Peak-Flow Data-Collection Methods for Streams in Arid Areas

ERNEST D. COBB

This paper describes methods of determining peak streamflows in arid areas, where unstable channels and ephemeral flows characterize many streams. Where these exist, special methods of obtaining peak flows are needed. Usually, flow is determined from a recorded stage and a relational curve of stage and discharge. In unstable channels, it may be difficult to obtain a peak stage because the flow may move horizontally away from the gage, or the sediment in the flow may bury the stage sensor. If the peak stage is measured, the flow may be difficult to determine because of the unstable rating. As a result, the peak flow determination for streams with unstable channels commonly has a high degree of uncertainty. A variety of techniques are used to reduce the uncertainty of peak-flow data. A variety of instruments that are used to measure a peak stage, streambed elevations, and velocities can improve data collection in some, but not all, streams. Attempts can be made to stabilize some channels in the area of measurement. Systems that alert field personnel when stream flow is high allow time for site measurement of discharge and verification of stage measurements. Ephemeral streams create special problems in maintaining the equipment during the dry season so that it will operate during periods of flow. Also, human activities such as bridge maintenance in the dry channels can add to the instability of the channel.

The purpose of this paper is to discuss methods used in determining peak streamflow in arid areas and conditions unique to collecting peak streamflow data in these areas. Some common characteristics of streams in arid areas are that many of them have unstable channels and that they frequently go dry. Gaging streams in arid areas with stable channels is in many ways no different than gaging those in humid areas.

A usual method for determining the peak flow at a site is to develop a stage-discharge relation (as shown in fig. 1), determine stage of the peak, and, from the relation, determine the peak discharge (*1, 2*). In streams with unstable channels, the stage may be difficult to monitor, adequate discharge measurements may be difficult to obtain, and the stage-discharge relation is unstable. The uncertainty of the peak flow is therefore often much greater for streams in arid areas than for streams in other areas.

Because the method of determining the entire flow hydrograph is often similar to that of determining the peak flow, this paper will generally refer to methods of collecting flow data in streams with unstable channels. It is also noted that there is an increasing demand to define discharge for the entire hydrograph.

U.S. Geological Survey, WRD, Reston, Virginia 22092.

GAGE-SITE CONSIDERATIONS

The location of the gaging site will be restrained by where the data are needed. This limits the stream reach that can be considered. Access and stream-channel characteristics are of primary concern within this reach. The gage site needs to be accessible under most conditions so the gage can be maintained, discharge measurements made, and data can be obtained from the gage. Channel and control stability are highly desirable features for a gaging station. There also needs to be a place nearby where discharge measurements can be made. If at all possible, the flow will be in a single narrow channel at all stages to provide for a sensitive rating.

Bridges are frequently selected as gaging sites because of easy access and because the bridge can sometimes provide a stabilizing effect on the stream channel. Furthermore, a bridge can sometimes provide a place from which to make a discharge measurement and on which to mount the gage structure.

On the other hand, bridges can, in places, create situations that are not hydraulically acceptable for a gage. Drift tends to collect on piers and the bridge may be at a large angle to the flow, which makes it difficult to take measurements. High velocity flow through bridges may accentuate scour in the measurement section.

There may be regulations against mounting a gage structure on a bridge, and bridge traffic can make for measurement hazardous if traffic is heavy and (or) the bridge is narrow.

Sometimes a gage is placed on or at a bridge, but, because of regulations that restrict work on the bridge, safety problems, or problems with flow conditions at the bridge, high-water discharge measurements are made from a boat or a nearby cableway.

It is important that all flow past the gage be in a single channel. If it is in two or more channels, the stage record obtained in one of the channels may not be representative of the stage or discharge in the other channels.

The flow should be tranquil past the gage, if at all possible. Fast, turbulent flow may result in pileup or drawdown at the sensor, and this can create problems in getting an accurate stage record.

An ideal gage site is seldom found, especially in unstable channel streams. Cost may be an overriding factor in site selection, and compromises often must be made with many of the factors that make a gage site desirable. Commonly, there are no sites on a stream reach having all, or even most, of the desired characteristics; and the best site is selected with little regard for cost.

