HABITAT QUALITY INDEX

PROCEDURES MANUAL

by

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Wyoming Game and Fish Department

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LIST OF ABBREVIATIONS

ADF - Average daily flow, sometimes called average annual flow (QAA).

ASFV - Annual stream flow variation.

BLM - United States Bureau of Land Management.

CPF - Critical period stream flow (also CPSF).

HQI - Habitat Quality Index.

USGS - United States Geological Survey.

USFS - United States Forest Service.

WGF - Wyoming Game and Fish Department

WRRI - Wyoming Water Resources Research Institute.

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ABSTRACT

The Habitat Quality Index (HQI) Procedures Manual is a step-by-step guide to the HQI method, which is used to evaluate trout habitat in Rocky Mountain streams. Purpose of the manual is to provide guidance and standards for conducting HQI evaluations. Subjects discussed include preliminary planning, station selection and layout, equipment, data sources, habitat measurements and HQI calculations.

The manual promotes familiarity with the HQI by explaining how and what to measure, as well as proper techniques and any useful short-cuts. Text instructions are augmented by photos and line drawings. Several examples and case studies illustrate HQI evaluation procedures.

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INTRODUCTION

Trout living in streams are influenced very strongly by their living quarters. A healthy habitat usually means an abundance of trout. Conversely, a stream with deficiencies in one or more key environmental features usually supports fewer trout. Severe habitat degradation often equates with a poor trout fishery.

An evaluation of trout habitat can provide valuable clues to the condition of a trout fishery, as well as to how the fishery will react to habitat alteration. Such information is a necessity where fishery resources face impacts from man's activities. Transbasin water diversion, increased demand for water by agriculture, industry and communities, increased mineral and petroleum exploration and extraction, and a continued demand for livestock grazing in streamside areas are habitat alteration activities that can damage trout fishery resources. Accurate habitat information is needed to minimize such impact so the fishery resource can be effectively protected and managed.

To be effective, an evaluation of a trout stream must identify any habitat deficiencies, as well as document existing habitat conditions and features. A properly done evaluation should not only characterize the existing habitat, but should provide valuable base line data against which future habitat alterations can be judged. A habitat evaluation method should also assess the ability of a stream to produce trout. To best aid the trout fishery, such an assessment should relate to trout standing crop. While various methods are available to assess fluvial trout habitat, most were developed for specific purposes, such as habitat inventory, and do not necessarily address the production aspect of a fishery.

Using these considerations, Wyoming Game and Fish Department personnel developed a method to evaluate fluvial habitat quality based on the relationship between habitat and trout standing crop (Binns 1979, Binns and Eiserman 1979). This method is the Habitat Quality Index (HQI).

The purpose of the HQI Procedure Manual is to provide guidance and standards for conducting HQI evaluations on Wyoming streams. The manual promotes familiarity with the HQI method by explaining how and what to measure, as well as proper techniques and any useful shortcuts. Questions and problems encountered to date have been kept in mind while writing the manual. If some sections seem to suffer from excess explanation, those are aspects of HQI work where procedural problems have been reported. The reader is asked to have patience and remember what is obvious to one person may be oblique to another.

THE HABITAT QUALITY INDEX

HQI Purpose and Use

The Habitat Quality Index was initially developed as a habitat evaluation tool. However, the HQI has also been used to predict trout standing crop and to assess the effects of habitat alterations. Additionally, the HQI method can support instream flow recommendations by quantifying changes in standing crop at different discharges. This latter use is currently being verified. The HQI is a relatively simple tool that can be used to assess fluvial trout habitat from the standpoint of expected trout carrying capacity. With the HQI, the fishery manager can quantify and compare trout habitat in standard terms.

Expertise Level Needed

An experienced fishery biologist should be able to easily learn and apply the HQI method, but proper training is necessary to obtain best results. As in any endeavor, the better the professional experience and expertise available, the better and easier the habitat evaluation. The amount of training needed is relative. For example, a fishery biologist with 20 years experience on Rocky Mountain streams will need much less training than a biologist trained in warmwater fisheries.

A satisfactory HQI evaluation demands that the evaluation crew understand trout in their fluvial environment. A knowledge of trout and trout streams is a primary prerequisite. Simply stated, one must understand where trout live in a stream and why, and also how they react to different conditions. While our knowledge of trout is imperfect as yet, one must be able to apply what is known. Salmonid life processes and requirements have been reviewed (Hynes 1972, White 1973) and such material can give insight into trout needs. However, a practical, working knowledge of trout obtained from field work is an invaluable aid in HQI work.

The HQI Process

In an HQI evaluation, an HQI station is established during late summer at the study stream. This station is designed to typify the existing habitat and contains at least ten equally spaced transects. Several stream habitat features, or attributes, are considered in each HQI evaluation. Width, cover for trout, water velocity and bank erosion are measured at the station. A water sample is collected for later analysis of nitrate nitrogen content. The benthic fish food fauna is sometimes sampled, depending on project needs, and preserved for later analysis of abundance and diversity.

Before leaving the site, preliminary ratings are assigned to the "Late Summer Stream Flow," "Annual Stream Flow Variation," "Maximum Summer Stream Temperature" and "Substrate" attributes. While ratings are assigned to as many attributes as possible before leaving the station, some attributes, such as nitrate nitrogen and fish food, cannot be rated until data analysis is completed.

After returning to the office, other data sources, such as gaging station records, are consulted to supplement the field data. Upon completion of data analysis, a final rating is assigned to each HQI attribute, using a rating table with standardized criteria. These ratings are then inserted in the proper HQI formula and an HQI score is calculated.

The key to a speedy evaluation is advance preparation and a familiarity with the HQI method. Assignment of final ratings and calculation of HQI Score can proceed rapidly if previous stream flow, chemical, temperature and fish food records have been located and made available. A summary of HQI procedure has been prepared to aid evaluation crews (Appendix IX).

PRELIMINARY PLANNING

Project Goals

An important first step in an HQI evaluation is to plan the project before entering the field. Proper planning prevents data gaps, improves evaluation quality, and insures that HQI seasonal and measurement requirements are met. All of which prevents later embarrassment and confusion. Proper planning before entering the field aids the field crew by reducing the time needed for study station selection.

A project plan should define the purposes and objectives of the evaluation. Some HQI uses include: (1) evaluation or inventory of existing habitat, (2) evaluation of habitat improvement potential, (3) prediction of trout standing crop, (4) evaluation of habitat improvement projects, (5) assessment of habitat degradation or alteration, and (6) to reinforce instream flow recommendations. While the basic HQI Technique is the same for each use, there are some subtle differences.

For example, a simple inventory of existing habitat requires only one evaluation during the late summer period. On the other hand, evaluation of instream flows requires HQI measurements at three or more flow levels at each station. Further, the impact of a stream alteration activity, such as a habitat improvement project, is best demonstrated by "before" and "after" evaluations. Proper planning can assure that measurements are taken at the proper times.

Model Selection

There are two HQI models available for evaluating fluvial habitat (Binns and Eiserman 1979, Binns, 1979). However, model II estimates trout standing crop with better precision and is thus the preferred model. Emphasis in the manual will be on Model II.

Study Areas

A good map of the study area is a valuable aid to any HQI evaluation. If available, USGS 7-1/2 minute topographical maps are usually best. However, USGS 15 minute and 1:250,000 quads can also be useful. Other useful maps are issued by the BLM, Wyoming Highway Department and the USFS.

Using the best available map, a general locality should be selected for each study station, taking into consideration habitat and geological features and the number of stations desired per stream. Determination of specific station location is best done in the field.

For a preliminary selection of study sites from maps, particular attention should be paid to: (1) station accessibility, (2) time, manpower and equipment constraints, (3) terrain type, (4) stream size and gradient, and (5) land ownership.

If manpower and time are limited, the number of evaluation stations should be reduced to preserve evaluation quality. One person can do an HQI evaluation on very small streams, but special equipment and extra effort is needed. On most streams, at least two persons are required to properly execute an HQI evaluation. An experienced two-man crew can usually obtain HQI field measurements in 2-3 hours on most waters. A third man acting as recorder can hasten the process. A large stream may require additional personnel and equipment.

Existing Data Review

Well before an HQI evaluation is scheduled, examine the crew library for aquatic habitat data that have previously been collected. Review state, federal and other agency reports to determine data availability for stream flow, water temperature, water quality and fisheries. This review will help determine what additional data must be collected to supplement the existing records. While this chore sounds simple, skipping this step can later result in considerable frustration when the time comes to rate the HQI attributes. WGF field crew records, graduate student theses, WGF special project reports and USGS reports are prime sources for habitat data. Arrange to acquire any reports and records needed for the evaluation. The better the data base on a given stream habitat, the easier and more precise will be the HQI evaluation.

A primary purpose of reviewing the existing data base beforehand is to identify any data gaps that might later hinder or block the HQI evaluation. For example, temperature and nitrate records are often incomplete or absent on many streams. However, if the need is identified before the field season, arrangements can be made for recording thermometers or chemical sample collection.

Equipment Review

Once evaluation data requirements have been determined, procurement of the necessary equipment can begin. A basic equipment list for HQI evaluations has been prepared (Appendix X). Additionally, the attribute measurement section contains a list of the basic equipment needed for measuring each attribute.

All equipment needed for the HQI evaluation should be assembled and examined for performance prior to the evaluation date. This will allow time for any needed equipment repairs.

RECORDING FIELD DATA

HQI field notes should be recorded in a uniform and professional manner, both as an aid to later steps in the evaluation and to insure all needed data are collected. Weatherproof field notebooks are highly recommended as a safeguard against water damage to the field notes. These notebooks are easily carried while making measurements and can be readily stuffed into a pocket to free hands. Such notebooks promote uniformity in field measurements, are easily filed and aid future data retrival.

A standard format should be used when recording HQI measurements (Table 1a,b). In addition to organizing field notes, this format serves as a checklist to insure no measurements are skipped. The stream name, station location and date should be written on each page to prevent later confusion as to which data goes with what station, especially if the notes are later xeroxed.

HQI STUDY STATIONS

Site Selection and Location

If a general study area was selected from maps during the planning phase, the HQI evaluation crew can proceed to that area and commence selection of a specific study site. Otherwise, they should have clear instructions as to station location. On arrival at the study area, the crew examines the area for potential habitat evaluation sites, noting the various habitat types that may be present. For best evaluation results, an HQI station must represent the fluvial habitat present in the study stream. Several HQI stations may be needed to adequately represent a stream.

If there is more than one distinct habitat type present, either locate a station in each habitat type, or establish one station that includes part of each habitat type. For example, if the area of interest includes a swift, boulder-strewn riffle that flows into a low gradient meadow section, then both riffle and meadow stations could be established (Figure 1). Alternatively, a station at the point where the riffle breaks into the meadow would include portions of both habitats. Choose the procedure that will give the best picture of available habitat conditions

Table 1a. Format used for recording HQI measurements on Rite-in-the-Rain waterproof survey sheets. Sheets one and two provide space to record data on width, thalweg, station area and cover.

(1)

LITTLE POPO AGIE RIVER 8/5/75

Upper end of Public Fishing Area

WATER TEMPERATURE________ TIME________

STREAM WIDTH

POINT	DISTANCE	WIDTH (FT)	THALWEG LENGTH (FT)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

SUM:________

MEAN:________

AREA OF SAMPLE STATION________

(2)

LITTLE POPO AGIE RIVER AT PFA 8/5/75

COVER

FOOTAGE	AREA	TYPE

Table 1b. Format used for recording HQI measurements on Rite-in-the-Rain waterproof survey sheets. Sheets three and four provide space to record data on eroding banks, velocity, substrate, miscellaneous records and attribute ratings.

(3)

LITTLE POPO AGIE RIVER AT PFA 8/5/75

ERODING BANKS (FT)

WATER VELOCITY (TIME OF TRAVEL)

______ minutes ______ seconds FIRST COLOR

______ minutes ______ seconds GOOD COLOR

TOTAL SECONDS ________

Velocity: thalweg/seconds = ______ / ______
= ft/sec

SUBSTRATE

(Approx.)		
______	%Fines	Vegetation
______	%Gravel	Est. Fish Food Abundance
______	%Cobble	
______	%Boulders	Probable Rating: ______

(4)

LITTLE POPO AGIE RIVER AT PFA 8/5/75

ATTRIBUTE RATINGS

ATTRIBUTE	PRELIM. RATING	DATA SUMMARY
CPSF	______	
ASFV	______	
TEMPERATURE	______	
NITRATES	______	
WATER VELOCITY	______	
SUBSTRATE	______	
COVER	______	
ERODING BANKS	______	
WIDTH	______	

MISC. RECORDS

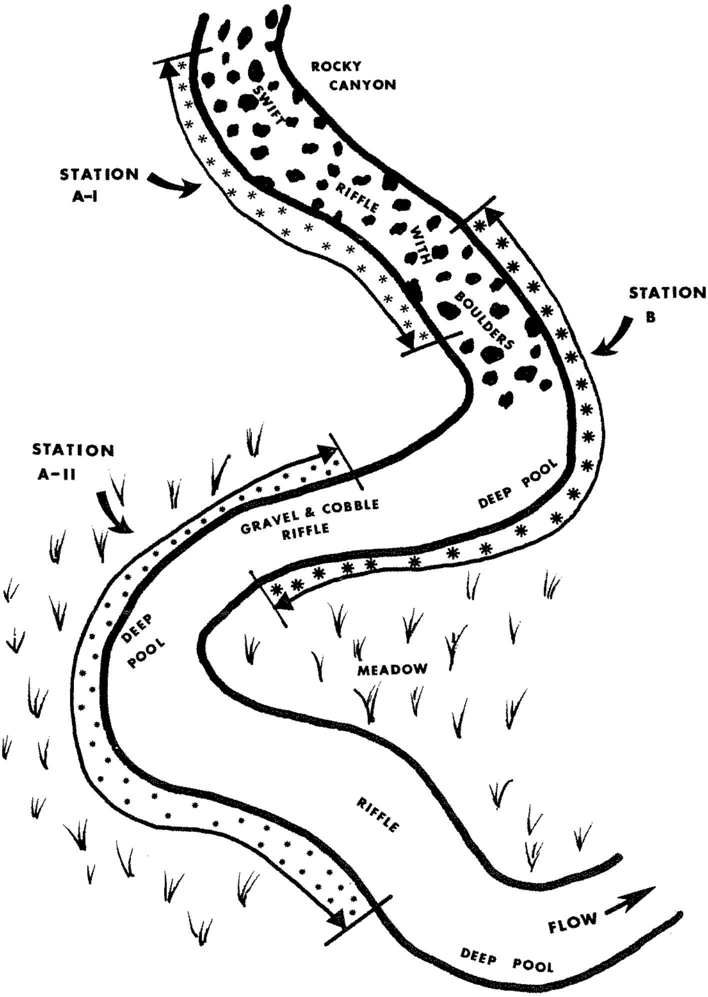


Figure 1. HQI station selection when two habitat types are present in the area to be evaluated. To adequately represent the area, samples are required from both meadow and canyon sections. Alternative A uses two stations-one for each habitat type. Conversely, alternative B samples both canyon and meadow with one long station. Alternative B would probably require less time to process.

within time and manpower constraints.

Station selection is much easier if the field crew understands why the evaluation is being done. Previous definition of project goals, objectives and time limitations assist the crew with decisions on sample station density and layout, especially in complex habitats.

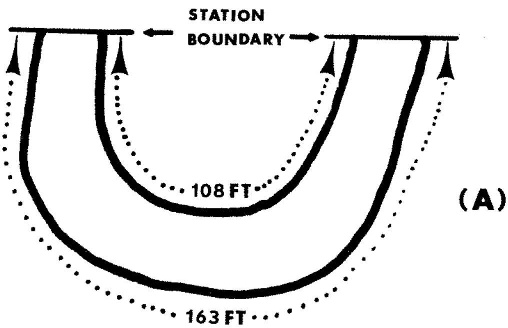
Avoid establishing study stations in channelized or altered stream sections, unless the purpose is to assess fish habitat in such areas. However, note that the HQI study station should reflect habitat conditions in the stream section being studied. Do not select only good habitat for HQI use if the overall habitat is generally poor, and vice versa. Every effort should be made to avoid bias when selecting HQI stations.

Station Layout

Once a site has been chosen, measure and mark the study station along one bank. After selecting either an upper or lower boundary, measure a long enough station to represent the local habitat features.

Care must be taken when laying out a station on a meandering stream. Since the inside curvature is shorter than the outside curvature at an acute meander loop, calculations of station area will be incorrect if only one loop is measured (Figure 2). To compensate for the difference in curvature distance, include an even number of loops in the station length. This procedure may not be practical on a large river because of the distances involved, but you should be aware of the potential error. An alternative procedure is to measure the station length along the mid-channel line.

Station length should be long enough to adequately sample the existing habitat, but short enough to minimize the time and effort needed to collect evaluation data.



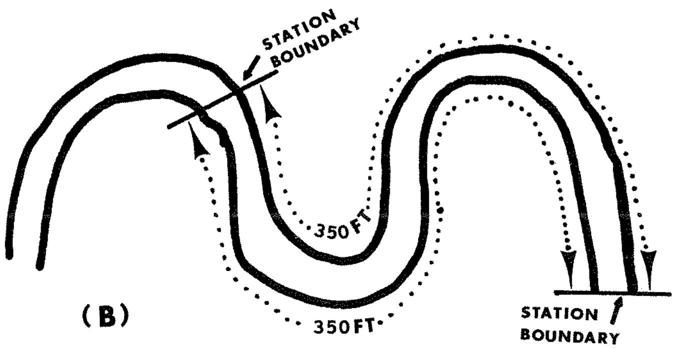


Figure 2. Incorrect (A) and correct (B) station layout on a meandering stream. Station (A) contains only one meander loop. If the station is laid out along one bank, as is usual, the calculated station area will be incorrect due to the shorter distance for the inside curvature. If two loops are included, as in (B), each bank includes an inside and outside curvature, and distances are the same.

Ideally, station length should vary according to stream size, with a short station on a small stream and a long station on a large river.

For example, to represent pools with a regular pool-riffle sequence, a station needs to include several pools and riffles. However, on a large stream, pools are often far apart so time and effort constraints may limit the station to one pool-riffle sequence.

A 100 foot (30 m) station may be satisfactory for very small creeks that are only a few feet wide. However, a large river like the lower Green River (average width about 300 feet; 91 m), requires a much longer station. One 100 foot (335 m) HQI station on the Green River included only a part of a riffle, a pool and its associated flat water down to the next riffle. This station required several hours work by four men.

In recent years however, a standard 300 foot (91 m) station length has been used by the Aquatic Habitat Crew on most small and intermediate-sized streams. This distance is usually adequate to sample habitat in such waters. Longer stations are used on large streams, or where there is an unusual situation, such as where multiple habitat types are present. Several short stations may be needed when evaluating a long stretch of stream.

Since at least 10 transects are desirable to determine average width, an efficient way to lay out a station is to mark the transects on one bank while measuring station length. For example, a 300 foot (91 m) station would have a transect every 30 feet (9 m). Including the starting point, this procedure gives 11 equally-spaced, but randomly selected, transects for width measurement.

Station boundaries and transects can be marked with everything from sticks and rocks to permanent metal stakes. Wooden survey stakes marked with orange surveyor's tape make satisfactory markers. If the station will be used again in future years, all transects and the upper and lower boundaries should be permanently marked. Even if you expect to use the station only once, a permanent mark at one boundary point will save time and confusion if the station is needed again at some future date.

ATTRIBUTE MEASUREMENT AND RATING

General Considerations

While the measurement and rating of HQI attributes is usually a relatively simple and straight-forward process, proper procedure will improve results. This section reviews the proper techniques for collecting the data needed to rate each attribute. Good data will help assure accurate and usable attribute ratings, and final HQI scores.

Organization is required to utilize available time and manpower at each station. Systematic data collection reduces confusion and insures that all needed data is, in fact, collected. The work plan need be nothing more than a sequential measurement of attributes and assignment of certain tasks to specific individuals. For example, one man may be responsible for obtaining photographs, fish food and nitrate nitrogen samples. Other crew members may be assigned to lay out station and make other measurements.

Attribute Measurement

The recommended work plan is as follows.

Fish food and nitrate nitrogen samples are collected first to insure that they accurately reflect existing conditions and are free of disturbances caused by the survey crew. Next, the station is measured and the transects are marked, working in a downstream direction along one bank. Afterwards, the crew works their way back upstream, measuring stream width at each transect marker. Thalweg length is measured on the next trip downstream. On their next pass upstream, the crew measures cover. Eroding stream banks are measured on the final downstream pass.

To measure water velocity, one person adds dye to the stream at the upper station boundary, while another person times the dye through the section. The station is then photographed to record existing conditions. Before leaving the station, the crew discusses and decides on preliminary ratings for those attributes, such as Annual Stream Flow Variation, that are not dependent on precise measurements.

Photographic Records

A sequence of photos showing the HQI station helps document habitat conditions at the time the evaluation was done. Such photos are often useful references when making the final attribute ratings after returning to the office. Color slides (35 mm) are usually best. ASA 64 works well on most streams but ASA 200 or 400 may be needed if the stream is deeply shaded.

Take a series of pictures at different points so all habitat features within the station are included. If possible, some photos should show the substrate type. Take plenty of pictures. If questions later arise about habitat conditions, the more photos, the better. The slides are labeled and stored in plastic sheets (file folders) so they will be readily available for later reference.

Measurement Accuracy

An important point to keep in mind when measuring HQI attributes is that you are not surveying for a precisely engineered project. A new highway bridge may need survey measurements accurate to several decimal places, but such precision is generally not possible in HQI work.

Measurement errors caused by tape sag, wind, or variable natural conditions, for example, may be hard to control without considerable effort. The gain in precision in such instances may not justify the extra work. Also, attribute rating criteria are broad enough to accept minor errors in measurement.

However, this does not justify sloppy or haphazard work. The maxim, "garbage in, garbage out", certainly applies to HQI habitat evaluations. A careful effort is required for good HQI results.

For example, measuring width to the nearest inch (cm) with a tape measure on a 300 foot (91 m) river is an exercise in self deception. Tape sag alone will cause some error, and if a breeze is blowing, the error may be several feet (m). But note that the percentage of error is still small in such a situation. In contrast, a 6 inch (15.2 cm) measurement error on a two-foot (0.6 m) wide brook is a serious mistake.

While the required measurement precision may vary between stations and attributes, rounding to the nearest whole number is often sufficient. For instance, measuring to the nearest foot (0.3 m) is adequate for station length, stream width, thalweg length, cover and length of eroding bank measurements on most streams. Small streams (about 5 to 10 ft., 1.5 to 3 m wide) are an exception to this rule though, and may need to be measured to the nearest half-foot (0.15 m). Tiny brooks (<5 ft., 1.5 m wide) should be measured to the nearest inch (cm) to prevent errors caused by rounding to the nearest foot (0.3 m).

Water temperatures are rounded to the nearest degree. Nitrate nitrogen demands an analytical accuracy to two decimals, e.g., 0.01 mg/ℓ.

Measurement Period

The last half of summer is often a critical time for trout in Rocky Mountain streams. The snowmelt runoff has largely ended and trout may be stressed by low stream flows and warm water, especially when water is diverted for crop irrigation. Other habitat features, such as cover and water velocity, may also stress trout when stream discharge drops to low levels. Since habitat conditions during late summer may act to limit trout abundance, the HQI method was designed to be used then. Also, conditions for sampling habitat attributes are usually optimal at that time.

Accordingly, the permissible sampling period for the HQI method is between August 1 and September 15. This is called the "Critical Period". While samples may be taken anytime during this six week period, sampling during the last half of August will usually avoid atypical habitat conditions caused by a delayed runoff or an early snowfall. Additionally, a shorter time frame will help reduce possible bias due to natural variations in fish food and nitrate nitrogen. If the habitat is to be monitored regularly over several years, then HQI measurements should be taken at the same date, discharge, and site each year.

If the HQI method is used for instream flow prediction, then cover, width, velocity and discharge measurements can be collected at other seasons when the desired study flows occur. However, the fish food, nitrate nitrogen and substrate attributes must be measured during the critical period because their rating criteria are keyed to that time. Water temperatures must be measured during the summer months.

THE LATE SUMMER STREAM FLOW ATTRIBUTE

Rating Criteria

Rating	Characteristics
0	Inadequate to support trout. (CPF <10% ADF)[a]
1	Very limited; potential for trout support is sporadic. (CPF 10-15% ADF)[a]
2	Limited; CPF may severely limit trout stock every few years. (CPF 16-25% ADF)[a]
3	Moderate; CPF may occasionally limit trout numbers. (CPF 26-55% ADF)[a]
4	Completely adequate; CPF very seldom limiting to trout. (CPF >55% ADF)[a]

[a] CPF = mean daily flow during August and the first half of September only; ADF = mean daily flow for the water year. Obtain both from gaging station records, if available.

Equipment Needed

1 - Rating Criteria (above).
2 - Stream discharge records, if available.
3 - Field notebook, waterproof.

Data Sources

Stream discharge records for USGS gages are compiled on a water year basis and issued annually (Anonymous 1980a, 1980b). The present analysis and publication delay is about a year, but preliminary records for a specific station are sometimes available earlier from the USGS Water Resources Division in Cheyenne. Records for past years may also be available from that office. Additionally, fishery management crew libraries have USGS stream flow records.

Another source for flow records is the Water Resources Research Institute (WRRI) computer program at the University of Wyoming (Smith et al., 1976). While there is a charge for the service, the WRRI program is the best source for flow records issued before 1964, as well as at state, WRRI, or discontinued gages.

The CPF/ADF ratio should be rated from gage station data wherever possible. Where these data are lacking, simulation of stream flow records on the study stream may be possible using established techniques (Lowham 1976, Smith et al. 1976, Wahl 1970).

If a stream discharge measurement is desired to supplement the HQI evaluation, additional equipment is needed. A current meter, stop watch, tape measure and wading boots are the minimum requirement (see Corbett 1962 for procedures).

Attribute Clarification

The late summer, or critical period, stream flow (CPF) is the mean daily discharge for the study stream from August 1 to September 15. Comparing CPF with average daily flow (ADF) provides a useful guide to late summer flow adequacy. The ratio CPF/ADF = %ADF can be easily calculated from stream flow gage records.

The late summer stream flow attribute evaluates the amount of water present during the vital late summer growing season. The basic question facing the evaluation team is simple. Is there adequate water for good trout production, or is stream flow low enough to act as a limiting factor? If so, then the team must decide how severely the fishery is limited by water quantity.

How the available water fits in the stream channel is also important. The actual quantity of water matters less than how well it fills the existing channel, regardless of stream size (Figure 3). For example, a stream flowing bank-full during August is more valuable to trout than is the same stream half-dry. A bank-full flow fills all possible holding areas in the channel, thus allowing the trout population to take better advantage of the available habitat. Conversely, a half-dry stream has much unavailable habitat during the important late summer growing period. This same stream would support more trout if a consistent, bank-full flow were available during late summer.

A stream is not less valuable, and should not be downgraded, just because it is small. Rather, keep an open mind and observe how and where the water occupies the channel, regardless of stream size. Is the water deep enough so most, or all, potential holding areas are usable by trout, or are there large shallow, or nearly dry, expanses unsuitable for trout? Consider also the size and age structure of the trout population. For example, a population of small, stunted brook trout can utilize shallow areas unsuitable for trout maturing at a larger size.

<u>Measurement and Rating</u>

To properly rate the late summer stream flow attribute, information is needed about the discharge regimen. The ideal situation would be to

Figure 3. A small stream with a consistent, bank-to-bank flow can provide valuable habitat for small trout. CPF was rated No. "4" in North Branch Crow Creek, whose mean width is 2.1 ft. The measured standing crop of trout in this creek was 224 lbs/ac (251 kg/ha).

obtain enough discharge measurements to accurately portray stream flow patterns. However, this takes much time and effort, and is seldom practical. In most instances, the late summer stream flow attribute can be accurately rated either from existing discharge records, or from careful observation of existing habitat conditions.

If a USGS gage station is present within a reasonable distance of the HQI station, then CPF can be rated from past records of stream flow, plus general observations of the stream at the study site. The amount of water diverted from or entering the stream between gage and HQI station determines if the gage records truly represents the flow regime at the HQI study site. If large tributaries enter the main stream between the two points, use the gage records with caution. Once the relevant stream flow records are located, calculating and rating CPF is a straight forward process.

To calculate the average daily flow during the critical period, add the daily flows recorded for the first half of September and the total flow for August (Appendix I). Divide by the 46 days in the period to get CPF. For example (From (D) in Appendix I):

Total September 1-15 flow	445 cfs
Total August flow	1,206 cfs
Total August 1-September 15 flow	1,651 cfs

CPF = 1,651 cfs/46 days = 36 cfs

Next, find the ADF, which is reported as 114 cfs under Average Discharge (from (A) in Appendix I), and calculate the %ADF.

%ADF = CPF/ADF = 36 cfs/114 cfs = 32%

Since 32 ADF falls between 26 and 55%, as listed in the rating criteria, CPF at this site is assigned a "3" rating.

For this example, CPF was rated on the basis of only one year's records. In practice, %ADF should be calculated for at least five years and averaged. A 10-15 year average is better still as it reduces possible bias from a few wet or dry years. The average %ADF is then used to determine the rating.

At some gages, USGS does not report ADF because data are available for only a few years. In this case, an approximate ADF can be calculated from the annual mean flow for the water year. This is reported near the bottom of the gage record sheet (from (E) in Appendix I). Simply average the yearly mean flows over the period of record. While this figure differs slightly from the average calculated by adding yearly flow totals and dividing by total days, it is quicker to compute and is sufficiently accurate for HQI purposes.

Using the Green River at Warren Bridge as an example, assume the only gage records are from 1976-80. Then we have the following discharge (Q) data from USGS records:

YEAR	DAYS	TOTAL Q (cfs)	MEAN Q (cfs)	MEAN CPF (cfs)
1976	366	197,488	540	496
1977	365	102,475	281	353
1978	365	201,030	551	546
1979	365	141,985	389	426
1980	366	170,909	467	353
Totals	1,827	813,887	2,228	2,174
Mean Q		445[a]	446	435

Average %ADF = 435/446 = 98%, a "4" rating.
Average Discharge (49 years) = 508 cfs
[a] 813,887 cfs/1,827 days = 445 cfs = ADF for the 1976-80 period.

Note the %ADF developed with five years data is considerable different from the 1980 figures (353/508 = 60% ADF). Also note that the five year

ADF is lower than the 49 year ADF, mostly because 1977 was extremely dry. Using flow data from 1970-80 gives an ADF of 506 cfs, which is a much better match. Here the 1977 drought was offset by two wet years (1971-72).

The point is, examine the available stream flow records and be aware of the past stream flow regime. If you have reason to believe the %ADF is skewed by dry or wet year bias in CPF or ADF calculations, then assign the attribute rating carefully, especially if the %ADF falls on the boundary between two ratings. You may wish to assign a higher or lower rating, depending on the amount of skew.

If no gage records are available, CPF must be rated from careful onsite observations of stream flow conditions (Figures 4, 5, 6, 7, 8, 9). Always assign at least a tentative rating to CPF before leaving the station. While ratings can be assigned later from photographic and other records, a careful first-hand examination of the stream improves rating accuracy. If time permits, several visits to the stream during the critical period may give a better appreciation of conditions.

