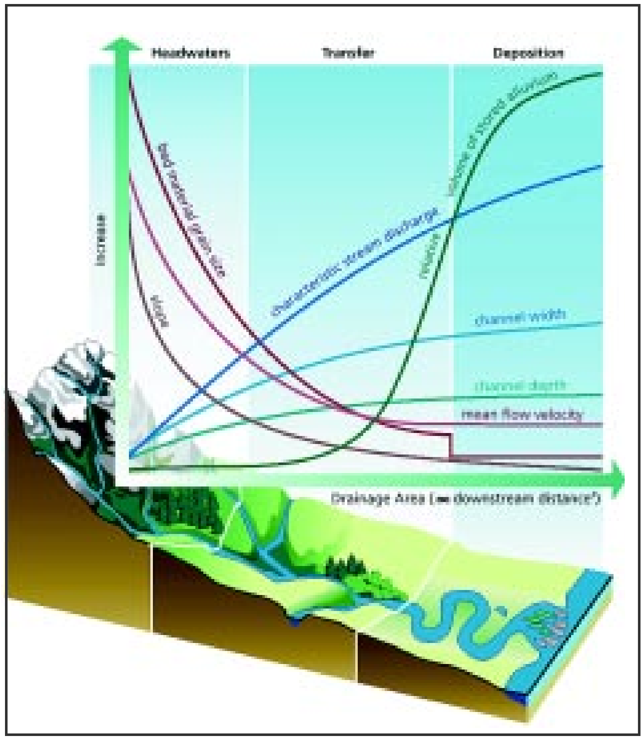
STREAM PROCESSES

A basic understanding of stream form and function is essential to good project design. The ability to recognize a stable stream, and understand causes of instability, is important for anyone who reviews, designs, and installs bridges, culverts, weirs, and other structures. These same skills play a crucial role in stream management, from riparian grazing to flood control.



In a general scheme, stream form and function can be divided into three broad categories:

Headwater Zone (sediment erosion)
Transfer Zone (sediment transport)
Depositional Zone (sediment deposition)

Headwater Zone (erosion)

- Headwater streams are frequently supply limited, meaning that they can carry more sediment than is available.
- Headwater streams are typically higher gradient, incised channels that carry sediment from slope and in-channel upland sources (Rosgen A-channel type).

Transfer Zone (transport)

- Transfer zone streams are usually characterized by wide, developed floodplains and meandering channel patterns (Rosgen B- and C-channel types).
- Transfer zone channels are moderate gradient, classic U-shaped glacial trough valleys.
- Channels can move large amounts of bed and bank sediments during peak flows.

Depositional Zone (deposition)

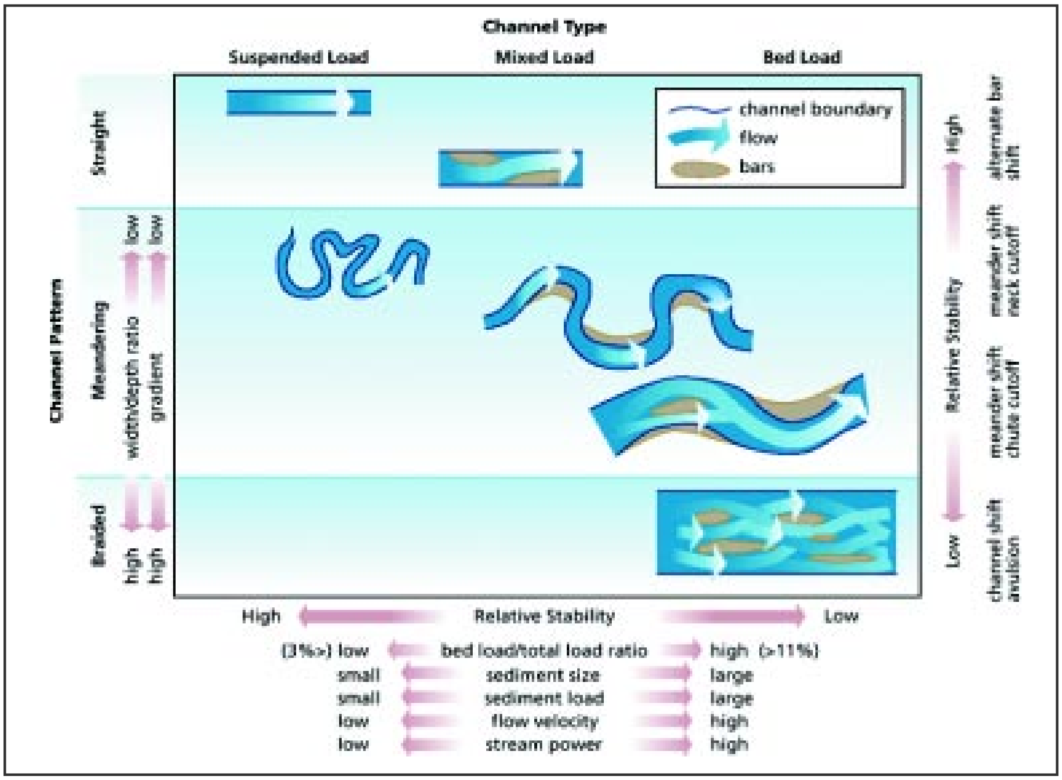
- Depositional streams feature a wide valley bottom, well-developed floodplains, and terraces (Rosgen C-, E- and D-channel types).
- This zone is functionally depositional, although significant transport through the valley bottom is also a dominant process depending on channel stability and channel type.
- The valley is typically flat, wide, and formed of glacial outwash (in glaciated terrains), and/or reworked stream and lake sediments.

In the depositional zone, channel stability is influenced by riparian vegetation more than in other zones, where terrain often confines the stream. Healthy riparian corridors usually enhance lateral stability and a stable meander pattern if there are no chronic sources of sediment, and if peak flows are within their natural range in terms of magnitude, frequency, and duration. A stable stream is one that maintains its general pattern and profile over time.

