RIVER RESTORATION ANALYSIS TOOL (RiverRat)

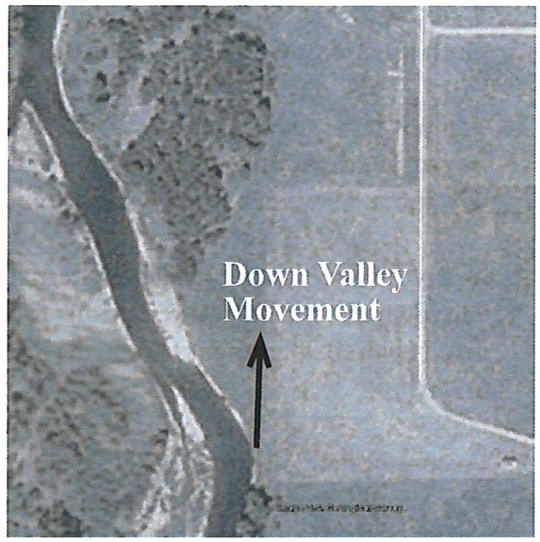
RiverRAT is a set of tools and guidance for stream project development and review, including:

- Understanding how engineering and management actions affect the physical stream processes at varying scales (e.g., site, reach, and watershed)
- Understanding that uncertainty is inherent to all engineering and management actions in rivers
- Promoting solutions to identified problems that address the root causes, rather than simply treating the symptoms of the problem
- Acknowledging that human influences are fundamental components of all ecosystems, at all scales

RiverRat Considerations

- Is the problem identified?
- Are causes identified at appropriate scales?
- Is the project part of a larger restoration plan?
- Does the project consider ecological, geomorphic, and socioeconomic context?
- Do goals and objectives address problem, causes, and context?
- Are the objectives measurable?
- Were alternatives considered?
- Is the uncertainty and risk associated with the selected alternative acceptable?
- Do project elements collectively support project objectives?
- Are design and performance criteria defined for project elements?
- Does the project work with natural stream processes to maintain channel function and habitat?
- Is the technical basis sound for each element of the project?
- Are plans and specs sufficiently detailed to execute project?
- Does the plan address potential implementation impacts and risks?
- Are maintenance and monitoring considered?

Most landowners don't have the ability to work at the reach or watershed scale. The underlying considerations of the RiverRAT methodology can nevertheless help guide understanding and project selection. It is important to consider channel processes and function at the reach scale to develop effective projects.



In 1995, this channel was fairly straight and appeared stable. The area was split into lots for potential future development.

By 2015, the meander had encroached into the hayfield and floodplain. Is this a localized response to a lack of woody vegetation, a reach scale response, or larger adjustment process in the watershed?

PROJECT DESIGN

Project Planning, Design and Implementation

The over arching philosophy of RiverRat relies on the following principles:

1. Understand cause and effect. Identify primary causes and processes before selecting remedies. Problems observed are often symptoms of distant or broader issues. For example, if bank erosion is caused by aggradation or avulsion, bank stabilization efforts may need to address sediment transport and channel geometry to be successful.

2. Look both ways, upstream and downstream. Consider the project in the context of stream process both up and downstream. Your project should fit into the environment, not be a sore thumb.

3. Do not repair what is not broken. Channel features that appear to indicate channel instability, such as eroding streambanks, can also occur in a natural channel that is dynamically stable and healthy. Do not assume that streams need to be fixed without understanding stream process.

4. Keep the door open. Evaluate alternatives and insure the project does not adversely impact adjacent landowners or limit future options for restoration efforts. For example, projects that impose a hard, fixed channel alignment can be detrimental and limit options for subsequent restoration or management.

5. Accommodate uncertainty. What we do not know is equally as important as what we do know. Projects should accommodate the uncertainties inherent to natural systems and our understanding.

6. Question constraints. Project alternatives may be dismissed because they conflict with what are perceived as fixed site constraints (e.g., established infrastructure or lack of property easements). Better projects may result from removing the constraint (e.g., moving a structure, using a wider bridge, obtaining an easement) than by trying to force a stream to accommodate a fixed constraint.