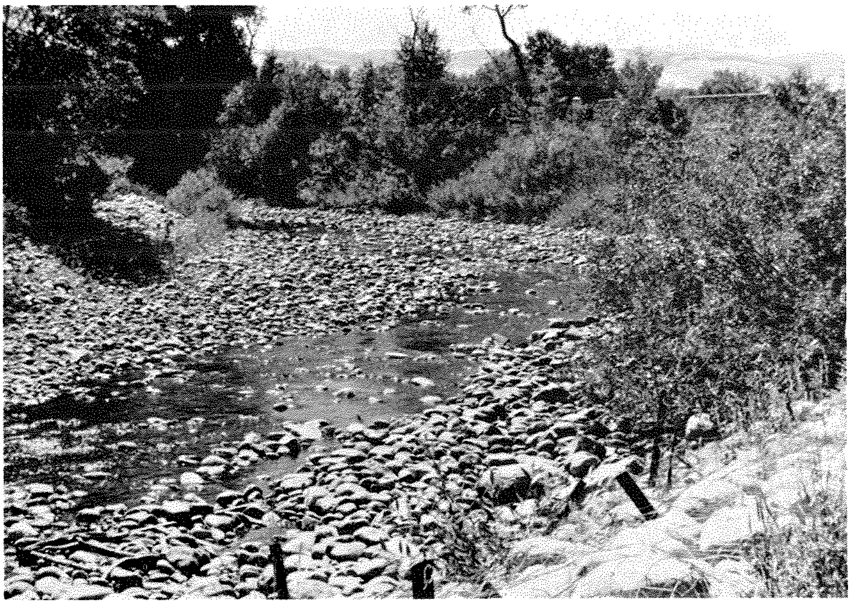


Figure 4. A stream rated No. "1" for CPF features a very limited supply of water during late summer and offers little habitat for trout.

Figure 5. In a stream rated No. "2" for the CPF attribute, discharge may act to limit trout numbers every few years.

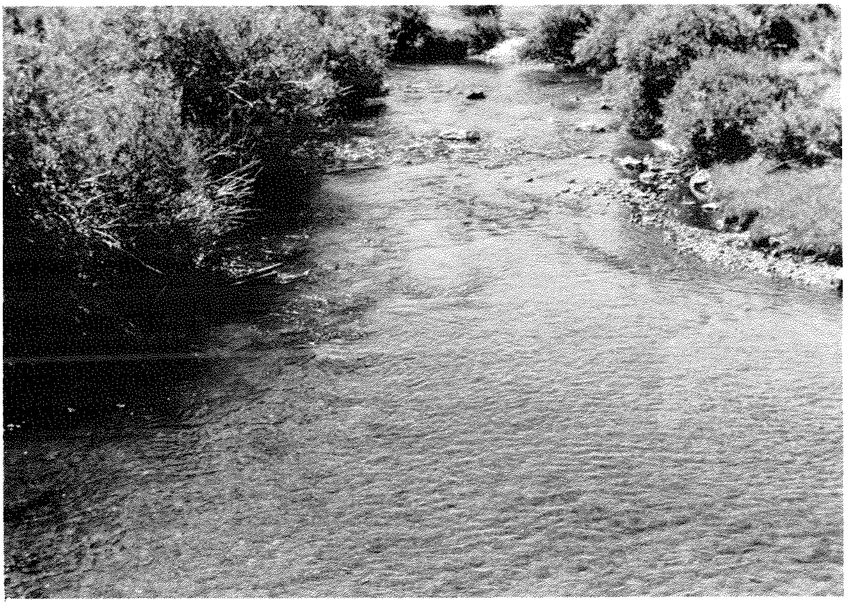


Figure 6. Although late summer flows are generally adequate for trout in a stream rated No. "3" for CPF, discharge during late summer may occasionally be low enough to limit trout numbers.

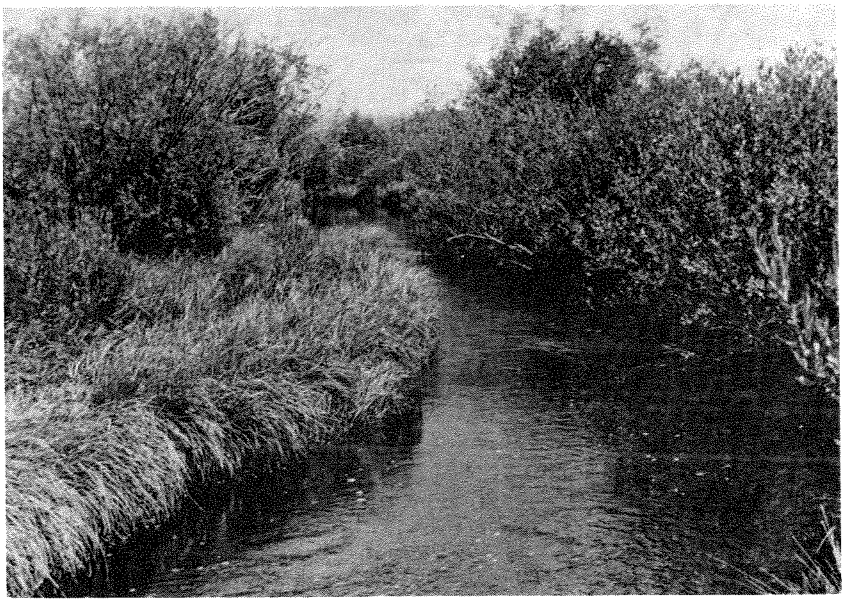


Figure 7. A stream rated No. "4" for CPF will feature a discharge that is completely adequate for trout during late summer.

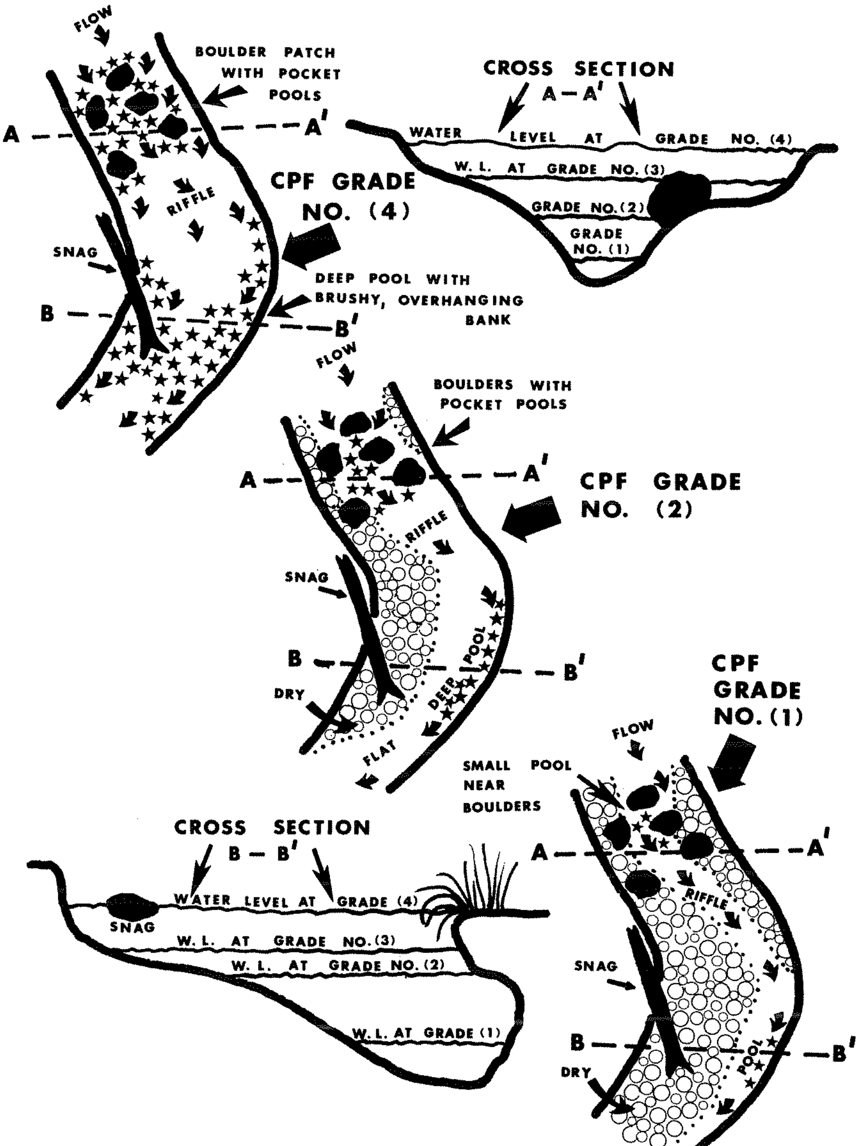


Figure 8. Change in the trout holding capability of a stream channel with change in stream flow during late summer. Reduced CPSF usually means a lower carrying capacity for trout. Trout holding areas are indicated by stars in the above sketches.

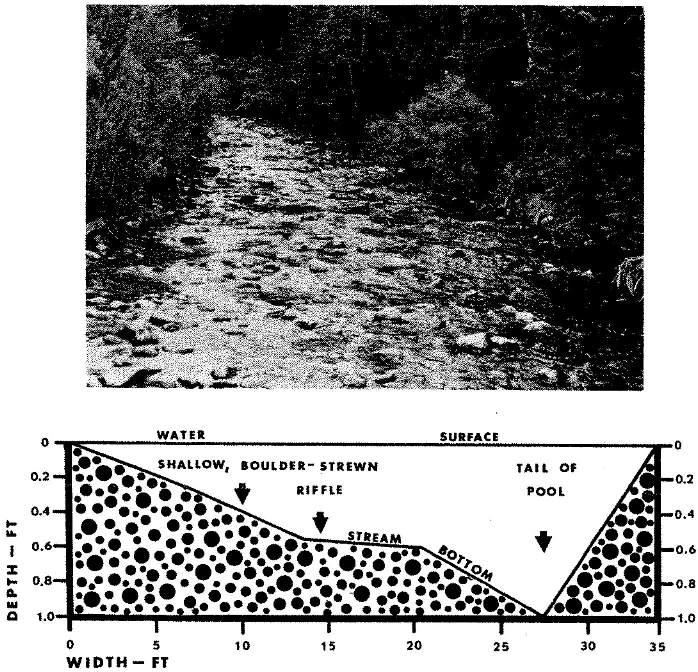


Figure 9. Late summer stream flow at the HQI station on North Brush Creek typically covers the entire stream channel (photo). A visitor is impressed by the apparent abundance of water and pocket pools around the boulders. On first impression, CPF should be rated a No. "3". However, closer examination reveals that much of the channel is too shallow to shelter trout. Only a few small, shallow pools and pool-runs offer living areas for trout other than young-of-the-year. A typical cross-section portrays the extensive shoal area present at this station (graph) and indicates that a No. "3" rating is too high for this station. The average CPF/ADF ratio was calculated from USGS records at a nearby gage station and confirmed that a No. "2" rating would be more realistic for CPF at North Brush Creek.

THE ANNUAL STREAM FLOW VARIATION ATTRIBUTE

Attribute Criteria

Rating	Characteristics
0	Intermittent stream. (ASFV Ratio 500 or greater)*
1	Extreme fluctuation, but seldom dry; base flow very limited. (ASFV Ratio 100 - 499)*
2	Moderate fluctuation, but never dry; base flow occupies up to two-thirds of channel. (ASFV Ratio 40 - 99)*
3	Small fluctuation; base flow stable, occupies most of channel. (ASFV Ratio 16 - 39)*
4	Little or no fluctuation. (ASFV Ratio 0 - 15)*

*ASFV Ratio = Annual Peak Flow (cfs)/Annual Low Flow (cfs).

Calculate the ratio for each year of record, then average over the period of record to get a mean ASFV Ratio. Use the mean ASFV Ratio to enter the table above.

Equipment Needed

1 - Rating Criteria for the annual stream flow variation attribute.
2 - Stream discharge records, if available.
3 - Field notebook, waterproof.

Data Sources

USGS discharge records can be used for judging annual variation in stream flow. See the previous section for a discussion of sources for flow records.

Attribute Clarification

In most Wyoming streams, stream discharge changes constantly during the year. Such continual variation in flow does much to shape the character of a stream and its trout population. Fluctuation in water flow can be an important limiting factor for trout, and often, flow variation and trout production are directly related.

Fluvial habitat stability in streams draining the Rocky Mountains is largely controlled by the steadiness of flow within the stream channel. When a steady flowage from springs is present, the habitat is stable and consistent, and often populated by a large trout population. Sand Creek in Crook County is a good example.

Conversely, water courses regularly scoured by severe flood episodes usually support few trout, especially if the floods are separated by long periods of sparse base flows. The Wiggins Fork, near Double Cabin, typifies the severe habitat instability and poor fishery often associated with extreme variation in stream flow.

Stream discharge in Wyoming normally follows an annual cycle where peak stream flows usually occur in May and June when the mountain snow pack melts. Afterwards, stream flow gradually decreases to a base level, with the annual minimum flow occurring in late summer or mid-winter. Annual variation in flow differs from stream to stream. Some are severely affected each year by wide fluctuations in flow, while other waters are affected only rarely.

In some streams, geological or climatic features may influence discharge stability. Other water courses may have an unnatural flow regime that is shaped by irrigation diversions or return flows, or by flow fluctuations originating at storage reservoirs. Still other streams may suffer periodic disruption by natural cataclysmic events, such as flash floods caused by severe local storms.

Whatever the cause, fluctuation in stream flow is a fact of life and is important to trout living in Wyoming streams. The annual stream flow variation (ASFV) attribute is designed to evaluate the impact of flow variation on fluvial habitat stability. While the HQI evaluation team needs to understand why stream flows vary, the team's primary concern is assessing how much the stream flow fluctuates from season to season, and from year to year.

Some streams reach their lowest discharge points during mid-winter, when snow and ice make difficult any attempt to observe habitat conditions. Severe winter conditions may seriously limit trout production in some waters. However, since low flow conditions often develop during late summer when the water courses can be easily observed, there is little need for winter evaluation of study sites. A typical stream channel in late summer offers many clues as to its annual flow regimen. Typical clues include high water marks, debris caught in streambank vegetation, the relation of flood marks to low flow and silt deposits. An alert HQI evaluation team will note these clues and use them to assess flow fluctuations, and the expected impact on habitat stability. Rating the ASFV attribute readily follows such observations.

Measurement and Rating

Unless one wishes to document flow fluctuations by making discharge measurements with a current meter over a several year period, the ASFV attribute requires no field measurements. The usual procedure for rating ASFV is to examine the stream channel for evidence of discharge fluctuation and use the attribute rating criteria to assign a rating. If gage records are available, then field observation and examination of the flow records will give valuable clues as to the proper rating.

When gage station records are available, first assure yourself that the gage accurately reflects the discharge regimen at the HQI station. If the gage and study site are widely separated, then the flow regimen at the gage may be different. Likewise, if many tributaries enter between the two points.

Second, examine the flow records for several years. If discharge differed, when did the peak and low flows occur. What pattern is there in annual flow variation. Next, calculate the ASFV Ratio. Extract the annual peak flow and low flow for the year (from (C) in Appendix I). Then: ASFV Ratio = Peak Flow/Low Flow.

For the Encampment River example (Appendix I):

ASFV Ratio = 1,190/17 cfs
= 70, a "2" rating.

However, this calculation is for only one year, which means a wet or dry year could give a false reading. To reduce this possibility, calculate ASFV Ratio for as many years of record as are available. At least ten years of record should be used, if possible, to compute an average ASFV Ratio. As an aid, ASFV Ratio has been calculated for some Wyoming streams (Appendix XII).

As an example, the following data are available for the Green River at Warren Bridge.

Year	ASFV Ratio	Year	ASFV Ratio
1964	41	1972	53
1965	60	1973	30
1966	26	1974	46
1967	40	1975	49
1968	31	1976	32
1969	23	1977	37
1970	58	1978	34
1971	58	1979	26
		1980	38

$n = 17$

$\bar{x} = 40$

Standard Deviation = 12.0

There are several items of interest in these data. First, note the variation in ASFV Ratio from year to year. This illustrates the necessity for calculating the ratio for more than one year. Second, the mean ASFV ratio (40) gives a rating of "2" instead of the "3" arrived at using only the 1980 data.

Thirdly, note that a ratio of 40 is on the boundary between a "2" and "3" rating. In this situation, the best course of action is to closely examine the stream channel before rating ASFV. If the stream fits in its channel well and there does not seem to be much impact from flow variation, you may wish to disregard the ASFV Ratio and use a "3" rating. On the other hand, obvious evidence of sizable flow fluctuation would reinforce the "2" rating suggested by the ASFV Ratio.

When reviewing the evidence of flow fluctuation, consider the regularity and severity of the variation. Is the fluctuation seasonable (predictable), or is it irregular, as from rare rain-induced flash floods?

How severe is the fluctuation: is it extreme or minimal?

Look for evidence of past floods along the stream banks, on the flood plain and within the channel itself. Where is the high water mark, as evidenced by debris left along the banks (Figure 10) and in the riparian vegetation?

Does the channel show evidence of severe scouring, or heavy bedload deposition? Large, exposed gravel or silt bars indicate first, the existence of past flooding strong enough to pick up (scour) and move the bed material and second, a base flow that is inadequate for the channel configuration. Such deposits imply considerable disparity between flood and base flows.

Thus, to judge ASFV, examine how the water fits in the channel at base flow. A large, exposed expanse of gravel bleaching in the sun with a small stream of water meandering in the middle (Figure 11) is a strong evidence for extreme flow fluctuation. This type of stream is often called a "flush" or "scour" stream and features raging floods followed by much reduced flows. Its ASFV rating is No. "1".

On the other hand, a steady-state, spring-fed stream graded No. "4" features bank-to-bank water flows, with very little or no exposure of the stream bottom (Figure 12). Boulders might dot the surface, but deep water surrounds the rocks. Conspicuous gravel and sand bars would be absent. There might, however, be deposits of fine sediments, carried into the system by rare floods, or formed by organic decomposition.

Flows in a No. "4" stream would be consistent and steady with rare flooding. Both vertical and horizontal fluctuation in water level would be minimal. Normal high flow is only about twice the base flow level at Sand Creek, where severe floods are rare.

Figure 10. Debris deposited along the high water line by past floods can be used to judge the extent of ASFV.

Figure 11. A stream rated No. "1" for ASFV typically has an extensive flood channel, of which only a small part is occupied by the base flow. Such a stream displays considerable dry gravel and cobble area. The base flow is generally very limited when compared with the overall flood channel.

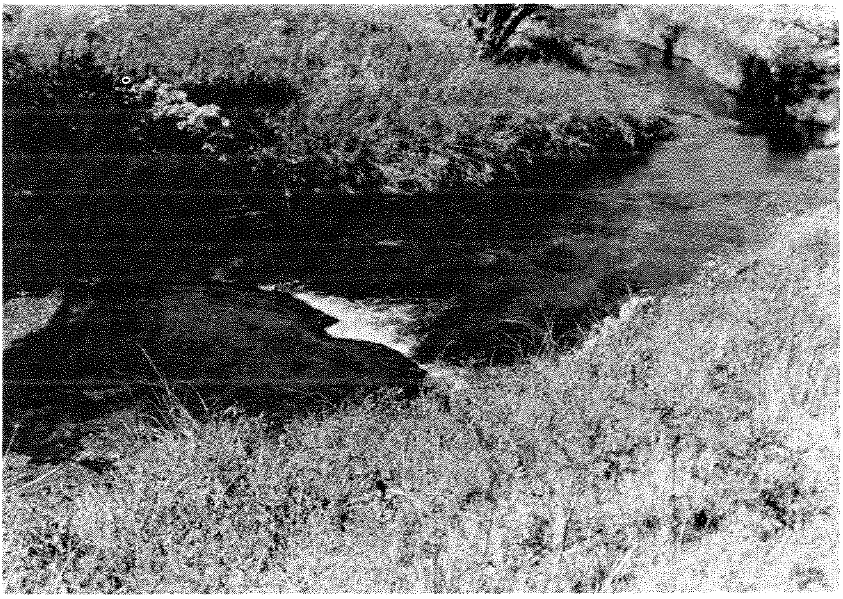


Figure 12. Little or no fluctuation, with bank-to-bank flows, characterize a stream rated No. "4" for ASFV. Such streams are usually spring-fed, with a steady year-around base flow.

A stream rated No. "3" for ASFV exhibits a small fluctuation in annual discharge (Figure 13). While some substrate exposure is expected, the base flow should occupy most of the channel. Base flow should be relatively stable without any sharp changes in flow level. Any fluctuation should be gradual.

Some streams cover all of their channels, but there is a vertical variation in water level. For example, a deep meadow stream may flow bank-to-bank, but water depth may vary periodically due to changes in irrigation return flows, or some similar reason. At first glance, this stream would appear to be a No. "4" grade. However, the vertical fluctuation decreases the stability of the system and the stream should be rated No. "3". If the vertical fluctuation is pronounced, then a No. "2" rating would be in order. A river flowing in a steep-walled canyon where flows are bank-to-bank is another example. Any variation in discharge would result in a vertical change in water level that might be difficult to detect without careful examination of the canyon walls. A visit to the stream at other times of year might also be necessary.

A No. "2" rating for ASFV is associated with moderate fluctuation in flows and is the normal condition expected for most snowmelt water courses. Base flows would be expected to cover between 20 and 66% of the high water channel (Figure 14). Floods are many times greater than the usual base flow, but the ASFV Ratio is not greater than 99.

The substrate exposure expected for a No. "2" rating includes boulders, as well as sand and gravel bars. Exposed boulders surrounded by water (Figure 15) may mislead a person into assigning an inaccurate rating. But note that high water marks on the rocks, debris trapped between rocks, and shallow water with deposits of sand and gravel in and around boulders are all

Figure 13. A stream rated No. "3" for ASFV displays small fluctuation in discharge. The base flow is relatively stable and occupies most of the channel. In the stream shown, discharge is controlled by two upstream reservoirs so a constant supply of water is available for a coal-fired power plant. Thus, base flows are generally steady through most of the year.

Figure 14. Moderate fluctuation characterizes a stream rated No. "2" for ASFV. The base flow occupies up to two-thirds of the flood channel. Dry cobble and gravel areas are often present but are not nearly as extensive as for a No. "1" rating.

Figure 15. Food deposited debris, bank damage and marks on rocks often indicate the high water line for a stream.

clues pointing to more variation in flow than might be evident at first glance.

When rating ASFV, keep in mind that a No. "2" rating represents the average, or usual, situation for Wyoming trout water. No. "0" or No. "4" ratings are rare. Examine the stream flow data and stream characteristics carefully before granting No. "3" or No. "4" ratings.

As a second cautionary note when rating ASFV, remember that a stream may rate differently at different locations. For example, if the ASFV Ratio indicates a No. "2" rating, but the river looks like Figure 11, then there is evidently considerable environmental instability at that location and a No. "1" rating is in order. Nash Fork Creek is another example. At the old UW Science Camp, this creek is a typical mountain stream with normal (No. "2") variation in discharge. However, at the WRRI gage located several miles downstream at the USFS Ski Area, Nash Fork Creek displays greater disparity between flood and base flows. Its average ASFV Ratio is 476, which suggests an unstable, fluctuating aquatic habitat. Inspection of the creek at the Ski Area confirms this impression.

Key considerations at the Nash Fork Creek include: (1) the distance between the gage and the HQI site, and (2) the different characters of the stream at the two locations. A No. "1" rating for upper Nash Fork Creek, based on the ASFV Ratio at the gage, would be inaccurate. A better procedure would be to disregard the gage data and rate ASFV at the Science Camp from field observations.

A third cautionary note when rating ASFV, is to watch for vertical fluctuation, especially in a confined channel. Considerable vertical variation in stream discharge is likely to equate with reduced stability in the fluvial environment. Since the customary clues, such as exposed gravel bars, may not be evident, the stream may easily be over-rated. The best defense is to know the stream and be alert for such abnormality.

THE TEMPERATURE ATTRIBUTE

Rating Criteria

	MAXIMUM SUMMER STREAM TEMPERATURE Characteristics			
	Low Range		High Range	
Rating	°F	°C	°F	°C
0	<43	<6	>80	>26.4
1	43-46	6-8	76-79	24.2-26.3
2	47-50	8.1-10.3	71-75	21.5-24.1
3	51-54	10.4-12.5	66-70	18.7-21.4
4	55-65	12.6-18.6		

Equipment Needed

1 - Rating Critera.
2 - USGS Temperature Records (Lowham, et al. 1975).
3 - USGS Water Quality Records (eg. Anonymous 1980a, 1980b).
4 - Fisheries Management Crew Records.
5 - Recording Thermometers (minimum-maximum or thermograph).
6 - Pocket Thermometer.
7 - Waterproof field notebook.

Data Sources

While water temperature is a very easy parameter to measure, temperature records can be very elusive and are often noted for their scarcity. Determining the maximum summer temperature for a stream can demand careful detective work to ferret out records.

USGS personnel record water temperature each time a gage station is visited, so USGS records are a primary data source for many Wyoming streams. Some of these records have been compiled in easy-to-use graphic form (Lowham, et al. 1975). Other USGS temperature records are reported in the annual data summaries for the various gage stations (Anonymous 1980a, 1980b), and may require some digging to uncover. These temperatures are those recorded at the time of visit and do not necessarily represent the daily maximum or mean.

Other water temperature data are sometimes available from fish planting records, card files, stream survey sheets and WGF administrative reports. However, considerable effort may be needed to assemble the needed information. Additional data may be available from WRRI (Smith et al. 1976).

When reviewing water temperature records, the history of the stream should be kept in mind because the temperature regimen can change if the stream flow pattern is altered. For example, if a dam was built on the study stream in 1970, temperatures recorded after that date are more likely to represent the present temperature regime than are the pre-impoundment data. Thus, you would not want to review pre-1970 records unless the natural, pre-dam temperature regime was needed.

The temperature attribute is one HQI parameter where advance planning is very helpful. Proper planning will allow the installation of recording thermometers prior to the HQI evaluation. If a recording thermometer is not available, a pocket thermometer can substitute, especially if the site is visited regularly during the summer.

Attribute Clarification, Measurement and Rating

The temperature regime of the study stream is measured indirectly by using the maximum summer water temperature of record as an indicator. While more specific data, such as mean daily temperature would be desirable, such data are rarely available. Peak temperature, on the other hand, is often readily available or easily measured.

The temperature attribute exerts much influence in the HQI models. Therefore, the better the data used to rate the temperature attribute, the more accurately will this attribute contribute to the final HQI output. A weekly series of pocket thermometer readings is better than a single temperature reading in late July. Better yet, are data from a recording thermometer, and best of all, are several years data from a thermograph. The point is, use the best temperature data possible!

Water temperatures in Wyoming streams usually follow a regular pattern. Most waters reach their peak temperature in late July or early August as stream flows recede. This period is relatively free from the cooling influences of the snowmelt run-off and fall weather. After the first part of August, stream temperatures often decrease, even though the weather may still be hot and dry. This trend reflects shorter days and the approaching fall season. Since there are exceptions to this pattern, especially if stream flow is controlled in some way, the characteristics of the study stream should be carefully examined.

Sometimes good temperature records at one location can be adapted to provide information for a second site on the same stream. This technique is especially valuable if access to the second site is poor.

For instance, from thermograph records, the maximum temperature is 79°C (26.1°C) at site A, which is several miles downstream from site B. On August 20th, site B is visited for an HQI evaluation and the stream temperature is 69°F (20.6°C) at 2:00 p.m. Since August 20th is past the the peak temperature period, 69°F probably does not represent the maximum temperature at B. At 2:30 p.m., you visit A, where the temperature is 76°F (24.4°C). The ratio 69/76 = x/79 gives a projected maximum of 72°F (22.2°C) for B. If a thermograph is still operating at site A, the 2:00 p.m. reading is used in the above ratio.

Note that this procedure makes some assumptions. First, the temperature and stream flow regimens are assumed to be relatively stable between the two points. That is, there are no large changes from major spring or tributary inflows. Second, the procedure assumes a short time span between readings. If a temperature is obtained for site B at 1:00 p.m., but you can't reach site A before 7:00 p.m., forget it; unless you had the foresight to install a thermograph at site A.

While this procedure can give valuable clues to maximum temperature, keep in mind that it is only an estimate. The best procedure is to install a recording thermometer. If this is not possible, the above procedure may give a better estimate than possible with only a single measurement. In the above example, the ratio approach suggested a "2" rating, while the single measurement indicated a "3" rating. This difference would cause a sizeable change in HQI Score.

If thermographs can be operated simultaneously for one summer at both sites, and there are several years records at site A, then correlation-regression analysis may be able to predict a better maximum temperature for site B. Assuming there is correlation between the two stations, the predicted maximum at B would be based on the several years of record at site A, instead of the single year recorded by the thermograph at site B.

Rating the temperature attribute is simple. Once the best estimate of maximum temperature is in hand, reference to the rating table readily yields a rating. However, if the temperature is borderline between two ratings, or if you lack confidence in the estimate, you may wish to see if additional records can be found.

THE NITRATE NITROGEN ATTRIBUTE

Rating Criteria

Rating	Characteristics: Low Range (mg/l)		Characteristics: High Range (mg/l)
0	<0.01	or	>2.0
1	0.01 - 0.04	or	0.91 - 2.0
2	0.05 - 0.09	or	0.51 - 0.90
3	0.10 - 0.14	or	0.26 - 0.50
4	0.15 - 0.25		

Equipment Needed

1 - Rating Criteria.
2 - Clean, one-liter sample bottles made of inert plastic.
3 - Access to professional laboratory facilities that are properly equipped to analyze trace amounts of nitrate nitrogen (DO NOT USE HACH KITS OR SIMILAR PORTABLE CHEMICAL KITS).
4 - USGS water quality records.
5 - Labels for bottles.

Sample bottles made from inert plastic, such as Nalgene (PVC) brand, are available from most scientific supply companies. These bottles must be properly prepared before use (Appendix II). Before water samples are collected, each bottle must be carefully washed and rinsed. The final wash-rinse cycle includes filling the bottle with a solution of sulphuric acid and distilled water, letting it stand for several days and then rinsing with de-ionized water. Finally, a 2 ml solution of reagent grade, concentrated sulphuric acid is added to the clean, empty bottle as a preservative. Caps must fit tightly to prevent acid leakage.

Arrangements should be made for sample bottles and nitrate nitrogen analysis at a competent laboratory well in advance of any HQI evaluation. Water analysis is available at the University of Wyoming, but WGF personnel should contact the Limnology Lab in Lander as they are familiar with HQI requirements.

Data Sources

Nitrate nitrogen data collected during HQI evaluations can sometimes be supplemented by USGS water quality records (Anonymous 1980a, 1980b). While not all streams are sampled by the USGS, nitrate nitrogen concentrations have been determined at many gaging stations (Anonymous 1980a, 1980b). Additional data may be available from crew records or from the WRRI computer program at Laramie (Smith et al. 1976).

Attribute Clarification

Nitrogen dissolved in water can be split into several components, such as nitrite, nitrate, organic, and ammonia. Nitrate nitrogen concentration is the form needed for an HQI evaluation. However, the other nitrogen components are sometimes reported, depending on the type of analysis.

An understanding of the interrelationships existing between the nitrogen components is helpful in making best use of water analysis data. Below are some common ways that nitrogen is reported and their relationships.

---

(1) Total Nitrogen = Organic Nitrogen + Inorganic Nitrogen.

(2) Total Kjeldahl Nitrogen = Ammonia Nitrogen + Total Organic Nitrogen.

(3) Total Nitrogen = Total Nitrite + Nitrate Nitrogen + Total Kjeldahl Nitrogen.

(4) mg/l (NO_3) Nitrate = mg/l Nitrate Nitrogen x 4.43.

(5) mg/l Nitrate Nitrogen = mg/l (NO_3) Nitrate x 0.2257

(6) A dissolved nitrate nitrogen concentration is determined from a filtered sample and usually represents a lower concentration than total nitrite + nitrate nitrogen.

A total nitrite + nitrate nitrogen concentration is determined from an unfiltered sample and is greater than dissolved nitrate nitrogen.

The desired output from a water analysis is nitrate nitrogen, but the above relationships can allow use of other data to supplement HQI samples.

USGS water quality books often report different nitrogen components for the same station in different years. While this probably reflects changes in methods of analysis, the results can be confusing and unusable for HQI purposes unless converted. A nitrate (NO_3) value reported in 1964 USGS records is not the same as a nitrate nitrogen concentration reported in 1970, nor is it the same as the nitrite + nitrate nitrogen reported in 1980. However, recall that mg/l nitrate nitrogen = mg/l (NO_3) nitrate x 0.2257. Also note that nitrite is usually very miniscule or absent in Wyoming waters, which means that a reported nitrite + nitrate nitrogen concentration is essentially an estimate of nitrate nitrogen. Therefore, conversion will allow all three reported concentrations to be used as estimations of nitrate nitrogen concentrations, thus increasing the sample size.

