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Channel-Forming Discharges

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What Is Channel-Forming Discharge?

Have you ever wondered why a stream is located where it is, is bigger or smaller than another stream, why it is crooked, or why some streams are wide and shallow while others are narrow and deep? The answers to these questions enable us to understand the origin and evolution of a stream system, which will help us to develop ways to protect, enhance, or sustain these complex and fragile ecosystems. Streams are constantly changing and, like any physical system, trying to create balance between all of the factors acting on them. The balance of constantly changing factors is called *dynamic equilibrium*. Two primary influences on the equilibrium of a stream system are the quantity and movement of both water and sediment. We call the movement of water or sediment *discharge*. The quantity and movement of both water and sediment tend to balance each other within the confines of the stream channel and this is what, ultimately, gives the stream bed and banks their shape or form. We also can call this movement

channel-forming discharge. The purpose of this fact sheet is to provide an explanation of channel-forming discharges, their importance to stream systems, and how they can be determined.

Factors That Give Stream Channels Shape

A natural stream running through the middle of a valley will have a main channel and a connected *active floodplain*—land closest to the channel that is flooded often (Figure 1). The channel carries water and sediment discharges through the system that is related to a specific, predictable amount of flow called the *bankfull discharge* or *effective discharge*. When the discharge is higher than the channel can hold within its banks, the extra water and sediment spills out over the banks and onto the floodplain. The active floodplain, if connected to the channel, helps to decrease the speed at which water is flowing and helps to maintain dynamic equilibrium so that the bed and banks are not washed away during a big storm event.

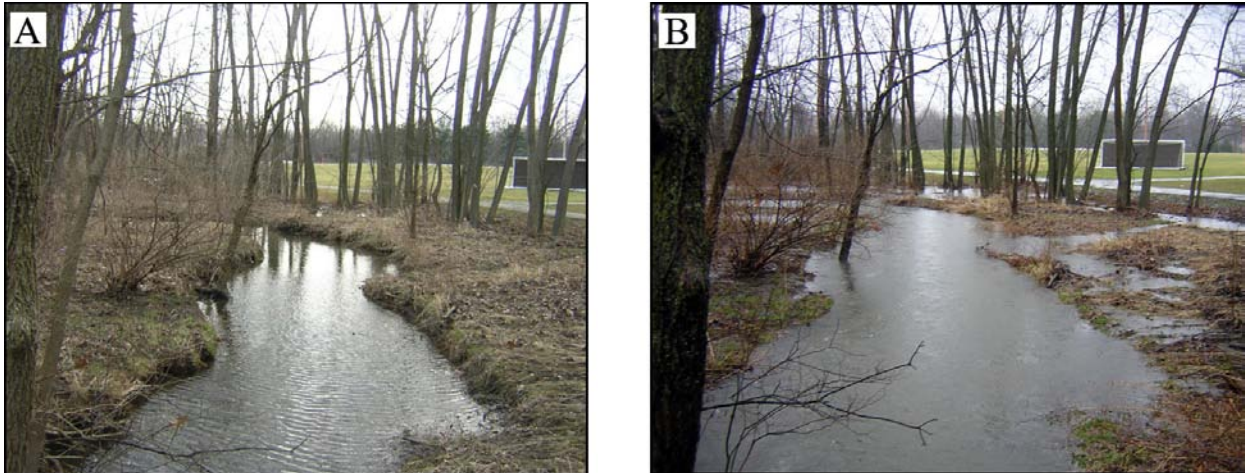


Figure 1. A small urban stream with a connected active floodplain containing less than the bankfull discharge; note the distinct shape and size of both stream banks. B: The same stream with a bankfull, or channel-forming discharge, after a rainstorm.

If we understand the balance between water and sediment discharges—or *fluvial processes*—we can begin to predict what happens to the stream when these factors are out of balance (Figure 2). For example, if higher water flow is not able to spill out onto the floodplain, it may be picking up sediment from the bed and banks. This is called *degradation* and can cause erosion and *scour* (Figure 2A, C). On the other hand, if water containing a lot of sediment is flowing very slowly because of a dam installed downstream, the heavier sediment particles will drop out of the water flow and deposit on the bed and banks. This is called *aggradation*, which is a build up of material (Figure 2B, D).

