CHAPTER 4: RIVER AND FLOODPLAIN ISSUES

The Dolores River falls into a category of streams in Colorado that share some unique characteristics. Like some other mountain streams in the state, it has a steep channel that is lined with rounded cobbles along the bed and banks. Principles of channel stabilization that apply to meandering sand channels cannot be directly applied to this river. Sand-bed channels can change shape and pattern with every rise in the water level, so there is some continuity in their response to increases in flow. By contrast, cobble-bed channels are stable until a certain threshold is reached and exceeded. Once that threshold has been exceeded, substantial physical changes can occur. While there are many rivers in Colorado that are very different from the Dolores River with regard to instability, some principles are general.

Rivers change course and experience erosion and deposition over time under natural conditions. River dynamics consist of a continual balancing of the energy inherent in moving water with resistance to motion inherent in riverbed and bank materials. We often ignore the dynamic nature of streams, not noticing or understanding the changes that may be occurring. For example, changes in runoff, changes in sediment types or amounts, changes in the makeup of streambed or banks, changes in channel shape, and even fallen trees may cause instability or channel movement while the river adjusts to new conditions. Those adjustments may take the form of changes to channel shape, size or location, stream steepness or velocity, riverbed or bank makeup or other parameters. Depending on site-specific conditions, stability may be reestablished quickly or may be measurable only in terms of geologic time. In healthy streams there is a general balance between sediment erosion (scouring of the bed and bank) and sediment deposition (the accumulation of particles on the riverbed). This balance is continually changing but the adjustments in a stable channel are relatively minor and vegetation can become established along the river corridor. Although a stable channel is in equilibrium, continual natural adjustments result in a condition referred to as “dynamic equilibrium.”

When the natural balance of a stream is disrupted by rapid changes from human or natural causes, the channel will attempt to achieve a new equilibrium, but this may take many years. The best management approach with respect to man-induced changes is to regulate land uses so as to recognize potential problems and design mitigation of stream stability impacts before allowing activities which may contribute to stream instability. When land use activities cause stream instability it may not be appropriate to wait for an impacted stream to repair itself and reestablish equilibrium through natural processes. This document is intended to help the Rico community understand river instability and provide recommendations to maintain stability or to return destabilized river reaches to a stable condition in the shortest reasonable time and maintain a stable state thereafter.

DYNAMIC EQUILIBRIUM

Under natural steady conditions the river dynamic equilibrium between channel resistance and energy of water flow is established over many years. Alterations to a river channel disrupt this dynamic equilibrium and cause changes to the channel hydraulic parameters. Encroachment into or near the river floodplain and riparian zone can have long-lasting impacts on the stream system by disrupting characteristics such as sediment load, stabilizing vegetation, floodplain boundaries, floodplain storage, channel resistance, runoff, diversion of flow, channel pattern and geometry. Adjusting even one parameter can upset the balance between these channel properties. Under balanced conditions rivers achieve stability by shaping and adjusting the channel bed and banks to accommodate the range of flows naturally occurring in the drainage basin. Left alone, a river will eventually regain a dynamic balance between river velocity, flow depth, gradient, and channel roughness, but in the case of severe disruptions the time for such a recovery may be unacceptable to the community.

Under conditions of dynamic equilibrium, a stream's energy is at a level that allows sediment loads entering a stream reach to equal those leaving it. If more free energy is available than is expended by the flow, the principle of continuity requires changes in some or all hydraulic variables, such as width and depth of flow, slope, velocity and flow resistance. If there is excess free energy available, morphologic changes result which lead to changes in sediment load. Whatever process occurs, it is directed toward attainment of a new equilibrium between available and expended energy.

DEFINING CHANNEL INSTABILITY

Channel instability relates to lateral (horizontal) and elevational (vertical) changes in the river bed, which leads to the following problems for the natural and human-built environment:

1. Threats to roadways, utilities, infrastructure and development in the geomorphologic floodplain,
2. Loss of property due to channel migration,
3. Loss of trout habitat, due to the change from a pool-riffle sequence to predominantly fast moving water in continuous riffle sections,
4. Loss of wetlands and riparian zones due to high width-to-depth ratios and lateral bank migration,

Channel instability, as a result of disruption of the channel equilibrium, is characterized by:

1. **Vertical Instability**, leading to changes in the channel bed elevation level by deposition of material (aggradation) or erosion of the bed material (degradation). This is a major problem at bridges where the foundations become exposed; at utility crossings where pipelines can be washed away; or at critical floodplain areas where water can overtop the riverbanks.

