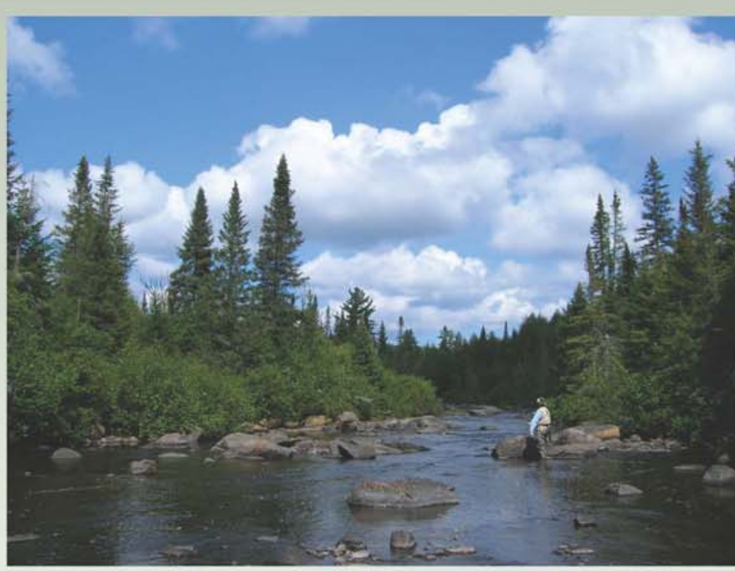
GREY VS GREEN

The Benefits of Natural Flood Control in a Changing Climate



by Trygg Danforth

TROUT UNLIMITED

Table of Contents:

Cover Photos: Top (John Braico), Bottom
(http://adirondacktrout.com/db1/00089/adirondacktrout.com/_uimages/Boreas.jpg)

Introduction

In the past few decades, as a result of our changing climate, major storms and associated flooding have become increasingly common events in the northeastern United States. “Hundred year floods” are now occurring at a much greater frequency due to a one-two punch of larger storms coupled with reduced floodplain capacity and more rapid runoff as development increases and impervious surfaces cover more watersheds and floodplains across the Northeast. These combined factors have produced floods that cause massive and widespread damage to human life, property and infrastructure. A common emergency response, when these events do occur, is to dredge and channelize stream and river beds with the perceived goal of reducing future flood impacts by increasing flood capacity and water conveyance. These actions disconnect streams and rivers from their natural floodplains, destroy critical habitat for fish and wildlife, cause erosion and sedimentation through channel and bank destabilization and worsen the effects of downstream flooding.

Functioning floodplains and wetlands have tremendous value to people and communities as well as fish and wildlife. These human benefits of natural resources are called “ecosystem services.” The many ecosystem services that floodplains provide do not have a commonly understood market value, which leads to their exclusion from critical decision making processes that affect them. This has been demonstrated in the 2011 emergency flood responses of cities, towns and hamlets across the northeastern United States, such as in Middlebury, Vermont, where the East Middlebury stretch of the Middlebury River was excessively dredged and “left basically devoid of any habitat.”[1] Research has shown that natural condition riparian areas and floodplains

[1] Stein, Andrew. "Middlebury Violated Clean Water Act." Addison County Independent [Middlebury] 12 Jan. 2012. Web. 16 Apr. 2012. <http://addisonindependent.com/201201middlebury-violated-clean-water-act>.

provide flood control and other hydrologic services to people while, at the same time, supply critical habitat for fish and wildlife species. These natural ecosystem services provide superior long-term flood control as compared to dredging, channel clearing and other commonly engineered responses to flood events.

This paper will provide a case for natural flood control by describing the benefits derived from rivers and floodplains in their natural condition, and by detailing the negative impacts of dredging and channelization, and by showing how climate change is contributing to the need for more holistic solutions to flooding. This paper looks closely at the successes of natural flood control and the failures of dredging and channelization, while reviewing the existing problems that lead to the perpetuation of inefficient and costly man-made flood control efforts. Finally, this report provides recommendations to build flood resiliency by utilizing the ecosystem service abilities of floodplains and wetlands as an integral part of future flood control planning and preparedness.