The *bankfull discharge* is often related to the amount of water flowing in a stream that fills the main channel and begins to spill onto the active floodplain^{1,2}. Bankfull discharge is a range of flows (volume per unit time) that is most important in forming a channel, floodplains (benches), and banks. When we talk about *bankfull discharge*, we also talk about the collection and/or analysis of data relating to the channel shape and size, or *dimension*^{3,4}.

The term *effective discharge* is the amount of water (again, volume per unit time) that transports the most sediment over the long term². When we talk about effective discharge we also talk about the collection and/or analysis of data related to the type and amount of sediment in that flow of water. This moving sediment is called the *suspended and/*

*or bedload sediment*⁵. Often, the terms *bankfull* and *effective discharge* are considered to be synonymous. For example, Leopold⁶ stated that bankfull discharge is “considered to be the channel-forming or effective discharge”. Powell and others⁷ found that, for large rivers in Ohio, the bankfull and effective discharge were often similar.

The term *bankfull* causes some confusion in some artificial, or constructed, channels such as agricultural ditches because the size of the ditch is unrelated to *fluvial processes*, or the size that nature would form naturally. In streams that are *entrenched* or *incised*, or too deep (this is common in urban and many rural settings), the bankfull stage is lower than the top of the bank and is identified as a bench, change in bank material and vegetation, the top of point bars, or a scour line. By taking measurements of the stream, we can predict the size and shape of the stream, or its *bankfull geometry*, when it is in equilibrium.

The force that flowing water exerts on the bed and banks of a stream channel is called *shear stress*. Shear stress is typically used to describe scouring or degrading of the bed and banks. Except on bends, it is related to the depth of flow of the water and the slope of the channel bed. The deeper the water, or the steeper the slope of the bed, the greater the force. For every place in a stream there will be some combination of water depth and bed slope that will cause the bed or banks to scour. A simple but approximate way of estimating when scour will occur is to use Andy’s