2. **Lateral Instability**, where erosion or deposition at the channel banks causes the low-flow channel location to migrate horizontally. This can drastically affect property and infrastructure, and is the most easily recognizable result of channel instability.

Instability occurs when the channel migrates laterally, or the channel bed is raised or lowered, thereby forcing changes in the flow hydraulics, especially during flooding conditions. This instability can lead to many negative impacts including river encroachment on property and buildings, floodplain alteration, exposure of buried utility lines, scouring around bridge piers, increased river sediment load, weakened bank stability, diminished aquatic habitat, destroyed wetlands and riparian vegetation, and reduced recreational opportunities. Development and river system coexistence are promoted when channel adjustments and fluctuating river conditions are more controllable and predictable. Channel restoration is necessary when conditions have caused a river to become unstable to the point where it becomes unmanageable.

Individual efforts to control and restrict the Dolores River in one location may cause subsequent damage in another area, and an extended reach may become unstable. Natural channel migration and sediment transport processes can continue as part of the river's effort to re-establish dynamic equilibrium, and the river will widen or incise with each subsequent flood. The massive transport of cobble that can occur during flood events may significantly alter the river's alignment and geometry. Attempts to stabilize the channel by restricting it to a narrow corridor may result in even more instability and uncontrolled damage to property.

The goals of channel stabilization and restoration include:

- Reduce active streambank erosion.
- Reduce land loss.
- Establish natural stability rather than artificial or constructed stability associated with hard controls such as riprap (rock) channelization, concrete and gabion baskets.
- Utilize native materials for stream stabilization.
- Improve fish habitat.
- Reduce loss of property, structures, and public access points.
- Improve aesthetics.

SHEAR STRESS

The key factor leading to instability in the Dolores River is mobilization of channel forming bed and bank cobbles. When these large particles begin to move, they roll and bounce along the riverbed bottom destabilizing the entire channel boundaries. Material transported along the bottom of the channel is known as ***Bedload*** and is the subject of channel instability for this river.

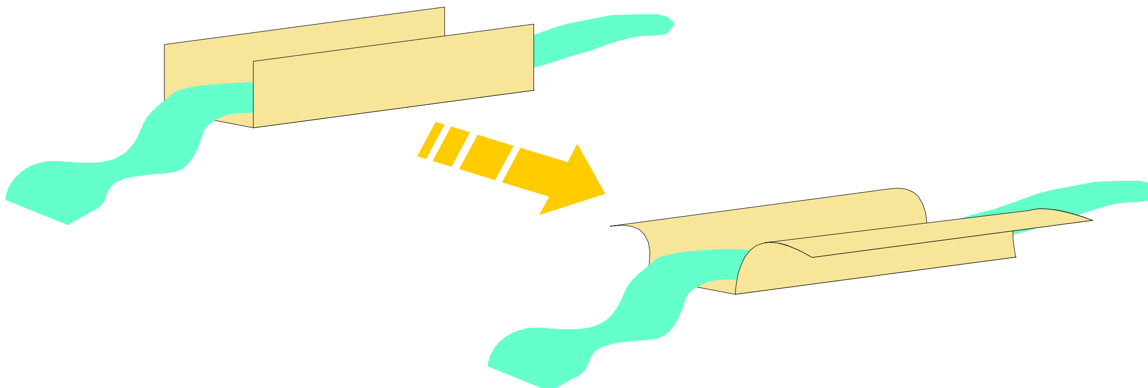
Finer particles of silts and sands are easily transported in suspension due to the high stream power known as ***Suspended Load***, and are no longer found in the top bed layer. Suspended sediment impacts water quality, but is less of a concern to channel stability on the Dolores River than bedload. Since instability begins only when these channel forming cobble particles move, channel stability can be defined by utilizing bedload transport equations.

