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THE RELATIVE MERITS OF THE MODIFIED SAG-TAPE METHOD FOR DETERMINING INSTREAM FLOW REQUIREMENTS

by

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Abstract

As part of an ongoing examination of waters impacted by the Bonneville Unit of the Central Utah Project, this study was undertaken to: (1) evaluate the effectiveness of the "modified sag-tape method" for determining instream flow requirements; (2) compare results derived from this study with results from application of the "Montana method" and the "Forest Service method" as used by the Bureau of Reclamation in the same study area. Based on this study, it was concluded that all three methods are effective in determining instream flow requirements. The "Forest Service method" is expensive and time-consuming. The "Montana method" and the "modified sag-tape method" are both quick, easy to apply, and relatively inexpensive. The readily available program analysis capability of the "modified sag-tape method" facilitates computed physical data for the actual streamflow at the time of measurement, as well as for selected water stages above or below the field measured value.

Acknowledgements

To all those who contributed their time and labors during the course of this study through data collection, review and comment, and encouragement, we extend our deepest thanks. Personal recognition and appreciation are extended to Mr. Eddie Kochman of the Colorado Division of Wildlife and Mr. Lee Silvey of the U. S. Forest Service, without whose help and advice this endeavor would have been next to impossible. Final thanks to "Mother Nature," whose natural resources benefit us all.

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Introduction

For some time now, biologists have been searching for a simplified method for measuring and recording stream flow information that would: (1) allow them to make flow recommendations for perpetuation of viable fisheries, and (2) be universally acceptable in both the scientific and legal worlds. It was with this in mind that this study was undertaken.

Our objectives were:

1. To evaluate the relative merits of the "modified sag-tape method" of channel cross section measurement for determination of instream flow requirements.

2. To compare stream flow recommendations made from application of the "Montana method," with recommendations derived from the "modified sag-tape method" (2,8).

3. To compare our results with those of the Bureau of Reclamation's study team, who, using a habitat inventory/discharge correlation methodology (Forest Service method) would update flow recommendations in the same study area (6).

Study Area

The stream chosen for this investigation was the Strawberry River, Wasatch County, Utah, a stream impacted by the Bonneville Unit of the Central Utah Project. The study was conducted on a 20-mile reach from Soldier Creek Dam downstream to the Strawberry River-Red Creek confluence (figure 1). The Strawberry River is especially well suited for such a study because:

1. It is easily accessible and provided a unique opportunity to collect data at various controlled flows released from Soldier Creek Dam.

2. The disparity between original recommendations made by the U. S. Fish and Wildlife Service (15 and 42 cfs) and the flow proposed by the Bureau of Reclamation (4 cfs) could be evaluated. The original two-flow recommendation made by the U. S. Fish and Wildlife Service in 1972 was derived from application of a modified "Montana Method."

3. It is designated as a blue-ribbon trout stream by the Utah State Division of Wildlife Resources, and establishment of flow criteria is important if this river is to remain a quality fishery.