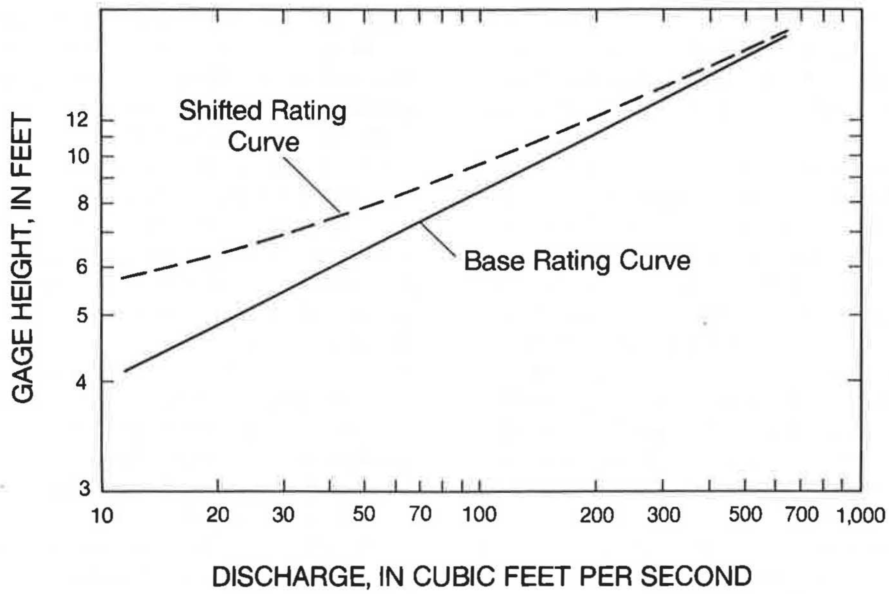

FIGURE 1 Base rating curve and a rating curve resulting from aggradation of the stream channel.

STAGE MEASUREMENT

Probably the most common method of monitoring stage is with a float and recorder in a stilling well (*2, 3*). The well may have openings directly to the stream, it may have intakes from a well set in the bank to the streamflow as shown in figure 2, or the bottom of the well may be open to the stream.

Streams in arid areas commonly transport large sediment loads. Stilling wells that are directly open to the stream may quickly fill with silt and have to be cleaned frequently. Wells with intakes can have problems with the intakes becoming buried or filled with sediment. Stilling wells are usually constructed with a sump or storage area below the lowest intake to hold the sediment that accumulates between cleanings. A trap may also be located in the intake system to collect the sediment before it gets into the well. Wells with the bottom open become plugged only if the channel fills with sediment around the gage.

Well intakes may be cleaned out with a special flushing system attached directly to the intake pipes. At times, the

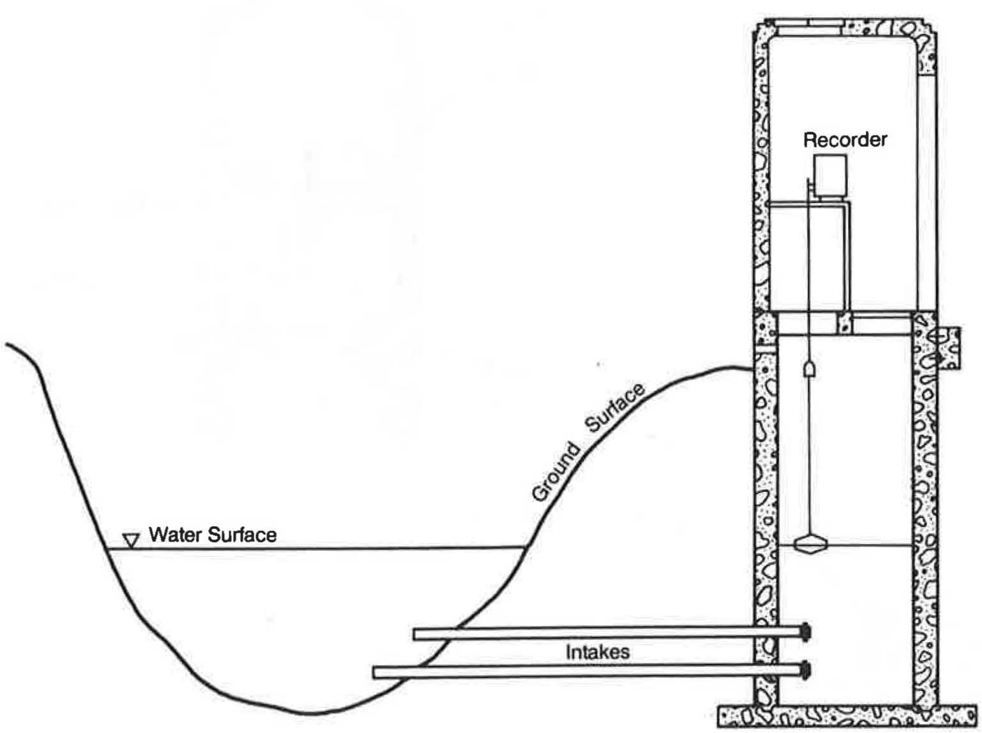

FIGURE 2 Typical stilling well with intakes installation.