STREAM CLASSIFICATION

Schumm and Rosgen classification systems

The Schumm diagram shows how channel plan form is related to hydraulic variables and process. The two photographs below illustrate a shift in channel stability related to channel straightening; the shift is also marked on the Schumm diagram. This type of channel is classified as a C channel in the Rosgen System. The Rosgen System (next page) divides channels into seven main types (A to G).



From *Classification of Alluvial Channels*, Schumm, 1977.

This channel (Rosgen C4 type) shows good stability.

An adjacent reach shows signs of instability due to channelization up- and downstream.

Relative stability – Rosgen Type A

Good

Poor

Rosgen A channel in good condition

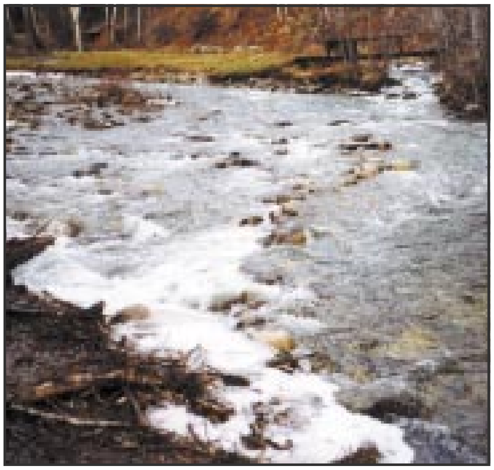
- Steep headwater channels.
- Step/pool with large woody debris.
- Low suspended sediment load.
- Quite stable when formed in cobbles or boulders.
- These channels can be important spawning areas for trout.

Activities that cause problems

- Sidecast road fill from forest roads.
- Loss of riparian trees and instream woody debris.
- Poorly installed culverts (too steep or too long) that block fish passage.
- Increased sediment from vegetation and timber removal or poor road drainage.
- Undersized culverts cause deposition at inlet, trap woody debris, or erode at the outlet.

Relative stability – Rosgen Type B

Good



Fair

Poor

Rosgen B channels

- Fairly steep (greater than 2% grade).
- Can be wide and shallow (width-to-depth ratio greater than 12).
- May be fairly stable, especially when formed in large cobbles.
- Frequently have irrigation diversions serving pastures lower in the valley.
- Can provide important spawning habitat for fish.

Stable B channels can adjust

- B channels can move lots of cobble and gravel at peak flow.
- Instability is not usually caused by minor land-use changes or channel projects.
- Geology plays an important role in structural changes.
- Vegetation also plays an important role in channel stability.
- Woody debris can provide important fish habitat, and should be left if possible.

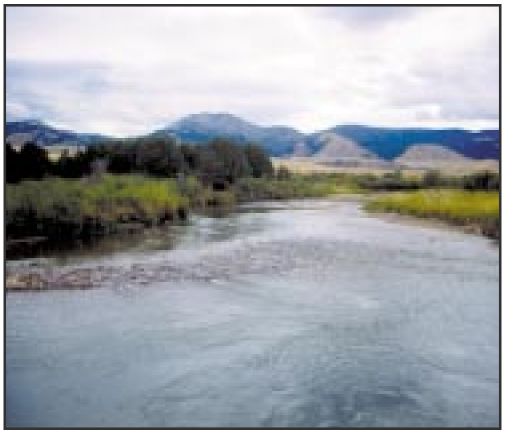
B channels can be unstable

- Channels may aggrade or degrade, or erode banks.
- Instability can be inherent where bedload transport is high.
- Ice jams and debris jams are frequent in these locations.
- Irrigation diversions and stream crossings should avoid constricting the channel.

STREAM CLASSIFICATION (*continued*)

Relative stability – Rosgen Type C

Good



Fair

Poor

C channels are common

- Meandering streams typical in broad valleys and/or cottonwood-willow riparian corridors.
- Can be wide and shallow (typically width-to-depth ratio greater than 12).
- May be fairly stable when banks and floodplain are well vegetated.
- The floodplain is active (floodprone).
- Provide important fisheries habitat.

C channels are sensitive to land use or hydrologic change

- C channels carry large amounts of sediment during peak flow.
- Channels rely on abundant vegetation to maintain a stable width-to-depth ratio.
- Lateral bank erosion up and downstream can be accelerated by poorly designed projects.
- Soft bioengineering should be considered as a substitute for hard methods such as rip-rap.

C channels are inherently dynamic systems

- Meanders migrate naturally over time.
- Restricting meander or bank movement is usually counter-productive to channel stability.
- Development of frequent mid-channel bars indicates reduced stability.
- Attempts at channelization can lead to severe instability.

Relative stability – Rosgen Type E

Good

Fair

Poor

E channels are narrow and deep

- Commonly a strongly meandering stream in agricultural areas.
- Low width-to-depth ratio (less than 12).
- Slope is gentle (less than 0.02).
- May be fairly stable when banks and floodplain are well vegetated.
- The floodplain is active (floodprone).
- May or may not have riparian shrubs/trees.
- Can provide important fisheries habitat.
- This “good” channel has been restored and is the same site as shown in the “poor” photo below.

E channels are sensitive to land use or hydrology

- Channels rely on vegetation to maintain a stable width-to-depth ratio.
- Lateral bank erosion up and downstream can be accelerated by poorly designed projects.
- Loss of vegetation or overgrazing can result in conversion to a wider and shallower C channel.
- Soft bioengineering works well and should be considered as a substitute for hard methods such as rip-rap.

E channels are common in pasture and agricultural areas

- Grazing and confined animal operations can have significant impacts on channel health.
- Road approaches to stream crossings may dike floodplains if fill is elevated.
- Hard bank stabilization can often be avoided by use of vegetative methods.
- Use of barbs/vanes should be avoided.
- Degraded E channels may heal quickly if allowed to revegetate.