For example, a single grab sample from the Encampment River in 1978 indicated an absence of nitrate nitrogen. Since a zero rating appeared low for this habitat, additional corroboration was needed. A search of the water quality records for a nearby USGS gage showed that the nitrate nitrogen concentration averaged 0.03 mg/l, a "1" rating, during 1967-78 (Table 2). Consolidating the available data increased the sample size and changed the nitrate rating for the HQI evaluation.

Measurement and Rating

Accurate determination of nitrate nitrogen concentration can be very difficult. Nitrate concentrations in natural waters often display considerable fluctuation during the year, and may vary daily. As noted earlier, a single grab sample may inaccurately reflect a nitrate regime in a stream. Therefore, the more samples that can be collected during August and early September, the better will be the estimate of nitrate content for the study stream.

In addition to potential problems from natural variations in concentration, nitrate samples are very susceptible to trace contamination and interference. Sample containers must be perfectly clean and properly prepared (Appendix II). Careful sample collection and analysis is necessary to insure best results (Appendix II).

From the fieldman's viewpoint, nitrate sampling appears simple. All one has to do is fill a sample bottle with water from the study stream. In reality, though, the situation is more complex. First, the sample bottles must be properly prepared. Second, the bottles must be filled without losing any of the acid preservative. Third, the samples must be properly labeled and transported to the analytical laboratory without undue stress from heat or light. The bottle label must include the date and

Table 2. Nitrogen concentration in the Encampment River, as reported for the USGS gage above the Hog Park Creek confluence (Gage No. 66238). Data source: USGS annual water resource data books similar to Anonymous (1980a).

Sample Date	Reported (NO_3) Nitrate (mg/l)	Reported Nitrate Nitrogen (mg/l)	Reported Nitrate + Nitrate Nitrogen (mg/l)	Converted Nitrate Nitrogen[a/] (mg/l)
7/25/67	0.3			0.068
8/30/67	0.6			0.135
7/25/68	0.2			0.045
8/20/68	0.2			0.045
9/12/68	0.0			0.0
8/19/69	0.0			0.0
9/17/69	0.0			0.0
8/24/70	0.2			0.045
8/24/72			0.02	0.02 [b/]
8/24/74		0.03		0.03
8/14/75		0.0		0.0
8/19/77		0.0		0.0
8/29/78		0.0		0.0 [c/]
			n = 13	
			$\bar{x}$ = 0.03	

a/ mg/l Nitrate Nitrogen = mg/l (NO_3) Nitrate x 0.2257.

b/ Assuming that the reported nitrite + nitrate concentration consists entirely of nitrate nitrogen.

c/ HQI nitrate sample.

specific location where the sample was collected. And last, the sample must be analyzed, using the proper chemical test and suitable expertise.

One very important point that must be understood is that, in Wyoming streams, the nitrate concentration is usually very small. These trace amounts can be missed if the laboratory analysis is not skillfully done. You must communicate to the laboratory personnel that your samples probably contain only trace amounts of nitrate, at best. Otherwise, the samples will likely be processed by automatic analyzer, which does not register trace amounts, and your samples will inaccurately read as zero. Fore-warned lab personnel will use an analytical method suitable for trace nitrate concentrations.

Nitrate nitrogen analysis for the original HQI samples was done by the phenoldisulfonic acid method (American Public Health Association, et al. 1971). However, methodology has improved and the technique presently used by the Limnology Lab in Lander is the cadmium reduction method (Appendix II) recommended by the Environmental Protection Agency (Anonymous 1979).

The former technique estimates nitrogen concentrations as nitrate nitrogen, but the latter yields nitrite plus nitrate nitrogen. Since nitrite is present in Wyoming streams only in micro-amounts, cadmium reduction basically estimates nitrate nitrogen. The current USGS water research data reports for Wyoming (Anonymous 1980a, 1980b) also report total nitrite plus nitrate nitrogen. This is currently the best estimate of nitrate nitrogen for Wyoming streams. The next best estimate is the dissolved nitrate nitrogen analysis (or the dissolved nitrite plus nitrate nitrogen) which are filtered samples that may yield a lower concentration.

A word of caution is necessary about nitrate nitrogen analysis that is reported as nitrite plus nitrate nitrogen. Previous sampling has established that nitrite concentrations in Wyoming streams are miniscule and can be safely ignored. However, this situation may not exist in other states and sample results reported as nitrite plus nitrate nitrogen should be used with caution unless there is adequate information about nitrite concentrations. If nitrite is present, its concentration must be determined and subtracted from the total to get an accurate estimate of nitrate nitrogen.

THE WATER VELOCITY ATTRIBUTE

Rating Criteria

	Characteristics				
	Low Range			High Range	
Rating	ft/sec	(cm/sec)		ft/sec	(cm/sec)
0	<0.25	(<8)	or	>4.0	(>122)
1	0.25-0.49	(8-15.4)	or	3.5-3.99	(106.6-122)
2	0.50-0.99	(15.5-30.3)	or	3.0-3.49	(91.4-106.5)
3	1.0 -1.49	(30.4-45.5)	or	2.50-2.99	(76.1-91.3)
4	1.50-2.49	(45.6-76)			

Equipment Needed

1 - Rating Critera.
2 - Fluorescent dye (water soluble).
3 - Stop watch.
4 - Container for dye.
5 - Waterproof field notebook.
6 - Tape measure, flexible, waterproof (fiberglass preferred).

The green fluorescent dye used by the Aquatic Habitat Crew was obtained from locator-dye packets taken from surplus U.S. Government life rafts. Since these packets contain finely powdered dye, the best procedure is to premix a dye solution in the lab by adding one dye packet to a large container of water. Smaller containers can be used to transport the mixed dye. Individual doses can be mixed in the field, but this sometimes leads to gross contamination of people, trucks and nearby objects.

Fluorescent dye can also be obtained in tablet form, which is much easier to transport and work with than the powder. One source for these tablets is: Formulabs, Inc., Fluorescent Dye Tracing Systems Division, 529 West Fourth Street, P.O. Box 1056, Escondido, California 92025. Both red and green dye is available.

Other dyes, such as food coloring, are much inferior to the fluorescent dye and are not recommended for HQI use.

<u>Data Sources</u>

All measurements are obtained in the field when the HQI work is done, so no records search is necessary.

<u>Attribute Clarification</u>

The average water velocity flowing through a section of stream can be measured in several ways. One method is to measure velocity at regular intervals with a current meter, but this approach is time consuming and tedious. Another technique is to time a slug-of-dye as it flows through a measured section of stream. Time-of-travel velocity can be precisely measured by a fluorometer and the technique is widely used by hydraulic engineers (Zimmerman 1970).

However, a fluorometer is expensive and the procedures can be complex. Therefore, a modified time-of-travel procedure was adapted for HQI use.

In the HQI method, the dye is added to the stream at the upper HQI station boundary. Then the primary dye cloud is timed through the study section. Measurement of thalweg length gives the distance traveled and water velocity, in feet per second, can be easily computed.

Since a fluorometer is not used, the dye cloud must be tracked visually and the results are more subjective than if dye density is measured by machine. However, careful observation of the dye cloud when it reaches the lower station boundary usually yields satisfactory results. The test is simple and can be easily repeated if necessary.

Measurement and Rating

(A) Thalweg

The track of the fluorescent dye through a study section usually follows the thalweg. Thus, the thalweg distance must be measured because the simple length-of-station distance will usually be too short. Although thalweg can be measured at any time during an HQI evaluation, watching the dye pass through a section of stream often helps clarify the thalweg line to be measured.

By definition, thalweg is the down-channel course of greatest cross-sectional depths (White and Brynildson 1967). Measuring the thalweg is relatively simple in most cases, but complications may occur when deep, unwadable pools are encountered. Deep, swift rivers present a formidable problem and will be discussed later.

For HQI purposes, the word thalweg is used loosely to describe the path followed by the dye as it flows through a study section. Since the dye often tracks through the deepest parts of the channel, there is usually no problem with the traditional definition. However, sometimes deep spots in a channel are offset from the primary water flow, especially during low flow conditions. This problem is also common in streams with boulder patches. The work crew must use their best judgment in such cases and watching dye passage may help determine the thalweg line. Strict measurement to always include the deepest points may give an incorrect thalweg for HQI use. Measuring the primary line-of-flow, while ignoring isolated deep spots is often more accurate.

Thalweg measurement requires two people (Figure 16), except on a very small stream where one person can measure with a range pole. Two people are necessary to hold the tape and maintain proper curvature.

Since water seldom flows in a straight line, measuring thalweg with rigid, straight lines will be inaccurate. With a little practice, two persons can "throw" the tape so it follows the natural curvature of the water flow.

When water flow is not too swift or deep, the upstream person can hold the tape while the other follows the thalweg downstream, playing out tape as he goes. The tape is allowed to lay on the stream bottom behind him. This technique is valuable where the thalweg wanders aimlessly, as in a boulder patch.

A downstream view is usually best for locating the thalweg, so the usual procedure for measuring thalweg is to start at the upper station boundary and work downstream. One person remains at the boundary while the second follows the thalweg downstream until a logical break point is reached, as where a pool breaks into a swift run. This point is marked with a range pole and the distance is read from the tape and recorded. The first worker stays put until the other person wades down to the break point and marks it with his range pole. He stays there while the second person again follows the thalweg downstream. The above procedure is repeated as many times

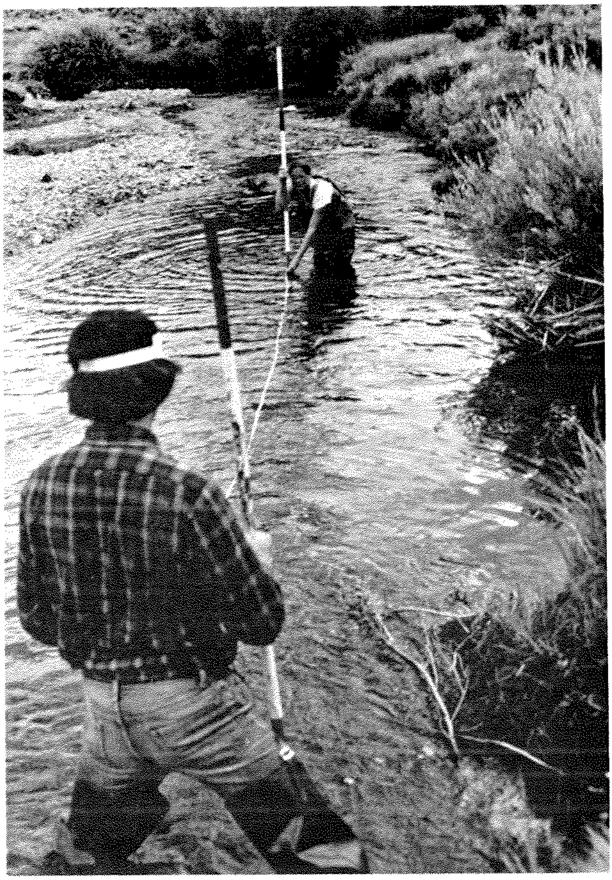


Figure 16. Thalweg is measured along the deepest part of the stream channel, using range poles and a flexible tape measure.

as necessary to traverse the study section (Figures 17, 18, and 19).

The thalweg is followed as closely as possible, except when a deep, unwadable pool is encountered. Then, the downstream person must walk around the pool, playing out tape as he goes until he reaches a wadable point below the pool. He then wades out to the deepest point, the tape is tightened up to match the natural curvature of the thalweg through the pool and the distance is recorded.

Large unwadable streams present a difficult thalweg measurement problem. There are several ways to overcome this problem. First, if water flow drops to wadable levels some time during the year, the thalweg can be measured then. This measurement can be coupled with the time-of-travel for the dye, as obtained during the critical period, to calculate water velocity. This technique assumes that the thalweg follows the deepest point in the channel, regardless of discharge level. This assumption may be invalid if many large boulders are present to deflect flow.

A second method is to use boats and survey equipment (transit, rod and tape). An exact map locating the thalweg can be constructed when this approach is used. However, adequate time and surveying expertise must be available.

A third approach to the problem is to use a range finder and range pole. While a thalweg determined in this way will be linear instead of curvilinear, a suitable approximation of thalweg can be obtained. Careful use of the range finder will increase accuracy, especially if short shots are taken.

A fourth technique involves estimating thalweg length by increasing station length by a percent, depending on stream size and apparent curvature of the thalweg. For example, with a 500 ft. (152 m) station length,

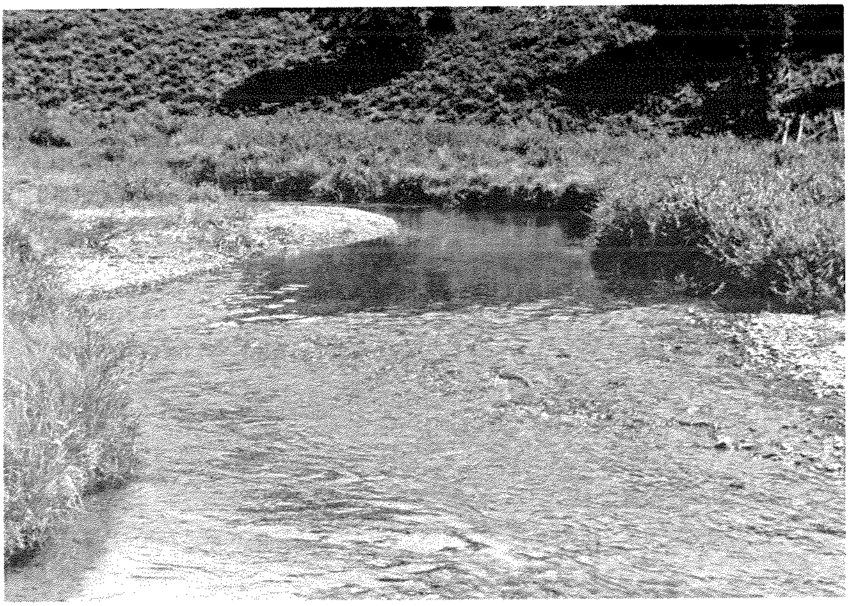
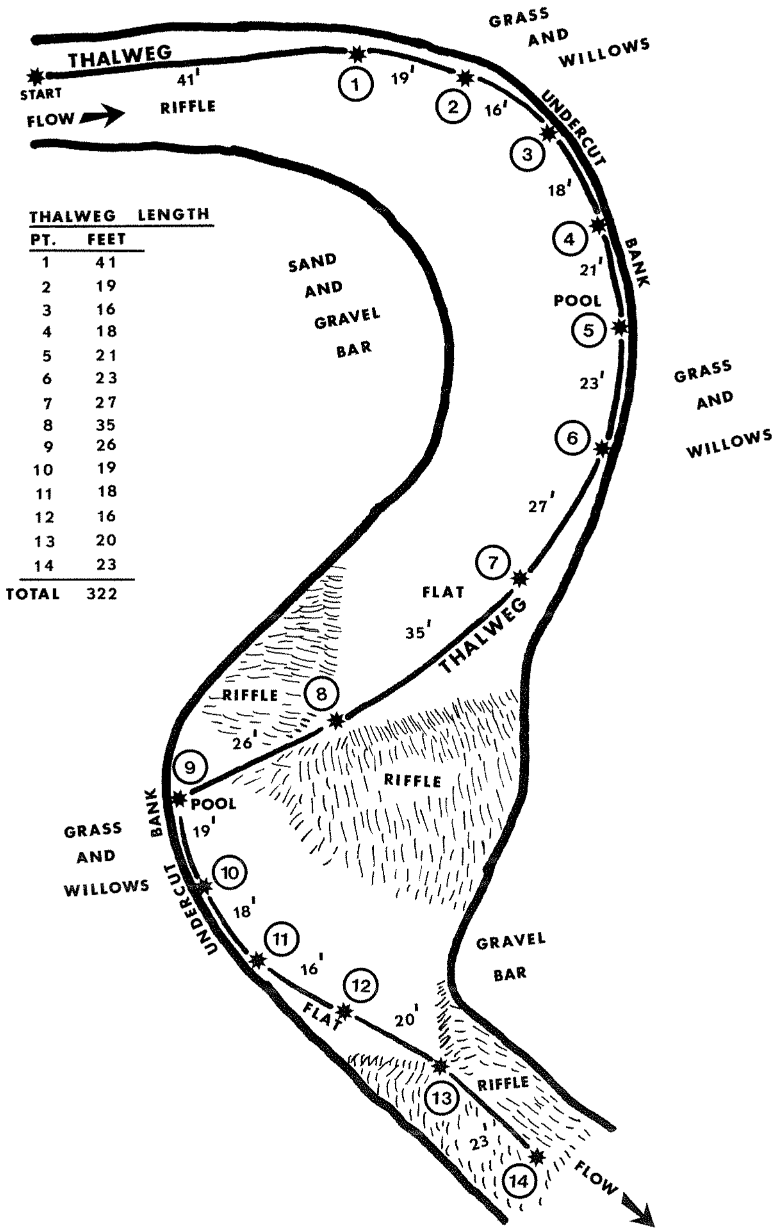


Figure 17. The upper part of the HQI station on Hobble Creek features a long, deep pool curving against a stable, well vegetated bank. Note the characteristic "V" where the thalweg enters the riffle.

Figure 18. Two riffles and a small pool-run next to an overhanging bank mark the lower part of the Hobble Creek HQI station. Note the typical "V"'s where the thalweg enter the two riffles.



THALWEG LENGTH

PT.	FEET
1	41
2	19
3	16
4	18
5	21
6	23
7	27
8	35
9	26
10	19
11	18
12	16
13	20
14	23
TOTAL	322

Figure 19. Thalweg measurement at a 300 ft (91 m) HQI station on Hobble Creek. Circled numbers indicate the sequence of measurements, which is normally done in a downstream direction from the upper station boundary. Where meander curvature is extensive, the thalweg is best measured by several short segments; long, straight runs require fewer segments. Note the characteristic "V" where the thalweg enters the lower two riffles (see also figures 17 and 18). Sketch is not drawn to scale.

one might add 20% to get an estimated thalweg length of 600 ft (185 m), if the thalweg meanders extensively. If the thalweg parallels the stream bank without much meandering, then 5% or less would be better (500 ft (152 M) + 25 ft (7.6 M) = 525 ft (160 M) thalweg). Such work yields a very rough approximation of thalweg length and should be used only where deep, swift water and other river characters do not permit thalweg measurement by other methods.

(B) Dye

The amount of dye needed depends on stream size and current speed. A large river may require a bucketful of dye, while a pop can will suffice for a brook. Within reasonable limits, too much dye is better than not enough, especially on a large or slow stream. If too little dye is used, the main dye cloud may be dispersed and difficult to see when it reaches the lower boundary.

The dye body usually dissipates rapidly downstream from the study area. While no complaints have been received to date from landowners or the public, some common sense is essential when using the dye. A good rule of thumb is to use as much as you need, but don't over do it. For example, if a heavy slug of dye leaves your study area and flows through the annual city water sports carnival, there may well be problems.

Dye is added to the stream at the upper station boundary. Usually, one person wades out to the thalweg line with the dye can. On signal, he dumps the dye, all at once, into the stream (Figure 20) and the observer starts the stop watch. The latter then goes to the lower station boundary to await the dye cloud. On swift streams, fast footwork is needed to beat the dye to the lower boundary.

As the dye tracks through a station, distinct parts of the dye cloud

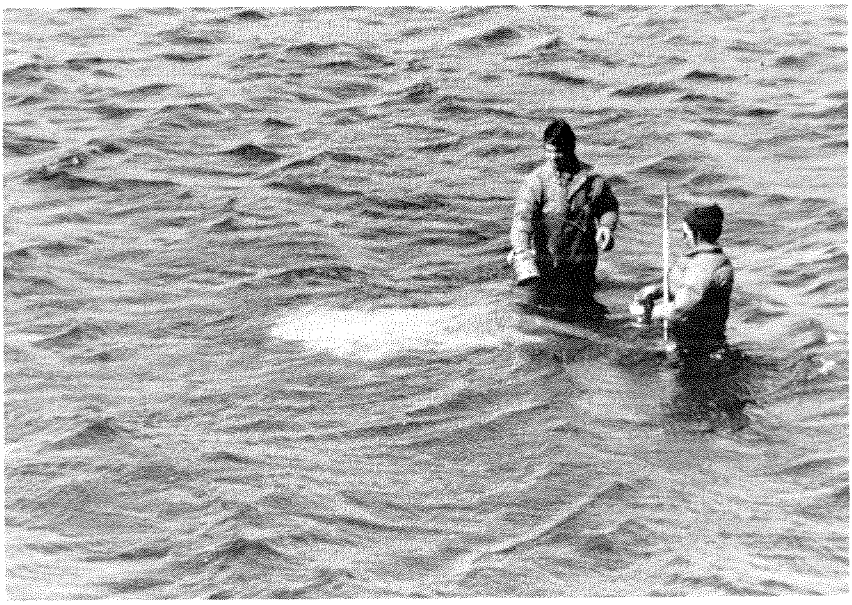


Figure 20. A fluorescent dye solution is injected into a stream for a velocity measurement. To start the measurement, all of the dye is dumped into the stream at the upper HQI station boundary.

can usually be seen (Figure 21). First past the observer are streamers of dye borne on the faster, surface layers of water. This is called "first color". Next is the main body of dye. Its front is marked by the first sign of good, solid color and is the part desired for the HQI.

Careful observation is needed to determine the proper time of arrival for the dye cloud. Since the dye body sometimes spreads out and colors a sizeable section of stream, an unwary observer can become confused by all the color. The arrival time desired is when a distinct, solid color is first present at the station boundary. This color will be at the front of the dye cloud, but do not confuse it with the first, faint streamers of dye.

As the dye reaches the lower station boundary, note the time of "first color" as a reference point. Then, as the dye flows past, monitor the stopwatch as the color deepens into "good color". After "good color" apparently has arrived, keep the stop watch running and watch the dye until a definite decision is made on proper time of arrival.

Some dye clouds travel as easy-to-time compact slugs (Figure 22), while others disperse throughout the study section. The latter type features much color and requires alertness to discern the "good color" point. In some slow streams, the dye may take an hour or more to traverse a 300 ft (91 m) section. Plan ahead in such cases so the overall evaluation will not be delayed by the dye work. When working mud bottom streams, do the dye test before the crew muddies up the stream.

(C) Computing Velocity

After the thalweg has been measured and the dye-cloud timed, computing water velocity is simple. For exmple:

Water velocity = thalweg length/time of travel
= 335 ft/120 sec.
= 2.8 fps = a "3" rating.

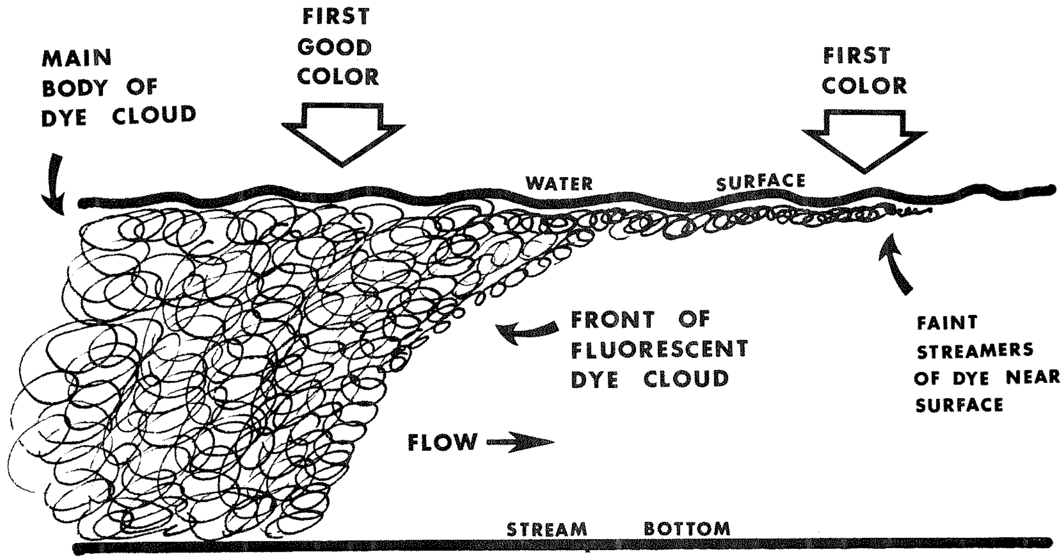


Figure 21. Characteristics of a typical fluorescent dye cloud flowing through an HQI study station. This is the form expected in most streams. However, in large or swift streams, dye dispersion may be different and the dye cloud may travel as a compact slug, which may obscure the expected characters.

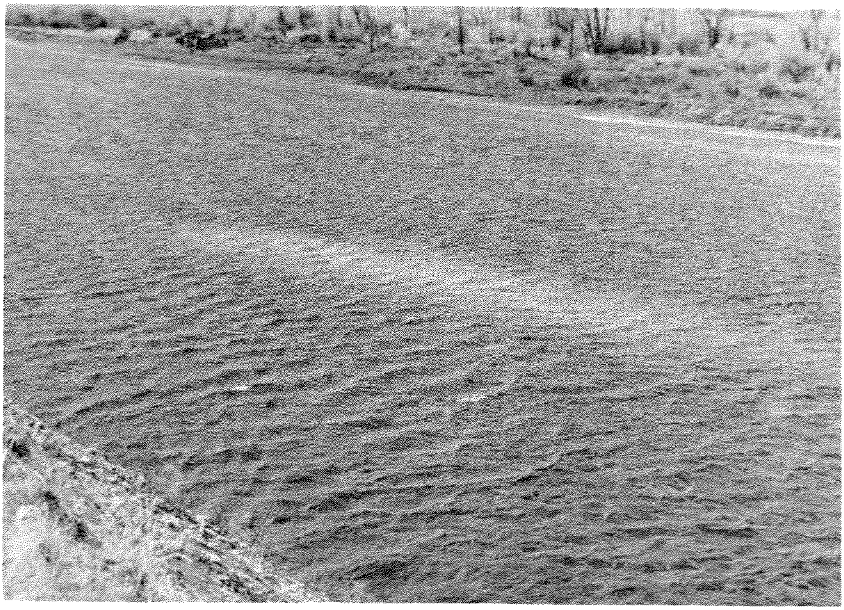


Figure 22. In a large stream, a fluorescent dye cloud may travel in a compact mass rather than dispersing from bank-to-bank as in smaller waters.

THE FISH FOOD ATTRIBUTES

Rating Criteria

(A) Fish Food Abundance

Rating	Number of Organisms/ft.^{2} (No./0.1 m^2)
0	<25
1	25 - 99
2	100 - 249
3	250 - 500
4	>500

(B) Fish Food Diversity

Rating	Diversity Score1/
0	<0.80
1	0.80 - 1.19
2	1.20 - 1.89
3	1.90 - 4.0
4	>4.0

1/ For the purpose of the HQI, Diversity Score (D_s) is defined as follows: D_s = antilog$_{10}$ D, where D is calculated for each taxon from the formula:

$$D = -\sum_{i=1}^{n} Pi \log_{10} P$$

When P_i is defined as 1/N, and N is the number of organisms, then the formula reduces to $D = \log_{10} N$, as discussed in Watt (1968). $\bar{D}$ is the mean of all the D values for the sample.

Equipment Needed

1 - Rating Criteria.
2 - Surber square foot sampler.
3 - Metal wash basin.
4 - Ziplock plastic bags.
5 - Formaldehyde and rubbing alcohol.
6 - Sample labels (cut from waterproof paper).

The Surber sampler is preferred because it is easily used, generally available, easily transported and sufficiently accurate for HQI purposes. The use of other samplers for HQI use is discouraged due to possible bias from a difference in organism collecting efficiency.

Data Sources

Fish food samples obtained during HQI field work are the primary data source for rating the fish food attributes. However, other fish food data are sometimes available from Game and Fish reports and files, as well as from graduate student reports. When available, such material can be used to supplement the HQI fish food samples.

Attribute Clarification

In most Wyoming streams, macro-invertebrates are a major food for trout. While fish, plankton and terrestrial insects may also be important food items, HQI analysis focuses on those benthic macro-invertebrates commonly captured by a Surber sampler. Aquatic annelids are not counted in the samples because these worms have a tendency to fragment after being preserved, thus giving a false total.

Measurement and Rating

Fish food samples are collected during August or early September, often at the same time the other HQI data are obtained. Care must be taken to avoid possible bias from natural fluctuations in macro-invertebrate populations. Samples taken in early August may not be comparable to those collected in mid-September due to natural changes in the macro-invertebrate population. Such variation may be sufficient to affect attribute ratings, the HQI Score and to negate interstream comparisons. To avoid this problem, either sample several times during the critical period, or collect all samples at one time.

Fish food samples should be obtained at an HQI study station before the area is disturbed by wading. Collect at least three foot-square samples from riffles. The samples should represent a cross section of the riffle habitat used by macro-invertebrates at the study station.

Macro-invertebrate samples are easiest to sort immediately after collection when the organisms are still alive. Since this procedure usually takes too much time, an alternative procedure is to preserve the entire sample. The sample is placed in a plastic sack, such as Ziplock, labeled, and preserved with a formaldehyde-alcohol mixture. After transporting to the lab, the sample is sorted by a sugar floatation method (Appendix III) (Anderson 1959). The organisms are then identified to the proper taxonomic level (Table 3), using keys such as are given in Pennak (1978), Edmonson (1959), Usinger (1956), Wiggins (1977), or Edmunds, et al. (1976).

If complete analysis of macro-invertebrate samples is not feasible, an alternative approach is to rough-count the organisms in the field. The sample is placed in a pan with water and the specimens are counted as they are removed. They are not identified. This procedure has two disadvantages: it is time consuming and it yields only a rough estimate of fish food abundance. No diversity calculations are possible.

Once analytical results are tabulated, abundance and diversity calculations are made (Table 4). The fish food attributes are rated using these calculations and the rating criteria.

Table 3. Macro-invertebrates collected in HQI fish food samples should be identified to the lowest taxon possible; analysis should proceed at least to the taxonomic level listed below.

Group	Minimum identification level	Example
Diptera (Flies)	Family	Chironomidae
Ephemeroptera (May flies)	Genus	Baetis
Plecoptera (Stone flies)	Genus	Acroneuria
Trichoptera (Caddis flies)	Genus[a/]	Hydropsyche
Coleoptera (Beetles)	Family	Elmidae
Odonata (Dragon and Damsel flies)	Family	Gomphidae
Lepidoptera (Aquatic Caterpillars)	Family	Pyralididae
Gastropoda (Snails)	Family	Lymnaeidae
Hydracarina (Aquatic mites)	Order	Hydracarina
Nematoda (Roundworms)	Phylum	Nematoda
Annelida (Worms)	Class	Oligochaeta
Amphipoda (Scuds)	Order	Amphipoda

a/ Except Limnephilidae and Philopatomidae, which are identified to the family level.

Table 4. Example of tabulation sheet for macro-invertebrate samples.

STREAM: South Tongue River LOCATION: Upper end of Shutts Flat

NO. SQUARE FOOT SAMPLES: 5 DATE: 8/24/77

TAXON	TOTAL NUMBER	NUMBER PER SQUARE FOOT	D[a]
Hydracarina	1	0.2	-0.69897
Diptera			
Tendipedidae	17	3.4	0.53148
Simulidae	494	98.8	1.99476
Tipulidae	5	1.0	0
Ephemeroptera			
Baetis	36	7.2	0.85733
Ephemerella	4	0.8	-0.09691
Rhithrogena	26	5.2	0.71600
Heptagenia	101	20.2	1.30535
Plecoptera			
Claassenia	7	1.4	0.14613
Acroneuria	12	2.4	0.38021
Trichoptera			
Potamyia	1	0.2	-0.69897
Oecetis	18	3.6	0.55630
Psychomyia	9	1.8	0.25527
Glossosoma	66	13.2	1.12057
Coleoptera			
Elmidae	39	7.8	0.89209
TOTALS	836	167.2	7.26066

No. Taxa = 15.
Mean No./ft^2 = 836/5 = 167.2 = a "2" rating.
$D_s = D_{total}/15$ = antilog 0.48404 = 3.05 = a "3" rating.

