Stream-Gaging Stations For Research on Small Watersheds

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Stream-Gaging Stations For Research on Small Watersheds

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Introduction

With an increasing population and per-capita consumption of water, nationwide concern has arisen about the adequacy of our water supplies. Some regions suffer acute shortages. Yet many areas sometimes sustain major damage from great floods.

Watershed research has shown that land use and treatment affect both water yield and peak flows. Under certain situations yield may be increased by vegetation management and other land practices; in other circumstances, peak flows may be reduced. This research is just being started in some parts of the country.

One of the accepted research techniques in watershed management is the measurement of streamflow from small experimental watersheds. Such measurement permits evaluation of the effect that manipulation of cover has on water-yield characteristics for fairly homogeneous areas.

During the past several years (since 1955), the authors have been responsible, or have had close contact with those responsible, for building 21 stream-gaging stations in small experimental watersheds in the Northeast, particularly on the Fernow Experimental Forest in West Virginia and the Hubbard Brook Experimental Forest in New Hampshire. This experience, a review of the literature, and information from several other workers in the field provide the basis for this handbook. It is prepared especially for researchers who have little experience in water measurement but are responsible for the construction and operation of stream-gaging stations.

Details of all aspects of stream gaging will not be discussed. This report is only a general guide on the design and construction of small stream-gaging stations. Additional details should be sought from the literature and from geologists, engineers, and hydraulic experts.

Stream gaging, as used here, is the measurement of the water leaving a watershed as flow in a natural stream channel. Water lost to deep seepage and not appearing as streamflow at the point of measurement cannot be measured by the stream-gaging station. Therefore, watersheds with minimum deep seepage are best for research.

Small watersheds include those of about 20 to 1,500 acres. Such watersheds are large enough—in the Northeast at least—to provide flow all or most of the time, but they are small enough so that construction of an artificial control is not impractical. On larger streams, gaging is usually done by using natural controls; such measurement is generally less precise than that with artificial controls on smaller streams.

A *control* is a natural constriction of the channel, a long reach of the channel, a stretch of rapids, or an artificial structure downstream from a gaging station that determines the stage-discharge relation at the gage (Langbein and Iseri 1960).[1]

There are many objectives of stream gaging in watershed research. In some cases one objective may be paramount; in others several may be about equally important.

A common objective is a continuous record of streamflow. To attain this goal, recording instruments that give a round-the-clock record are required. Usually yearlong records are obtained, but records for the growing season or some other short period may suffice. Measurements may be made to determine maximum flows and runoff volumes for major storm periods, low flows, or all flow leaving the watershed.

The research program will specify the number of stream-gaging stations required. Ordinarily two or more watersheds, as nearly identical as possible, are chosen. This permits the development during the pretreatment period of an expression for predicting flow of one watershed from that of the other; after treating one of the watersheds, differences between predicted and measured flow indicate the effect of treatment.

Sometimes only one watershed is used, and flows before and after treatment are compared to determine treatment effects. In this case, equations for predicting flow must be developed from climatic measurements in the calibration period.[2] Comparison through a control watershed partly counteracts the difficulties experienced because of differences in climate from year to year or before and after treatment (Reinhart 1958).

In this handbook, the types of gaging stations with which the authors have had personal experience will be discussed in some detail. Other types of stations will be considered in a more general way to provide an overall treatment of the subject.

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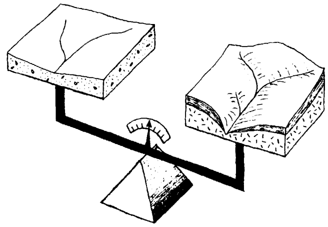
[1] Names and dates in parentheses refer to Bibliography, p. 31.

[2] Reigner, Irvin C. Calibrating a watershed by using climatic data. U.S. Forest Serv. Res. Paper NE-15, 45 pp., illus. Northeast. Forest Expt. Sta., Upper Darby, Pa. 1964.



Choosing the Stream-Gaging Site

Selection of a stream-gaging site depends mainly on two factors: The objectives of the research program and the physical land features necessary to meet these goals.

For example, if the objective is to measure total streamflow, the site must be one where all streamflow can be channeled through the measuring device. Limestone, permeable gravel beds, or other soil or bedrock conditions may make it virtually impossible to measure all or even almost all of the outflow from a watershed. However, if measurement of stormflow is the objective, primary consideration should be given to a site suitable to handle large flows, and low or subsurface flows can be disregarded. And where the measurement of flows in sluggish, low-gradient streams with porous channels is the aim, a totally different set of gaging-site requirements must be met.

Because technical requirements are perhaps more rigid for measurement of total flows than for other types of flow, primary consideration will be given to the selection of sites for this purpose.

First, to find the best location on the stream, it should be determined whether the watershed above the site is suitable in regard to cover type, acreage, anticipated flows, uniform terrain, elevation differences, soils, geology, etc.

Factors influencing the choice of the site include: (1) Presence of impermeable material, (2) stream gradient, (3) stream alinement, (4) character of streambanks, (5) depth of channel, (6) topography and drainage at site, (7) gaging-station design, and (8) accessibility.

Impermeable material (soil or bedrock) in the stream channel over which all streamflow must pass may be the primary requisite for site location. The depth to such impermeable material may determine the feasibility of the site. Depth to bedrock or impermeable material may be determined by observation of outcrops in the vicinity, by digging of preliminary pits, or by use of a soil tube or auger.

The gradient of the stream channel must be considered. If the gradient is too steep or too low, it may be impossible, difficult, or costly to meet certain hydraulic requirements for the gaging station (these will be described later). Stream-gaging stations such as V-notch weirs require sufficient elevation to create a ponding basin in the channel. But some flumes can be installed in streams with as little as 3-percent gradient.

Straight and uniform stretches of the stream are generally the best approaches to the gaging site. However, such stretches are not required if a gaging-station design that eliminates the influence of upstream flow characteristics is selected.

The width between banks will greatly govern the size of the installation, the excavation necessary, and the type of station; that is, a simple cutoff wall is usually needed if the streambed is narrow, but a more elaborate structure is generally needed if it is wide.

The depth of channel and width between banks at the site approach will partly determine whether the site is suitable for funneling all flow through the gaging station during peak runoff periods.

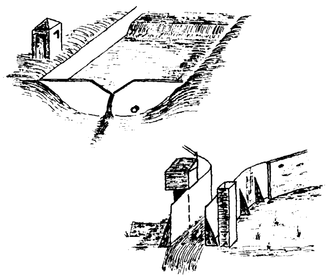
V-shaped stream channels of impermeable subsoil or bedrock are very desirable for stream-gaging sites because low flows may be easily led from the confining natural channel through the measuring device, and construction of the gaging station may be less costly. Where such ideal stream channels may not exist—for example, in glaciated terrain—compromises in site selection will be necessary.

Determining the drainage area above the gaging station is often a problem. The topography and drainage characteristics in the vicinity of a proposed site, such as the presence of springs, should be studied. Often, selecting a site a short distance upstream or downstream may permit a better determination of watershed boundaries.

In selecting gaging sites, consideration should be given to the gaging-station design most suitable for that site. However, modifications of standard stream-gaging designs may be needed to fit local site conditions.

Inspection of the stream during extremely low flow will often indicate the reaches where flow is restricted to the surface because of soil or geologic conditions and those where flow is below the surface. The stream should be inspected during high-flow periods to estimate maximum discharge and to see if the banks at the site can carry the flow.

An additional consideration is accessibility. Gaging sites that meet the technical requirements may be impractical because of excessive traveltime to the site, difficulty of hauling in construction materials and equipment, lack of workspace, and inaccessibility in certain seasons.



Types of Stream-Gaging Stations

The basic components of a stream-gaging station are the control and the water-stage recorder. The control and the volume of flow determine the elevation of the water surface at the recorder location. The relation between height of the water at the gaging point and rate of flow over the control is called the stage-discharge relationship or rating. Generally artificial controls are used for research on small watersheds, so only those controls will be considered in this handbook.

For most measurements, the control must be constructed so that nearly all outflow from the watershed goes over it; flow under it or around it will escape measurement.

The most common types of stream-gaging stations are weirs and flumes. With weirs, water is ponded above the control, and changes in the elevation are related to discharge. Weirs have often been preferred for gaging of small watersheds. The weir, when properly set and maintained, is considered one of the most accurate means of measuring flowing water (Parshall 1950). Where heavy sediment-laden flows are common, particularly as bedload movement, flumes should be used; a flume is a stabilized channel (without an impoundment) with access to a stilling well. Flumes also must be used where the gradient of the stream is particularly low.

The various objectives for which stream-gaging stations have been built, and the related conditions, have resulted in many different types of weirs and flumes.

Weirs or flumes are constructed of various materials. Concrete, because of its strength and permanence, probably is used the most. Treated wood, concrete blocks, metal, and many other materials are also used. The weir notch is often a steel blade set into concrete, and flumes are often lined with steel for permanence.

WEIRS

Weir may denote a notch of regular form (rectangular, triangular, trapezoidal, circular, or parabolic) through which water flows, or it may mean the structure containing the notch. As used in this handbook, *weir* includes all components of a stream-gaging station that incorporates a notch control.

An impoundment of water (the weir basin) is formed upstream from the wall or dam containing the notch. A stilling well with water-level recorder is connected to the weir basin. A gagehouse or some other type of shelter is provided to protect the recorder.

The cutoff wall or dam is used to divert through the notch all water (above or below the streambed) moving down the channel. Where possible, the cutoff wall is tied into bedrock or other impermeable material so that no water can flow under or around it. But where leakage is apt to occur the weir basin is sometimes constructed as a watertight box (see p. 15).

The edge or surface over which the water flows is called the *crest*. Weirs can be either sharp crested or broad crested. **A sharp-crested weir** has a blade with a sharp upstream edge so that the passing water touches only a thin edge and springs clear of the rest of the crest. The blades of the 90° and 120° V-notch weirs installed by the authors are of ¼-inch angle iron or ⅜-inch steelplate ground to a sharp edge at a 45-degree-angle.

A **broad-crested weir** has a flat or broad surface over which the discharge flows. There is a large variety of broad-crested weirs. Some have sharp right-angle corners with vertical sides and horizontal crests; some have rounded corners; some have sloping crests; and some have rectangular, triangular, or trapezoidal cross sections. Broad-crested weirs are generally used where sensitivity to low flows is not critical and where sharp crests would be dulled or damaged by sediment or debris. A broad-crested weir is shown in figure 1. Tracy (1957) discusses discharge characteristics of broad-crested weirs.

The sheet of water flowing over the weir is the *nappe*. The weir has free discharge if the nappe discharges into the air: air circulates freely on all sides of the flow issuing from the weir notch. Adherence of the nappe to the weir blade or cutoff wall can cause an appreciable increase in the rate of flow for a given head (Thomas 1957). If the

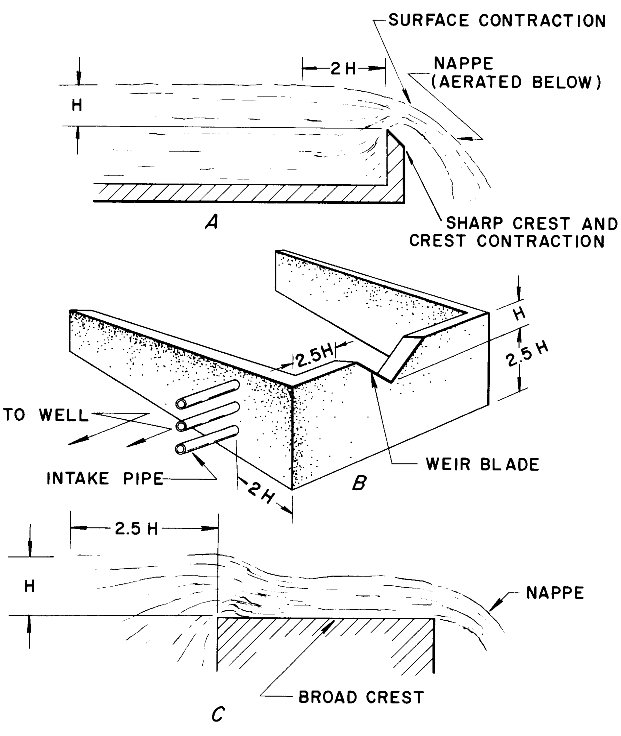


FIGURE 1.—Schematic diagrams of general hydraulic relationships for weirs, based on King (1954): *A*, Flow characteristics over a sharp-crested weir; H is the depth of water producing the discharge; *B*, minimum requirements for proper discharge when H equals greatest expected depth for a sharp-crested V-notch weir with end and crest contractions; *C*, flow characteristics over a broad-crested weir of rectangular cross section.

discharge is partially underwater, the weir is submerged or drowned (King 1954). This happens if there is insufficient fall below the weir crest or when the channel below the weir cannot carry the flow off rapidly enough. Submerged flow is at best relatively unstable, and measurements made by a submerged weir should be considered approximate only (Thomas 1957). When positioning the notch during construction, consideration should be given to maximum expected flows and likelihood of submergence.

As the nappe flows through the notch, the velocity of flow increases, and the nappe cross section is reduced or contracted. This contraction is affected by the shape of the notch and basin characteristics immediately upstream from the notch.

Where the depth of water from the crest to the basin floor is less than 2.5 times the head of water over the crest, the crest contraction of the nappe is partially suppressed. Velocity of approach will increase, and actual discharge will be greater than that shown by the normally used formulas and tables (fig. 1).

If the basin is the same width as the crest, the weir has its end contractions suppressed. For complete end contractions, the distance from the edge of the notch to the side of the weir basin or channel should be at least 2.5 times the head being measured (King 1954). A narrower weir basin or channel results in increased velocity of approach and increased flow for a given head.

For best results, the velocity of approach should be held to a maximum of 0.5 foot per second (Thomas 1957). Where velocities of approach are appreciable, the discharge should be corrected (U.S. Bureau of Reclamation 1953).

Water discharging over the crest of a weir drops slightly in elevation immediately upstream from the crest. This decrease is caused by the water's acceleration in velocity as it approaches the crest. Such a drop is called surface contraction or drop-down. In sharp-crested weirs the effect of this surface contraction extends upstream from the crest a distance twice the head of water flowing over the crest (King 1954). Therefore, the intake to the stilling well should be located upstream from the crest a distance equal to or greater than twice the head of the maximum anticipated flow (fig. 1).

Fully contracted weirs are generally preferred in research; however, site characteristics sometimes dictate suppression of end contractions.

These factors are particularly important if laboratory determinations of the stage-discharge relationship are to be used. A discussion of the conditions of flow over a weir can be found in King's *Handbook of Hydraulics* (1954).

The **rectangular weir** has vertical sides and a horizontal crest (fig. 2). Its height and width can be varied considerably, depending on the anticipated flow. The ratio of height to width is usually about 1:3 or 1:4. Its major advantage is its capacity to handle large flows. However, the rectangular weir cannot provide for precise measurement of the low flows of small experimental watersheds—a small increase in head will give a greatly increased discharge. Therefore, small errors in measurement of head produce relatively large errors in discharge.

An example of a broad-crested rectangular weir is the Trenton type of control, developed by the U.S. Geological Survey (Corbett and others 1943).

The **trapezoidal weir** is similar to the rectangular weir. Its sides, of course, are inclined from the vertical (fig. 3). It has a larger capacity than a rectangular weir of the same crest length; the discharge is approximately the sum of discharges from the rectangular and triangular sections.

