The Effects of River Alteration and Restoration on Instream Biota and Human Needs

Executive Summary
The primary issues that are being addressed by this risk assessment are the effects of stream alteration on the environment, instream biota, and humans. Altered stream systems have negative impacts on instream biota which in turn affect human benefits derived from natural stream ecosystems. A literature review on the effects of altered stream systems concluded restoring streams to maximize instream biodiversity was the best focus for restoration efforts. While restoring a stream to pristine conditions is generally unrealistic, we suggest restoring streams to Vermont Department of Environmental Conservation water quality classification system’s class B or higher. This specific standard is set for Vermont waters, but the general principles and guidelines can be used and adapted to fit waters in other locations as well.
Introduction

Problem Statement:
Stream systems continue to be altered to meet human needs. These altered stream systems have a negative impact on instream biota and the ecology of stream systems. The loss of instream biota has many negative consequences on cultural, aesthetic, and economic values derived from stream and river systems.

Justification:
Streams have historically been an important resource. To better serve these needs, streams are often altered from their natural state for a diverse array of purposes. Many streams were dredged and cleared of structure and debris to allow timber transport (Muotka et al. 2002). Others are altered to support agricultural and other land uses (Lau et al. 2006).

The negative ecological effects of these practices are far reaching. Most cases of stream alteration result in the creation of a homogeneous habitat within the stream channel (Petersen et al. 1987). Channelization of streams creates a loss of structural complexity, simplified flow patterns, and a loss of microhabitats that support aquatic biota (Peterson et al. 1987). The removal of debris and other structures dramatically reduces the ability of a stream to retain allochthonous inputs (Muotka and Lassonen 2002). As the main source of energy for many streams, the loss of this nutrient source can have devastating impacts on the entire dynamics of the streams biota (Vannote et al. 1980). Although it does not necessarily have a direct effect on instream characteristics, alteration of stream banks and riparian zones can be just as detrimental. Agriculture and infrastructure, such as roads along waterways, often limit the ability to maintain effective riparian buffers. This lack of buffer allows an increase in chemical and sediment runoff into streams which can have serious impacts on instream biota (Nerbonne and Vondracek 2001). Additionally, stream banks are often heavily armored to limit erosion potential and channel movement, which could threaten valuable infrastructure (Wyzga 2001). This armoring creates a more homogenous habitat that limits structural complexity, negatively impacting diversity of the stream (Peterson et al. 1987).

Humans are negatively affected by these practices as well. Economic impacts are felt by the loss of revenue due to a decrease in sport fish populations. Additionally, the degradation of key spawning grounds for anadromous species such as Pacific salmon can have trickle down effects throughout the entire commercial fishing industry (Quinn 2005). The cultural and aesthetic value of a healthy stream system is also lost through stream alteration (Meyer 1997).

Goal:
The goal of our project is to evaluate the impact altered stream systems have on instream biota, how this loss impacts human interests, and what restoration focuses would lead to increased levels of instream biota without adversely impacting infrastructure or other human needs in the area.

Objectives:
Our first objective is to identify the most common ways that stream systems are altered by humans. These impacts are viewed as stressors and evaluated to see what impact they have on instream biota. Next we will gauge the negative impacts that decreased biota levels have. Our final objective is to identify restoration focuses that would increase levels of instream biota without adversely impacting other human needs.

Methods
We performed a literature review using the search engines JSTOR, Web of Science, Academic Search Premier, and Google Scholar. The keywords we used included, but were not limited to: stream, armoring, infrastructure, macroinvertebrates, stream health, stream alteration, stream restoration, instream biota,
stream channelization, riparian buffer, instream habitat. These articles provided the information for the introduction and findings sections. We interviewed Todd Menees, a River Management Engineer for the Vermont Department of Environmental Conservation, Water Quality Division, Rivers Program for the Springfield district.