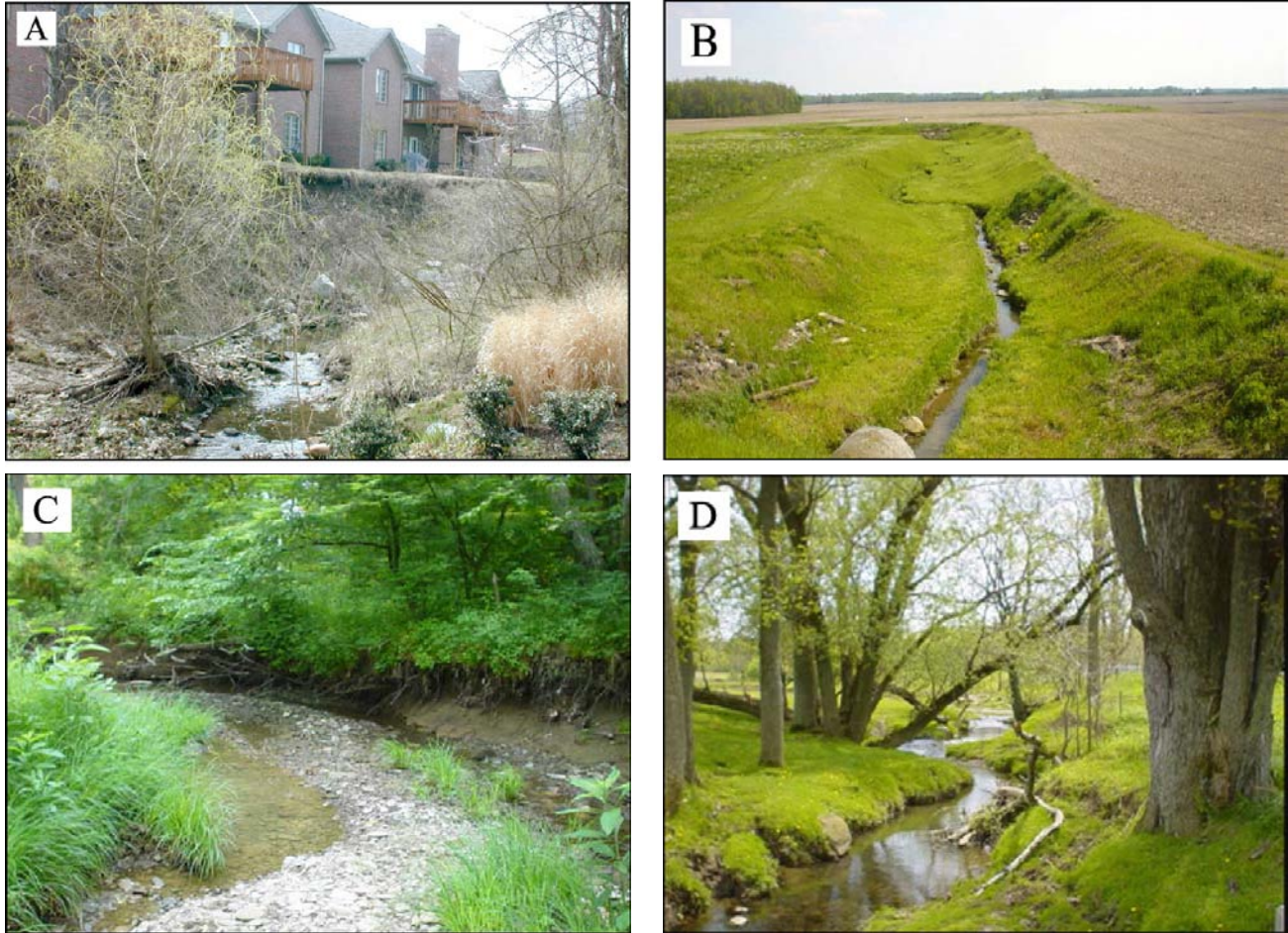


Figure 2. A: A deeply incised stream that is out of equilibrium due to urbanization. B: An agricultural ditch was built too wide and has naturally started forming a new floodplain and is changing its form to regain equilibrium. C: Aggradation of sediment, called a flat point bar, on the left is occurring to regain equilibrium; the point bar will continue to build up until it is at the same level as the connected active floodplain on the left side of the picture. D: An incised rural stream that has become unattached from its active floodplain, the pasture on either side of the trees.

Rule, which states, “if the depth of flow is 1 foot and the bed slope is 1% then the average size bed material that will start to move will be 1 inch.” If you use those particular units, multiplying depth and slope will give you the approximate sediment diameter. For example, if the depth of flow in the channel is 4 feet and the bed slope is 0.5% then the average size bed material (called the d_{50}) that will move with the flow of water will be 2 inches (4 multiplied by 0.5).

For many streams that are in equilibrium we will find, by using Andy’s Rule, that the average bed material size is related to the average bankfull depth and the bed slope. The method is not exact and in some cases the shear stress is better related to other factors. If there is no relationship between bankfull

depth, bed slope, and bed material size, it might be an indication that the stream is not in equilibrium. In a straight section of a stream (called a *reach*) average shear stresses on the banks are about 80% of those on the bed. On the outside of a bend, the shear stresses on the banks might be several times larger than those on the bed. This is the main reason why banks erode and streams shift their position.

What Data Do I Need To Determine Channel-Forming Discharges?

Obtaining highly detailed stream data, also called *surveying*, can be a time consuming and difficult activity, particularly in large rivers. Fortunately, useful guidelines for smaller, shallower streams—also

called *wadeable*—are available⁸. For each *reach*, data are collected over a stream length equal to at least 20 times the channel width so that the survey includes at least two bends in the channel. Channel width and depth measurements depend on an ability to correctly measure the location of the *bankfull elevation*. Signs of *bankfull elevation* in a stream can be found at the back of point bars, significant breaks in slope, benches, changes in vegetation, or at the top of the bank. Determining the bankfull elevation is not an easy thing to do and requires a lot of practice and good observation skills (Figure 3).