Effects of Urbanization and Climate Change

In the northeastern United States, climate change has had very tangible impacts on human infrastructure as well as natural ecosystems. An increase in extreme precipitation events combined with changes in land use has led to an increase in freshwater floods across the region.[2] These changes in land use, such as urbanization, which leads to increases in impervious surface cover and floodplain development, along with deforestation to accommodate expanding agriculture and industry, have led to increased runoff and serve to amplify the effect of

---

[2] Spierre, S. G., and C. Wake. Trends in Extreme Precipitation Events for the Northeastern United States 1948-2007. *Carbon Solutions New England*. March, 2010.

increasing precipitation.[3] The trend of increasing amounts of flooding is clearly exemplified by the "100 year" floods that occurred in southern New Hampshire in 2005, 2006 and 2007, as well as the tropical storm and hurricane related flooding that New England experienced in recent years, especially in 2011 due to Tropical Storm Irene. During the 20th century, floods caused more loss of life and property damage than any other natural disaster in the United States.[4] In recent decades, average annual losses from freshwater floods have increased dramatically from $3.35 billion in the 1940s, to $7.96 billion in the 1990's and $9.94 billion in the 2000's (adjusted for inflation).[5]

In his book "A View of the River", pioneer river scientist, professor and former USGS Chief Hydrologist Luna Leopold (1915-2006), used the Seneca Creek watershed in Maryland to exemplify how increasing amounts of impervious surfaces drive the flashier nature of runoff, causing quicker and sharper peaks in flows. Prior to urbanization of the watershed (1931-1960), the mean annual flood was 2,973 cubic feet per second (cfs), but after the watershed became increasingly urbanized (1961-1990), the average annual flood was 6,014

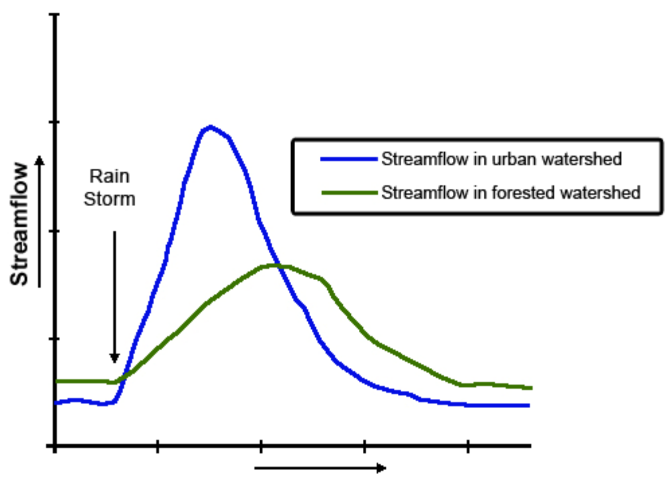


Figure 1: Flow Response to Precipitation in an Urban and Forested Watershed.

[3] Spierre, S. G., and C. Wake. 2010.
[4] Easterling, D. R., J. L. Evans, P. Ya. Groisman, T. R. Karl, K. E. Kunkel, and P. Ambenje. 2000. Observed variability and trends in extreme climate events: A brief review. *Bull. Amer. Meteor. Soc.*, 81, 417–425.
[5] "Flood Loss Data." *NOAA.gov*. NOAA's National Weather Service. Web. 02 Mar. 2012. <http://www.nws.noaa.gov/hic/>.

cfs, an increase of over 100%.[6] Seneca Creek can hold 2,000 cfs within its banks so the larger and more frequent flood peaks had a huge impact on people living close to the stream. Between 1931 to 1960, Seneca Creek's flows exceeded its 2,000 cfs bankfull capacity 35 times—increasing to 66 times from 1961-1991.[7] Leopold, the son of equally renowned ecologist Aldo Leopold, attributed Seneca Creek's increases in flood peaks and flood frequencies entirely to effects of increased urbanization.

In 2010, Carbon Solutions New England and Clean Air-Cool Planet produced a scientific paper examining the increase in the frequency of extreme precipitation events in the Northeast. Through studying the data produced by 219 National Weather Service stations across the northeastern United States from 1948-2007, they found that the occurrences of extreme precipitation events and the intensity of rainfall are increasing, with the most significant escalation occurring recently during the spring and fall seasons.[8] Over the next generation, the Northeast region is expected to grow by 26%, adding about 18 million residents.[9] With this projected growth,