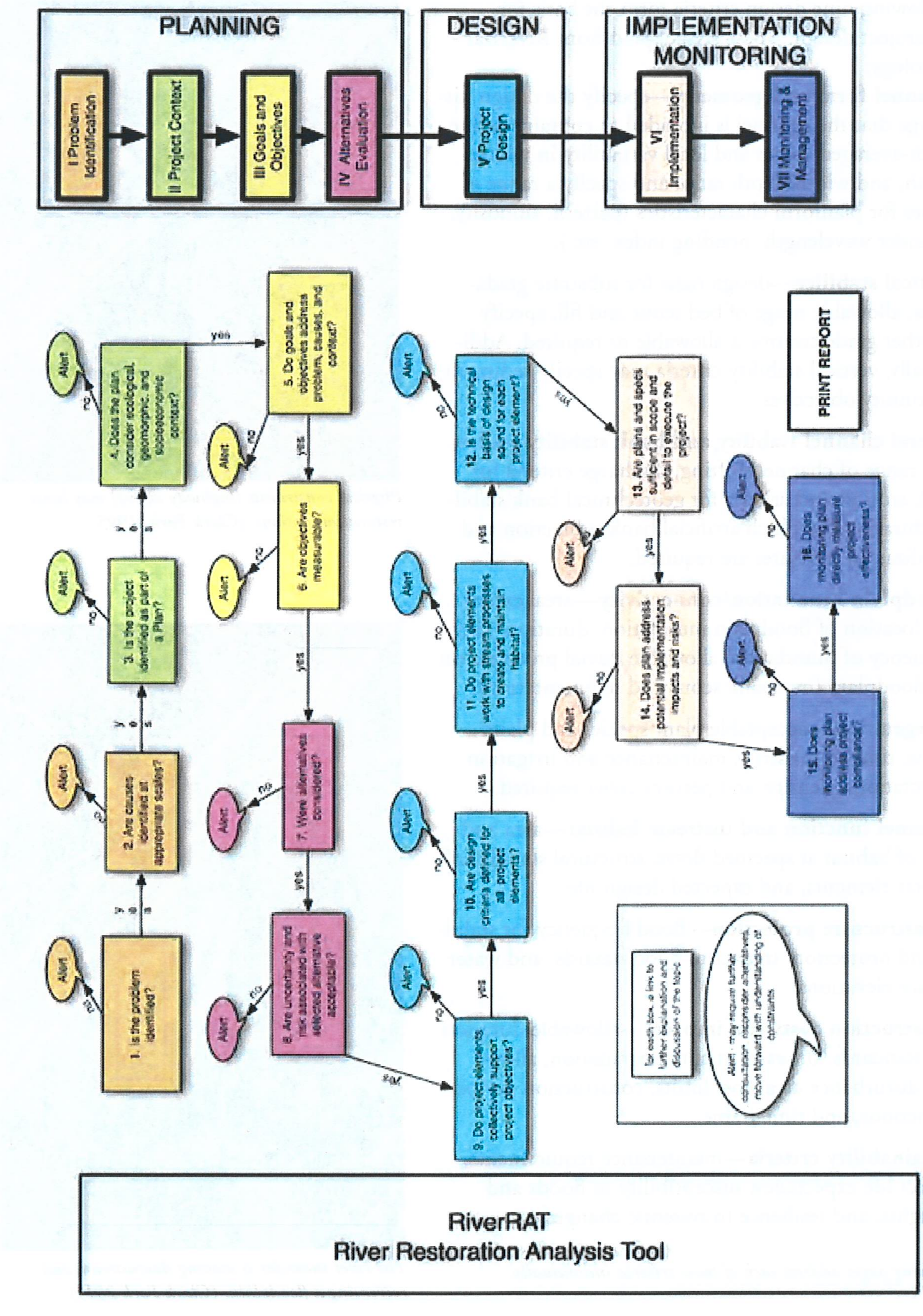
7. Promote natural stream processes. Stream projects are more successful when they restore, rather than constrain, natural stream processes. Take the long view and work with the river. Constructed features should restore process, not just form. Adding large wood to a stream can be beneficial, but equivalent or better results may be achieved in the long term by revegetation strategies that restore processes and recruit wood naturally.

8. Do no lasting harm. Short-term project impacts, such as those associated with construction activities, are often necessary or unavoidable. Strive to avoid any lasting, adverse impacts from a project.

9. Invest wisely and protect your investment. Good projects are resilient. They promote a dynamic equilibrium that allows them to respond to change by adjusting the channel and floodplain. Even successful and resilient projects need protection. Easements, buffer strips and riparian corridors, instream flow protection, and designs that make allowances for change rather than introduce constraints on stream processes serve to protect successful projects.

(Adapted from RiverRat)

RIVERRAT SCHEMATIC



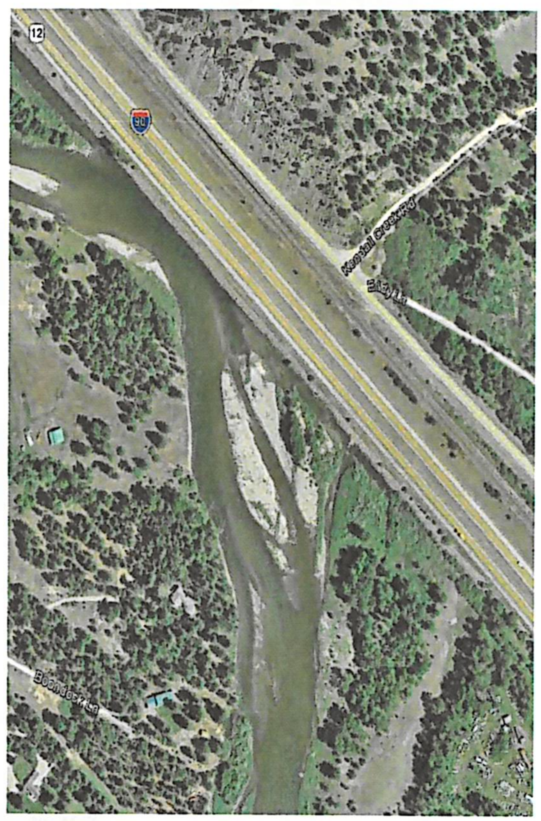
RIVERRAT DESIGN CRITERIA

The following nine design criteria form the basis for stream project design. These are adapted from RiverRat methodology.