One channel width and depth measurements are taken at the *bankfull elevation*, data can be plotted on a graph (using a basic spreadsheet program like Microsoft Excel) and related to watershed size—or *drainage area*—for the channel. The relationship is indicated with a trend line, and an equation for predicting each component is generated. When many of these measurements from different locations are plotted on the same graph for the same watershed over a range of drainage areas, these relationships are called *regional curves* (Figure 4). To illustrate this idea we will use data for the Scioto River near Higby, Ohio, which has a drainage area at this location of 5,131 square miles. The measured bankfull width is 567 feet, the measured mean bankfull depth is 12.1 feet, and the bankfull cross-sectional area (width multiplied by depth) is 6,880 square feet. Using the regional curve for the Scioto River shown in Figure 4, the predicted (calculated using the equations on

the graph) bankfull width is 475 feet, the predicted mean bankfull depth is 14.1 feet, and the bankfull cross-sectional area is 6,710 square feet. It is not uncommon for estimates obtained from a regional curve and measured values to vary by 50% or more, so regional curves should be used with caution.

Determining the Bankfull Discharge

Discharge in a channel can be calculated by knowing just a few pieces of information. This is illustrated in the following sequence of equations. Discharge is calculated by knowing the cross-sectional area of the stream and the average velocity of the flowing water:

$$q = va$$

This is also called the *equation of continuity*, where q is the discharge (ft^3/sec), a is the cross-sectional area of the stream (ft^2) and v is the average velocity of flowing water (ft/sec). Bankfull velocities for low gradient channels (<2% bed slope) will usually be between 2 and 5 ft/s . At the Higby gage the bankfull velocity is about 4 ft/s . To determine the average velocity, v , you must know the slope, S , of the bed (ft/ft), the hydraulic radius, R , of the channel (ft) and something called a Manning's roughness coefficient, n . This velocity calculation is called *Manning's equation*:

$$v = \frac{1.49}{n} R^{2/3} S^{1/2}$$

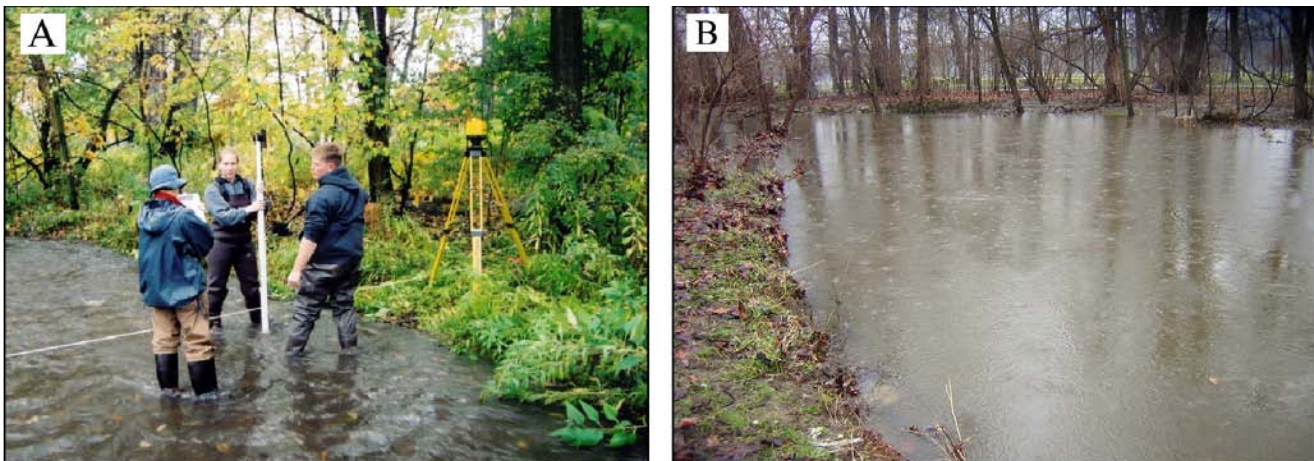


Figure 3. A: Measuring bankfull features in an urban stream. B: Bankfull flow in the same stream with water depths and currents that make taking measurements unsafe.