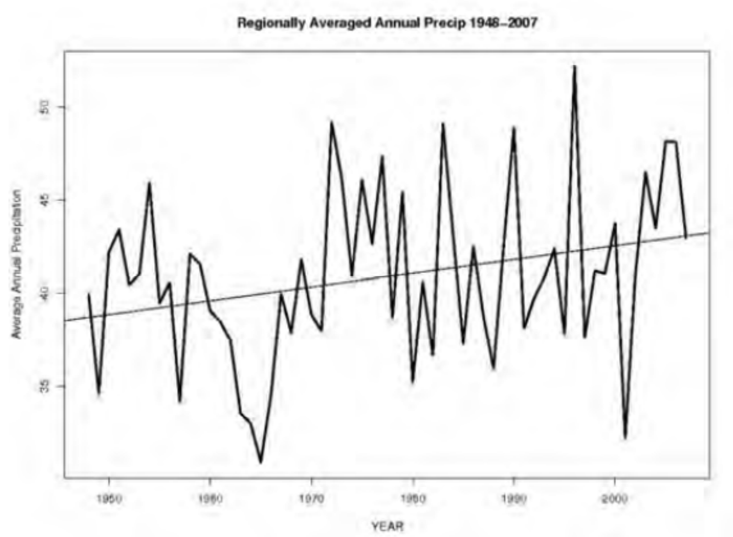


Figure 2: Regionally Averaged Annual Precipitation 1948-2007. (Wake et al. 2010)

[6] Leopold, Luna B. A View of the River. Cambridge, MA: Harvard University Press, 1994. Print.
[7] Leopold, 1994.
[8] Spierre and Wake. 2010.
[9] Paul. "Urban Growth in the Northeast Megaregion - America 2050." *America2050.org*. America 2050, 24 Mar. 2011. Web. 02 Mar. 2012. <http://www.america2050.org/2011/03/urban-growth-in-the-northeast-megaregion.html>.

development and infrastructure will progressively encroach on the region’s rivers and floodplains. Increasing trends in extreme precipitation events coupled with development will lead to larger and more frequent floods, as well as costing billions more dollars in damages. If smart, “green” flood mitigation solutions that utilize natural flood storage capabilities of functioning floodplains are not commonly understood and implemented, billions of taxpayer dollars will continue to be spent on “gray” infrastructure such as dams, levees and river channelization that, on the watershed scale, ultimately make flooding worse, pass the problems downstream, disrupt natural river processes and perpetuate a flood-damage-repair cycle that has devastating costs to life, property, taxpayers and the environment.[10]

Benefits of Floodplains

In their natural condition, floodplains, riparian areas and wetlands provide a multitude of ecosystem services that people depend on, as well as critical habitat for a wide variety of fish and wildlife. The ecosystem services that floodplains provide include clean water, recreational benefits and flood control. Floodplains and wetlands provide clean water by serving as natural filters and facilitating groundwater recharge. Nutrients, pesticides, organic waste and other pollutants are absorbed from water that flows through floodplains making rivers healthier for drinking, swimming and supporting plants and animals.[11] Floodplains also provide groundwater recharge essential to sustaining subterranean aquifers that supply our water for consumption,

[10] “Natural Defenses: Safeguarding Communities from Floods.” American Rivers. Report. 2010.
[11] Miller, Brian K. "Wetlands and Water Quality." *Purdue.edu*. Purdue Department of Forestry and Natural Resources. Web. 02 Mar. 2012. <http://www.ces.purdue.edu/extmedia/WQ/WQ-10.html>.

supporting reservoirs and helping to maintain base stream flows later in the year.

