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Virtual Rivers: Understanding Historical Human Impacts to Rivers in the Context of Restoration

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Abstract

A virtual river is one that preserves a simplified albeit attractive form, but that has lost function because hydrologic and geomorphic processes no longer create and maintain the habitat and natural disturbance regime necessary to ecosystem integrity. The concept of a virtual river is particularly important in the context of river restoration, where public perception of a river's condition often drives the decision to undertake restoration, as well as the type of restoration attempted. Determining the degree to which a river has become virtual, or has been altered from reference conditions, requires knowledge of historical land use and associated affects on rivers. Rivers of the Colorado Front Range, USA are used to illustrate how historical land uses such as beaver trapping, placer mining, tie drives, flow regulation, and construction of transportation corridors continue to affect contemporary river characteristics. Ignorance of regional land use and river history can lead to restoration that sets an unrealistic goal because it is based on an incorrect assumption about a river's reference condition, or incorrect assumptions about the influence of persistent land-use effects.

Introduction

River restoration is commonly undertaken with the intent of creating a river that meets expectations of appearance and/or function. Expectations can be based on some hypothetical river condition assumed to exist prior to disturbance or on more idealized conceptions of how a river should look (Kondolf, this volume). Although restoration sometimes focuses on river function as expressed through restoring processes that provide self-sustaining aquatic or riparian habitat, the appearance of the river is more likely to be the focus of localized reach- or segment-scale restoration projects.

Emphasis on appearance only can be misleading. A segment of river can meet many people's expectations of a healthy river if the water is clear and the stream banks are not rapidly eroding. Such a healthy-looking river can in fact have highly compromised function if stream flow and sediment are no longer moving downstream in a manner that maintains the diversity of habitats requisite to diverse aquatic and riparian communities. This dichotomy between appearance, or form, and function gives rise to the concept of a virtual river. A virtual river is one that preserves a simplified albeit attractive form, but that has lost function because hydrologic and geomorphic processes no longer create and maintain the habitat and natural disturbance regime necessary to ecosystem integrity.

The concept of a virtual river is particularly important in the context of river restoration, where public perception of a river's condition often drives the decision to undertake restoration, as well as the type of restoration attempted. If a river appears relatively attractive and healthy, there is less likely to be inquiry into the history of land use and river responses that have directly influenced the current condition of the river. The net effect of most land use is to reduce the complexity and diversity of river form and function. At some point these reductions cross a threshold and the river is perceived as compromised and in need of restoration. This threshold can be very high, however. Alteration of flow regime, disconnection of the stream channel from the adjacent floodplain and hyporheic zone, reduction of aquatic and riparian habitat diversity, and loss of macroinvertebrate, fish and riparian vegetation diversity can all be severe before the general public perceives that the river has lost function. Conversely, a river that is considered unattractive is more likely to be considered compromised and in need of restoration, even if the river's current appearance reflects the expected response to climatic and geologic conditions within the drainage basin. Braided rivers, or rivers along which large floods periodically reconfigure the channel and valley bottom, are more likely to be perceived as needing restoration even if form and function have not been compromised relative to a reference condition.

Delineation of a reference condition can be very difficult in a region where most river systems have changed to some degree as a result of land-use patterns. Reference condition in this context refers to the most probable state of a river in the absence of human influences. Reference condition can be estimated using (i) unaltered but otherwise analogous rivers, if these are present; (ii) the river characteristics likely to be present for given climatic and geologic characteristics (Figure 1); or (iii) historical records of what a river was like prior to human influence and how the river has changed as a result of land use. Regardless of how reference condition is estimated, knowledge of historical change in rivers as a result of land use forms a critical component of restoration design because it provides a context for the causes, duration, spatial extent, and intensity of human-induced changes in a river (Petts, 1989; Sear, 1994; Kondolf and Larson, 1995). When combined with knowledge of unaltered rivers or of likely river characteristics given regional climate and geology, historical knowledge also helps to constrain what is possible in restoration. For example, rivers in a region with a history of placer mining may have been meandering prior to mining, and unaltered rivers nearby may still be meandering. But restoration to a self-sustaining meandering form of mined rivers that are now braided may not be possible because of continuing high sediment yields from unstable mining tailings upstream.