**Findings**

Streams and rivers have always played a pivotal role in the lives of humans. They have provided countless services by facilitating transportation and improving the ability to live and work on the land (Palmer et al. 2005). However, these services usually have come at a price. Almost all major rivers in the Northern Hemisphere have been altered in some form or another (Gergel et al. 2002). The findings section will outline these alterations, explore how they have impacted in-stream biota, and look at how they might be mitigated. It will also explore the human aspect of these alterations and the balance that must be achieved between natural stream conditions and human needs.

**Channelization**

Stream channelization is a widespread practice which has had large effects on instream biota (Laason et al. 1988). Brooker (1985) states “Channelization is the group of engineering practices used to control flooding, drain wetlands, improve river channels for navigation, control streambank erosion and improve river alignment.” Stream channelization has been an anthropogenic solution to the negative impacts of a stream's natural dynamics on human infrastructure. On a small scale, individual landowners have increased farmland by channelizing streams, which results in decreasing flooding and the rapid movement of excess water off the land (Beugly and Pyron 2010; Lau et al. 2006). On a larger scale, rivers have been channelized to ease navigation (Brooker 1985) and protect man-made structures from flooding. These practices have had wide ranging negative effects on instream biota as well as humans (Figure 1) (EPA 2005; Beugly and Pyron 2010). The primary effect on biota has been the alteration of habitat. Channelization has caused increased erosion, sediment loads, destruction of riparian zones, removal of accumulated debris and alteration of instream sinuosity, all of which have created a more homogenous habitat structure (Lau et al. 2006). As a result of channelization there are fewer ecological niches and more unstable substrate and flow patterns (Lau et al. 2006). Several studies have shown that these habitat alterations have caused significant reduction in the integrity of biotic communities. One study on stream channelization in Indiana, found that nine species present in natural streams were completely absent in those that had been channelized. This loss of biodiversity was attributed to the reduction in riffle and pool quality within channelized streams (Lau et al. 2006). Another study showed that the modification of naturally meandering streams led to a significant increase in temperatures and the drying out of streams, therefore having negative impacts on fish and macroinvertebrate communities (Beugly and Pyron 2010).
Figure 1. This diagram summarizes the negative effects that occur in stream and river ecosystems. Channelization can have negative effects on both instream and bankside aspects of the riparian system (Brooker 1985).
Impacts of Riparian Land Use
Land use adjacent streams can have a significant impact on stream water quality, water chemistry, and overall function of the stream (Roth et al. 1996). Removed or diminished riparian buffers along a stream can drastically increase the amount of bank erosion. This increases the turbidity of the water (Sovell et al. 2000), changes the temperature of the water (Roth et al. 1996), and alters the amount and makeup of nutrients available (Nerbonne and Vondrak 2001). One source of stream impairment is nonpoint source pollution from agriculture. This is the lead cause for pollution and impairment of 70% of streams that are considered impaired by the National Water Quality Inventory (Nerbonne and Vondrak 2001). Streams that are exposed to constant grazing of livestock have increased turbidity, increased number of fecal coliforms, and lower presence of a woody riparian buffer (Sovell et al. 2000). Sediment is the main pollutant attributed to water pollution by agriculture, which was a contributing factor in 50% of impaired streams in a study by the National Water Quality Inventory (Nerbonne and Vondrak 2001). Another challenge is urbanization, which often causes increased runoff. This increases the magnitude and frequency of flooding events, which can destabilize stream banks and cause erosion (Wang et al 2001). The impacts on streams from urbanization and agriculture directly affect the instream biota. Sedimentation in small streams reduces the diversity of fish and lowers the productivity of fish populations (Waters 1995). Impacts can also be seen on invertebrate populations, which can be highly diverse in a natural system, but decrease along agricultural stretches and further decrease in urban stretches (Lenat and Crawford 1994).

Although the notion stands that the ideal riparian buffer consists of woody species, Sovell et al. (2000) and Nerbonne and Vondrak (2001) found that ideal riparian buffers were made of grass. More specifically, Sovell et al. (2000) states that grass riparian buffers remove 50%-60% of sediment entering the buffer zones. They also found on low order streams that are up to four meters wide, grass riparian buffers may act equally effective as wooded riparian buffers at maintaining lower water temperatures. Maintaining a steady temperature through the summer months is important for fish species, especially salmonids.