[a] Diversity column can be omitted if macro-invertebrate sample is for use in Model II, where diversity is not used.

THE SUBSTRATE ATTRIBUTE

Rating Criteria

Rating	Characteristics
0	Submerged aquatic vegetation lacking; would expect <25 macro-invertebrates per ft.^{2}. Fish food occurrence is poor.
1	Little submerged aquatic vegetation; would expect 25-99 macro-invertebrates per ft.^{2}. Fish food occurrence is fair.
2	Occasional patches of submerged aquatic vegetation; would expect 100-249 macro-invertebrates per ft.^{2}. Fish food occurrence is moderate.
3	Frequent patches of submerged aquatic vegetation; would expect 250-500 macro-invertebrates per ft.^{2}. Fish food occurrence is good.
4	Well developed and abundant submerged aquatic vegetation; would expect >500 macro-invertebrates per ft.^{2}. Fish food occurrence is excellent.

Equipment Needed

1 - Rating Criteria.
2 - Macro-invertebrate sampling equipment as listed under the fish food attributes (optional).
3 - Waterproof field notebook.

Data Sources

Direct observation at the study site furnishes most of the data needed for this attribute, but refer to the data sources listed under the fish food attributes for other potential sources of information.

Attribute Clarification

Benthic macro-invertebrates are easily collected from most streams, but sample sorting and identification is often tedious and time consuming. Calculation of HQI scores can be seriously delayed while samples are processed. Also, many fishery workers do not have the expertise, or the time, to process macro-invertebrate samples.

Consequently, the substrate attribute was developed to replace the fish food attributes in Model II. Because benthic macro-invertebrate occurrence is a function of available food and cover, which can be furnished by submerged aquatic vegetation, the assumption is that benthic macro-invertebrate occurrence can be estimated by careful observation of vegetation abundance on the stream substrate.

Thus, the substrate attribute does not deal with the physical substrate, but is an attempt to estimate benthic macro-invertebrate occurrence. Both aquatic vegetation abundance and macro-invertebrate occurrence on rocks and debris must be carefully observed. Local habitat conditions and overall stream productivity must be considered. Otherwise, a meaningful rating for the substrate attribute will not be possible.

Evaluating aquatic vegetation abundance should be done cautiously. While most streams have a clear relationship between macro-invertebrate occurrence and aquatic vegetation abundance, there are exceptions. Some streams may have an abundant aquatic flora, but poor macro-invertebrate production. This problem is especially prevalent at high elevations where the aquatic flora may consist of a single moss species, which may carpet the stream bottom. Superficial examination would suggest a "4" rating. A more detailed examination of debris, rocks and moss patches in such streams often reveals a paucity of macro-invertebrates. Thus, a lower substrate rating is realistic for such streams. Streams with well-developed macro-invertebrate populations often have a good diversity of plant types.

Other streams may suffer from a delayed snow melt runoff or a steep gradient, meaning that aquatic vegetation may develop poorly or late in the summer. In such cases, the macro-invertebrate fauna may be more abundant than indicated by the aquatic flora. A substrate rating in early August at such a stream may be inaccurate.

An alternative procedure is to collect several square foot samples from riffles in the study area. Place each sample in a pan, one at a time, and make a quick, rough count of organisms present. Calculate an average abundance value, assign a rating and insert it in Model II.

Measurement and Rating

Estimation of macro-invertebrate abundance by examining stream bottom conditions is at best an educated guess. If Surber square foot samples are feasible, or have been taken previously, by all means use those data to rate the substrate attribute. In this instance, determine the mean number of organisms present per square foot, as detailed in the fish food attribute section. Assign a substrate attribute rating from the Rating Criteria. For example, 126 macro-invertebrates/$ft.^2$ would be assigned a "2" rating. This "2" rating is used in the substrate section of Model II.

If no square foot samples are available, you will have to estimate macro-invertebrate abundance. Visit each riffle in the study section and observe substrate, flora and fauna conditions as discussed below. Rate each riffle separately and calculate an average rating for the station. Use this average rating in Model II.

While examining substrate conditions, mentally try to estimate how many macro-invertebrates are present. For example, if very few organisms can be found, the basic decision is probably between a "0" or a "1" rating. Look under the rocks, probe the vegetation patches and pick through the debris. Do you feel a square foot sample would contain fewer than 25 specimens, or would the total number likely be between 25 and $100/ft^2$? Are there more than $100/ft^2$?

Basically, you are trying to decide if benthic macro-invertebrate (fish food) occurrence is poor, fair, average, good or excellent. Previous experience in working with aquatic macro-invertebrates is very helpful.

THE COVER ATTRIBUTE

Rating Criteria

Rating	Cover Present (%)[1/]
0	<10
1	10-25
2	26-40
3	41-55
4	>55

1/ % Cover = total amount of cover (ft^2 or m^2)/total area in study section (ft^2 or m^2).

Equipment Needed

1 - Tape measure, waterproof, fiberglass preferred.
2 - Range poles, with foot (or 0.1 m) marks.
3 - Waterproof field notebook.
4 - Common sense.

Data Sources

All measurements are obtained at the study stream and no search of records is necessary.

Attribute Clarification

Resting, hiding and shelter areas used by trout are often referred to as cover. Adequate cover is essential to good trout production and numerous studies have documented the relationship between cover and trout abundance.

For HQI purposes, cover refers to those places where trout live in a stream. Cover is where trout find refuge from stressful conditions, such as swift currents. While trout may temporarily move into other areas to spawn or feed, they are generally found in predictable locations. Such "holding-water" offers protection and concealment from enemies, shelter from swift currents, food, shade and a secure place to rest.

Since trout do not normally use all parts of a stream, the trick is to recognize the places they do use. Fallen trees, undercut banks, debris in the channel, pocket pools near large rocks, deep pools, surface turbulence, rubble on the stream bottom, brush piles, aquatic and overhanging vegetation and dead snags all form sheltered pockets that attract trout. Shallows, riffles, and exposed pool sections do not normally qualify as cover.

Measurement and Rating

To measure cover for HQI use, identify each pocket of cover, measure its area, total the area measurements and calculate the percent cover present in the study area.

As possible, wade through the entire station identifying and measuring each patch and pocket of cover (Figures 23, 24 and 25). Very few

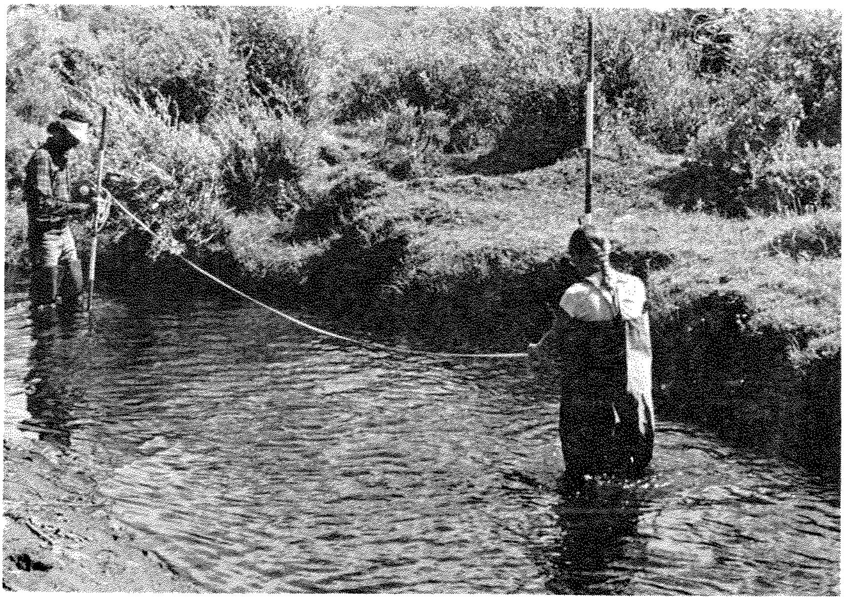


Figure 23. The approximate area of a pool that is usable as cover by trout can be calculated by measuring pool length and width with a tape measure.

Figure 24. Measuring the length of an undercut bank with a range pole.

Figure 25. A range pole is useful to measure the breadth of an undercut bank.

pockets of cover have a regular shape, so the easiest procedure is to "square up" each pocket of cover (Figures 26, 27, 28 and 29).

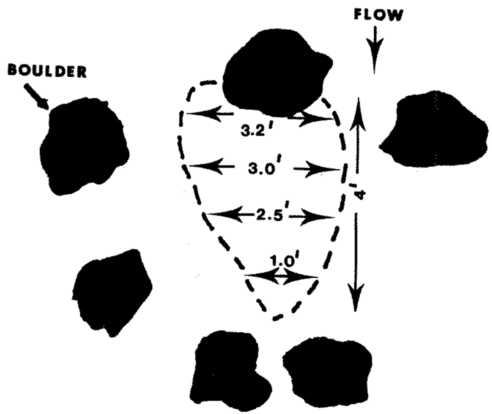
On large sections of cover, several length and/or width measurements may be needed to determine an average length and width from which to calculate area. Systematic data recording will aid cover calculations.

Several considerations are important when measuring cover. First, what species of trout are present? For example, brown trout are secretive and may use everything from brushy snags and undercut banks to muskrat holes. Cutthroat trout, on the other hand, seem to be more pool oriented, while rainbow trout may tolerate faster currents.

Second, how large is the stream and how uniform is its substrate? A large river with a monotonous substrate, like the lower Green River, presents different measurement problems than does a boulder-studded creek. Third, what is the age and length structure of the trout population? The young-of-the-year trout (usually those less than 4-5 in, 100-130 cm) are usually ignored when measuring cover. However, if the fish population consists of mature 4-5 in (10-13 cm) brook trout, alertness is required when measuring cover. Such small fish may use areas of the stream that are not normally measured as cover when dealing with larger fish.

And finally, keep in mind that not all deep water is cover. Pools lacking overhead cover or protection from swift currents may not offer shelter for trout. Trout require deeper water for cover if surface turbulence or overhaning vegetation is absent. Exposed portions of a pool are not effective cover and should not be included in cover measurements, unless the water is quite deep in relation to channel size.

Trout also need protection from swift currents. This is especially true in large, deep rivers where pool velocities are generally greater



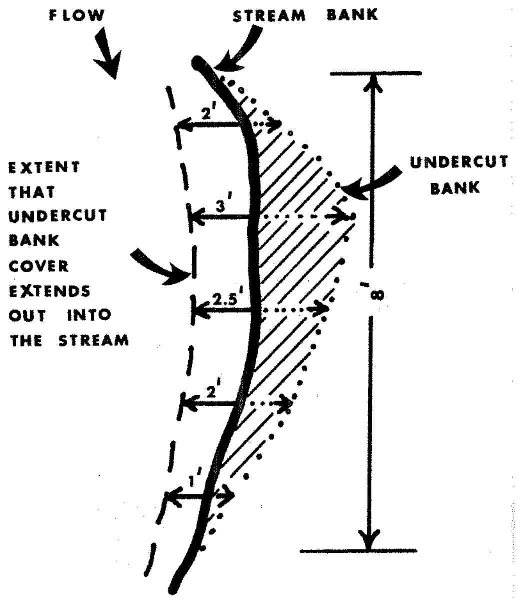
AREA OF POCKET POOL

WIDTH	LENGTH
3.2'	4'
3.0'	
2.5'	
1.0'	

$\Sigma = 9.7/4 = 2.4$ FT = MEAN WIDTH

AREA = $2.4 \times 4 = 9.6 = 10\ FT^2$

Figure 26. A boulder cluster often has many small pocket pools that can provide shelter for trout. These pockets of cover are usually irregularly shaped, so their area is best determined by "squaring-up" the pool, using average width and length. Pocket pool suitability as cover for trout is determined by water depth, surface turbulence, substrate type and color and location and strength of water currents.



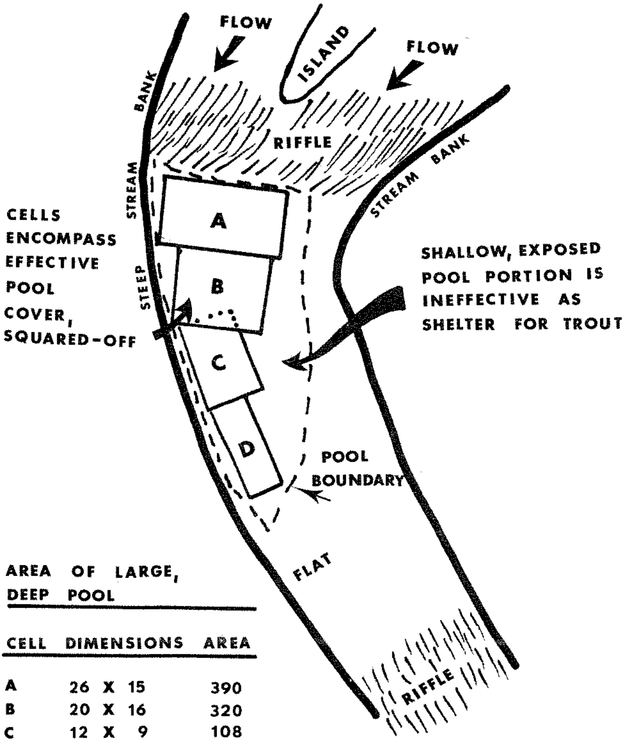
AREA OF UNDERCUT BANK

WIDTHS	LENGTH
2'	8'
3'	
2.5'	
2'	
1'	

$\Sigma = 10.5' \div 5 = 2.1$ FT = MEAN WIDTH

AREA = $2.1 \times 8 = 16.8 = 17$ FT^2

Figure 27. An undercut bank often furnishes valuable shelter for trout. Part of the cover offered by an undercut bank is furnished by a narrow strip of open water along the face of the bank. Trout often use this area for feeding and resting, moving back under the bank only under stress. Thus, this area must be included when measuring the amount of cover offered by an undercut bank. The width of this strip of water varies depending on depth, overhanging vegetation and the amount of debris. Careful assessment of the situation is needed to accurately measure the amount of cover associated with an undercut bank.



AREA OF LARGE, DEEP POOL

CELL	DIMENSIONS	AREA
A	26 X 15	390
B	20 X 16	320
C	12 X 9	108
D	8 X 21	168
	TOTAL	986 FT^2

Figure 28. Cover in a large, deep pool is measured by dividing the pool into smaller cells, which are easier to measure. Two or more measurements may be needed to determine width in each cell. By placing a man on each side of the deep, unwadable part of the pool, the tape measure can be lengthened or shortened, as necessary, as the crew works each cell. The crew works sequently downstream, measuring each cell in turn. Cell length can often be determined from the transect markers that were set out when the station was laid out.

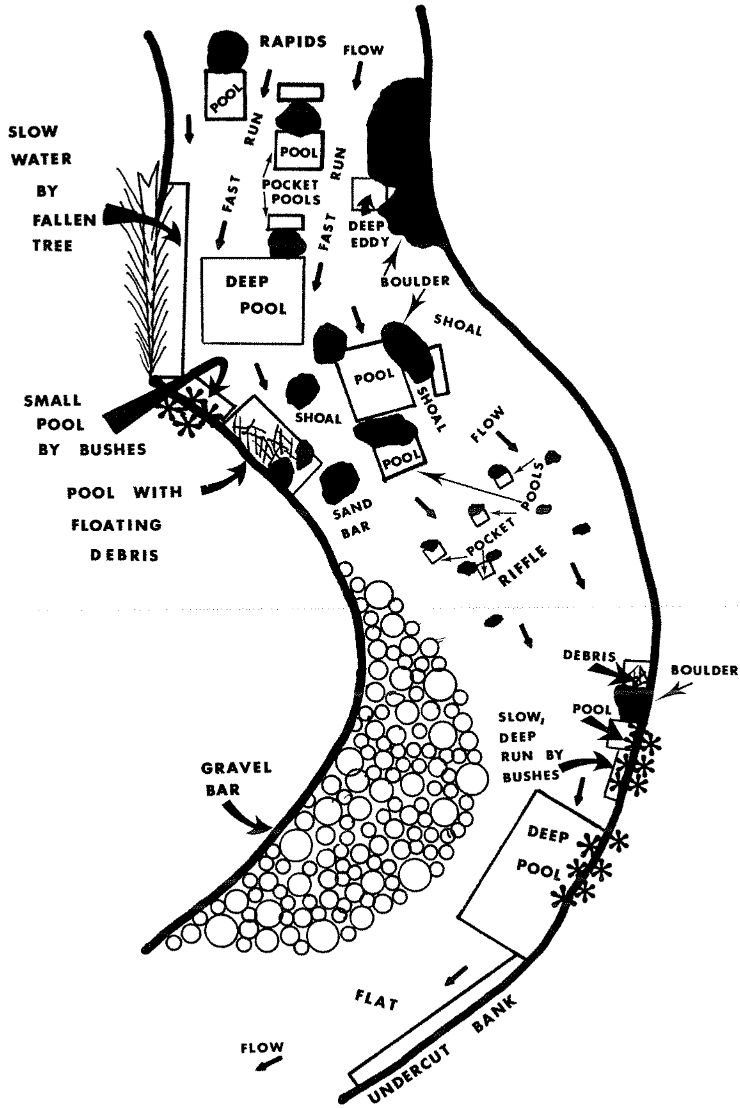


Figure 29. Hypothetical stream section showing areas measured as trout cover (rectangles) using the "square-up" method.

than in smaller streams. The lower Green River is a good example of trout cover-velocity-depth relationships. When the discharge is 1600 cfs (45 m^3/sec.), the Green River is about 250 feet (76 m) wide at the HQI station (Figure 30). Pools in this area are typically long and deep, and appear to offer large blocks of cover for trout. However, this is a false impression as not all of the deep pool area can be classed as cover.

Several clues support this conclusion. Fish in the study area are easily observed from the high west bank. Most trout occur in a narrow strip along the west side of the river. A second clue is that the stream substrate away from the trout bearing strip has a swept, pavement-like appearance. No boulders or debris are present. Finally, the water velocity increases sharply east of the 50 foot (15 m) point (Figure 31). Even though the water depth is adequate to shelter trout, much of the pool is classed as poor cover due to marginal water velocity. Thus, the effective cover is only about 50 feet (15 m) wide, instead of 200 feet (61 m), as first thought.

Example

The upper Smiths Fork River contains cutthroat trout, although an occasional brown trout may be present. There is an adequate water supply for trout from snowmelt, springs and surface runoff. The stream meanders moderately in a relatively broad mountain valley. Pools, flats, runs and riffles are relatively well defined. Cover is provided by pools, undercut banks, overhanging vegetation and debris.

A 300 ft HQI station was established on the Smiths Fork River (Figures 32 and 33). Numerous patches of cover were identified and measured (Figure 34), but the overall cover rating was only fair (Table 5).

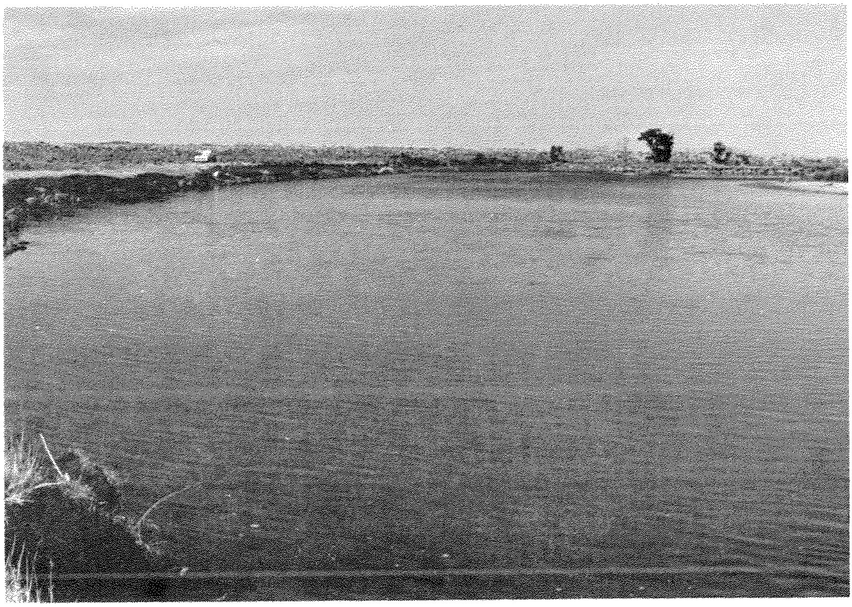


Figure 30. The lower Green River at the HQI station located near the confluence with the Big Sandy River. The high bank on the left is the west bank referred to in Figure 31.

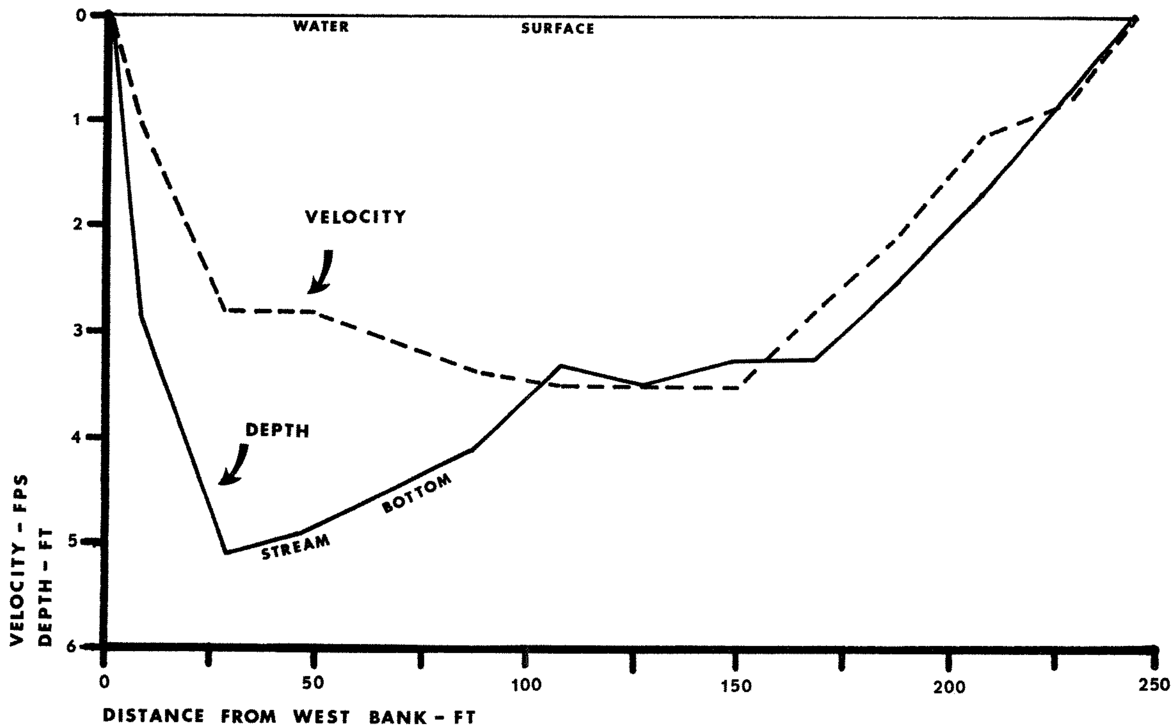


Figure 31. Water velocity and depth profile across a pool at the lower Green River HQI station. Velocity was measured at six-tenths of the distance from the water surface. River discharge was 1600 cfs. While water depth appears adequate to shelter trout across much of the river, marginal water velocity greatly reduces the pool area that is usable as cover by trout. Except for occasional feeding forays into the swifter parts of the pool, most trout stay in the slow, deep water along the west bank.

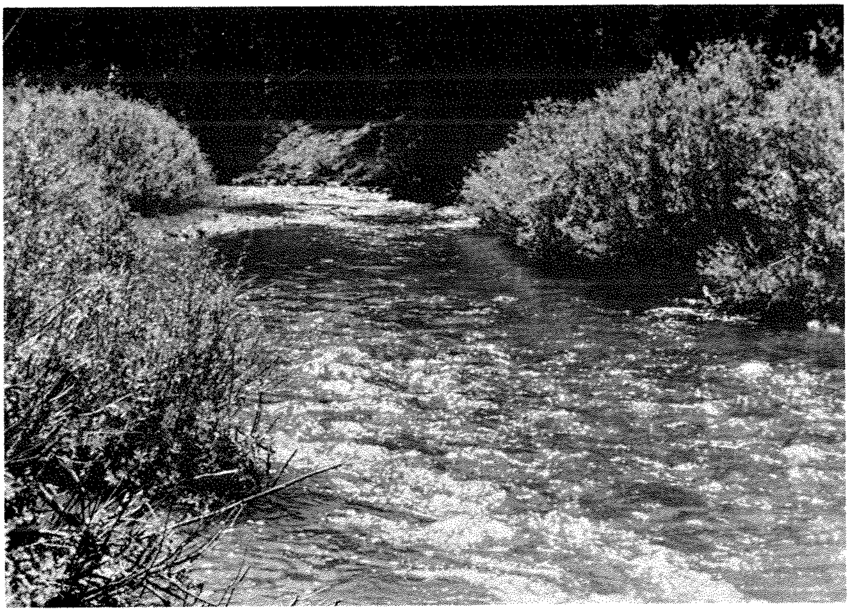


Figure 32. The HQI station on the upper Smiths Fork River. Pool (I) (see Figure 34) is in the center foreground. The upper station boundary is at the top of the photo.

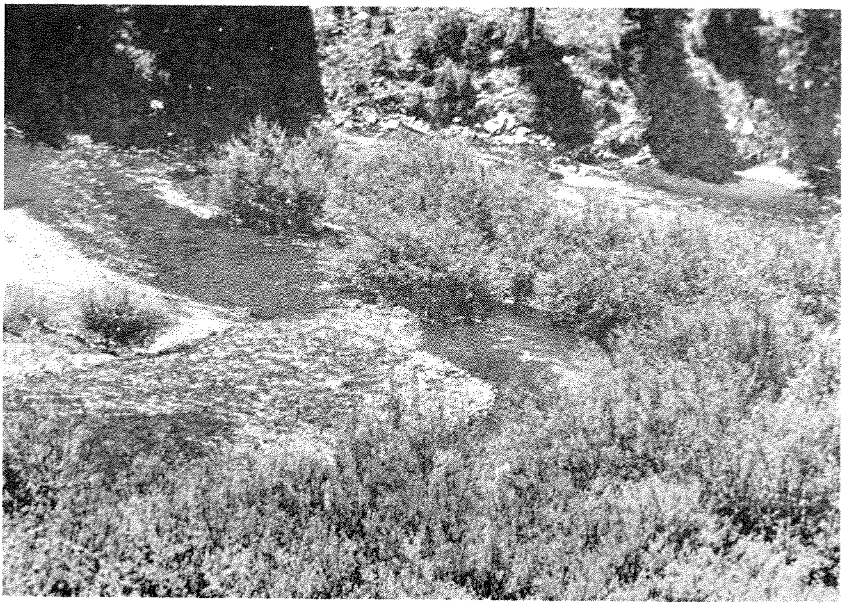


Figure 33. The lower part of the Smiths Fork River HQI station. The deep pool (C) (see Figure 34) is located to the right of the small gravel island.

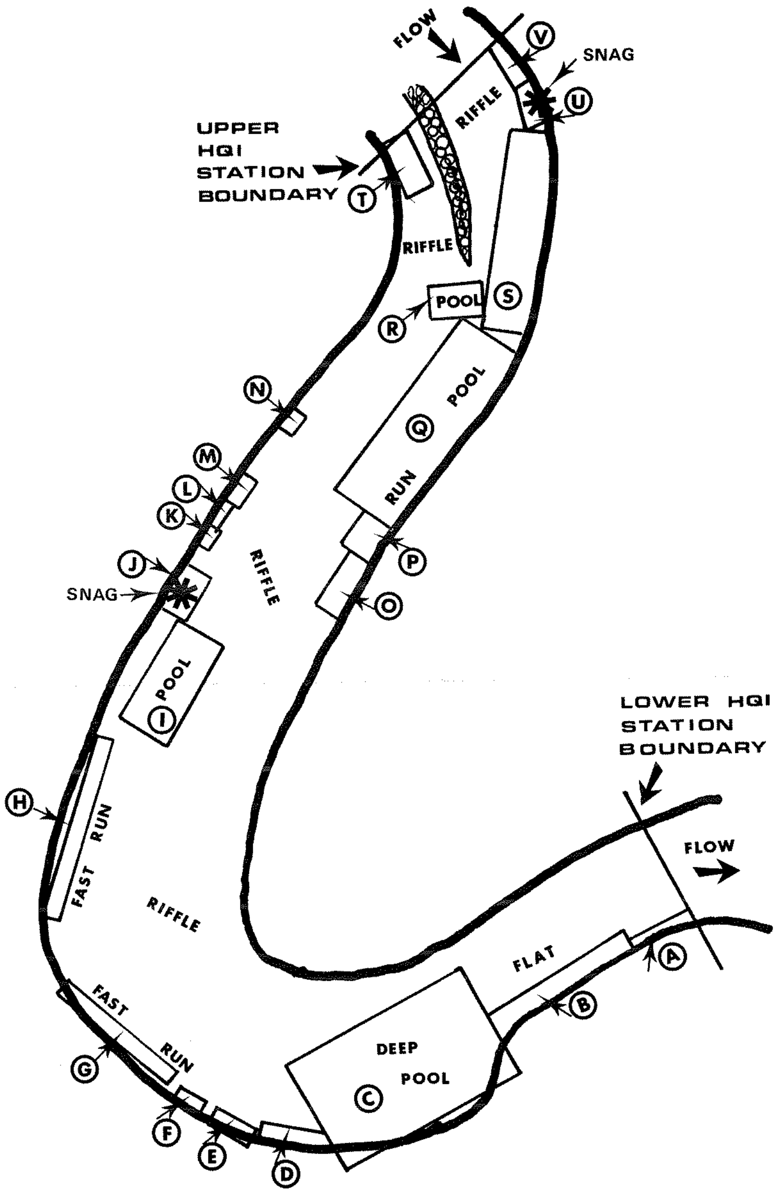


Figure 34. Sketch map of the HQI station on the upper Smiths Fork River showing areas measured as cover for trout. Circled letters locate cover patches itemized in Table 5. Note sketch is not drawn to scale.

Table 5. Cover measurements and calculations at the Upper Smiths Fork River HQI Station, as depicted in Figure 34 (station length = 300 ft; mean width = 30.5 ft.; station area = 9,150 ft^2).

Cover patch	Footage (ft.)	Area (ft.^{2})	Cover type
A	2 x 10	20	Debris and brush along willows
B	3 x 18	54	Pool-run under willow bush
C	13 x 22	286	Deep pool
D	4 x 8	32	Run next to bank
E	2 x 7	14	Undercut bank
F	2 x 5	10	Pocket pool near bank
G	3 x 20	60	Run along bank (undercut bank plus overhanging brush)
H	2 x 30	60	Run along bank (undercut bank plus overhanging brush)
I	9 x 20	180	Pool
J	4 x 10	40	Pool around snag
K	3 x 6	18	Run along bank under bushes
L	2 x 7	14	Run along bank under bushes
M	3 x 6	18	Run along bank under bushes
N	2 x 3	6	Pocket under small bush
O	3 x 12	36	Run along bank under bushes
P	5 x 7	35	Run along bank under bushes
Q	8 x 23	184	Pool and pool-run along bank by bushes
R	3 x 12	36	Small pool-quiet water where currents join
S	5 x 28	140	Pool-run along bank under bushes
T	7 x 35	245	Pool under bushes in side channel
U	3 x 4	12	Pool-run around undercut snag and bushes
V	3 x 18	54	Backwater pool above riffle

Total = 1554 ft.^{2}

% Cover = 1554 ft.^{2}/9150 ft.^{2} = 17%, a "1" rating.

THE ERODING STREAM BANK ATTRIBUTE

Rating Criteria

Rating	Eroding Banks (%)
0	75 - 100
1	50 - 74
2	25 - 49
3	10 - 24
4	0 - 9

Equipment Needed

1 - Tape measure, waterproof, fiberglass preferred.
2 - Range pole with footage marks.
3 - Collapsible survey rod (helpful when only one person is taking measurements).
4 - Waterproof field notebook.