1. **Channel form and geometry**—specify the design discharge that the channel is intended to contain; define reach-averaged values and local variability in width, depth, and width/depth ratio; and specify a range of values for planform characteristics (pattern, sinuosity, meander wavelength, braiding index, etc.).
2. **Vertical stability**—design basis for substrate gradations, allowable range of bed scour and fill, specify whether grade control is allowable or required. Additionally, vertical stability criteria may specify sediment continuity objectives.
3. **Lateral channel stability and bank stability**—allowable range of channel shifting, discharge criteria for bank erosion and criteria for geotechnical bank stability, duration for which artificial bank protection and stabilization measures are required.
4. **Floodplain inundation/connectivity**—areal extent and location of floodplain inundation, duration, and frequency of inundation; allowable fluvial processes on the floodplain (overbank scour and sedimentation).
5. **Revegetation**—acceptable plant species and plant forms, time to maturity, maintenance and irrigation expectations, density, and percent cover required.
6. **Channel function and instream habitat**—area and type of habitat at specified flows, structural stability of habitat elements, and expected design life.
7. **Infrastructure protection**—flood frequency for stability and protection, impact to flood hazards, and water surface elevations.
8. **Construction costs and impacts**—allowable duration and standards for water quality degradation, allowable disturbance area, cost limits, construction period restrictions, and time frame.
9. **Sustainability criteria**—maintenance requirements, project life expectancy, susceptibility to floods and droughts, and resilience to systemic change.

The following pages address each of these criteria individually.

Physical constraints (highway above) may limit restoration options. (Clark Fork, 1995)

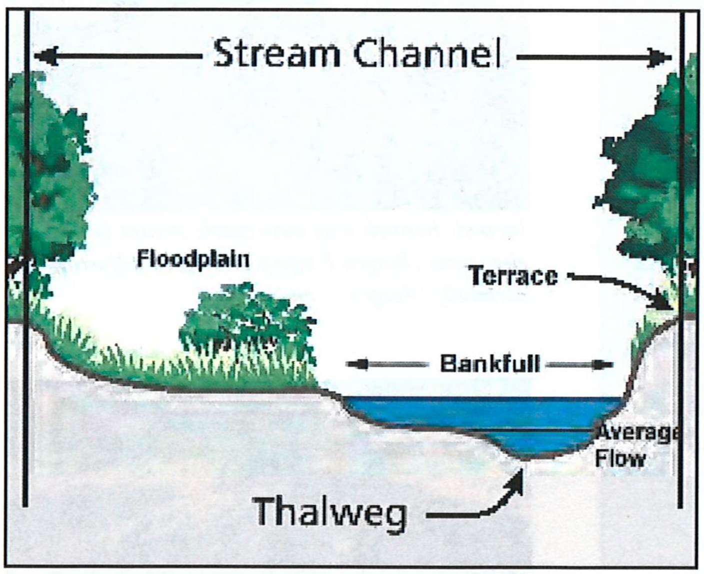


The river meander is moving downstream and recreating a floodplain. (Clark Fork 2015)

DESIGN CRITERIA: CHANNEL FORM AND GEOMETRY

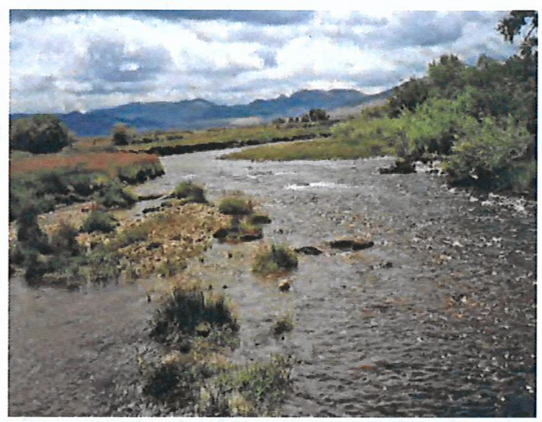
The following approach is common for geomorphic channel cross section design:

- Specify the design discharge the channel is intended to contain, including composite floodplain and bankfull dimensions
- Define reach-averaged values and local variability in width, depth, and width/depth ratio.
- Specify a range of values for planform characteristics (pattern, sinuosity, meander wavelength, braiding index, etc.).
- Design by replicating analogue/reference reach, design by hydraulic analysis and engineered stability criteria.
- Define cross section using bankfull, or composite channel with bankfull and constructed floodplain within engineered terrace.