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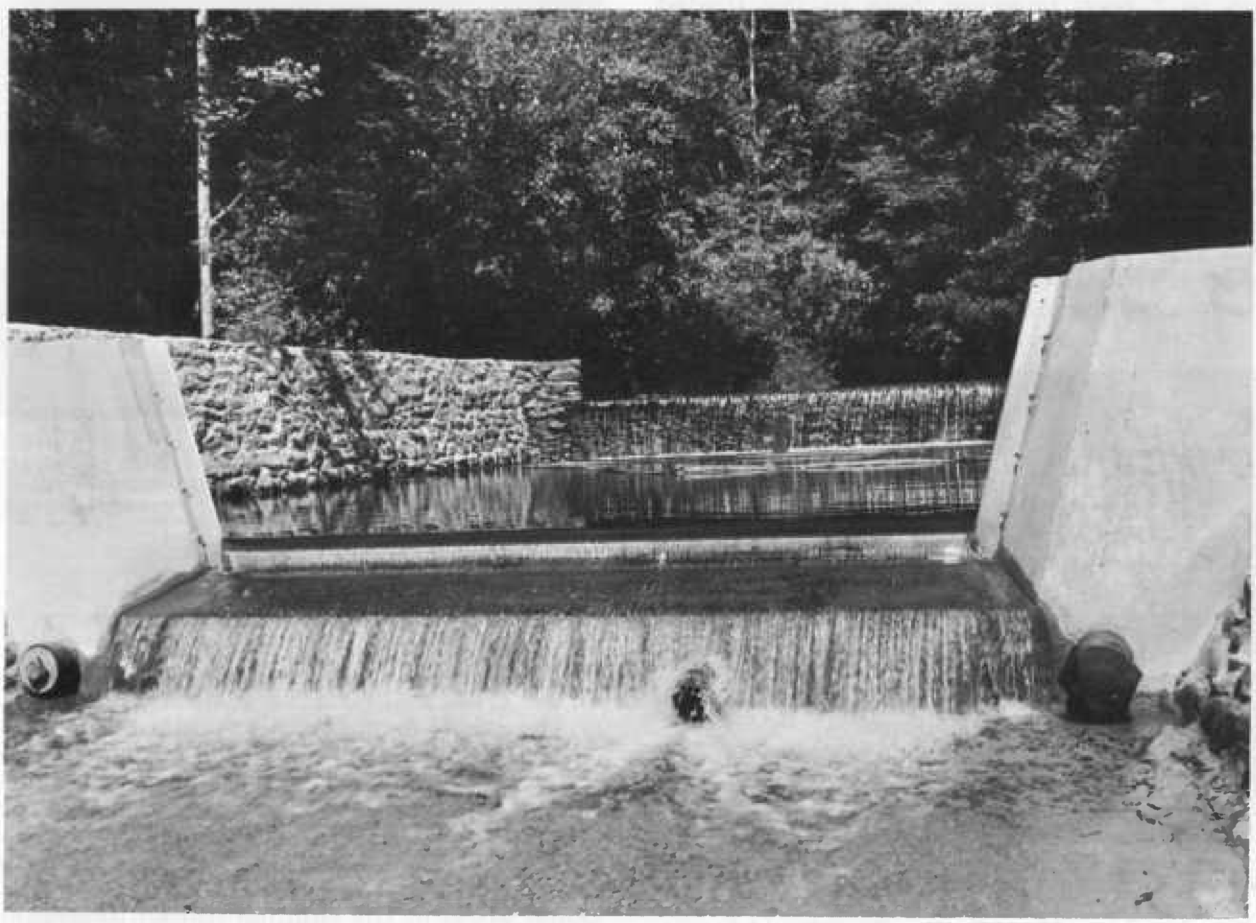
FIGURE 2.—A 6-foot rectangular weir with angle-iron knife-edge blade is used on watersheds where flow ranges from 0.70 to 90 cubic feet per second. Coweeta Hydrologic Laboratory, Franklin, N.C.



F-469733

FIGURE 3.—An 8-foot Cipolletti trapezoidal weir with knife-edge blade is used on watersheds of approximately 2,000 acres. Coweeta Hydrologic Laboratory, Franklin, N.C.

The Cipolletti weir is a special trapezoidal weir that does not require a correction for end contractions. Sides are sloped one unit away from the vertical for each four units of rise. The flow (with end contractions) is about equal to the flow of a rectangular weir of equal crest length that has a channel width the same as the crest (weir with end contractions suppressed).

Sharp-crested V-notch or **triangular** weirs are often used where accurate measurements of low flows are important. In the V-notch weir, a small increase in flow during low flow will produce a relatively large increase in head and a good sensitivity of measurement. A V-notch weir may have a rectangular section above to accommodate infrequent high flows.

The two most common sharp-crested V-notch weirs are the 90° notch (fig. 4) and the 120° notch (fig. 5), with metal blades ground to a sharp edge and built into a concrete cutoff wall. The 90° type gives greater sensitivity at low flows; the 120° type covers a wider range of flows. V-notch weirs are usually constructed to accommodate heads up to 2 feet; however, both in the United States and elsewhere V-notch weirs capable of handling gage heights in excess of 2 feet are in use.

Broad-crested triangular weirs with 2:1, 3:1, and 5:1 (fig. 6) side slopes (with notches approximately 127°, 143°, and 157°, respectively) were developed and rated by the Soil Conservation Service for measuring flows up to about 1,000 c.f.s. (Harrold and Krimgold 1943). The shape and thickness of the crest permits comparatively free passage of debris and minimizes the effect on the stage-discharge relationship of small irregularities of the crest and of trash temporarily lodged on the crest. A reasonably straight and practically level channel for 50 feet above the weir, with the notch 6 inches above the bottom of the approach channel, is essential for accuracy. Rating tables have been developed which give discharges corresponding to heads up to 6 feet and also for cross-sectional areas of the channel 10 feet upstream from the center of the crest (U.S. Agricultural Research Service 1962).

F-503131

FIGURE 5.—A 120° V-notch weir similar to the 90° V-notch weir, but capable of handling flows almost twice as large. This 2-foot-high notch has a capacity of about 24 c.f.s. Fernow Experimental Forest, Parsons, W. Va.

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FIGURE 6.—A triangular weir with 5:1 side slopes, recorder shelter, and stilling well on the 330-acre watershed operated by the Agricultural Research Service near Fennimore, Wis.

F-503137

FIGURE 4.—A 90° V-notch weir with sharp-edge blade is designed for great sensitivity at low flows. It is used on watersheds of 5 to 50 acres. The 2-foot-high notch has a capacity of about 14 c.f.s. Hubbard Brook Experimental Forest, West Thornton, N.H.

The **Columbus deep-notch weir** has a parabolic notch and is designed to give accurate measurement of a wide range of flows. The notch, often lined with bronze for permanence, accommodates low flows; a larger, nearly rectangular section, with crest sloping very gently toward the notch, accommodates high flows. The throat of the notch is convex (along the axis of flow) to permit passage of debris. A modified Columbus deep-notch weir, with shortened sloping crest and a rectangular section directly above, is in use in several U.S. Forest Service installations (fig. 7).

F-469491

FIGURE 7.—A modified Columbus deep-notch weir with a bronze liner in the notch is used for a wide range of flows, especially where extreme sensitivity at low flows is required. Coweeta Hydrologic Laboratory, Franklin, N.C.

In one modification (fig. 8), the Trenton weir is converted from rectangular to triangular by constructing it with slopes upward away from the center at a rate of 1:10 (notch is approximately 169°). It may have vertical wingwalls at the side to accommodate high flows.

PENN STATE UNIVERSITY PHOTO

FIGURE 8.—Trenton weir above a 90° V-notch. The slope above the notch has a ratio of 1:10. Leading Ridge Watershed near State College, Pa. A Pennsylvania State University School of Forestry photo.

Economical stream gages using weir principles are sometimes placed in existing structures such as highway culverts and bridges. Examples of these are the Villemonte weir sill and the Virginia V-notch weir (U.S. Agricultural Research Service 1962).

Abbreviated rating tables for several types of weirs are given in table 1. Because all necessary conditions of flow are not detailed, this table should be used only for comparison of weir types and not for determining actual flows.

TABLE 1.—*Comparative discharges for several types of weirs at various heads, in cubic feet per second*

Head (feet)	Rectangular (sharp-crested); crest length, 1 foot[1]	Cipolletti (sharp-crested trapezoidal); crest length, 1 foot[2]	V-notch (sharp-crested)		Triangular (broad-crested); side slopes of—			Columbus deep notch (broad-crested)[6]	Trenton (broad-crested rectangular); discharge per foot of length[7]
			90°[3]	120°[4]	2:1[5]	3:1[5]	5:1[5]		
0.1	0.113	0.107	0.008	0.016	0.017	0.025	0.037	0.026	0.079
.2	.314	.301	.047	.086	.094	.132	.215	.055	.245
.3	.569	.553	.129	.232	.252	.364	.590	.085	.470
.4	.868	.852	.262	.470	.514	.757	1.23	.145	.752
.5	1.206	1.190	.455	.811	.903	1.35	2.15	.280	1.080
.6	1.576	1.565	.714	1.268	1.44	2.16	3.45	.530	1.450
.7	1.977	1.972	1.044	1.850	2.16	3.21	5.18	.935	1.87
.8	2.406	2.409	1.452	2.565	....	....	....	1.54	2.32
.9	2.861	2.875	1.943	3.423	....	....	....	2.49	2.80
1.0	3.340	3.367	2.520	4.430	....	....	....	3.89	3.31
2.0	9.252	9.522	13.96	24.19	....	....	....	62.30	10.15

[1] By Formula: $Q=3.34H^{1.47}$ (King 1954).
[2] By Formula: $Q=3.367\ LH^{3/2}$ (King 1954).
[3] By Formula: $Q=2.52H^{2.47}$ (King 1954).
[4] By Formula: $Q=4.43H^{2.449}$ (Hertzler 1938).
[5] (Harrold and Krimgold 1943).
[6] Northeastern Forest Experimental Station files; rating made by U.S. Geological Survey.
[7] Rating table furnished by U.S. Geological Survey, Trenton, N.J.
Note: In these formulas, Q is discharge in c.f.s., H is head in feet, and L is length of crest in feet.

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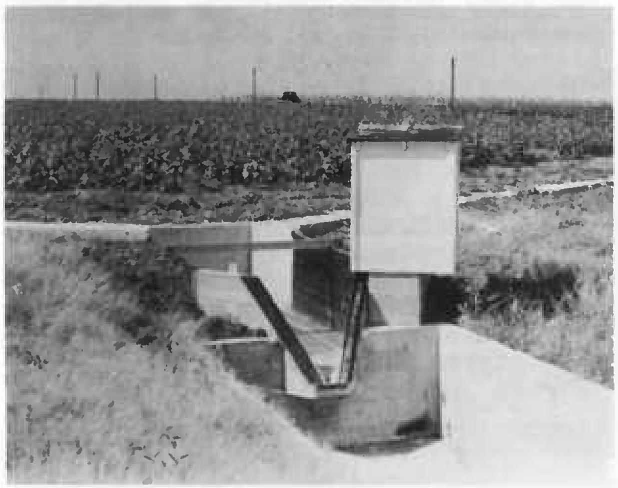
FLUMES

A flume is an artificial open channel built to contain flow within a designed cross-section and length. The types of flumes that have been used on small watersheds are described here.

HS, H, and HL flumes developed and rated by the Soil Conservation Service have converging vertical sidewalls cut back on a slope at the outlet to give them a trapezoidal projection (Harrold and Krimgold 1943) (fig. 9). These have been used largely to measure intermittent runoff. Maximum depths of waterflow are 1 foot for the HS type, 4.5 feet for the H type, and 4 feet for the HL type. Maximum flows are 0.8, 84, and 117 c.f.s., respectively. These flumes are in use at many Agricultural Research Service installations (U.S. Agricultural Research Service 1962) and a number of other locations. The above-cited publications give details of construction and ratings for these flumes.



ARS-20315

FIGURE 9.—An H-type flume. View looking upstream at flume and recorder house on small watershed operated by Agricultural Research Service near Riesel, Tex.

The **Venturi flume** (fig. 10) has a gradually contracting section leading to a constricted throat and an expanding section immediately downstream (King 1954; Parshall and Rowher 1921). The floor of the Venturi flume is the same grade as the stream channel, whereas that of the Parshall flume (described below) is depressed in the throat section. Stilling wells for measuring the head are at the entrance and at the throat; the difference in head at the two wells is related to discharge. Venturi flumes are rectangular, trapezoidal, triangular, or any other regular shape. They are widely used in measurement of irrigation water.

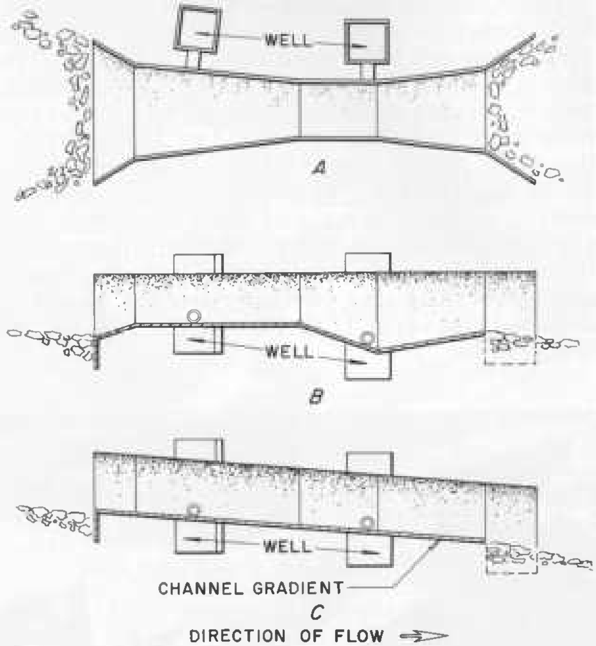


FIGURE 10.—Schematic diagram of Venturi flume. It requires measurement of stage at two points. Floor is same grade as stream channel: *A*, Plan view of Venturi flume; *B*, cross section of Parshall flume; *C*, cross section of Venturi flume.

The **Parshall flume**, a modification of the Venturi flume, measures water in open conduits and is widely used, especially for measuring irrigation water (Parshall 1950). It consists essentially of a contracting inlet, a parallel-sided throat, and an expanding outlet, all of which have vertical sidewalls. It can measure flows under submerged conditions. Two water-level recorders are used when measuring submerged flow, one in the sidewall of the contracting inlet and the other slightly upstream from the lowest point of the flow in the throat. When measuring free flow, only the upper measuring point is used.

An inexpensive **trapezoidal flume** for gaging hard-to-reach locations in mountain streams (fig. 11) was developed for the Rocky Mountain Forest and Range Experiment Station (Goodell 1950; Robinson 1960). This flume could be rated with a velocity head rod (Wilm and Storey 1944).

The **San Dimas flume** (figs. 12–14) was designed on the San Dimas Experimental Forest of the U.S. Forest Service to measure debris-laden flows in mountain streams (Wilm et al. 1938). It is rectangular and has a sloping floor (3-percent gradient) that functions as a broad-crested weir except that the contraction is from the sides rather than the bottom; therefore, there is no barrier to cause sediment deposition. Depth measurements are made in the parallel-walled section at about the midpoint. Rapid flow keeps the flume scoured clean.

F-504455

FIGURE 11.—Trapezoidal flume used to gage streamflow of Upper Fool Creek, Fraser Experimental Forest, Fraser, Colo. The man in the picture is holding a velocity head rod that has been used to rate this flume.

F-504454

FIGURE 13.—A 1-foot San Dimas flume (on left) and broad-crested weir used to gage streamflow of Fool Creek, Fraser Experimental Forest, Fraser, Colo.

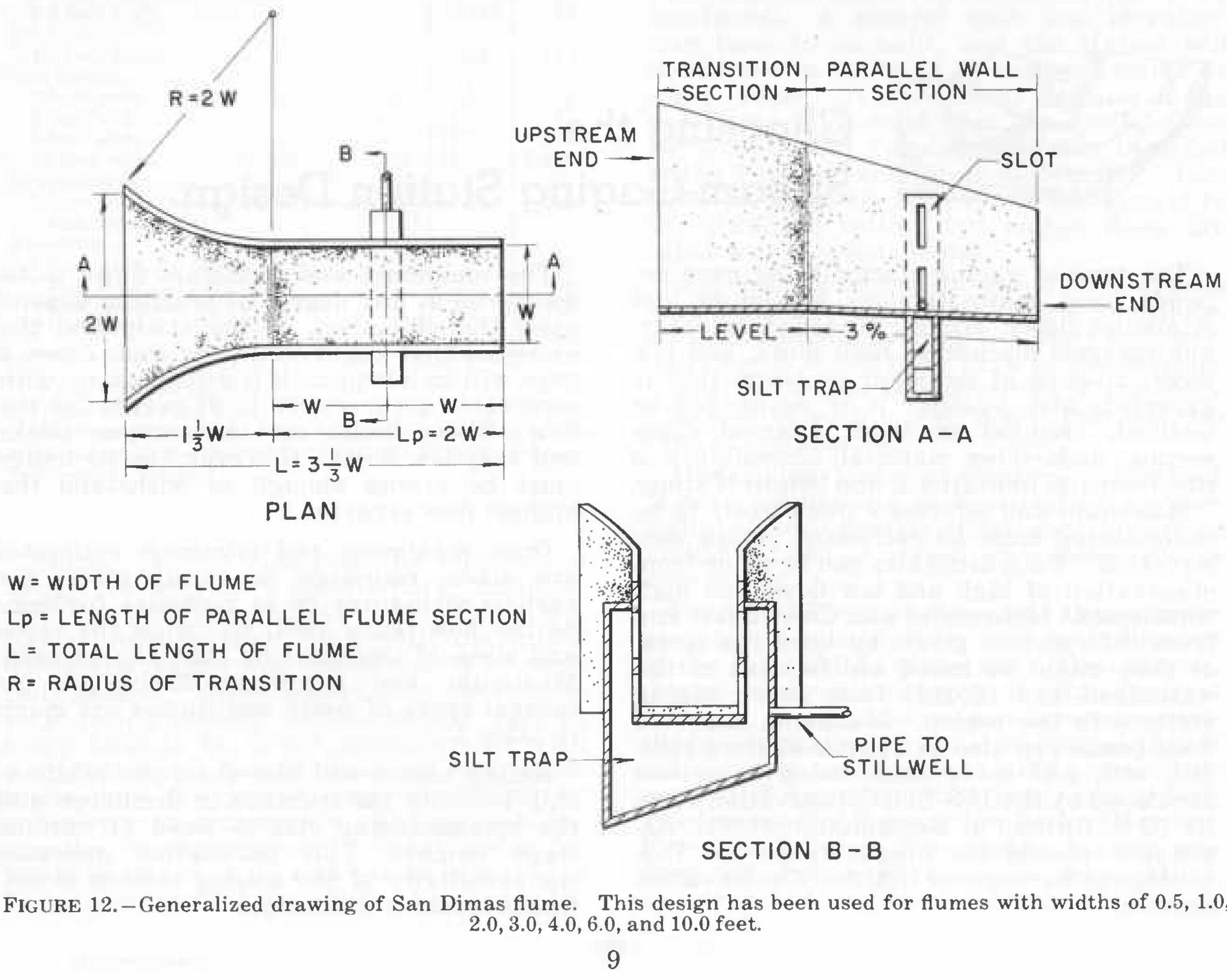
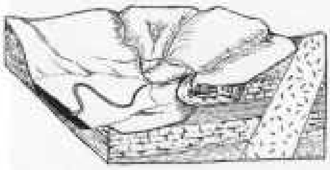


FIGURE 12.—Generalized drawing of San Dimas flume. This design has been used for flumes with widths of 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 10.0 feet.