Movement of the bed particles occurs when drag forces (calculated as ***Shear Stress***) caused by the water over the bed material exceed resisting forces of the bed and banks and the particle weight. Shear stress on bed and bank particles is primarily a function of two factors: 1) mean flow depth and 2) the slope of the river (actually, "energy grade line" slope). Once the threshold for ***Incipient Motion*** (beginning of motion) is surpassed, the majority of particles which comprise the surface layer of the channel bed start moving., At that point, the horizontal and vertical control of the channel is diminished. The result is an unstable braided or meandering river pattern, which forms when high flows mobilize the coarse bed material. The channel pattern always adjusts toward an equilibrium. It makes those adjustments through lateral channel migration (meanders), and longitudinal profile changes (vertical erosion and deposition). In reaches where the floodplain widens or the channel slope flattens, shear stress is reduced and the bedload is deposited. These fluctuations in sediment transport capacity cause cobble-bed channels to be unstable as the bedload moves in pulses.

The key to cobble-bed channel stabilization is maintenance of broad floodplains to dissipate the river's energy during flooding.

Levees or ***berms*** installed along the bankfull channel are intended to protect property adjacent to the river from overbank flooding. While they may perform this function in the short run, they also focus all of the river's energy in the channel which causes the river to become unstable. This pattern of instability is displayed by lateral bank erosion and vertical instability where berms have been installed along the Dolores River through Rico. A wide floodplain will dissipate the water's energy during a flood and reduce the overall channel mean depth, which consequently reduces shear stress on the bed particles. Restoration programs on the Dolores River may require removal of levees and berms to restore or improve floodplains and to ensure that the floodplains are connected to the channel. Installation of new levees to protect existing structures requires a set-back from the low-flow channel so that remaining floodplain width will be roughly four times the river's bankfull width.

The following figures demonstrate how man-made controls placed on the river to protect property from flooding can intensify the stresses on the main channel during a flood. To define the instability problem, it is important to understand the river has a certain amount of energy at a given flow which must be balanced against its controls to maintain stability. Alterations to the channel disrupt this equilibrium and lead to aggradation or degradation of the channel bed and banks.



Removing levees and properly constructing overbank sections will improve channel stability and keep the channel shaping cobbles in-place by dissipating the energy of flood flows across a broader area. This is analogous to carefully placing marbles across the bottom of a box and flowing water over the top while trying to keep the marbles from washing out. At the depth of flow just before the marbles begin to move, the edges of the box should be opened up to spread the energy of the water across a larger area.

BEDLOAD SEDIMENT TRANSPORT

Bedload transport is the channel-defining process for the Dolores River. When we are talking about cobbles, the transport of bedload is limited by transport capacity, not by supply of material on the Dolores River, except for the Chutes area. The channel bed and banks contain an abundant supply of cobble-sized particles, however, the mean annual flow lacks the stream power to mobilize these large particles. The situation is different when we talk about smaller particles. Any fine particles are either protected by a layer of cobble or have long since been washed away, and their transport is supply-limited due to the high available stream power.

Changes in the channel hydraulic geometry and discharge rate can affect the transport of cobble. Increases in flow depth and slope will increase the shear stress on the particles, and if this shear stress is beyond the critical threshold value for the particle size and shape, incipient motion will occur. Changes to the bedload transport capacity along the river can cause scour or deposition, and result in variations of bed material storage. These changes in storage produce irregular fluctuations in the bed level. As a result, bed level will rise and fall as bedload moves downstream. Bedload will be mobilized and transported downstream in pulses and waves as shear stresses respond to bed level variations.

Cobble-bed channels are stable only when the transport capacity of the river is limited so that shear stress on the particles remains below the critical shear stress threshold. Limiting transport capacity in cobble-bed rivers is paramount to effective channel stabilization. The equilibrium established in a cobble-bed river results in a stable channel under base flow conditions. However, flood flows have higher transport capacity and can result in mobilization of bed particles. Since the higher flows cause the instability in cobble-bed channels, it is important to focus on flood conditions when designing a stable channel.