Benefits of Stream Restoration
Stream ecosystems can be one of the most difficult ecosystems to manage because of their high variability, complexity, and structure. While the water that runs its course is abiotic, it supports an immense amount of life that depends on the ebb and flow of the stream. Instream biota is sensitive to any changes made to instream flow, which can adversely affect habitat and available nutrients (Kline and Cahoon 2006). Organic matter and detritus provide the primary sources of nutrients for the varying trophic levels of a stream ecosystem (Jullian et al. 2011).

The physical structure of a stream is the direct template for the cycling of nutrients, sediment, and detritus that provide for the high diversity of organisms (Negish and Richardson 2003). Channelized streams have a much lower leaf litter and particulate organic matter retention because they lack back-current and eddies that trap these inputs (Negish and Richardson 2003). Back-flows are created by boulders, large woody debris, and shallow riffles, which are removed when a stream is channelized (Figure 3). Leaf litter and organic matter tend to accumulate in back-flowing areas and provide habitat and hold foods for detritivores and macroinvertebrates, which in turn provide alimentation for many other species. Natural streams that have a highly varying physical structure can also provide future protection of the stream ecosystem against raised water levels and flooding. Large woody debris and boulders can create drop and pool systems that can help mitigate stream velocity and minimize the destructive power of fast moving water (Figure 2) (Jullian et al. 2011).
There are many experiments that have been conducted over the last several decades that aimed to prove this reliance of particulate retention on varying stream structure. Lepori et al. (2005) examined the effects of stream restoration on previously channelized streams, due to forestry practices in the 19th and 20th centuries, by replacing large boulders and restoring sinuosity to the stream. The study concluded that restoring a stream from a previously channelized state significantly increased detritus and leaf litter retention. Accompanying this experiment, the relative abundance of detritivores and macroinvertebrates were measured and concluded no increase in abundance from the channelized stream to the restored streams through the study period of 16 years (Lepori et al. 2005). Another study similarly concluded that recently restored streams retained a significantly higher amount of particulate organic matter, but found no significant increase in macroinvertebrate populations (Laasonen et al. 1998). This shows the creation of back-current and eddies does not necessarily result in the restoration of stream biota. A stream that has been channelized for such an extended period of time could require a much longer recovery period before populations of detritivores and macroinvertebrates repopulate the stream. Laason et al. (1988) mentioned the importance of moss in the recovery of stream ecosystems in that it aids in the retentiveness of organic matter and helps increase macroinvertebrate populations. Mosses are known to be slow growing and were not able to make a full recovery during the time allotted for this study, even though the observation period lasted sixteen years (Laason et al. 1988). This again shows that simply altering stream morphology will not always result in an immediate return to healthy stream conditions.

In contrast to the previous studies, a larger number of investigations have found that there is a significant increase in macroinvertebrate populations that occur with increasing amount of detritus and organic matter. Negishi and Richardson (2003) concluded that stream morphology restoration of channelized streams using boulder dams as flow deflectors significantly increased both particulate retention by 550% and abundance of detritivores and macroinvertebrates by 280%. The study determined that the channel
structure and its retentive efficiency can be a limiting factor for productivity in detritus based ecosystems (Negishi and Richardson 2003). Another similar study determined that the presence of macroinvertebrates is significantly dependent on the presence of detritus and particulate organic matter located in the substrate, and that by increasing the detritus, the population of macroinvertebrates increases as well (Culp et al. 1983). It is important to note that although the abundance of detritivores and macroinvertebrates has been shown likely to increase, it does not equate to an increase in species diversity (Gortz 1998). Along with this, the success of the macroinvertebrate populations does not conclude that there is a higher abundance or diversity of other forms of biotic life, such as fish or amphibian species. The increased retention of detritus and particulate organic matter and the increased abundance of macroinvertebrates is merely an indicator of the increasing ability of the stream to support biota (Gortz 1998).

