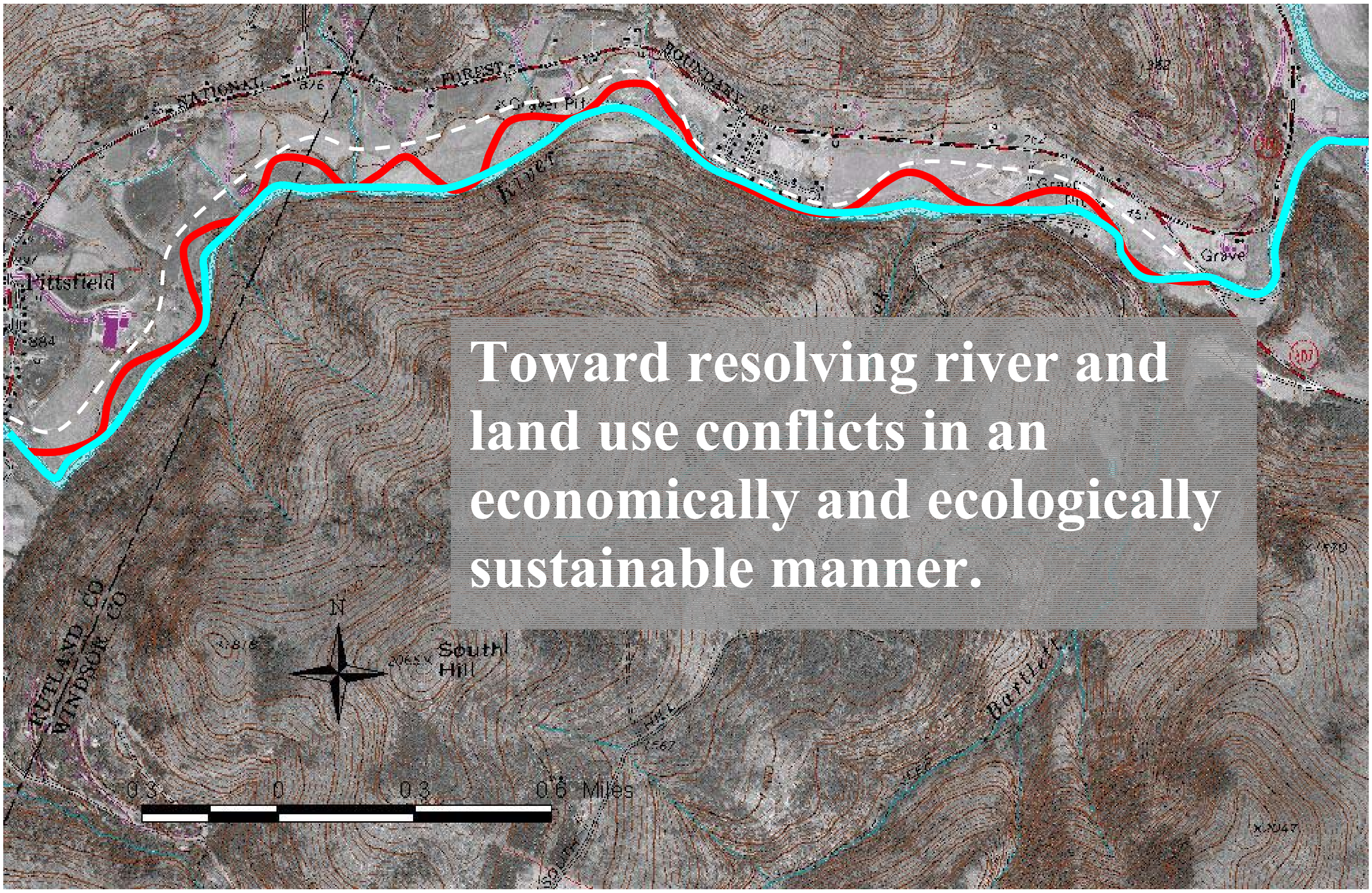
Alternatives for River Corridor Management

Vermont DEC River Management Program Position Paper



The following **Position Paper** on Alternatives for River Corridor Management has been prepared by the Vermont Department of Environmental Conservation (DEC), River Management Program. The paper reviews the history of river use and conflict in Vermont; explains the changes in river science and engineering that are currently being advanced nationally and internationally; and offers the Program's perspective on the costs, risks and benefits associated with four different river corridor management alternatives.

The goal of this River Management Program initiative is to find agreement for resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner. We invite your comments. We especially encourage organizations and agencies involved in watershed planning and river resource management to offer their positions to further the discussion started by this paper. The paper includes a glossary of terms. A slide show has been prepared which we would be glad to share upon your request.

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Vermont has found itself in an unending and escalating cycle of spending millions of dollars to maintain river channels, repair and rebuild flood damaged roads and bridges, and protect adjacent land uses from destruction by erosion or flooding, only to see these river management investments: a) fail during the next flood; or b) result in increased damage elsewhere. Riparian landowners are increasingly strident about real and perceived failures of state river management policies to address their concerns as they lose valued property with every significant runoff event. At the same time, stream channel erosion is increasingly cited as one of the most significant statewide water resource concerns, as evidenced by physical and biological indicators of aquatic ecosystem health.