Data Sources

All measurements and data are collected at the HQI study station. Thus, no records search is needed.

Attribute Clarification

Unstable, eroding stream banks are common on many Wyoming streams. Actively eroding banks contribute much silt to streams, where it increases water turbidity and coats the substrate. Silt acts against trout by smothering fish food organisms and fish eggs, reducing light penetration, filling pools, clogging riffle interstices, altering the rate of temperature change and may lead to oxygen depletion (McKee and Wolf 1963). Trout may also be directly affected by gill damage from silt particles (McKee and Wolf 1963).

Actively eroding banks are easily recognized by their raw appearance (Figure 35). Also, clumps of earth and sod are often present at the base of an eroding bank (Figure 36).

Some stream banks are undercut by water flow and may eventually slump into the stream. This is a natural process. Such banks do not usually present an eroding appearance and should not be counted when measuring eroding banks. However, if such slumping is extensive (Figure 37), the bank is unstable and should be measured.

Streams examined at low flow may have receded from eroding banks, thus giving a false picture of stability (Figure 38). This is especially true when some annual plant growth has occurred along the bank. Note however, that such banks are actively eroding during high water and should be measured. Only if there is extensive growth of perennial plants and grass should the bank be ignored (Figure 39). Examine such banks carefully to determine if they are actively eroding.

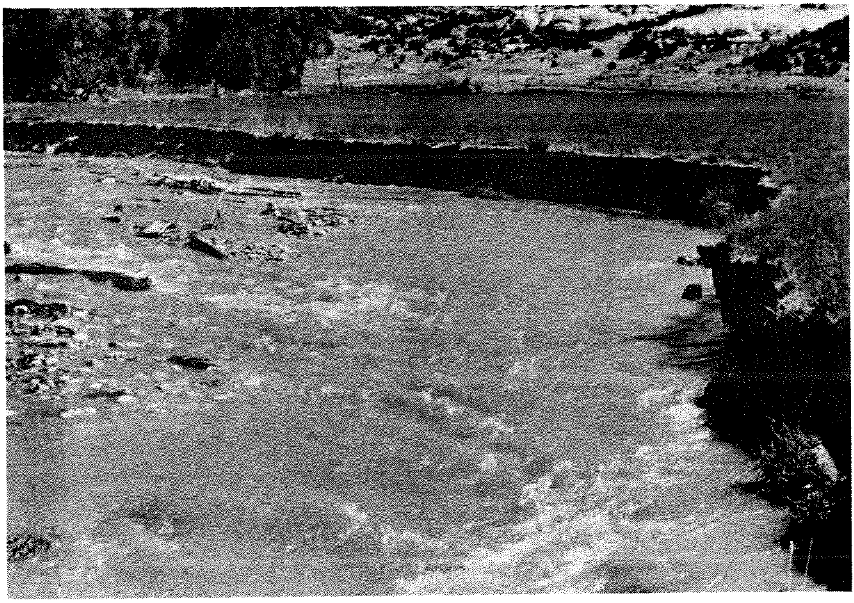


Figure 35. Actively eroding stream banks are characterized by steep, raw sides and often have clumps of grass, sod and dirt along their base.

Figure 36. Bare, unvegetated dirt, with shear edges where the stream has cut away the dirt, mark an actively eroding stream bank.

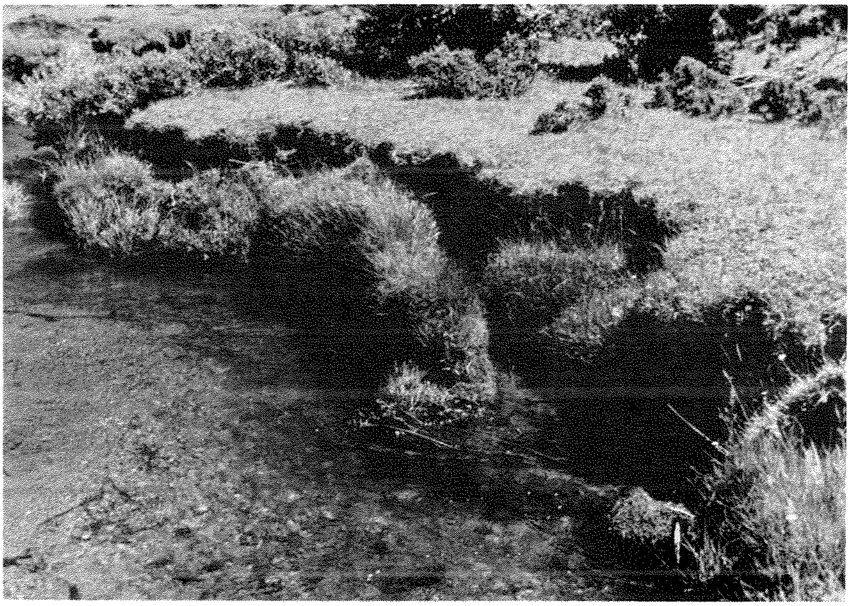


Figure 37. Extensive slumping of grass sod and dirt is a symptom of an unstable stream bank. While some slumping of overhanging banks is normal on streams with stable banks, widespread collapse indicates active bank erosion.

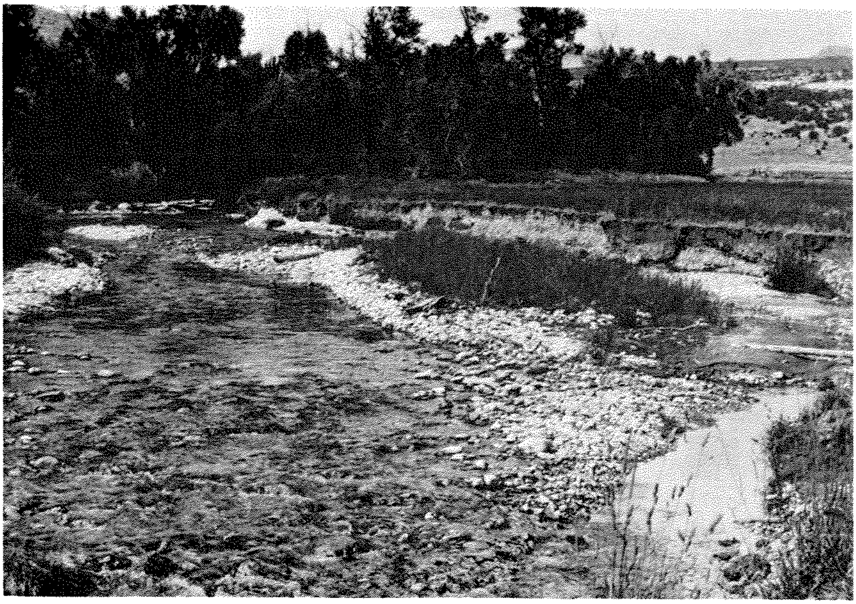


Figure 38. At base flow, some streams pull back away from an eroding bank. This may give a false impression that the bank is not actively eroding, especially if vegetation develops in the flood channel. Observation at high flow can give a better perspective. The bank shown here is the same bank in Figure 35.

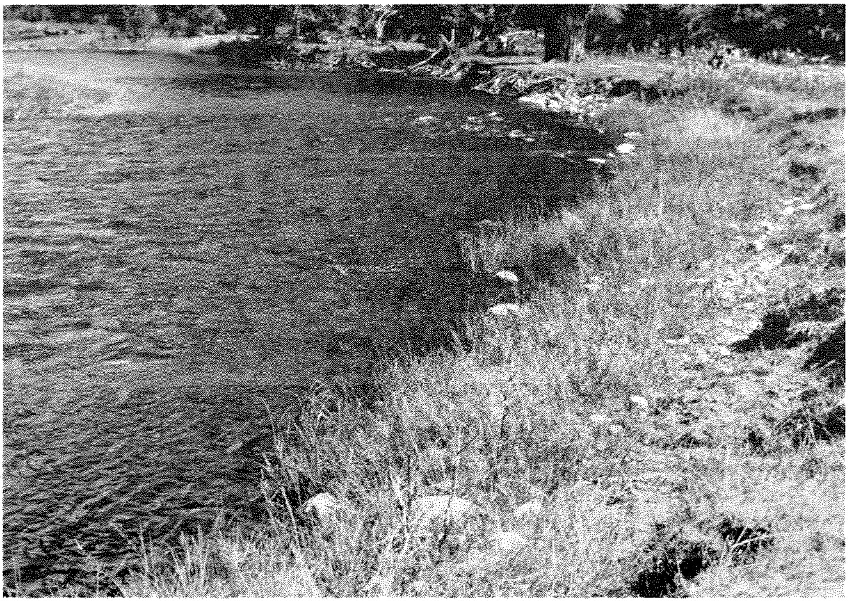


Figure 39. A questionable eroding bank. While bank erosion could occur at high flow, a more probable cause of the bank damage is cattle trampling. The distance from the water, the extensive plant growth between the water and the bank damage, and the fact that stream flow is relatively steady, being controlled by an upstream reservoir, all suggest a stable stream bank.

Banks trampled by livestock at a trail crossing point are generally not classed as eroding banks, nor are stream banks showing isolated cattle/horse prints. However, if there is extensive trampling of the stream bank by livestock, the bank should be classed as eroding (Figure 40).

Streams flowing through rocky areas may have an eroded appearance due to loss of smaller rock particles. However, most such banks are effectively armored by large rocks and cannot be classed as eroding. Only considerable erosion of soil qualifies a bank as eroding. Banks with well developed riparian vegetation and bound with a stout network of roots need to be carefully examined to determine the actual amount of erosion.

Measurement and Rating

Bank erosion points on a stream normally alternate from side to side following the meander pattern. Thus, both sides of a stream need to be measured (Figure 41). The percent eroding banks is calculated by dividing the total length of eroding banks by the total length of the study section.

Some streams may show erosion damage on opposite banks. These are usually channelized streams, or streams with poor riparian vegetation that have been scoured by floods. In this case, measure bank erosion on the outside of the meander line. Since such streams often score a zero for the eroding bank attribute, the question of which side to measure is often immaterial.

Stream bank erosion may not always be as prominent as in Figure 36, but may occur in small, isolated patches. At any rate, the procedure is the same. Each patch must be identified and measured, and the percent eroding banks computed.

Figure 40. Bank instability can be caused by cattle trampling, as well as by water erosion. Severe bank damage, as shown here, qualifies as an unstable, eroding bank and should be measured as such.

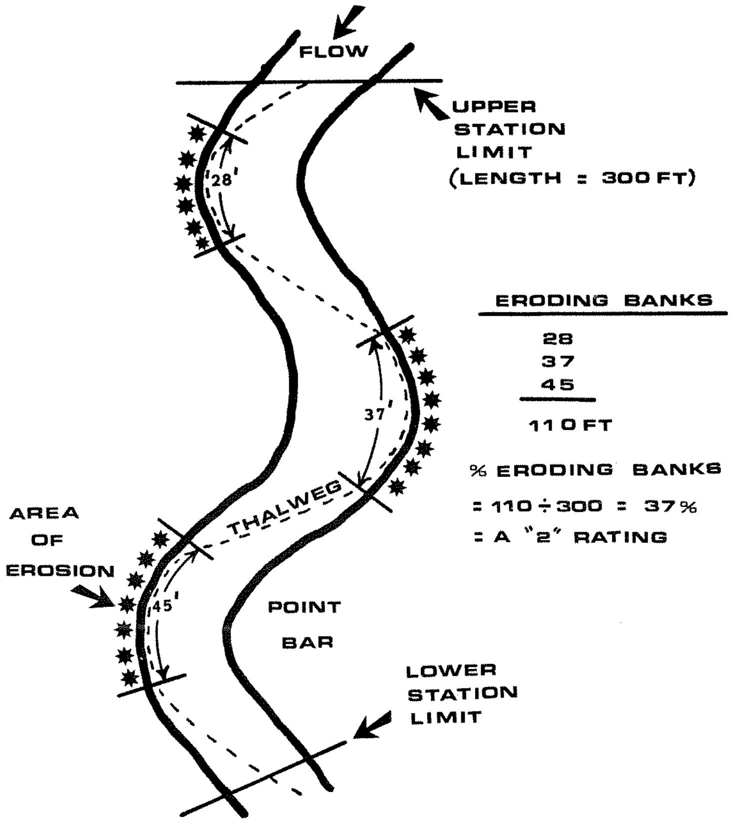


Figure 41. In an unaltered stream, erosion of stream banks often occurs on the outer edge of meanders and on alternate sides. Thus, eroding banks are measured on both sides of a stream channel flowing through an HQI study station. Since a point bar is an area of deposition, it may lack vegetation and appear as bare earth. However, it is not an eroding bank. A true eroding bank will show unmistakable signs of periodic scour by the stream and will often have dirt and grass sod slumpage into the stream from the affected bank. Note sketch is not drawn to scale.

THE STREAM WIDTH ATTRIBUTE

Rating Criteria

Rating	Characteristics Low Range (ft)	(m)	High Range (ft)	(m)
0	<2	<0.6	>150	>46
1	2-6	0.6-2.0	75-149	23-46
2	7-11	2.1-3.5	50-74	15.1-22.9
3	12-17	3.6-5.3	23-49	6.7-15
4	18-22	5.4-6.6		

Equipment Needed

1 - Tape measure, waterproof, fiberglass preferred, 100 ft. length is adequate for most streams, but 300 ft. is better for large rivers.
2 - Range finder (optional for deep, swift rivers).
3 - Waterproof field notebook.

Data Sources

Stream widths are measured at the HQI station, so a search of records is not necessary.

Attribute Clarification

The width of a stream is apparently directly related to both fish food and trout production (Binns 1979). A tiny stream may not contain adequate water for best trout production. On the other hand, a large river has plenty of water, but this advantage is often offset by increased current velocity. An optimum stream width appears to be about 20 feet (6.1 m). There is insufficient data to clearly delineate the width at which a river becomes too large for good trout production. However, present information suggests that swift currents do adversely affect trout production in large Wyoming rivers. Consequently, an upper limit of 150 feet (45.7 m) has been set for HQI purposes.

Stream width can be measured in several ways, but the width desired for HQI use is the distance from wetted edge to wetted edge (Figures 42 and 43).

Measurement and Rating

If the HQI station has been properly laid out, there should be at least ten regularly spaced transects within the station. To insure a random sample, stream width is to be measured only at these cross sections. The mean width calculations may be biased if personnel are allowed to select non-random width measurement points.

Width measurements are made for each transect at right angles to the main water flow (Figure 44). Each width measurement is recorded in the field book. The mean width is calculated from all width measurements and used, with station length, to compute station area. The width attribute is rated from the rating criteria and the mean width.

Figure 42. Stream width is measured from waters edge to waters edge.

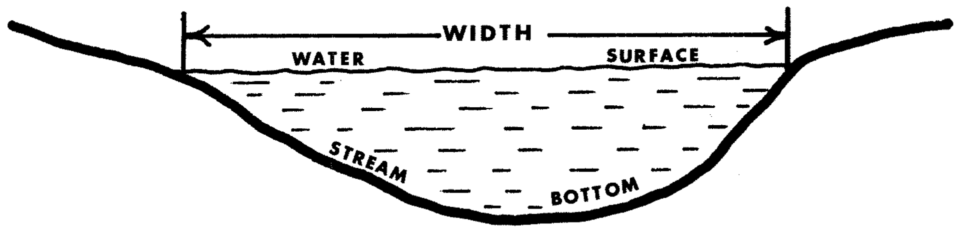


Figure 43. For HQI purposes, stream width is the distance from water's edge to water's edge along the water surface.

HQI Score Computation

To calculate HQI Score with Model II, enter $(X_1 + 1)$, $(X_2 + 1)$, $(X_3 + 1)$, $(F + 1)$ and $(S + 1)$, and complete calculations (Table 7). While the computations can be done on any calculator with log or exponential keys, the easiest procedure is to use a programmable calculator. Since many Wyoming fisheries crews have HP25, or similar, calculators, a program has been prepared to calculate HQI Score (Appendix IV). An additional program is included for the HP-67 calculator.

Note that the above formulas yield trout standing crop as pounds per acre. To convert to kilograms per hectare, multiply HQI Score by 1.12085. Also note that (1.0) was added to the attribute, e.g., $(X_1 + 1)$, to avoid problems with zero in logarithmic calculations. Thus, (1.0) must also be subtracted at the end of the computations (Table 7).

HQI Score is converted to Habitat Units by multiplying by 1.08 (Model II). A trout habitat unit is the amount of habitat quality needed to produce an increase in the trout standing crop of 1 lb/ac (1 kg/ha).

INSTREAM FLOW EVALUATION

General Considerations

HQI evaluations have been used in Wyoming to support instream flow recommendations. While this work is still experimental, an HQI procedures manual would be incomplete without information on this application of the HQI. Several streams have been evaluated by the Aquatic Habitat Crew with promising results. A more extensive evaluation of HQI/instream flow methodology is underway by the Instream Flow Crew.

An HQI/instream flow evaluation differs from a standard HQI evaluation in that some attribute measurements are made outside of the critical period. Deviation from the critical period is necessary because desired flows may not occur during the critical period. For example, the annual minimum discharge may occur only in late winter. By measuring a desired discharge when it occurs, ratings for the water velocity, stream width, eroding banks, cover, annual stream flow variation and late summer stream flow attributes are based on actual conditions. Ratings for the remaining attributes (temperature, substrate and nitrate nitrogen) are projected for the late summer period, using data collected during the critical period and an assumption that the specified study flow is the actual mean flow for the critical period.

When adequate records are available, this approach provides good objectivity. However, the technique becomes more subjective if good background data are not available to assist in rating the attribute.

After three or more specific discharges are evaluated with the HQI, the resultant HQI Scores are plotted and a curve is fitted to the data.

The curvilinear analysis allows prediction of trout standing crop at any desired discharge. Thus, if a certain flow regimen was established, as below a dam, the associated loss or gain in trout standing crop can be predicted.

Prelminary work indicates that trout standing crop in a stream increases to a thus far undefined optimum level, after which it declines due to increased velocity and other stress factors associated with higher discharges. This relationship is hard to confirm because attribute measurement is difficult at high flows. However, since most problems with instream flows occur at lower discharge, the HQI analysis is confined to the ascending limb of the curve. For comparison purposes, the optimum standing stock level is assumed to occur at the average daily flow. Changes in stock density with changes in discharge can then be expressed as a percent of the optimum level.

Example

While HQI/instream flow relationships have been investigated at several Wyoming streams, the lower Green River offers the best illustration of the technique. HQI data were collected at a study station near the Big Sandy River confluence (Figure 30) and supplemented with data collected previously by state and federal agencies. The Green River represents a "best-case" situation due to the generous amount of background information available. The discharge of the lower Green River is presently controlled by Fontenelle Dam and summer flows are held at about 1600 cfs (45 m^3/sec). Consequently, the trout fishery is adapted to this flow regimen.

HQI measurements were made at four discharges: 302; 620; 1,010 and 1,614 cfs (8.6, 17.6, 28.6 and 45.7 m^3/sec) (Figures 45 and 46). The attribute data have been summarized (Appendix V). While most of the

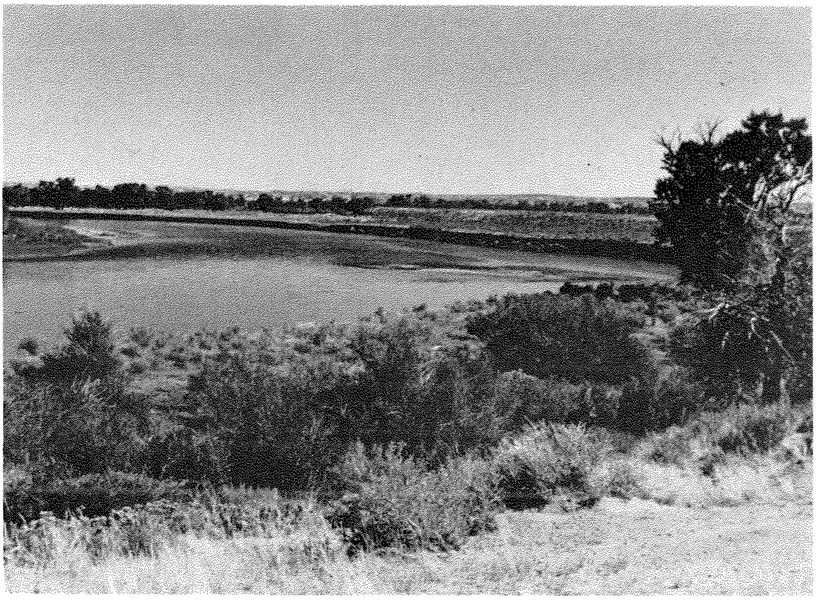


Figure 45. The lower Green River HQI station at a discharge of 1614 cfs. Most of the channel is covered at this flow, which is only slightly less than the ADF.

Figure 46. The lower Green River HQI station at a discharge of 300 cfs. Note the large amount of stream bed exposed at this flow.

attributes were measured at the time of visit, the temperature, substrate and nitrate nitrogen attributes were rated using data collected during the critical period. The technique used was to search the flow records for years when the critical period flow was similar to the study discharge. For example, the mean August 1 to September 15 discharge in 1977 was 367 cfs (10.4 m^3/sec) which is close to the 302 cfs (8.6 m^3/sec) study flow. Chemical and temperature records for 1977 were then examined to determine the probable nitrate nitrogen concentration and maximum temperature at the study flow.

Substrate ratings were assigned from macro-invertebrate file data and an estimate of the fish food population probable for that particular flow regimen. For example, warmer temperatures would be expected for an unusually low flow, such as 300 cfs (8.6 m^3/sec). This, in turn, would encourage abundant aquatic plant growth, which would provide food and cover for a larger than normal population of macro-invertebrate organisms.

HQI scores were calculated for each discharge (Table 8) and plotted. A log curve offered the best fit to the data (Figure 47) and was used to predict the loss in trout standing crop (Table 9).

Several water development schemes have been proposed for the lower Green River and the HQI/instream flow evaluation helps assess their impact on the trout fishery. The instream flow advocated by most water development proposals is 300 cfs (8.5 m^3/sec). A reduction in the discharge regimen to this level would severely degrade the ability of the river to support trout, leading to a serious decline in the trout fishery (Table 9).

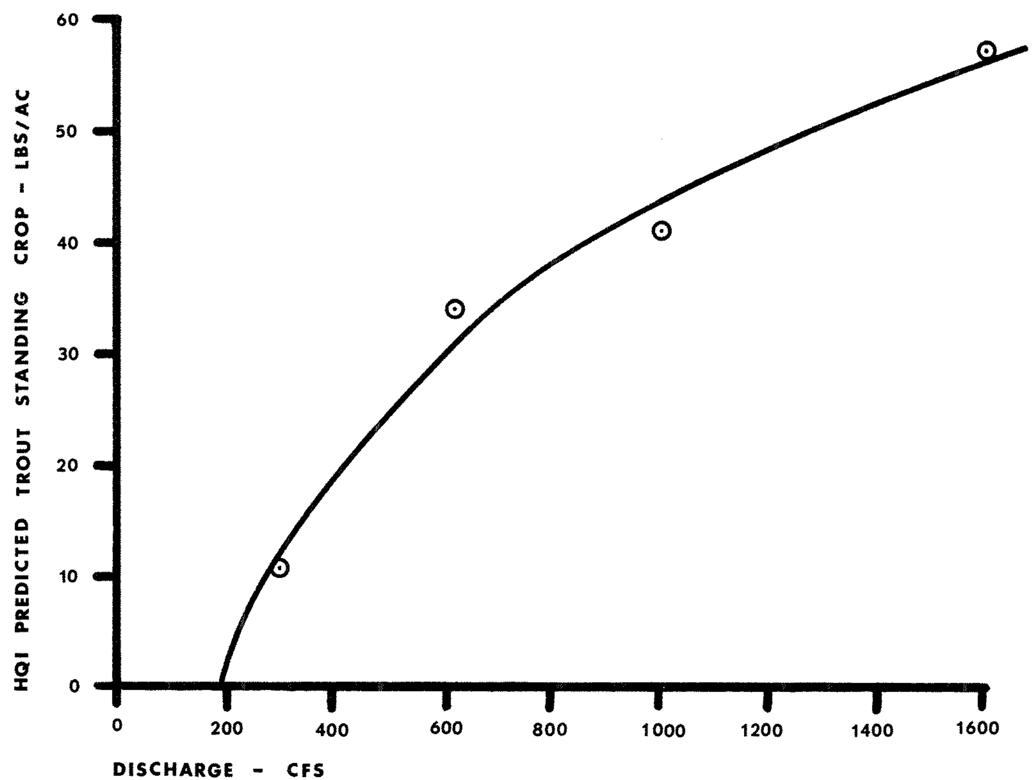


Figure 47. Relationship of trout standing crop and stream discharge for the Green River near its confluence with the Big Sandy River, as predicted from an HQI evaluation of habitat conditions at several flow levels. A logarithmic curve offered the best fit (r = 0.9913) of several curves tested.

Table 8. HQI Scores for the Green River near the Big Sandy River confluence at different discharges.

Date	Discharge (cfs)	Discharge (m^3/sec)	Predicted Trout Standing Crop (lbs/ac)	Predicted Trout Standing Crop (g/ha)	Correlation (Discharge vs. Standing Crop)
9/21/78	1614	46	57	64	
4/23/81	1010	29	41	46	
3/31/81	620	18	34	38	
9/27/78	302	8.6	11	12	r = 0.9913

Table 9. Impact on the trout fishery of the lower Green River of various discharge regimens, as predicted by the HQI.

Discharge (cfs)	Discharge (m^3/sec)	% ADF	Predicted Trout Standing Crop (lbs/ac)	Predicted Trout Standing Crop (kg/ha)	Predicted Standing Crop Loss (%)
1714	48	100	58	65	0
1200	34	70	48	54	17
860	24	50	40	45	31
565	16	33	28	31	52
300	8.5	18	12	13	79

CASE STUDIES

1) Little Popo Agie River

2) Sand Creek

3) Muddy Creek

CASE STUDIES

Preceding sections reviewed specific aspects of HQI methodology, but there is need to demonstrate the HQI process as a whole. Accordingly, three case studies are presented below to illustrate step-by-step procedures for HQI evaluations. The examples represent poor, intermediate and good trout waters.

USGS stream discharge data have been assembled to serve as source material for each case study (Appendices VI, VII and VIII). This limited data base does not represent normal, long-term stream flow conditions. Rather, its purpose is to allow demonstration of the stream flow calculations needed for the HQI.

Little Popo Agie River

The Little Popo Agie River drains 125 mi^2 (324 km^2) from the southeast corner of the Wind River Mountains, discharging about 58,000 acre-feet of good quality water per year. Its stream flow is essentially natural as there is only a small amount of irrigation withdrawal above the gage station. Discharge was monitored by the USGS from 1947 to 1971, but no chemical records are available (Table 10, Appendix VI).

Population estimates with electrofishing gear indicate that the river supports about 50 lbs/ac (56 kg/ha), most of which are wild brown trout. The fishery is self-supporting and no hatchery fish are stocked. Fishing pressure at the time of the HQI evaluation was moderate. Much of the river flows through private lands that are closed to public fishing.

The HQI study station is located at the upper end of the WGF Public Fishing Area (Figures 48 and 49). Field measurements for the HQI evaluation

Figure 48. The HQI station at the upper public fishing area on the Little Popo Agie River. The upper station boundary is near the old culvert at the top-center part of the photo.

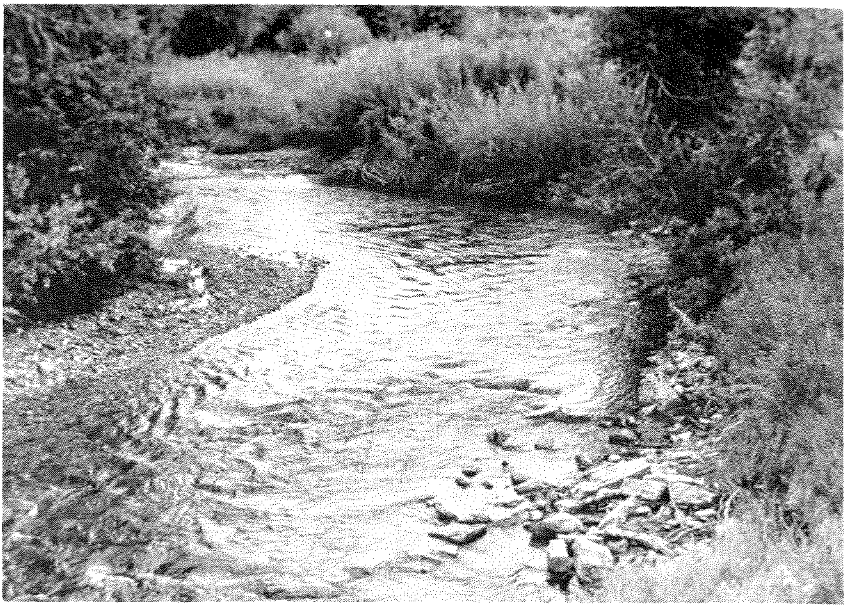


Figure 49. The lower portion of the Little Popo Agie River HQI station. Pool-runs (H) and (I) (see Figure 51) are visible at the top-center section of the photo.

Table 10. Stream flow data for the Little Popo Agie River gage near Highway 28, as calculated from USGS discharge records (Appendix VI).

Year	Average Daily Flow (cfs)	Average Daily Flow (m^3/sec)	Average Critical Period Stream Flow (cfs)	Average Critical Period Stream Flow (m^3/sec)	ASFV Ratio
1967	107	3.0	60	1.7	995/16 = 62
1968	83	2.4	57	1.6	830/20 = 42
1969	94	2.7	46	1.3	1200/18 = 67
1970	73	2.1	51	1.4	466/18 = 26
1971	113	3.2	64	1.8	960/17 = 56
Means	94	2.7	56	1.6	51

were obtained in August, 1975 (Table 11) at a 300 foot (91 m) station (Figure 50). Eleven patches of cover were identified within the station (Figure 51). The overall cover rating was good.

After nitrate nitrogen and macro-invertebrate samples were processed, a final rating was assigned to each habitat attribute (Table 12). These ratings were used to calculate HQI Score, which was 61 lbs/ac (67 Kg/ha) (Table 13).

Sand Creek

Sand Creek drains 267 mi^2 (692 Km^2) of the Black Hills, flowing generally northeast through federal, state and private lands to join with Redwater Creek near the state line. Except for runoff from snow melt and rain, the stream is dry above the large springs on Ranch A, located just below the national forest boundary. The spring-fed portion meanders in a narrow canyon with towering cliffs. Water flow is stable, except for an occasional flash flood, such as occurred in June, 1976.

The USGS recorded stream discharge near Ranch A (1974-76) and at a site located about 3 mi (4.8 Km) downstream from the HQI station (1976-80) (Appendix VII and Table 14). The HQI study site is located at the mouth of Hospital Gulch (Figures 52 and 53). Although the station is located within the Sand Creek Country Club, which contains numerous summer homes, the riparian area at the station is essentially natural. No USGS chemical records exist, but water quality is good. Chemical, biological and physical data are available from WGF files and an extensive study (Rockett 1964).