The flow which move the most material over time is knows as the ***Dominant Discharge***, and is likely about a 1 in 5-year flood event on the Dolores River. For sand bed channels, the dominant discharge is usually considered to be a 2-year event. Therefore, the most effective channel stabilization measures should protect up to at least the 5-year flood event. Critical channel stabilization structures should be designed to withstand a greater event, such as the 100 or 500-year event, but the benefits are diminished when designing against a less frequent event.

BASIS FOR CHANNEL STABILIZATION

A well vegetated streambank with little or no active erosion is a sign of a stable channel. When instability occurs, excessive erosion or sediment deposition can result. Streambank erosion and bank failure can sweep large quantities of material off banks, causing deposits of sediment downstream. Gravel or sandbars that change location frequently are evidence of an erosion problem. The objective for channel stabilization is to reduce channel erosion or excess deposition. A stable channel is balanced with its surroundings so that the water has enough energy to prevent sediment deposition, yet not so much energy that channel erosion will occur. E. W. Lane (1955) developed the following relationship:

$$Q * S \text{ is proportional to } Q_s * D_{50}$$

Where:

Q is the discharge,
S is the slope of the channel,
Q_s is sediment transport capacity, and
D_{50} is the mean particle size composing the channel bed and banks.

In this equation, **discharge** and **channel slope** are proportional to **sediment transport** and the **size of the particles**. If one factor changes, another factor must also change to compensate. Using this basic relationship, sediment transport capacity can be reduced and channel stabilization can be achieved either by:

1. Reducing the channel bed slope,
2. Reducing the flow, and/or
3. Increasing the particle size in the channel.

Reducing the Channel Slope

Channel slope is reduced by the creation of meanders which act to lengthen the total channel distance between two fixed elevation points, thereby reducing the channel slope. Sinuosity is not simply an aesthetic characteristic of rivers, but is also a natural result of channel equilibrium achieved by reducing the slope and consequently the stream power.

Frequent widening of a channel is a sign that the river is in the process of achieving a new slope. As more sediment is deposited into streams, the streambed may aggrade and become shallower, forcing water to spread out and widen the stream. Widening of the stream causes more bank erosion and more sediment deposition. Sediment deposition fills in pools needed by larger fish and destroys valuable trout habitat.

Another method of reducing the channel slope is to construct one or more grade control structures. **Drop Structures** are used to dissipate the water's energy at a controlled location and reduce the channel slope between the structures. If the vertical drop in a channel (where the river derives its energy) is controlled, the stream power is better controlled.

Reducing the Flow

Wild rivers rage uncontrolled during the spring runoff. However, in an attempt to capture some of this excess runoff, reservoirs have been constructed. Reservoirs acting in a flood control capacity reduce the peak flow downstream. This peak flow is responsible for transporting most of the sediment and erodes the channel. Reducing the flow correspondingly reduces erosion of the channel. Streams that do not experience great changes in flow and velocity tend to have more stable sandbars and banks.

Increasing the Particle Size

It is not practical to increase the particle size throughout a channel except in critical local scour areas. In those areas, this can be accomplished by adding rock riprap. Channels naturally tend towards greater stability by increasing the channel particle size through a process known as ***Armoring*** the bed. Armoring is a process whereby larger particles interlock through the jostling and vibration of constant water friction, forming a barrier to smaller, looser sediment in the substrate. A streambed with a cobble surface underlain by finer material is armored against sediment transport of the small particles. An armored layer is formed when fine particles are transported away more rapidly than they are replaced by the inflowing sediment load. This condition does not reduce the stream's potential to transport sediment, but rather limits the supply of finer sediment particles exposed to the flow. The result is an interlocking bed surface of coarse materials with fine particles found only under this bed surface layer. At high flow conditions, the surface cobbles are moved and jiggled into the most stable configuration with the other surrounding cobbles. This layer of the bed is formed in such a manner so the cross-sectional area of the particles exposed to flow is minimized. The layer can be disrupted by man's activity or by flood events large enough to mobilize the surface cobbles.

The Dolores River channel clearly shows this armoring effect where the bed surface is composed solely of cobbles all aligned with the long face angled away from the flow. Disruption of this armored layer results in rapid erosion of the bed until a new armored layer is formed. Therefore, any work in the riverbed should attempt to preserve this armored layer to maintain channel stability and reduce sediment loading in the river.