intakes and wells are both cleaned out by pumping water directly into the well until the pressure of the increasing hydraulic head forces the sediment out of the pipes. Sometimes, the sediment in a well must be bucketed out of the well.

Another method of monitoring stage is to use a bubbling gas system and a manometer (*2, 3*). The system bubbles gas through a line into the stream, as shown in figure 3, while the manometer measures the back pressure resulting from the head of the water over the bubbler orifice. This system has some obvious advantages over the stilling-well system. There are no intake pipes or stilling well to fill with sediment. If the bubbler orifice becomes buried, it is a relatively easy matter to move the orifice. A related advantage is that the orifice can readily be relocated if the flow moves laterally across the channel. The use of the bubbler-manometer system is a common method of measuring stage in streams with unstable channels.

A system designed for storm sewers (*4*) is being investigated by the U.S. Geological Survey for use in open channels, which, if accepted, will replace the manometer. This system uses a pressure transducer instead of a manometer to measure the back pressure from the stream.

Crest-stage gages (CSGs) are used to determine the peak stage or to confirm the peak stage obtained by the recording system (*2, 3*). This is especially recommended with bubble gages. The CSG usually consists of a 2-inch pipe with a stick inside fixed on a pin of known stage. Ground cork located in the bottom of the CSG floats as water enters the gage through holes in the bottom of the CSG. The cork adheres to the stick at the highest stage and remains there as the water stage recedes. The CSG is an economical way of obtaining a peak stage and has been used extensively on small streams throughout the United States. The use of a CSG by itself will provide data only on the highest stage reached by the stream. Frequently the hydrograph is desired, and for this a continuously recording system is needed.

The Geological Survey uses an ultrasonic ranger at some sites that have large sediment loads. The ultrasonic ranger, shown in figure 4, is a device that sends an ultrasonic signal from a transmitter mounted on a bridge or other suitable structure to the water surface. The returning, or "bounced" signal, is monitored, and the time the signal travels is a measure of the distance of the water surface below the sensor. There are a variety of similar commercial devices on the market. The ultrasonic ranger is accurate to about 0.1 foot and can measure stages up to 35 feet below the sensor. When the sensor is at its maximum distance of 35 feet above the water surface, there must be a 13-foot diameter clear water-surface area under the sensor, as shown in figure 4.

The ultrasonic ranger has the advantage of not having any equipment in the water; therefore, it cannot be filled with or buried by sediment. The device can be mounted on a bridge, it can be suspended from a cable, or it can be placed on a cantilever over the stream. On all but the cantilevered device, the sensor can be readily moved across the channel so that it is directly over the water surface if the flow moves laterally.

Another device similar to the ultrasonic ranger is being tested by the Geological Survey. The device uses millimeter waves, and its accuracy is about 0.01 foot—more accurate than the ranger. The cost is higher than the cost of the ranger unit. Insufficient testing has been done with this unit to determine all its characteristics, but it appears to be promising.