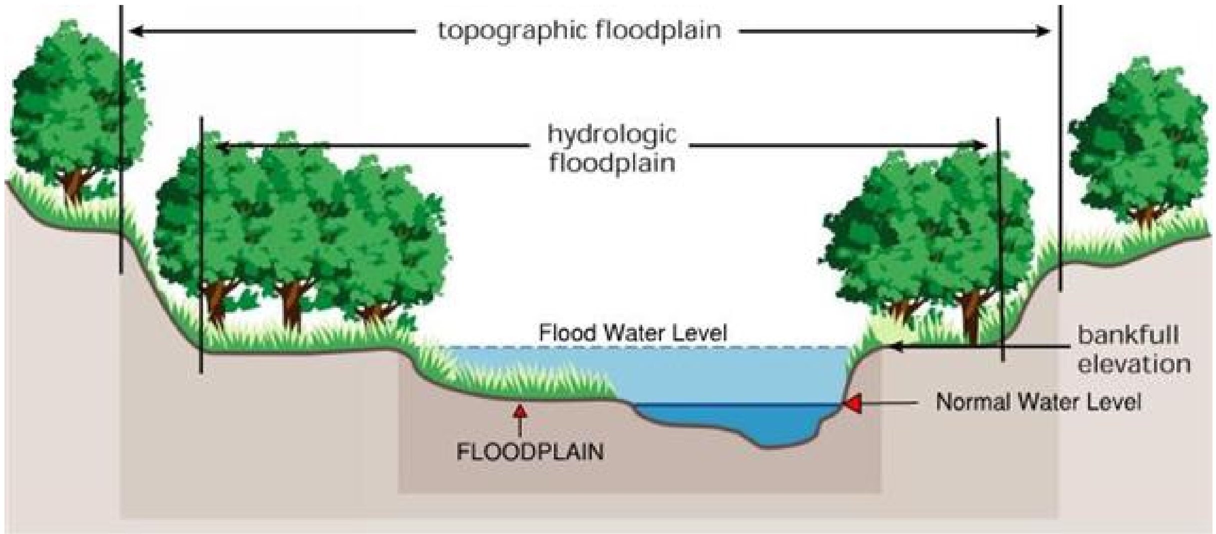


Figure 3: Typical Cross Section of a Stream System. (USDA-NRCS, 1998)

Recreational benefits of floodplains include activities such as fishing, hunting, bird watching, photography, ecotourism and hiking, all of which significantly boost local recreation economies and enhance property values.[12] More than 82 million Americans took part in these types of activities in 2001, spending more than $108 billion on these pursuits.[13] The nationwide economic impact of recreational fishing was estimated at $116 billion in 2001 and wetlands and floodplains play a crucial role in the life history of up to 90 percent of the fish caught recreationally. [14] In Vermont alone, the recreational fishing industry brings in over $64 million annually to the state's economy.[15]

[12] Golet, G.H., M.D. Roberts, E.W. Larsen, R.A. Luster, R. Unger, G. Werner and G.G. White (2006), "Assessing societal impacts when planning restoration of large alluvial rivers: A case study of the Sacramento River Project, California," *Environmental Management 37*, 862, 879

[13] "Economic Benefits of Wetlands." EPA.gov. United States Environmental Protection Agency. Web. 2 Mar. 2012. <http://www.epa.gov/owow/wetlands/pdf/EconomicBenefits.pdf>.

[14] "Economic Benefits of Wetlands."

[15] U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

A healthy wetland, floodplain, and streamside area performs three basic functions. It catches, stores, and releases water slowly over time. When wetlands and floodplains are developed, they lose their ability to catch and store water, and instead quickly release it—often over the banks. A single acre of wetland, saturated to a depth of one foot, will retain 330,000 gallons of water, enough to flood thirteen average-sized homes thigh-deep.[16] With billions of dollars of damage in flooding every year, and predictions that such flooding will increase, perhaps the most valuable ecosystem service floodplains provide is flood attenuation. A river's natural flow, with a meandering channel and adjacent floodplains give the river more room to disperse flood energy and spread out when flooding does occur. Additionally, floodplains act as natural sponges, reducing peak flows as well as storing and slowly releasing floodwaters after peak flows have passed. The value of natural flood protection is quite extraordinary when compared to the record of "gray" flood control projects. Despite spending $123 billion (adjusted for inflation) on structural projects nationwide, flood damages continue to rise.[17] Berms, dikes, levees and channelization typically cause severe environmental harm that eventually makes the flooding worse and often do not provide the promised levels of protection.

In addition to the benefits that floodplains and riparian areas provide to people and local communities, river ecosystems in their natural condition with sinuous channels and healthy adjacent floodplains provide critical habitat for a wide range of fish and wildlife. In the United States, over 50% of threatened and endangered species inhabit wetlands at some point in their life.[18] Brook trout, native to the northeastern United States, survive in only the coldest and cleanest water and serve as indicators of the health of the watersheds they inhabit. In pre-

[16] Miller, 2012.
[17] "Natural Flood Protection: Working with Nature." AmericanRivers.org. American Rivers. Web. 02 Mar. 2012. <http://www.americanrivers.org/our-work/restoring-rivers/floods-floodplains/natural-flood-protection.html>.
[18] "Economic Benefits of Wetlands."