Manning's n is an indicator of how much resistance to flow a channel bed has and can be found in a hydrology textbook estimated from other equations^{9,10}. Most channels in Ohio will have a Manning's n value of 0.025 to 0.05. To calculate the hydraulic radius of the channel, R , you need to know P , the wetted perimeter (ft) of the channel cross-section (see Figure 5):

$$R = \frac{a}{P}$$

Determining the Effective Discharge

Effective discharge is related to the sediment transport rate (Figure 6). Low discharges—or smaller flow rates—associated with small storm events transport a small amount of sediment, and high discharges—or larger flow rates—associated with large storm events transport a very high amount of sediment (Figure 6A). However, the largest storm events producing the largest discharge flow rates do not happen very

often so the total sediment load carried over many years is very small (Figure 6B). Small storm events producing smaller discharge flow rates happen very often so the total amount of sediment carried is large (Figure 6B). When the frequency of a discharge event is multiplied by the rate at which sediment is transported for that frequency, we obtain Figure 6C, which is a measure of the total sediment load carried for that particular discharge. Therefore, in Figure 6C, the *effective discharge* rate, which carries the most sediment over time, is around 17,000 cubic feet per second (cfs) and is carrying 100,000 tons of sediment per year.

This approach for determining the amount of sediment moving through a system—also called *geomorphic work*—is known as the Wolman-Miller model¹¹. The reason the data do not all fall on the trend line in Figure 6A is because there are seasonal and annual changes in land use that affect a stream system. For example, a large storm producing a lot of

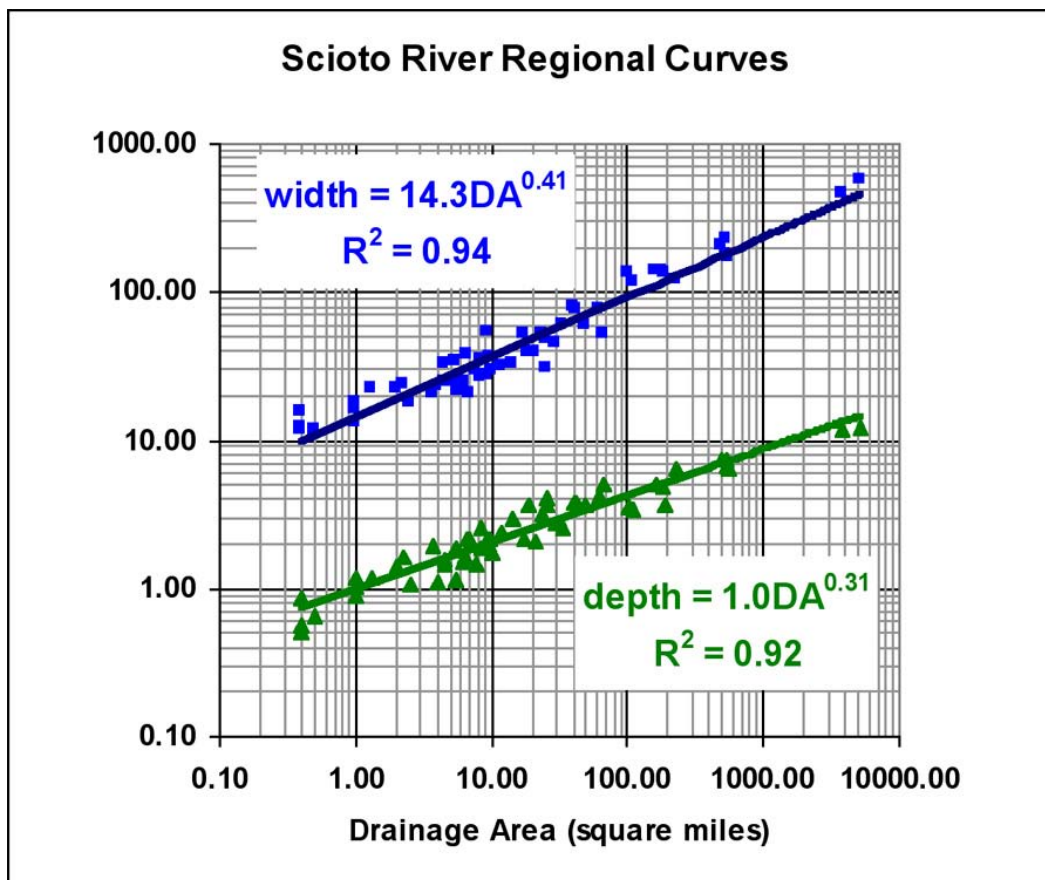


Figure 4. Regional curve for the Scioto River watershed near Higby, Ohio.

runoff during frozen conditions might contain little sediment while a much smaller storm producing runoff might contain high sediment loads from a recently plowed field or land disturbed by a development project.

How Often Do We Get Channel-Forming Discharges?