Recognize that:

- A significant percentage of Vermont rivers have undergone channelization. Typically, channelized streams are straighter, steeper, wider, and largely devoid of the instream and riparian features that maintain natural channel stability and provide a diversity of aquatic and riparian habitats.

- Channelization practices that were started over 100 years ago to accommodate early settlement, roads, railroads, logging, farms, mills, and other "human investments" have been periodically maintained through gravel removal, realignment, channel armoring, and post flood remediation projects.

- Many channels have incised, eroding downward, losing access to floodplains which are essential to maintaining natural channel stability over time. Many miles of rivers have lost access to their floodplains during frequent run-off events (1-10 year floods) and in some cases even rare events involving very large discharges (50-100 year floods) resulting in a tremendous increase in channel adjustment and erosion.

- Adjacent to incised and adjusting channels, land uses, including agriculture, residential and commercial development, and transportation infrastructure, have encroached into the lands previously used by river meanders and flood water.

- While some channelization continues today, many straightened, incised reaches are now widening and aggrading (building up with sediment transported from upstream). Recent major storm events have energized these channelized stream systems with inputs of water and sediment and, in so doing, have accelerated these physical adjustment processes (widening and aggradation), as new flood plains develop along the rivers.

- The physical adjustment processes (most commonly observed as stream bank erosion) lead to the planform or meander changes that are imperative for the river system to attain a natural balance within its watershed. These adjustments cause property damage that, in many cases, have become increasingly intolerable for current landowners.

Managing Conflict, the Options:

Managing the conflict between people's land use expectations and river dynamics should be based on an examination of alternatives and cost-benefit analyses, in both the short and long-term, to both private and public interests. To avoid the growing conflict between the changing course of Vermont rivers and our land use expectations, the DEC and in collaboration with its partners must:

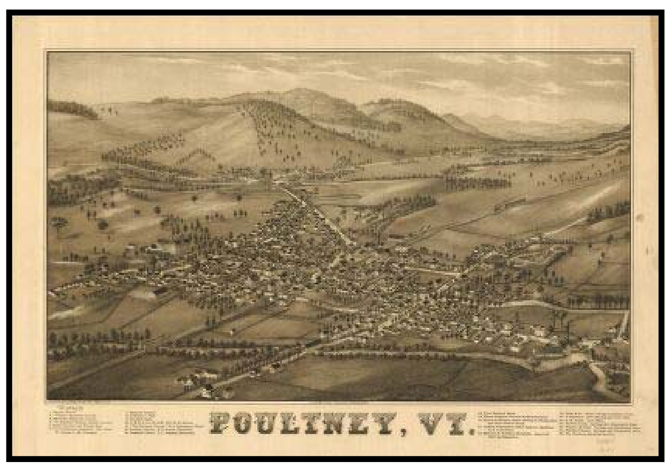
1) acknowledge these on-going physical processes and the circumstances leading to their existence today;
2) understand and be able to articulate the implications and consequences of different conflict management options; and
3) develop the ability to effectively address conflicts with riverine systems through the application of one or a combination of the following alternatives.

River corridor management alternatives for resolving historic and ongoing conflicts between river dynamics and land use expectations:

- Channelization: Maintain rivers in a channelized state through dredging and bank armoring applications. Active revegetation and long-term protection of a wooded riparian buffer is important to this alternative.
- Active Geomorphic: Restore or manage rivers to a geomorphic state of dynamic equilibrium through an **active** approach that may include human-constructed meanders, floodplains, and bank stabilization techniques. Typically, the active approach involves the design and construction of a management application or river channel restoration such that dynamic equilibrium is achieved in a relatively short period of time. Active riparian buffer revegetation and long-term protection of a river corridor is essential to this alternative.
- Passive Geomorphic: Allow rivers to return to a state of dynamic equilibrium through a **passive** approach that involves the removal of constraints from a river corridor thereby allowing the river, utilizing its own energy and watershed inputs to re-establish its meanders, floodplains, and self maintaining, sustainable equilibrium condition over an extended time period. Active riparian buffer revegetation and long-term protection of a river corridor is essential to this alternative.
- Combinations of the Above Alternatives: Use a combination of alternative approaches to accommodate the varying constraints that typically occur along a project reach.