Sand Creek contains a large population of wild brown trout. Population levels reflect the stable flow conditions and are reduced when flash floods occur. Fisherman use on the Country Club is controlled by a trespass fee

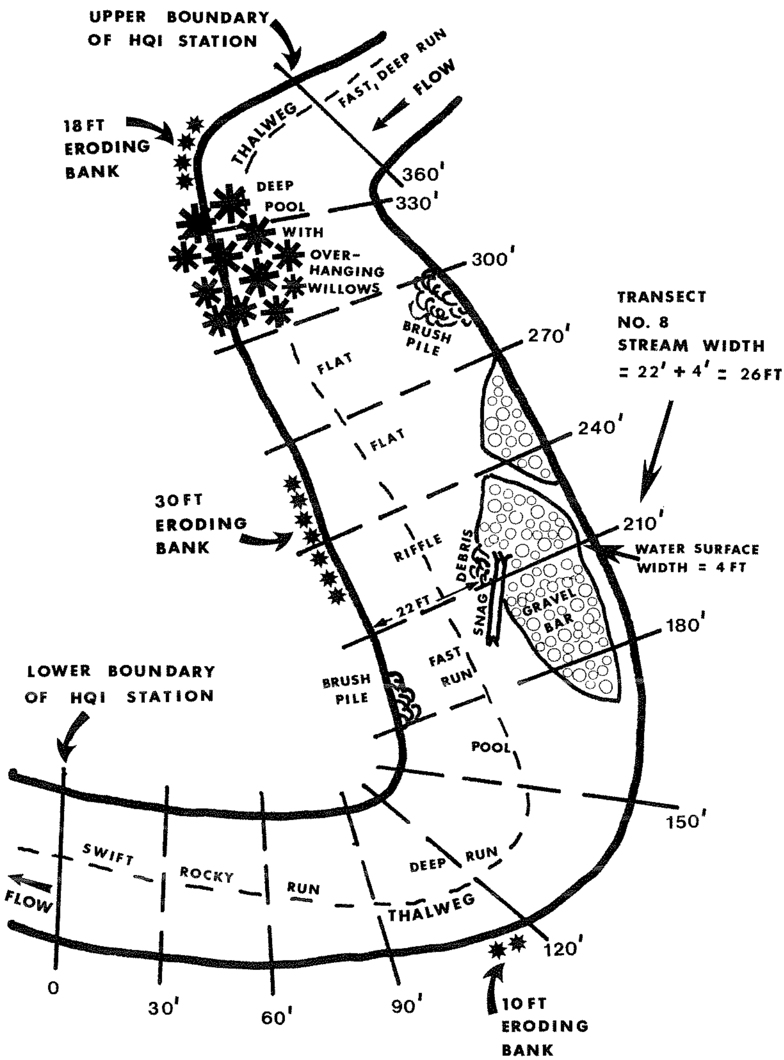


Figure 50. Sketch showing station layout, transects for measuring stream width, eroding banks, thalweg and other habitat features at the Little Popo Agie River HQI station. Note: sketch not drawn to scale.

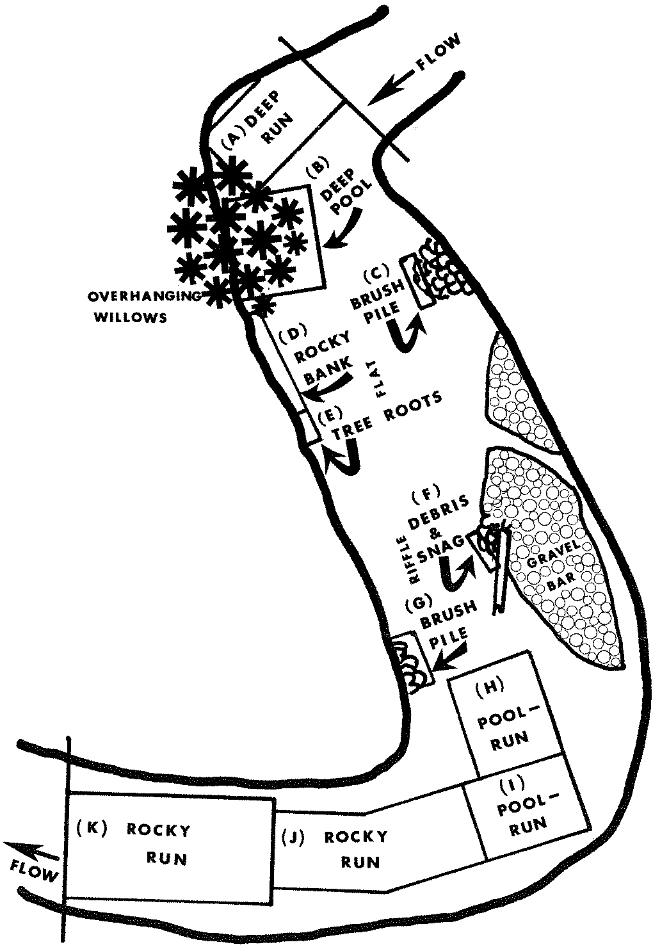


Figure 51. Trout cover measurements at the Little Popo Agie River HQI station. See Table 10 for dimensions of each cover patch. Note: sketch is not drawn to scale.

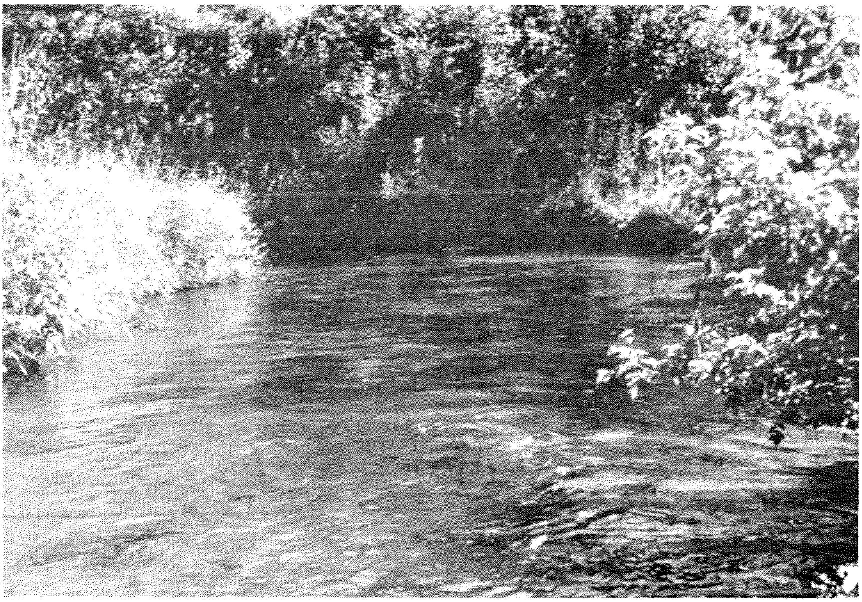


Figure 52. Part of the Sand Creek HQI station. Undercut bank (C) (see Figure 55) is at the left-center of the photo.

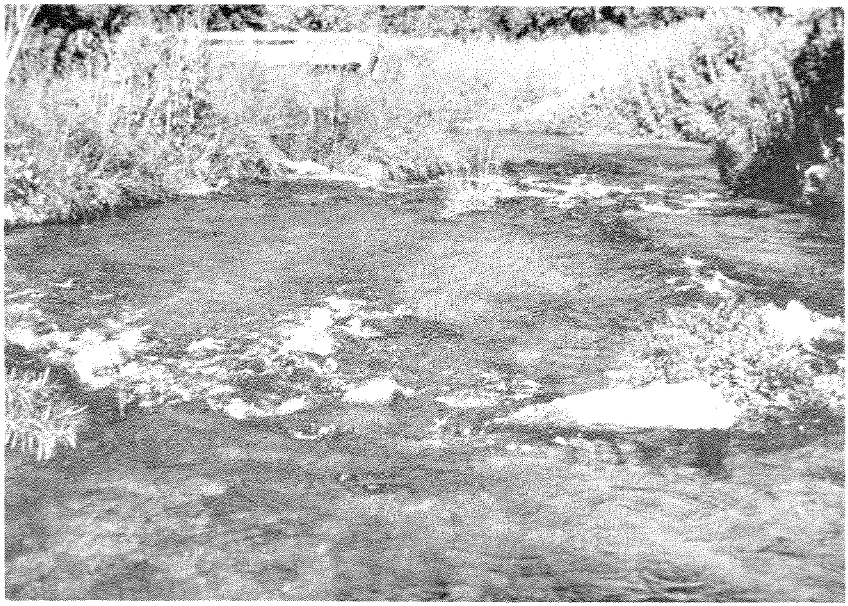


Figure 53. The lower part of the Sand Creek HQI station, showing area (A) (see Figure 55).

Table 11. Field data for the HQI station at the Little Popo Agie River. Note upper case letters in the cover section refer to the specific areas shown in Figure 51.

LITTLE POPO AGIE RIVER 8/5/75 (1)

Upper end of Public Fishing Area

WATER TEMPERATURE 62°F TIME 1500

STREAM WIDTH

POINT	DISTANCE	WIDTH (FT)	THALWEG LENGTH (FT.)
1	0	37	22
2	30	40	75
3	60	27	22
4	90	27	31
5	120	34	79
6	150	35	38
7	180	31	31
8	210	26	55
9	240	35	353' Total
10	270	35	
11	300	34	
12	330	26	
13	360	27	
	Sum:	414'	
	Mean:	31.8'	

AREA OF SAMPLE STATION

31.8' x 360' = 11,448 ft^2

LITTLE POPO AGIE RIVER AT PFA 8/5/75 (2)

COVER

FOOTAGE	AREA	TYPE
22 x 30	660	(A) Pool-run by old pipe
14 x 30	420	(B) Pool by bushes
4 x 10	40	(C) Brush pile
5 x 30	150	(D) Rocky bank
5 x 10	50	(E) Root clusters along bank
2 x 9	18	(F) Snag at edge of riffles
2 x 10	20	(G) Brush pile, east bank
20 x 30	600	(H) Pool-run
20 x 30	600	(I) Pool-run
20 x 60	1200	(J) Rocky run w/pocket pools
25 x 60	1500	(K) Rocky run w/pocket pools
	5258 ft^2	5258/11448 = 46%

(Continued)

Table 11. (Continued)

LITTLE POPO AGIE RIVER AT PFA 8/5/75 (3)

ERODING BANKS (FT)

18

30 58'/360' = 16%

10

58 ft. total

WATER VELOCITY (TIME OF TRAVEL)

____	minutes	____	seconds	FIRST COLOR
1	minutes	48	seconds	GOOD COLOR

TOTAL SECONDS 108

Velocity = thalweg/seconds = 353/108

= 3.27 ft/sec

SUBSTRATE

(Approx.)		Vegetation
10	% Fines	Scattered algae growth on riffles
40	% Gravel	
40	% Cobble	Est. Fish Food Abundance
10	% Boulders	Fair - sample taken

Probable Rating: 2

LITTLE POPO AGIE RIVER AT PFA 8/5/75 (4)

ATTRIBUTE RATINGS

ATTRIBUTE	PRELIM. RATING	
CPSF	4	check gage records
ASFV	2	check gage records
TEMPERATURE	3	68°F-USGS & WGF records
NITRATES	-	(sample to lab)
WATER VELOCITY	2	3.27 fps
SUBSTRATE	-	(sample to lab)
COVER	3	46%
ERODING BANKS	3	16%
WIDTH	3	31.8 ft.

MISC. RECORDS

WGF thermographs operated in 1976-77.

Table 12. Rating Summary sheet for the HQI station at the Little Popo Agie River.

STREAM: Little Popo Agie River LOCATION: Upper end of PFA

DATE DATA COLLECTED: 8/5/75 HQI SCORE = 61 lbs/acre

TROUT STANDING CROP: (1975) 38 lbs/acre = 65 trout habitat units
(if available) (1976) 55

ATTRIBUTE (Symbol)	(Name)	DATA	RATING
(X_1)	Late Summer Stream Flow (Critical Period Stream Flow - CPSF)	USGS gage 2 miles downstream; records 1967-71; 5 yrs.; ADF - 94 cfs Avg CPSF = 56 cfs 56 cfs/94 cfs = 60%	4
(X_2)	Annual Stream Flow Variation	ASFV Ratio = 51	2
(X_3)	Maximum Summer Stream Temperature	WGF thermographs 1975-76 68 °F ____ °C	3
(X_4)	Nitrate Nitrogen	0.012 mg/l	1
(X_5)	Fish Food Abundance	131 organisms/square foot	2
(X_6)	Fish Food Diversity	D_s = 1.675	2
(X_7)	Cover	46 % of total area	3
(X_8)	Eroding Stream Banks (Bank Stability)	16 %	3
(X_9)	Substrate		2
(X_{10})	Water Velocity	Time of Travel = 3.27 ft/sec Velocity = ____ cm/sec	2
(X_{11})	Stream Width	3.18 feet	3

$F = X_3(X_4)(X_9)(X_{10}) = (3)(1)(2)(2) = 13$

$F + 1 = 13$

$S = X_7(X_8)(X_{11}) = (3)(3)(3) = 27$

$S + 1 = 28$

(put HQI calculations on back of sheet) (See Table 13)

Table 13. HQI Calculations for the HQI Evaluation at the Little Popo Agie River.

STREAM: Little Popo Agie River 8/5/75

$X_1 + 1 = $ 5

$X_2 + 1 = $ 3

$X_3 + 1 = $ 4

$F + 1 = $ 13

$S + 1 = $ 28

HQI SCORE

60 lbs/acre

65 trout Habitat Units (English)

67 kg/hectare

73 trout Habitat Units (metric)

$$\log_{10}(\hat{Y}+1) = (0.903) + (0.807)\log_{10}(5) + (0.877)\log_{10}(3)$$
$$+ (1.233)\log_{10}(4) + (0.631)\log_{10}(13)$$
$$+ (0.182)\log_{10}(28)$$
$$= (\text{antilog}_{10}\ 1.79)$$
$$\hat{Y} = 61 - 1.0$$
$$= 60 \text{ lbs/ac}$$

Table 14. Stream flow data for the Sand Creek gage near Ranch A, as calculated from USGS discharge records (Appendix VII).

Year	Average Daily Flow (cfs)	Average Daily Flow (m^3/sec)	Average Critical Period Stream Flow (cfs)	Average Critical Period Stream Flow (m^3/sec)	ASFV Ratio
1976	27	0.76	31	0.88	700/17 = 41
1977	28	0.79	27	0.76	43/25 = 1.7
1978	30	0.85	23	0.65	96/22 = 4.4
1979	24	0.68	22	0.62	34/16 = 2.1
1980	22	0.62	21	0.59	31/19 = 1.6
Means	26	0.74	25	0.71	10.2

and fishing pressure at the study site is probably sporadic.

Field measurements for the HQI evaluation were obtained on September 3, 1975 (Table 15) at a 330 ft (100 m) station (Figure 54). Shelter for trout is very good at this site, being furnished by aquatic vegetation, debris, pools and undercut banks (Figure 55).

The HQI attributes rated good to excellent at the Sand Creek station (Table 16). HQI Score calculated from these ratings was high (613 lbs/ac, 662 kg/ha) (Table 17).

Muddy Creek

Muddy Creek flows in a shallow gorge cut below the level of the surrounding sandy, desert plain. The drainage area is 332 mi^2 (860 km^2), but discharge is influenced more by irrigation practices than by drainage area. Stream flow often fluctuates widely during the year, but is usually high in summer due to irrigation return flows. The advent of sprinkler irrigation may have reduced variation in flows during recent years.

While discharge has been measured at the USGS gage since 1949, the earlier gage records may not apply to the present situation due to changes in irrigation practices. Recent stream flow data is available for the gage (Appendix VIII, Table 18), but no chemical data have been collected there. Water quality is poor and the stream is usually muddy. The stream bottom is essentially shifting sand with some cobble and gravel. Consequently, fish food production is very poor.

Trout may occasionally enter the study area, especially from Boysen Reservoir. However, for all practical purposes, the trout stock is nil at the study site.

Field measurements were collected on August 6, 1975 (Table 19) at a

Table 15. Field data for the HQI station at Sand Creek.

Sand Creek at mouth of Hospital Gulch 9/3/75 (1)

WATER TEMPERATURE 54°F TIME 1030

STREAM WIDTH

POINT	DISTANCE	WIDTH (FT.)	THALWEG LENGTH (FT.)	
1	0	21	35	12
2	30	21.5	32	19
3	60	21.5	17	27
4	90	28	19.5	30
5	120	25	17.5	27
6	150	16.5	14.5	26
7	180	23	30	353.5'
8	210	18	17	
9	240	25	14	
10	270	20	16	
11	300	23		
12	330	21.5		
	Sum:	243 feet		
	Mean:	20.25 feet		

AREA OF SAMPLE STATION

$20.25 \text{ ft} \times 330 - 6682 \text{ ft}^2$

Sand Creek at Hospital Gulch 9/3/75 (2)

COVER

FOOTAGE	AREA	
20 x 120	2400	(A) Pool-run, with many undercut banks, weed beds, snags and pocket pools
10 x 30	300	(B) Deep pool
2 x 30	60	(C) Undercut bank
20 x 90	1800	(D) Weed bed
2 x 30	60	(E) Undercut bank
Total:	4620 ft^2	
	$4620 \text{ ft}^2/6682 = 69\%$	

(Continued)

Table 15. (Continued)

Sand Creek at Hospital Gulch 9/3/75 (3)

ERODING BANKS (FT)

Less than 10%, bank stability very good.

WATER VELOCITY (TIME OF TRAVEL)

3 minutes 0 seconds FIRST COLOR

3 minutes 18 seconds GOOD COLOR

TOTAL SECONDS 198

Velocity = thalweg/seconds = 354/198

= 1.79 ft/sec.

SUBSTRATE

(Approx.)		Vegetation
30	%Fines	Abundant plant growth. Watercress, crowfoot, pondweed and speedwell are common.
45	%Gravel	
20	%Cobble	
5	%Boulders	

Est. Fish Food Abundance

Over 500/ft^2 (samples taken)

Probable Rating: 4

Sand Creek at Hospital Gulch 9/3/75 (4)

ATTRIBUTE RATINGS

ATTRIBUTE	PRELIM. RATING	DATA SUMMARY
CPSF	4	Check gage records
ASFV	4	Check gage records
TEMPERATURE	3	68°F WGF records
NITRATES	-	(sample to lab)
WATER VELOCITY	4	1.79 fps
SUBSTRATE	4	(sample to lab)
COVER	4	69%
ERODING BANKS	4	less than 10%
WIDTH	4	20.25 ft

MISC. RECORDS

Stream fed by springs, flow usually stable, except for occasional flash floods. Bottom calcified by spring deposits.

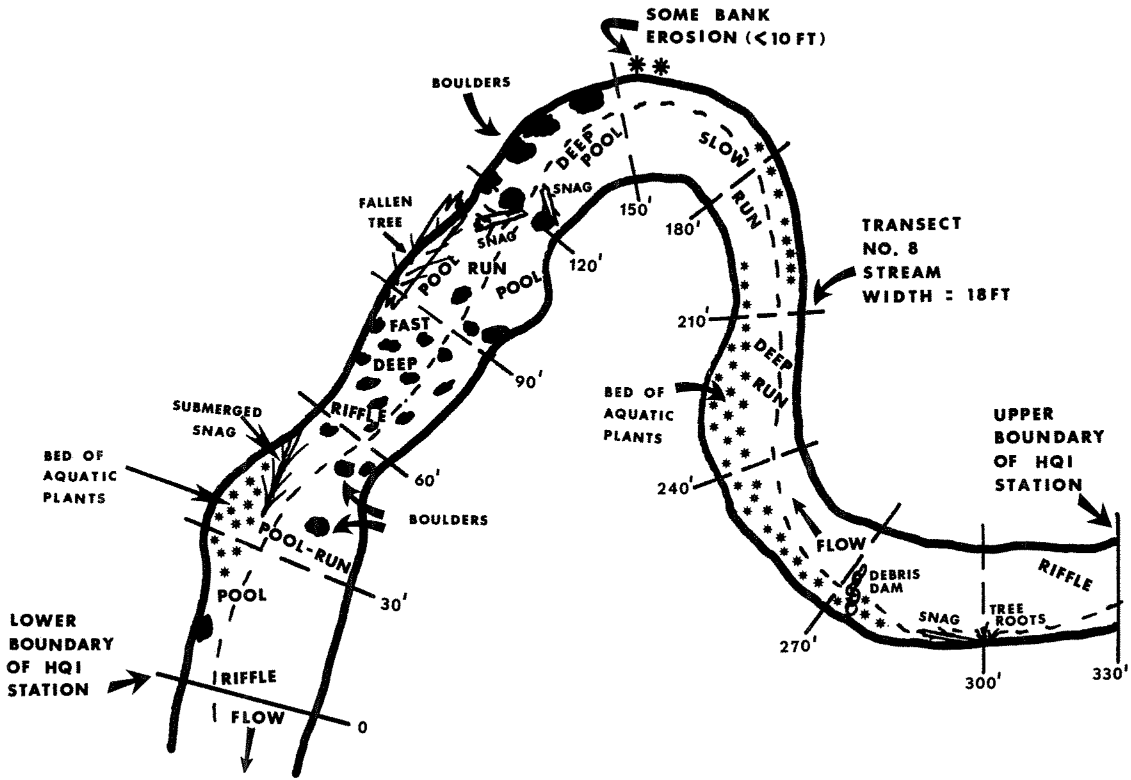


Figure 54. Sketch showing station layout, transects for measuring stream width, eroding banks, thalweg and other habitat features at the Sand Creek HQI station. Note: sketch is not drawn to scale.

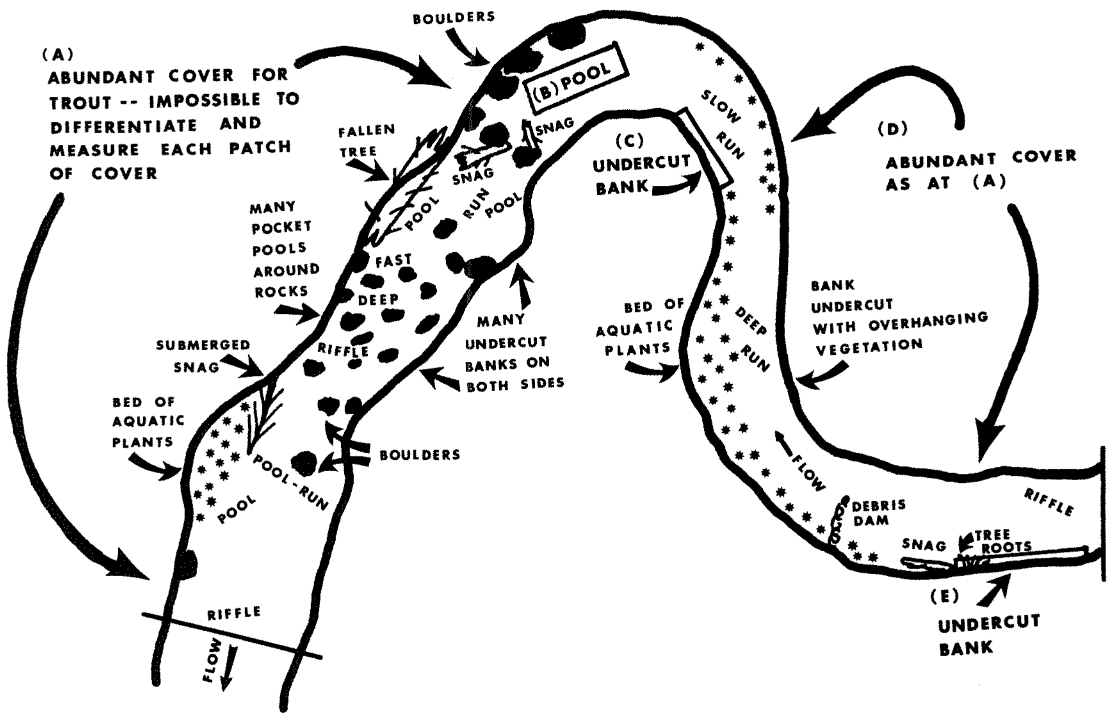


Figure 55. Trout cover measurements at the Sand Creek HQI station. See Table 14 for dimensions of each patch of cover. Note: sketch is not drawn to scale.

Table 16. Rating Summary sheet for the HQI station on Sand Creek at Hospital Gulch.

STREAM: Sand Creek

Location: Upstream from road bridge at Hospital Gulch

DATE DATA COLLECTED: 9/3/75

HQI Score = 613 lbs/acre
= 662 trout habitat units

TROUT STANDING CROP: 566 lbs/acre
(if available)

ATTRIBUTE (Symbol)	(Name)	DATA	RATING
(X_1)	Late Summer Stream Flow (Critical Period Stream Flow - CPSF)	USGS gage records available for 1975-80, 6 years of record. ADF = 25.9 cfs; Avg. CPSF = 24.8 cfs 25.9 cfs/24.8 cfs = 104%	4
(X_2)	Annual Stream Flow Variation	ASFV Ratio = 8.9	4
(X_3)	Maximum Summer Stream Temperature	WGF file data 68 °F ____ °C	3
(X_4)	Nitrate Nitrogen	0.188 mg/l	4
(X_5)	Fish Food Abundance	935 organisms/square foot	4
(X_6)	Fish Food Diversity	D_s = 4.243	4
(X_7)	Cover	69 % of total area	4
(X_8)	Eroding Stream Banks (Bank Stability)	<10 %	4
(X_9)	Substrate		4
(X_{10})	Water Velocity	Time of Travel = 1.79 ft/sec. Velocity = ____ cm/sec.	4
(X_{11})	Stream Width	20.25 feet	4

$F = X_3(X_4)(X_9)(X_{10}) = (3)(4)(4)(4) = 192$

$F + 1 = 193$

$S = X_7(X_8)(X_{11}) = (4)(4)(4) = 64$

$S + 1 = 65$ (Put HQI calculations on back of sheet) (See Table 17)

Table 17. HQI Calculations for the HQI Evaluation of Sand Creek.

STREAM: Sand Creek at Hospital Gulch

$X_1 + 1 = 5$

$X_2 + 1 = 5$

$X_3 + 1 = 4$

$F + 1 = 193$

$S + 1 = 65$

HQI SCORE

613 lbs/acre

662 trout Habitat Units (English)

688 kg/hectare

742 trout Habitat Units (metric)

$$\log_{10}(\hat{Y}+1) = (0.903) + (0.807)\log_{10}(5) + (0.877)\log_{10}(5) + (1.233)\log_{10}(4) + (0.631)\log_{10}(193) + (0.182)\log_{10}(65)$$

$$\hat{Y} = (\text{antilog}_{10}\ 2.79)$$

$$= 614 - 1.0$$

$$= 613 \text{ lbs/ac}$$

Table 18. Stream flow data for the Muddy creek gage near Boysen Reservoir, as calculated from USGS discharge records (Appendix VIII).

Year	Average Daily Flow (cfs)	Average Daily Flow (m^3sec)	Average Critical Period Stream Flow (cfs)	Average Critical Period Stream Flow (m^3/sec)	ASFV Ratio
1975	30	0.85	51	1.44	358/3.6 = 99
1976	42	1.19	89	2.52	265/5.2 = 51
1977	17	0.48	12	0.34	258/5 = 52
1978	19	0.54	33	0.93	303/3.5 = 87
1979	23	0.65	37	1.05	81/1.2 = 68
Means	26	0.74	44	1.25	71

Table 19. Field data for the HQI station at Muddy Creek.

Muddy Creek at USGS gage station 2.5 miles upstream from Boysen Reservoir 8/6/75 (1)

WATER TEMPERATURE 72°F TIME 1400

STREAM WIDTH

POINT	DISTANCE	WIDTH (FT)	THALWEG LENGTH (FT)
1	0	19.5	47
2	30	23	17
3	60	22.5	34
4	90	20	59
5	120	21	49
6	150	20	32
7	180	18	25
8	210	21	30
9	240	19	263' Total
10	270	25	
11			

Sum: 209

Mean: 20.9

AREA OF SAMPLE STATION

$270 \text{ ft} \times 20.9 \text{ ft} = 5{,}643 \text{ ft}^2$

Muddy Creek near Boysen Reservoir 8/6/75 (2)

COVER

FOOTAGE	AREA	TYPE
107 x 1	107 ft^2	(A) Undercut banks
30 x 9	270 ft^2	(B) Pool
TOTAL:	377 ft^2	

$377 \text{ ft}^2/5243 \text{ ft}^2 = 7\%$

(Continued)

Table 19. (Continued)

Muddy Creek near Boysen Reservoir 8/6/75(3)

ERODING BANKS (FT)

133 ft total

122'/270' = 49%

WATER VELOCITY (TIME OF TRAVEL)

___ minutes	___ seconds	FIRST COLOR
1 minutes	20 seconds	GOOD COLOR
TOTAL SECONDS 80		

Velocity = thalweg/seconds = 293./80

= 3.66 ft/sec

SUBSTRATE (Approx.)

60	% Fines - Sand
30	% Gravel
10	% Cobble (sm.)
0	% Boulders

Vegetation

Some algae, veg. generally lacking

Est. Fish Food Abundance

poor, <25/ft^2

Probable Rating: 0

Muddy Creek near Boysen Reservoir 8/6/75(4)

ATTRIBUTE RATINGS

ATTRIBUTE	PRELIM. RATING	
CPSF	4	Check gage records
ASFV	1 ? poor	Check gage records
TEMPERATURE	0	86 F
NITRATES	?	(sample to lab)
WATER VELOCITY	1	3.66 fps
SUBSTRATE	0 ? poor	(foot square sample to lab)
COVER	0	7%
ERODING BANKS	2	49%
WIDTH	4	20.9 ft

MISC. RECORDS

Stream very murky, bottom not visible.

Cobble and gravel is embedded in sand and silt.

Most of station is shallow with swift flow - very little pool area.

270 ft (82 m) station (Figures 56 and 57). Cover graded very poor at this site (Figure 58). Only one pool with some debris and a marginal undercut bank offer shelter for trout.

Many of the HQI attributes received zero ratings (Table 20). HQI Score was also zero (Table 21).

Figure 56. The HQI station on Muddy Creek. Pool (B) (see Figure 58) is at the center of the photo, where the stream curves.

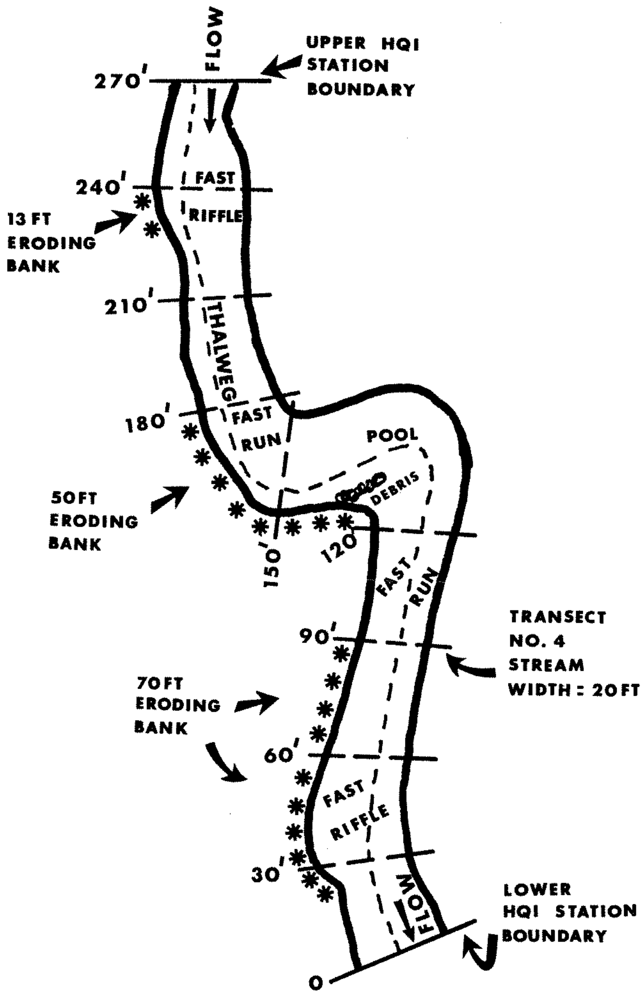


Figure 57. Sketch showing station layout, transects for measuring stream width, eroding banks, thalweg and other habitat features at the Muddy Creek HQI station. Note: sketch is not drawn to scale.