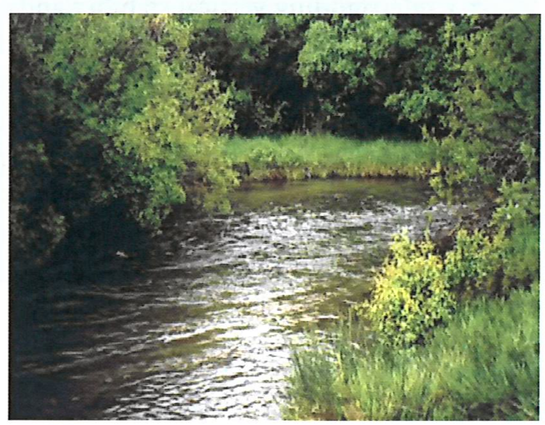


Bankfull cross section dimensions are fundamental to geomorphic design geometry. Bankfull corresponds to approximately the 1.5 year flood, which is the dominant flow that forms self maintaining alluvial channels.

Degraded C4 (wide, shallow channel) trending to D4 (multiple thread, unstable form). This channel could recover through riparian management to promote woody vegetation.



Channel type C headed to D.



Potential restoration goal for degraded C channel (above).

DESIGN CRITERIA: VERTICAL STABILITY-INCISION

Channel incision occurs both as natural process and through land use changes, channelization, human impacts, and changes in runoff regime.

Loss of floodplain connectivity and impaired riparian vegetation are major consequences of channel incision.

Alluvial channels without access to a functional floodplain at or near bankfull elevation can undergo substantial adverse adjustments. With loss of floodplain and overbank flows, hydraulic forces increase substantially at higher stage discharges resulting in accelerated channel incision and lateral erosion. This process is the channel's means of re-establishing a floodplain at a new base level.

Degraded and incised channels can sometimes be restored to a previous base level (bed elevation), but often will require restoration at the existing, post-impact elevation. In extreme cases, relocation of the stream reach may offer a more cost-effective means of restoration. Designs should consider the following:

- Look at design basis for substrate gradations and allowable range of bed scour and fill, and specify whether grade control is allowable or required
- Vertical stability criteria may specify sediment continuity objectives.
- Understanding vertical stability and scour and fill process is particularly important if "hard" structures such as wiers, vanes, or other in-channel rock features are being considered.
- Active channels with dynamic scour/fill and high sediment loads are challenging environments for hard structures.

Incised channels are associated with stream channel downcutting and loss of floodplain connectivity.

Incised channels may have stable stream bed elevations (Rosgen F type), or may be adjusting vertically (Rosgen G type).

Attempting to control flooding on aggrading channels with excavation and berms is rarely successful because the channel continues to fill.

VERTICAL STABILITY: AGGRADATION

Aggradation

Aggradation is a common cause of "abnormal" flooding conditions due to reduced channel capacity. Aggradation, or channel filling, results when more sediment enters a stream than the water can move.

Aggradation is common in depositional areas on alluvial fans, transitions at narrow canyons to wide valleys, and in flat valleys with certain sediment, slope, and discharge characteristics. Aggrading channels have high lateral instability (severe bank erosion) and may be braided with large gravel point bars and medial bars.

The tendency to aggrade or braid is natural in many river systems, but can be accelerated by channel changes (slumps, dewatering, land use, dikes or disturbance) that influence sediment supplies and carrying capacity.

Aggradation influences flooding conditions

Bankfull floods occur approximately every 1.5 to 2 years. Natural overbank flows should be expected frequently in channel types with a well- developed floodplain. Frequent flooding is not necessarily an indication of abnormal stream conditions.

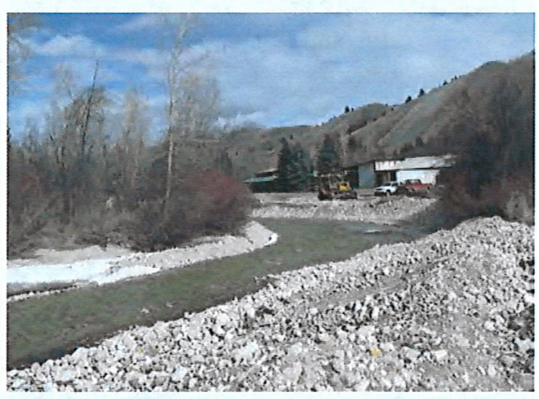
Abnormal floods occur when streams experience non-equilibrium conditions, such as aggradation (channel filling), channel constriction (undersized structures), and extreme debris or ice jams.

Restoration of channel plan, profile, and geometry including floodplain function is generally required to address flooding associated with aggradation.

Streams need to move both sediment and water. Designs need to consider both.

The main channel (left side of photo) has completely filled with sediment and the channel has become laterally unstable.

Aggrading "filling" channels result from excess sediment supply or reduced transport capacity.



Gravel excavation in aggrading channels seldom results in satisfactory solutions to flooding.