Other Parameters Affecting Channel Stabilization

Other hydraulic parameters can also be adjusted to improve channel stability that are not included in Lane's Relationship. These include cross-sectional geometry and channel resistance. Proper width-to-depth ratios in the channel are critical to balancing erosion and deposition in a river. Areas where the channel broadens out and becomes shallow cause sediment to drop out of suspension and become unstable. Areas where the channel is constricted are potential zones of erosion. Resistance is also important to slow flood water and reduce overall stream power. Heavy brush and dense riparian vegetation resists the flow of water next to the bank and improves bank stability.

CAUSES OF INSTABILITY

Channel equilibrium has been disrupted over the years by development encroaching upon the river and the construction of levees to protect property from inherent flood hazards. Levees limit the channel width during flooding and prevent the river from expanding laterally in wide meanders. There is clear evidence that once levees are constructed along a given channel bank, bank erosion can occur on the opposite bank.

Individual efforts to control and restrict the river in one location can cause subsequent damage in another area, making the whole reach unstable.

The following characteristics and factors have been identified as contributors to channel instability:

1. Inadequate Streambank Protection

   - Unstable streambanks - Erosion of the channel banks further adds coarse sediment into the channel and results in accelerated land loss.
   - Damage to riparian vegetation - Native vegetation has been altered, leading to accelerated streambank erosion. Possible causes include overgrazing and land development.

2. Excessive Longitudinal Channel Slope

   - Steep stream slope - Low sinuosity causes the channel bed slope to match the geologic slope of the valley, which is too steep for a stable channel in most conditions.
   - Straightening the channel - Instability caused by straightening the channel results in a steeper bed slope which contributes to accelerated bank erosion and lateral extension of the channel. As a result, increased sediment deposition occurs downstream.

3. Flood Protection Levees - Constructed levees installed within the floodplains to protect riverside property from inherent flood hazards can concentrate excessive energy of the river against the streambanks and channel bed across and downstream from the confining structures. This also leads to accelerated streambank erosion and a reduction in channel diversity. The result is a higher proportion of fast-moving riffle sections and a lower proportion of slow-moving pool sections.

4. High width/depth ratios – Excessive channel width resulting from lateral channel migration and deposition of sediment creates an overly large bankfull cross-sectional area. This widening precludes the regeneration of riparian vegetation and leads to further instability.

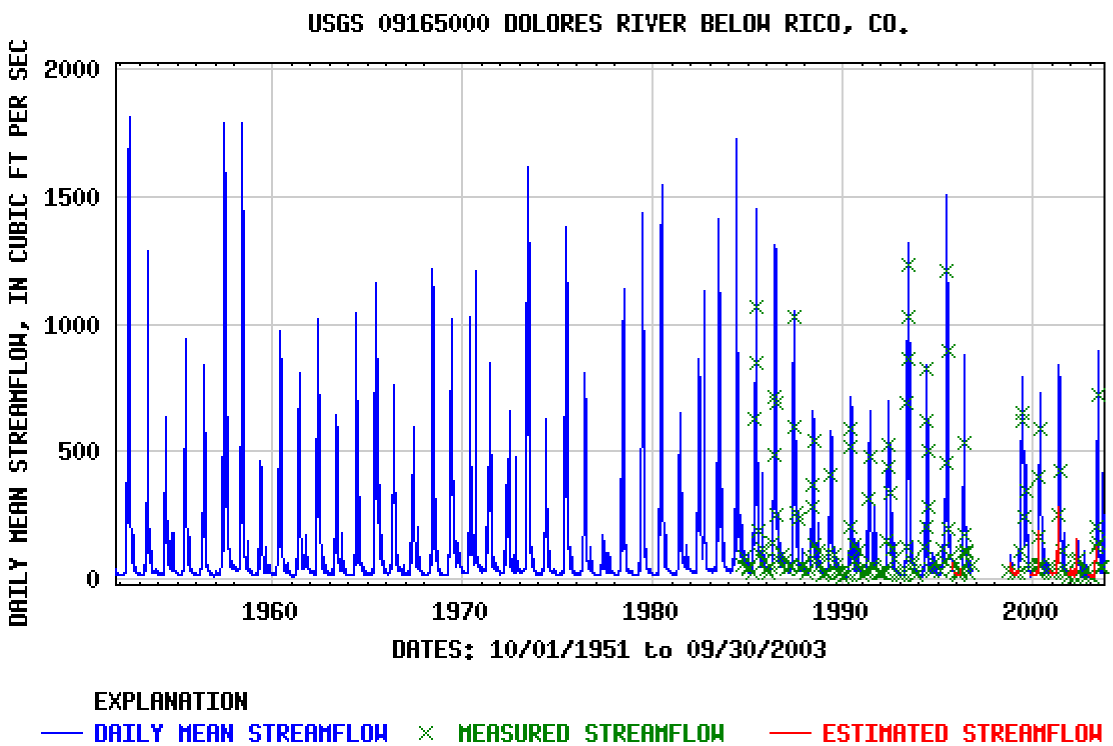
5. High bedload sediment supply - The supply of coarse sediment from both the upstream watershed and from erosion of the streambank and streambed contributes to excessive deposition downstream. Stabilizing the channel will improve channel stability downstream.