It is desirable to confirm the peak stage, where possible,

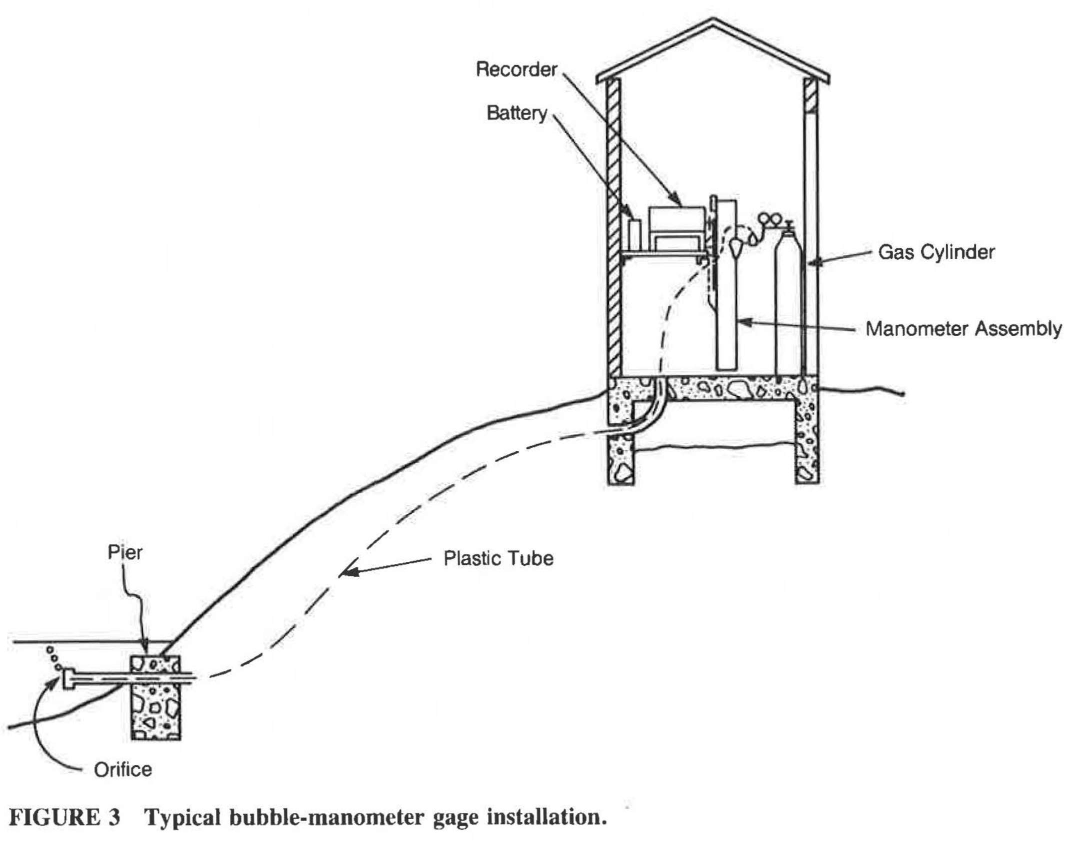

FIGURE 3 Typical bubble-manometer gage installation.

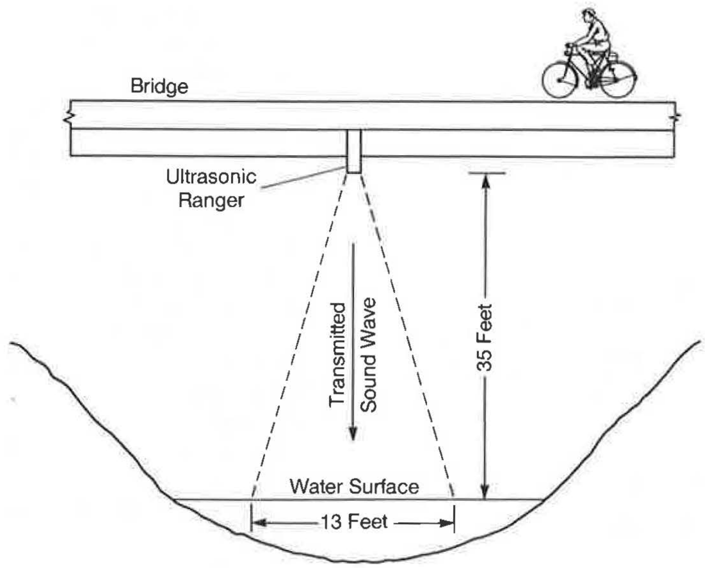

FIGURE 4 Ultrasonic ranger.

by checking for outside high-water marks, such as drift lines, and determining the elevation of any observed marks. This provides confirmation that the equipment was operating properly during the high-flow event.

Sometimes an observer is hired to read the gage or to provide information on high flows so that a stream gager can go to the gage to make a measurement. Such observers can act as a deterrent to vandals and can also notify the person responsible for maintaining the gage if there is a malfunction of the equipment or if other problems with the gage are detected.

Data-collection platforms (DCPs) can be useful in providing a central office with near real-time data on the stage of a stream at a remote site. Many Geological Survey offices query the stage at all stations with DCPs in their area each morning to determine the stage and the operating condition of the gage. This prompts the field person to visit the gage when the stage data from the DCP indicates high stages at the stream site or that the stream is rising. The DCP data also alerts the field person that a visit to the station may be needed for maintenance or repair.

