Understanding Streambank Erosion and Failure

Constructing a successful streambank protection project without understanding why the bank is eroding or failing probably reflects more on happenstance than common sense. Understanding the principles of streambank erosion and failure requires study and then considerable thought in applying these principles to a particular problem. The time spent in careful study of this section of the pamphlet may mean the difference between construction of a successful bank protection project and a waste of time and money.

As mentioned earlier, the terms streambank erosion and streambank failure are often used interchangeably to describe the condition of a distressed bank; however, these terms are entirely different in concept. *Erosion* occurs when individual soil particles at the bank's surface are carried away. Streambank *failure* differs from streambank erosion in that a relatively large section of a bank fails and slides into the channel. The major causes of *streambank erosion* are:

- —Stream currents
- —Rainfall
- —Seepage
- —Overbank drainage
- —Obstacles in the stream
- —Wave attack
- —Freeze-thaw and wet-dry cycles
- —Ice and debris
- —Changes in land use

Whereas the major causes of *streambank failure* are:

- —Swelling of clays due to absorption of water
- —Pressure of groundwater from within the bank
- —Minor movements of the soil or creep
- —Changes in channel shape due to bed scour or erosion of the bank face
- —Increase of load on top bank
- —Rapid drawdown of water against the bank face

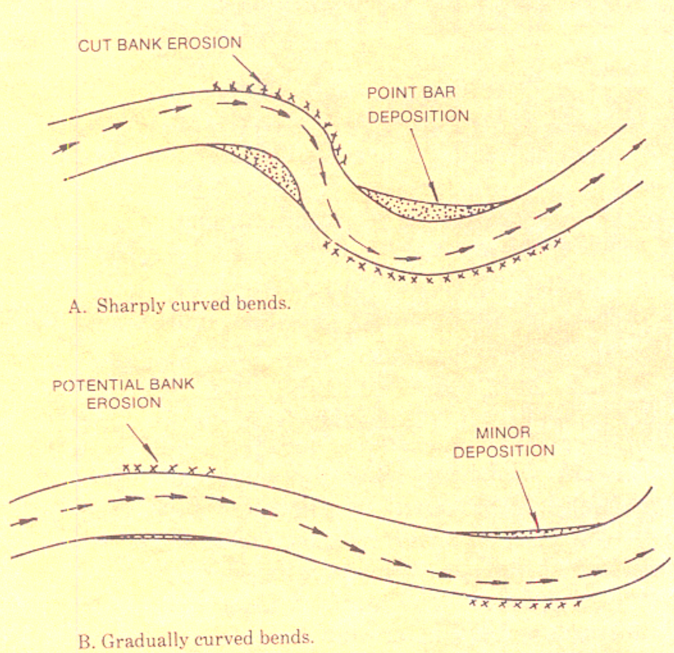
Often, several of these causes work in combination to place a streambank in a distressed condition.

STREAMBANK EROSION

STREAM CURRENTS. Soil particles carried away from a bank by currents (or flowing water) are removed by a *tractive force* which tends to pull particles along with the streamflow. The removal of particles by tractive force is similar to rubbing your hand across a bank surface and picking up soil particles, except that in the case of streamflow, the moving water in contact with the bank rubs against the particles and, once they are dislodged, carries them along with the flow. The strength of a stream's tractive force increases as the water velocity and depth of the stream increase; therefore, erosion is more likely to occur during a flood than during normal flow.

As a particle comes under attack by passing currents, it must be able to resist the tractive force of the streamflow or be carried away. The outcome is dependent on the strength of the attack as counterbalanced by the particle's size and cohesive properties. The larger particles weigh more and are harder to move, thus gravel is less likely to be carried away by swift currents than sand. On the other hand, a clay particle is more likely to stay in place on a bank than a silt particle because of cohesion among clay particles.

As streamflow moves through a bend under normal flow conditions, the velocity increases toward the outside of the bend (or cut bank) increasing the tractive force to as much as twice that in a straight reach of the channel upstream or downstream from the bend. As a result erosion can occur along much of the cut bank, often extending



Sharply and gradually curved bends under normal flow conditions. Arrows indicate the path of the maximum stream velocity. During floodflow this path moves across the channel against the point bar.