All of the causes of instability listed above (*weak streambanks, steep slopes, confinement by levees, high width-to-depth ratios and excessive bedload sediment supply*) are present in the Rico region of the Dolores River watershed.

FLOOD HISTORY AND GAGE RECORDS

This section of the report includes information concerning the history of flooding on the Dolores River, as told by stream gages on the river.

There are only two active USGS gages located on the main stem of the Upper Dolores River: "Below Rico" and "At Dolores." The **Dolores River below Rico, Colorado** gage has operated 1951 through present (currently active), which gives us over 50 years of record, which initially seems adequate. Unfortunately that gage record does not provide enough data for a detailed statistical analysis and does not include some of the more major floods that occurred prior to the installation of the gage. Below is a graph of all stream gage data available for that gage.



To better understand the history of channel instability and its occurrence, the recent history of flooding was documented using USGS gage records. The above graph shows flooding has occurred on the Dolores River in the years 1952, 1957, 1958, 1973, 1980, and 1984. Droughts with very low peak flows were recorded for 1977 and 2002. It would appear that no floods have occurred within the last 50 years that approach a 100-year flood; however, the data shows *average* peak day flows rather than *instantaneous* flows which are often higher. Channel instability is particularly evident during and after a flood event. It is during times of flood that the channel often shifts its location and can move to a new location. The channel may move or change slowly during normal flows, but instability problem areas are prevalent after a significant flood event.

The largest flood events occurred in June 1884 and October 1911. The 1911 flood destroyed 11 houses, 1 stable, the city feed yards and every bridge in Rico. It is important to note that no flood control reservoirs have been constructed to reduce the flood hazard potential on the Upper Dolores River at Rico.

FLOODPLAIN STUDIES

The Dolores River floodplain through Rico was first studied by Chris Wilbur, PE in September 1995 in a report titled, “Documentation for Hazard & Constraint Maps, Town of Rico Colorado.” The Colorado Water Conservation Board completed an evaluation of the floodplain study in September 2000 titled, “Floodplain Information Report,” which adopted the Wilber report.

The recommended 100-year hydrology for the floodplains in Rico is as follows:

Dolores River at Rico	2,800 cfs
Silver Creek	700 cfs

The approximate floodplain has been digitized onto **Figure 6-1: Summary of Previously Proposed Issues and Improvements**.

RIVER ISSUES

Issues related to ***Watershed Protection*** through the Town of Rico, as discussed in the preceding sections of Chapter 4, are illustrated graphically on the following **Exhibit 4.1: Current River Issues**. These issues were identified by the consultant team and do not necessarily include all issues. The stakeholder group and Rico community should review, add and update this map as issues arise.

A second map, titled **Exhibit 4.2: Potential Future Changes** summarizes development and changes that may occur that could impact the Dolores River watershed. This mapping exercise is also known as the “Rumors Map” because it shows changes that have been discussed, but may or may not be implemented. This list was also compiled by the consultant team and may not include all upcoming changes. The stakeholder group and Rico community should review, add and update this map as future potential changes come up in discussions.

Insert Issues Map

Insert Rumors Map