**Human Benefits of Altered Stream Systems**

Historically, it was common to build along river systems. Water was a resource needed to create energy, irrigate fields and transport goods to and from communities. These structures are still present in many areas, along with more recently established infrastructure. The establishment of communities along rivers used to be a necessity to have access to an energy source. Due to the advancement of energy-producing technology and transport, there is no longer a need to harvest this energy from most rivers. There is an increase of infrastructure within floodways, which due to the dynamic nature of streams, natural disaster and peak flow event areas along riverine systems can put infrastructure at risk (Hermans et al. 2007). When there is infrastructure present within these risk areas it becomes important to protect both the stream and the infrastructure.

Rivers are systems that are not constrained by political boundaries. When Tropical Storm Irene passed through Vermont in the fall of 2011, there were many instances when the river redirected itself and posed a threat to structures along the rivers. Armored stream systems are used to help reduce the impact high flow events have on the surrounding infrastructure and protect houses, bridges, roads, and land (Hermans et al. 2007). Its purpose is to direct water away from infrastructure by strengthening stream banks (Hermans et al. 2007).

To better understand the perspective of landowners and the need for stream armoring we interviewed Todd Menees. Menees is a River Management Engineer for the Vermont department of Environmental Conservation. We discussed with him a series of questions regarding the importance of stream management techniques as a way to protect infrastructure. When Menees is planning stream management he is always thinking about stream health and reaching the center of the sustainability model (Figure 4). He expressed to us that this is unfortunately not the way the law is written. Ideally, when implementing stream management the law must be followed. The laws include the protection of water quality discharge, fisheries habitat, flood fluvial erosion, and stream dynamic equilibrium. However, when implementing the objectives based on the laws with constraints of budget and human ideals the environment often suffers in the sustainability model (Menees, interview, 2 April, 2012).
Along with the economic constraints there are social values that can disrupt stream management. Landowners rightfully become attached to their property. Difficulties can arise when a landowner has a different idea about how their streamside property should be managed after a destructive storm event. Menees brought to our attention that in most cases a person's Emotional Quotient out weights their Intellectual Quotient. When describing cause and effect to landowners and when certain management techniques are or are not suitable you must account for people's emotions (Menees, interview, 2 April, 2012).

**Human Benefits of Instream Biota Restoration**

Although the list of ecological benefits for stream restoration is virtually limitless, stream restoration is a very expensive undertaking. The median cost for stream restoration projects in the United States is about $45,000 with over $1 billion spent each year (Bernhardt et al. 2005). Very few people or organizations are willing to spend this amount of money if the project is not beneficial.

The improvement of fish populations is one of the more obvious human benefits of stream restoration. Fish species are often very vulnerable to the alteration of natural stream conditions. Increased sedimentation can cover important spawning substrate, limiting the reproductive ability of certain species (Louhi et al. 2011). Likewise, channelized streams with faster moving currents can limit spawning success (Carline and Klosiewksi, 1985; Lukas and Orth 1995). Many species are susceptible to changes in water temperature or quality limiting their ability to survive and compete against more generalist, and often less desirable species (Sharma and Jackson 2007). The removal of structure in streams can reduce the number of fish both directly by limiting the amount of habitat available for fish, and indirectly through the loss of benthic macroinvertebrates, an important food source for many species (Lehane et al. 2002, Muotka and Laasonen 2002). The restoration of streams back to more natural conditions can remove these stressors and have a major impact on the abundance and diversity of fish.
There are many benefits that result from the reestablishment of healthy fish stocks. Economic benefits are often cited as the most important. Having healthy fish stocks generates income for the local economy via sales of licenses, bait, tackle, gas, food, and lodging. Many anadromous species such as Pacific salmon support multi-million dollar commercial fisheries each year (Quinn 2005). These species require healthy stream systems to successfully spawn. Restoring additional streams which have historically been important spawning grounds will help this fishery. These same species are often key components for returning nutrients from ocean systems back into inland areas. These recycled nutrients are able to improve the health of other aquatic and terrestrial wildlife species. The surrounding forests indirectly connect the livelihoods of countless people who otherwise may not care about the health of stream ecosystems (Naiman et al. 2002).