It is difficult to determine exactly how many times each year a channel-forming discharge will occur on a particular stream reach because we usually do not have detailed enough data to make those predictions. Based on an analysis of annual discharge data for humid and semi-humid regions, the channel-forming discharge generally may occur or be exceeded several times a year. The return period is the likelihood a storm event will occur or be exceeded. For example, the 10-year recurrence interval storm event has a 10% chance of occurring in any given year. In Ohio's streams, *bankfull discharge* may be associated with a return period that is less than the 1-year recurrence interval event⁷. However there are many streams where it is in the 1 to 2 year range, and some streams where the recurrence interval approaches 5 years. Information on the recurrence interval of channel-forming discharges should only be used as one piece of evidence in determining the bankfull characteristics of a channel.

Figure 7 shows recurrence interval information for discharges on the Scioto River near Higby, Ohio. Using the data in Figure 7, for an *effective discharge* of 17,000 cfs the regression lines predict RIs of 0.45 and 0.92 years. For an *effective discharge* of 26,000 cfs the two lines provide RIs of 1.1 and 1.3 years. Because of the limitations of data available or methods developed to analyze them, we advise caution in interpreting discharge and recurrence interval data. To illustrate this using the data for the Scioto River near Higby, Ohio, there are on average more than 24 days a year with discharges exceeding 17,000 cfs. Yet, in 1954 there were no daily discharges larger than 17,000 cfs while in 1996 there were 10 events, lasting a total of 73 days, which exceeded 17,000 cfs. As a general guideline, it should be expected that, for most streams and rivers in Ohio, flows exceeding the channel forming discharge would occur at least a few times annually.

What About Discharges That Are Not Channel-Forming?

A question that we might ask is, why do smaller or larger discharges than the *effective discharge* not form channels, banks, benches, and bars that are different than those associated with the stream channel? The answer to this question is not simple. There probably

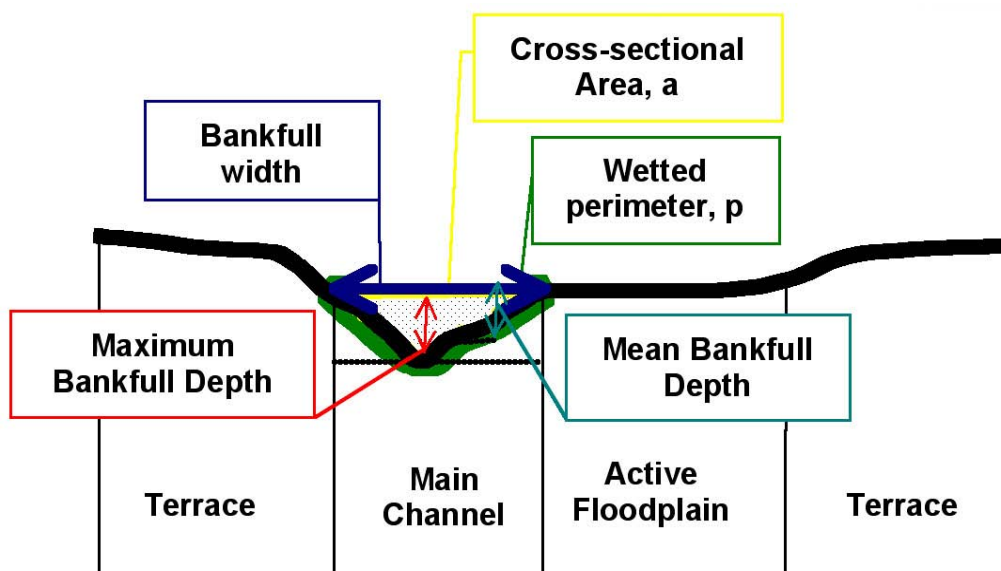


Figure 5. Cross-section of a channel with an active floodplain and terraces.