Serious streambank erosion is occurring on the right bank of this bend, while a point bar is building up on the left bank.

a short distance downstream from the end of the bend. On the inside of the bend the stream velocity decreases allowing suspended sediments to deposit and build up a point bar. Sharply curved bends are more likely to experience erosion along the cut bank than gradually curved bends. During flood flow the path of maximum velocity moves across the channel against the point bar, often removing material that was deposited during normal flow conditions.

The previous discussion does not suggest that straightening a channel will eliminate erosion problems . . . quite the contrary. Straightening a channel will shorten it and steepen its bed slope, which in turn may upset the balance of the stream (see "Reroute the Stream," page 31, as a method of bank protection).

RAINFALL. As raindrops strike the earth's surface, the accumulating water can move overland as surface runoff or can infiltrate into the soil. Raindrops splashing on a sloping streambank tend to loosen soil particles and reduce the infiltration capacity of the soil. With the infiltration capacity reduced, more and more of the rainfall will run down the sloped bank which will increase the tractive force of the runoff, and in turn, possibly increase erosion.

If the combined action of splashing raindrops and surface runoff removes particles in thin layers, the soil loss is called *sheet erosion*. If the runoff down the bank slope forms small channels as it carries away soil, the process is termed *rill erosion*. The net effect of sheet and rill erosion, in addition to loss of soil particles that hold vegetation in place, is to remove mineral nutrients and organic matter leaving coarser, less fertile soil behind. Thus, once the surface of a bank has been eroded, natural reestablishment of vegetation may be difficult.

SEEPAGE. The portion of the rainfall that does not move down the bank slope as surface runoff infiltrates downward through the subsurface layers of soil and rock eventually joining the groundwater flow unless the path is blocked by impermeable material. If the infiltrating rainfall does successfully reach the water table, it will move with the groundwater flow to a lower elevation.

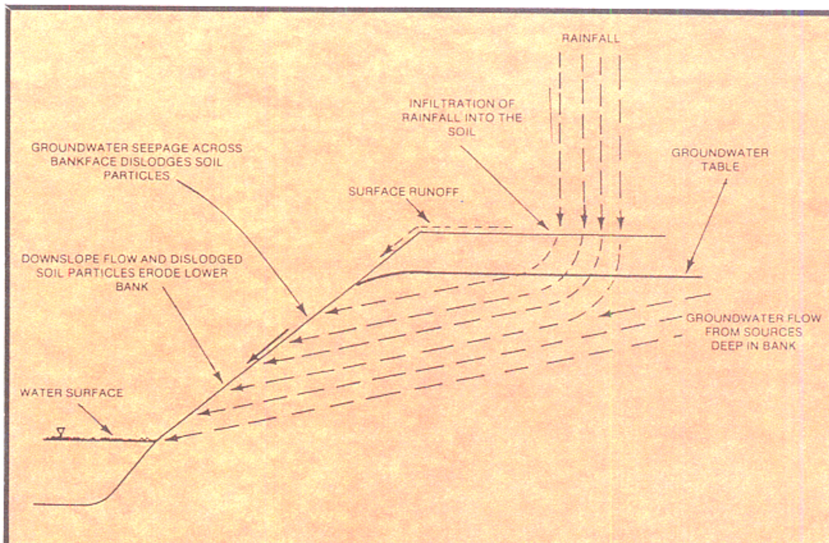
Groundwater seepage across the face of a streambank is caused by exposure of the groundwater table. The water slightly below the bank's surface is forced onto the face of the bank by pressure from groundwater movement deeper inside the bank. As seepage occurs, soil particles at the bank's surface may be forced loose. The resulting downslope movement of seepage water and loosened soil particles can further erode the bank. Groundwater seepage can be observed as a *wet* bank face or as piping flow from small holes on the slope.

OVERBANK DRAINAGE. Closely related to the problem of streambank surface erosion due to rainfall and seepage is erosion caused by overbank drainage. Unless properly controlled, overbank drainage can result in severe sheet and rill erosion. Although this problem occurs under natural conditions, it is more frequently associated with land clearing and plowing near top bank where provisions have not been made for surface drainage control.