Colonial times, brook trout were present in nearly every coldwater stream and river in the eastern United States. Currently, intact stream populations of brook trout inhabit only 5% of their historic range due to poor land management, sedimentation, loss of riparian habitat, high water temperatures, stream fragmentation and urbanization.[19]

In Vermont, in the aftermath of Tropical Storm Irene, in-stream activity detrimental to aquatic habitat quality and diversity resulted in homogeneous, over-widened stream channels comprised of small substrates and lacking diversity of habitats, flows and depths necessary to support robust aquatic populations.[20] The quality and diversity of aquatic habitats is directly linked to the ability of fish populations to withstand and recover from flood events.[21] In Vermont alone, a total estimate of approximately 406,000 feet, or nearly 77 miles, of stream were identified with major degradation of in-stream habitat from post-flood channel alteration activities and an additional 45,000 feet (8.6 miles) of stream channel were estimated with minor

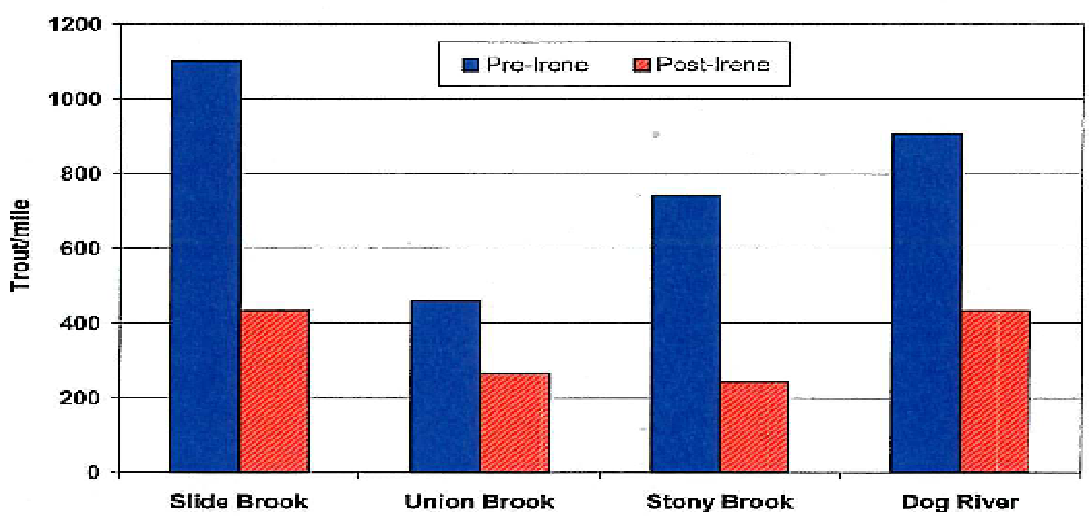


Figure 4: Wild Trout Populations Before and After Tropical Storm Irene. Vermont Department of Fish and Wildlife Surveys. (Kirn, 2012)

[19] "Eastern Brook Trout: Status and Threats." Eastern Brook Trout Joint Venture. Trout Unlimited. Web. 2 Mar. 2012. <http://www.easternbrooktrout.net/docs/brookiereportfinal.pdf>.
[20] Kirn, Rich. 2012. Impacts to Stream Habitat and Wild Trout Populations in Vermont Following Tropical Storm Irene. *Vermont Fish and Wildlife Department Annual Report*. Study No. IX.
[21] Kirn, 2012.

impacts.[22] These estimates are considered conservative as only stream reaches accessible/visible by public roads were assessed; not all streams and watersheds were evaluated and additional activity may have occurred after this assessment took place. Long-term monitoring studies in Vermont indicate that in the absence of post-flood channel alterations, wild trout populations generally recover within 2-4 years.[23] Where people have severely altered aquatic habitat, complex habitat features will need to re-establish before improvements in fish and aquatic populations can be expected and while short reaches of impacted streams may recover in a matter of years, the recovery of longer reaches may take decades.[24]

When rivers and streams are dredged and channelized, and their banks are armored to become storm dikes, rivers lose a variety of critical functions including: maintenance of habitat diversity, channel sinuosity, pool-riffle sequences; cooling of stream temperatures from shading and riparian zones; availability of in-stream "cover"; and connectivity to functioning floodplains and wetlands.[25] All these combined effects make it difficult to support an indicator species like brook trout or the myriad of other fish, amphibian, waterfowl or other species that depend on the diversity of habitats that connected fluvial ecosystems provide.[26] Fisheries biologist J.C. Congdon (1971) reported in the American Fisheries Society publication that fish biomass in channelized sections of the Chariton River, Missouri were about 80 percent less than in natural sections of the same river.[27]

---

[22] Kirn, 2012.
[23] Kirn, 2012
[24] Kirn, 2012.
[25] Brooker, M. P. "The Ecological Effects of Channelization (The Impact of River Channelization)." *The Geographic Journal,* 1985, 151, 1, 63-69, The Royal Geographical Society (with the Institute of British Geographers).
[26] Brooker, 1985.
[27] Congdon, J.C. 1971. Fish populations of channelized and unchannelized sections of the Chariton River, Missouri. In: '*Stream Channelisation: A Symposium*'. (Schneberger, E. and Funk, J. L., eds) *Am. Fish. Soc. Spec. Publ.* No. 2: 52-83