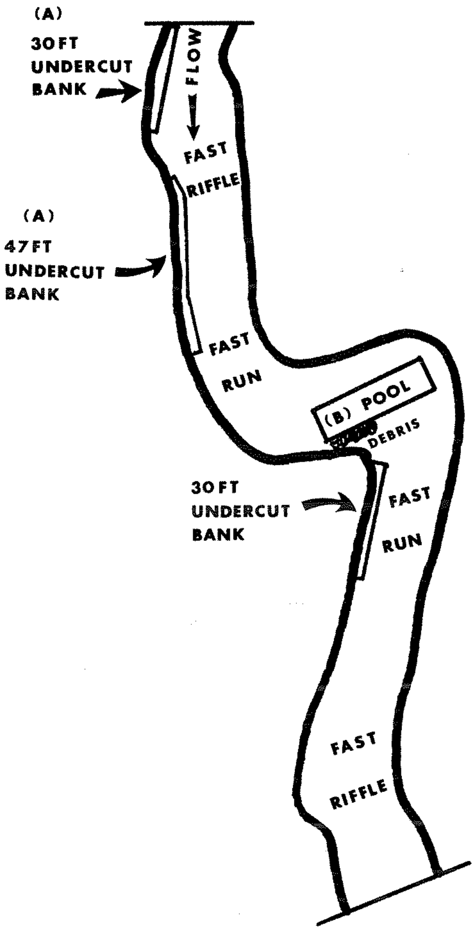


Figure 58. Trout cover measurements at the Muddy Creek HQI station. Refer to Table 18 for dimensions of cover patches. Note: sketch is not drawn to scale.

Table 20. Rating Summary sheet for the HQI station on Muddy Creek.

STREAM: Muddy Creek

LOCATION: at USGS gage 2.5 miles upstream from Boysen Reservoir

DATE DATA COLLECTED 8/6/75

HQI SCORE = 0 lbs/acre
= 0 trout habitat units

TROUT STANDING CROP: 0
(if available)

ATTRIBUTE (Symbol)	(Name)	DATA	RATING
(X_1)	Late Summer Stream Flow (Critical Period Stream Flow - CPSF)	USGS gage records 1975-79; 5 yrs; ADF = 26 cfs - 169% 44 cfs/26 cfs = 169%	4
(X_2)	Annual Stream Flow Variation	ASFV Ratio 1975-79 = 71	2
(X_3)	Maximum Summer Stream Temperature	USGS records 86 °F ____ °C	0
(X_4)	Nitrate Nitrogen	0.096 mg/l	2
(X_5)	Fish Food Abundance	8.5 organisms/square foot	0
(X_6)	Fish Food Diversity	D_s = 0.699	0
(X_7)	Cover	7 % of total area	0
(X_8)	Eroding Stream Banks (Bank stability)	49 %	2
(X_9)	Substrate		0
(X_{10})	Water Velocity	Time of Travel = 3.66 ft/sec. Velocity = ____ cm/sec.	1
(X_{11})	Stream Width	20.9 feet	4

$F = X_3(X_4)(X_9)(X_{10}) = (0)(2)(0)(1) = 0$

$F + 1 = 1$

$S = X_7(X_8)(X_{11}) = (0)(2)(4) = 0$

$S + 1 = 1$ (put HQI calculations on back of sheet) (see Table 21)

Table 21. HQI calculations for the HQI evaluation at Muddy Creek.

STREAM: Muddy Creek 8/6/75

$X_1 + 1 =$ 5

$X_2 + 1 =$ 3

$X_3 + 1 =$ 1

$F + 1 =$ 1

$S + 1 +$ 1

HQI SCORE

0 lbs/acre

0 trout Habitat Units (English)

0 kg/hectare

0 trout Habitat Units (metric)

$$\log_{10}(\hat{Y}+1) = (-0.903) + (0.807)\log_{10}(5) + (0.877)\log_{10}(3)$$
$$+ (1.233)\log_{10}(1) + (0.631)\log_{10}(1)$$
$$+ (0.182)\log_{10}(1)$$
$$\hat{Y} = (\text{antilog } 0.08) - 1.0$$
$$= 0.2 \text{ lbs/ac}$$

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APPENDICES

Appendix I . Stream discharge records for the USGS gage on the Encampment River. Data from Anonymous (1980a).

PLATTE RIVER BASIN

06623800 ENCAMPMENT RIVER ABOVE HOG PARK CREEK, NEAR ENCAMPMENT, WY
(Hydrologic bench-mark station)

LOCATION.--Lat 41°01'25", long 106°49'27", in NE1/4SW1/4 sec. 10, T.12 N., R.84 W., Carbon County, Hydrologic Unit 10180002, Medicine Bow National Forest, on left bank 0.6 mi (1.0 km) upstream from Hog Park Creek and 13 mi (21 km) south of Encampment.

DRAINAGE AREA.--72.7 mi^2 (188.3 km^2). Area at mouth, 265 mi^2 (686 km^2).

WATER-DISCHARGE RECORDS

PERIOD OF RECORD.--October 1964 to current year.

GAGE.--Water-stage recorder. Altitude of gage is 8,270 ft. (2,521 m), from topographic map.

REMARKS.--Records fair except those for winter months, which are poor. No diversion above station.

(A) AVERAGE DISCHARGE.--16 years, 114 ft^3/s (3.228 m^3/s), 82,590 acre-ft/yr (102 hm^3/yr).

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 1,680 ft^3/s (47.6 m^3/s) about June 13, 1965 (gage height not determined), from slope-area measurement of peak flow; minimum daily, 9.5 ft^3/s (0.27 m^3/s) Dec. 31, 1968.

(B) EXTREMES FOR CURRENT YEAR.--Peak discharges above base of 750 ft^3/s (212 m^3/s) and maximum (*):

Date	Time	Discharge (ft^3/s)	Discharge (m^3/s)	Gage height (ft)	Gage height (m)	Date	Time	Discharge (ft^3/s)	Discharge (m^3/s)	Gage height (ft)	Gage height (m)
May 23	1800	836	23.7	4.10	1.250	July 2	0330	962	27.8	4.31	1.314
June 12	2100	*1,190	33.7	4.67	1.423						

(C) Minimum daily discharge, 17 ft^3/s (0.48 m^3/s) Jan. 29, 30, Apr. 11-16.

WATER YEAR OCTOBER 1979 TO SEPTEMBER 1980.

Appendix I continued.

ENCAMPMENT RIVER ABOVE HOG PARK CREEK, NEAR ENCAMPMENT, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1979 TO SEPTEMBER 1980
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG (D)	SEP
1	22	22	21	20	19	20	18	110	571	585	51	29
2	21	25	24	21	20	20	19	108	580	722	50	26
3	21	30	25	21	21	22	19	103	655	504	46	24
4	20	34	24	21	22	20	19	108	758	426	43	23
5	20	35	24	22	22	20	18	114	848	361	42	23
6	20	35	24	18	22	20	18	135	914	313	40	23
7	20	34	23	22	22	20	18	152	890	304	39	24
8	18	32	25	22	20	20	18	196	902	344	38	29
9	19	29	23	22	18	19	19	219	950	260	40	35
10	20	27	22	21	19	20	20	221	974	228	38	32
11	20	27	20	21	21	19	17	245	1020	206	35	30
12	20	26	19	21	22	19	17	226	1050	190	35	48
13	19	25	20	22	22	19	17	166	1000	180	34	43
14	19	25	22	22	22	20	17	148	992	163	38	30
15	19	25	24	23	22	20	17	154	938	138	67	26
16	21	24	24	23	22	20	17	159	854	124	54	23
17	24	26	23	24	22	19	18	163	854	114	47	22
18	25	28	23	24	22	19	20	147	866	108	39	22
19	25	28	22	25	22	20	23	182	878	100	35	21
20	25	26	22	23	21	21	26	248	830	94	38	30
21	24	27	23	23	22	21	31	340	836	86	34	29
22	23	27	23	23	21	20	38	494	830	81	32	26
23	25	26	23	24	20	20	48	670	824	77	30	24
24	26	26	21	23	21	20	60	704	818	70	33	24
25	29	24	22	23	19	20	66	548	782	68	35	24
26	33	24	22	22	21	19	70	544	794	64	48	23
27	30	23	22	21	22	19	72	562	752	61	34	22
28	25	21	22	19	20	18	76	605	630	56	30	21
29	24	18	20	17	22	20	86	620	576	54	27	22
30	23	19	20	17	---	20	99	585	595	54	25	22
31	22	---	20	18	---	20	---	605	---	55	29	---
TOTAL	702	798	692	668	611	614	1021	9581	24761	6190	1206	800
MEAN	22.6	26.6	22.3	21.5	21.1	19.8	34.0	309	825	200	38.9	26.7
MAX	33	35	25	25	22	22	99	704	1050	722	67	48
MIN	18	18	19	17	18	18	17	103	571	54	25	21
AC-FT	1390	1580	1370	1320	1210	1220	2030	19000	49110	12280	2390	1590

CAL YR 1979 TOTAL 53709 MEAN 147 MAX 1280 MIN 15 AC-FT 106500
(E) WTR YR 1980 TOTAL 47644 MEAN 130 MAX 1050 MIN 17 AC-FT 94500

Appendix II. Proper procedures for sampling the nitrate nitrogen attribute. To insure accurate results, carefully follow steps listed below.

Step	Procedures
A.	<u>Container Preparation</u> 1. Obtain 1000 ml PVC bottle. 2. Add concentrated reagent grade H_2SO_4, plus distilled water. Let stand for several days. 3. Rinse with distilled water at least three times. 4. Add 2 ml concentrated, reagent grade H_2SO_4 to container. Cap must fit tightly.
B.	<u>Sample Collection</u> 1. Fill container carefully, being careful not to lose any of the acid. 2. Cap and tilt bottle several times to mix acid and water. 3. Properly label bottle; label must include date and specific location. 4. Transport to lab without undue stress from heat or light. 5. When possible, analysis should be completed within 28 days after collection of sample.
C.	<u>Sample Analysis</u> 1. Use EPA approved analytical method for nitrate nitrogen analysis. Where nitrite concentration is known to be minuscule or absent, the cadmium reduction method can be used. In that case, proceed with step 2. If nitrite is present or if the nitrite concentration is unknown, you must either test for and establish the nitrite level, or use a different analysis. 2. If automated cadmium reduction equipment is available, screen all samples to detect those over 0.40 mg/l. If such equipment is not available, proceed to step 3. All samples under 0.40 mg/l should be analyzed as in step 3. 3. Analyze samples with the EPA method for Nitrogen-Nitrate-Nitrite analysis, Storet No. 00630 (Anonymous 1979).

Appendix III. Sugar floatation method used to sort HQI macroinvertebrate samples (see also Anderson 1959).

Step	Procedure
1	Mix 2½ cups white granulated sugar into a gallon of hot water.
2	Separate sample from preservative liquid, using a fine screened sieve.[a]
3	Place sample in metal pan, add some sugar solution and remove the organisms as they float on the surface. Be alert for specimens that do not float.
4	After organisms no longer float, remove the sugar solution by sieving and place sample in plain water to restore isotonic balance.
5	Repeat steps 2-4 as necessary, but note that organisms will eventually become saturated and will no longer float. They will then have to be picked off the bottom of the pan. Heavy vegetation will also interfere with float success.

[a] A suitable sieve can be made from brass strainer cloth, which is available at hardware stores, or sieves can be purchased from biological supply houses.

Appendix IVa. Program for HQI Score using Model II and an HP25C calculator.

(A) Program

STEP	INSTRUCTION	STEP	INSTRUCTION
01	enter X_1+1	17	R/S
02	RCL 1	18	enter F + 1
03	f Y^x	19	RCL 4
04	RCL 0	20	f Y^x
05	x	21	STO x 7
06	STO 7	22	R/S
07	R/S	23	enter S + 1
08	enter X_2+1	24	RCL 5
09	RCL 2	25	f Y^x
10	f Y^x	26	STO x 7
11	STO x 7	27	RCL 7
12	R/S	28	RCL 6
13	enter X_3+1	29	-
14	RCL 3	30	STO 7
15	f Y^x	31	GTO 00
16	STO x 7		

Constant	Register Stored in
.125	0
.807	1
.877	2
1.233	3
.631	4
.182	5
1.0	6
Sum (lbs/ac)	7

(Continued)

(B) To Run Program

(1) Load Program & constants
(2) In RUN mode, push (F PRGM)
(3) Put X_1 + 1 on keyboard, push (R/S)
(4) Put X_2 + 1 on keyboard, push (R/S)
(5) Put X_3 + 1 on keyboard, push (R/S)
(6) Put F + 1 on keyboard, push (R/S)
(7) Put S + 1 on keyboard, push (R/S)

Display reads out in lbs/acre (which is stored in reg. #7)
Multiply display by 1.12085 to get kg/ha.
Multiply lbs/ac by 1.08 to get habitat units (English)
Multiply kg/ha by 1.08 to get habitat units (metric)

(C) Example

X_1 = Critical Period Stream Flow

X_2 = Annual Stream Flow Variation

X_3 = Maximum Summer Stream Temperature

F = Temperature (Velocity) (Nitrate) (Substrate)

S = Cover (Width) (Bank stability)

IF:

$X_1 + 1 = 4$ $\qquad F + 1 = 9$

$X_2 + 1 = 3$ $\qquad S + 1 = 13$

$X_3 + 1 = 3$

Load 4, push (R/S)
Load 3, push (R/S)
Load 3, push (R/S)
Load 9, push (R/S)
Load 13, push (R/S)

Display = 23.79 lbs/ac
Multiply by 1.12085 to get kg/ha

APPENDIX IVb. Program for HQI Score using Model II and an HP 67 calculator.

(A) Program

STEP	INSTRUCTION	STEP	INSTRUCTION	Constant	Register Stored In
01	f lbl A	21	h Y^x	.125	0
02	enter X_1 + 1	22	STO x 7	.807	1
03	RCL 1	23	R/S	.877	2
04	h Y^x	24	enter S + 1	1.233	3
05	RCL 0	25	RCL 5	.631	4
06	x	26	h Y^x	.182	5
07	STO 7	27	STO x 7	1.0	6
08	R/S	28	RCL 7	1.12085	8
09	enter X_2 + 1	29	RCL 6		
10	RCL 2	30	-		
11	h Y^x	31	h RTN		
12	STO x 7	32	R/S		
13	R/S	33	f lbl B		
14	enter X_3 + 1	34	RCL 7		
15	RCL 3	35	RCL 6		
16	h Y^x	36	-		
17	STO x 7	37	RCL 8		
18	R/S	38	X		
19	enter F + 1	39	h RTN		
20	RCL 4				

(B) To Run Program

1- Put X_1 + 1 on keyboard, push (A)

2- Put X_2 + 1 on keyboard, push (R/S)

3- Put X_3 + 1 on keyboard, push (R/S)

4- Put F + 1 on keyboard, push (R/S)

5- Put S + 1 on keyboard, push (R/S)

Display is HQI Score in lbs/acre

Push (B) to get HQI Score in kg/ha

(Continued)

(C) Example

X_1 = Critical Period Stream Flow

X_2 = Annual Stream Flow Variation

X_3 = Maximum Summer Temperature

F = Temperature (Velocity) (Nitrate) (Substrate)

S = Cover (Width) (Bank stability)

$X_1 + 1 = 4$ $F = L = 9$

$X_2 + 1 = 3$ $S + 1 = 13$

$X_3 + 1 = 3$

Load 4, push (A)

Load 3, push (R/S)

Load 3, push (R/S)

Load 9, push (R/S)

Load 13, push (R/S); display = 23.79 lbs/ac

(Push (B) to get 26.67 kg/ha)

Appendix Va. HQI evaluation at the instream flow station on the Green River at a discharge of 302 cfs.

HABITAT QUALITY INDEX ATTRIBUTE RATING SUMMARY SHEET

STREAM: Green River LOCATION: 1.25 miles above Big Sandy River confluence

DATE DATA COLLECTED: 9/27/78 HQI SCORE = 11 lbs/acre

TROUT STANDING CROP: ______ = ______ trout habitat units
(if available) DISCHARGE: 302 cfs at Fontenelle gage

ATTRIBUTE (Symbol)	(Name)	DATA	RATING
(X_1)	Late Summer Stream Flow (Critical Period) Stream Flow - CPSF)	USGS Fontenelle gage: 15 yrs of record. ADF = 1714 cfs 302 cfs/1417 cfs = 18%	2
(X_2)	Annual Stream Flow Variation		2
(X_3)	Maximum Summer Stream Temperature	1977 mean critical period flow = 367 cfs 1977 Max. Temp. GR City = 84° 78 °F (Assumed) At dam = 68° (Probable range at sta. = 76-79°)	1
(X_4)	Nitrate Nitrogen	0.06 mg/l (mean for July-Aug 1977 at USGS Stations)	2
(X_5)	Fish Food Abundance	____ organisms/square foot	-
(X_6)	Fish Food Diversity	D_s = ______	-
(X_7)	Cover	28 % of total area	2
(X_8)	Eroding Stream Banks (Bank Stability)	100 %	0
(X_9)	Substrate		3
(X_{10})	Water Velocity	Time of Travel = 1.14 ft/sec. Velocity = ____ cm/sec.	3
(X_{11})	Stream Width	236 feet	0

$F = X_3(X_4)(X_9)(X_{10}) = (1)(2)(3)(3) = 18$

$F + 1 = 19$

$S = X_7(X_8)(X_{11}) = (2)(0)(0) = 0$

$S + 1 = 1$ (put HQI calculations on back of sheet)

Appendix Vb. HQI evaluation at the instream flow station on the Green River at a discharge of 620 cfs.

HABITAT QUALITY INDEX ATTRIBUTE RATING SUMMARY SHEET

STREAM: Green River

LOCATION: 1.25 miles above Big Sandy River confluence

DATE DATA COLLECTED: 3/31/81

HQI SCORE = 34 lbs/acre

= ______ trout habitat units

TROUT STANDING CROP: ______ lbs/acre (if available)

DISCHARGE: 620 cfs at Fontenelle gage

ATTRIBUTE (Symbol)	(Name)	DATA	RATING
(X_1)	Late Summer Stream Flow (Critical Period Stream Flow - CPSF)	USGS Fontenelle gage: 15 yrs. of record ADF = 1714 cfs 620 cfs/1714 cfs = 36%	3
(X_2)	Annual Stream Flow Variation		2
(X_3)	Maximum Summer Stream Temperature	1966 mean August flow = 862 cfs, max. temp. then was 73°F. ______ °F ______ °C	2
(X_4)	Nitrate Nitrogen	0.07 mg/l = mean for Aug-Sept. 1966 at USGS Sta.	2
(X_5)	Fish Food Abundance	166 organisms/square foot Mean flow Aug 15-Sept 15, 1966 = 692 cfs on 9/14/66	-
(X_6)	Fish Food Diversity	D_s = ______	-
(X_7)	Cover	28 % of total area	2
(X_8)	Eroding Stream Banks (Bank Stability)	100 %	0
(X_9)	Substrate	(see fish food abundance above)	2
(X_{10})	Water Velocity	Time of Travel = 1.63 ft/sec. Velocity = ______ cm/sec.	4
(X_{11})	Stream Width	224 feet	0

$F = X_3(X_4)(X_9)(X_{10}) = (2)(2)(2)(4)$

$F + 1 = 33$

$S = X_7(X_8)(X_{11}) = (2)(0)(0) = 0$

$S + 1 = 1$

(put HQI calculations on back of sheet)

Appendix Vc. HQI evaluation at the instream flow station on the Green River at a discharge of 1,010 cfs.

HABITAT QUALITY INDEX ATTRIBUTE RATING SUMMARY SHEET

STREAM: Green River LOCATION: 1.25 miles above Big Sandy River confluence

DATE DATA COLLECTED: 4/23/81 HQI SCORE = 41 lbs/acre

TROUT STANDING CROP: ______ lbs/acre = ______ trout habitat units
(if available)

DISCHARGE: 1010 at Fontenelle gage

ATTRIBUTE (Symbol)	(Name)	DATA	RATING
(X_1)	Late Summer Stream Flow (Critical Period Stream Flow - CPSF)	USGS Fontenelle gage: 15 yrs. of record ADF = 1714 cfs 1010 cfs/1714 cfs = 59%	4
(X_2)	Annual Stream Flow Variation		2
(X_3)	Maximum Summer Stream Temperature	______ °F ______ °C 1979 mean critical period flow = 965 cfs. Max temp. at G.R. City is 73.4°. Probable peak at sta. is 71-72°F.	2
(X_4)	Nitrate Nitrogen	0.05 mg/l Mean of USGS samples in 1979	2
(X_5)	Fish Food Abundance	______ organisms/square foot	-
(X_6)	Fish Food Diversity	D_s = ______	-
(X_7)	Cover	34 % of total area	2
(X_8)	Eroding Stream Banks (Bank Stability)	100 %	0
(X_9)	Substrate		2
(X_{10})	Water Velocity	Time of Travel = 2.14 ft/sec. Velocity = ______ cm/sec.	4
(X_{11})	Stream Width	256 feet	0

$F = X_3(X_4)(X_9)(X_{10}) = (2)(2)(2)(4) = 32$

$F + 1 = 33$

$S = X_7(X_8)(X_{11}) = (2)(0)(0) = 0$

$S + 1 = 1$

(put HQI calculations on back of sheet)

Appendix Vd. HQI evaluation at the instream flow station at the Green River at a discharge of 1,614 cfs.

HABITAT QUALITY INDEX ATTRIBUTE RATING SUMMARY SHEET

STREAM: Green River

LOCATION: 1.25 miles above Big Sandy River confluence

DATE DATA COLLECTED: 9/21/78

HQI SCORE = 57 lbs/acre

TROUT STANDING CROP: ______ lbs/acre (if available)

= ______ trout habitat units

DISCHARGE: 1614 cfs at Fontenelle gage

ATTRIBUTE (Symbol)	(Name)	DATA	RATING
(X_1)	Late Summer Stream Flow (Critical Period Stream Flow - CPSF)	USGS Fontenelle gage: 15 yrs of record. ADF = 1714 cfs 1614 cfs/1714 cfs = 94%	4
(X_2)	Annual Stream Flow Variation		3
(X_3)	Maximum Summer Stream Temperature	71.6 °F ___ °C 1973 mean (in 1973, summer flow was about 1600 cfs)	2
(X_4)	Nitrate Nitrogen	0.062 mg/l Mean of 6 samples for Aug-Sept 1973 at USGS stations	2
(X_5)	Fish Food Abundance	______ organisms/square foot	-
(X_6)	Fish Food Diversity	D_s = ______	-
(X_7)	Cover	36 % of total area	2
(X_8)	Eroding Stream Banks (Bank Stability)	100 %	0
(X_9)	Substrate		3
(X_{10})	Water Velocity	Time of Travel = 2.90 ft/sec. Velocity = ______ cm/sec.	3
(X_{11})	Stream Width	284 feet	0

$F = X_3(X_4)(X_9)(X_{10}) = (2)(2)(3)(3) = 36$

$F + 1 = 37$

$S = X_7(X_8)(X_{11}) = (2)(0)(0) = 0$

$S + 1 = 1$

(put HQI calculations on back of sheet)

Appendix VI. Stream discharge records for the USGS gage on the Little Popo Agie River. Data from USGS records similar to Anonymous (1971).

YELLOWSTONE RIVER BASIN

06233000 LITTLE POPO AGIE RIVER NEAR LANDER, WYO.

LOCATION.--Lat 42°43'00", long 108°38'34", in NE1/4SE1/4 sec. 27 T.32N., R.99W., Fremont County, on left bank 700 ft downstream from bridge on State Highway 28, 2.5 miles downstream from Red Canyon Creek, and 9.5 miles southeast of post office in Lander.

DRAINAGE AREA.--125 sq mi.

PERIOD OF RECORD.--March 1946 to current year.

GAGE.--Water-stage recorder. Datum of gage is 5,436.49 ft above mean sea level.

AVERAGE DISCHARGE.--25 years, 80.3 cfs (58,180 acre-ft per year).

EXTREMES.--Current year: Maximum discharge, 960 cfs June 18 (gage height, 5.33 ft); minimum daily, 17 cfs Jan.5.

Period of record: Maximum discharge, 2,010 cfs June 16, 1963 (gage height, 6.64 ft); minimum daily, 12 cfs Jan. 20, 21, Feb. 26 to Mar. 2, 1960, Jan. 10, 11, 18, 19, 1963.

REMARKS.--Records good except those for winter period, which are poor. Diversions for irrigation of about 540 acres above station. Slight regulation by Christina Lake (capacity, about 3,860 acre-ft).

REVISIONS.--WSP 1709: Drainage area.

WATER YEAR OCTOBER 1970 TO SEPTEMBER 1971.

YELLOWSTONE RIVER BASIN
06233000 LITTLE POPO AGIE RIVER NEAR LANDER, WYO.

LOCATION.--Lat 42°43'00", long 108°38'34", in NE1/4SE1/4 sec. 27, T.32N., R.99W., Fremont County, on left bank 700 ft downstream from bridge on State Highway 28, 2.5 miles downstream from Red Canyon Creek, and 9.5 miles southeast of post office in Lander.

DRAINAGE AREA.--125 sq mi.

PERIOD OF RECORD.--March 1946 to current year.

GAGE.--Water-stage recorder. Datum of gage is 5,436.49 ft above mean sea level.

AVERAGE DISCHARGE.--24 years, 79.0 cfs (57,240 acre-ft per year).

EXTREMES--Current year: Maximum discharge, 466 cfs June 10 (gage height, 4.13 ft); minimum daily, 18 CFS Jan. 5, 6.

Period of Record: Maximum discharge, 2,010 cfs June 16, 1963 (gage height, 6.64 ft); minimum daily, 12 cfs Jan. 20, 21, Feb. 26 to Mar. 2, 1960, Jan. 10, 11, 18, 19, 1963.

REMARKS.--Records good except those for winter period, which are poor. Diversions for irrigation of about 600 acres above station. Slight regulation by Christina Lake (capacity, about 3,860 acre-ft).

REVISIONS.--WSP 1729: Drainage area.

WATER YEAR OCTOBER 1969 TO SEPTEMBER 1970.

Appendix VI. Continued.

YELLOWSTONE RIVER BASIN

6-2330 LITTLE POPO AGIE RIVER NEAR LANDER, WYO.

LOCATION.--Lat 42°43'00", long 108°38'34", in NE1/4SE1/4 sec. 27, T.32N.,R.99W., Fremont County, on left bank 700 ft downstream from bridge on State Highway 28, 2.5 miles downstream from Red Canyon Creek, and 9.5 miles southeast of post office in Lander.

DRAINAGE AREA.--125 sq mi.

PERIOD OF RECORD.--March 1946 to current year.

GAGE.--Water-stage recorder. Datum of gage is 5,436.49 ft above mean sea level.

AVERAGE DISCHARGE.--23 years, 79.3 cfs (57,450 acre-ft per year).

EXTREMES.--Current year: Maximum discharge, 1,200 cfs June 8 (gage height, 5.66 ft); minimum daily, 18 cfs Dec. 30.

Period of record: Maximum discharge, 2,010 cfs June 16, 1963 (gage height, 6.64 ft); minimum daily, 12 cfs Jan. 20, 21, Feb 26 to Mar. 2, 1960, Jan. 10, 11, 18, 19, 1963.

REMARKS.--Records good escept those for winter period, which are poor. Diversions for irrigation of about 600 acres above station. Slight regulation by Christina Lake (capacity, about 3,860 acre-ft).

REVISIONS:--WSP 1729: Drainage area.

WATER YEAR OCTOBER 1968 TO SEPTEMBER 1969.

CHEYENNE RIVER BASIN
06429905 SAND CREEK NEAR RANCH A, NEAR BEULAH WY

LOCATION.--Lat 44°31'13", long 104°05'00", in SE1/4SW1/4 sec.5, T.52N., R.60W., Crook County, Hydrologic Unit 10120303, on left bank 1.0 mi (1.6 km) upstream from Bear Gulch, and 1.6 mi (2.6 km) south of Beulah.

DRAINAGE AREA.-- 267 mi^2 (692 km^2).

PERIOD OF RECORD.--October 1976 to current year.

GAGE.--Water-stage recorder. Altitude of gage is 3,600 ft (1,100 m), from topographic map.

REMARKS.--Records good.

AVERAGE DISCHARGE.--26.7 ft^3/s (0.76 m^3/s) 5 years (water years 1975-79)

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 96 ft^3/s (2.72 m^3/s) Apr. 29, 1978, gage height, 5.73 ft (1.746 m); minimum daily, 16 ft^3/s (0.45 m^3/s) Apr. 15-21, 1979.

EXTREMES OUTSIDE PERIOD OF RECORD.--Maximum discharge, 700 ft^3/s (19.8 m^3/s) June 15, 1976, gage height, 7.77 ft (2.368 m), from slope-area measurement of peak flow at site 3 mi (4.8 km) upstream.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 34 ft^3/s (0.96 m^3/s) Oct. 15, 16, gage height, 5.23 ft (1.594 m); minimum daily, 16 ft^3/s (0.45 m^3/s) Apr. 15-21.

WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979.

CHEYENNE RIVER BASIN

06429905 SAND CREEK NEAR RANCH A, NEAR BEULAH, WY

LOCATION.--Lat 44°31'13", long 104°05'00", in SE1/4 SW1/4 sec. 5, T.52N., R.60W., Crook County, Hydrologic Unit 10120303, on left bank 1.0 mi (.16 km) upstream from Bear Gulch, and 1.6 mi (2.6 km) south of Beulah.

DRAINAGE AREA.--267 mi^2 (692 km^2).

PERIOD OF RECORD.--October 1976 to current year.

GAGE.--Water-stage recorder. Altitude of gage in 3,600 ft (1,000 m), from topographic map.

REMARKS.--Records good.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 96 ft^3/s (2.72 m^3/s) Apr. 29, 1978, gage height, 5.73 ft. (1.746 m); minimum daily, 22 ft^3/s (0.62 m^3/s) Feb. 1 to Mar. 2, 1978.

EXTREMES OUTSIDE PERIOD OF RECORD.--Maximum discharge, 700 ft^3/s (19.8 m^3/s) June 15, 1976, gage height, 7.77 ft. (2.368 m), from slope area measurement of peak flow at site 3 mi (4.8 km) upstream.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 96 ft^3/s (2.22 m^3/s) Apr. 29, gage height, 5.73 ft. (1.746 m); minimum daily, 22 ft^3/s (0.62 m^3/s) Feb. 1 to Mar. 2.

WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978.

CHEYENNE RIVER BASIN

06429905 SAND CREEK NEAR RANCH A, NEAR BEULAH, WY

LOCATION.--Lat 44°31'13", long 104°05'00", in SE1/4SW1/4 sec. 5, T.52N., R.60W., Crook County, Hydrologic Unit 10120303, on left bank 1.0 mi (1.6 km) upstream from Bear Gulch, and 1.6 mi (2.6 km) south of Beulah.

DRAINAGE AREA.--267 mi^2 (692 km^2).

PERIOD OF RECORD.--October 1976 to September 1977.

GAGE.--Water-stage recorder. Altitude of gage is 3,600 ft (1,100 m), from topographic map.

REMARKS.--Records good.

EXTREMES OUTSIDE PERIOD OF RECORD.--Maximum discharge, 700 ft^3/s (19.8 m^3/s) June 15, 1976, gage height, 7.77 ft (2.368 m), from slope-area measurement of peak flow at site 3 mi (4.8 km) upstream.

EXTREMES FOR CURRENT YEAR.--Maximum daily discharge, 43 ft^3/s (1.22 m^3/s) May 3; minimum daily, 25 ft^3/s (0.71 m^3/s) for many days.

WATER YEAR OCTOBER 1976 TO SEPTEMBER 1977.

CHEYENNE RIVER BASIN
06429900 SAND CREEK AT RANCH A, NEAR BEULAH, WY

LOCATION.--Lat 44°25'42", long 104°06'34", in SW1/4 sec. 18, T.52N., R.60W., Crook County, Hydrologic Unit 10120203, on right bank 0.35 mi (0.6 km) downstream from headquarters building of Fish Genetic Laboratory, 0.9 mi (1.4 km) upstream from Hospital Gulch, and 3.6 mi (5.8 km) south of Beulah.

DRAINAGE AREA.--260 mi^2 (673 km^2).

PERIOD OF RECORD.--October 1974 to September 1976 (discontinued).

GAGE.--Water-stage recorder. Altitude of gage is 3,750 ft (1,143 m), from topographic map.