OBSTACLES IN A STREAM. The potential for bank erosion can be substantially increased or decreased when man-made or natural obstacles are built in, dumped in, or fall into a stream. The word *obstacles* is used here in a very broad sense to include dams, bridge piers, boat docks, rubble, fallen trees, etc. These obstacles can cause significant changes in streamflow characteristics as well as changes in the location of the channel and in the amount of erosion or sediment deposition occurring in the bed or on the banks of the stream. Obstacles in a stream can be divided into three general categories: obstacles that

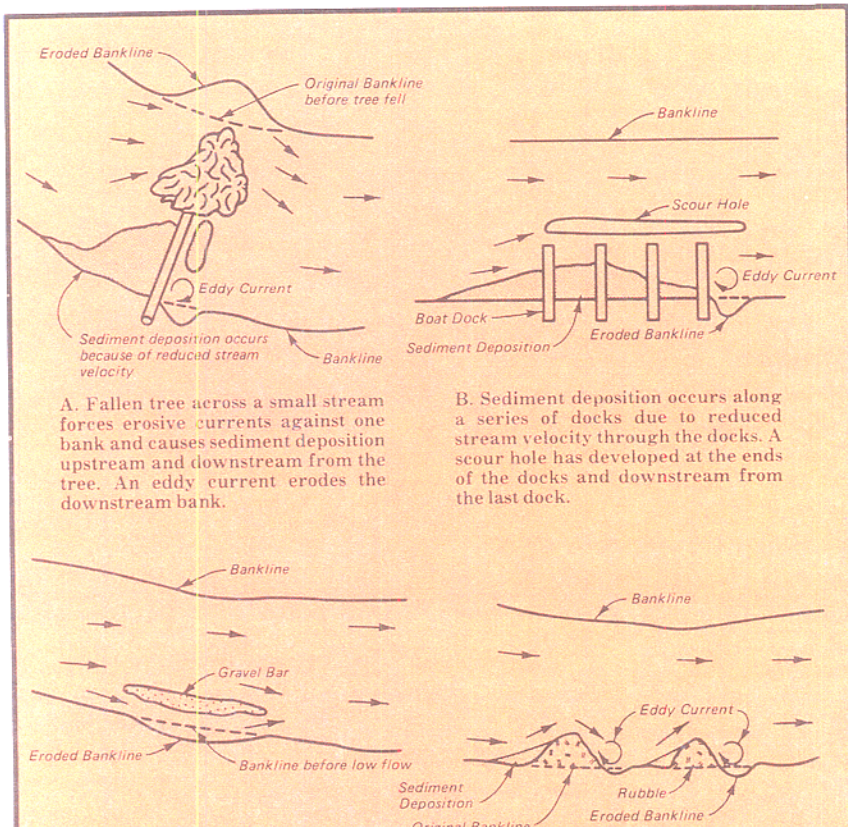
—are built completely across the stream
—constrict the streamflow
—deflect the streamflow

The most frequently encountered man-made obstacle that is built completely across a stream is a dam. Dams are built for a wide range of positive objectives including water conservation, flood control, power generation, navigation improvement, sediment retention, and recreation. Because most dams are operated as multipurpose structures, their effect on streambank erosion, if any, is difficult to assess. Landowners or local governments having a bank erosion problem upstream or downstream from a dam should seek professional assistance during development of a plan to protect the eroding bank. This will insure that the selected bank protection method will work hand in hand with operation of the dam so that maximum protection benefits will be realized for the time and money invested in the project.



Streambank erosion caused by groundwater seepage across bankface.

Streambank sheet and rill erosion resulting from overbank drainage.



A. Fallen tree across a small stream forces erosive currents against one bank and causes sediment deposition upstream and downstream from the tree. An eddy current erodes the downstream bank.

B. Sediment deposition occurs along a series of docks due to reduced stream velocity through the docks. A scour hole has developed at the ends of the docks and downstream from the last dock.

C. Erosive currents are deflected against bank by gravel bar exposed during low flow.

D. Irregular bankline caused by dumped rubble sets up eddy currents which erode bank. Sediment deposition is occurring upstream from the rubble.

Obstacles in a stream can deflect current flow causing complex erosion and sediment deposition patterns.

Streamflow constrictions can be either natural in origin or man-made such as a bridge. The net effect of any constriction is a reduction in the width of the stream. When a constriction attempts to pass flow, the water approaching the upstream end of the constriction begins to move faster which in turn raises the potential for streambank erosion both upstream from and through the constriction. As the fast-moving water leaves the constriction, it spreads out. If the *spreading* water or main flow cannot follow the bankline, a rotating current, called an *eddy*, will be set up next to the bank. The eddy can cause severe erosion if the bank is not properly protected. Further downstream from the end of the constriction, the main flow will contact the bank, possibly causing additional erosion.