Rivers in the Front Range of Colorado, USA provide an example of how historical land use activities have compromised the function of rivers that can appear deceptively pristine (Wohl, 2001). These mountain streams have a suite of characteristics that result from regional climate and geology, as well as two hundred years of human land use. These characteristics in turn impose constraints on river restoration. Being aware of these constraints and working within them can result in effective river restoration that promotes self-sustaining diversity of form and function. Being ignorant of the constraints or attempting to override them is more likely to result in river restoration that fails to provide the benefits intended from the restoration (e.g. Uvas Creek, California in Kondolf et al., 2003).

The following sections summarize the physical context of rivers in the Colorado Front Range; the history of human activities that have affected these rivers; the resulting change from reference conditions; and the use of knowledge of historical change in establishing rehabilitation priorities.

Physical context of rivers in the Colorado Front Range

The Front Range forms the eastern-most part of the Colorado Rocky Mountains. Stretching approximately 275 km from north to south, and 100 km from east to west, the Front Range is drained by streams of the upper South Platte River basin (Figure 2). More than ten streams heading close to 4300 m elevation along the Continental Divide flow east toward the base of the range at 1520 m elevation, joining beyond the mountain front to form the South Platte River that then flows into the Missouri River and ultimately the Mississippi River. Changes in climate, vegetation and flow regime are associated with changes in elevation. Mean annual precipitation drops from approximately 100 cm at the highest elevations to 36 cm along the base of the range. Alpine vegetation in the headwaters gives way downstream to subalpine spruce-fir forest, montane pine forest, and eventually steppe vegetation. The major streams are perennial, with a snowmelt peak in late spring and early summer. Convective storms also generate summer rainfall that produces infrequent flash floods below approximately 2300 m elevation. These rainfall floods can generate a peak discharge as much as forty times the size of snowmelt flood peaks (Jarrett, 1989).

Rivers in the Front Range tend to have a very steep gradient ($\geq$ 0.01 m/m) and a narrow valley bottom with a limited floodplain. Channels are likely to have step-pool or pool-riffle sequences, but channel and valley morphology is longitudinally quite variable because of downstream changes in geology, glacial history, and beaver activity. Most river segments have a coarse streambed formed in cobble- to boulder-sized sediment. Widespread mobilization of the abundant sand and gravel underlying the streambed does not occur during the average annual snowmelt flood, but does occur infrequently during summer rainfall floods. Only these floods generate sufficient stream power to mobilize the coarse surface streambed and to substantially reconfigure channel and valley-bottom morphology. Flooding can also be exacerbated by a hillslope disturbance, such as a forest fire, that introduces large quantities of sediment into the river. The rivers are thus normally stable, with relatively low sediment loads, but they periodically exhibit dramatic response to disturbance from floods and hillslope instability.

Organisms adapted to cold, oxygenated water, coarse stream substrates, and turbulent flow are most common in the Front Range rivers. Macroinvertebrate abundance and species richness are low in the headwater reaches of these mountain streams, and increase from the montane zone down to the foothills as a result of increasing water temperature and habitat diversity (Ward, 1992). Fish diversity also increases downstream. Salmonids include native greenback cutthroat trout (*Oncorhynchus clarkia stomias*) in the highest elevation stream segments, and nonnative brook trout (*Salvelinus fontinalis*), rainbow trout (*Salmo gairdneri*) and brown trout (*Salmo trutta*) in the middle and lower stream segments (Campbell et al., 1984; Raleigh et al., 1986). Other common species include western longnose suckers (*Catostomus catostomus griseus*), northern creek chub (*Semotilus atromaculatus atromaculatus*), fathead minnow (*Pimephales promelas*), and longnose dace (*Rhinichthys cataractae*) (Forest Service, 1980).

Historical land-use patterns in the Colorado Front Range

People have lived in the Colorado Front Range for at least 12,000 years (Eighmy, 1984; Grant, 1988; Benedict, 1992), but there is no evidence that population densities or land-use patterns produced changes in the region's rivers until the first decades of the 19th century. Once people of European descent began to settle the region, numerous types of land use swiftly became widespread and substantially altered hillslopes and stream channels (Table 1). The following sections briefly summarize a few of the effects of the earliest land-use patterns.

Beaver trapping

Members of the 1804-06 Lewis and Clark expedition noted the abundance of beaver in the western United States and, once the expedition ended, these men helped open the region to fur trapping. Trapping quickly became so intense that most of the beavers were trapped within two decades. John Charles Fremont rarely saw an active beaver lodge during his journey through the Front Range in 1842-43, but he wrote of many abandoned beaver dams falling into disrepair.