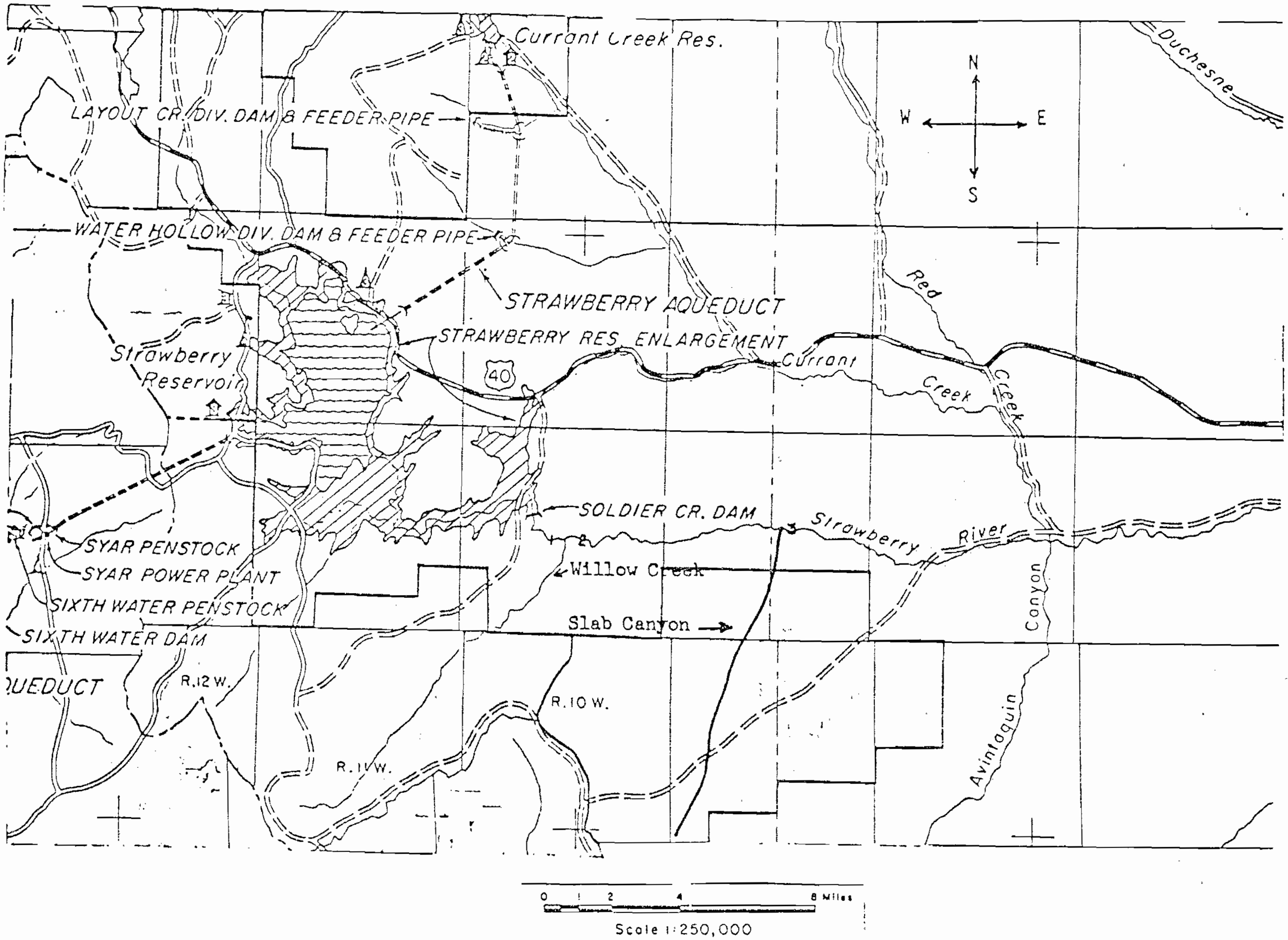


Figure 1 - Study Area Map

Methods

Collection of field data was preceded by the selection of three "critical area" cross sections. A critical area as it applies here is a riffle that would be most drastically affected by a change in flow and supplies the following: (1) a spawning area, (2) a food production area, or (3) a travel lane from pool to pool. Reduction or removal of a stream's capacity to supply these attributes is "critical" to maintaining a viable fishery. The locations of the three critical area cross sections are (figure 1):

Station #1 - 1 1/4 miles below Soldier Creek Dam
Station #2 - 2 miles below Soldier Creek Dam
Station #3 - 100 yards below Slab Canyon

The "sag-tape method," developed by C. A. Shumway and further refined by the U.S. Forest Service (1), was modified by us to include the use of a stadia rod and transit. The transit was used to obtain more accurate water depth measurements and slope determinations.

The first step in our procedure involved driving two wooden stakes, one at each end of the cross section (figure 2). Each stake was placed so the cross section was at right angles to the direction of streamflow and representative of the bank slopes. It is important that the stakes be placed far enough above the water's surface so projections of higher or lower flows can be manipulated by the computer later on.

Next, the transit was set up and leveled on the near bank in direct line with the cross section. The near bank stake was established as our zero point (ZP), and a first transit reading was taken from the stadia rod placed at ground level next to the ZP stake (figure 3). This reading was noted and recorded on the data form. (Appendix A)

The far bank stake, established as the end point (EP), was then set to match the reading taken at the ZP stake. This establishes an imaginary reference datum line (RDL) parallel to the water's surface, thus eliminating variations in sag of the tape. After the stakes were in place and parallel to the water's surface, a tape was stretched across the cross section and fastened to stakes at both ends.

Figure 2

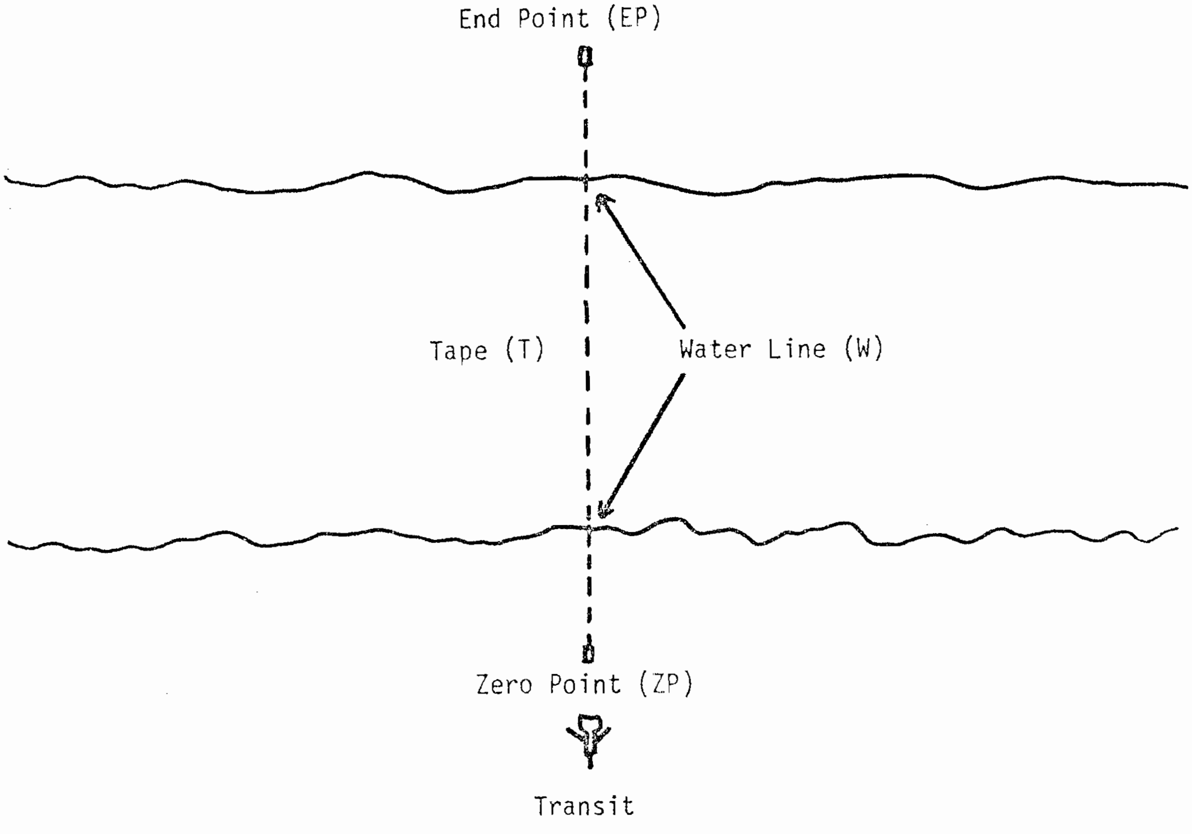
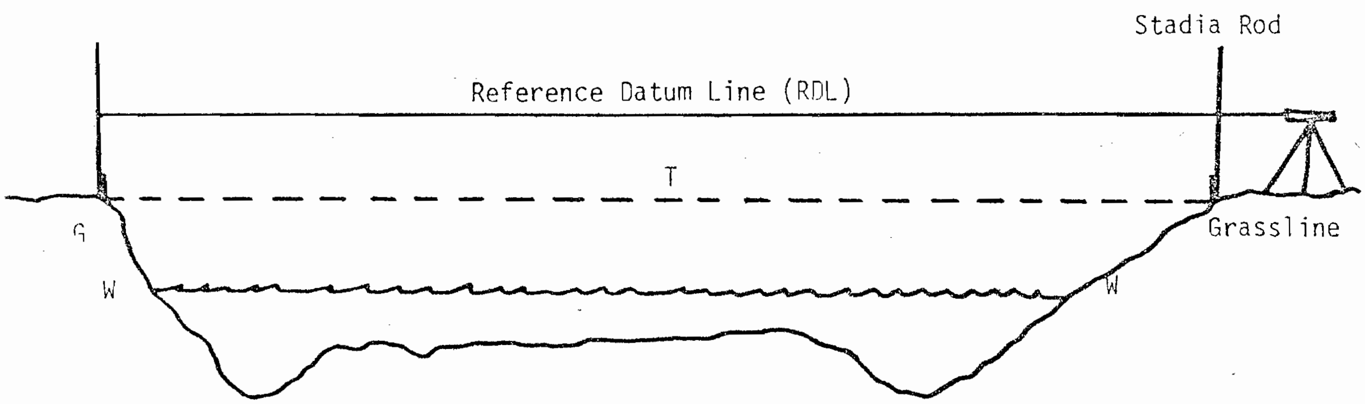