Typical obstacles that deflect streamflow are fallen trees, rubble, boat docks, sand and gravel bars, irregular banklines, etc. If the obstacle is aligned with the stream current such that erosive currents are deflected away from the bank and eddy currents are not set up, then the obstacle will protect the bank and possibly cause deposition. On the other hand, if stream currents are deflected against one of the banks by the obstacle or if eddy currents develop, then serious bank erosion can occur.

WAVE ATTACK. Passing boats or wind can set up waves on a stream. As the waves come into contact with a streambank the repeated agitation tends to dislodge soil particles. Wave attack can be an erosion force on streams with heavy commercial traffic and recreational activity or on streams with large areas of open water where the wind can build up waves. Wave attack is generally not a serious problem on small streams.

FREEZE-THAW AND WET-DRY CYCLES. In many parts of the United States temperature variations during the winter months can cause banks to undergo one or more freeze-thaw cycles. After the surface of a bank has frozen, an ice layer often forms below the surface. As the ice layer grows thicker, the surface bank materials are pushed outward. When thawing occurs the bank materials settle back into position in a loosened and more erodible condition.

Drying of exposed wet clay and silt on a streambank slope can lead to shrinkage and cracking of the material near the surface, forming a layer of soil that can be easily eroded. During the next period that water moves over the bank face all or part of the layer may be removed. As the newly exposed material dries out the cycle can repeat itself.

ICE AND DEBRIS. After formation of an ice pack, the ice remains essentially *in place* during the winter months and causes very little streambank erosion. As the pack thaws in the spring, the ice breaks up into chunks and begins floating downstream. During this period, the amount of damage to the streambanks is largely determined by whether the banks are still frozen or have begun to thaw. Frozen banks generally sustain little soil loss; however, structures such as boat docks, as well as trees and other vegetation, may be stripped away from the frozen banks by the impact of the ice chunks or pressure buildup from an ice jam. If the chunks of pack ice pass through a channel where the banks have already thawed, severe bank erosion can occur, mainly due to grinding of the ice against the streambank (abrasion). Debris, like ice, can cause streambank erosion by either abrasion or impact. The most common debris found in streams are the remains of fallen trees.

CHANGES IN LAND USE. Under natural conditions, a bank may show no signs of erosion for many years. On the other hand land-use changes that influence streamflow past the bank and the amount of sediment in the flow can cause an otherwise erosion-free bank to rapidly become a serious problem.

The increasing area needed for urbanization and the continued clearing of forest

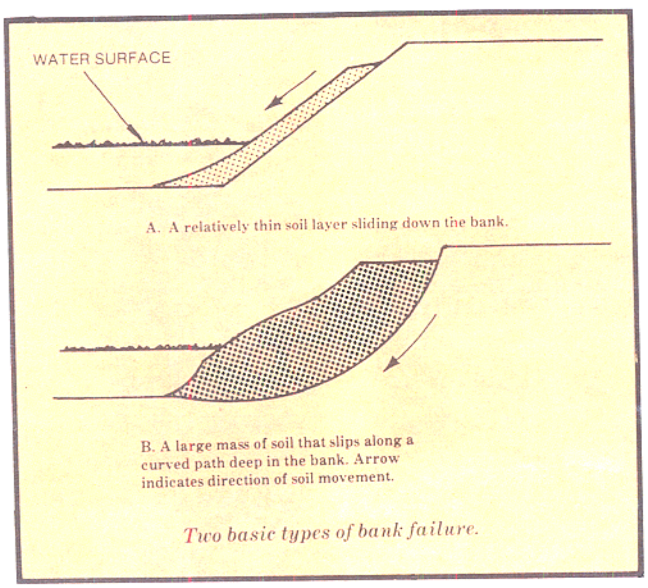
Wave attack on a streambank.

Ice generally remains in place during the winter months and causes very little streambank erosion.

Debris can cause streambank erosion due to abrasion or impact.

ABOVE: Continued urbanization has left many areas without the vegetation cover needed to effectively control rainfall runoff. BELOW: Clearing land for agricultural purposes can significantly increase the sediment load of nearby streams.