One problem occurs with gaging some streams that have unstable channels when the flow moves laterally in its channel. This is commonly a problem at low flows, but it can also be a problem at high flows on some streams. There are a variety of ways to handle this problem. One is to dig a trench from the flow to the gage intake or orifice; another is to locate several stilling wells across the stream channel to try to have one where the flow will be. Bubbler orifices can be readily moved to where the flow is. If the gage is an ultrasonic device mounted on a bridge, it can be moved easily to a point over the water.

STREAMBED MEASUREMENTS

The stage of the water surface of some streams may not be a good indicator of the flow in that stream because the streambed may be filling and scouring. Streams have been observed where the flow changed drastically while the water-surface stage remained fairly constant as a result of scour or degradation of the streambed. In these situations, unless the streambed elevation, or depth, can be monitored, there is little hope for relating flow to a stage observation alone.

Two very similar devices to monitor streambed elevation have been developed. Both devices consist of pipes mounted vertically in the stream channel with the bottom of the pipe buried in the channel. Both devices mount sensors at selected intervals throughout the length of the pipe. One device uses conductivity sensors, and the other uses a device that puts out a heat pulse that is then monitored to determine its die-off characteristics. Both devices assume that the sensor will detect different responses if the sensor is in water rather than if it is buried in sediment. These devices are still being tested.

A limitation to these devices is that they monitor the bed elevation only at the location of the monitor. They can also interfere with the flow, resulting in local scour around the sensor. On some streams, this may be representative of the entire streambed, but on others it may not be. One way to determine what is going on with the streambed in a more general way is to place several monitors across the channel. This can be expensive, however, and also can require considerable data storage.

Various sounding devices using acoustic or ultrasonic signals have been used to monitor streambeds. This is usually done only when a person is at the site to operate the equipment. The author is not aware of any field sites where such equipment is operated on a continuous basis without an operator present.

It has been suggested that an ultrasonic velocity meter, as shown in figure 5, used to send a signal across a stream to measure water velocity also has a signal component that bounces off the streambed. This signal component could be monitored to provide a measure of the streambed elevation. This methodology has not yet received much study. The method would monitor the bed elevation primarily near the center of the stream.

Another factor that affects the stage for a given discharge is the bed regime of the channel (*2*). It has been suggested

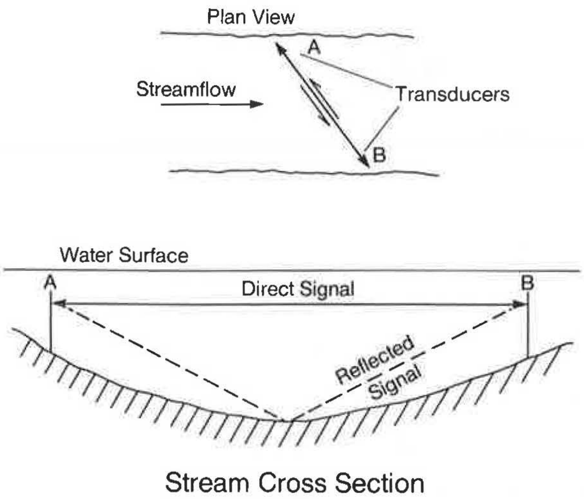

FIGURE 5 Ultrasonic velocity meter.

that time-lapse photography of the stream surface could provide clues to what is happening to the stream-bed. Sand dunes on the bed create boils in the water surface, whereas a plain bed will have a smooth water surface. Other bed features also provide their imprint on the water surface.

DISCHARGE MEASUREMENTS

Unstable channels present difficulties in making discharge measurements. The streambed can change significantly while a measurement is being made, adding uncertainty to the measurement. Conventionally, velocity observations are made at 0.2 and 0.8 depths and averaged or, for shallow depths, at the 0.6 depth to represent the average velocity in a vertical. This is based on the assumption that there is a normal vertical-velocity distribution, as shown in figure 6. The presence of sand dunes and holes in the streambed add uncertainty to assumptions concerning the vertical-velocity distribution. Instead of making observations at the 0.6 depth or the 0.2 and 0.8 depths, it may be necessary to make additional velocity observations in the vertical section.