F-412245

FIGURE 14.—A 3-foot San Dimas flume in lower center. Note larger 10-foot-wide flume upstream and 90° V-notch weir to left. The 3-foot flume can accommodate flows up to 77 cubic feet per second, whereas the 10-foot flume can handle flows to 1,000 cubic feet per second. San Dimas Experimental Forest, Glendora, Calif.

The types of weirs and flumes that have been discussed are those most used in research. In some cases, structures have been built to incorporate features of more than one type; for example, a 90° V-notch recently built into a Trenton-type weir at The Pennsylvania State University. When a wide range in flow or sediment load is anticipated, it may be advantageous to install more than one device at the same site. On several watersheds at the San Dimas Experimental Forest in California, stormflows are measured with a 3-foot San Dimas flume and low flows are diverted to a 90° V-notch weir (fig. 14). A somewhat similar arrangement was constructed for several watersheds on the Hubbard Brook Experimental Forest in New Hampshire. On the Sierra Ancha Experimental Watersheds in Arizona, a 90° V-notch weir for low flows and a Cipolletti weir for high flows are in use.



Choosing the Stream-Gaging Station Design

The type of gaging station to be used depends upon many factors: Maximum and minimum flows; accuracy needed in determining total discharge, high flows, and low flows; amount of sediment or debris that is expected, and whether it is suspended or bedload; channel gradient; channel cross section; underlying material; accessibility of site; financial limitations; and length of study.

Maximum and minimum flows likely to be encountered must be estimated before construction. Such estimates can be made from observation of high and low flows and high watermarks (Johnstone and Cross 1949) and from information given by local residents, or they might be based on the area of the watershed and records from other gaging stations in the region. Maximum expected flood peaks can also be estimated from rainfall, soil, and cover data, using a method developed by the U.S. Soil Conservation Service (U.S. Bureau of Reclamation 1960). Assistance should be sought from the U.S. Geological Survey and U.S. Soil Conservation Service.

The maximum and minimum flows to be measured at any degree of precision depend upon the objectives of the study and the extremes that might occur. In some cases, a gage will be adequate if it will measure, with acceptable accuracy, 90 to 95 percent of the flow. These limits exclude extreme peaks and very low flows. However, the structure must be strong enough to withstand the highest flow expected.

Once maximum and minimum estimates are made, reference to rating tables for various structures or to formulas for computing flow (King 1954) will show the types and sizes of installations that can be used. Maximum and minimum discharges for several types of weirs and flumes are given in table 2.

Rating tables will also show the relationship between the increase in discharge and the corresponding rise in head at various stage heights. This association indicates the sensitivity of the gaging station at different levels of discharge.

TABLE 2.—*Maximum and minimum discharges for several types of weirs and flumes in cubic feet per second (approximate)*

WEIRS

Type	Minimum	Maximum
Sharp-crested weirs:		
2 feet high, 90° V-notch	<0.001	14
2 feet high, 120° V-notch	<.001	24
2 feet high, 6 feet wide rectangular	[1] .24	56
2.75 feet high, 8 feet wide Cipolletti	[1] .30	123
4 feet high, 12 feet wide Cipolletti	[1] .46	323
Broad-crested weirs:		
Triangular 2:1 side slopes	[2] .017	[3] 510
Triangular 3:1 side slopes	[2] .025	[3] 803
Triangular 5:1 side slopes	[2] .037	[3] 1,440
2 feet high Columbus deep notch	.026	62

FLUMES

Type	Minimum	Maximum
HS type:		
0.4 foot high	[1] 0.001	0.1
1.0 foot high	[1] .002	.8
H type:		
1.0 foot high	[1] .004	2
2.0 feet high	[1] .007	11
4.5 feet high	[1] .015	84
HL type:		
4.0 feet high	[1] .03	117
San Dimas:		
1 foot wide	.1	6
3 feet wide	2	77
6 feet wide	10	318
10 feet wide	36	1,000
Trapezoidal:		
1-foot-wide throat, 4 feet high, 30° side slopes.	[1] .15	350
Parshall:		
1 foot wide, 2.5 feet high	.4	16
2 feet wide, 2.5 feet high	.7	33
4 feet wide, 2.5 feet high	1.3	68
8 feet wide, 2.5 feet high.	4.6	140

[1] Flow at 0.05-foot head.
[2] Flow at 0.1-foot head.
[3] Flow at 6-foot head with cross-sectional area of 300 square feet in the channel of approach 10 feet upstream from center of crest.

Rating can be simplified by choosing a design for which a stage-discharge relationship has been determined in the laboratory. Before construction, the conditions under which the design was tested should be carefully studied. After construction, the laboratory rating should be checked at various stage heights by direct measurement with a current meter, velocity head rod, or another instrument for determining velocity, or by volumetric measurements. Rating-table discharges of sharp-crested V-notch weirs for heads of less than 0.2 foot can be expected to be inaccurate (Thomas 1957). For heads below 0.2 foot, the weir can be rated in the field, as will be described later.

If a design is used for which a rating has not been determined, the installation is rated by making measurements at various stages, using a current meter (Pierce 1941a; Corbett and others 1943) or other means. Peak flows may be difficult to measure.

Where excessive amounts of suspended sediment, bedload, and floating debris are encountered, flumes are preferable. Weirs would be unsatisfactory because the basin would trap this material, which would alter the weir rating, and debris would clog the crest of the weir, giving grossly inaccurate measurements. Broad-crested weirs are often used on agricultural watersheds where grass and other debris would lodge on a sharp-crested weir and invalidate the rating curve (U.S. Agricultural Research Service 1962).

The gradient of the stream channel may affect choice of design. If the gradient is too low, it may be impossible to install a weir that will meet the requirements of a standard rating (depth of water below crest equal to at least 2.5 times the maximum head to be measured). A control with less elevation may have to be built, and the station will then have to be rated by current meter or other means. It was largely because of the low channel gradient that the combination 90° V-notch and Trenton weir was installed at the Pennsylvania State University. Low flows through the 90° V-notch correspond to the standard rating, but higher flows are rated with a pygmy meter.

The channel cross section and streambanks may dictate design. Under some conditions, a cutoff wall high enough to satisfy rating requirements would have to be of considerable length to tie into solid material at the sides. The cost of such a wall might rule out this type of installation.

Underlying material must be considered. If permeability is a problem, either a watertight-box weir design, which can support an artificial head of water, or a flume will be necessary.

The type of weir or flume and the material used in its construction may be influenced by the accessibility of the site. For example, though ready-mix concrete is often the best material, it cannot be used on forested watersheds where the terrain is so rugged that it would not be practicable to build access roads capable of accommodating ready-mix trucks. The trapezoidal flume of the Rocky Mountain Forest and Range Experiment Station was designed for sites of poor accessibility, some reached only by packhorse.

Length of study and financial limitations influence the choice of construction materials. For a long-term study, concrete is best. It should be of the best grade in order to prevent leakage, reduce erosion, and insure maximum strength. Weir crests of concrete may be eroded, with resultant change in rating. Crest erosion may be excessive where water is especially acid – a notch of brass or some other noncorrosive material should be installed. Concrete blocks were used in recent weir construction by personnel of the Rocky Mountain Forest and Range Experiment Station and on the Baltimore City Watershed in Maryland.

Wood, preferably treated for decay resistance, is often used for economy in structures that will be in service for a limited time (Whipkey 1961). The H-type flumes, which have been described, are constructed of sheet brass or galvanized iron.

A satisfactory but inexpensive weir-basin liner of 8-mil black vinyl plastic has been used at experimental watersheds in Baltimore, Md. The liner was placed inside a weir box 10 feet wide and 20 feet long built of 2-inch oak planks. A V-notch blade was bolted, over the plastic, to the box. The vinyl was cemented to the box and plate with asphalt-asbestos roofing cement. Cost figures for this weir are given in the appendix.

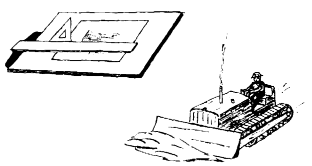
With weirs, sharp crests give greater accuracy than broad crests. Blades of sharp-crested weirs are constructed of angle iron or steelplate, ground to a sharp edge or to a flat edge one-sixteenth inch wide, and set into concrete cutoff walls or dams. Blades may be dented, bent, rusted, and clogged with debris. In many locations they must be screened to prevent clogging, and care should be exercised when working near them; some maintenance, such as annual painting, is required.

At the Coweeta Hydrologic Laboratory in North Carolina the following criteria were used in selecting weir designs: [3]

1. Sharp-crested weirs were used where sediment production would not exceed that from protected watersheds.
2. 90° V-notch weirs were used where discharge 95 percent of the time was expected to be 0.01 to 8 c.f.s.
3. 120° V-notch weirs were used where flow 95 percent of the time was expected to be between 0.10 and 20 c.f.s.
4. Rectangular and Cipolletti weirs were used where flows less than 2 c.f.s. would seldom occur and where there was frequent need to measure discharges greater than 30 c.f.s. Rectangular weirs less than 5 feet long are so restricted in the range of flows measured as compared with the 120° V-notch that they were never used.

Flumes are often satisfactory where weirs are impracticable. They can handle debris-laden flows better; even so, such flows may be difficult to measure. With flumes, velocity of approach is less of a problem than with weirs. There is less loss in head with flumes than with weirs; thus, they can be used in channels with low gradients; this is one of the main reasons why flumes are used in measurement of water for irrigation. And flumes, requiring no excavation for ponding, may be easier and cheaper to install.

[3] Personal correspondence with Marvin D. Hoover, June 6, 1961.



A Sharp-Crested 120° V-Notch Weir

A sharp-crested V-notch weir is excellent for measuring streamflow in small mountain streams. Under certain conditions, highly accurate measurements can be taken of both high and low flows. For example, a 2-foot-high 120° V-notch weir can be used to accurately measure flows approaching 25 c.f.s. and those 0.086 c.f.s. or less. This type of weir has been used since the 1930's at the Coweeta Hydrologic Laboratory of the U.S. Forest Service, where a stage-discharge formula was developed (Hertzler 1938). The formula is: $Q = 4.43\ H^{2.449}$, in which Q is the discharge in cubic feet per second and H is the head in feet (measured 6 feet upstream from the blade). The stilling basin of the weir on which this formula was determined was large enough to obtain a minimum side contraction 2.5 times the head, with a bottom contraction of 2.5 feet.

The following section presents the design and method for constructing a sharp-crested 120° V-notch weir 2 feet high. Detailed descriptions of other types of stream-gaging stations are not given. Except for their blade design, rectangular, trapezoidal, and Cipolletti weirs are similar in design and function to sharp-crested V-notch weirs. Sharp-crested 120° V-notch weirs are illustrated in figures 5 and 15.

F-503138

FIGURE 15.—A 2-foot, 120° V-notch weir with blade of 3/8-inch galvanized metal plate. Hubbard Brook Experimental Forest, West Thornton, N.H.

DESIGN

The simplest weir in design and construction consists of a watertight cutoff wall that spans the stream channel, creating a pond or stilling basin upstream. The ends and base of the cutoff wall are tied into bedrock or other impermeable material.

A tighter container is required where the channel bottom is permeable, where bedrock is cracked or irregular, or where the stream channel does not follow naturally worn V-shaped bedrock; such conditions are common in glaciated areas. Here a watertight box is required—a box that is open at the top and upstream end. The box may be equipped on the upstream end with wingwalls that extend into the sides of the streambank. These walls will funnel the streamflow into the box and thus serve in part as a cutoff wall. This design makes it possible to intercept all of the surface flow at the upstream edge of the box; the artificial head created to satisfy weir requirements does not result in increased leakage through a permeable channel bottom as it would with the simpler cutoff wall design.

Where the stream gradient is low and the geology permits, a four-sided box may be sunk in the stream channel. Streamflow enters the box by dropping down a vertical wall on the upstream side.

The three types of weir basins described here are shown in figure 16. All of them have a blade mounted in a notch on the downstream wall, drain and intake pipes, instrument shelter or gagehouse, and stilling well. The watertight box is more complicated, and construction is more costly than for the cutoff wall type.

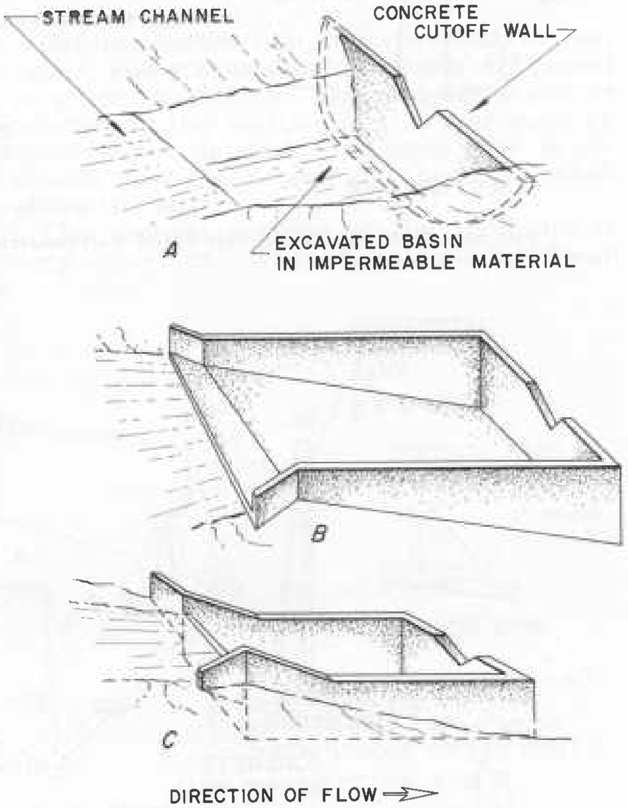


FIGURE 16.—Three types of weir basins: *A*, Weir basin formed by simple cutoff wall spanning stream channel; *B*, weir basin formed by watertight box with front wall, two sidewalls, and floor with open upstream end; *C*, weir basin formed by sunken watertight box with four sides and floor.

Cutoff Wall

A cutoff wall was constructed on the Fernow Experimental Forest, near Parsons, W. Va. The concrete wall was built across the stream channel, with its base firmly imbedded in the impermeable bedrock. Structural views of this cutoff wall are given in figure 17.