Restoration of macroinvertebrate populations is critical to the overall health of the entire stream ecosystem (Laasonen et al. 1998). In most temperate small forested streams, allochthonous inputs are the primary source of energy in the system. There is often too little light for autochthonous production in the stream by algae or other macrophytes. Macroinvertebrates are key components of the system that are essential in breaking down these allochthonous inputs, making energy available to the entire stream system (Vannote et al. 1980). Without this process occurring, the productivity of downstream systems would be lowered dramatically, limiting any biological benefits humans can receive.

Stream restoration has many other human benefits that are not economically based. The aesthetic and cultural value of a healthy stream system are often overlooked. Even if someone does not actually go fishing, there is value to an individual knowing the resource is there if they ever wanted to access it. Additionally, being able to walk along a stream or river and see fish, insects, or other plants and wildlife in it is important (Meyer 1997). Although there is no economic value to these aspects, the personal value of these experiences still exists.

Possible Focuses of Restoration
There are several endpoints where a manager could focus their restoration effort. Specific restoration objectives will be different for each system evaluated. One course of action appropriate for one stream may be completely ineffective for another. What the manager focuses on as their endpoint, however, can be evaluated across most systems.

One method is to leave the system as it is. The results of this would largely depend on the system and the level of impact that each stressor had. In minimally degraded systems, natural recovery might be possible over a certain period. Highly degraded systems, however, may be much less likely to successfully recover. This is especially the case if the stressor was never removed from the system. For example, if debris continues to be removed from a stream to enhance drainage from agricultural land, the system may never recover.

A second method is to focus restoration efforts on meeting human needs. For example, if a river is continuously undercutting a roadway, installing riprap along the stream bank may be the restoration action chosen. Although this meets direct human needs, it does not improve the ability of a stream to restore itself to more natural conditions.

Habitat restoration is another focus that could be chosen. A manager could evaluate what the natural instream habitat of the stream should be, and aim to restore it to that level. Focusing on this level of restoration aims at providing the foundation for natural processes to retake control, but for it to be successful the original and continuing human stressors on the system must be removed. The level of restoration will largely be determined by the level of degradation of the system. A highly degraded system will need additional work to not only restore instream habitat, but also provide additional framework for natural restoration to begin. For example, riparian habitat may need to be restored to
provide additional allochthonous inputs or improve the water quality and temperature conditions of the stream.

A fourth method is to focus directly on restoring instream biota levels to desired levels. This method would focus on restoring the natural habitat and but also actively managing the processes of a stream as well to reach target levels of instream biota. Again, the stresses must be largely removed from the system. The level to which these can be removed and the natural state returned will determine to what extent biota levels will be returned. The specific endpoint of each project may vary, depending on the extent of the restoration.

Focusing efforts on restoring natural stream dynamics is the broadest and most encompassing alternative. This would entail restoring the entire stream system and surrounding landscape so that it could function as natural as possible. To be effective, this approach would have to focus on the entire stream, and not just restoration of particular sections. Any human presence would be removed from the stream and the landscape would be restored to a state similar to that prior to any human influence. Although this would create the most natural system possible, it would have to take priority over any other human influence in the area around it.

**Recommendations**

Although all potential focuses of restoration have their own merits, it is our recommendation that restoring instream biota to a desired level should be the primary focus of stream restoration efforts. This focus will allow managers to restore the ecology of stream ecosystems to a healthy state without being detrimental, and therefore achieve our goal outlined in the beginning of this paper.

Having a focus on restoring natural stream dynamic was found to be unrealistic for most stream restoration projects. In most situations, there is generally limited information present on the pristine state of a stream and its ecosystem. Even if this information were present, returning to this state should not be the goal of restoration projects (Muotka et al. 2002). Stream alteration is often driven by the desire to meet some human need, including transporting goods or to protect infrastructure. While in some cases this human use continues to exist, often times they become outdated and no longer serve their intended purpose. Vestiges of it are likely to always exist and it is impractical, if not impossible, to completely remove its presence. Instead, restoration goals should focus on creating a dynamic stream system which supports a self-sustaining and diverse community assemblage appropriate to its area (Osborne et al. 1993).