Figure 3

Cross-Section Profile



Distances from the ZP to waterlines (W) on both near and far banks were noted and recorded on a field data form. (Appendix A) Starting from the ZP, transit readings were taken at one-foot intervals across the entire cross section by placing the stadia rod on the ground surface or channel bottom and recording the readings gained by sighting through the transit.

The stream gradient was determined by measuring 50 feet upstream, placing the stadia rod at W and recording the transit reading. The difference between this reading and the W measurement taken at the cross section yields the gradient or slope of the stream reach. While this is the technique we used for determining the slope, we now realize it would have been better to measure 50 feet upstream and 50 feet downstream in determining gradient.

The next step of our procedure involved onsite measurements of stream flow taken at the time the cross section was measured. To accomplish this task, a calibrated rod suspension Gurley meter (No. FE-39) equipped with AA cups was used.

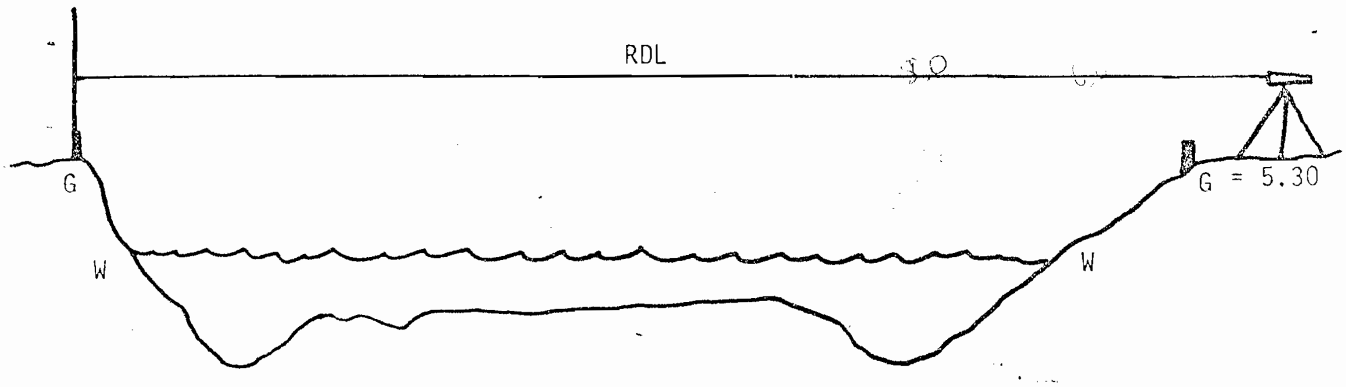
The method employed for collection of flow data, similar to the method used in establishing the cross section profile, was to begin at the near-bank waterline and record water depths and revolutions in time at one-foot intervals across the entire section. Each flow measurement was taken by setting the Gurley meter cups at six-tenths of the water's depth at that point. Velocities were derived from application of the USGS rating table, i.e., conversion of revolutions in time (seconds) to velocities in feet per second. Velocities in feet per second were then converted to cubic feet per second (cfs). Photographs were taken of the cross section, for identification purposes and a visual representation of each flow level.