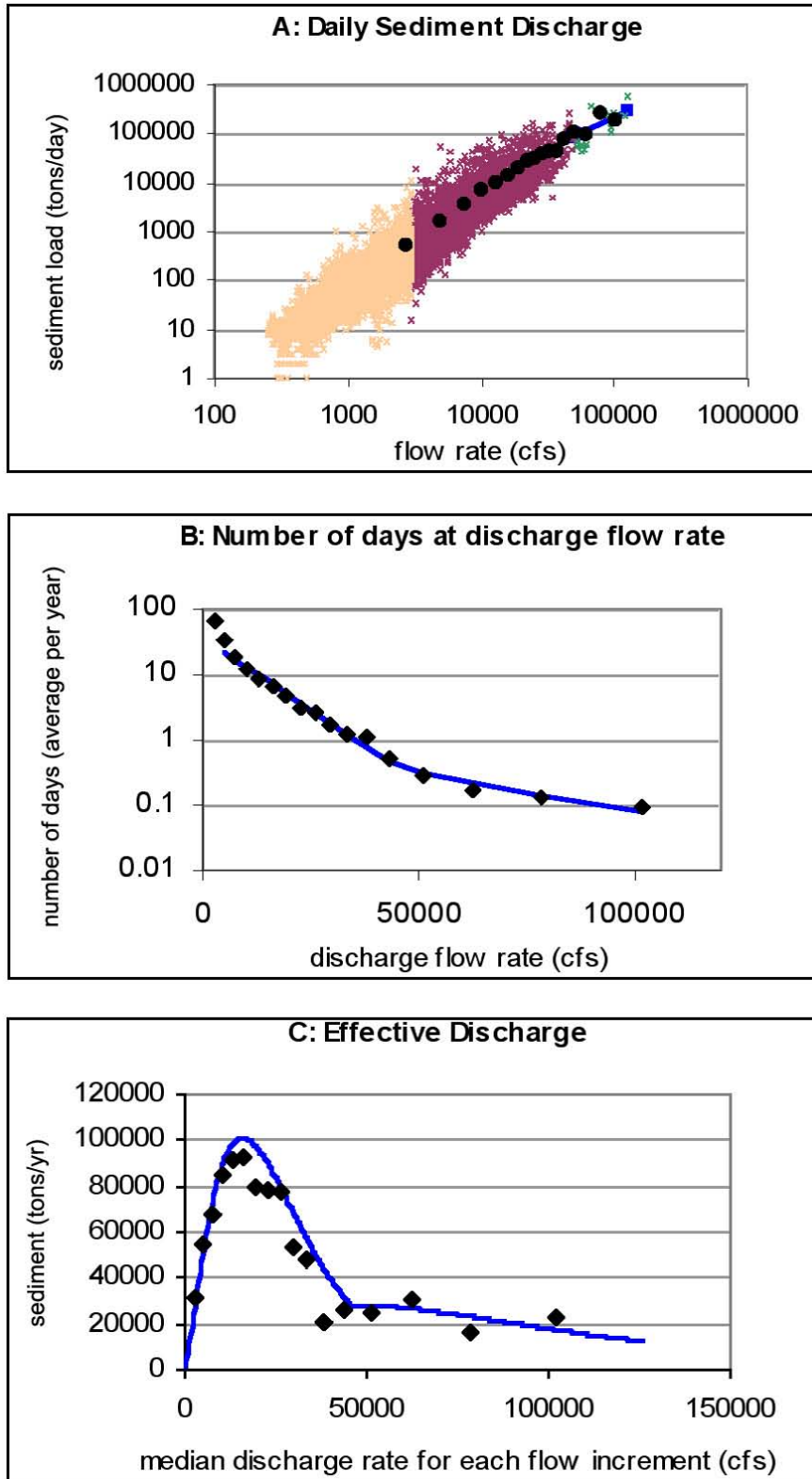


Figure 6. Illustration for Scioto River, Ohio, explaining that effective discharge carries the largest total sediment load. A: Plot of measured discharge and sediment data. B: Frequency of different median discharge rates. C: Plot of sediment load versus median discharge—the peak sediment load occurs at the effective discharge value.

is a wide range of discharges that have the potential to shape a river channel. For example, we have found in Northwest Ohio discharges associated with high subsurface drainage flows form a low bench in most agricultural drainage ditches. Why are similar features not formed in natural rivers or other ditches? First, very low discharges are ineffective in moving sediment and can only transport very fine material such as clay. If fine clays are not available, there will be little or no sediment transport. Second, the ability of these low discharges to scour the bed and banks of a channel also is very low. Third, if beds, banks, and benches are to be formed as primary features of the system, then there must be a way to effectively stabilize the deposited sediments so they do not eventually wash downstream. In the case of many agricultural ditches, vegetation provides stabilization and it grows very quickly on these features.