The Physical Imperatives of River Systems

Changes to the shape of a river channel or changes in the inputs of water and sediment often lead to imbalance, and cause adjustments in river and floodplain geometry until balance is re-established. Natural adjustments to the river channel occur continually, but often dramatically manifest themselves during large flood events. These adjustments, however, have been overshadowed or largely magnified during the past two centuries by those resulting from human-imposed changes to the depth and slope of rivers related to intensive watershed and riparian land uses. Nearly every Vermont watershed has streams "in adjustment" from the following sequence of events:



Deforestation – led to dramatic increases in the volume of water and sediment runoff;

Snagging & ditching – clearing boulders and woody debris for logging and flood control, and ditching poorly drained land for agricultural improvements increased the rate of water and sediment runoff;

Villages, roads, and railroads – early settlements led to the first attempts to straighten rivers and streams which resulted in increases in channel slope, stream bed degradation, and floodplain encroachments;

Mills, dams, and diversions – led to alterations in the amount and rate of water and sediment runoff. While dozens of dams are in place in each Vermont watershed today, historically there were hundreds;

Floods and flood works – each major flood event brought enormous loads of sediment into channels that were already aggrading or degrading, causing damage to human infrastructure which in turn led to new efforts to straighten and deepen the rivers;

Gravel removal – advocated as a way to maintain straighter, deeper channels; large-scale commercial gravel mining resulted in bed degradation, head cutting, channel over-widening, and severe bank erosion;

Encroachment – investments on lands previously occupied by river meanders or inundated during floods created unrealistic and unsustainable human expectations in the absence of continuous or periodic channel management activities; and

Stormwater and urbanization – increases in impervious surface and ditching to support economic development and land use conversion increased the rate and volume of water and sediment runoff entering stream systems.

Rivers are in a constant balancing act between the energy they produce and the work that must be done to convey the runoff of sediment and debris produced in their watersheds. The slope and depth of a river dictate how much transporting energy it contains. For example, a wide and shallow river will have less energy than one that is narrow and deep, resulting in a lower capacity to move sediment. During large runoff events, the shallow river channel may aggrade, filling with gravel. On the other hand, a steep or high gradient river will have more energy than one of lower gradient, resulting in a greater capacity to move sediment. River channels that have become steeper will often degrade, eroding bed and banks, then widening and aggrading until the meanders and floodplains necessary to expend the excess energy have been established. It is a physical imperative within river systems that over time an energy balance with watershed inputs is achieved and maintained. This balance is achieved through adjustment of channel dimensions and longitudinal slope, and its elevation relative to the floodplain.

When a natural stream achieves a depth and slope in balance with its water and sediment loads, the channel and flood plain geometry are primarily maintained by the boundary conditions established by coarse sediment on the bed and/or the soil cohesiveness and soil binding attributes of vegetative root systems on the banks. When these stabilizing influences are disturbed, the resistance of the bed and bank to erosion is largely diminished. Grade control structures and rip-rap have been used on streams to replace boulder steps, cobble riffles and the deep, soil binding roots of trees and shrubs. These structures work but are not self-maintaining or replenishing like the boundary materials of naturally stable streams, and thus, must be periodically maintained. Human-placed boundary conditions may work for many years where the channel and floodplain geometry are in equilibrium, but typically initiate other channel adjustments or fail with the next flood when placed on channels that are in adjustment through stages of aggradation, degradation or seeking balance through longitudinal slope adjustment and plan form change.

The Conflict: Today's Accounting

Conflict between river corridor land uses and riverine flooding and erosion is as old as our imprint on the landscape. Traditional floodplain and channel management practices implemented to reduce or manage these conflicts have largely worsened the problem, or transferred it to an adjacent landowner, out of a lack of respect for or understanding of the physical imperatives of river systems.

Each time a river has been straightened, dredged, bermed, and armored to mitigate flood damage without respect for the physical form and function of its channel and floodplain, adjustments were set in motion that, more often than not, led to further erosion. The decades that often intervene between major floods have given people the misperception that their channelization projects actually worked. Generations have passed and people have forgotten that the rivers have been altered multiple times to "protect" human investments.

In Vermont, there are many rivers and streams that were channelized with little thought to how river systems work. As rivers adjust to regain a balance between their form and function, they are likely to undergo a period of significant bank erosion. This period will be particularly painful for people to watch or experience. Especially as our population and global economy grow, the conflict between what is a physical imperative of the river system and our land use expectations becomes more and more intractable.

The floods of the 1990's in Vermont resulted in over $60 million in mostly erosion-related damages (VTDEC Act 137 Report). Some severely aggraded channels were dredged, others were armored with rip-rap. But unlike the damaging floods of the 1970's, when commercial gravel mining was in its heyday, the rivers were not dredged and bermed as extensively during the 1990's. This has caused great concern for some interests, because, although the rivers have begun the adjustments necessary to reach equilibrium, the erosion and changes in planform are threatening current day investments in lands adjacent to the rivers.

Today's accounting shows a significant amount of the Vermont land base to be threatened by flood-related erosion due to historic channel management, changes in watershed hydrology and sediment regime, and riparian land use practices and encroachments. The expenditure of millions of dollars will be necessary to restore or manage rivers and property after future floods. The high cost of restoration or management may be mitigated over time at a watershed scale where an understanding of the physical processes of rivers (fluvial geomorphic science) is used to restore both channel and floodplain function and protect riparian corridors from future ill-advised developments. Where there is neither the will nor the means to compensate people for their current investments, the cost of post-flood remediation and property protection will remain high in perpetuity.