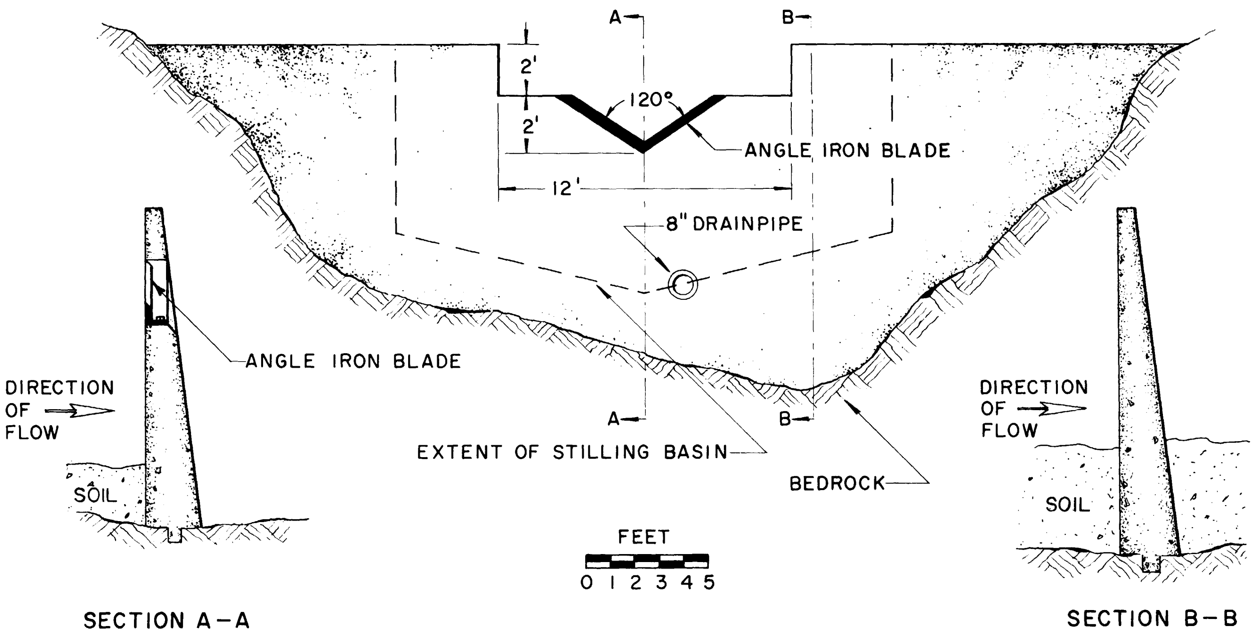


FIGURE 17.—Plans for concrete cutoff wall constructed at Fernow Experimental Forest, Parsons, W. Va.

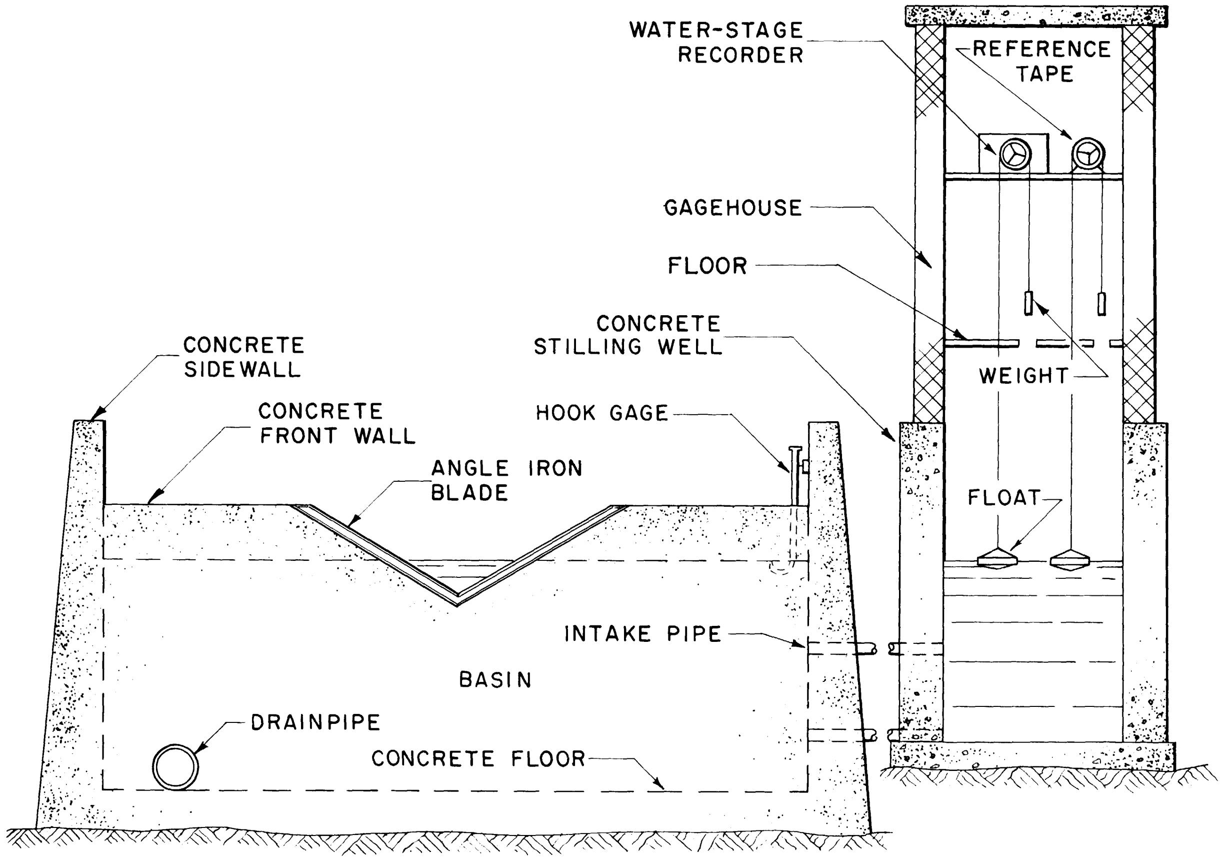


FIGURE 18.—Schematic diagram of 120° V-notch weir, watertight-box design.

The top of the cutoff wall is level with the top of the V-notch. At the streambanks, the cutoff wall projects 2 feet higher to provide a rectangular section above the V to accommodate flows that exceed the V-notch capacity. The width of this rectangular section is 12 feet.

Watertight Box

The watertight-box type is an elaboration of the cutoff-wall design. Instead of spanning the width between natural streambanks, the cutoff wall is joined on both ends by sidewalls (fig. 18). A concrete floor forms the bottom of the basin if the natural floor is permeable.

A watertight box was constructed at the Hubbard Brook Experimental Forest, West Thornton, N.H. Component parts are the same as in the cutoff-wall design; that is, a concrete front wall, two sidewalls (watertight concrete for the watertight box), blade, and drainpipe. A concrete foundation (poured first) served as a watertight floor and as a base for the walls. Plans are shown in figure 19.

The wall design (shape, thickness, foundation, reinforcement, concrete mix, etc.) for the cutoff wall or watertight-box design should be carefully chosen. Selection should be based on soil, bedrock, or impermeable material conditions, possible ice pressures, anticipated flood peaks, and other factors that might influence the reliability of the walls. Here again engineering advice should be sought.

CONSTRUCTION

Layout

Before construction, the site should be surveyed, and stakes should be carefully placed to guide operations. Channel alinement in relation to the position of the weir must be considered. Generally, straight flow is desirable through the weir and through a reach above the weir.

The vertical position of the structure is very important. Where the simple cutoff wall

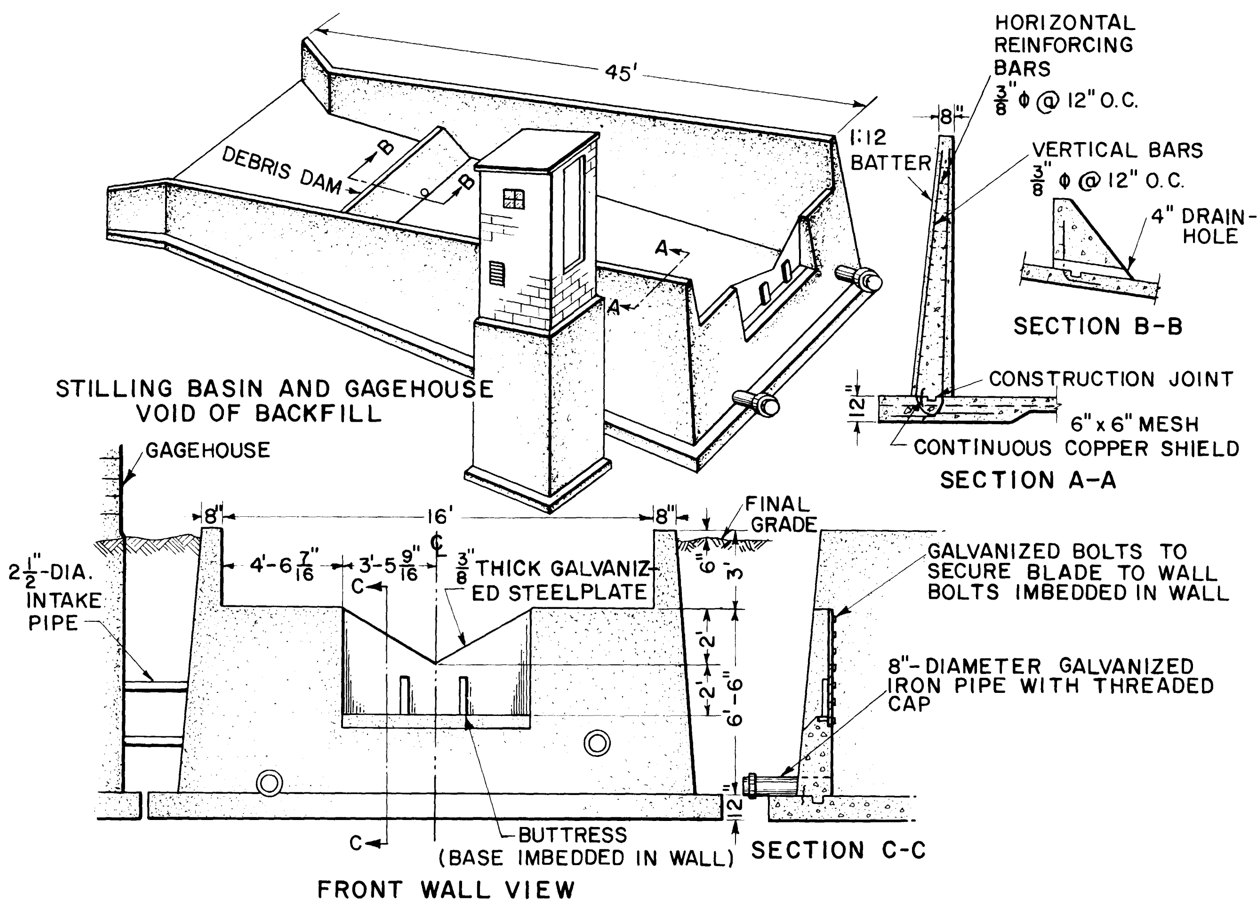


FIGURE 19.—Plans for concrete weir of watertight-box design constructed at Hubbard Brook Experimental Forest, West Thornton, N.H.

is used, one guideline is to maintain the original stream gradient above the weir basin. The vertex of the notch should ordinarily be at the elevation of the original streambed or somewhat lower. Thus, the impounded water will be contained in the basin and will not back up into the natural stream channel.

The dimensions of the basin must be determined and staked out. The width should be at least the width of the notch plus a distance on each side of the notch equal to 2.5 times the maximum head. Thus, for the 120° V-notch for an expected head of 2 feet, the width should be at least 17 feet.

Determining the length of the basin is often more difficult. One objective in operating a weir is to spread the flow evenly over the whole cross section at the upstream edge of the basin. Where this can be done, a short weir basin suffices. Generally, the flow does not enter uniformly even if efforts are made to spread it; therefore, the weir basin should be long enough to even out the flow before it reaches the stilling well intake pipes and the notch. Basins are often constructed 20 to 30 feet long for weirs with notches 2 feet high.

Where it is not feasible to dig a basin below the normal stream channel—for example, where hard bedrock forms the channel—the length of the basin will be governed by the slope of the stream channel. A channel with a gradient of one vertical unit to three horizontal units is almost ideal; it would require a basin about 25 feet long. If the stream gradient is very low, it may be impractical to use the watertight-box stream-gaging design because the length of the basin walls necessary to fulfill the hydraulic requirement would be prohibitive.

The recommended depth of the weir pond at the notch (at least 2.5 times the head below the vertex of the V), the stream gradient, and the material underlying the stream channel should also be considered in determining the length of the basin. In some cases, setting the elevation of the notch as previously described would require considerable excavation below the level of the streambed if the basin were short. One answer might be to lengthen the basin.

Besides consideration of the layout of the stream-gaging site, provision should be made for sufficient workspace around the site for workers, tools, equipment, and forms, and for unloading and storing materials. If concrete is to be used, the operation should be planned so that the materials and mixer or ready-mix trucks are above the highest point in the structure. This will ease the job of transporting the concrete to the forms.

Excavation

The first phase in the construction of a stream-gaging station is excavation. It is undertaken for one, two, or all three of the following reasons: (1) To reach impervious material to restrict water loss around the control; (2) to secure a firm foundation for the structure; and (3) to provide a pond in the channel above the control.

The type and size of the stream-gaging station and the characteristics of the soil and underlying strata will determine the dimensions of the excavation.

Unnecessary excavation should be avoided. Excavation increases the possibility of the streambanks becoming unstable and eroding. Also, unconsolidated fill material may permit seepage loss. The material removed in excavating should be piled away from the channel to prevent it from washing into the stream.

Excavation may be done by mechanical equipment such as a bulldozer, backhoe, or shovel. Handwork will be necessary to complete the operation where the bedrock is fissured or uneven, or where mechanized equipment cannot operate. In some cases dynamite may be used to blast trenches, remove uneven rock ledge, or make depressions for stilling basins. However, it should be used sparingly and carefully, for the explosions may shatter the bedrock or create cleavages that could result in serious leakage.

If a simple cutoff wall will be a satisfactory control, excavation will only involve the digging of a trench across the streambed and into the banks on both sides, and hollowing a cavity for a stilling basin.

Cutoff Wall

Because one of the prime functions of the cutoff wall is to force all water within the basin to flow over the control notch, the cutoff wall must make a watertight junction with underlying natural material.

If the wall is to rest on bedrock, the stability of the wall and watertightness of the wall-bedrock junction may be achieved in one of several ways. Keys, 1½ to 2 inches wide and deep, may be drilled in the bedrock (fig. 20). This key will add to the watertightness by creating a larger surface area at the joint; it will also secure the concrete wall to the bedrock, preventing sliding of the structure. Steel anchor pins, imbedded in both the rock ledge and the concrete wall, also secure the walls. Footings of poured concrete perhaps 3 feet wide may provide both stability and watertightness.

If the wall is to be built on tight subsoil, it may be well to cut trenches or keys. Care should be taken so cracks do not form and so

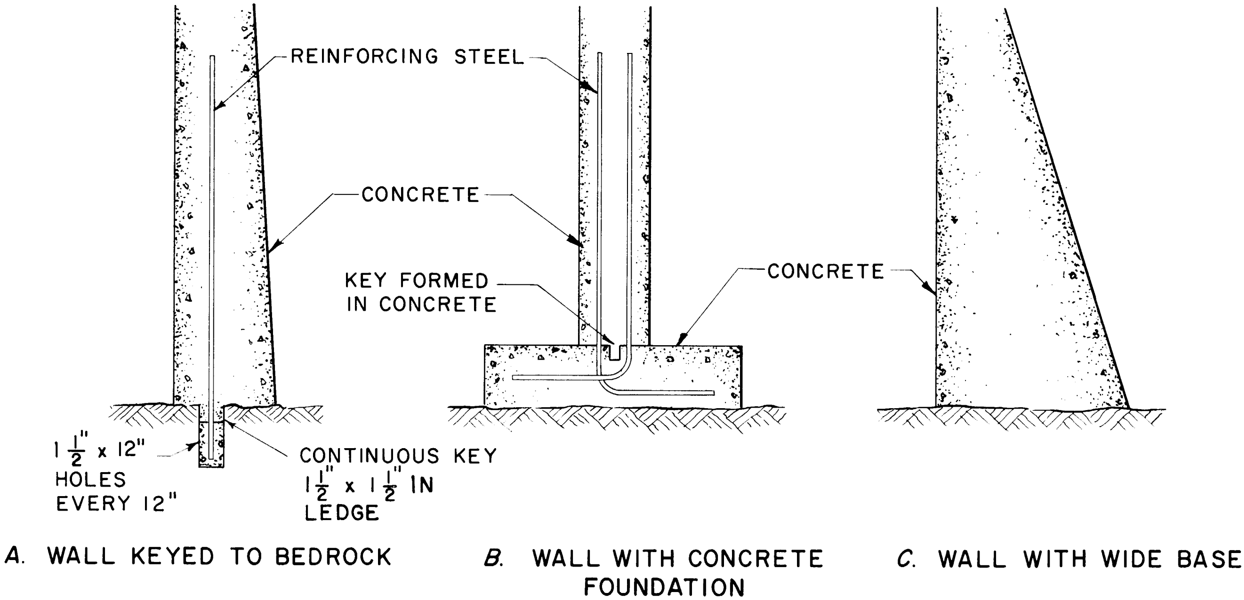


FIGURE 20.—Methods used to secure concrete walls to rock ledge.

the material is not shattered during excavation. With some subsoils, it may be advisable to pour a concrete footing considerably wider than the wall proper. The width of the footing depends on the bearing strength of the soil. Engineering advice should be sought if there is any question on this point.

A simple cutoff wall is not suitable where the substratum is permeable or where impermeable material does not form a confining channel; for example, an impermeable substratum may be present on one bank but may dip away from the other bank. Then a new site must be found, or a watertight weir box must be built on the one excavated.