This procedure was followed at each of the three "critical areas" and remained the same throughout the study. Cross section profiles and flow measurements were taken at four controlled releases from Soldier Creek Dam of 4, 12, 25, and 50 cfs.

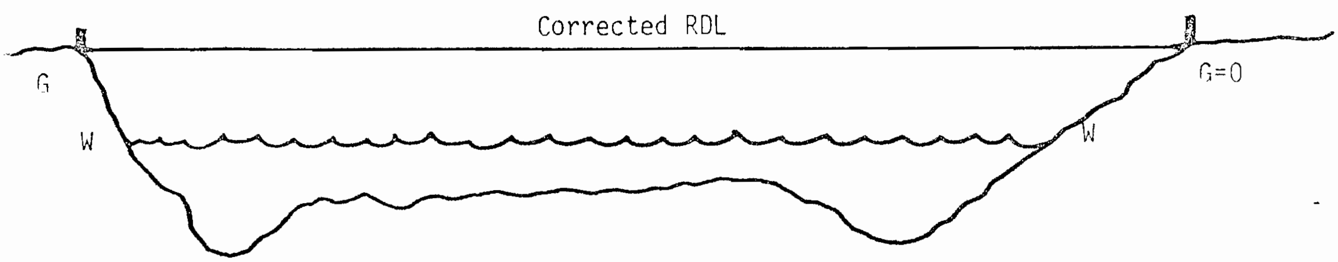
Once the field data were collected, they were then prepared for computer analysis. The first step was to correct the RDL to grassline (G). This was accomplished by subtracting the depth measurement at G from all other depth measurements across the cross section. This procedure effectively lowers the RDL to a level that is truly representative of the channel, making G = 0 (figure 4).

After reestablishing the RDL at a usable level, our field data were then analyzed via the R-2 cross program on a computer system

Figure 4



Grassline = 5.30-5.30=0



provided by the Colorado Division of Wildlife, Denver, Colorado. Our data were analyzed a second time, using the same methodology, by U.S. Forest Service Hydrologist Lee Silvey, with virtually identical overall results. We applied the R-2 cross program as explained in the following steps (1,3).

Step A - The Basic Computer Plot of the Measured Cross Section

Step A produces a channel cross section printout and, if desired, a "plot" of the measured cross section on 10 x 10 to the inch graph paper can be produced by a Calcomp plotter. The printout will also list the cross section area in square feet, maximum depth in feet from the water level to the thalweg, wetted perimeter in feet, hydraulic radius (area/wetted perimeter) in feet, measured slope or gradient of the stream reach in percent; selected or calculated Manning's "n" (roughness coefficient), water flow in cubic feet per second, and average velocity in feet/second.

The "maximum depth" value given on the Step A printout is used to establish the reference datum line on the graph paper "plot" (or the cross section printout). Simply measure with a scale, vertically up from the deepest point shown on the cross section, the maximum depth as shown. A line drawn perpendicular to this vertical will then become the "reference datum" and represent the computer corrected tape line. In the case where those hydrologic data are listed on the Step A printout, the computer has assumed a water level equal to the reference datum line. Measurements from the reference datum line to the actual water level, or selected water levels, are used in the following program Steps B and C.

Step B - Developing Information to Calculate a Manning's "n" Value

To complete the CROSS program analysis, accurate field measurements of the stream discharge or flow are needed. It is also important to have noted on the field form the distance from the zero point to both the first and furthest waterlines. The waterline or level, as interpreted from the field notes, is drawn directly on the graph paper "plot," or in the event a Calcomp plotter is not available, the cross section printout can be used. The necessary data to run Step B includes:

1. A depth value, identified in the program writeup as "depth to water," which is the difference between the maximum depth from the "reference datum" to the channel bottom and the actual water depth at that point. In effect, this value is the distance to the nearest tenth of a foot from the computer corrected RDL level to the waterline.

2. Two distance values: the distance in feet from the zero point to the first streambank-waterline intersect and the distance in feet from the zero point to the furthest streambank-waterline intersect. These data are obtained from the cross section "plot" on which the waterline has been drawn.

3. Total length of tape spanning the cross section, in feet, from zero point to end point.

4. A selected or theoretical Manning's "n" (roughness coefficient) value. A value developed from field observations may be used, or if unknown, use .055 for the "B" run.

5. The slope or gradient of the stream reach in percent.

Step B provides a list of hydrologic parameters described in Step A for the cross section as it existed at the time of measurement, along with a second cross section printout. Once the data from Step B are obtained, they are used to calculate a new Manning's "n" value for use in Step C. Manning's formula is solved for "n" using the area, hydraulic radius, and slope data from the Step B printout; and the field measurement of stream discharge. A rerun of Step B using the calculated "n" value results in a computed flow that matches the field measured flow almost exactly.

Step C - Stream Discharge and Hydrologic Parameters at Various or Selected Water Stages, Above or Below the Waterline Existing at the Time of Field Measurement

Step C provides a range of hydrologic parameter values related to changes in the water stage of the cross section. These value ranges are used in supplement with aquatic or esthetic parameters to determine or estimate the minimum instream flows necessary at the location of the described cross section.

To run Step C, simply change the depth to water value (the distance from the "reference datum" to the new or selected waterline) and determine the corresponding changes in waterline-streambank interest distances using the "plot" from Step A (or the cross section printout), and enter these data on the card-punch form. Also, enter the calculated value for Manning's "n" developed in Step B. The remaining information necessary for running Step C includes the same total length of tape and slope data as used in Step B. Step C will produce a cross section and printout with the above described hydrologic parameters (Step A) for each new or selected water stage, and while we used up to 10 different stages, as many or as few as desired may be run.