On the alternative side, taking no action or simply focusing efforts on bettering human needs prioritizes the importance of infrastructure, but does not address any factors associated with restoring the natural system. As a consequence, none of the human benefits of a healthy stream system are present. We believe that it is possible to balance these two different restoration objectives.

Focusing on a habitat structure endpoint has the potential to create this balance. If done successfully, a healthy ecosystem could be created while working around and maintaining the integrity of other human needs. We believe that this method left open a greater possibility of failing to fully restore all the ecological processes needed to create a healthy and beneficial stream system. Even if habitat space was successfully created, focusing solely on this does not address other potential factors that may limit the ability of a stream to return to a more natural state.

If the restoration focus is placed on restoring healthy levels of instream biota, restoration efforts are more likely to adequately address all the ecological processes that must exist to create a healthy stream system. A stream that supports a healthy and appropriate population of biota for the given system will be stable and self-sustaining. Appropriate habitat structure will need to be present, as will healthy levels of nutrient
input, and acceptable water quality. At the same time, restoration efforts can be designed to interfere as little as possible with other human needs. Some tradeoffs may need to be made, but this will likely be necessary in any restoration effort that takes place.

In order to assess instream biota we have chosen to use the Vermont Department of Environmental Conservation’s (VTDEC) Water Quality Standards (VTWQS) for aquatic life (VTDEC 2004). These standards have been used by the DEC’s bio-monitoring project to assess fish and macroinvertebrate communities and biological impairment of these communities. The standards are used to first determine a reference condition for a specific stream and then determine the degree of change from this reference condition. A reference condition is an ecosystem with minimal anthropogenic impacts and increased degree of change from this condition indicates greater biological impairment. Based on degree of change, a stream is determined to pass or fail water quality standards. For our assessment we have decided that a stream which has at least attained Class B, or Class A categories will be sufficient (Figure 5). This means that a stream has had moderate changes from the reference condition, but is still ecologically functional. This provides room for tradeoffs between restoration efforts and other human needs to take place while still allowing a stream to receive passing marks. Our research shows that many stream alterations create systems which would not likely meet these standards. Focusing restoration efforts on restoring the impaired levels of biota will allow these streams to be brought up to standard.

![Figure 5](image_url)

**Figure 5.** Vermont Department of Environmental Conservation water quality classification system. Reaching Class A through restoration is generally unrealistic, thus, a reasonable goal would be to be within the Class B criteria (VTDEC 2004).

Assessing instream biota using this method is also useful because it gives a better picture of the streams overall ecosystem health (VTDEC 2012). Biological communities reflect the overall ecological integrity of a stream. Therefore a system such as the VTDEC’s bio-monitoring project can be used to assess the status of a stream with respect to its primary goal, The Clean Water Act. Biological communities also
integrate the effects of different stressors and are thus better assessment points for synergistic impacts than traditional water quality tests. These biotic communities change dynamically over time allowing for long term monitoring of fluctuating environmental conditions. Biological assessments allow for the assessment of stressors which are not currently regulated such as non-point sources. The biological integrity of a stream is important because it is of direct interest to the people as a measure of a pollution free environment. While these standards are specifically for Vermont they can be generally applied to streams beyond Vermont by adjusting the reference sites and basic parameters.

If restoration managers use this measure of biological success as the focus of their efforts, the systems created will be in a sustainable balance between human and ecological needs. The stream may not be returned to a pristine state and this type of restoration is unlikely to ever be successful. Ensuring healthy levels of biota are created and sustained in a stream system can benefit humans both directly and indirectly. The infrastructure necessary for meeting human needs can be maintained, while also creating instream goods and services that will benefit us economically, culturally, and aesthetically. If these two things are accomplished, any restoration effort can be deemed a success.

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