Beavers exert a strong influence on water and sediment movement along a river by building low dams of woody debris (Naiman et al., 1986, 1988). These dams create ponds that act as sediment traps, gradually filling to create swamp or meadow environments. The ponds and meadows also provide flood control, because as the rising waters of a flood spread into the pond they move downstream more slowly. The stepped profiles of beaver-influenced rivers, with narrow, deep, sinuous reaches above the ponds and shallower reaches of swifter flow below the ponds, maximize the diversity of riparian and aquatic habitats (Figure 3).

Between 1810 and 1860, tens of millions of beavers were trapped along rivers in the western U.S. Once fur trappers discovered an area, the majority of the beavers were usually trapped within a few decades (Olson and Hubert, 1994). With the removal of beavers, the beaver dams were breached, and some of the rivers probably rapidly incised to become gullies. Incised channels have larger, more flashy, floods; increased sediment yield from unstable and eroding streambed and banks; and less diverse habitat (Brayton, 1984; Maret et al., 1987).

No one was keeping records of the response of Front Range rivers to beaver trapping during the early 19th century, but we can infer this response from modern analogs. Contemporary studies indicate that flow downstream from beaver ponds contains 50-75% fewer suspended solids than that of equivalent stream reaches without these ponds (Parker, 1986). When beavers were reestablished along Wyoming's Currant Creek during the 1980s, daily sediment transport decreased from 30 to 4 metric tons (Brayton, 1984). Downstream channel slope decreased, as did bank erosion during spring high flows, which was the main source of sediment to the river.

The net effect of beaver removal along rivers in the Front Range was probably a reduction in diversity and stability as channels incised, flood peaks and sediment transport increased, and riparian and slow-velocity habitats were lost. However, the channel changes caused by removal of beaver were probably much less substantial than those associated with changes in regional land use that began with wide-scale mining during the 1860s.

Placer mining

The removal of placer metals such as gold and silver from streambed sediments in Colorado began near Denver in 1859. Placer deposits were discovered throughout the Colorado mountains during succeeding decades. Miners initially used hand-operated gold pans or shovels and sluices to process sediment and metals. An experienced miner using hand tools can process 0.4-0.6 m^3 of sediment in 10 hours. These methods were usually quickly replaced by hydraulic systems in which large hoses were used to direct pressurized water at the valley-bottom sediment deposits. Two people operating a hydraulic system can process 2-4 m^3 of sediment in 10 hours. Commercial operators installed dredge boats at many sites. These boats were processing plants: streambed sediment was dredged up with large shovels, the placer metals were removed on the boat using physical separation or chemical separation via mercury amalgamation, and the remaining sediment was dumped back into the stream (Figure 4). A dredge boat can process 6,000-6,600 m^3 of sediment during 10 hours (Silva, 1986). The usual practice in either hydraulic or dredge boat mining was to remove and process the streambed sediment down to the bedrock contact and back to the valley side slopes.

The effects of placer mining on river form and function are threefold. First, the disruption of bed and bank sediment renders the sediment more susceptible to being moved by flow in the river. This can cause downcutting of the river at the location of the mining, or change a meandering river to a braided river (Hilmes and Wohl, 1995). Smaller sediments are preferentially mobilized from the disturbed area and accumulate downstream. Downstream accumulation can reduce the river capacity and cause enhanced flooding. Water quality is degraded by the increase in suspended sediment, further degrading aquatic habitat for a variety of species (Wagener and LaPerriere, 1985; Van Nieuwenhuyse and LaPerriere, 1986). The remaining coarse lag can be too large to provide spawning gravels for fish, whereas the finer sediment carried downstream can preferentially fill pools and cover downstream spawning gravels. The river at the mining site remains less stable for decades after mining has ceased because the fine-grained bank sediment that formerly supported stabilizing riparian vegetation is now gone (Hilmes and Wohl, 1995). Placer mining along the mountainous headwaters of Colorado's Clear Creek produced so much excess mobile sediment that an 1894 photograph taken from a balloon clearly shows sediment deposition along the creek well beyond the mountain front. This sediment in turn caused problems for newly built irrigation intake structures along the downstream portion of Clear Creek flowing through the Great Plains.