With the completion of Step C, calculations were done to determine average depth and percent wetted perimeter for each projected water stage. These values, along with average velocity and flow (cfs) for each of the 10 water stages were arranged in tabular form for comparison (tables 1-4). Average depth, average velocity, and percent wetted perimeter were the parameters used to determine instream flow requirements at the location of the critical cross sections. The criteria for judgment, as used by the Colorado Division of Wildlife and accepted by other state and federal biologists, are as follows (3,5):

Average depth = .4 of a foot
Average velocity = > 1 foot per second
Wetted perimeter = 50%+

~~where have these~~ What is rationale for these #'s.

Note: for maintenance of streams > 20 feet and < 60 feet in width, a minimum of 50 percent wetted perimeter must be maintained while meeting at least one of the other requirements. Maintenance and optimum flows were determined for each station at each controlled release from Soldier Creek Dam. All results were analyzed and final recommendations were formulated. We then compared our results with results derived from the "Montana method" and the "Forest Service method."

Station #1 (5.57 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.88	1.77	96	48	
2	.80	1.64	95	40	
3	.71	1.52	95	32	
4	.62	1.38	94	26	>22
5	.52	1.24	93	19	
6	.43	1.08	93	14	>12
7	.33	.92	92	9	
8	.24	.80	82	6	
9	.35	.98	38	4	
10	.29	.85	35	3	

Station #1
(5.57 cfs)

Station #2 (8.15 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.65	4.19	93	113	
2	.55	3.77	92	87	
3	.46	3.31	92	63	
4	.36	2.82	91	42	
5	.26	2.31	89	25	25
6	.17	2.10	66	14	>11
7	.10	1.93	46	8	
8					
9					
10					

Station #2
(8.15 cfs)

Station #3 (21.21 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.65	2.93	95	72	
2	.55	2.63	95	55	
3	.46	2.32	94	40	
4	.36	1.97	94	26	26
5	.27	1.74	82	17	>16
6	.49	2.49	31	15	
7	.42	2.25	29	11	
8	.38	2.06	26	8	
9					
10					

Station #3
(21.21 cfs)

Table 1 - Strawberry River, 4 cfs release at Soldier Creek Dam. Measured flows noted in parentheses. (Recorded September 4-5, 1975.)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.56	3.17	94	53	
2	.47	2.80	93	39	
3	.37	2.40	92	26	26
4	.28	2.04	88	17	
5	.29	2.03	60	11	11
6	.35	2.30	35	9	
7	.26	2.03	30	6	
8					
9					
10					

Station #1
(16.78 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.81	2.21	94	77	
2	.72	2.04	93	62	
3	.62	1.85	93	49	
4	.52	1.66	93	37	
5	.41	1.42	90	24	24
6	.32	1.20	89	16	
7	.23	1.00	85	10	10
8					
9					
10					

Station #2
(36.31 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.62	3.60	95	88	
2	.52	3.22	94	66	
3	.42	2.85	91	47	
4	.34	2.45	87	31	31
5	.25	2.10	80	19	>18
6	.40	2.75	37	17	
7	.40	2.81	27	13	
8	.36	2.55	24	9	
9					
10					

Station #3
(46.12 cfs)

Table 2 - Strawberry River, 12 cfs release at Soldier Creek Dam. Measured flows noted in parentheses. (Recorded July 8, 1975.)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.56	3.17	94	53	
2	.47	2.80	93	39	
3	.37	2.40	92	26	26
4	.28	2.04	88	17	
5	'.29	2.03	60	11	11
6	.35	2.30	35	9	
7	.26	2.03	30	6	
8					
9					
10					

Station #1
(16.78 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.81	2.21	94	77	
2	.72	2.04	93	62	
3	.62	1.85	93	49	
4	.52	1.66	93	37	
5	.41	1.42	90	24	24
6	.32	1.20	89	16	
7	.23	1.00	85	10	10
8					
9					
10					

Station #2
(36.31 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.62	3.60	95	88	
2	.52	3.22	94	66	
3	.42	2.85	91	47	
4	.34	2.45	87	31	31
5	.25	2.10	80	19	>18
6	.40	2.75	37	17	
7	.40	2.81	27	13	
8	.36	2.55	24	9	
9					
10					

Station #3
(46.12 cfs)

Table 2 - Strawberry River, 12 cfs release at Soldier Creek Dam. Measured flows noted in parentheses. (Recorded July 8, 1975.)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.74	3.13	94	72	
2	.65	2.86	93	57	
3	.56	2.58	93	44	
4	.46	2.28	92	32	
5	.37	1.99	87	21	21
6	.29	1.69	83	14	>12
7	.39	2.08	37	10	
8	.38	1.98	31	7	
9	.28	1.74	26	5	
10					

Station #1
(31.76 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.76	2.56	94	83	
2	.67	2.35	93	66	
3	.57	2.12	93	51	
4	.48	1.87	92	37	
5	.37	1.58	90	24	24
6	.27	1.32	87	15	
7	.21	1.11	61	7	7
8	.32	1.47	25	5	
9					
10					

Station #2
(37.07 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.73	2.81	95	81	
2	.63	2.56	94	64	
3	.54	2.33	91	49	
4	.47	2.10	87	36	
5	.37	1.81	85	24	24
6	.28	1.50	84	15	>14
7	.37	1.84	41	12	
8	.43	1.97	29	10	
9					
10					

Station #3
(49.27 cfs)

Table 3 - Strawberry River, 25 cfs release at Soldier Creek Dam. Measured flows noted in parentheses. (Recorded August 4-5, 1975.)