REMARKS.--Records good.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 700 ft^3/s (19.8 m^3/s) June 15, 1976, gage height, 7.19 ft (2.192 m) from rating curve extended above 60 ft^3/s (1.70 m^3/s) on basis of slope area measurement of peak flow; minimum daily, 17 ft^3/s (0.481 m^3/s) Feb. 6, 1976.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 700 ft^3/s (19.8 m^3/s) June 15, gage height, 7.19 ft (2.192 m), from rating curve extended above 60 ft^3/s (1.70 m^3/s) on basis of slope-area measurement of peak flow; minimum daily, 17 ft^3/s (0.481 m^3/s) Feb. 6.

WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976.

SAND CREEK NEAR RANCH A, NEAR BEULAH, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1979 TO SEPTEMBER 1980
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	22	22	24	22	21	19	20	22	23	24	21	22
2	22	23	24	22	21	19	20	22	24	24	21	22
3	21	23	23	22	20	19	20	22	24	24	21	22
4	21	24	23	22	20	19	20	21	24	24	20	22
5	21	23	23	22	20	19	20	21	24	24	20	21
6	21	23	23	23	20	19	20	22	25	24	20	21
7	21	23	23	23	20	19	20	22	25	24	20	22
8	21	23	22	23	20	19	20	22	24	24	20	21
9	22	24	22	23	20	20	20	22	24	24	20	22
10	22	24	22	23	20	20	20	22	24	24	20	22
11	22	23	22	22	20	20	20	22	24	24	20	23
12	22	23	22	22	20	20	20	22	24	24	21	24
13	22	23	22	22	20	20	20	22	24	23	20	22
14	22	23	22	22	20	20	20	22	26	23	20	22
15	22	23	22	22	20	20	20	22	26	23	20	22
16	22	24	22	22	20	20	20	22	26	23	20	22
17	22	24	22	21	20	20	20	22	24	22	20	22
18	22	24	22	21	20	20	20	22	24	22	20	22
19	22	23	22	22	20	20	20	22	24	23	21	22
20	22	23	22	22	20	20	20	22	24	22	21	22
21	23	23	22	22	20	20	21	22	24	22	21	21
22	23	22	22	21	20	20	21	23	24	22	21	21
23	23	23	22	21	20	20	21	24	24	22	21	21
24	23	23	22	21	20	20	21	24	24	22	21	21
25	23	23	22	22	20	20	21	23	24	22	21	22
26	24	23	22	22	20	20	20	23	24	22	21	22
27	23	23	22	22	20	20	21	23	24	22	21	22
28	23	24	22	21	20	20	21	23	24	21	21	21
29	23	24	22	21	19	20	21	23	24	21	21	21
30	23	24	22	21	---	20	22	23	24	21	21	21
31	23	---	22	21	---	20	---	23	---	21	22	---
TOTAL	688	697	691	678	581	612	610	692	727	707	638	653
MEAN	22.2	23.2	22.3	21.0	20.0	19.7	20.3	22.3	24.2	22.8	20.6	21.8
MAX	24	24	24	23	21	20	22	24	26	24	22	24
MIN	21	22	22	21	19	19	20	21	23	21	20	21
AC-FT	1360	1380	1370	1340	1150	1210	1210	1370	1440	1400	1270	1300

CAL YR 1979 TOTAL 8534 MEAN 23.4 MAX 28 MIN 16 AC-FT 16930
WTR YR 1980 TOTAL 7974 MEAN 21.8 MAX 26 MIN 19 AC-FT 15820

SAND CREEK NEAR RANCH A, NEAR BEULAH, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	28	28	27	27	25	24	22	24	25	26	24	21
2	28	27	27	27	25	24	22	24	25	26	24	21
3	28	28	26	26	25	23	22	24	25	26	23	21
4	28	27	26	27	25	24	22	24	25	26	23	21
5	28	27	26	26	26	24	22	24	24	27	23	21
6	28	27	26	26	26	24	23	24	24	27	23	21
7	28	27	26	26	26	25	23	24	24	27	23	21
8	29	27	26	26	25	25	22	24	24	26	23	21
9	28	27	26	27	25	24	23	24	24	26	23	21
10	29	27	26	26	26	24	22	24	24	26	23	21
11	29	27	26	27	26	24	20	24	24	26	23	21
12	28	27	26	27	25	25	20	24	24	25	23	22
13	28	27	26	27	25	25	19	24	25	26	22	21
14	28	27	26	27	26	23	17	23	24	25	22	21
15	29	27	26	26	25	24	16	23	24	25	22	21
16	29	27	26	25	24	24	16	24	27	25	23	21
17	29	26	26	25	24	24	16	24	28	25	23	21
18	29	26	26	25	24	24	16	24	26	25	23	21
19	29	26	26	25	24	23	16	24	26	25	23	21
20	29	26	26	25	24	23	16	24	26	25	23	21
21	29	26	26	26	24	23	16	24	26	24	23	21
22	29	26	26	27	24	23	18	24	24	24	22	21
23	29	26	26	26	24	23	22	24	24	24	22	21
24	29	26	26	25	24	23	22	24	25	24	22	22
25	29	26	27	25	24	23	22	24	26	25	23	22
26	28	27	26	25	24	23	22	25	26	24	22	22
27	28	27	27	25	24	23	22	25	26	24	23	22
28	28	27	27	25	24	23	23	25	26	24	22	22
29	28	27	27	25	---	23	23	25	26	25	21	22
30	28	27	27	25	---	23	23	26	26	24	21	21
31	28	---	27	25	---	23	---	26	---	24	21	---
TOTAL	882	803	814	802	693	733	608	750	753	781	701	637
MEAN	28.5	26.8	26.3	25.9	24.8	23.6	20.3	24.2	25.1	25.2	22.6	21.2
MAX	29	28	27	27	26	25	23	26	28	27	24	22
MIN	28	26	26	25	24	23	16	23	24	24	21	21
AC-FT	1750	1590	1610	1590	1370	1450	1210	1490	1490	1550	1390	1260

CAL YR 1978 TOTAL 10750 MEAN 29.5 MAX 73 MIN 22 AC-FT 21320
WTR YR 1979 TOTAL 8957 MEAN 24.5 MAX 29 MIN 16 AC-FT 17770

Appendix VII. Continued.

SAND CREEK NEAR RANCH A, NEAR BEULAH, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	30	28	26	24	22	22	26	47	39	34	31	29
2	28	28	26	23	22	22	27	39	39	33	30	29
3	29	28	26	23	22	23	26	34	39	31	30	28
4	27	29	26	23	22	23	26	38	38	31	30	29
5	27	28	25	23	22	24	26	36	38	31	28	29
6	27	28	25	23	22	26	26	22	39	31	28	29
7	29	29	25	23	22	25	26	37	39	31	28	29
8	28	29	25	23	22	26	26	37	39	31	28	29
9	28	29	25	23	22	26	27	38	38	31	28	29
10	28	28	25	23	22	26	27	42	38	29	28	28
11	28	28	25	23	22	26	28	66	37	30	28	28
12	28	29	25	23	22	26	28	65	36	30	28	28
13	28	28	25	23	22	26	28	58	37	31	28	28
14	28	28	26	23	22	28	28	54	37	32	28	28
15	28	29	26	23	22	28	27	55	37	32	29	28
16	29	29	26	23	22	30	28	50	36	32	28	28
17	29	29	26	23	22	29	28	48	36	32	28	28
18	29	29	25	23	22	29	29	48	36	31	28	28
19	30	29	25	23	22	29	29	48	36	31	28	28
20	30	29	25	23	22	30	29	49	34	31	28	28
21	30	29	24	23	22	30	29	48	35	33	28	28
22	30	28	24	23	22	30	29	45	35	32	28	28
23	30	29	24	23	22	31	29	43	35	31	28	28
24	30	28	24	23	22	31	30	41	35	31	28	28
25	29	28	24	23	22	31	30	39	34	31	28	28
26	28	27	24	23	22	30	31	39	34	31	28	28
27	28	27	24	23	22	28	32	39	34	30	28	28
28	28	26	24	23	22	25	32	38	33	30	29	28
29	28	26	24	23	---	25	73	39	33	31	29	28
30	28	26.	24	23	---	26	65	40	34	31	29	28
31		---	24	23	---	26	---	39	---	30	29	---
TOTAL	885	845	772	714	616	837	925	1373	1090	966	882	848
MEAN	28.5	28.2	24.9	23.0	22.0	27.0	30.8	44.3	36.3	31.2	28.5	28.3
MAX	30	29	26	24	22	31	73	66	39	34	31	29
MIN	27	26	24	23	22	22	26	34	33	29	28	28
AC-FT	1760	1680	1530	1420	1220	1660	1830	2720	2160	1920	1750	1680

CAL YR 1977 TOTAL 10416 MEAN 28.5 MAX 43 MIN 24 AC-FT 20660
WTR YR 1978 TOTAL 10753 MEAN 29.5 MAX 73 MIN 22 AC-FT 21330

Appendix VII. Continued.

SAND CREEK NEAR RANCH A, NEAR BEULAH, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1976 TO SEPTEMBER 1977
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	26	26	25	27	25	25	25	42	33	33	27	27
2	26	25	25	27	25	26	25	42	33	34	27	27
3	26	26	25	27	25	26	25	43	33	34	27	27
4	26	26	25	27	25	26	25	42	33	33	27	27
5	25	26	25	27	25	26	26	41	33	33	27	26
6	26	26	25	27	25	26	26	38	33	33	28	26
7	25	26	25	26	25	26	27	37	33	32	28	27
8	26	26	25	26	25	25	27	35	34	32	28	27
9	26	26	25	26	25	26	27	34	34	31	27	27
10	26	26	25	26	25	26	27	34	34	31	27	27
11	26	26	25	26	25	25	27	34	34	31	27	27
12	25	26	25	26	25	26	27	34	34	31	27	27
13	26	26	25	26	25	26	27	34	34	30	27	27
14	25	26	25	25	25	26	28	35	34	30	27	27
15	25	26	25	25	25	25	28	39	34	30	29	27
16	26	26	25	25	25	25	28	39	34	29	27	27
17	26	26	26	25	25	26	29	38	35	30	27	27
18	25	26	26	25	25	26	30	36	34	29	27	27
19	26	26	26	26	25	26	30	40	34	29	27	27
20	26	26	25	25	25	25	30	40	34	29	27	27
21	26	25	25	25	25	25	30	38	35	29	27	27
22	26	25	25	25	25	25	29	37	35	28	27	27
23	26	25	25	25	26	26	29	35	35	28	27	28
24	26	25	26	25	25	26	32	34	35	28	27	27
25	27	25	26	25	25	26	33	34	35	28	27	28
26	26	25	26	25	25	26	33	34	35	28	26	28
27	27	25	26	25	25	26	36	34	35	28	26	28
28	27	25	26	25	25	26	36	34	35	27	26	28
29	26	25	26	25	---	27	36	34	34	27	26	28
30	26	25	26	25	---	26	39	34	34	26	27	29
31	26	---	27	25	---	26	---	34	---	26	27	---
TOTAL	803	769	787	795	701	799	877	1139	1022	927	838	816
MEAN	25.9	25.6	25.4	25.6	25.0	25.8	29.2	36.7	34.1	29.9	27.0	27.2
MAX	27	26	27	27	26	27	39	43	35	34	29	29
MIN	25	25	25	25	25	25	25	34	33	26	26	26
AC-FT	1590	1530	1560	1580	1390	1580	1740	2260	2030	1840	1660	1620

WTR YR 1977 TOTAL 10273 MEAN 28.1 MAX 43 MIN 25 AC-FT 20380

YELLOWSTONE RIVER BASIN
06258000 MUDDY CREEK NEAR SHOSHONI, WY

LOCATION.--Lat 43°17'10", long 108°16'30", in NE1/4NW1/4 sec. 34, T.4N., R.5E., Fremont County, Hydrologic Unit 10080005, on left bank 2.5 mi (4.0 km) upstream from normal high-water line of Boysen Reservoir at elevation 4,725 ft (1,440 m) and 9.0 mi (14.5 km) northwest of Shoshoni.

DRAINAGE AREA.--332 mi^2 (860 km^2).

PERIOD OF RECORD.--March 1949 to September 1968, October 1972 to current year.

GAGE.--Water-stage recorder. Altitude of gage is 4,780 ft (1,457 m), from topographic map. Prior to May 13, 1949, water-stage recorder at site 50 ft (15 m) upstream at different datum.

REMARKS.--Records good except those for November to May, and September, which are poor. Natural flow of stream affected by regulation of Bureau of Indian Affairs reservoir system in the head-waters, diversions for irrigation, and return flow from irrigated areas.

AVERAGE DISCHARGE.--25 years (water years 1950-68, 1973-78), 20.3 ft^3/s (0.575 m^3/s), 14,710 acre-ft/yr (18.1 hm^3/yr).

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 1,430 ft^3/s (40.5 m^3/s) July 22, 1951, gage height, 7.50 ft (2.286 m); no flow at times in some years.

EXTREMES OUTSIDE OF PERIOD OF RECORD.--Flood of July 24, 1923, reached a discharge of 16,300 ft^3/s (462 m^3/s), from slope-area measurement of peak flow.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 303 ft^3/s (8.58 m^3/s) May 18, gage height, 3.80 ft (1.158m); maximum gage height, 3.84 ft (1.170 m) Mar. 21 (backwater from ice); minimum daily discharge, 3.5 ft^3/s (0.10 m^3/s) Jan. 2.

WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978.

YELLOWSTONE RIVER BASIN
06258000 MUDDY CREEK NEAR SHOSHONI, WY

LOCATION.--Lat 43°17'10", long 108°16'30", in NE1/4NW1/4 sec. 34, T.4N., R.5E., Fremont County, Hydrologic Unit 1008005, on left bank 2.5 mi (4.0 km) upstream from normal high-water line of Boysen Reservoir at elevation 4,725 ft (1,440 m) and 9.0 mi (14.5 km) northwest of Shoshoni.

DRAINAGE AREA.--332 mi^2 (860 km^2).

PERIOD OF RECORD.--March 1949 to September 1968, October 1972 to current year.

GAGE.--Water-stage recorder. Altitude of gage is 4,780 ft (1,457 m), from topographic map. Prior to May 13, 1949, water-stage recorder at site 50 ft (15 m) upstream at different datum.

REMARKS.--Records good except those for winter period, which are poor. Natural flow of stream affected by regulation of Bureau of Indian Affairs reservoir system in the headwaters, diversions for irrigation, and return flow from irrigated areas.

AVERAGE DISCHARGE.--24 years (water years 1950-68, 1973-77), 20.4 ft^3/s (0.578 m^3/s), 14,780 acre-ft/yr (18.2 hm^3/yr).

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 1,430 ft^3/s (40.5 m^3/s) July 22, 1951, gage height, 7.50 ft (2.286 m); no flow at times in some years.

EXTREMES OUTSIDE PERIOD OF RECORD.--Flood of July 24, 1923, reached a discharge of 16,300 ft^3/s (462 m^3/s), from slope-area measurement of peak flow.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 285 ft^3/s (7.31 m^3/s) May 3, gage height, 3.45 ft (1.052 m); minimum daily, 5.0 ft^3/s (0.14 m^3/s) Jan. 10.

WATER YEAR OCTOBER 1976 TO SEPTEMBER 1977.

Appendix VIII. Continued.

YELLOWSTONE RIVER BASIN
06258000 MUDDY CREEK NEAR SHOSHONI, WY

LOCATION.--Lat 43°17'10", long 108°16'30", in NE1/4NW1/4 sec 34, T.4N., R.5E., Fremont County, Hydrologic Unit 10080005, on left bank 2.5 mi (4.0 km) upstream from normal high-water line of Boysen Reservoir at elevation 4,725 ft (1,440 m) and 9.0 mi (14.5 km) northwest of Shoshoni.

DRAINAGE AREA.--332 mi^2 (860 km^2).

PERIOD OF RECORD.--March 1949 to September 1968, October 1972 to current year.

GAGE.--Water-stage recorder. Altitude of gage is 4,780 ft (1,457 m), from topographic map. Prior to May 13, 1949, water-stage recorder at site 50 ft (15 m) upstream at different datum.

REMARKS.--Records good except those for winter period and period of no gage-height record, Dec. 17 to Feb. 26, which are poor. Natural flow of stream affected by regulation of Bureau of Indian Affairs reservoir system in the headwaters, diversions for irrigation, and return flow from irrigated areas.

AVERAGE DISCHARGE.--23 years (water years 1950-68; 1973-76), 20.5 ft^3/s (0.581 m^3/s), 14,850 acre-ft/yr (18.3 hm^3/yr).

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 14,30 ft^3/s (40.5 m^3/s) July 22, 1951, gage height, 7.50 ft (2.286 m); no flow at times in some years.

EXTREMES OUTSIDE OF PERIOD OF RECORD.--Flood of July 24, 1923, reached a discharge of 16,300 ft^3/s (462 m^3/s), from slope-area measurement of peak flow.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 265 ft^3/s (7.50 m^3/s) Aug. 1, gage height, 3.74 ft (1.140 m); minimum daily, 5.2 ft^3/s (0.15 m^3/s) Feb. 7.

WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976.

Appendix VIII. Continued.

YELLOWSTONE RIVER BASIN
06258000 MUDDY CREEK NEAR SHOSHONI, WYO.

LOCATION.--Lat 43°17'10", long 108°16'30", in NE1/4NW1/4 sec 34, T.4N., R.5E., Fremont County, on left bank 2.5 mi (4.0 km) upstream from normal high-water line of Boysen Reservoir at elevation 4,725 ft (1,440 m) and 9.0 mi (14.5 km) northwest of Shoshoni.

DRAINAGE AREA.--332 mi^2 (860 km^2).

PERIOD OF RECORD.--March 1949 to September 1968, October 1972 to current year.

GAGE.--Water-stage recorder. Altitude of gage is 4.780 ft (1,457 m), from topographic map. Prior to May 13, 1949, water-stage recorder at site 50 ft (15 m) upstream at different datum.

AVERAGE DISCHARGE.--22 years (1949-68, 1972-75), 19.6 ft^3/s (0.555 m^3/s), 14,200 acre-ft/yr (17.5 hm^3/yr).

EXTREMES.--Current year: Maximum discharge, 358 ft^3/s (10.1 m^3/s) July 3, gage height, 4.30 ft (1.311 m); minimum daily, 3.6 ft^3/s (0.10 m^3/s) Dec. 26.

Period of record: Maximum discharge, 1,430 ft^3/s (40.5 m^3/s), July 22, 1951, gage height, 7.50 ft (2.286 m); no flow at times in most years.

Flood of July 24, 1923, reached a discharge of 16,300 ft^3/s (462 m^3/s), from slope-area measurement of peak flow.

REMARKS.--Records good except those for winter period, which are poor. Natural flow of stream affected by regulation of Bureau of Indian Affairs reservoir system in the headwaters, diversions for irrigation, and return flow from irrigated areas.

WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975.

MUDDY CREEK NEAR SHOSHONI, WYO.
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	35	21	9.0	4.3	7.5	11	26	16	45	53	60	37
2	59	18	9.2	4.5	7.8	12	27	14	41	49	60	44
3	40	15	9.3	4.7	7.7	13	28	12	30	157	57	37
4	26	15	9.5	4.9	7.5	14	20	10	37	129	60	43
5	16	16	9.7	5.0	7.5	14	22	53	44	71	63	47
6	13	14	9.9	5.1	7.7	13	20	33	35	60	68	35
7	12	14	9.7	5.1	8.0	12	20	53	32	58	68	26
8	11	14	9.5	5.2	8.2	12	19	73	34	98	62	26
9	10	14	9.5	5.2	8.1	11	19	52	68	94	64	27
10	9.7	13	8.9	4.9	8.2	11	19	29	68	93	67	40
11	9.6	13	7.2	4.8	8.4	12	17	26	58	85	69	45
12	9.5	12	7.4	4.8	8.7	12	17	48	45	70	71	39
13	9.7	12	7.6	5.0	9.0	13	18	59	48	66	71	26
14	9.8	12	6.6	5.2	9.2	14	19	53	44	62	66	24
15	9.5	13	5.8	5.4	9.0	15	19	48	43	60	125	23
16	9.7	13	5.3	5.8	8.7	16	20	60	45	53	111	22
17	9.7	13	5.0	6.2	8.5	17	22	87	44	48	80	28
18	10	16	5.1	6.5	8.4	18	22	75	74	50	69	31
19	11	14	5.3	6.6	8.5	19	19	60	147	53	68	36
20	12	14	5.4	6.8	8.7	20	18	79	91	54	56	35
21	13	16	5.6	6.9	8.9	20	18	127	112	56	41	36
22	15	19	5.4	6.8	9.1	19	14	144	118	62	41	33
23	13	16	4.9	7.0	9.3	18	19	107	98	73	37	26
24	12	15	4.2	7.4	9.5	17	19	73	100	48	32	23
25	12	14	3.8	7.5	10	16	19	62	93	43	33	23
26	13	14	3.6	7.4	10	15	19	56	97	36	31	20
27	13	12	3.7	7.2	10	13	19	53	59	36	45	21
28	12	11	3.8	7.0	11	13	16	43	58	39	44	25
29	13	11	4.0	7.0	---	14	31	42	50	39	45	28
30	17	10	4.1	7.1	---	18	26	35	48	46	45	28
31	20	---	4.1	7.3	---	24	---	44	---	56	35	---
TOTAL	485.2	423	201.2	184.6	243.1	466	614	1726	1906	1997	1844	934
MEAN	15.7	14.1	6.49	5.95	8.68	15.0	20.5	55.7	63.5	64.4	59.5	31.1
MAX	59	21	9.9	7.5	11	24	31	144	147	157	125	47
MIN	9.5	10	3.6	4.3	7.5	11	16	10	30	36	31	20
AC-FT	962	839	399	366	482	924	1220	3420	3780	3960	3660	1850

CAL YR 1974 TOTAL 8255.6 MEAN 22.6 MAX 88 MIN 3.6 AC-FT 16370
WTR YR 1975 TOTAL 11024.1 MEAN 30.2 MAX 157 MIN 3.6 AC-FT 21870

MUDDY CREEK NEAR SHOSHONI, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	78	18	12	6.0	10	16	18	33	93	78	142	57
2	68	18	13	5.9	9.8	15	18	22	64	70	133	55
3	28	18	13	5.8	10	14	17	21	56	74	179	55
4	17	18	13	5.9	9.7	14	16	20	47	75	154	48
5	13	19	13	6.1	9.0	15	16	20	35	71	140	41
6	12	19	12	6.1	6.9	16	17	22	31	60	146	45
7	12	19	12	6.2	5.2	17	18	25	27	55	140	47
8	12	19	12	6.2	5.7	18	17	37	28	58	147	60
9	11	17	13	6.3	6.5	19	16	30	32	60	150	71
10	11	17	13	6.4	7.9	20	16	28	28	45	141	87
11	11	17	12	6.5	8.0	21	16	27	40	52	131	99
12	11	17	11	6.7	8.3	20	19	37	41	57	119	105
13	13	17	11	6.6	8.9	19	20	37	48	51	115	109
14	19	16	11	6.4	8.8	20	21	33	68	52	87	142
15	16	16	10	6.3	8.7	19	22	42	90	66	80	115
16	14	15	9.3	6.5	8.5	20	23	41	108	63	79	113
17	14	14	7.8	7.1	8.4	21	25	40	115	58	65	111
18	14	14	6.9	7.1	8.3	22	35	40	110	61	64	111
19	14	13	7.0	7.0	8.2	23	68	44	142	70	62	118
20	14	13	7.0	6.9	8.0	22	18	51	161	77	61	114
21	14	13	7.0	6.8	8.0	21	14	54	164	85	68	114
22	16	14	6.9	7.0	8.3	21	26	64	161	75	56	102
23	16	14	6.7	7.8	8.7	22	34	81	150	77	50	101
24	14	15	6.7	8.5	10	24	25	82	140	81	51	103
25	14	14	6.7	8.2	11	26	19	78	131	81	54	93
26	14	13	6.9	7.9	13	27	30	85	121	84	60	91
27	14	13	7.0	8.2	14	27	67	98	121	65	62	94
28	16	13	6.7	8.8	14	25	81	103	114	89	60	94
29	15	13	6.5	9.5	15	24	69	99	102	90	60	90
30	15	13	6.4	11	---	23	69	98	94	93	63	89
31	17	---	6.1	10	---	20	---		---	102	58	---
TOTAL	567	469	292.6	221.7	266.8	631	870	1591	2662	2195	2977	2674
MEAN	18.3	15.6	9.44	7.15	9.20	20.4	29.0	51.3	88.7	70.8	96.0	89.1
MAX	78	19	13	11	15	27	81	103	164	102	179	142
MIN	11	13	6.1	5.8	5.2	14	14	20	27	45	50	41
AC-FT	1120	930	580	440	529	1250	1730	3160	5280	4350	5900	5300

CAL YR 1975 TOTAL 11243.3 MEAN 30.8 MAX 157 MIN 4.3 AC-FT 22300
WTR YR 1976 TOTAL 15417.1 MEAN 42.1 MAX 179 MIN 5.2 AC-FT 30580

MUDDY CREEK NEAR SHOSHONI, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1976 TO SEPTEMBER 1977
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	94	10	9.2	5.8	6.4	15	23	93	8.4	6.4	19	22
2	53	10	9.2	5.6	6.8	15	23	119	8.2	6.1	14	11
3	34	10	9.2	5.6	6.9	15	23	168	12	7.7	9.2	8.8
4	26	10	9.4	5.6	7.2	14	23	108	7.3	7.7	8.0	8.8
5	22	10	9.3	5.6	7.6	15	23	93	8.4	7.3	7.1	8.0
6	18	10	9.2	5.4	7.8	16	24	68	6.9	6.4	7.7	7.7
7	15	9.6	8.6	5.2	7.8	17	24	60	7.1	6.2	7.7	7.3
8	15	10	8.6	5.2	7.8	18	24	50	18	6.2	7.7	7.1
9	14	10	8.6	5.2	7.6	18	24	48	15	6.4	6.6	6.2
10	14	10	8.6	5.0	7.8	19	28	29	10	6.1	6.4	6.9
11	13	10	8.5	5.2	8.4	19	34	29	9.6	5.7	11	6.4
12	12	10	8.4	5.2	9.8	19	37	49	8.0	5.7	6.2	6.4
13	12	10	8.3	5.2	10	20	35	35	7.1	5.8	5.8	6.4
14	12	10	8.0	5.2	11	20	39	28	6.6	5.8	5.8	5.7
15	11	10	7.8	5.2	11	20	43	42	7.1	6.6	6.6	5.7
16	11	10	7.4	5.2	11	20	39	32	7.1	5.8	6.2	6.9
17	12	11	6.8	5.2	11	20	36	26	7.1	5.8	6.9	7.5
18	12	12	6.6	5.3	11	20	38	20	7.1	5.8	10	6.4
19	12	11	6.4	5.3	11	22	36	20	7.1	5.8	9.6	6.0
20	11	10	6.2	5.3	11	23	32	19	7.5	6.2	11	6.1
21	11	10	6.0	5.3	12	23	29	18	7.7	6.6	8.4	7.3
22	11	10	6.2	5.3	13	23	26	15	7.7	7.4	7.1	8.0
23	12	10	6.4	5.3	13	25	22	14	10	11	7.7	10
24	12	10	6.4	5.3	13	27	20	13	6.6	9.8	6.9	18
25	10	10	6.4	5.3	13	27	25	12	6.2	40	6.6	20
26	12	9.6	6.4	5.6	13	26	28	12	6.1	44	15	19
27	10	9.2	6.4	5.8	13	25	55	13	5.6	32	40	20
28	10	9.0	6.2	6.4	14	24	201	10	5.6	24	47	18
29	10	9.0	6.2	6.4	---	23	208	9.6	6.6	21	48	20
30	11	9.0	6.2	6.2	---	19	148	9.6	6.0	26	42	18
31	10	---	6.0	6.2	---	22	---	9.2	---	23	34	---
TOTAL	542	299.4	233.1	169.6	282.9	629	1370	1271.4	243.7	370.3	435.2	315.6
MEAN	17.5	9.98	7.52	5.47	10.1	20.3	45.7	41.0	8.12	11.9	14.0	10.5
MAX	94	12	9.4	6.4	14	27	208	168	18	44	48	22
MIN	10	9.0	6.0	5.0	6.4	14	20	9.2	5.6	5.7	5.8	5.7
AC-FT	1080	594	462	336	561	1250	2720	2520	483	734	863	626

CAL YR 1976 TOTAL 15163.0 MEAN 41.4 MAX 179 MIN 5.2 AC-FT 30080
WTR YR 1977 TOTAL 6162.2 MEAN 16.9 MAX 208 MIN 5.0 AC-FT 12220

MUDDY CREEK NEAR SHOSHONI, WY
DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	15	9.2	12	4.2	6.0	11	17	22	28	34	38	15
2	14	8.0	12	3.5	6.5	10	16	28	37	35	43	15
3	13	9.2	11	3.7	8.4	10	15	30	32	35	44	14
4	14	8.2	11	3.9	9.0	10	14	28	26	30	41	15
5	13	8.8	10	4.0	9.2	10	13	26	29	26	39	15
6	11	8.8	10	4.1	9.4	10	13	23	27	30	47	16
7	10	9.2	10	4.1	9.6	11	12	22	30	27	52	16
8	9.2	9.2	10	4.1	9.6	11	11	24	26	24	44	17
9	9.2	7.8	9.6	4.2	9.8	13	10	23	25	22	39	20
10	8.2	8.2	9.4	4.2	9.4	15	10	20	26	22	32	20
11	8.0	8.5	9.4	4.2	8.5	14	9.2	17	28	22	29	23
12	7.7	8.6	9.6	4.4	7.2	13	8.4	19	31	20	29	28
13	8.2	8.8	9.8	4.5	7.0	12	8.0	17	33	19	30	33
14	8.0	9.1	9.4	4.6	7.0	12	8.0	14	30	20	35	32
15	7.5	9.4	9.0	4.6	7.0	11	8.0	16	35	24	42	31
16	7.7	9.6	8.8	4.5	7.2	11	8.0	17	33	30	50	34
17	7.5	9.8	8.5	4.3	7.2	12	7.7	29	35	30	51	39
18	9.2	9.8	8.4	4.4	7.0	14	112	130	34	28	47	42
19	9.6	9.6	8.4	4.7	7.0	17	95	43	37	30	54	40
20	8.2	9.4	8.2	5.2	7.2	20	79	32	34	32	56	37
21	8.4	9.1	8.1	5.2	8.0	19	70	23	31	30	59	35
22	8.0	9.2	8.0	5.0	8.9	19	18	19	28	32	59	39
23	7.1	9.8	7.6	4.9	10	30	28	18	30	32	42	38
24	6.9	10	7.4	4.8	11	27	38	18	26	32	30	37
25	6.9	12	7.3	5.0	12	23	23	14	28	29	24	36
26	7.1	13	7.0	5.2	12	21	23	15	30	22	24	36
27	6.9	13	6.4	5.3	11	19	29	16	34	23	23	36
28	6.9	13	6.0	5.6	11	19	23	21	45	25	26	36
29	6.9	13	5.6	5.8	---	18	19	17	33	28	23	36
30	7.3	12	5.1	5.8	---	17	19	18	37	32	20	35
31	12	---	4.7	5.6	---	14	---	18	---	36	17	---
TOTAL	282.6	293.3	267.7	143.6	243.1	473	764.3	777	938	861	1189	866
MEAN	9.12	9.78	8.6	4.63	8.68	15.3	25.5	25.1	31.3	27.8	38.4	28.9
MAX	15	13	12	5.8	12	30	112	130	45	36	59	42
MIN	6.9	7.8	4.7	3.5	6.0	10	7.7	14	25	19	17	14
AC-FT	561	582	531	285	482	938	1520	1540	1860	1710	2360	1720

CAL YR 1977 TOTAL 5931.3 MEAN 16.3 MAX 208 MIN 4.7 AC-FT 11760
WTR YR 1978 TOTAL 7098.6 MEAN 19.4 MAX 130 MIN 3.5 AC-FT 14080