Debris can also be a problem when making a measurement but, in general, it is no more a problem in a stream with an unstable channel than it is in other streams. In the case of either a fairly rapidly changing streambed or of heavy debris, the field person may use short-cut methods when making a discharge measurement. This involves reducing the times for velocity observations and using fewer sections for depth and velocity observation. In such cases, the measurement should be repeated using different verticals to measure depth and velocity.

Unstable channels can present safety hazards for personnel making discharge measurements. If the measurement is made by wading, a scour hole can present a hazard. If a boat measurement is being made, turbulence from various bed forms can create hazardous navigation conditions, which, in turn, usually makes for poorer quality measurements.

Some surface-velocity measuring devices have been developed. The devices measure the velocity of the water surface, and a coefficient is applied to obtain a mean velocity in the vertical. One such device, an optical current meter, uses a system of rotating mirrors to fix on floating objects (*2*). The speed of rotation of the mirrors is adjusted so that the objects appear to stand still. The speed of rotation is proportional to the velocity of the floating object. Consideration is being given in the Geological Survey to the use of radar guns, similar to those used by law enforcement agencies to check the speed of cars, for use on floating objects in the water.

In some streams, dilution methods of flow measurement can be used effectively (*5*). In this method, a tracer is injected into the stream at a constant rate, and after it has mixed with the flow samples are taken at a downstream location. The flow is determined by measuring the dilution of the tracer. This method does not depend on knowing the channel shape or having smooth uniform flow. In fact, turbulence is desirable since it promotes mixing of the tracer in the total flow. This method has been used for making discharge measurements, but not much has been done with this method to continuously measure the flow of a stream. Fine sediment affects some tracers and reduces their effectiveness for discharge measurements. In addition, the amount of tracer required for continuous measurement may be cost prohibitive for all but very small streams. It is likely the method of continuous measurement using tracers may be usable only on a few streams.

Indirect measurements of peak flow are often made when it is not possible to obtain a direct observation of flow at or near the flow peak (*2, 6*). The lack of a direct measurement may be the result of not being able to get to the site; or it may be that the flow is too turbulent or the physical facilities to make a measurement are not available, as when a bridge used for measuring has washed out.

Making indirect measurements depends on knowing about the channel geometry, the hydraulic roughness of the channel and, in some cases, the water slope of the stream at the peak. Conventionally, high-water marks are found along a reach of stream on both banks and surveyed in for location and elevation. These marks are used to determine stage, water-surface slope, and for contracted-opening type measurements,

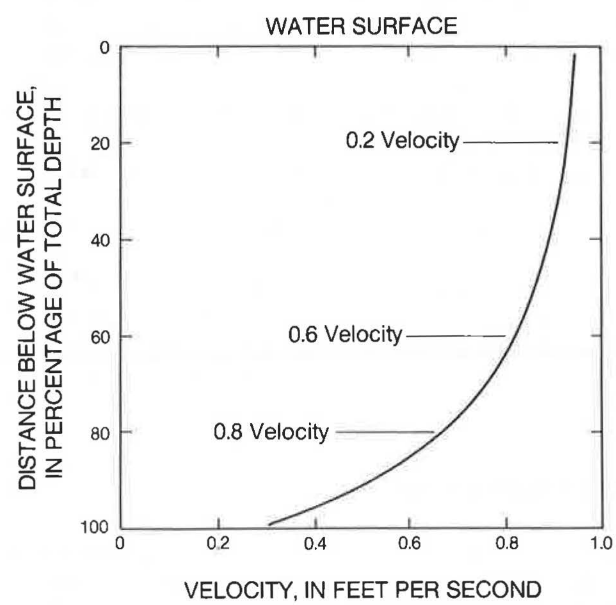

FIGURE 6 Typical vertical-velocity curve.

the hydraulic head drop through the contraction. A series of CSGs can be used to help obtain high-water marks in a stream reach, established in advance for indirect measurements.

Unstable channels add uncertainty to indirect measurements. There is commonly some question as to where the streambed was at the time of the peak. The n-value (roughness coefficient) for movable-bed streams is not accurately known. The bed forms at the time of the peak and the effect that they might have on the channel roughness coefficient are usually not known. Nevertheless, the peak-flow determination may have to depend on an indirect measurement. In that situation, the user needs to be aware of the factors affecting the accuracy of the peak-flow determination.