Station #1 (31.76 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.74	3.13	94	72	
2	.65	2.86	93	57	
3	.56	2.58	93	44	
4	.46	2.28	92	32	
5	.37	1.99	87	21	21
6	.29	1.69	83	14	>12
7	.39	2.08	37	10	
8	.38	1.98	31	7	
9	.28	1.74	26	5	
10					

Station #2 (37.07 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.76	2.56	94	83	
2	.67	2.35	93	66	
3	.57	2.12	93	51	
4	.48	1.87	92	37	
5	.37	1.58	90	24	24
6	.27	1.32	87	15	
7	.21	1.11	61	7	7
8	.32	1.47	25	5	
9					
10					

Station #3 (49.27 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.73	2.81	95	81	
2	.63	2.56	94	64	
3	.54	2.33	91	49	
4	.47	2.10	87	36	
5	.37	1.81	85	24	24
6	.28	1.50	84	15	>14
7	.37	1.84	41	12	
8	.43	1.97	29	10	
9					
10					

Table 3 - Strawberry River, 25 cfs release at Soldier Creek Dam. Measured flows noted in parentheses. (Recorded August 4-5, 1975.)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.84	3.41	93	87	
2	.74	3.15	93	71	
3	.65	2.88	92	56	
4	.54	2.62	88	42	
5	.45	2.31	87	31	
6	.36	1.98	87	21	21
7	.36	1.96	62	14	>13
8	.46	2.25	38	12	
9	.41	2.12	33	9	
10					

Station #1
(56.41 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.75	2.97	93	94	
2	.65	2.71	92	74	
3	.55	2.44	92	57	
4	.45	2.13	89	40	
5	.35	1.82	89	26	26
6	.26	1.49	86	16	
7	.22	1.38	54	8	8
8	.32	1.69	24	6	
9					
10					

Station #2
(57.16 cfs)

Projections	Average depth (ft.)	Average velocity (f/s)	% wetted perimeter	Flow (cfs)	
1	.74	3.45	94	101	
2	.65	3.15	94	80	
3	.55	2.83	93	61	
4	.44	2.48	91	42	
5	.35	2.11	90	28	28
6	.25	1.77	85	17	17
7	.45	2.51	33	16	
8	.37	2.17	33	11	
9					
10					

Station #3
(61.16 cfs)

Table 4 - Strawberry River, 50 cfs release at Soldier Creek Dam. Measured flows noted in parentheses. (Recorded August 19, 1975.)

Results

Tables (1-4) represent computer analyses of the three critical cross sections at four different controlled releases from Soldier Creek Dam. Stream discharge and other parameters at selected water stage projections, above or below the waterline existing at the time of field measurement, were developed by application of the R-2 cross program. These values are used to determine instream flow requirements at the location of the critical cross sections.

Maintenance flows can be determined by applying judgment criteria to comparative projections as shown in tables 1-4, e.g., table 1, station 1, projection 7 shows ample wetted perimeter, 0.92 feet/second average velocity, and an average depth of .33 of a foot. This projection does not meet the judgment criteria, i.e., average depth and average velocity are below accepted levels; therefore, further consideration must be given to establishment of a higher maintenance flow. Table 1, station 1, projection 6 exceeds requirements for maintenance flow in all three categories; therefore, interpolation between projection 6 and 7 yielded a maintenance flow of 12 cfs $(\frac{9 + 14}{2} = 11.5$ or $12)$.

A small drop in flow reduces average depth and average velocity far below accepted levels, thereby eliminating further considerations.

Optimum flows may also be determined by noting that point beyond which little is gained (i.e., maximum benefits from minimal discharge), thereby conserving water without sacrificing the fishery, e.g., Table I, station 3, projection 4 shows 94 percent wetted perimeter, 1.97 feet/second average velocity, and an average depth of .36 of a foot. Increased flows beyond this point offer very little overall benefit. An increase of 14 cfs (Table I, station 3, projection 3) does not increase wetted perimeter; average velocity increases by only .35 feet/second, and average depth only .10 of a foot.

Based on the aforementioned parameters, determinations of maintenance and optimum flows (in cubic feet per second) are summarized in Table 5.

Instream flow requirements derived form application of the three methods are shown in Table 6.

Table 5
Summary of Maintenance and Optimum Flows (in cfs)
for the Strawberry River, Utah

	Station #1		Station #2		Station #3	
	Maintenance	Optimum	Maintenance	Optimum	Maintenance	Optimum
Table #1	12	22	11	25	16	26
Table #2	11	26	10	24	18	31
Table #3	12	21	7	24	14	24
Table #4	13	21	8	26	17	28
Means	12	22	9	25	16	28

During the course of the study, through examination of measured flows at various releases (tables 1-4), it was noted that there were accreted flows downstream from Soldier Creek Dam. The main source of this accretion, felt between station #1 and station #2, was Willow Creek (figure 1). Additional accretions were caused by numerous springs and seeps adjacent to the river channel. While accretions of this magnitude may not always be felt, even during dry cycles, some accretion could be counted on.

With this in mind, it logically follows that if flow requirements are met at station #1, then downstream flow requirements would more than be met at station #2 and almost always be met at station #3 (assuming no diversions). Final recommendations for instream flow requirements on the Strawberry River were based on mean maintenance and optimum flows from station #1.

Stations established in Wm Fork Drainage not at head of reach as is the case in this reference

Table 6
Recommended Maintenance and Optimum Flows
for the Strawberry River Derived
from Three Different Methods

	Maintenance	Optimum
Modified sag-tape method	12	22
*Montana method	9	19
**Forest Service method	12	25

*The maintenance level represents 30 percent of the mean annual flow. The optimum level represents 60 percent of the mean annual flow (8).