STREAM CLASSIFICATION (*continued*)

Rosgen Types D, F, and G

D channel

F channel

G channel

D channels are braided and unstable

- Braided channels have poor lateral bank stability and scour depths can be extreme.
- Braided channels carry large amounts of bedload gravel.
- Design of stream crossings or channel restoration is difficult.
- Stream crossings should avoid braided reaches.
- C channels risk becoming D if disturbed by land use or other factors.

F channels typically have high unstable banks

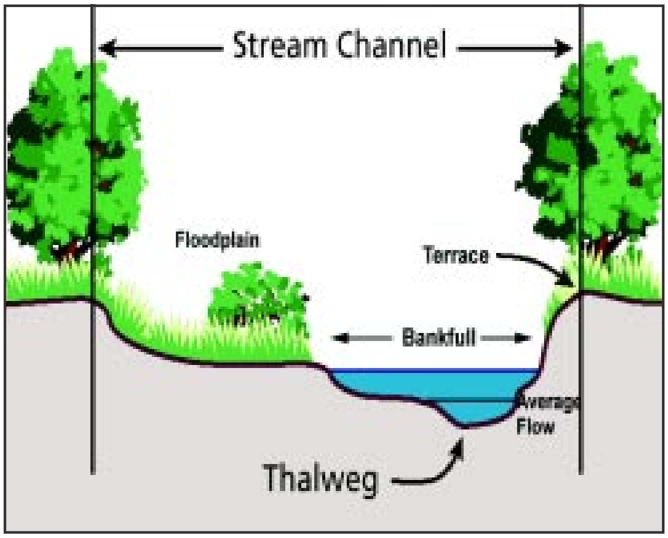
- Photo above shows E channel becoming established in a former F channel.
- F channels are deeply incised or downcut, and meandering.
- May develop in response to severe impacts (channelization, overgrazing, augmented flows), or be natural remnants of climate change.
- Challenging to repair, and usually cannot be restored to former floodplain.

G channels are typically characterized as gullies

- Found on alluvial fans, downcutting channels, or severely disturbed stream systems.
- Can deliver large amounts of sediment to downstream reaches.
- Rock weirs may help with grade control.
- Revegetation efforts may meet with limited short-term success.
- Restoration may be expensive.

FLOW CHARACTERISTICS

Understanding stream flow is essential for successful stream management. An understanding of both peak flow and low flow conditions is required when evaluating stream-related structures.



Discharge and channel geometry

Average discharge

Average discharge is defined as that flow rate which, if continued every day of a year, would yield the annual volume of water produced by the basin. The average discharge usually fills a channel to about one-third the channel depth, and this flow rate is equaled or exceeded about 25 percent of the days in a year.

Bankfull discharge

Bankfull discharge is defined as the discharge at which channel maintenance processes are the most effective. That is, the discharge that moves sediment, forms or removes bars, forms or changes meanders, and generally does the work that results in the average characteristics of the channel. The bankfull flow has an average return interval of approximately 1.5 to 2 years, although this number can vary from 1.1 to 2 years or more.

Understanding bankfull dimensions is important for evaluating the design of culverts, bridges, and other instream structures. These structures should be designed to maintain sediment transport and convey water. Replicating stable bankfull dimensions of width, depth, and slope will help ensure that sediment transport processes remain in a natural range. Significant deviation from bankfull dimensions may lead to increased bank erosion, lateral instability, and stream bed aggradation or degradation.

The average flood event (usually with a recurrence interval of 1.5 to 1.8 years) is associated with channel changes, especially in streams with reaches that are not structurally controlled, such as portions of the Bitterroot or Yellowstone rivers. Adjustments may include lateral scour, channel abandonment (avulsion and formation of meander cut-off chutes), pool filling, channel straightening, and local changes in slope.

DETERMINING BANKFULL FLOW

USGS gage records

Bankfull elevation can be determined from U.S. Geological Survey (USGS) gage station records, through flood frequency analysis and development of hydraulic geometry, or from the following principal indicators:

Point bar indicators

Point bars can be used as an approximation of bankfull elevation. The point bar is the sloping surface that extends into the channel from the depositional side of a meander. The top of the point bar is at the level of the floodplain because floodplains generally develop from the extension of point bars as a channel moves laterally by erosion and deposition over time. Depositional, flat features are the best indicator of bankfull elevation.

Vegetation indicators

The bankfull level is usually marked by a change in vegetation, such as the change from point bar gravel to forbs, herbs, or grass. Shrubs and willow clumps are sometimes useful but can be misleading. Willows may occur below bankfull stage, but alders are typically above bankfull. Confirm vegetation indicators with depositional features.

Topographic breaks

A topographic break is often evident at bankfull elevations. The stream bank may change from a sloping bar to a vertical bank, or from a vertical bank to a horizontal plane on top of the floodplain. Bankfull is often marked by a change in the size distribution of sediment and soil materials at the surface.

Bankfull definition also generally describes the mean high water mark in the 310 law. Jurisdiction for conservation districts includes the mean high water mark and the immediate banks of the river or stream.

Point bars can provide an indicator of bankfull height in the field.

This bridge stringer is set at bankfull height. Projects should avoid this situtation, which traps debris.

Bankfull is not always obvious and can be difficult to visualize in some channel types.

FLOOD/PEAK FLOW

Estimating peak flow in Montana

Peak flow is closely related to precipitation, drainage area, channel dimensions, and other easily measured variables. Peak flow can be estimated from equations developed by the U.S. Geological Survey (USGS 92-4048).