In a natural channel we might think of discharges lower than the effective discharge either: (1) being too small to scour and/or transporting sufficient sediment to create permanent features; or (2) occurring too frequently to allow the deposited materials to stabilize. Perhaps harder to understand and visualize is why discharges larger than the *effective discharge* do not scour and wash away the banks, benches, and bars. In places along a river system, extreme storm events

might cause bank instability problems, but on average, most channel and floodplain features that are in dynamic equilibrium have relatively stable banks and beds. Once balanced, they do not *aggrade* (build up due to sediment deposits) or *degrade* (downcut due to scour) because discharges larger than the effective discharge spread out across the floodplain, have low velocities when they flow across these features, and in the main channel have similar forces on the bed and banks to those produced by the *effective discharge*.

Why Is My Channel the Shape It Is?

We have seen that the size of a channel is related to the forces on the bed and banks, the size of the bed and bank material, the discharge that carries the most sediment over a long period of time, the bed slope, and the depth of flow associated with the channel-forming discharge. So, why are channels not the same shape?

In a pasture, where there are clay soils that are stabilized by dense grass roots, we might find a narrow but deep channel. In a woodland, where there are clay/loam soils and large sparse tree roots that anchor the soil, we might find a wide and shallow channel. The constant degrading and aggrading of stream beds and banks leads to bends forming in the channel and the channel, if not constrained by valley walls, to moving

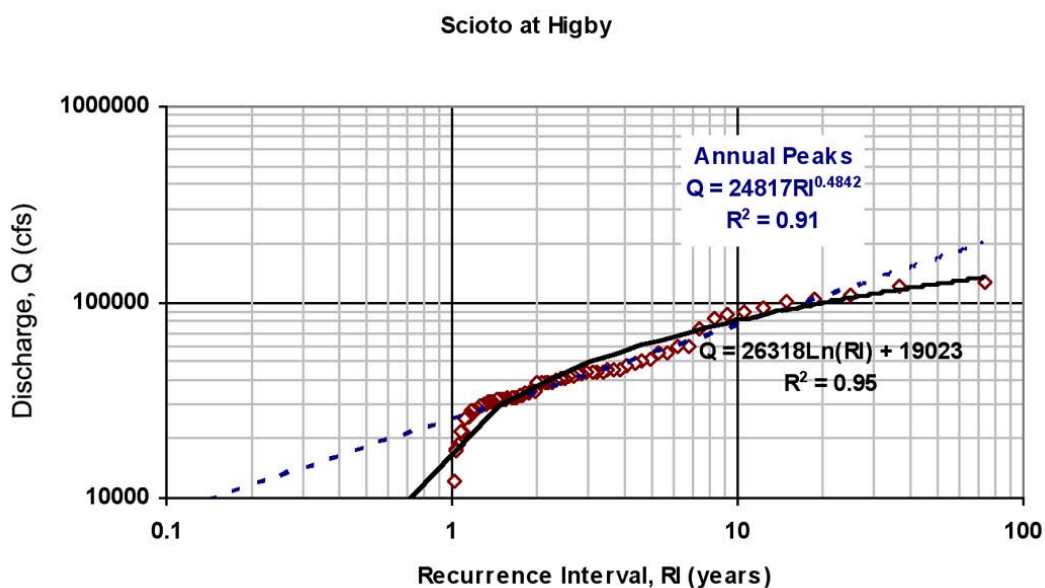


Figure 7. Discharge versus recurrence interval relationships at the Higby, Ohio USGS stream gage.

through a valley over time. This is mainly related to the resistance of the beds and banks to scour and the stability of the banks. Some materials will scour more easily than others. For example, if a channel bed has degraded to bedrock (this can be thought of as its foundation) it will have trouble getting deeper. To maintain dynamic equilibrium, the banks will scour and the channel will widen. In other cases, vegetation on the banks will help to stabilize the bank materials and it might be easier for the bed to scour than the banks. If we understand the balance between water and sediment discharges—or *fluvial processes*—we can begin to predict what happens to the stream when these factors are out of balance.

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