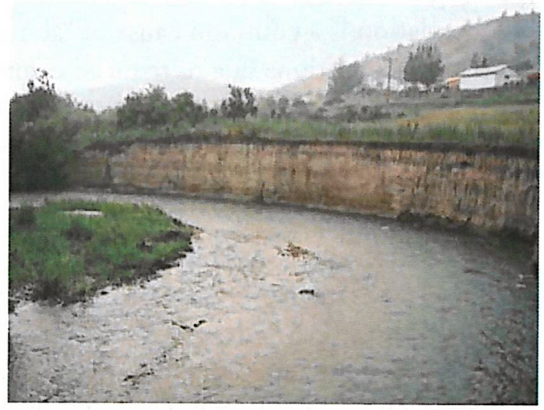
DESIGN CRITERIA: LATERAL CHANNEL STABILITY AND BANK STABILITY

Bank stability objectives should balance the need for limiting channel movement with the ecological value of allowing alluvial channels to migrate.

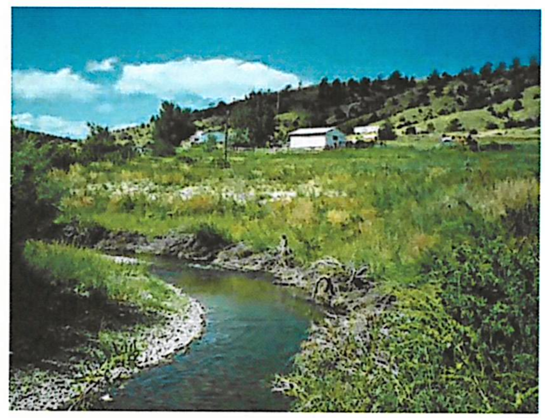
An allowable range of channel movement, deformable banks and design life for stabilization measures should be defined.

Designs that emulate natural stability but do not harden banks beyond the range of natural should be considered where feasible.

- Channel adjustment is common in many channel types (especially C channels)
- Channel adjustment is often a natural process the stream uses to adjust sediment and water balance.
- River movement provides fresh substrate for rejuvenation of riparian vegetation (old stands of willow/cottonwood are replaced by new stands).
- Overgrazing, loss of riparian vegetation, extreme floods, channel blockages, and channelization must be considered.

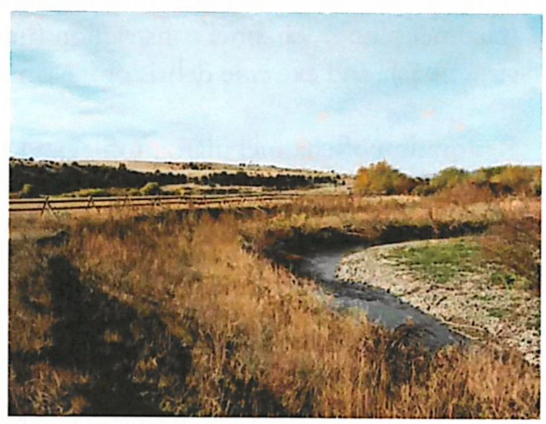


Eroding terrace before restoration on Rosgen C3 channel type.



Restored bank using woody debris and sod transplants at the toe of the slope.

Eroding terrace on Rosgen C3 channel type before restoration.



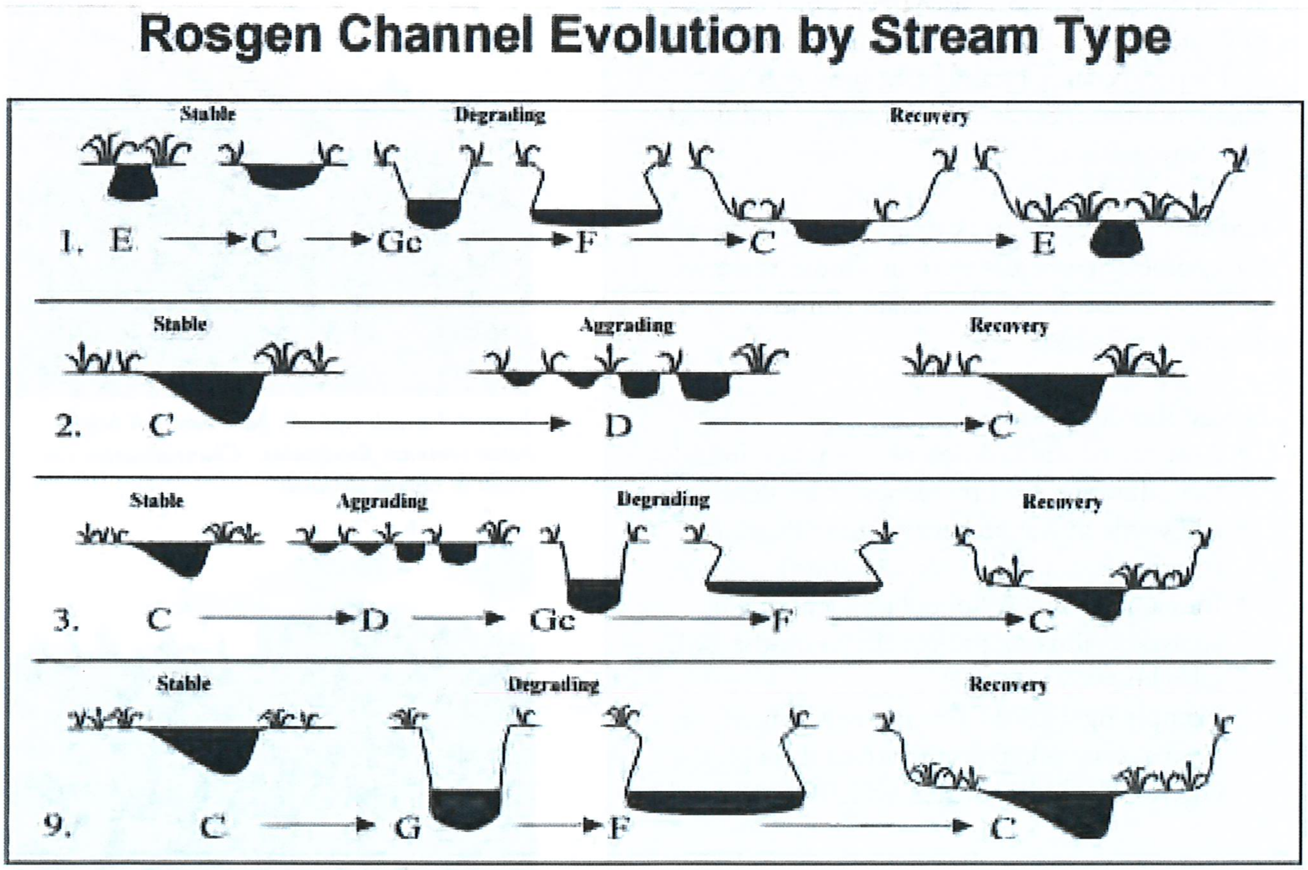
Terrace with brush layer toe and geotextile fabric bankfull bench. This project failed after three years and returned to a similar condition as pre-construction.