(Photos provided by Soil Conservation Service)



Two basic types of bank failure.

and grasslands for agricultural purposes have dramatically changed the land use in many parts of the United States. Statistics compiled by the U.S. Department of Commerce indicate that nearly half of our surface soils have been disturbed and are potentially erodible if not properly managed. Further, much of the land now in urban areas is no longer available for rainfall infiltration due to the construction of buildings, highways, and parking lots.

The inevitable results of removing vegetative cover, disturbing surface soils, and decreasing the area available for rainfall infiltration are downstream flooding and increased sediment loads. Streambanks that once suffered no erosion now are subjected to greater stream velocities during unprecedented flood flows. In addition, as the flood flow subsides, the excessive sediment load may be deposited on the bed of the stream, thereby reducing the channel's flood-carrying capacity. If the deposited material is not scoured out before or during the next flood, the stream may attempt to widen itself to carry the flow, thus further eroding the banks.

STREAMBANK FAILURE

A streambank will remain stable as long as those factors resisting failure are stronger than those factors that could cause the bank to collapse, or in the language of the engineer: "The shear strength of the bank soil must be greater than the shear stresses in the bank." Two basic types of bank failures can occur:

- ☐ A relatively thin soil layer sliding down a bank
- ☐ Or a large mass of soil that slips along a curved path deep in the bank

Regardless of the type of failure that occurs, the general conclusion is that "the bank sloughed off." A decrease in the shear strength of the soil or an increase in the shear stresses in the bank can individually or in combination lead to a bank failure.

DECREASE IN SHEAR STRENGTH. The major causes for a decrease in bank soil shear strength are:

- Swelling of clays due to absorption of water
- Increased pressure of groundwater from within the bank
- Minor movements of the soil or creep

Swelling clays or indications that excessive groundwater pressure is building up in a bank cannot be directly observed. Evidence of soil creep can be observed by the development of bank cracks that generally run parallel to the stream.

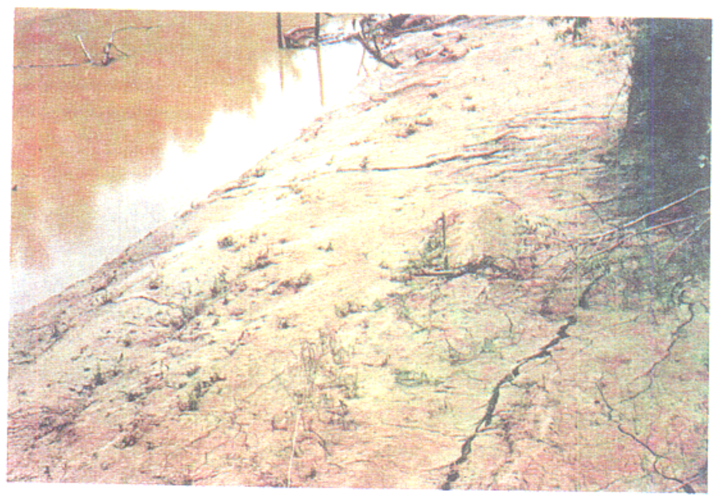
INCREASE IN SHEAR STRESS. Increases in shear stress that can lead to bank failure are most commonly the result of

- Changes in channel shape due to bed scour or erosion of the bank face
- Increase in the load on top of the bank (buildings, roads, etc.)
- Rapid drawdown of water against the bank face