Flood frequency analysis

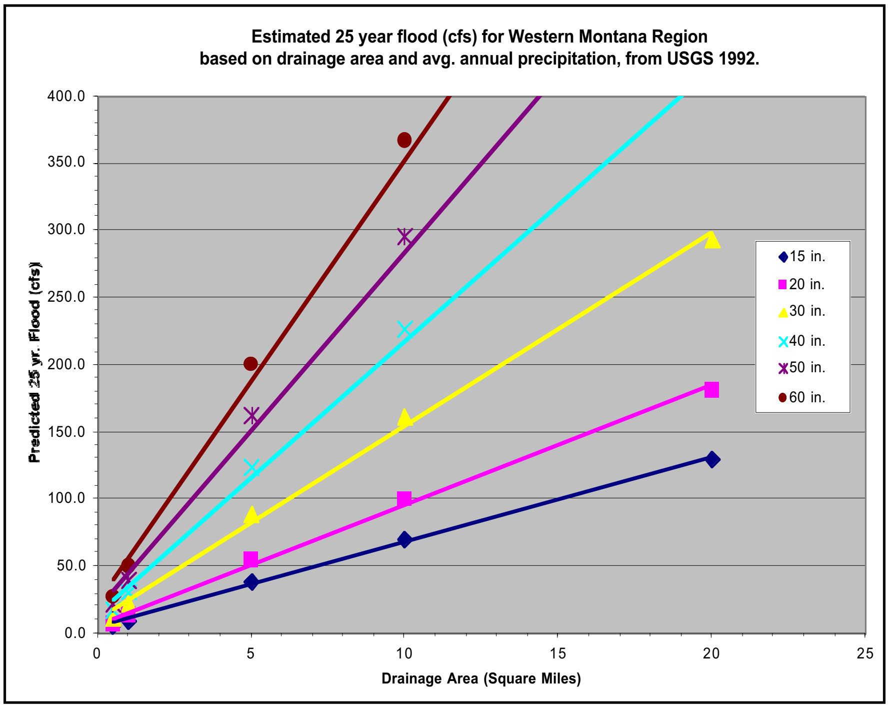
Flood frequency is expressed in terms of recurrence interval. This interval is the period of time, on average, that the associated flow will be equaled or exceeded one time (for example, a 100-year flood).

Estimating flood frequency and size

Peak flows for small Montana watersheds can be estimated using equations developed by the U.S. Geological Survey. These equations are generally most applicable to watersheds smaller than 20 square miles. Equations have been developed for eight regions in Montana. The equations relate peak flow frequency to easily measured variables, and provide a good first estimate of expected flood events.

For gaged sites (or paired watersheds), flood frequency can be determined by analyzing annual maximum flow values (the largest flow peak that occurred during each year of record). Few smaller watersheds have adequate flow information, and determination of flood discharges usually must be estimated from USGS equations or other methods.

Designing instream structures to the bankfull dimension (with recurrence interval of 1.5 to 2 years) often does not meet requirements for good stream function. Standard design criteria require passing the 25-year or 100-year flood event depending on the site situation. In the Columbia River Basin, the U.S. Forest Service currently requires that stream crossings be capable of passing a design flow equivalent to the 100-year flood. Some projects will need to comply with local floodplain regulations, which may limit the allowable backwater caused by a project.



From Water Resources, Investigation Report 92-4048 (1992), USGS.
Note: the 100-year flood is 30 to 50 percent larger than the 25-year flood.

FLOOD/PEAK FLOW (*continued*)

USGS equations for peak flow in Montana

Region / Regression equation	Standard error of estimate (percent)	Average standard error or prediction (percent)	Equivalent years of record
West Region			
$Q2 = 0.042\ A^{0.94}\ P^{1.49}$	51	52	1
$Q5 = 0.140\ A^{0.90}\ P^{1.31}$	45	47	2
$Q10 = 0.235\ A^{0.89}\ P^{1.25}$	44	45	2
$Q25 = 0.379\ A^{0.87}\ P^{1.19}$	44	45	3
$Q50 = 0.496\ A^{0.86}\ P^{1.17}$	45	46	3
$Q100 = 0.615\ A^{0.85}\ P^{1.15}$	46	48	4
$Q500 = 0.874\ A^{0.83}\ P^{1.14}$	53	55	4
Northwest Region			
$Q2 = 0.266\ A^{0.94}\ P^{1.12}$	41	44	2
$Q5 = 2.34\ A^{0.87}\ P^{0.75}$	30	34	8
$Q10 = 7.84\ A^{0.84}\ P^{0.54}$	27	31	13
$Q25 = 23.1\ A^{0.81}\ P^{0.40}$	23	27	26
$Q50 = 25.4\ A^{0.79}\ P^{0.46}$	22	26	39
$Q100 = 38.9\ A^{0.74}\ P^{0.50}$	32	38	24
$Q500 = 87.1\ A^{0.67}\ P^{0.49}$	52	59	18
Southwest Region			
$Q2 = 2.48\ A^{0.87}\ (HE+10)^{0.19}$	84	88	1
$Q5 = 24.8\ A^{0.82}\ (HE+10)^{-0.16}$	67	69	2
$Q10 = 81.5\ A^{0.78}\ (HE+10)^{-0.32}$	60	63	3
$Q25 = 297\ A^{0.72}\ (HE+10)^{-0.49}$	57	60	4
$Q50 = 695\ A^{0.70}\ (HE+10)^{-0.62}$	60	63	5
$Q100 = 1{,}520\ A^{0.68}\ (HE+10)^{-0.74}$	62	66	5
$Q500 = 7{,}460\ A^{0.64}\ (HE+10)^{-0.99}$	75	80	5
Upper Yellowstone—Central Mountain Region			
$Q2 = 0.117\ A^{0.85}\ (E/1000)^{3.57}\ (HE+10)^{-0.57}$	69	72	2
$Q5 = 0.960\ A^{0.79}\ (E/1000)^{3.44}\ (HE+10)^{-0.82}$	50	53	7
$Q10 = 2.71\ A^{0.77}\ (E/1000)^{3.36}\ (HE+10)^{-0.94}$	43	46	12
$Q25 = 8.54\ A^{0.74}\ (E/1000)^{3.16}\ (HE+10)^{-1.03}$	40	44	14
$Q50 = 19.0\ A^{0.72}\ (E/1000)^{2.95}\ (HE+10)^{-1.05}$	42	46	14
$Q100 = 41.6\ A^{0.70}\ (E/1000)^{2.72}\ (HE+10)^{-1.07}$	46	50	14
$Q500 = 205\ A^{0.65}\ (E/1000)^{2.17}\ (HE+10)^{-1.07}$	58	63	15