On another part of the ledger, the cumulative impact of human actions have degraded physical habitat necessary to support healthy populations of some fish species and other aquatic life. Repeated channelization reduces the river bed and riparian structures upon which aquatic biota rely for shelter, food, and reproduction. Worldwatch Institute research (Abramovitz, 1996) cited dams and channelization as the two most pervasive threats to freshwater ecosystems today, with dramatic effects on species abundance and diversity.

Unfortunately the growing conflict with river dynamics can not be treated as a one-dimensional economic problem to be solved for short term gain. The social, economic, and ecological return for implementing river corridor management practices that work toward equilibrium at the watershed scale will be largely enjoyed by generations to come. The long term challenge is to have more predictable investments with less erosion and healthier aquatic ecosystems, while minimizing short term economic losses along the way.

Short vs. Long Term Solutions: A Choice of Management Scenarios

For the straightened river, it is only a matter of time before a flood drops a very large load of sediment at some point along its course. The wedge of sediment that builds in the channel during the recession of the flood may cause the river to avulse, or leave the channel, and head cut back through the landscape from the point where it returns to the channel further downstream. These events can erode river banks tens of feet and sometimes create whole new channels through adjacent lands, often someone's farm field.

A common, understandable response from landowners is to get the gravel out, return the river to where it was, and repair the eroded river bank with rock. This **"dredge and armor"** response should be used with great caution. We can all agree and recognize that the current pattern of land use investment and expectation along river corridors is not sustainable without some level of intervention or channel maintenance. The key is to assure that the maintenance is done in an informed way through acknowledgment of past mistakes and moves us all toward a more economically and ecologically sustainable relationship with the river.

Success, in the long term, will primarily be measured by our ability to solve problems at the watershed and river corridor scale; and secondarily, by how we resolve conflicts at individual erosion sites. From a geomorphic standpoint, this means recognizing that rivers transport and deposit sediment; and that natural stability and balance in the river system will depend on the river's opportunity to build and access a floodplain and create depositional features such as point bars, steps, and riffles to evenly distribute its energy and sediment load in a sustainable manner.

Gravel removal could continue to be an acceptable alternative to deal with erosion and flooding conflicts where the result is consistent with the natural form and function of the river and influences the physical adjustment processes in a way that reduces the long term conflicts rather than just pushing the problem into the future to be dealt with by our children and grandchildren.

As with the "dredge and armor" response, the **"do-nothing"** response has limited application, and should be used with caution and consensus. Projects that would restore and enhance aquatic habitat, aesthetics, and/or river recreation as primary objectives, **in the absence of river and land use conflicts**, should strongly consider the do nothing alternative. Where river and land use conflicts exist, the do-nothing response is rarely a viable alternative. Watersheds and river corridors freed of human encroachment would heal themselves in time, but unresolved conflict at one location may create more conflict and unintended consequences for both the river and adjacent landowners. Sometimes, the river management practices that must be implemented after a period of doing nothing (as the conflicts have worsened) may, in the end, be worse than those avoided in the first place.

Understanding that river and riparian habitats are formed and maintained by fluvial processes at the watershed scale is essential to resolving conflicts and carrying out river corridor management activities that, while seemingly detrimental to an existing habitat feature, nevertheless represent meaningful long-term solutions that support the river's ecological potential. In the end, the riparian corridor and floodplain functions provide the basis for instream habitat-forming processes. Opportunities to establish long-term buffer agreements that minimize future corridor encroachments and support riparian woodlands should be supported even where site-specific habitat features may be compromised in the short-term. The major exception to such a policy would be that a long term solution should not compromise habitat that is critically limited in geographical extent, especially rare, threatened or endangered species habitats.

In some situations, the "dredge and armor" and "do nothing" approaches may support positive land use and/or habitat-related outcomes for a certain period of time. When the alternatives are not well known, articulated or understood, it is human nature to seek out or repeat solutions that protect the status quo, even if that same solution just failed. It would be wrong though, to pursue a short term approach that is doomed to failure and/or did not resolve the conflict at the expense of long-term solutions. A guide to both the short and long term costs and benefits associated with the four different management alternative and examples of how each alternative might be pursued as a river management project are offered in an appendix to this paper.

Informing the Alternatives Selection Process

The decision to armor an eroding bank or dredge a river to protect investments in the land becomes easy if you focus only on the short term costs and benefits. While one armoring or gravel removal project to stop erosion may be relatively benign, the problem arises from the cumulative effects of dredging and armoring up and down a river valley. At some threshold, bank armoring, post flood channelization, and changes in stormwater runoff combine to move a river out of equilibrium. In Vermont over the past century, a high percentage of riparian landowners, with government assistance, have considered and applied the dredge and armor approach. Meanwhile, commercial and residential development, transportation infrastructure, logging, and agricultural practices have altered the quantity and rate of water and sediment runoff. The resulting watershed-level instability places the viability of individual, seemingly benign, bank protection projects in jeopardy where significant channel adjustments are now underway. Even so, gravel removal and bank armoring may be the necessary short-term "band-aid" solutions that are applied in areas of irresolvable conflict until significant watershed problems can be documented through geomorphic assessment and addressed through the application of best management practices.