Even though the weirs described in this report do not impound so much water that their failure would endanger life and property, the simple cutoff wall and the front or downstream wall in the watertight-box design must be built according to sound engineering principles. It is more practicable to provide a large safety factor than to determine precise strength requirements. Sliding, overturning, and uplift forces should be calculated. Engineering assistance may be needed. Forces affecting concrete gravity dams and requirements for stability are given in "Design of Small Dams" (U.S. Bureau of Reclamation 1960).

As noted in figures 17 and 19, the concrete cutoff wall and front wall have a vertical upstream face and a battered or gently sloping downstream face, which makes the wall thicker at the bottom than at the top. The battered wall is more stable than a vertical wall; it can withstand greater pressures resulting from high flows, ice pressure within the basin, or frost action from soil around the basin. The larger basal surface area in the battered wall also helps maintain a watertight joint. Slopes for the battered face may vary from 4 to 12 vertical units to 1 horizontal unit. The steeper slopes (such as 12:1) are recommended only when reinforced concrete is used.

Where freezing temperatures are persistent, reinforced concrete should be used. Reinforcing steel in concrete permits the use of considerably less concrete for equal strength and also lessens the possibility of wall cracks resulting from the expansion and contraction of the concrete with temperature changes. An example of the amount of reinforcing steel required for a 12:1 battered wall is given in figure 19.

Upstream and downstream forms are needed for constructing the walls. Form material usually consists of horizontal sheathing (1-inch tongue-and-groove boards or ¾-inch plywood) with vertical 2- by 4-inch studs for support. The vertical studs should be spaced 12 inches on centers. If tongue-and-groove boards are used, they should be fastened to the 2- by 4-inch studs with a single six-penny nail at each stud. Figures 21, 22, and 23 illustrate one method of form construction.

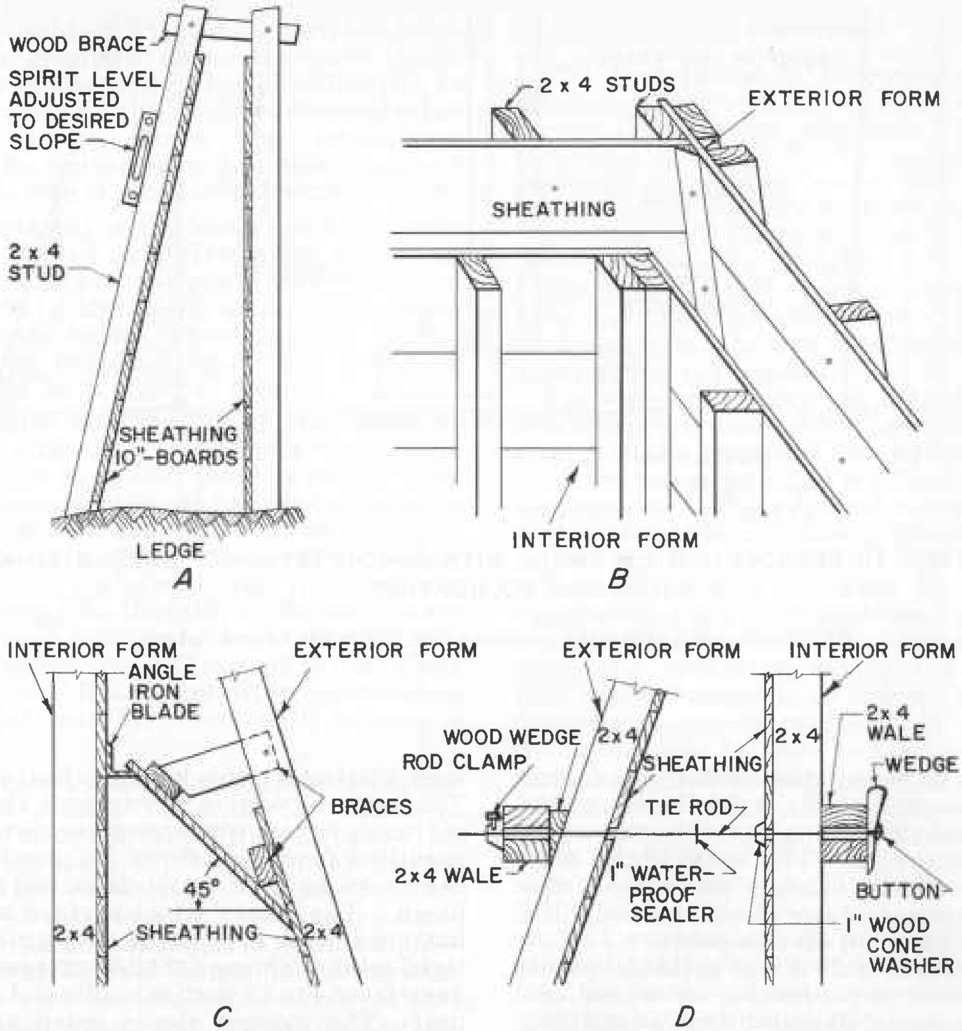


FIGURE 21.—Plans for constucting forms for concrete walls for weir at Hubbard Brook Experimental Forest, West Thornton, N.H.: *A*, cross section of wall forms; *B*, top view of corner arrangement of wall forms; *C*, cross section of wall at the sloping section where blade is attached; *D*, details of tie-rod arrangement for bracing wall forms.

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FIGURE 22.—Downstream view of forms for concrete basin walls. Most of the interior form is complete. Note vertical iron reinforcing rods in place, exposed bedrock foundation, and flaring upstream wingwalls. Weir constructed at Hubbard Brook Experimental Forest, West Thornton, N.H.

F-503140

FIGURE 23.—Front corner view of weir shown in figure 22. Interior form is complete, and exterior form is almost complete. Note position of blade, reinforcing iron, tie rods passing between both forms, and horizontal wales for bracing.

Although plywood is commonly used for sheathing in the building trades (because it can be used repeatedly), matched boards are generally preferred for weir construction because they can be more easily fitted to the rough surface upon which the structure will rest. A poured concrete footing will eliminate much of the rough surface and speed up form construction; bolts placed in the concrete can be used to anchor the forms.

Because a tremendous amount of pressure develops against the forms when the concrete is poured, the forms should be rigidly braced to prevent their shifting out of position.

Several methods may be used to keep the forms separated and braced. Wire (No. 9, A.W.G.) may be strung and tied between the two forms at 2-foot intervals, both horizontally and vertically. Tie rods (¼-inch steel rods and fittings) can keep the forms properly separated and can reduce considerably the additional bracing needed. Where small sections of wall are involved, the separate walls may be braced independently of each other by external wood braces. If wires or tie rods are used, they should pass through the entire form and be tightly secured at each end to horizontally placed braces or wales set perpendicular to the vertical studs. To be effective the wales should span four or more studs, and wale junctions should overlap two studs. Figures 21, 22, and 23 illustrate a method of bracing forms with tie rods.

In constructing the forms, provision should be made for placement of the weir blade and drainpipes.

The weir blade or a template of it should be mounted temporarily in its proper location on the wall forms. Bolts that will ultimately hold the blade in place should be positioned and secured to the forms so that they will not move during the concrete pouring. This may be done by inserting them through accommodating holes in the template or blade and by wiring them to the forms.

Where angle iron is used for the weir blade, the portion of the concrete directly below the V should be sloped sufficiently to prevent obstruction of the free-falling water. Construction of forms for these sloping walls requires considerable time and effort.

Building the forms requires some skill and careful planning. No attempt will be made to discuss all construction details; however, figures 21, 22, and 23 illustrate some of the techniques. To maintain the same slope for all battered surfaces, a carpenter's level should be used – one whose spirit level can be adjusted to any 360° position. The desired slope, for example 6:1, can be made by fastening a board to form the hypotenuse to a 1-foot horizontally placed board and a 6-foot vertically placed board. When the carpenter's level is placed on the board forming the hypotenuse, the spirit level should be adjusted to the level position. The carpenter's level may then be used to set all studs to the proper battered slope.

Where concrete walls are designed to jut into the streambank, the earth sides of the trench dug into the bank may be satisfactory form walls. This obviates the need for backfill and helps reduce the chance of seepage between streambanks and wall. Where backfilling is done, the choice of material is important. Backfill consisting of four parts loam soil and one part Bentonite clay mixed dry in a cement mixer has been used successfully at the Fraser Experimental Forest in Colorado.

The best time for constructing the cutoff wall is during periods of low flow. The stream may be diverted around the construction by a flume or ditch along the bank. Or it may be passed over the cutoff wall or through the notch by a flume or pipe. Another alternative is to route it through the drainpipe in the base of the cutoff wall. A moderate amount of ponded or still water in the excavation is permissible; the concrete when poured will displace it. But even a small amount of flow or seepage of moving water through the concrete before it has set will be disastrous; it will carry the cement away from the mix, and leaks will result.

Sidewalls

Watertight sidewalls used in the watertight-box design are constructed similarly to the front or cutoff walls. Intake pipes to the well under the gagehouse have to pass through one sidewall, and they should be provided for in the forms.

Where the cutoff wall alone is relied upon to control streamflow, construction requirements for sidewalls are not exacting, for their purpose is merely to prevent slumping of the banks and erosion by water. These sidewalls should not be watertight because water held back would exert pressures that might cause damage. A porous dry-built stone wall is satisfactory (fig. 24). Concrete blocks, without mortar, can be used. Wood planks or logs, preferably treated for decay resistance, will also be suitable. They should be supported by posts securely tied into the banks; for example, by use of buried anchor logs. A pole across the basin above the high water level may also be used to keep the sides vertical. Under some conditions, the sides of the basin can be sloped so that building of a wall is not necessary. Planting grass on the banks will help control erosion.

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FIGURE 24.—Dry-built stone wall serving as a side of the basin. Note low wall at upstream end of pond. The horizontal angle iron at middle far right is a mount for the hook gage.

In a sunken weir the basin is dug in the natural stream channel. Water entering the basin must fall from the channel to the water surface below. A low soil-retaining wall, composed of the same materials used in the sidewalls, can be constructed between the floor of the basin and the natural stream channel. The top of this wall should be level, and the streambed above it should be shaped so that flow will enter the weir pond more or less uniformly over the entire cross section. Spreading the flow lowers the velocity of approach in the weir basin.

Floor

The concrete floor for the watertight-box design may be poured within the confines of the previously constructed walls. Or, a complete concrete floor can be poured before pouring the concrete for the walls; the floor then serves as a foundation for the walls (fig. 19). The first type of floor should be 2 to 6 inches thick, whereas the second type should be thicker, 4 to 12 inches. In both types reinforcing steel mesh is added for support.

The quality of the concrete used is very important. Watertight concrete should be used throughout the structure. Thus, the water should be carefully measured, and the mix should be composed of the best available sand, aggregate, and cement. Advice of an engineer familiar with local materials should be sought. Where frost damage is possible, air entrainment is desirable. Use of a vibrator to settle concrete into forms is recommended. Several references listed in the bibliography describe in detail the design and control of concrete mixes and the construction of forms.

Weir Blade

Angle iron, ¼ by 3½ by 3½ inches, has been most commonly used in constructing weir blades. More recently, steelplates have been used because of their several advantages. The angle-iron blade is mounted on a concrete cutoff or front wall by means of bolts partially buried in the concrete. Somewhat similar techniques could be used for other weir shapes—for instance, trapezoidal or rectangular ones. The upper edge is ground to a flat or sharp edge and should have a 45-degree bevel below the edge. For a 2-foot 120° V-notch blade, two sections of angle iron are cut and welded to form a 120° angle between the edges. The length of each section along the edge is 4 feet (fig. 25).

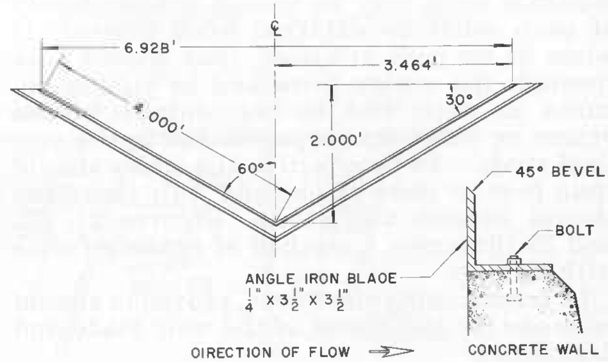

FIGURE 25.—Detailed plans for a 2-foot 120° angle-iron weir blade.

Slots are made in the base section of the angle iron to accommodate the bolts and to facilitate placement of the blade. The upstream face of the angle iron should be placed as vertical as possible and flush with the concrete wall. Also, a vertical line through the bottom of the V should bisect the angle. To do this, shims are inserted between the blade and concrete, or the blade is adjusted by threading leveling screws through the base of the angle iron so they extend below the base. By turning the screws the position of the blade can be adjusted quite rapidly. A layer of asphalt roofing cement, or some other nonhardening cement, is placed between the blade and concrete to assure a watertight juction.

The basal section of the angle iron and the concrete wall below may obstruct the free fall of the nappe at very low flows. The situation is aggravated in winter if ice develops on the angle iron and concrete surfaces.

The steelplate blade is made by cutting a notch in a rectangular section. It is bolted to the concrete flush with the upstream face of the wall over a rectangular or U-shaped opening in the wall. For a ⅜-inch metal plate, as shown in figures 15 and 19, buttresses of ¼- by 3- by 3-inch angle iron, 2.5 feet long, are set into the concrete and bear against the plate to provide rigidity. This type of blade allows unobstructed free fall of water from the notch. It is easier to fabricate than the angle-iron blade, and its use simplifies construction of the cutoff wall and placement of the blade in the wall. On the other hand, the plate is more expensive than the angle iron.

The blade, whether angle iron or sheet metal, should be treated with a primary coat of rust-preventive paint and then a coat of aluminum paint. Galvanizing the entire blade provides longer protection. Although galvanizing assures rust-free service, the upstream surface and edge of the blade may not be smooth and uniform unless galvanizing is done with care.

To accommodate flows that exceed the capacity of a 2-foot V-notch weir, rectangular sections of varying length and height are commonly added above the V-section (fig. 5). When flows exceed the V-notch capacity, the horizontal section above the notch assumes in part the characteristics of a broad-crested rectangular weir. Rating of these flows is very difficult, and discharge measurements are usually less accurate.

It is probably better to extend the V-notch higher than 2 feet than to rely on a rectangular section above the V to accommodate high flows. As a large V would be difficult to install properly, a 2-foot V-notch should probably be fabricated and precisely positioned, and the additional height should be added later. If possible, for rating purposes, current-meter measurements should be made during high flows.

Drainpipes

A drainpipe should be set in the cutoff wall to drain the basin for cleaning. It should be large enough to accommodate the highest flow expected during maintenance. A 6- or 8-inch inside-diameter pipe is usually satisfactory. Its length depends on the thickness of the wall. It should be located so that the bottom of the pipe is at the low point on the floor of the channel along the cutoff wall. The drain should not be placed directly under the notch.

The pipe should be tilted slightly downstream. The downstream end of the pipe should extend about 4 inches beyond the surface of the wall and should be fitted with a screw-on cap. Iron lugs about 4 inches long and 1 inch in diameter should be welded to the side of the pipe to prevent the pipe from turning in the concrete when the cap is screwed on and off. A stout, short section of 1½- to 2-inch pipe welded across the cap will provide a mechanical hold for a steel lever for turning the cap.

Sometimes a second drainpipe is installed at a higher elevation. Such an arrangement permits draining most of the water and yet retention of accumulated debris in the basin for measurement. It will also facilitate draining the weir when a large accumulation of sediment blocks the lower pipe.

Debris Dam and Baffles

To minimize the debris that enters the weir basin and to help distribute flow evenly through the cross section, a dam can be built upstream across the channel. It can be made of rock, logs, timber, concrete, or other substantial construction; otherwise, it might wash out during high flow and do more harm than good. The top of the dam should be about 2 feet higher than the bottom of the notch. In the watertight basin the dam should be placed so that the water that is ponded upstream from the dam is within the confines of the walls and floor of the weir basin.

In cold climates where much ice develops, the debris dam should have a sloping surface on the downstream side to relieve ice pressure that may develop in the basin. Figure 26 gives an example of a debris dam.

Baffles of various designs are sometimes used in weir ponds to reduce velocity and distribute the flow uniformly across the pond.

F-503141

FIGURE 26.—Debris dam in basin of watertight box.

Captive floating baffles can relieve ice pressure. Baffles should be firmly secured to prevent them from becoming flotsam during floods.

Gagehouse and Well

Many shapes, sizes, and materials have been used for gagehouses. These vary from simple wooden box shelters just large enough to house the recording instrument to large concrete structures equipped with recorder, heater, telephone relay systems, and other apparatus (figs. 5, 8, 9, 11–13, and 27–29). The design depends on factors such as building and maintenance costs, accessibility of materials, duration of installation, and susceptibility to vandalism.