STAGE-DISCHARGE RELATION

The stage-discharge relation may shift considerably in an unstable channel (*1, 2, 7*). Usually the channel shifts most at high flows, but the impact of the shifted channel is most noticeable on the low-flow rating curve, as shown in figure 1. The effect, however, can be substantial on the high-flow rating as well. In order to define these shifts, many discharge measurements may be needed. If a number of peaks occur between discharge measurements, the uncertainty of the flows between peaks may be greatly increased.

At times, the shifting may be so great that there is no definable stage-discharge relation. When this occurs, the gage may need to be moved or the flow determined entirely from discrete discharge measurements, which requires many measurements.

STREAM CHANNEL AND CONTROL STABILIZATION

In most streams with unstable channels, it is not practical to install a laboratory weir or flume. One is usually content to simply stabilize the channel or control section affecting the stage-discharge relationship.

Usually, concrete controls are not used in unstable channels because there is a tendency for the underlying material to settle or move; this causes the control to crack and fail. There also is a tendency for the water to undercut the downstream side of the structure and thus cause the structure to fail unless deep cutoff walls are constructed. Gabions can be used successfully in some channels; however, they are not successful in channels where material underlying the streambed is unstable for tens of feet under the surface. Gabions should be placed so they do not create much of a fall of water over the gabion or so that undercutting will not occur on the downstream side of the gabions; otherwise the gabions could sink into the resulting scour hole. Gabions, as well as any other material or structure, should be keyed well back into the stream banks to prevent a washout around the ends of the gabions. The lack of adequate keying into the stream bank is a common cause of failure of stabilization efforts.

Sheet piling can be used on some streams to help stabilize the channel. Again, the pilings should be keyed deeply into the banks to prevent washouts around the ends of the piling. Such sheet piling weirs should be placed low in the channel with a minimum of fall in the water surface, and they should be designed for submergence at high flows.

A dual-weir concept has been used at some installations using sheet piling or other material as the structural component. The idea is to use an upstream and a downstream weir with the downstream weir lower than the upstream weir. The flow over the upstream weir creates increased turbulence that keeps the space between the weirs free from deposited sediment. The water surface is measured between the weirs with the downstream weir being the rated weir. A problem with this approach is that the dual weirs behave differently for different flows. For example, at low flows the spacing between weirs may be great enough for deposition of sediment to take place and for the flow between weirs to be fairly calm. At higher flows, the water between the weirs may be turbulent; this keeps the sediment from depositing between the weirs but makes it difficult to measure the stage between the weirs. The spacing should be planned for the flows of greatest interest. The dual weir concept is acceptable for small to intermediate size streams, especially streams with stable material near the surface of the bed.

When streams need to be gaged where the flow meanders back and forth across the channel, channel stabilization measures are to be avoided. Aside from cost, there is increased probability of the stream washing around the sides of the stabilization structure.

Concrete weirs and flumes can be placed in some unstable channels (*8*). For all but very small streams, the cost is likely to be high and there will be increased backwater (increased heads) upstream from the structure.

EPHEMERAL STREAMS

Ephemeral streams can create special problems for obtaining flow information. During the dry season, channels near bridges are sometimes worked in with tractors doing bridge maintenance work, thereby changing the stage-discharge relation established at an earlier time. Insects and other small creatures tend to get into dry wells, intakes, and orifices, plugging them so they do not work when flows occur. If there is a distinct seasonal flow, as there is on the west coast of the United States, the station may be visited and made ready to operate near the end of the dry season but before flow is expected.

Ephemeral streams are often flashy, that is, flow quickly peaks and recedes. This makes them difficult to get to during a flow event and may make it difficult to obtain a discharge measurement.

DATA UNCERTAINTIES

Peak-flow data for unstable streams in arid areas may contain large uncertainties. The reasons for these uncertainties include the following:

1. The stage-discharge relation is unstable.
2. A continuous stage record cannot be obtained because—
   a. the flow moves away from the gage,
   b. the stilling well fills with silt, or
   c. the intakes or orifice are covered with silt.
3. The flow at the gage is in multiple channels.

4. Scour occurs around bridge piers and debris accumulates on bridge piers where discharge measurements are made.
5. The vertical-velocity distribution is not normal when a discharge measurement is made because of sand dunes and scour holes in the measurement section.
6. The hydraulic roughness and the vertical location of the streambed are not well known, hindering indirect measurements.
7. Multiple peaks occur between discharge measurements, and the amount of change in the rating is not defined during these periods.