The DEC River Management Program is working with its partners to focus on the long term benefits of a geomorphic management approach to both property owners and riparian ecosystems. The largest challenge will not be in applying the science to understand the river's slope and planform requirements, but rather how to redefine the relationship of public and private investments with fluvial dynamics in an equitable manner over time within a valley. The larger short term costs associated with using a geomorphic-based approach, where land conversion is necessary, become more acceptable and economically justifiable where channelization projects have failed repeatedly or in post flood remediation where major erosion, property damage, and channel avulsions have occurred. A passive geomorphic approach may be the most desirable alternative due to its lower maintenance costs but is highly dependent upon landowners willing to accept what may be significant changes in land use expectations. It is extremely important that State and Federal agencies involved with river resource management work together to provide economic incentives and technical assistance to towns and landowners to make decisions that resolve immediate conflicts with the long term watershed solutions in mind.

Watershed planning and the year-to-year implementation of management / restoration projects will require information about the geomorphic condition of the watershed. Using the Vermont ANR Stream Geomorphic Assessment Protocols, the River Management Program and its partners will gain critically important information on:

- **stream condition** or the current degree of departure of the channel, floodplain, and valley conditions from the reference (natural or equilibrium) condition for parameters such as channel dimension, pattern, profile, sediment regime, and vegetation;
- **sensitivity** or the likelihood that a stream will respond to a watershed or local disturbance caused by natural event and/or anticipated human activity; and
- **adjustment process** or type of change that may be underway due to natural causes or human activity that has or may result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes).

The assessment of stream condition, sensitivity, and adjustment process is an ideal tool for problem solving in a watershed context because it will not only show the proximity of river reaches undergoing channel adjustment, but will explain how one reach may be affecting the geomorphic condition of another. The physical stream condition is largely a function of the type and magnitude of channel adjustments that are happening in response to changes in runoff patterns and the channel and floodplain modifications that have occurred in a watershed.

Ideally, watershed plans involving all stakeholders would articulate how public and private land use and infrastructure investments would be balanced with the goal of achieving an equilibrium condition in the river. In addition to that, an incentives-based, multi-agency river management program that seeks incremental progress with each landowner toward protecting, managing, and restoring the river corridor should be established. Either way, real progress will be measured over decades.

Glossary of Terms as used in this paper

Aggradation: Raising or building up of the channel bed or flood plain through the deposition of sediment transported from upstream.

Armoring: Increasing the erosion resistance of the channel bed and banks through structural treatments such as rock rip rap or gabions.

Avulsion: Catastrophic relocation of the channel, typically across a peninsula-shaped flood plain or through a flood chute usually during a major flood event.

Belt Width: The meander belt width is the horizontal distance between the opposite outside banks of fully developed meanders. The belt width is an area critical to unconfined streams as they adjust their slope consistent with their sediment regime.

Channelization: Channel and flood plain alterations that typically straighten and increase the longitudinal slope, raise the elevation of the banks or lower the elevation of the bed and often includes bank armoring.

Degradation: Lowering of the streambed typically due to an imbalance between a) sediment supply and transport capacity or b) resistance of the bed materials and the energy of flowing water.

Dynamic Equilibrium: A state of balance whereby a stream, over time and in the present climate, transports the flow, sediment, and debris of its watershed in such a manner that it maintains its dimension, pattern, and profile without aggrading or degrading.

Fluvial: Related to the river system

Geomorphic: 1) Refers to a condition within which a fluvial system is in dynamic equilibrium or 2) refers to the complex interaction of physical landscape parameters that influence river form and function.

Incise: See Degradation.

Longitudinal Slope: The profile of the river or the rate at which it drops in elevation in relation to the horizontal length it travels.

Physical Adjustment Process: If a stream reach is forced out of a state of dynamic equilibrium (generally as a result of channel, floodplain or watershed disturbances), it will adjust its dimension, plan form and profile until balance between the watershed inputs and its ability to transport those inputs is re-established.

Plan Form: Channel geometry in plan view; meander pattern.

Riparian: Relating to the river or in geographic proximity to river.

Sediment: Soil materials ranging from boulders to clay particles that may be transported or deposited in the channel or flood plain.

Structure: Natural or human-introduced materials, typically wood or rock, that create physical features along the bank or bed.

Appendix to the Alternatives for River Corridor Management
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Example Projects

The following project considerations are offered as a way to begin distinguishing between the four alternatives described in this paper. Prior to the selection of **any** management alternative:

- the economic and ecological consequences to both on and off-site areas, properties, and infrastructure should be understood through the completion of stream geomorphic assessments of the project reach as well as upstream and downstream reaches; and
- essential riparian values should be protected, maintained, and/or restored by establishing long-term agreements with landowners to establish and maintain a wooded buffer between the channel and adjacent land uses.