DESIGN CRITERIA: LATERAL CHANNEL STABILITY AND BANK STABILITY (continued)

Interpreting Channel Stability Through Channel Evolution

Understanding streambank stability often requires an interpretation of geomorphic process. Stream channels commonly adjust to environmental stresses by changing bed elevation, width-to-depth ratio, channel form, and other morphometric variables. The process can commonly involve conversion from one channel type to another, and sometimes recovery to the original channel type occurs over time. Channels may also convert to a new type. Processes of scour and fill enable to channels to adjust to their environment. Understanding the existing stream condition is important for project design.

The diagram below illustrates several common scenarios for the stream channel adjustments. These adjustments frequently involve widening or deepening of the channel in response to land-use changes. Reestablishment of equilibrium conditions may result when environmental stress is relieved. Active restoration can be beneficial to accelerate this process.



Common examples of four potential evolutions/progressions in stream type are shown above. These are examples of degradation, aggredation, and equilibrium process.

DESIGN CRITERIA: FLOODPLAIN CONNECTIVITY

Maintaining or restoring floodplain innundation, connectivity and function is a high priority for overall river function, ecological values, and channel stability. Project designs in aggrading of degrading (incised) stream reaches should carefully evaluate floodplain connectivity as part of the design. Projects that channelize, structurally harden banks or restrict lateral channel movement generally work against natural processes that maintain channel stability.

For most alluvial channels (e.g., Rosgen C, D and E), the floodplain begins to carry overbank flows at the bankfull flood event. This is typically the 1.5 to 2 year peak flow discharge. The benefits of connected floodplains include improved lateral and vertical channel stability, healthy riparian plant communities, floodwater storage and flood peak attenuation.

Channel and stream bank designs based on bankfull geometry and cross sections should endeavor to preserve of enhance floodplain connectivity whenever possible.

Design should consider:

- Area extent and location of floodplain inundation, duration, and frequency of inundation
- Allowable fluvial processes on the floodplain (overbank scour and sedimentation)
- In mapped FEMA floodplains, a hydraulic analysis evaluating project effects on the BFE (also known as no-rise)
- Complying with the no-rise requirement, or having a rise >0.00 ft authorized through the CLOMR/LOMR process, which can be costly

Channelization of streams frequently results in incised channels in disconnected floodplains. Big Spring Creek near Lewistown was channelized at the turn of the century.

Incised channels typically have bankfull heights below remnant floodplains. Channelization can result in incised channels.

Reactivating floodplains is a major objective in many restoration projects. This is Big Spring Creek in Lewistown after restoration.

FLOODPLAIN CONNECTIVITY (continued)

If channel flooding is abnormal due to on-site channel obstruction, the problem can be corrected by removing the blockage or replacing the structure to handle peak flows, ice, or debris.

If the channel is aggrading, cause and effect must be carefully evaluated. Finding a long-term solution may be difficult. The sediment source may be located off site, or the problem may be large scale, or regional. Dikes are of limited use because further aggradation may occur as dike or bank elevation is increased. Channel excavation or dredging is often a temporary solution because channels rapidly refill with sediment. Levees may raise flood water elevations, increasing flood stages upstream or across the river. Always consult your local floodplain administrator before building a dike or levee.

This dike was stabilized to protect downstream development from flooding, although the landowner with the dike did not particularly want to constrain the river.

