration of the senior rights of others. This report provides a summary of the investigations relating to the hydrological conditions in the Snowmass Creek watershed; the analysis regarding the projected demands for snowmaking, municipal and other uses by senior water rights; and

Wheeler's conclusions with respect to the availability of water for the proposed diversions, assuming strict administration of water rights on the Colorado River and its tributaries.

PART 4 SNOWMASS CREEK HYDROLOGY

As described in the application in Case No. 92CW307, the proposed snowmaking diversions are to be made at existing facilities operated by the SWSD, either on East Snowmass Creek or the main stem of Snowmass Creek. Although Snowmass Creek is a major tributary of the Roaring Fork River, there are no long-term records of the flow in this stream. Therefore, it is necessary to estimate the streamflow by hydrologic correlation to other similar streams in the area which do have historic flow records. Such streams in the immediate vicinity include the Roaring Fork at Aspen, Castle Creek, Maroon Creek and the Crystal River. For this analysis, the Maroon Creek watershed was judged to be the most hydrologically similar to the Snowmass Creek basin and the records at the USGS stream gage on Maroon Creek were used to synthesize flows in Snowmass Creek. The Maroon Creek drainage is directly adjacent to Snowmass Creek, it has a similar aspect, similar mean basin elevation (above the gage on Maroon Creek in comparison to above the SWSD diversion on Snowmass Creek) and similar annual precipitation. The hydrologic characteristics of the two drainage basins are summarized in Table 4. The location of the drainage basins is shown on Figure 2.

TABLE 4
MAROON CREEK AND SNOWMASS CREEK
DRAINAGE BASIN CHARACTERISTICS

NAME	DRAINAGE AREA (SQ-MI)	MEAN BASIN ELEVATION (FT. MSL)	GAGE ELEVATION (FT. MSL)	AVERAGE PRECIPITATION (IN/YR)
Maroon Creek	35.4	11,350	8720	41.6
Snowmass Creek	39.5	11,190	8240	37.9

It is also noted that as part of the extensive hydrologic investigations performed by the USFS for the Burnt Mountain FEIS, Maroon Creek was adopted for purposes of estimating the flows in Snowmass Creek.

The USGS recorded flows at the Maroon Creek gage from October 1969 through September 1994. This study period includes the extremely dry runoff years experienced during 1977 and 1978. Inspection of longer term flow records of the Roaring Fork River, measured at Glenwood Springs, indicates that the minimum flow conditions during the fall and winter months of 1977 and 1978 were approximately the same as those experienced during other dry year cycles, including those of the mid-1950 and mid 1960's. Accordingly, the study period of 1969 through 1994 is considered to be representative of long term hydrologic conditions and use of these records is appropriate for this study.

After review of the hydrology studies performed for the Burnt Mountain FEIS, it was reasonable and appropriate, in our judgment, to adopt a similar approach to correlate Snowmass Creek flows to those of Maroon Creek. The initial step in the process was to develop a synthetic hydrograph for both drainage basins using procedures outlined by the USGS in "Water Resources Investigation Report 85-4086; Estimation of Natural Streamflow Characteristics in Western Colorado". This methodology provides a generalized means of estimating mean monthly flows based on multiple regression analyses using measured flow records for 264 stream gages in Western Colorado, including most of the gages in the vicinity of Snowmass Creek. The regression equations relate streamflows to a number of characteristics of the respective drainage basins, including tributary drainage area, mean basin elevation, mean annual precipitation and mean slope of the basin. Although a generalized approach, it provides a means of directly relating the hydrology of the two basins based on characteristics directly related to runoff.

Mean monthly discharge values for the months of October, November and December were estimated using the USGS procedures. For each month, the ratio of the synthesized flow for Snowmass Creek (at the SWSD diversion) over the synthesized flow of Maroon Creek (at the USGS gage) was determined. These monthly ratios were then multiplied by the actual measured flow at the Maroon Creek gage to generate mean monthly flows for Snowmass Creek. The correlation analyses resulted in the following adjustment factors, representing the ratio of Snowmass Creek flows to the measured flows at the Maroon Creek gage. For purposes of comparison, the adjustment factors derived from the USFS correlation studies in the FEIS are also shown. Note that the adopted factors are slightly more conservative than those used in the FEIS.

TABLE 5 MONTHLY ADJUSTMENT FACTORS FOR MEAN MONTHLY DISCHARGE		
MONTH	ADJUSTMENT FACTOR	FBS FACTOR
OCT	0.815	0.88
NOV	0.861	0.88
DEC	0.872	0.91

The adjustment factors shown in Table 5 and the daily flows measured at the USGS gage on Maroon Creek were used to generate daily flow values at the SWSD diversion structure on Snowmass Creek. These flows can be considered as "virgin flows" unaffected by any upstream diversions and/or depletions attributable to the activities of man. The results of the flow simulation analysis are summarized in Table 6 which is a summary of the mean daily flow for each month of the snowmaking season for the 1969-1993 study period.

TABLE 6 ESTIMATED MEAN DAILY FLOW OF SNOWMASS CREEK AT SNOWMASS CREEK PIPELINE DIVERSIONS (Values in cfs)			
YEAR	OCT	NOV	DEC
1969	30.0	23.8	18.5
1970	35.9	29.5	22.2
1971	28.7	23.4	19.6
1972	29.9	25.0	18.0
1973	28.6	21.4	17.9
1974	23.4	22.2	19.2
1975	27.5	21.3	16.9
1976	27.7	19.9	16.5
1977	14.7	12.9	10.5
1978	22.9	18.3	14.8
1979	27.2	19.7	15.7
1980	32.6	23.7	19.7
1981	26.9	21.0	15.2
1982	47.3	29.6	22.2
1983	37.9	30.2	25.0
1984	54.8	38.3	31.4
1985	41.9	33.4	25.8
1986	50.2	37.7	25.9
1987	28.7	24.3	20.3
1988	27.9	23.1	18.8
1989	24.3	19.4	13.2
1990	24.3	19.4	15.0
1991	26.9	21.5	17.8
1992	30.6	24.1	21.0
1993	41.1	33.9	25.6
AVG	31.7	24.7	19.5