(Continued on the next page)

FLOOD/PEAK FLOW (*continued*)

USGS equations for peak flow in Montana (continued)

Region / Regression equation	Standard error of estimate (percent)	Average standard error or prediction (percent)	Equivalent years of record
Northwest Foothills Region			
$Q2 = 0.653\ A^{0.49}\ (E/1000)^{2.60}$	78	88	4
$Q5 = 3.70\ A^{0.48}\ (E/1000)^{2.22}$	43	52	13
$Q10 = 8.30\ A^{0.47}\ (E/1000)^{2.10}$	37	48	19
$Q25 = 20.3\ A^{0.46}\ (E/1000)^{1.95}$	38	50	25
$^{*}Q50 = 47.7\ A^{0.47}\ (E/1000)^{1.62}$	41	54	28
$^{*}Q100 = 79.8\ A^{0.48}\ (E/1000)^{1.40}$	47	62	28
$^{*}Q500 = 344\ A^{0.50}\ (E/1000)^{0.98}$	71	75	31
* Equation not valid if the ungaged stream originates in the Northwest Region.			
Northeast Plains Region			
$Q2 = 15.4\ A^{0.69}\ (E/1000)^{-0.39}$	81	85	3
$Q5 = 77.0\ A^{0.65}\ (E/1000)^{-0.71}$	60	63	6
$Q10 = 161\ A^{0.63}\ (E/1000)^{-0.84}$	52	56	10
$Q25 = 343\ A^{0.61}\ (E/1000)^{-1.00}$	51	53	14
$Q50 = 543\ A^{0.60}\ (E/1000)^{-1.09}$	49	53	17
$Q100 = 818\ A^{0.59}\ (E/1000)^{-1.19}$	51	56	18
$Q500 = 1{,}720\ A^{0.57}\ (E/1000)^{-1.37}$	63	68	18
East-Central Plains Region			
$Q2 = 141\ A^{0.55}\ (E/1000)^{-1.88}$			
$Q25 = 1{,}545\ A^{0.50}\ (E/1000)^{-1.79}$			
$Q100 = 2{,}620\ A^{0.49}\ (E/1000)^{-1.62}$			
Southeast Plains Region			
$Q2 = 537\ A^{0.55}\ (E/1000)^{-2.91}$			
$Q25 = 3{,}240\ A^{0.51}\ (E/1000)^{-2.55}$			
$Q100 = 5{,}850\ A^{0.50}\ (E/1000)^{-2.51}$			

Variables:
Q - flood magnitude in cubic feet per second
t - the given recurrence interval, in years
A - drainage area, in square miles
P - mean annual precipitation, in inches
HE - percentage of basin above 6,000 feet elevation
E - mean basin elevation, in feet

Reference: *Analysis of the Magnitude and Frequency of Floods and the Peak-Flow Gaging Network in Montana, Water Resources Investigations Report 92-4048 (1992)*. U.S. Geological Survey, Helena, Montana.

CAUTION:

These equations provide an initial estimate for perennial streams, but may not be accurate in all situations. To avoid inaccuracies in estimating peak flow, first read and understand the reference cited at left.

FLOOD/PEAK FLOW (*continued*)

Example of calculations from USGS publication 92-4048.

Example 1. (Using the regression equations when the drainage basin is in one region)

Determine the flood magnitude for a recurrence interval of 100 years for an ungaged site in the Southwest Region where the contributing crainage area (A) is 16.4 mi^2 and the percentage of absin above 6,000 ft. elevation (HE) is 75.

From the Southwest Region equations (table 2), the flood magnitudes for 10, 25, and 100-year recurrence intervals are:

$$\begin{aligned} Q_{10} &= 81.5\ A^{0.78}\ (HE+10)^{-0.32} \\ &= (81.5)\ (16.4)^{0.78}\ (75+10)^{-0.32} \\ &= (81.5)\ (8.86)\ (0.241) \\ &= 174\ ft^3/s \end{aligned}$$

$$\begin{aligned} Q_{25} &= 297\ A^{0.72}\ (HE+10)^{-0.49} \\ &= (297)\ (16.4)^{0.72}\ (85)^{-0.49} \\ &= (297)\ (7.49)\ (0.1134) \\ &= 252\ ft^3/s \end{aligned}$$

$$\begin{aligned} Q_{100} &= 1{,}520\ A^{0.68}\ (HE+10)^{-0.74} \\ &= (1{,}520)\ (16.4)^{0.68}\ (85)^{-0.74} \\ &= (1{,}520)\ (6.70)\ (0.0373) \\ &= 380\ ft^3/s \end{aligned}$$

Example 2. (Using the regression equations when the drainage basin is in two regions)

Determine the flood magnitude for a recurrence interval of 50 years for a site in northeastern Montana where 12.5 mi^2 of the total drainage area is in the Northeast Plains Region and 35.2 mi^2 of the total drainage area is in the East-Central Plains Region. That part of the drainage absin in the Northeast Plains Region has a mean basin elevation (E) of 3,120 ft. That part of the drainage basin in the East-Central Plains Region has a mean basin elevation (E) of 2,780 ft.