Channelization Projects involve the design and implementation of practices intended to resolve conflicts and meet the goal of protecting property and certain other social values. New channel straightening efforts are rarely permitted today, but many dredge, berm, and armor practices are carried out on channels that were historically straightened. They are essentially maintenance projects to re-establish the flow capacity of the altered channel and/or rip rap banks that have begun to fail. All stream channels in equilibrium will move over time, and therefore any project that attempts to lock in the planform or meander geometry of a stream is, in part, a channelization project. An armored or fixed channel that has or is constructed to have the dimension, pattern, profile, and median sediment size of its regime or equilibrium condition will perform more ecological functions (see list below) than one that is armored as a straightened channel.

Active Geomorphic Projects involve the design and implementation of practices intended to resolve conflicts and meet the goals of protecting and/or restoring property, social values and ecological functions. Primary ecological functions as defined by the U.S. Army Corps of Engineers (Fischenich, 2003) include:

Stream Dynamics involving stream evolution processes, energy management, and riparian succession
Hydrologic Balance involving water storage processes, surface/subsurface water exchange, seasonal flow condition (hydrodynamic character)
Sediment processes involving sediment continuity, substrate and structural processes, and quantity and quality of sediment
Biological Support involving biological communities and processes, necessary habitats for all life cycles, and trophic structures and processes
Chemical Processes and Pathways involving water and soil quality, chemical processes and nutrient cycles and landscape pathways

Active geomorphic projects would include designs supported by survey-level stream geomorphic assessments and involve the long-term protection of a river corridor necessary to accommodate the channel slope and planform adjustments that support the functions of stream dynamics and sediment processes. These corridors could support land uses (e.g. agriculture and silviculture) but would limit investments that could lead to further conflict and channelization practices. Active geomorphic project designs would typically involve the human construction of channel and floodplain segments with dimension, planform, and/or slope requirements similar to a reference equilibrium condition. Structures used to treat exposed bank soils and encourage the establishment of woody vegetation are selected to avoid future conflict (where it can be reasonably anticipated), in consideration of other social values, and with respect to the long-term restoration of ecological functions. In the appropriate settings, bank treatments would be temporary in nature until root systems have a chance to take hold and re-enforce the boundary conditions of the channel.

Passive Geomorphic Projects involve all the assessment and design elements of an active geomorphic project with the exception of human constructed channel and floodplain geometry. The stream bed and banks are not treated, and the channel evolution process is allowed to proceed unimpeded. Passive geomorphic projects may involve the removal of constraints from a geomorphically designed river corridor; thereby allowing the river, utilizing its own energy and watershed inputs to re-establish its meanders, floodplains, and equilibrium condition, over an extended time period.

The Do Nothing Alternative literally involves doing nothing. This alternative does not involve the resolution of existing conflict. Doing nothing may support other social values and other ecological functions until conflict resolution becomes imperative.

In most cases, to balance social values and ecological functions, project designs will combine elements of the four alternatives based on the nature of the conflicts and the time and resources available for project implementation. Geomorphic assessment, basin planning, and alternatives analysis at the watershed scale will support strategic restoration that is both economically and ecologically sustainable.

Preferred Alternatives

The Vermont DEC River Management Program offers the following situations where each alternative for river corridor management may be preferred.

The **Passive Geomorphic Approach** may be the most preferred alternative due to the lower risk and maintenance costs associated with its implementation and the long term economic and ecological sustainability that is accrued. But, due to the potentially higher costs associated with changes in land use and/or buyouts, the passive geomorphic approach may be preferred more often where conflicts are in the minor to moderate range. There are also risks to upstream and downstream reaches and adjacent landowners (associated with active adjustment processes) that should be factored.

The **Active Geomorphic Approach** is also a highly preferred alternative due to the benefits associated with long term economic and ecological sustainability. The active geomorphic approach may be applied where conflicts are high, but is tempered by the fact that short-term costs and risks are also high due construction and maintenance, as well as the land use changes that may be engendered. The construction of a river channel and its floodplain may be the most cost effective and preferred alternative in a post-flood situation where avulsions and property damage are severe and remediation costs are already high. Pre-Disaster Mitigation plans may also identify the active geomorphic approach as a viable alternative.

The **Channelization Approach,** exclusively involving dredge and armor practices and the maintenance of straightened channels, is not generally the preferred alternative due to high construction costs, long-term maintenance costs and greater impacts to ecological functions. The channelization approach may be preferred and offer the only viable alternative where conflicts are high to extreme and land use conversions are not possible.

The **Do-Nothing Approach,** may be preferred where land use conflicts are low to non-existent. The do-nothing approach is not a preferred alternative where conflicts are in the moderate to high range and its selection only postpones the implementation of a different alternative and/or adversely affects fluvial processes in upstream and downstream reaches. Delays in resolving conflicts typically result in higher costs and fewer management options.

Matrix of Alternative Constraints, Cost, and Benefits

A matrix for evaluating the short and long term costs and benefits associated with river management alternatives is presented on the following pages.