**Recommendations derived from application of the "Forest Service method" were provided upon request by the Bureau of Reclamation study team (4).

Discussion

The "modified sag-tape method" for determining instream flow requirements requires the acceptance of the assumption that if flows are provided to maintain adequate food production, spawning areas, and travel lanes within the critical area, then flows will also be adequate to maintain pools and other cover areas. In the case of the Strawberry River, onsite observations within the study area substantiate this assumption.

The "modified sag-tape method" is a simple method for measuring and recording changes in stream channel cross sections. It requires minimal field work, yet provides adequate data to make flow recommendations comparable with other "state of the art" methods. The computer capability of this method is designed to calculate various hydrologic parameters based on field data collected at the critical cross sections and Manning's formula for stream discharge. The program produces a computer plot of the measured cross section, and with completion of the three steps (A, B, and C), 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 ten or more selected water stages (1). A total of 435 man-hours were required for testing of this methodology. Manpower requirements could be substantially reduced with a reduction in the number of cross sections run. The Colorado Division of Wildlife currently makes flow recommendations based on two cross sections, one from both the upper and lower reach of the stream being evaluated.

The "Montana method" is an expedient and easy method of determining flows to protect aquatic resources. Its application requires only .5 man-hour (field observations excluded). Recommendations for instream flow requirements are based on percentages of mean annual flows derived from analyses of historical flow records and flow duration curves. Ten percent of the average flow is a minimum flow recommended to sustain short-term survival habitat for most aquatic life forms. Thirty percent of the average flow is recommended as a base flow to sustain good survival habitat for most aquatic life forms. Sixty percent of the average flow is recommended to provide excellent habitat for most aquatic life forms during their primary periods of growth and for the majority of recreational uses (2,8). Intensive use of this method includes stream visitation to observe, photograph, sample, and study flow regimes approximating 10, 30, and 60 percent of the average flow. These additional field investigative procedures greatly increase the investments of manpower and money, depending on the number and duration of field trips deemed necessary. Additional field investigations were not done during this study.

The method employed by the Bureau of Reclamation's study team was a combination of the "Forest Service method" and the "critical-area" concept. Qualitative habitat factors such as pool riffle ratio, pool quality, stream bottom materials, bank cover, and bank stability derived from application of the "Forest Service method" were related to physical and hydrological parameters derived from application of the critical-area technique. Habitat measurements were taken at 19 stations within the study area, with each station consisting of five transects. Additional physical and hydrological parameters were measured at four stations selected as "critical areas." This procedure was followed at each of the four releases from Soldier Creek Dam. The Bureau of Reclamation's methodology did not include synthesized flows above or below field measured values, nor did it employ computer analyses of the critical-area data (6). A total of 2,880 man-hours were required for application of this methodology; however, it is anticipated that this figure could be reduced (4). This technique is an intensive onsite field approach that attempts to consider the total aquatic environment. It requires considerable expenditure of manpower and money from the field measurement stage through analysis and development of flow recommendations.

As is shown in table 6, flow recommendations derived from application of the three methods are very close. The "Montana method" is the quickest and requires the smallest investment of money and manpower (excluding field work). The "Forest Service method," on the other hand, is most demanding and requires the largest investment of money and manpower. The "modified sag-tape method" strikes a middle ground between the two in that it is relatively simple and requires a modest investment of money and manpower. If the intensive use of the "Montana method" is used (i.e., including field work), the investment of money and manpower required for assessment of instream flow needs places it about equal to that required by the "modified sag-tape method."

Incidental to the Strawberry River study, we ran the "modified sag-tape method" and the "Montana method" on three other streams within the Bonneville Unit of the Central Utah Project. The results from the two methods were comparable in determinations of instream flow requirements (table 7). The more extensive "Forest Service method" was not applied to these additional streams.

Table 7
Determinations of Instream Flow Needs Using
the Modified Sag-Tape and Montana Methods

Stream	Montana Method		Modified Sag-Tape Method	
	Maintenance	Optimum	Maintenance	Optimum
West Fork Duchesne River	11	23	14	30
Currant Creek	8	15	6	13
Rock Creek	43	86	40	96

Conclusions

From this study and associated work (table 7), we have concluded that:

1. Final recommendations derived from the three methods are comparable.

2. The method used by the Bureau of Reclamation's study team, while effective, is expensive and time-consuming and, therefore, limits widespread practical application.

3. The "Montana method" is an effective method for determining instream flow requirements. It is quick, easy, and has a very broad application (8).

4. The "modified sag-tape method" is an equally effective method for determining instream flow requirements. It, too, is quick, easy, and has a broad application. It may be used on streams where flow records are not available. It also has the advantage of computer analysis of physical data for the actual streamflow at the time of measurement, as well as for selected water stages; and visual representation of the stream profile at each selected level.