From the Northeast Plains Region equations, the flood magnitude for a 50-year recurrence interval is:

$$\begin{aligned} Q_{50} &= 543\ A^{0.60}\ (E/1{,}000)^{-1.09} \\ &= (543)\ (47.7)^{0.60}\ (3.12)^{-1.09} \\ &= (543)\ (10.17)\ (0.289) \\ &= 1{,}600\ ft^3/s \end{aligned}$$

From the East-Central Region equations, the flood magnitude for a 50-year recurrence interval is:

$$\begin{aligned} Q_{50} &= 2{,}100\ A^{0.49}\ (E/1{,}000)^{-1.72} \\ &= (2{,}100)\ (47.7)^{0.49}\ (2.78)^{-1.72} \\ &= (2{,}100)\ (6.64)\ (0.172) \\ &= 2{,}400\ ft^3/s \end{aligned}$$

The weighted average flood magnitude for a 50-year recurrence interval is:

$$\begin{aligned} Q_{50} &= 1{,}600\ (12.5/47.7) + 2{,}400\ (35.2/47.7) \\ &= 419 + 1{,}771 \\ &= 2{,}190\ ft^3/s \end{aligned}$$

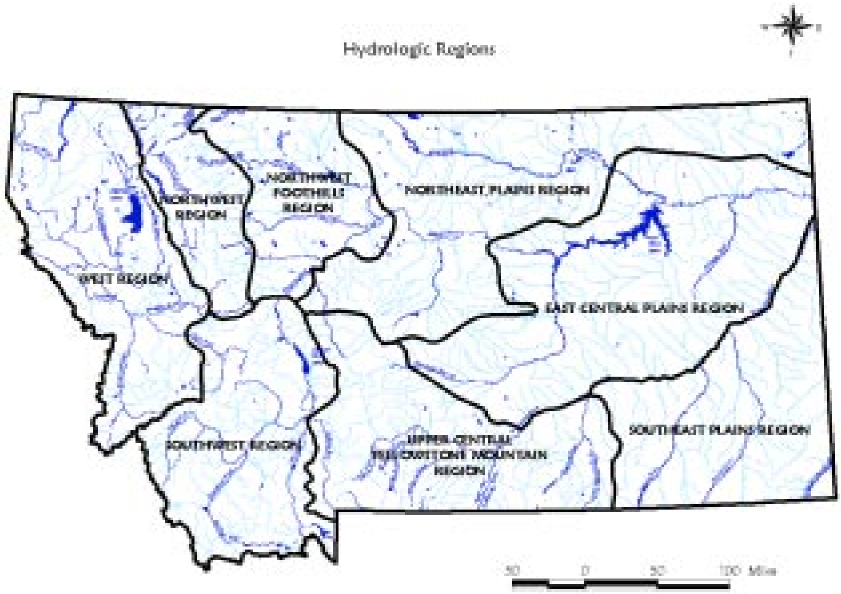
FLOOD/PEAK FLOW (*continued*)

Example 3. (Transferring data from a gaged site)

Determine the flood magnitude for a recurrence interval of 100 years for the Tobacco River near Eureka, Montana, at an ungaged site where the drainage area is 310 mi^2. From table 1 (West Region), the drainage area of the gaged site (station 12301300) is 440 mi^2 and the 100-year recurrence interval flood is 3,220 ft^3/s. Because the ungaged drinage area (310 mi^2) is between 0.5 and 1.5 times the gaged drainage area (440 mi^2), equation 3 can be used to calculate the flood magnitude. From the equations for the West Region (table 2), the exponent for drainage area (A) for a 100-year recurrence interval flood is 0.85. Using equation 3, the flood magnitude for a 100-year recurrence interval at the site is:

$$
\begin{aligned}
Q_{100} &= (310/440)^{0.85}\,(3{,}220)\\
&= (0.743)\,(3{,}220)\\
&= 2{,}390 \text{ ft}^3\text{/s}
\end{aligned}
$$

HYDROLOGIC REGIONS MAP



From *Analysis of the Magnitude and Frequency of Floods and the Peak-Flow Gaging Network in Montana, Water Resources Investigations Report 92-4048* (1992). U.S. Geological Survey, Helena, Montana.

BANK AND CHANNEL STABILITY

Aggrading (filling in or depositing) channel reaches can be indicative of streams out of balance.

Degrading (scouring/downcutting) channels are common when streams have been straightened.

Scour and deposition still occur in equilibrium channels, and can be accelerated by removal of vegetation.

Understanding why streambanks erode or channels are unstable requires an awareness of stream dynamics.

Dynamic equilibrium and channel stability

Maintaining the balance

A stable channel is able to transport the flows and sediment in such a manner that the dimension, pattern, and profile of the river is maintained without either aggrading (filling) or degrading (scouring). Stream systems naturally tend toward minimum work and uniform distribution of energy, or "dynamic equilibrium." This means that changes in channel form (such as bank erosion) are the stream's attempt to maintain a balance in water and sediment. Stable streams do move over time, and stream management should accommodate these natural changes.

Sediment in equals sediment out

Under conditions of dynamic equilibrium, streams achieve a balance so sediment loads entering a stream reach are equal to those leaving it (sediment/water balance). Imbalance results in either aggradation or degradation. When more sediment enters a reach than leaves it, aggradation will occur as the stream's transport capacity is exceeded. In contrast, degradation occurs when a stream has excess energy and more sediment leaves a reach than enters it. Bank instability problems are frequently apparent where streams are aggrading or degrading.

Channel shape varies to keep the balance

The ability of a stream to carry its sediment load largely depends on cross-section geometry and channel slope. A channel cross section that maintains a stable geo-metry and channel slope will generate enough force to transport sediment and convey water through the reach. Channel geometry adjusts to accommodate sediment input and discharge.

Land use makes a difference

Stream management can influence how the stream responds to flood events. Both human and natural factors can cause significant changes in channel stability.