The most common type of gagehouse is like a telephone booth, 3 to 4 feet square, and constructed of wood or concrete blocks. It shelters both the recording instrument and anyone servicing the instrument.

Screened openings or other ventilating devices should be provided in the walls. A barrier should be placed over the well to prevent water vapor from entering the water-level recorder or condensing on the tape. The instrument should rest on an immovable base. Plans for a gagehouse at the Hubbard Brook Experimental Forest are given in figure 30.

Concrete-block gagehouses (fig. 30) are more expensive than other types, but they are exceedingly durable and weathertight, maintenance is negligible, accessibility to the well is good, movement of reference points or instrument is practically nil, and they are virtually vandalproof.

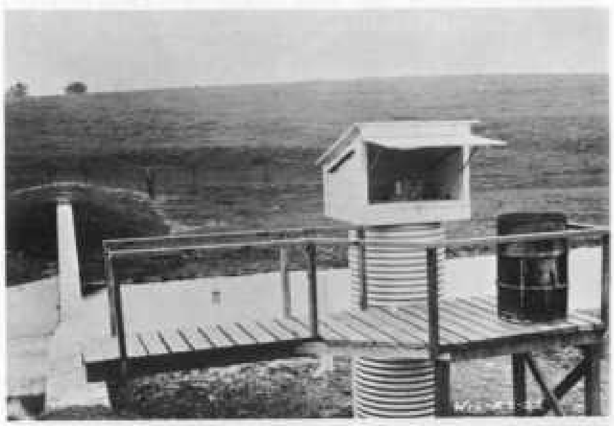

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FIGURE 27.—Box-type instrument shelter with weir, stilling well, and observation platform on 330-acre watershed operated by the Agricultural Research Service near Fennimore, Wis.

In the stilling well under the gagehouse, the recorder float rises and falls as the water stage fluctuates. The stilling well, as its name implies, reduces wave action from the

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FIGURE 28.—Corrugated cylinder instrument shelter, Onion Creek Experimental Watersheds, Calif.

F–503133

FIGURE 29.—Wood-frame gagehouse at Fernow Experimental Forest, Parsons, W. Va.

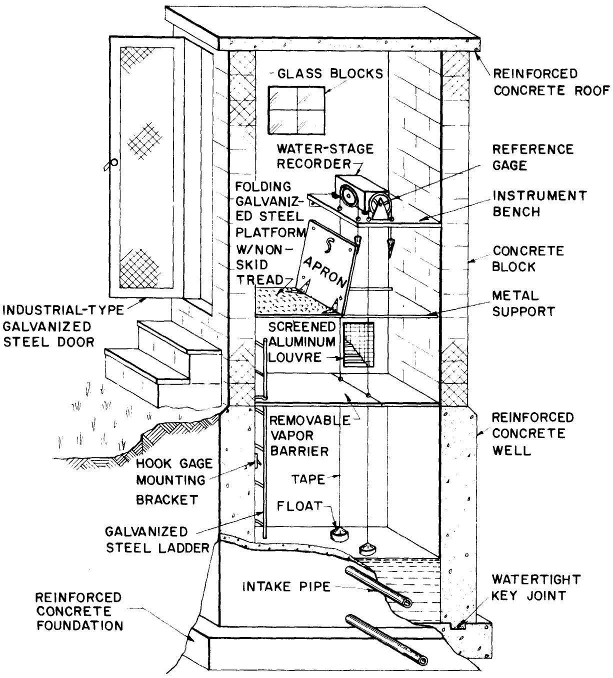


FIGURE 30.—Cutaway section for concrete-block gagehouse for stream-gaging station at Hubbard Brook Experimental Forest, West Thornton, N.H.

weir basin, thereby lessening fluctuation of the hydrograph trace on the record chart.

Wells may be enclosed with corrugated steel cylinders, poured concrete, or concrete blocks. A firm foundation should be provided for the walls, especially when they support the gagehouse.

The well should have adequate height to permit the recorder and floats to operate properly at the full capacity of the weir. Some wells, principally those of corrugated cylinders, can accommodate only the float and counterweight. In cold regions, additional space may be required for placing an oil cylinder in the well to prevent freezing. In some cases it is desirable to construct wells large enough to permit a man to enter to adjust floats, clean, make hook-gage readings, and break up ice.

The location of the gagehouse and stilling well in relation to that of the weir basin is not critical if the relative positions of the intake pipes and weir blade are satisfactory. For cold regions, some people advocate that there be 1 to several feet of earth between the weir basin and stilling well because of the possibility of ice formation in the well. Sometimes the stilling well is placed within the weir basin; however, unless the basin is much larger than usually necessary to meet hydraulic requirements, this may interfere with even flow through the basin. When the well is placed outside a basin of watertight-box design, intake pipes and connections between weir basin and stilling well, and the stilling well itself, must be watertight.

Intake Pipes

The gage well is connected to the weir basin or stream channel by intake pipes. Two or more intake pipes are used, one placed higher than the other, to reduce the lag in well elevation during rapid changes of water stage in the basin, and to reduce the risk of an obstructed pipe and thus lost records. The pipes should be level.

Intake pipes also function as drainpipes when the pond is drained for cleaning.

In the watertight-box design, the intake-pipe opening to the basin may be set flush with the basin wall. In a simple cutoff wall, where the natural streambanks form the sides, the intake pipes should extend into the stream channel or basin, but not farther than the middle of the stream. A complete discussion of the design and construction of intake pipes is given by Pierce (1941b).

Metal pipes of wrought iron, steel, or galvanized iron are most commonly used. Inexpensive asphalt-impregnated composition pipe may be satisfactory where freezing is not prevalent or for short-term installation. Where freezing is a problem, intake pipes should be insulated.

In the watertight-box design at the Hubbard Brook Experimental Forest, two 2½-inch inside-diameter galvanized iron pipes were placed 12 inches apart (one above the other), with their basin or stream ends flush with the inside of the basin wall, oriented at right angles to the stream channel, and with the openings located approximately 6 feet upstream from the blade.

The vertical placement of the pipes will depend on the location of the bottom of the V-notch and the position of the gagehouse. A feasible arrangement might be as follows: The upper pipe located 1 foot below the notch and the lower pipe about 1 foot above the basin floor or bed of the stream channel. Two additional pipes may be advantageous for handling stormflows: one located 1 inch below the V-notch and another 1 foot above the V-notch. If the weir will be subject to sediment deposition or thick ice layers, the number and location of pipes must be adequate to permit free flow of water between the basin and the well even though some of the pipes may become blocked.

Because it is essential to maintain the same water level in the well and basin during all stages of flow, the ratio of the total cross-sectional area of the intake pipes to the stilling well should be at least 1:500, and preferably 1:100.

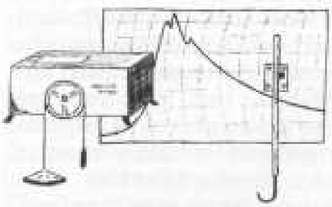
The basin ends of the intake pipes should be threaded, and a coupling should be attached. This will allow installation of reducers or baffles if necessary to assure equal levels in both the basin and the well during periods of high flow.

Placing the well directly in the weir basin eliminates the need for intake pipes. For example, a corrugated cylinder can be placed in or immediately adjacent to the basin, and a hydraulic connection between the basin and well can be obtained by cutting openings in the cylinder.

Cost of Construction

The cost of weir construction depends primarily on the type and size of the weir and expected duration of its use. Weirs made of a simple concrete cutoff wall and wooden frame gagehouse with corrugated steel well will probably cost between $2,000 and $3,000. More elaborate weirs of the watertight-box design may cost between $4,000 and $10,000.

The appendix contains time, material, and cost figures for constructing weirs at the Fernow Experimental Forest near Parsons, W. Va.; the Hubbard Brook Experimental Forest in West Thornton, N.H.; the Leading Ridge Watersheds near State College, Pa.; and the Baltimore, Md., Watersheds.



Instrumentation

WATER-LEVEL RECORDER

The purpose of a stream-gaging station is to measure the water that passes through it. Most stream-gaging stations do this indirectly. What is actually measured is the level of the water surface, either the height of the water ponded upstream from the control and influencing the amount of water passing over the control, or the actual height of water passing over the control. This height of water may be converted to quantity if the control section has been rated (stage-discharge relations derived).

When continuous records of streamflow are desired, a water-level recorder is employed. The recorder makes a continuous or staccato trace of the water stage on a time chart. Where the installation is serviced infrequently (at intervals of more than 1 week but less than 6 months), a recorder employing a weight-driven continuous-roll chart is used (fig. 31). If the site can be visited frequently (once a week), a spring-driven drum-type weekly chart is satisfactory (fig. 32).

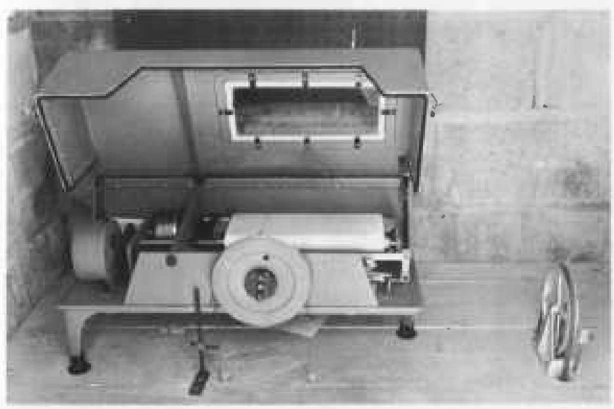


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FIGURE 31.—Stevens type A-35 water-level recorder for continuous roll chart. Note reference tape on right.

Water stage is conveyed to the recorder by a flexible tape or cable with an attached float. For the recorders shown in figures 31 and 32, a metal tape or cable rides over a pulley attached to the recorder. A counterweight is affixed to the other end of the tape or cable to balance the float. The counterweight should be placed on the tape so that at zero flow (at the counterweight's highest point of travel) it is barely below the pulley. No obstructions should be met by the float or its counterweight throughout their travel from the highest to lowest position. Relative sizes of floats and float wells are discussed in the Hydraulic Data Book (Stevens n. d.).

For gaging stations where streamflow is intermittent, an automatic trigger device has been developed for FW-1 water-level re-

F–503135

FIGURE 32.—FW–1-type water-level recorder.

F–503142

FIGURE 33.—Hook gage on mounting post.

corders to set the recorder in operation when flow commences (Curtis 1960).

Recent advances in instrumentation have aided in the development of several promising water-measuring instruments that may eventually replace those in use today. One of these, the bubbler gage, eliminates the need for a stilling well and float. The bubbler gage operates by releasing a given rate of gas at a fixed point below zero flow over the control. When the water stage changes, the water pressure at the gas release point will also change. A device for relating gas pressure to stage height is attached to a regular water-stage recorder (Barron 1960).

Another apparatus has been developed that tape punches, in binary code, stage-heights at predetermined time intervals. The data on this tape can be translated onto punchcards, and these cards and those with a punched rating curve can be run through electronic computers to get the discharge for days or other time periods. Both of these instruments are being tested by the U.S. Geological Survey.

HOOK GAGE

A hook gage is used to accurately measure the stage height of water above zero elevation in the control section. The gage consists of a pointed hook attached to a calibrated rod (fig. 33). The hook-gage point is placed beneath the water surface and raised slowly until the point (pointing upwards) just touches the liquid surface. A vernier on the gage is then read. The elevation of the water can be determined by comparing the hook-gage reading to the surveyed relationship between the zero elevation in the control section and the base setting on the hook gage. Hook gages are available commercially.

The hook gage can be used in the weir basin or within the stilling well. When hook gaging is done in the stilling well, clogging of intake pipes, if it occurs, may not be discovered. The well is a better location because there is minimum disturbance to the water surface. In either location the mount for the hook gage should be firmly fixed to a permanent, immovable base. In the weir basin the hook-gage mount may be fastened to a sidewall of the basin (if it is sufficiently firm and not subject to settling) or to a concrete pier made for that purpose. In the well the mount can be fastened to the inside of the well wall.

One type of mount consists of a support made from a piece of 3½ by 3½ by ¼-inch angle iron, and a mounting plate. Figure 34 shows a suggested design for the hook-gage mount.

Where the hook-gage point cannot be readily seen, a portable, electric water-depth gage may be used (Wilm and Collet 1941).

REFERENCE TAPE

Frequent water-level measurements can be taken with a calibrated reference tape equipped with float. A hook gage is needed

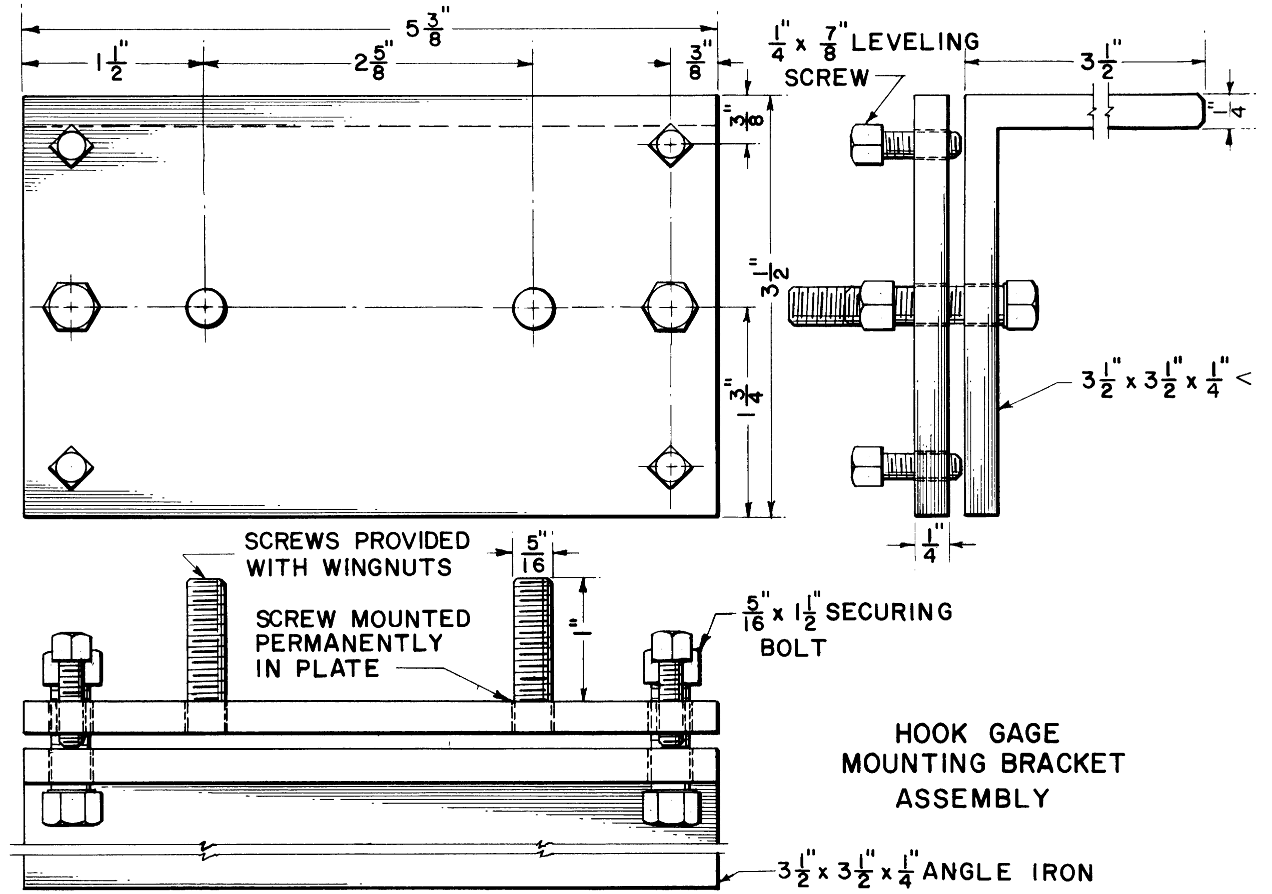


FIGURE 34.—Plans for hook-gage mount.

occasionally to establish or check the elevation of the reference float.

The tape rides on a pulley mounted on the instrument bench, and it has a counterweight. A pointer, also mounted on the bench, can be adjusted and set at a given point on the tape. Once the relationship between the zero elevation in the control section and the base setting on the hook gage is known, any water level can be determined by the hook gage, and the reference-tape pointer can be adjusted to the corresponding level on the reference tape. The water-stage height for the instrument chart is taken from the reference tape.

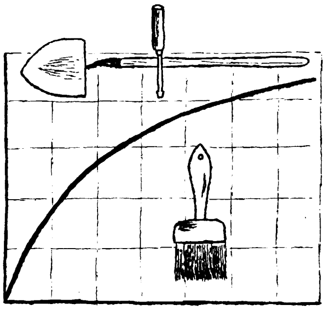
Water levels obtained with the reference tape or hook gage are referenced to zero level on the control section by running levels from the control section to a reference point or hook gage. References should be checked periodically.