Channel Excavation

Channel excavation may be appropriate when:

- Cause and effect are clearly understood (flooding is due to a culvert backwater or hillside slump into the channel)
- Cause can be addressed to prevent recurrence
- Gravel excavation occurs in a limited area, requires a single entry, and upstream sources are unlikely to rapidly refill the excavated section of the channel
- Fisheries and channel stability impacts are judged to be minimal

Dikes and Levees

Dikes and levees may be appropriate when:

- Protection of public infrastructure takes precedence over stream function
- Dikes can be designed to avoid substantial stream and floodplain impacts
- An engineered design meets all permit requirements
- Alternatives to dikes are unacceptable

Alternatives

Alternatives to dikes and levees include:

- Raising the grade of structure(s) threatened by frequent flooding
- Using berms to deflect flooding from a specific structure, rather than confining the stream channel
- Relocating threatened structures
- Restoring the channel to address channel instability issues

These alternatives to dikes can provide long-term security, can be cost effective compared to on-going maintenance typical of flood control projects, and are preferred by permitting agencies.

DESIGN CRITERIA: REVEGETATION

Bioengineered stream banks rely on successful vegetation of the site to restore naturally supported bank stability. Revegetation strategies for woody species can require 5 years for strong plant establishment, and 10+ years for plants to fully mature.

The first several years of plant growth focus on establishing healthy root systems, and less so leafy coverage. Irrigation through the first few growing seasons can greatly enhance survival and establishment of cuttings and plantings. Local native plant sources should be used whenever possible, rather than introducing non-native species.

Channel and streambank restoration projects should specify:

- Acceptable plant species and plant forms (cuttings, plugs, bareroot,seed, native sod)
- Time to maturity
- Maintenance (protection from browse (netting, chemical protection)
- Irrigation expectations
- Planting density
- Percent cover or stem count survival requirements

Creating an appropriate moisture regime is key to establishment of wetland and riparian species. Willow cuttings should be placed deep enough to intercept the water table.

Restoration of channel geometry goes hand-in-hand with revegetation efforts.

In 1999, the creek had unstable banks and poor riparian vegetation.

After channel reshaping, bank revegetation, and fencing, the bank recovered to a healthy riparian shrub and tree cover. (2014)

DESIGN CRITERIA: CHANNEL FUNCTION AND INSTREAM HABITAT

- Creating habitat should first focus on channel and floodplain form, function, and flexibility.
- Channel function includes ability to accommodate a range of flows, ability to adjust position, profile and dimensions. This dynamic is integral to creating bedform hydraulic diversity/complexity (i.e., habitat) and to promote healthy, self-sustaining riparian and wetland vegetation.
- Wood will degrade over time and bank stability will rely on deeply rooted vegetation.
- Constructed habitat features such as log jams, rootwads, log structures, boulders are commonly designed to be relatively non-deformable and securely anchored in place.
- Habitat complexity is an important attribute, structures that can adjust and evolve with the alluvial channel are preferred.
- Unfixed log jams may result in more natural channel features than fixed structures and be more cost effective.
- Habitat structures should be constructed with natural materials from local sources.
- Habitat structures can serve multiple functions, including grade control, protect the banks through flow deflection or by armoring.
- Structures can create pool habitat through local scour, create gravel bars in the lee zone, and provide sorted gravels for habitat. Shallow backwater areas and beaver dams (or constructed analogues) can provide rearing habitat.

Fish rely on hydraulic diversity in the channel bedform and woody debris is a key component of fish habitat.

Young fish benefit from microhabitat and velocity distributions, which are a function of channel form and structural components such as rock and wood debris. Diversity, not uniformity, makes for good fish habitat.

This dewatered channel provides an opportunity to see the five foot pool depth created by scour with a woody debris feature.

DESIGN CRITERIA: CHANNEL FUNCTION AND INSTREAM HABITAT (continued)

Design Considerations

The following factors should be considered for the creation of habitat features:

- Hydraulics - Potential effects on flow direction, water (i.e., flood) elevation, erosion, scour, etc.
- Scour depth - Streambed scour created by a structure is a key factor in stability.
- Buoyancy and drag forces - Must be evaluated for large woody debris that is submerged or projects into the stream.
- Materials - Use of native materials that are naturally present in the stream is preferable.
- Height/dimensions - Consider what is needed for a structure to be functional and fit the channel.
- Safety - Public safety (including recreational users) and potential for structures to block bridges/culverts must be considered.
- Design life/Performance Criteria - how long the structure is required to function, what range of flooding or channel adjustment will it withstand.
- Failure mode - what is likely to happen to the structure after it has ceased to be functional.

Fish habitat is provided by woody debris, healthy functioning riparian systems, and a variety of water depths and velocities. Side channels and backwater areas can provide important refuge for young fish.

DESIGN CRITERIA: INFRASTRUCTURE PROTECTION

River and stream management projects commonly involve protection of infrastructure from flooding or bank erosion/migration. Roads, houses, driveways, bridges, culverts that have been located within the pathway of the river may be unexpectedly at risk. Often these risks are predictable, but sometimes infrastructure has already been built in harm's way.

The costs of managing a river can be extensive. Bank stabilization costs can exceed $600/ running ft of stream bank. Careful consideration is necessary to determine if managing the river/stream outweighs the costs of managing/relocating the infrastructure.