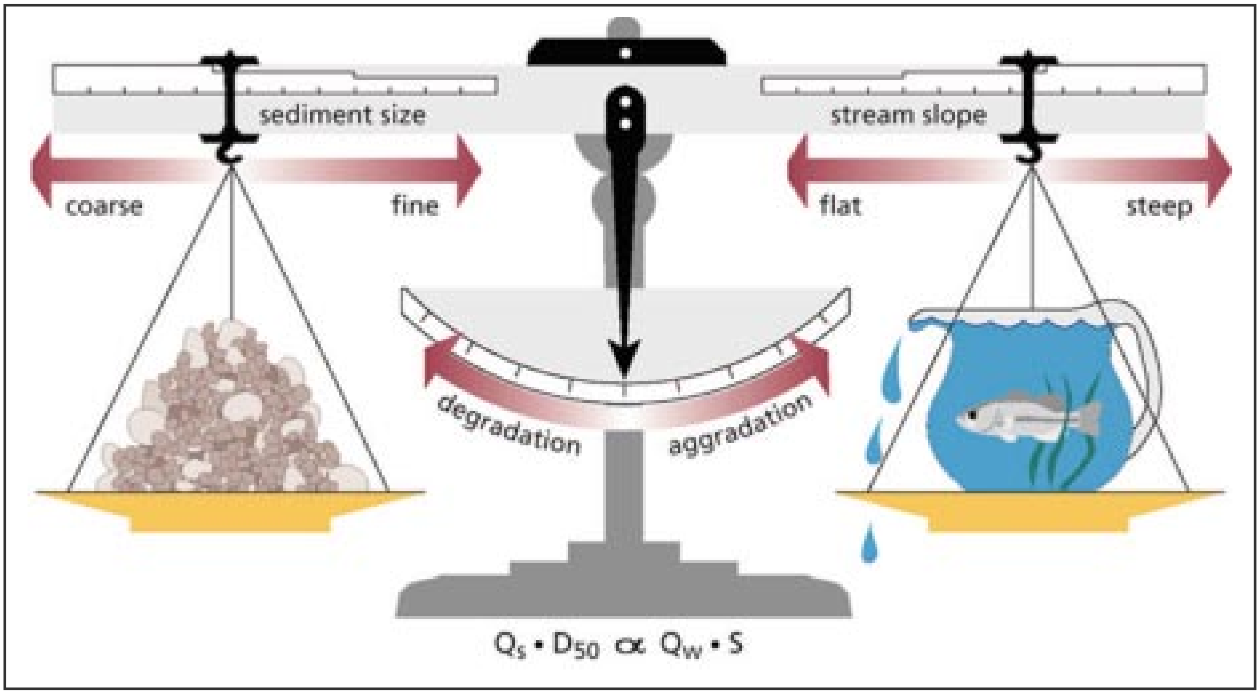
LANE'S DIAGRAM

Lane's diagram – don't leave home without it!

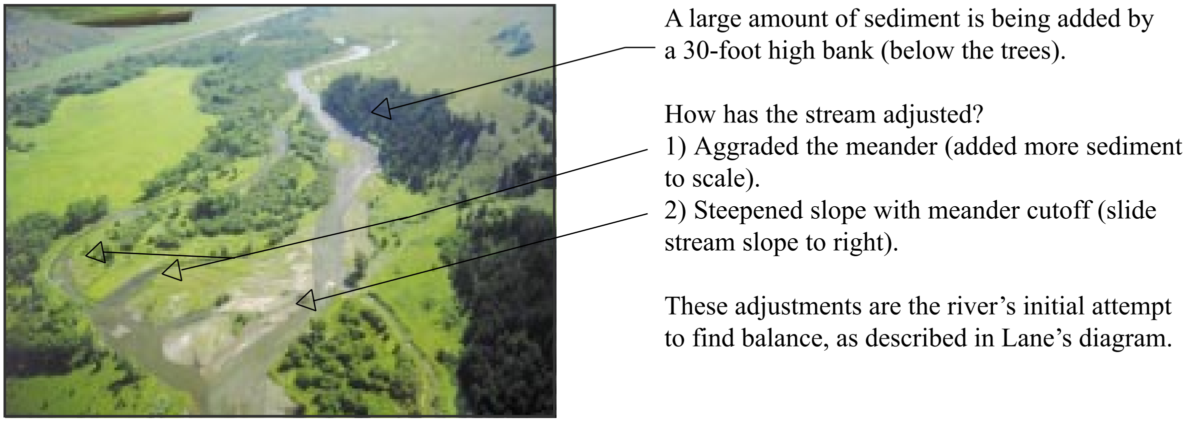
Lane's relationship shows stream process is a function of four main factors:

- Sediment discharge (Qs)
- Sediment particle size (D50)
- Streamflow (Qw)
- Stream slope (S)

Lane's relationship suggests that a channel will be maintained in dynamic equilibrium when changes in sediment load and bed-material size are balanced by changes in streamflow or channel gradient. A change in one of these factors causes changes in one or more of the other variables such that a stable condition tends to become re-established.



Lane (1955). American Society of Civil Engineers.



A large amount of sediment is being added by a 30-foot high bank (below the trees).

How has the stream adjusted?
1) Aggraded the meander (added more sediment to scale).
2) Steepened slope with meander cutoff (slide stream slope to right).

These adjustments are the river's initial attempt to find balance, as described in Lane's diagram.

THE LANE DIAGRAM (*continued*)

Lane's diagram shows that, qualitatively, for a stream to remain in "balance," sediment size times sediment quantity moved by a stream is directly proportional to the slope of the stream times the discharge:

$$(\text{sediment quantity}) \times (\text{sediment size}) \propto (\text{stream slope}) \times (\text{water discharge})$$

It is apparent that an increase in a variable on one side of the "equation" will cause a decrease in the other variable; likewise, a decrease in one forces an increase in the other.