Second, toxic materials such as heavy metals or mercury used during mining are introduced to the stream and valley-bottom sediments. These materials are very persistent in the environment, as shown by the contemporary correlation between 19th century mining sites and 20th century Superfund sites (EPA, 1994). The most general effect of any pollutant is to reduce community diversity within and along a river (Mackenthun and Ingram, 1966). Toxic materals interfere with the respiratory, growth, and reproductive functions of members of the entire river food web. The toxic materials can act as a time bomb, for they have an impact across time and space. The initial introduction is followed by processes of bioaccumulation and biomagnification over a period of years to decades. In biomagnification, some toxic materials are not expelled by organisms, but accumulate in fatty or other tissues. Any predator thus ingests all of the toxins accumulated by each of its prey organisms, so that concentrations of toxins increase with distance up the food chain. Longer-lived organisms can also continually ingest more of the toxin without expelling it, leading to bioaccumulation. The toxins may be adsorbed onto clay or silt particles, lie buried in a sediment deposit, and then be remobilized decades later by streambed erosion or lateral channel shifting during a flood (Graf et al., 1991).

Third, placer mining indirectly affected rivers by altering the amounts of water and sediment entering the rivers. These alterations usually resulted primarily from destabilization of the valley slopes as a result of timber harvest associated with settlement of the region. Lumber was needed for sluices, flumes, stamp mills, mine timbers for lode mines, houses and other buildings, cooking and heating, and the fires that drove steam-operated stamp mills and smelters. After Congress passed the Free Timber Act of 1878 to protect forests by prohibiting the cutting of live trees on the public domain for commercial purposes, mining communities reacted by setting forest fires to create standing charcoal and dead trees that could then be legally harvested. Placer mining also redistributed sediment in valley bottoms, often removing lateral support at the base of hillslopes. Construction of roads, railroads and buildings along hillslopes compacted slope surfaces and increased the weight over portions of the slopes, further destabilizing slopes and increasing sediment yield to rivers. Widespread deforestation and slope instability caused an increase in debris flows and landslides noted by contemporary observers (Clark, 1861; Tice, 1872).

As with beaver trapping, the net effect of placer mining and associated activities in the Colorado Front Range was to reduce river diversity and stability. The contemporary activities of floating railroad ties to collection booms, regulating and diverting streamflow, and constructing transportation corridors further impacted rivers. Together, these activities affected almost every creek and river in the Front Range, and effectively overwhelmed the channel alterations associated with beaver trapping.

Tie drives

From the 1860s, when railroad companies began to lay tracks in the western U.S., until the completion of most of the major commercial or mining routes in the 1890s, the construction of railroads placed a heavy demand on western timber resources. Most of the wood for the railroad crossties came from the mountains, and rivers provided a convenient route for transporting the ties from the mountains to downstream collection points such as Fort Collins or Greeley. Millions of logs were rafted down the Front Range rivers; more than 200,000 ties a year went down the Poudre River during 1868-1870, for example (Wroten, 1956).

The mountain channels were altered to facilitate conveyance of the logs. Naturally-occurring wood and large boulders were removed; overbank areas and marshes were separated from the main channel by dikes; and meanders were artificially straightened with cutoffs. The log masses themselves had the effect of a giant scouring brush as they moved down the channel (Figure 5). When rivers that had tie drives are compared to analogous rivers without tie drives, the effects of the tie drives are still discernible a hundred years after the last tie drive. Rivers with tie drives have less diverse and less mature riparian vegetation; wider, shallower channels with less pool volume; and less naturally occurring wood (Young et al., 1990).

Secondary channels and overbank areas increase stream stability by providing places where flow energy is dissipated during floods, and increase habitat diversity by providing environments characterized by shallower, slower flows or ephemeral flow, increased hyporheic exchange, and storage of finer sediment and organic materials (Bayley, 1991; Stanford et al., 1996; Kasahara and Wondzell, 2003). The disconnection of secondary channels and overbank areas from the main channel as a result of channel modifications for tie drives reduced habitat diversity and channel stability along mountain streams.

Numerous studies in the Rocky Mountains and coastal ranges of the U.S. have documented the important functions of naturally occurring wood in mountain streams (Harmon et al., 1986; Richmond and Fausch, 1995). Wood stores wedges of sediment and organic materials upstream and thus contributes to substrate diversity and habitat complexity at various scales. Wood creates pools by either causing a step in the channel profile and associated plunging flow, or directing the current toward a portion of the streambed or bank. These pools form backwaters that provide critical summer and winter habitat and serve as refuges and rearing areas for fish. Wood also provides habitat and food for stream insects on which fish feed. Removal of wood in streams during tie drives eliminated or severely reduced all of these functions.