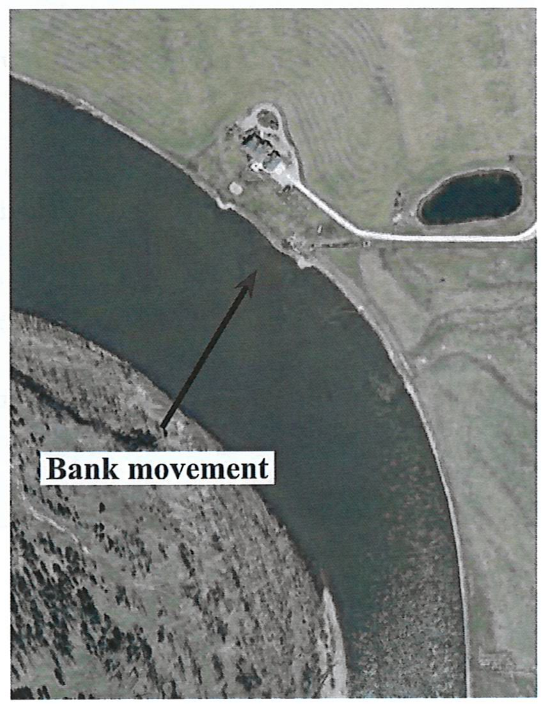
In FEMA mapped floodways/floodplains, projects that require protection of infrastructure may require engineering and hydrologic analyses to demonstrate the project:

1. Can withstand the 100 year flood
2. Does not raise or lower the 100 year flood elevation by more than 0.00 ft
3. Will not result in any adverse impacts to up or downstream landowners

Engineering and permitting costs for infrastructure protection can be costly.

New projects or infrastructure located near rivers or within floodplain should carefully consider all available information, including FEMA floodplain mapping, channel migration zones (CMZs, where available), and local understanding and experience with river dynamics.

Homes built on river terraces may be out of the floodplain but at risk from river migration. Protecting these sites can be costly and technically challenging.



Managing movement of large rivers is not assured of long-term success, and often requires ongoing maintenance and intervention.

CAUTION

- Costs of managing a river can quickly outstrip the value of a marginal property or development.
- Consultation with engineering or other qualified hydrology professionals is needed for design and permitting of projects to protect infrastructure.

DESIGN CRITERIA: CONSTRUCTION COSTS AND IMPACTS

Cost for bank restoration with bioengineering methods can range from $150 to $500 per linear foot, including design, permitting, materials and construction. Careful planning can help improve efficiency and minimize cost. Project cost is highly site-specific.

- Permitting costs for floodplain and 404 permits where biological assessments are required can add substantially to overall project costs.
- The construction window may have limited dates to protect spawning game fish. Minimizing potential impacts to water quality and aquatic life requires careful planning.
- Barrow sources for fill, vegetation, and large woody debris must be selected to minimize impacts on wetlands, floodplain or adjoining uplands.
- Allowable duration and standards for water quality degradation are typically defined through 318, 310 and other permitting processes. These should be clearly spelled out in the plan, including provisions for site dewatering during construction.
- Disturbance to the surrounding vegetation and wetland areas should be minimized whenever possible.

Construction should seek to minimize the amount of flowing water through the site.

Bioengineering treatments can be labor intensive, especially for installation of fabric. Bioengineering is preferred where vegetation treatments can be successfully established.

Flowing water through a construction site can result in severe water quality impacts. Potential sediment release must be addressed during the permitting process.

DESIGN CRITERIA: SUSTAINABILITY CRITERIA

Rivers and streams are dynamic, evolving natural systems. Gravel bed rivers naturally migrate across the floodplain and adjust to environmental change and land use.

Projects that promote and work with natural process are more likely to function well in the long term. Interventions that contradict river natural process are expensive and often high-maintenance.

Defining "long run" sustainability and resilience means understanding natural channel process, understanding project objectives and project design life, and potential limitations.

In many river environments, conditions such as lateral bank erosion displace to a different location (often downstream) over time. Over the course of 10 or 20 years, erosive forces may move due to downstream meander migration or avulsion.

Project design should consider the required longevity and strength of bank treatments. Bioengineered "soft" treatments are often sufficiently robust to protect banks for the needed duration.

Recognize that "permanent" solutions are rarely permanent. Strategies that accommodate natural channel movement and self-maintaining vegetation are generally the most resilient long-term approaches for streambank and floodplain stability.

Design criteria should clearly identify performance expectations. Deformable banks and allowable channel adjustments should be identified.

Floodplain permitting criteria may require protection from erosion the 100-year flood for structural protection. For many projects, this degree of hardened channel is contrary to sustainability or natural resilience.

Any instream structures, including habitat features, require careful design and placement to be successful. Channel scour and fill can result in structure failures.

The structure functioned well and was located just upstream of the above photo. Success of in-stream structures can be highly site-specific.

This bioengineered bank is deforming as the river undercuts the encapsulated soil lifts. Deformable banks are frequently incorporated into restoration strategies, but may be undesirable for structural protection.