The first page looks at whether certain design constraints affect the successful implementation of projects that attempt to follow one of the alternatives. These constraints include the inability of the project design to 1) establish and maintain channel boundary conditions with a wooded buffer; 2) establish and maintain channel equilibrium through floodplain access and a belt width to accommodate slope adjustments; and 3) deal with sediment regime problems related to changes in the water and sediment inputs of the watershed.

The second page of the matrix looks at the short and long term costs/risks and benefits to the property owners and other project proponents. Construction and maintenance costs are discussed as well as the risks associated with project failure. The cost of land use conversion is also factored. The third page begins to look at the costs and risks to the ecological functions of the river system, including habitat features and habitat forming processes.

References

1. Abramovitz, J. 1996. Imperiled Waters, Impoverished Future: The Decline of Freshwater Ecosystems. Worldwatch Institute, Worldwatch Paper 128. Washington DC.

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3. Vermont Department of Environmental Conservation. 1999. Act 137 Report: Options for State Flood Control Policies and a Flood Control Program. Waterbury, VT.

Alternatives Analysis of Management/Restoration Approaches – Vermont DEC River Management Program

	Channelization	Active Geomorphic	Passive Geomorphic	Do Nothing
General Description – Each approach is described as a stand-alone alternative. The chosen alternative for a management / restoration project may be a combination or blending of approaches which may share the strengths and weaknesses of the approaches used.	Maintain rivers in a channelized state through dredging and bank armoring applications. Includes maintenance of sites where the dimension, pattern, and profile are not consistent with the fluvial processes and geomorphic condition. Active revegetation and long-term protection of a wooded riparian buffer is important to this option.	Maintain or restore rivers to a geomorphic state through an active approach that may include human-constructed meanders, floodplains, and temporary bank stabilization practices. Active revegetation and long-term protection of a wooded riparian corridor is imperative to this option.	Restore rivers to a geomorphic state through a passive approach that involves river-constructed meanders and floodplains. Temporary bank maintenance activities may be applied as the geomorphic condition is achieved. Active revegetation and protection of a wooded riparian corridor is imperative to this option.	No maintenance or restoration activities pursued. Erosion of bed and banks allowed to proceed. No revegetation and protection of a wooded riparian corridor is pursued.
Management constraints that may limit the success of the project.				
Buffers - Lack of long term agreement for the conservation of an appropriately sized and managed wooded buffer.	Minor influence on channel stability depending on bank armoring application. Limits buffer functions (e.g., formation or restoration of aquatic and riparian habitats).	Is a constraint. A wooded buffer is imperative for bank resistance to erosion. The width necessary to perform buffer functions is dependent on the bank stabilization techniques that are used and maintained.	Is a constraint. A wooded buffer is imperative for bank resistance to erosion. The width necessary to perform buffer functions is dependent on whether bank stabilization techniques are ultimately used and maintained.	N/A
Flood plain and Meanders - Inability or unacceptability to create access to floodplain and/or limitations to provide adequate belt width (meander amplitude) and longitudinal slope.	Is a constraint where channel has become incised due to human activities and the bed is comprised of fine grained sediments; will cause project failure during flood due to structural undermining. Limits natural habitat-forming processes.	Is a constraint where the management approach is for a geomorphic channel form based on a geomorphic reference condition and depends on adequate flood plain, meander width and balance between stream power and bed/bank resistance. May limit natural habitat-forming processes.	Is a constraint where the management approach is for a geomorphic channel form based on the geomorphic reference condition and depends on adequate flood plain and meander width. May limit natural habitat-forming processes.	N/A
Watershed Inputs and Fluvial Processes - Watershed and reach level instability from hydrologic modifications and/or sediment regime imbalances (between sediment load, transport and deposition).	May become a constraint where accelerated erosion is due to increased discharge of water and aggradation of sediment from upstream; project may transfer impacts associated with increased velocity and sediment to downstream reaches.	May be a constraint where the management approach is for a channel form based on a geomorphic reference condition; especially where energy dissipation and sediment storage is limited elsewhere in the reach and/or watershed.	May become a constraint where the management approach is for a channel form based on a geomorphic reference condition.	N/A