STAFF AND CREST GAGES

Stage height can be read directly with a staff gage, a metal plate marked in easily read divisions and mounted on an immovable base. If it is mounted at the proper elevation (by surveying levels from the control to the staff gage), the head of water flowing over the control may be read directly.

Crest gages are simple devices that record high watermarks. They insure against the loss of peak-flow records during flood discharges. A variety of these gages are available (Collet 1942; Ferguson 1942; U.S. Agricultural Research Service 1962). Most use a floating device or material (cork or wood chips) that is deposited at the high water stage.

A crest gage may be made from a 1-inch-diameter pipe capped on the bottom. Several ¼-inch holes are provided in the pipe near the cap. The pipe is fastened in an upright position in the basin so that the holes are well below minimum flow. Finely ground cork is placed on the water surface in the pipe. A wood dowel or stick as long as the inside length of pipe is inserted in the pipe, a top cap is screwed on, and ¼-inch-diameter holes are drilled in the pipe next to this cap. When high water occurs, the cork will rise and leave a ring on the stick at the water's maximum elevation.



Operating Procedures and Maintenance

Although the discussion in this section deals principally with weirs, it also is generally applicable to flumes.

The major chores after installation of the water-level recorder and associated instruments are rating the weir, periodic chart changing, checking water levels with the hook gage or reference tape, cleaning and care of the instruments, and cleaning of the basin or channel.

RATING THE WEIR

Check measurements of the stage-discharge relationships (rating curve) should be made after the stream-gaging station has been built. The control section of the station should be built, if possible, according to the specifications of a model that has been rated under laboratory conditions. If this has been done, the rating curve of the laboratory model can be used unless there are differences between the two—for example, upstream approach conditions or weir blade surfaces or edges.

If the field model does not conform exactly to the specifications of the laboratory model, or if the field-control section has no laboratory model, the control must be rated by measuring water flowing over it throughout the range of stage heights. In any case, some check measurements should be made after the station has been constructed.

Flows over a 120° V-notch weir up to 0.6-foot head may be measured by collecting in buckets or tanks the water passing over the weir in a selected time. At 0.6-foot head, use of a 400-gallon tank is advisable. A V-shaped trough of sheet metal can be used to direct the flow into the container. The position of the trough must not prevent aeration of the nappe.

The flow in cubic feet per second is computed from the time it takes to collect a container full of water; this is related to the stage height at the time. Eight to 10 stage heights well distributed between 0- and 0.6-foot head, with 2 to 4 replicates at each stage, are sufficient for this portion of the curve.

Stages are seldom at the proper height when it is convenient to test them. If flow is higher than the stage at which a test is desired, part of the flow may be diverted around the weir basin by a flume or a pipe (2- to 4-inch aluminum irrigation tubing is lightweight and convenient). Using this procedure, two different low-flow stages can be rated during one visit to the installation.

Usually it is between 0- to 0.6-foot head that the measured flow varies appreciably from the laboratory rating. Slight variations in the structure of the blade will influence the discharge characteristics much more at low flows than at high flows.

Flows greater than 0.6 foot (approximately 1.27 cubic feet per second for a 120° V-notch weir) become unwieldy to measure by containers and are measured with a current meter. Generally, velocities in the weir basin are too low to permit use of the current meter there.

Therefore, a natural nonturbulent section of the stream channel, directly above or below the artificial control, is used. A temporary flume made of boards, concrete, or other materials will provide a suitable measuring section. If the flume is constructed with sides of uniform width or regular geometric shape, the cross-sectional area may be readily computed.

The pygmy current meter with wading rod, a modification of the Price current meter, is used to rate field installations. A measuring tape is first stretched across a straight section of the stream. Measurements are made along the cross section so that each segment between the points of measurement accounts for about 5 percent of the total flow. At each point, total water depth is measured with a rule, and velocity of flow is determined with the meter and stopwatch. The meter has an earphone, and the number of clicks in the measuring period (usually 1 minute) indicates the velocity. When water depth is 0.5 foot or less, the meter is lowered halfway between the surface and the bottom; for depths between

0.5 and 2.0 feet, measurement is made at a point 0.6 of the depth from the surface; for depths over 2.0 feet, measurements are made at 0.2 and 0.8 of the depth and averaged.

The area and velocity of flow in each section are determined by averaging measurements of depth and velocity made at each side of the section; flow through the section is determined by multiplying area in square feet by velocity in feet per second. Total discharge is determined by adding the flow of the separate sections. Detailed instructions for making current-meter measurements have been given (Pierce 1941a and 1941b; Corbett et al. 1943).

Flow through a rectangular section above a V-notch weir (fig. 5) creates a rating problem. If the flow has not been rated by a current meter or by laboratory tests, a crude estimate of flow can be made by summing (1) the discharge of the V-notch weir at full capacity, and (2) the discharge of a broad-crested rectangular weir of the given width and a head measured from the base of the rectangular section.

PERIODIC CHART CHANGING

The time between chart changes depends on the instrument used, accessibility of the gaging station, and chart interval suitable for office handling. Although some recorders will run for 6 months unattended, it is advisable, if possible, to visit the gages weekly or at other frequent intervals to check for malfunctions.

CHECKING WATER LEVELS

Each time the chart is changed or the installation is serviced, the water level should be measured by hook gage or reference tape and recorded, along with the date and time of observation, both on the chart removed and on the new chart. This level indicates whether the instrument has been keeping an accurate account of the water stage and, if not, the corrections of the instrument or chart that should be made.

INSTRUMENT AND BASIN

A regularly scheduled instrument checkup and cleaning program is good practice. Where several gages are operated, it is advisable to have an extra instrument or spare parts, particularly clocks, ready as immediate replacements.

Maintenance checks should also be made of the weir basin, walls, and weir blade. As necessary, the blade should be repainted and the nicks mended, and debris should be removed from the basin. Basin leaks can be reduced or stopped by coating the walls and floor with asphalt cement, bentonite, or vinyl plastic, depending on the structural material.

The weir basin should be drained and cleaned before accumulation of sediment and other debris (such as leaves) reduces water depth beyond the point necessary to meet hydraulic requirements. It may also be necessary to clean out the stilling well. The frequency of draining and cleaning the weir basin will vary with the amount of sedimentation and basin size; it is often done annually.

TRASH SCREENS

Leaves, twigs, or other material lodged in the notch can cause considerable error in the stream-discharge record. To reduce this error, trees should be removed from the immediate vicinity of the gaging station (perhaps for a distance equal to the height of the trees), and a trash screen should be placed in the notch (fig. 35).

Trash screens are usually needed only during low flows, because high flows have sufficient volume and velocity to flush most floating debris through the notch. At high flows the screen should be removed, because debris adhering to the screen may alter the discharge characteristics of the weir.

Small screens—18 to 24 inches long, 12 inches wide, and 8 to 12 inches high—are being used at both the Fernow and Hubbard Brook Experimental Forests (Reinhart et al. 1961). Iron rods, one-fourth inch in diameter and welded together, support the 1-inch-mesh poultry netting or ¼- to ¾-inch-mesh hardware cloth. The screens have a trigger, pulley, and weight device designed to raise them automatically out of the notch section when a predetermined stage height is reached.

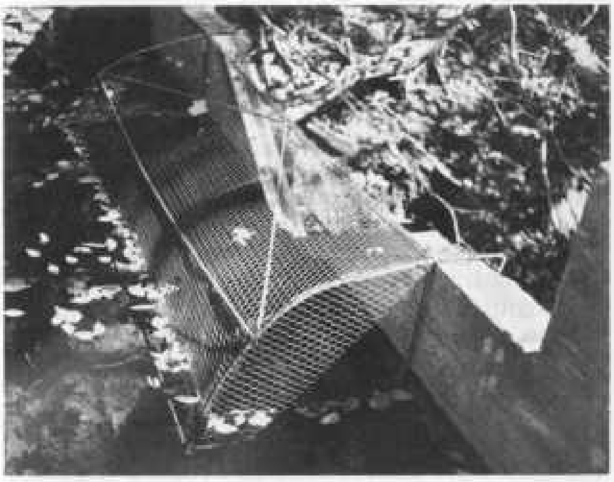


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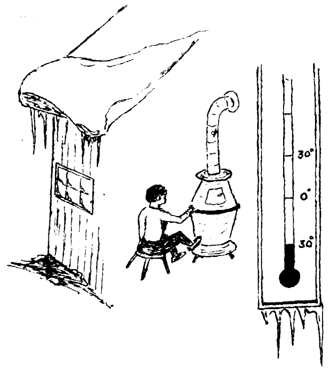
FIGURE 35.—Trash screen used to prevent floating debris from clogging the notch.



Cold Weather Maintenance

In winter gaging, the well must be kept free of ice because the formation of even a thin layer in the stilling well would disrupt the rise and fall of the float. Equipment used to prevent ice formation in the well includes well enclosures, subfloors, oil cylinders, and heating appliances.

ENCLOSURE OF WELL

Ice will form more quickly in a well in an enclosure that is completely exposed to the atmosphere than in one that has its lower section surrounded by earth. Surrounding soil supplies heat to the well walls and provides insulation against heat loss to the atmosphere. The more the well structure is enclosed in earth, the higher the water temperature in the well, and the less chance for ice to develop.

SUBFLOOR

A subfloor between the main floor and the water reduces heat loss from the well and prevents condensation of water vapor from the well on the recording instrument. The subfloor should be built well below ground line but high enough so that it will not interfere with the float at maximum flood stages. It should be constructed of light material such as plywood or tongue-and-groove boards, and be made in sections to facilitate easy removal. It should have a minimum area of openings for the float tape and counterweights. A blanket of insulating material over the subfloor will further retard heat loss.

OIL CYLINDER

A cylinder can be used to confine a layer of oil, such as kerosene or fuel oil, on the water. The float is then placed on the oil surface. From 5 to 20 gallons[4] of oil will prevent freezing. The oil cylinder may be made of galvanized sheet metal; it should be about 3 inches larger than the diameter of the float, open at both ends, and with perforations in the lower part (well below the lowest possible flow) to allow free access to water. The sides of the cylinder above the perforated section should be watertight. In position the top of the cylinder should be slightly higher than the maximum expected stage. (An extra length should be allowed for the oil layer above the water.) The cylinder can rest on the stilling-well floor or can be hung from the wellsides or gagehouse floor; if the cylinder does not rest on the bottom, perforations are not necessary. When winter ends, the oil is drained from the cylinder.

Although the layer of oil may prevent the formation of ice in the tube, ice may develop in the unprotected parts of the gage well, and it must be removed to permit operation of the hook gage, reference float, or other measuring devices. Reference floats should be kept out of the water except when measurements are being made. Permanently installed hook gages must also be raised above the water level when not in use.

Use of oil causes the float to rest above the true water level. Therefore, if hook-gage measurements used to set and adjust the recorder pen are made at an oil-covered point, a correction for oil depth must be made.

HEATING APPLIANCES

For very low temperatures, portable space heaters may be necessary. The most common heater uses bottled gas. Other heaters operate on electricity, kerosene, or gasoline. A small gasoline lantern may provide enough heat to prevent freezing in the well. Most heaters require frequent attention, and unless they are controlled by a thermostat, they waste heat.

A simple heater used at the Hubbard Brook Experimental Forest consists of a single gas-pilot burner (similar to pilots for hot-water

[4] Amount depends on diameter of oil tube and the occurrence of subfreezing temperatures. For conditions at Hubbard Brook, 15 gallons of kerosene is sufficient to prevent freezing in a 19-inch cylinder.

heaters) mounted on an empty airtight 1-gallon can that serves as a float to keep the heat close to the water surface (fig. 36). A piece of sheet zinc is fastened in a semicircle (Quonset-hut style) to the can and over the burner. One end of a short section of copper tubing is connected to the burner, and the other end to plastic tubing which leads to a tank of bottled gas (propane). One 20-pound tank of gas will keep the well free of ice for about 2 months.

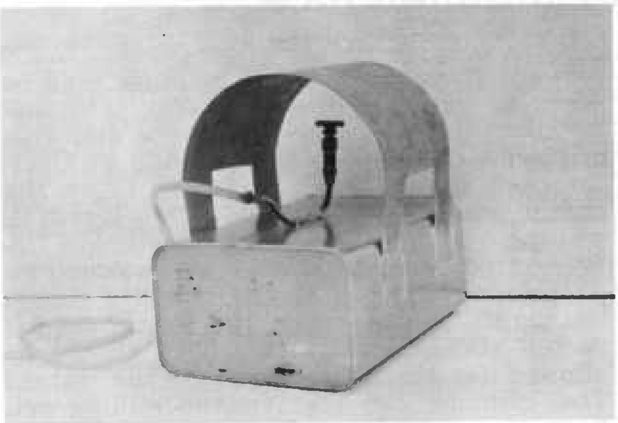


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FIGURE 36.—Portable space heater used for eliminating ice in wells: Pilot burner (used for hot water heaters) mounted on an airtight 1-gallon can which serves as a float; 1/4-inch plastic tubing connects burner to regulator on bottled gas tank; hood (sheet zinc) fastened to float reflects heat to float and water surface.

ICE IN THE WEIR BASIN

During extremely cold weather a considerable depth of ice may develop in the weir basin. However, this ice usually does not greatly interfere with the normal discharge of water over the control. Ice may develop around the control at all points where the water is not constantly moving, and it may also form on surfaces immediately downstream from the control (fig. 37). To obtain an accurate stage reading, the ice must be removed several feet above and below the notch or control section. Ice should also be removed periodically around the notch to prevent excessive ice pressure, which might spring the metal blade out of line. This ice removal is usually done when the station is visited for chart changing, or during other regularly scheduled maintenance visits.

The stage height prior to ice removal and 15 minutes after such removal should be noted on the chart. Ice should also be removed at the reference point so that a hook gage or reference tape and float may be used to determine the actual water level. The correct water level should be noted on the chart and, if necessary, the recorder should be adjusted.

During extremely cold periods, ice may build up on the downstream side of the blade so that an ice siphon tube forms. This malfunction is indicated by sharp fluctuations in the trace on the recorder chart. When this occurs, water is siphoned from the basin down to zero stage or lower. At this point the siphoning action is broken, the stage rises to normal flow, and the process is repeated.

An antifreezing hood for retarding or eliminating freezing in the discharge section of V-notch weirs has been described by Johannessen (1957). The hood resembles a gabled roof and is made of aluminum-foil-lined plywood. It is supported by rods attached to a swinging beam at the side of the weir, and is designed so that high flows will force the hood clear of the notch so it will not interfere with discharge.

Reduction or elimination of ice in the weir basin may be possible if the basin can be completely covered with insulating material to restrict heat loss from the water surface. Such a covering, however, should be capable of withstanding the weight of accumulating snow and should not interfere with discharge.

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FIGURE 37.—Ice and snow accumulation in basin and below sharp-crested 90° V-notch weir.

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Appendix

COSTS FOR CONSTRUCTING STREAM-GAGING STATIONS

A. One 2-foot 120° sharp-crested V-notch weir of the cutoff-wall design at the Fernow Experimental Forest near Parsons, W. Va., in 1956.

Figures for this weir are based on the average cost of Fernow weirs 8 and 9. The average volume of concrete in the cutoff wall was 14 cubic yards, and the average area of the watersheds was 37 acres. The cost per weir—they were one-fourth mile apart—was probably less than the cost of building a single weir. The cost of building an access road is not included.

Cutoff wall and weir basin:	
Labor, general (544 hours)	$680.00
Labor, carpenter, who also assisted in pouring and dressing concrete (70 hours)	156.00
Bulldozing basin, TD-9 bulldozer (4 hours)	32.00
Lumber, for forms and sidewalls (2,000 board feet)	170.00
Cement (95 bags)	116.00
Crushed stone (14 tons)	32.00
Sand (13 tons)	33.00
Hauling cement (12-mile haul)	20.00
Hauling stone (35-mile haul)	80.00
Hauling sand (30-mile haul)	70.00
Cement mixer, rental (2 days)	10.00
Air compressor, rental (9 operating hours)	25.00
Transporting mixer and air compressor to site (33-mile truck haul on hard road, 1-mile tractor tow on access road)	48.00
V-notch form, fabrication in woodworking shop	11.00
Blade, ¼- x 3½- x 3½-inch angle iron, contracted to machine shop	50.00
Drainpipe with cap, 8-inch diameter, 3 feet long, secondhand	11.00
Bolts, tie wires, nails, miscellaneous	25.00
	1,569.00
Gagehouse (wood frame) and stilling well:	
Labor (32 hours)	48.00
Lumber (600 board feet)	100.00
Culvert pipe, steel (2-foot diameter, 10 feet long)	60.00
Miscellaneous	10.00
	218.00
Instruments:	
Water-level recorder, Stevens A–35	360.00
Hook gage (assuming gage used for one weir only)	80.00
Mount for hook gage	15.00
Installation (8 hours)	15.00
	470.00
Total, complete installation	$2,257.00

B. Two-foot 120° sharp-crested V-notch weir of the watertight-box design with concrete-block gagehouse (weir No. 2, Hubbard Brook Experimental Forest, West Thornton, N.H., built in 1956).