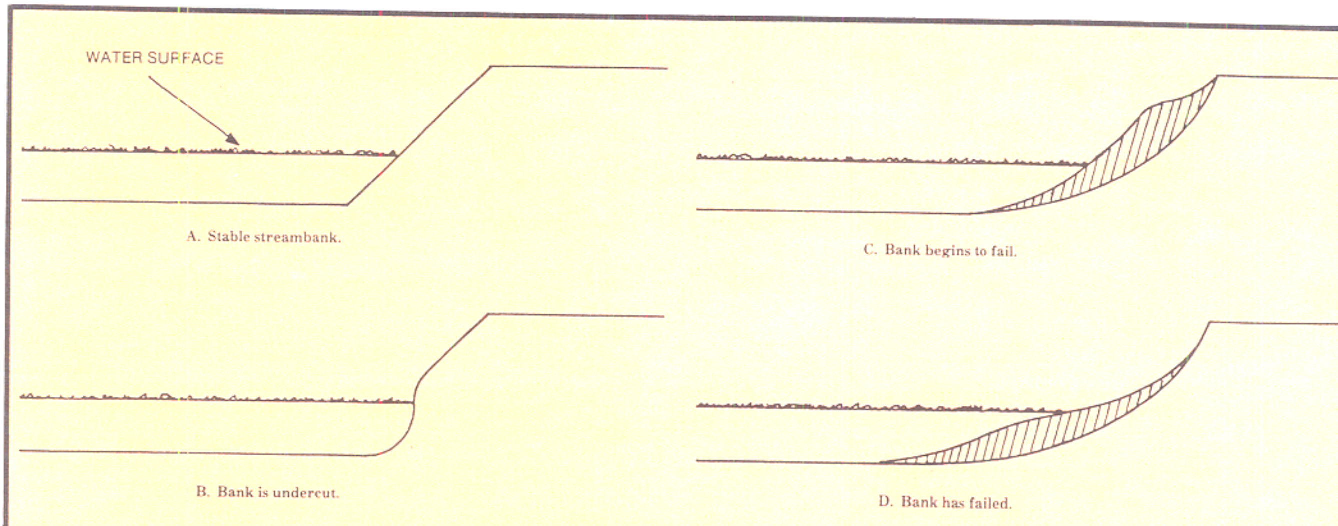
As the bed of a channel is scoured out by passing streamflow, the height of top bank above the bed increases. The bank may fail if its height continues to increase (see photo next page). Erosion of a bank face can increase shear stress in two ways: by undercutting the toe that buttresses the bank or by steepening the bank slope.

During periods of high water, banks can become saturated by inflow from the stream, by infiltration due to rainfall or

Streambank sloughing.



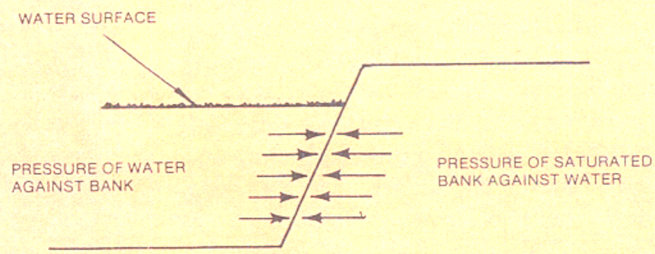
Development of bank cracks running generally parallel to a stream may indicate that soil creep is taking place. This type of movement decreases the shear strength of the soil and increases the probability of a bank failure.



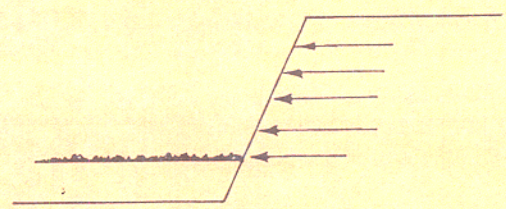
Failure of streambank due to undercutting at the toe.

Bed scour in effect raises the height of top bank which in turn may lead to bank failure.

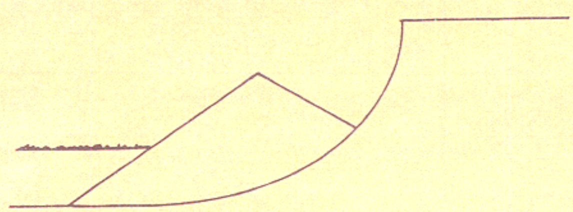
runoff, or by groundwater sources deep in the bank. When the bank face is covered by water, a pressure balance exists between the water in the channel and the weight of the saturated bank. This balance helps keep the bank in place. If the pressure of the stream water is suddenly removed by a rapid drop in water surface elevation (or *rapid drawdown)* and the soil cannot drain quickly, a pressure imbalance will exist. This imbalance may cause the streambank to slough off if the bank does not have sufficient shear strength to resist failure. Bank failures caused by rapid drawdown are most likely to occur as floodwaters recede or when a streambank is subject to water-surface-elevation fluctuations resulting from operation of a stream-regulating structure.



A. Pressure balance of stream water and saturated bank.



B. If the water surface elevation drops rapidly and the bank cannot drain quickly, a pressure imbalance will develop.



C. Bank may fail because of pressure imbalance.

Bank failure due to the water against a saturated bank being lowered faster than the bank can drain (rapid drawdown).