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Glossary

accretion - the gradual increase in flow of a stream due to influent seepage

average depth - the mean depth of water in a stream channel

$$\text{average depth} = \frac{\text{flow (cfs)}}{\text{stream width} \times \text{average velocity}}$$

critical area - areas that contain the limiting factors for streamflow for a particular parameter in that stream reach

end point - the far bank stake or end of the cross section

grassline (G) - the high waterline of the stream channel, normally where streambank vegetation begins, essentially bank full

maintenance flow - that water level at which a fishery may be maintained

Manning's "n" - a factor used when computing the average velocity of flow of water in a channel which represents the effects of roughness of the confining bottom material upon the energy losses in the flowing water

$$n = \frac{1.486}{Q} (A) (R^{2/3}) (S^{1/2})$$

where: 1.486 = constant
Q = discharge in cfs
A = area in square feet
R = hydraulic radius
S = slope, in percent; expressed as a decimal

solved for "n", the roughness coefficient

mean - an average, having an intermediate value between extremes

minimum flow - a short term survival level optimum flow - that level at which maximum fishery benefits are gained from minimal water

percent wetted perimeter - the length of the wetted contact between the stream of flowing water and its containing channel

$$\% \text{ WP} = \frac{\text{existing WP}}{\text{maximum WP (from Step A readout, expressed as}} \times 100$$

R-2 Cross Program - computer analyses of physical data gathered via the sag-tape method

reference datum line (RDL) - a standard point or plane of stated elevation created by the sighting plane through the transit; used for water level manipulations in the R-2 Cross Program

thalweg - the line following the deepest part or middle of the bed or channel of a river or stream

waterline (W) - the interface between the water's edge and the streambank

zero point - the near bank stake or the beginning of the cross section

APPENDIX A

"R-2 CROSS" FIELD DATA FORM - SAG TAPE

STEP "A" Cross-section Plot

1. LOCATION:
(Card one - Title Card)
(Col. 3-80 as needed)

Watershed Name: 3 _ 23

Cross-Section Location: 24 _ 44

Date: 45 _ _ _ _ 50 Mil.Time 52 _ _ 55 Observers: 57 _ 80

2. LOCATION:
(Card Two)

Region _ 1 Forest No: _ _ 2 3 Watershed No: _ _ 4 5 Latitude: 6 _ _ _ _ _ _ _ _ 14

Longitude: 15 _ _ _ _ _ _ _ _ 23

State: 24 _ _ _ _ _ _ _ _ _ 33 County: 35 _ _ _ _ _ _ _ _ _ 44 Township: _ _ _ _ 45 48 Range: _ _ _ _ 50 53 Section: _ _ 55 56 Qtr. _ _ 58 59

3. SAG TAPE DATA:
(Card Three - Data Cards)

Cross-Section No.: 1 _ _ 3 Tape Wt., lbs/ft. . _ _ _ 4 7 Tape Tension, lbs _ _ . _ 8 10

11 14	15 17	18 21	22 24	25 28	29 31	32 35	36 38	39 42	43 45	46 49	50 52	53 56	57 59	60 63	64 66	67 70	71 73
Dist	Dep	Dist	Dep	Dist	Dep	Dist	Dep	Dist	Dep	Dist	Dep.	Dist	Dep	Dist	Dep	Dist	Dep

NOTE: Use following letter designation for Waterline: W; and Grassline: G; inserted above distance data in appropriate block. Enter 9999 in Dist Column and 999 in Depth Column to denote end of cross section data - measurement.

STEP "A" Cont. R-2Cross Field Form

4. Card 4 - See 6600-4

5. Card 5 - Control Data for Step A (Col. 1-10 Blank)

Distance in Feet from "O"-Point to last Depth measurement or at stake. (Col. 11-15)	11 — — — . — 15
Total Length of Tape used to span cross-section. (may be same as above) (Col. 16-20)	16 — — — . — 20
Manning's "n", roughness coefficient use theoretical value of .055, or select value per USGS reference, etc. (Col. 21-25)	21 — . — — — 25
Slope or gradient of stream reach - in percent i.e.: 6% = .060, .5% = .005 (Col. 26-30)	26 — . — — — 30
Enter 99 to indicate to computer a plot is to be made. (Col. 31-35)	31 — — — 9 9 35
Set Scale for x-axis (horizontal) Divide maximum width by 8 and round up to next higher No., or enter selected value. (Col. 36-40)	36 — — — . — 40
Set Scale for y-axis (vertical) Divide maximum measured depth by 6 and round up to next whole number - enter. (Col. 41-45)	41 — — — . — 45

6. Card 6 EOF See 6600-4

7. Card 7 EOF See 6600-4

STREAMFLOW - VELOCITY DATA

Dist from "O" Point	Water Depth ft.	Revolutions or Counts	Time in Seconds	Velocity in feet/sec.

NOTES - REMARKS

Estimated Discharge:
Ave. Depth ______ ft x Width ______ ft = X-Sect Area ______ sq. ft. x Ave.Vel ______ ft/sec = ______ CFS

Air Temp ______ °F

Water Temp ______ °F

Type of Meter Used: ______.

STEP "B" R-2 CROSS OFFICE FORM

FILE DATA: ______________________
x-sect No. & Watershed

Develope Data for Manning's "n" Calculation.
(Control Card - Card Five type)

NOTES: REMARKS:

(Col. 1-5) Depth to Water at time of discharge measurement, i.e.: Max, Depth from Ref. Datum Line to bottom minus depth of water at that point.	_ _ _ _ . _ 1 5
(Col. 6-10) First Streambank - Waterline Intersect, Distance in feet from "0"-point, from computer plot.	_ _ _ _ . _ 6 10
(Col. 11-15) Furthest Streambank - Waterline Intersect, Distance in feet from "0"-point, from computer plot.	_ _ _ _ . _ 11 15
(Col. 16-20) Total length of tape spanning cross-section. Feet.	_ _ _ _ . _ 26 30
(Col. 21-25) Manning's "n" value. Roughness coefficient. May use .055	_ _ . _ _ _ 21 25
(Col. 26-30) Slope, or gradient of Stream Channel reach, in percent. i.e.: enter 6% as .060 etc.	_ _ . _ _ _ 26 30