Flow diversion and regulation

Flow diversions from rivers in the Front Range began with placer mining in 1859. The magnitude and extent of diversions increased dramatically during subsequent decades as irrigated agriculture and urban communities grew along the base of the Front Range. The lower Platte River of the western Great Plains was historically a broad, shallow channel with an extensive, largely unvegetated floodplain. The river had late spring-early summer floods when snowpack melted in the Rockies, but for much of the year the flow was shallow and turbid with suspended sediment. Reservoirs were built to store water for use late in the growing season and water removed from the river was spread across the adjacent lands by a network of irrigation canals constructed between 1860 and 1900. As a result, the regional water table rose, the annual peak flow decreased, and base flow in the river increased. Riparian vegetation including cottonwood and willow became established on the bars and banks of the river. This vegetation increased the hydraulic roughness of the river and reduced flow velocity, increasing sediment deposition to the point where the river began to narrow. Between the late 1800s and the first decades of the 1900s, some reaches of the Platte River decreased from 460 to 90 m in width (Nadler and Schumm, 1981). The formerly broad, open channel of the South Platte now meanders between thickly vegetated banks, and migratory birds that rely on open sandbars for feeding and resting are now restricted to short reaches of the river. Flow diversions have generally had less physical effect on mountain streams in the South Platte basin, but aquatic and riparian organisms have been affected by changes in the timing and magnitude of flow associated with diversions (Merritt, 1999; Rader and Belish, 1999).

Construction of transportation corridors

Structures such as bridges or road side slopes that impinge directly on a river channel can alter river form by creating a constriction that leads to increased velocity, scour of the streambed, and a resulting coarsening of the bed sediments (Figure 6). The structures can also alter the characteristics of water and sediment entering the river by changing the stability and permeability of adjacent hillslopes. During construction, disturbance of the hillslopes and river often results in a marked increase of clay- to gravel-sized sediment moving in the river. This can continue after construction if the road is unpaved or if traction sand and gravel are used on the road during icy conditions. Erosion of a single unpaved road provided 25% of the basin's sediment in one 130-hectare catchment tributary to the Big Thompson River (Balog, 1977). Pools along Black Gore Creek near the Interstate-70 corridor were completely filled with traction sand and gravel coming from the road (Lorch, 1998). Pollutants such as oil can also reach the river from the road surface, and greater access to the river can result in increased disturbance of the streambed and banks by people, mountain bikes, or off-road vehicles.

Change from reference conditions: virtual rivers?

Every river in the Colorado Front Range was affected by at least one of the land-use activities summarized in Table 1. A few were primarily affected by beaver trapping, but most river segments were altered by the combined effects of beaver trapping, flow regulation, construction of transportation corridors, and associated recreation and urbanization. In the absence of detailed historical records pre-dating the start of beaver trapping, the characteristics of the rivers prior to the 19th century cannot be known with certainty or precisely quantified. Reference conditions can be estimated by comparing rivers with multiple and continuing land-use affects to rivers with relatively few historical or contemporary alterations. In the Front Range, North St. Vrain Creek and the South

Fork of the Poudre River are relatively unaffected by land use. Although beaver were trapped along both rivers, and timber was harvested in their catchments, neither river had placer mining, flow regulation, extensive tie drives, roads or railroads along their length, or extensive grazing or recreational use. The characteristics of these rivers can thus be used to calibrate estimates of likely river condition (eg. pool volume, wood loading, substrate grain-size distribution and stability) given the geologic and climatic setting of the Front Range. Comparative studies of pool volume (Goode, in preparation) and wood loading (Wohl, in preparation) on relatively altered and unaltered stream segments are currently being conducted in the Front Range, but quantitative data are not yet available.