Labor (1,616 man-hours)	$2,477.00
Equipment rental:	
D-7 caterpillar tractor (4 hours)	48.00
Compressor and jackhammer (11 hours)	88.00
Materials:	
Cement (187 bags)	300.00
Reinforcing steel, ½-inch diameter (880 feet)	70.00
Crushed rock, washed (26 tons)	98.00
Sand, washed (18 tons)	37.00
Concrete blocks (300)	86.00
Glass blocks (4)	4.00
Lumber (2,200 board feet)	220.00
Nails (23 pounds)	3.00
Pipe, 2 feet of 6-inch pipe and 10 feet of 2½-inch pipe	24.00
Blade, ¼- x 3½- x 3½-inch angle iron	114.00
Form ties (100)	15.00
Hook-gage support	10.00
Steel door, frame, ladder, floor, and supports	167.00
Miscellaneous hardware	12.00
Instrumentation: (Stevens A–35 water-level recorder and reference gage, hook gage)	482.00
Total cost	$4,255.00

C. Combination 90° (18-inch deep) V-notch and Trenton weir with concrete-block gagehouse built at Leading Ridge Watershed near Pennsylvania State University, University Park, Pa., in 1958.

Materials:	
Ready-mix concrete (22 cubic yards)	$366.00
90° V-notch (1)	22.00
Lumber (850 board feet)	77.00
2 drainpipes, 6 inches x 2½ feet, with cap	21.00
Nails (32 pounds); reinforcing steel (63 feet of ½-inch-diameter steel) and reinforcing wire mesh (5 x 23 feet)	29.00
Tie wire (1 roll)	4.00
Miscellaneous materials and services	44.00
Concrete blocks (310)	64.00
2 pipes, 2 inches x 16 feet	18.00
Five pieces of angle iron (¼ x 2 inches x 1½ inches x 5 feet) to support gagehouse floor and recorder table	13.00
Wood door (1)	24.00
Glass blocks (4)	4.00
2 pipes, 4 inches x 9 feet	21.00
Culvert (15 inches x 5 feet)	20.00
Steel ladder	1.00
Cement (3 bags)	4.00
Equipment rental: John Deere tractor (22 hours)	121.00
Labor: (656 man-hours)	1,048.00
Instrumentation: FW–1 water-level recorder, staff gage, hook gage	285.00
Total cost	$2,186.00

D. One-foot 120° sharp-crested V-notch weir of watertight-box design. Wooden box built of 2 by 8-inch planks, no floor, plate-steel weir blade, interior of box lined with vinyl plastic. Built on Baltimore City Watershed.

Lumber for box and gagehouse (about 1,000 board feet)	$100.00
Vinyl plastic liner (22 x 40 feet)	40.00
Instrumentation, FW–1 recorder and hook gage	285.00
Labor (18 man-days)	225.00
Weir blade (¼-inch plate steel, 2 x 7 feet)	216.00
Total cost	$866.00

PARTIAL LIST OF STREAM-GAGING STATIONS BEING USED FOR RESEARCH ON SMALL WATERSHEDS IN THE UNITED STATES

Operating agency	Location	Type of gaging station	Remarks
Northeastern Forest Experiment Station (Upper Darby, Pa.).	Hubbard Brook Experimental Forest, West Thornton, N.H.	90° and 120° V-notch weirs, watertight-box design; combined 3-foot San Dimas flume and 90° V-notch.	6 watersheds, 30 to 104 acres.
	Fernow Experimental Forest, Parsons, W. Va.	120° V-notch weirs, cutoff-wall design.	9 watersheds, 29 to 96 acres.
	Pocono Experimental Forest, Gouldsboro, Pa.	Columbus deep-notch weir...	1 watershed, 560 acres.
	Dilldown watershed, Blakeslee, Pa.	Columbus deep-notch weir...	1 watershed, 1,530 acres; in cooperation with Pa. Dept. of Forests and Waters and U.S. Geol. Survey.
	Baltimore (Md.) municipal watershed.	120° V-notch weirs, concrete-block walls, watertight-box design. 120° V-notch weir, wooden box with vinyl plastic liner.	3 watersheds, 26 to 48 acres; in cooperation with City of Baltimore.
	Newark (N.J.) municipal watershed.	120° V-notch weirs, watertight box.	3 watersheds, 24 to 68 acres; in cooperation with City of Newark.
Southeastern Forest Experiment Station (Asheville, N.C.).	Coweeta Hydrologic Laboratory, Franklin, N.C.	90° V-notch weirs................	5 watersheds, 22 to 50 acres.
		120° V-notch weirs...............	11 watersheds, 31 to 212 acres.
		Rectangular weirs, crest length, 5–6 feet.	4 watersheds, 350 to 943 acres; not currently in operation.
		Cipolletti weirs, crest length, 6–8 feet.	2 watersheds, 501 and 940 acres; not currently in operation.
		Cipolletti weirs, crest length, 12 feet.	2 watersheds, 1,788 and 1,877 acres.
		Columbus deep-notch weirs...	2 watersheds, 23 and 145 acres; weir on larger watershed not currently in operation.
	Piedmont Research Center, Union, S.C.	90° V-notch weirs................	3 watersheds, 15 to 22 acres.
		90° V-notch weir and 2-foot San Dimas flume in tandem.	1 watershed, 13 acres.
Central States Forest Experiment Station (Columbus, Ohio).	Dover, Ohio........................	90° V-notch weirs, temporary).	2 watersheds, 18 and 23 acres; on land of Muskingum Conserv. Dist.
Lake States Forest Experiment Station (St. Paul, Minn.).	LaCrosse, Wis.....................	90° V-notch weirs, concrete-box type.	Spring-fed stream.
		2-foot San Dimas flumes, fabricated steel.	Storm runoff only.
		H-type trapezoidal flumes, fabricated steel.	Do.
Southern Forest & Range Experiment Station (New Orleans, La.).	Tallahatchie Research Center, Oxford, Miss.	H-type flume, galvanized iron construction.	Mostly for storm runoff.
Rocky Mountain Forest & Range Experiment Station (Fort Collins, Colo.).	Fraser Experimental Forest, Fraser, Colo.	Combination San Dimas flume and rectangular weir with orifice plate for low winter flows; combination broad-crested trapezoidal weir with rectangular flume notched into center; 120° V-notch weir.	Velocity head rod used to check rating.
	Prescott National Forest, Arizona.	1-foot 120° V-notch weirs in series with San Dimas flumes; San Dimas flume.	....
	Front Range, near Fort Collins, Colo.	2-foot San Dimas flume and 30-inch, 90° V-notch weirs.	....

Operating agency	Location	Type of gaging station	Remarks
Rocky Mountain Forest & Range Experiment Station (Fort Collins, Colo.) (Continued).	Castle Creek, Willow Creek, and Thomas Creek, near Beaverhead, Ariz.	5 weirs, 120° V-notch, 3-foot head.	
	Campbell Blue, near Apline, Ariz.	Villemonte Sill in culvert	
	Sage Brush watersheds, near Dubois, Wyo.	3 V-notch weirs, 120°	Wooden cutoff walls
	3-Bar watersheds, near Roosevelt, Ariz.	4 V-notch weirs, 90° and 120°	Concrete-block dams.
	Natural drainages, Sierra Ancha Experimental Forest, Ariz.	4 V-notch weirs, 90°	
	Parker & Pocket Creeks, Sierra Ancha Experimental Forest, Ariz.	Combination Cipolletti and 90° V-notch weirs.	
	Workman Creek, Sierra Ancha Experimental Forest, Ariz.	2 V-notch weirs, 1 trapezoidal flume, 1 combination Cipolletti and V-notch weir.	
	Black Mesa, Near Grand Junction, Colo.	3 V-notch weirs, 120°	
	Beaver Creek, near Prescott, Ariz.	14 modified trapezoidal flumes.	Some in combination with V-notch; flume has capacity of 0.5 to 300 c.f.s.
Intermountain Forest & Range Experiment Station (Ogden, Utah).	Dog Creek Watersheds, near Reno, Nev.	Combination broad-crested 120° V-notch weirs.	
	Davis County Experimental Watershed, near Farmington, Utah.	Modified Venturi trapezoidal flumes.	
		O-Gee control section	Operated in cooperation with U.S. Geol. Survey.
		Self-cleaning flumes	
		90° and 120° V-notch weirs	In planning stage.
	Parrish Creek, near Farmington, Utah.	120° V-notch weir	
	Great Basin Research Center, near Ephraim, Utah.	Self-cleaning flume; 120° V-notch weirs.	
	Tailholt Creek, Payette National Forest, Idaho.	O-Gee control section	In cooperation with Payette National Forest, Idaho.
	Benton Creek, Priest River Experimental Forest, near Priest River, Idaho.	2 Cipolletti weirs	
Pacific Northwest Forest & Range Experiment Station (Portland, Oreg.).	H. J. Andrews Experimental Forest, near McKenzie Bridge, Oreg. (Corvallis Research Center).	Trapezoidal flumes	3 watersheds, 149 to 250 acres; rated by velocity head rod.
	Bull Run watershed, near Portland, Oreg.	Trapezoidal flumes	3 watersheds, 150 to 300 acres; rated by velocity head rod; in cooperation with City of Portland.
	South Umpqua Experimental Forest, near Tiller, Oreg.	120° V-notch weirs	2 watersheds, average 150 acres.
	Entiat Watersheds, near Portland, Oreg.	120° V-notch weirs, 3 feet high.	3 watersheds, concrete-block weir construction, 500 to 1,000 acres.
Pacific Southwest Forest & Range Experiment Station (Berkeley, Calif.).	San Dimas Experimental Forest, Glendora, Calif.	Combination 90° V-notch weir and 3- and 10-foot flumes.	
	Teakettle Experimental Forest, near Fresno, Calif.	Combination 90° V-notch weir and 6-foot Cipolletti weir.	Watersheds range from 70 to 550 acres; operated in cooperation with U.S. Geol. Survey.
	Onion Creek Experimental Forest, near Soda Springs, Calif.	120° V-notch weirs	Watersheds range from 120 to 560 acres; operated in cooperation with U.S. Geol. Survey.

PARTIAL LIST OF STREAM-GAGING STATIONS BEING USED FOR RESEARCH ON SMALL WATERSHEDS IN THE UNITED STATES—Continued

Operating agency	Location	Type of gaging station	Remarks
Pacific Southwest Forest & Range Experiment Station (Berkeley, Calif.)—Continued.	Castle Creek Experimental Area, near Soda Springs, Calif.	Parshall flume	1 watershed, 4 square miles; operated in cooperation with U.S. Geol. Survey.
	Sagehen Experimental Area near Hobart Mills, Calif.	Variable-notch weir	1 watershed, 11 square miles; gaging by U.S. Geol. Survey.
	Yuba Gap Experimental Area, near Sierraville, Calif.	Rated section	1 watershed, 7.6 square miles; gaging by Calif. Dept. of Water Resources.
Alaska Forest Research Center (Juneau, Alaska).	Young Bay, Admiralty Island, Alaska.	Broad-crested weirs	2 watersheds, 2,500 and 3,000 acres.
Agricultural Research Service (stations operated by Soil and Water Conservation Research Division except as noted in remarks).	Cohocton, N.Y	1:10 broad-crested V-notch weir.	Switzer Creek Watershed, 2,215 acres.
	Dutchess County, N.Y	1:10 and 1:2 broad-crested V-notch weirs.	Millbrook school, 76 to 1,570 acres.
	College Park, Md	H-type flumes	
	Watkinsville, Ga	1:5 broad-crested V-notch weir.	1 drainage area, 19 acres.
	Blacksburg, Va	H-type flumes; 1:2 broad-crested V-notch weir; rectangular culverts with Virginia V-notch low-flow controls.	Culvert stations at widely dispersed watersheds; drainage areas, 185 to 2,000 acres.
	Monticello, Ill	1:5 broad-crested V-notch weirs.	2 drainage areas, 46 and 82 acres. Operated by Agr. Engin. Dept., Univ. of Illinois.
	East Lansing, Mich	H-type flumes	Operated by Michigan Agr. Expt. Sta.
	Coshocton, Ohio	Dual Parshall flumes, with 15-foot main throat and 1-foot low-flow throat; Columbus deep-notch low-flow control at current meter-rated section; 1:5 broad-crested V-notch weirs; H-type flumes of several sizes.	Drainage areas of 1 to 17,500 acres.
Agricultural Research Service (Continued).	Moorefield, W. Va	4.5-foot H-type flumes	4 drainage areas, about 10 acres each.
	Fennimore, Wis	1:3 and 1:5 broad-crested V-notch weirs.	23- to 330-acre drainage areas.
	LaCrosse, Wis	Trapezoidal flumes	About 3-acre drainage areas.
	Colby, Wis	1:5 broad-crested V-notch weir	1 drainage area, 345 acres.
	Stillwater, Okla	Rectangular highway culverts equipped with weir sill for low-flow measurement.	16- to 206-acre drainage areas.
	Cherokee, Okla	H-type flumes	About 5-acre drainage areas.
	Riesel, Tex	15-, 10-, and 6-foot Parshall flumes with Columbus deep-notch low-flow control; Columbus deep-notch low-flow control at current meter-rated section; H-type flumes.	Drainage areas of 3 to 4,400 acres.
	Hastings, Nebr	1:3 broad-crested V-notch weirs for low-flow control at current meter-rated sections; H-type flumes.	Drainage areas of 3 to 4,400 acres.
	Safford, Ariz	1:3 and 1:5 broad-crested V-notch weirs.	Drainage areas of about 700 acres.
	Tombstone, Ariz	Tombstone critical-depth flumes.	Drainage areas, 360 to 28,100 acres; capacity of largest flume, about 18,000 c.f.s.
	Albuquerque, N. Mex	1:3 broad-crested V-notch weirs.	Drainage areas, 40 to 170 acres.

PARTIAL LIST OF STREAM-GAGING STATIONS BEING USED FOR RESEARCH ON SMALL WATERSHEDS IN THE UNITED STATES—Continued

Operating agency	Location	Type of gaging station	Remarks
Agricultural Research Service (Continued).	Santa Rosa, N. Mex	Tombstone critical-depth flume.	1 drainage area, 42,900 acres; capacity of flume about 18,000 c.f.s.
	Oxford, Miss	Current meter-rated stations; H-type flumes; trapezoidal flumes.	Flumes on areas of less than 5 acres; current meter-rated stations, 100 acres to 117 square miles.
	Newell, S. Dak	Water-level recorders on large-capacity stock ponds.	Drainage areas of 30 to 1,110 acres.
	Danville, Vt	1:10, 1:5, and 1:3 broad-crested V-notch weirs; current meter-rated section.	Drainage areas of 150 to 27,500 acres.
School of Forestry, Penn State University (University Park, Pa.).	Leading Ridge Watersheds and Shale Hills Watersheds, near State College, Pa.	Combination 90° V-notch and Trenton control weirs; combination 4.5-foot H-type flume with sharp-crested 60° V-notch weir; composite 30°–150° sharp-crested V-notch weir; sharp-crested parabolic-notch weir.	6 watersheds, 25 to 300 acres; in cooperation with Pa. Dept. of Forests and Waters and Northeast. Forest Expt. Sta.
U.S. Geological Survey	Tar Hollow State Park, Ohio.	V-notch weir, wide-angle, broad-crested, rated.	1 forested watershed, 1.5 square miles.
	Lebanon State Forest, New Jersey.	Trenton-type weirs	2 watersheds, about 1,500 acres each; in cooperation with N.J. Dept. of Conserv. and Econ. Devlpmt. and Rutgers Univ.
Tennessee Valley Authority (Knoxville, Tenn.).	White Hollow Watershed, Union County, Tenn.	Modified Albany weir	1 watershed, 2.68 square miles; calibrated in TVA laboratory.
	Pine Tree Branch, near Lexington, Tenn.	Columbus deep-notch weir	1 watershed, 88.2 acres.
	Parker Branch Research Watershed, near Asheville, N.C.	Modified Albany weir	1 watershed, 966 acres; in cooperation with North Carolina State Col.
	Western North Carolina Research Watersheds, near Waynesville and Asheville, N.C.	2-foot H-type flumes; $1\frac{1}{2}$-foot San Dimas flumes.	4 watersheds, 3.7 to 5.6 acres; in cooperation with North Carolina State Col.
	North Citico Creek, near Tellico Plains, Tenn.	Rectangular weir, 66 feet long by 3 feet deep, with low-water section, 10 feet by 1 foot.	1 watershed, 7.04 square-miles; in cooperation with U.S. Forest Service.

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