For example, if a stream has been straightened between two points, the distance the water flows in the channel is decreased, but the elevation difference between the points remains the same. Since slope is defined as the elevation change divided by the distance traveled, the slope of the stream increases with channel straightening. If slope is increased, the scale begins to tip towards degradation.

Several adjustments may occur as a result of increased slope, maintaining the balance of the Lane diagram. The immediate adjustment is usually erosion, or increased sediment quantity being washed through the straightened reach. A second adjustment is a tendency for the remaining bed sediment particle size to increase, or "armoring". This occurs as smaller bed sediment particles are carried downstream, leaving behind the larger ones. A third adjustment may be local change in channel slope as eroded sediment is redeposited downstream of the straightened reach (aggradation). Erosion moving upstream of the straightened reach may also contribute increased sediment quantities. These sediment transport changes lead to a readjustment of slope (and channel shape). Thus, it can be seen that changes in one factor (slope, in this case) can lead to simultaneous adjustments in the other Lane Diagram variables.

CHANNELIZATION

Streams react to channelization

Channelization–or straightening–is harmful to most stream systems, and problems eventually shift to adjoining stream reaches.

On straightened streams, the channel slope steepens, which can result in channel adjustments such as:

- Headcut formation upstream.
- Channel downcutting.
- Increased bank erosion rates.
- Aggrading or degrading reaches.

Diking for flood control is also a form of channelization, and can have significant consequences for stream stability and adjoining landowners. Stream projects should seek to avoid channelization of natural streams whenever possible.

In some cases, straightened streams can be restored by re-creating natural meanders or installing grade control structures to compensate for over-steepened conditions.

Some bank stabilization measures can be detrimental to stream integrity. Often erosion shifts to unreinforced reaches where natural meander patterns can be re-established. Strongly meandering Rosgen Type C and E channels are especially sensitive to channeliation or poorly planned bank stabilization.

Channelized streams seek to re-establish equilibrium by forming meanders with scour and deposition. This stream is depositing sediment in an overwide channel, and is re-establishing a meandering, bankfull dimension channel.

Rivers constrained by extensive highway and railroad embankments may suffer widespread instability.

This river has maximized meander length given infrastructure constraints, but remains unstable over much of its length.

CHANNELIZATION (*continued*)

The width-to-depth ratio is out of balance on this straightened reach of stream. The channel is slowly rebuilding a new floodplain and meandering channel.

Comparing the elevation of the straightened channel and the old channel streambed (background) gives some indication of the degree of downcutting.

Rip-rap for bank protection is a common response to erosion on channelized rivers, but hard bank stabilization may prevent the river from re-establishing the missing channel length and stable meandering form.

The legacy of channelization

Historic, large-scale channel straightening and realignment continue to result in channel adjustments with each spring runoff. Bank stabilization, especially with inflexible structural methods, is commonly proposed on historically channelized reaches. Hard stabilization does not generally promote good stream health, and soft methods may not be successful in channelized reaches unless the underlying problem can be addressed.

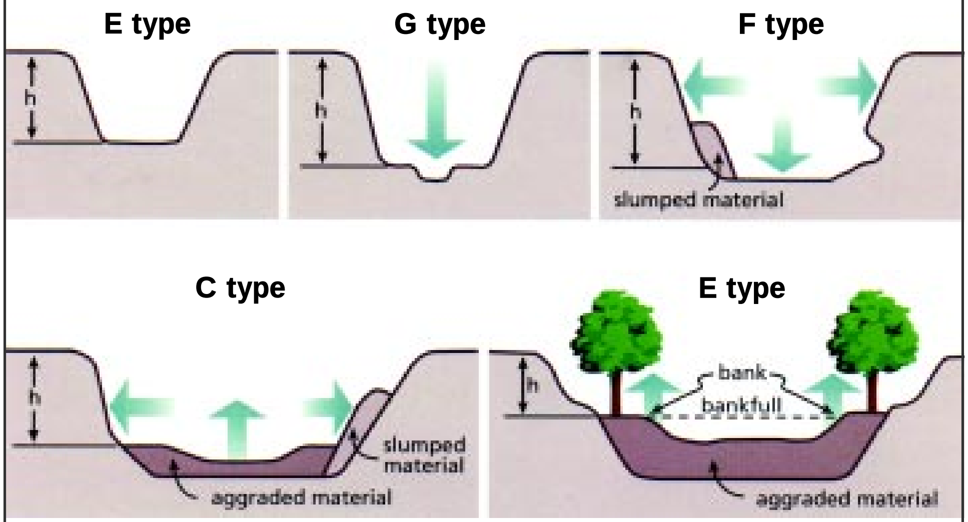
Increasing meander length, or allowing the stream to erode banks and rebuild floodplains naturally may be the best strategy to restore stream integrity. This approach can be difficult to accept in situations where valuable land is lost or structures are threatened.

Whenever possible, natural stream function should be promoted as an alternative to potentially harmful structural stabilization. As landowners (and managers) learn more about stream process, they gain a greater appreciation of the long-term consequences of bank stabilization efforts.

Changes in channel characteristics (width, depth, slope, entrenchment, sinuosity, and velocity) commonly follow an evolutionary sequence as illustrated in the diagram on the following page.

CHANNEL DOWNCUTTING AND RE-ESTABLISHMENT OF EQUILIBRIUM

In response to channelization, or imposed higher flows, the channel downcuts and begins to widen (E type to G to F).



As the channel re-establishes equilibrium at a new elevation, the new floodplain is colonized by riparian vegetation (C type to E type). This process can take decades or more to complete.

This channel has downcut severely due to excessive flow introduced for irrigation (Rosgen G type).

Downstream in the drainage, a new equilibrium channel with meanders, point bars, and floodplain is beginning to develop (F channel moving to C).