The following practices can be used to reduce these uncertainties:

1. Select a site with a relatively stable channel.
2. Stabilize the channel in the vicinity of the gage where possible.
3. Use a noncontact stage sensor such as an ultrasonic ranger, where large sediment loads are likely to fill a stilling well with silt or cover intakes and orifices.
4. Avoid making discharge measurements in the vicinity of bridge piers when possible.
5. Determine if the vertical-velocity distribution is normal, and obtain additional measurements of velocity in the vertical if it is not.
6. Continue to look for equipment that can continuously measure the bed elevation or depth of flow.
7. Inspect the gage and make discharge measurements more frequently.

In general, the determination of flow in unstable channels, which are commonly found in arid areas, is more expensive and the data contain more uncertainties than for stable channels.

SUMMARY

Streams in arid areas commonly have unstable channels, frequently are ephemeral, and, when flowing, transport large sediment loads.

A streamflow gage should be placed in the area of greatest channel stability. This, possibly more than anything else, will help to produce acceptable streamflow records.

Stilling wells and bubble gage-manometer systems are most commonly used for obtaining measurements of stream stage. The heavy sediment loads transported by many arid area streams can fill a stilling well with sediment or bury intakes and orifices. For this reason, gages that do not have to be in the water, such as the ultrasonic ranger, are sometimes used to measure stream stage.

Commonly, stream discharge is determined from a stage-discharge relation. In streams with severely unstable channels, such a relation does not exist. In such situations, it may be more appropriate to relate discharge to the depth of flow. A measure of the depth of flow can be obtained by measuring the stage of the water surface and the stage of the streambed. Some work has been done to measure the stage of the streambed with a scour meter. It also has been proposed that the signal reflected from the streambed by an ultrasonic velocity meter also may be used to monitor the stage of the streambed.

Streambed stabilization is sometimes possible on small- and medium-size streams. Usually, because of the large sediment load transported through the stream system, it is not practical to totally stabilize the channel in the area to be gaged. A dual weir is useful in providing a fairly stable stage-discharge relation in some streams.

Discharge measurements may be more complex on sand-channel streams with dunes and scour holes than on other streams. This is partly because the vertical-velocity curve is not normal, and additional velocity observations may be needed.

Many arid-area streams are ephemeral and are flashy, making it difficult to obtain discharge measurements. Dry stream channels near bridges commonly are disturbed by maintenance crews; this alters stage-discharge relations.

Many factors, such as shifting stream channels and buried sensors, increase the uncertainty in the measurement of stage and discharge in streams in arid areas. However, techniques and instruments such as the ultrasonic ranger and the scour meter have been developed to reduce these uncertainties.

REFERENCES

1. E. J. Kennedy. Computation of Continuous Records of Streamflow. U.S. Geological Survey, *Techniques of Water-Resources Investigations*, book 3, chap. A13, 53 p., 1983.
2. S. E. Rantz and others. *Measurement and Computation of Streamflow*. U.S. Geological Survey, Water-Supply Paper 2175 (2 volumes), 631 p., 1982.
3. T. J. Buchanan and W. P. Somers. Stage Measurements at Gaging Stations. U.S. Geological Survey, *Techniques of Water-Resources Investigations*, book 3, chap. A7, 28 p., 1968.
4. F. A. Kilpatrick, W. R. Kaehrle, J. Hardee, E. H. Cordes, and M. N. Landers. *Development and Testing of Highway Storm-sewer Flow Measurement and Recording System*. U.S. Geological Survey, Water-Resources Investigations Report 85-4111, 98 p., 1985.
5. F. A. Kilpatrick and E. D. Cobb. Measurement of Discharge Using Tracers. U.S. Geological Survey, *Techniques of Water-Resources Investigations*, book 3, chap. A16, 52 p., 1985.
6. M. A. Benson and T. Dalrymple. General Field and Office Procedures for Indirect Measurements. U.S. Geological Survey, *Techniques of Water-Resources Investigations*, book 3, chap AI, 30 p., 1967.
7. E. J. Kennedy. Discharge Ratings at Gaging Stations. U.S. Geological Survey, *Techniques of Water-Resources Investigations*, book 3, chap. A10, 59 p., 1984.
8. F. A. Kilpatrick and V. R. Schneider. Use of Flumes in Measuring Discharge. U.S. Geological Survey, *Techniques of Water-Resources Investigations*, book 3, chap. A14, 46 p., 1983.