Another approach to estimating change from reference conditions is to assess ecological indicators such as habitat quality and availability, biotic diversity (eg. macroinvertebrate distributions), or presence of endangered species such as the greenback cutthroat trout. Aquatic and riparian communities integrate the effects of changes in physical and chemical environment, and the influence of introduced species. The limited contemporary distribution of native greenback cutthroat trout, for example, may reflect the presence of brook trout as much as the loss of habitat diversity, pool volume, and wood in the rivers. Use of species distribution to estimate change from reference conditions depends on knowledge of the habitat (substrate, flow, water chemistry, etc) required by a species. Absence of the species when suitable habitat is available may reflect competition from introduced species. Detailed studies of the habitat requirements of various aquatic and riparian species native to the rivers of the Colorado Front Range are ongoing (Merritt, 1999; Pepin, in preparation), but results to date suggest that some native species such as the cutthroat trout would have wider geographic distributions than at present in the absence of introduced competitors, whereas other organisms such as river birch (*Betula fontinalis*) (Merritt, 1999; Merritt and Wohl, in review) or macroinvertebrates (Rader and Belish, 1999) are compromised primarily because of physical changes such as altered flow regime.

Establishing restoration priorities

The rivers of the Colorado Front Range are not for the most part virtual rivers. Despite a widespread reduction in channel diversity and stability as a result of beaver trapping, flow regulation, wood removal, and road construction, these rivers continue to support stable, if less abundant and diverse, aquatic and riparian communities. Most of the restoration recently undertaken or proposed in the region focuses on relatively short segments of stream that are perceived to be unsightly (eg. Blue River in Silverthorne, Colorado; B. Bledsoe, pers. comm.); unstable to the point of creating flood or sediment hazards (eg. Little Snake River near Slater, Wyoming; B. Bledsoe, pers. comm.); or compromised with respect to water quality and/or aquatic habitat (eg. Boulder Creek in Boulder, Colorado; Ferguson, 1991). Restoration attempts generally occur within constraints imposed by rapid growth in urban populations and recreational use; high demand for consumptive water uses; and existing structures such as roads that impinge on the stream channel. Under these conditions, ignorance of regional land use and river history can lead to restoration that sets an unrealistic goal because it is based on (i) an incorrect assumption about a river's reference condition, or (ii) incorrect assumptions about the influence of persistent land-use effects. An example of the former would be a restoration project that attempts to stabilize a braided river, assuming that the river is braided because of anthropogenically-driven increased sediment yields, when in fact the river was braided prior to intensive land use because of naturally high sediment supply (Jaquette et al., in review). An example of the latter would be a restoration project that attempts to restore fish habitat along a portion of a river still receiving heavy metals leaching from an upstream 19th-century mining site.

Stepping back from reach-scale river restoration to questions of regional river management, knowledge of historical land use patterns and associated effects on rivers is critical to maintaining an awareness of the contemporary "starting point." In the case of rivers in the Colorado Front Range, several years of drought combined with rapid population increases have revitalized proposals to build additional or larger reservoirs on several rivers. These proposals should be viewed in the context of a drainage network already seriously compromised by beaver trapping, timber harvest, placer mining, tie drives, existing flow regulation, and other land uses. Rivers have a history, and restoration or other management activities conducted in ignorance of this history are a disservice to river ecosystems and to human society.

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List of Figures

1. Schematic representation of control and response variables that influence river form and function. In this cross-sectional view of a river channel and adjacent hillslope, variables such as geology (rock type, structure, tectonic regime) and climate (precipitation, temperature) interact to control weathering of bedrock and the resulting soils, vegetation, and downslope pathways of water and sediment. Geology and climate operate across the entire drainage basin and are not influenced by hillslope and channel processes; hence their designation as independent variables. Geology, climate and land use indirectly influence rivers by determining the water and sediment yield to the channel, the downstream gradient of the valley bottom, and the composition of the streambanks. Water and sediment dynamics and channel geometry respond to introduced water and sediment, as well as bank composition, and thus reflect ultimately reflect changes in the basin-scale control variables.

2. Location map of the Colorado Front Range, USA. Principal tributaries draining east from the Continental Divide to form the South Platte River are labeled. The Front Range is shaded light gray; the metropolitan area of Denver is a darker gray.

3. Beaver dams along a small stream create a stepped longitudinal profile and segments of ponded water where sediment deposition increases.

4. A 1995 view of dredge-boat tailings along the Middle Fork South Platte River near Fairplay, Colorado. Active mining has not occurred for several decades, yet the tailings remain largely unvegetated and the stream here is braided and unstable.

5. Ties and saw logs cut from a forest sale area in the Cheyenne National Forest of Wyoming. (Photograph courtesy of the American Heritage Center, University of Wyoming)

6. A 1995 view of Boulder Creek constricted between a road on the right and a former railroad track converted to a pedestrian and bicycle path on the left. Artificial bank material on both sides of the stream effectively precludes riparian vegetation.