	Channelization	Active Geomorphic	Passive Geomorphic	Do Nothing
General Description – Each approach is described as a stand-alone alternative. The chosen alternative for a management / restoration project may be a combination or blending of approaches which may share the strengths and weaknesses of the approaches used.	Maintain rivers in a channelized state through dredging and bank armoring applications. Includes maintenance of sites where the dimension, pattern, and profile are not consistent with the fluvial processes and geomorphic condition. Active revegetation and long-term protection of a wooded riparian buffer is important to this option.	Maintain or restore rivers to a geomorphic state through an active approach that may include human-constructed meanders, floodplains, and temporary bank stabilization practices. Active revegetation and long-term protection of a wooded riparian corridor is imperative to this option.	Restore rivers to a geomorphic state through a passive approach that involves river-constructed meanders and floodplains. Temporary bank maintenance activities may be applied as the geomorphic condition is achieved. Active revegetation and protection of a wooded riparian corridor is imperative to this option.	No maintenance or restoration activities pursued. Erosion of bed and banks allowed to proceed. No revegetation and protection of a wooded riparian corridor is pursued.
Costs/Risks and Benefits to Property				
Short term	Moderate construction costs depending on the amount and availability of rock armor; lower costs associated with land conversion and buffer creation; lower failure risk, unless degradation and/or aggradation existed prior to treatment then failure risks may be high; increased risks to upstream and downstream channel instability; benefits accrued from resolving erosion-related conflicts at the treated site.	Low construction and maintenance costs where channel alignment is at or near the geomorphic reference, high costs where planform construction is necessary; higher costs associated with land conversion and buffer creation; failure risk lowers after root structures of vegetation are established; reduced risks to upstream and downstream instability; benefits accrued from resolving erosion-related conflicts along the restored reach.	Minor construction cost if project involves some bank stabilization as planform approaches the geomorphic reference; higher costs associated with land conversion and buffer creation; minimal risk due to low cost and reduction of investment in protected riparian corridor; adjustment-related sediments may create risks to downstream reaches; benefits accrued from resolving erosion-related conflicts along reach.	No construction costs; no costs associated with land conversion and buffer creation; continued risks to upstream and downstream reaches where erosion is related to channel adjustments (aggradation or degradation); no benefits accrued from resolving erosion-related conflict.
Long Term	High risk of repeated failure where 1) watershed is producing high loads of sediment, 2) the rivers bed is comprised of fine grain sediments, 3) upstream and downstream reaches are in adjustment or have also been channelized; high structural maintenance costs associated with repeated failures; potentially high loss of land and other investments when structures fail during floods.	Low risk of repeated failure where wooded corridor has been protected; moderate risks where upstream and downstream reaches are in adjustment or have been channelized; low structural maintenance costs as river is moderated by natural vegetation and bed form controls; little or no loss of additional land or other investments during flood; long term conflict resolution.	Low risk of repeated failure where wooded corridor has been protected; moderate risks where upstream and downstream reaches are in adjustment or have been channelized; low structural maintenance costs as river is moderated by natural vegetation and bed form controls; little or no loss of additional land or other investments during flood; long term conflict resolution.	Channel adjustments continue until property risks become intolerable and restoration is pursued; further investments in the corridor may force an approach involving a higher costs and a higher degree of channelization; potentially high loss of land and other investments when structures fail during floods.

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Costs/Risks and Benefits to Ecological Function				
Short Term	Fair to good quality runs and pools may form along rip-rap depending on the bank line curvature; increased sediment transport through straightened reaches reduces deposition-formed bed features including steps and riffles; risks to aquatic biota from temperature increases; increased velocity and bed load transport may impact downstream reaches; aquatic habitat benefits of riparian buffer accrued where bank vegetation is established and wood recruitment occurs; less erosion of sand/silt may decrease embeddedness downstream.	Good to reference quality riffles/ steps, runs and pools will form where the pre-existing or constructed channel and flood plain morphology is consistent with the fluvial processes (deposition/scour of sediment and debris into the different scaled bed forms) occurring in the reach or watershed; temporary bank stabilization may result in reduced pool quality; aquatic and riparian habitat benefits accrued with establishment of corridor vegetation and wood recruitment; less erosion of sand/silt may decrease embeddedness.	Poor quality habitat may persist for some time period. Good to reference quality riffles/ steps, runs and pools that pre-exist or form where channel and flood plain morphology adjusts to become consistent with the fluvial processes occurring in the reach or watershed; temporary bank stabilization may result in reduced pool quality; aquatic and riparian habitat benefits accrued with establishment of corridor vegetation and wood recruitment; erosion resulting from adjustment processes may lead to aggradation and/or embeddedness impacts in downstream reaches.	Poor quality habitat may persist for some time period. Good quality runs and pools associated with scour and depositional features may persist until impacted by plan form adjustments; aquatic and riparian habitat benefits not realized where corridor vegetation and wood recruitment are lacking; erosion resulting from adjustment processes may lead to upstream degradation and downstream aggradation and embeddedness impacts.
Long Term	Habitat quality is fair at best; very limited structure and complexity at micro, meso, and macro habitat scales; where the channelization approach (dredging and armoring) has become the prevailing and repeated post-flood practice in a watershed, biological productivity is far less than its potential.	Physical habitat is near its potential. Depth and cover within pools are restored as bank vegetation and bed features control the boundary conditions of the channel and large wood recruitment continues. Water temperature lowers as channel narrows and canopy is restored.	Physical habitat is near its potential. Depth and cover within pools are restored as bank vegetation and bed features control the boundary conditions of the channel and large wood recruitment continues. Water temperature lowers as channel narrows and canopy is restored.	Lack of corridor protection and increased land use investments may lead to further conflicts with channel adjustments and erosion processes; options for restoration my become limited to channelization and associated habitat impacts.