Impacts of Dredging and Channelization

When streams and rivers are dredged and channelized in emergency post-flood responses, the short-term and long-term ecological, geomorphic and economic costs often greatly outweigh the perceived benefits. When channelized and straightened, rivers and streams are kept from meandering, new habitat formation is essentially lost. The elimination of meandering leads to a loss of key river features like deep pools on the alternating outside bends with glides and interspersed riffles. These channel bed undulations along with woody debris, undercut banks and healthy riparian zones with overhanging vegetation provide the vital habitat that sustains fish and other aquatic life.[28] Straightened and deepened channels do not have the same hydrology (i.e., high flows are higher and low flows are lower) and they lose important hydrologic connections to adjacent wetland and floodplain habitats, which are some of the most diverse and productive habitats in the Northeast.[29]

In geomorphic terms, dredging and channelizing rivers does not provide the expected flood control; in fact, it often makes the situation worse. While river channelization practices may provide some short-term protection against flooding, erosive powers of the next major flood will erode the armored stream bank and necessitate further dredging after floodwaters recede.[30] Most importantly, dredging and channelization increase the vulnerability of downstream people, property and infrastructure. This occurs because when reaches are straightened, the slope of the river bed is increased while boundary and in-stream roughness are removed. This in turn causes

---

[28] Kline, Mike. *River Corridor Management in a Flood Resilient Vermont*. State Rivers Program. 2011.
[29] Kline, 2011.
[30] "Management Measure for Physical and Chemical Characteristics of Surface Waters." EPA.gov. United States Environmental Protection Agency, 13 Jan. 2010. Web. 02 Mar. 2012. <http://www.epa.gov/owow/NPS/MMGI/Chapter6/ch6-2a.html>.

increased flow energy and speed as it passes unimpeded through the reach augmenting local sediment transport resulting in channel incision, while speeding debris downstream. Where channelization ends, channel slope and depth decrease, which results in flow energy and sediment transport capacity decreasing as well, due to the reestablishment of proper slope, sinuosity and boundary roughness.[31] These downstream reaches from channelized sections are where sediment will deposit, resulting in channel migration and avulsions (i.e. formation of new river channels), thus making private or public property located below a channelized reach more vulnerable to flood damage than before the channelization took place. [32] If these downstream property owners respond in like manner by straightening, dredging and armoring their reaches, the damage and vulnerability will perpetuate to an even greater degree further downstream—as will the cost of recovery.[33]

Johns Brook, for example, located in Keene Valley, New York, was extensively dredged and channelized after Tropical Storm Irene. A one-mile long stretch above a bridge was reworked by the Town of Keene without guidance, monitoring, permitting or any training in either stream management or the state and federal laws that regulate instream activities. United States Fish and Wildlife biologist Carl Schwartz stated the project was both “gruesome” and ineffective as a method of long-term flood control.[34] “This was the completely wrong approach for the stream. You could not have done it in a worse way,” Schwartz stated in an article in the Albany Times Union. He went on to say that lining a stream bank with rock cuts off a stream from its natural floodplain, where water can collect safely to reduce the energy of a flood. And the absence of rocks and boulders scattered in a stream, which act to deflect and slow water,

[31] Kline, 2011.
[32] Kline, 2011.
[33] Kline, 2011.
[34] Nearing, Brian. "State's Haste Proving to Be a Waste." TimesUnion.com. Times Union, 20 Dec. 2011. Web. 02 Mar. 2012. <http://www.timesunion.com/local/article/State-s-haste-proving-to-be-a-waste-2416196.php>.

means floodwaters flow faster and with more power, making the next flood worse. “The work simply made the stream into a funnel and pointed it at the people downstream,” Schwartz said. “This is not about caring more about fish than people.”[35] Unfortunately, it is often the case that highway departments, from local to federal levels, performing emergency flood control efforts lack staff with hydrology and geomorphology training to advise about the longer term consequences of their actions. Even when such staff is present in other “sister” agencies, they are often not consulted because of the perceived need to act as quickly as possible.

Figure 5: Johns Brook post-Irene dredging (top) and the same stream a short distance away in a natural, undredged condition (bottom). (Photos: Naj Wikoff)

In addition to ecological and geomorphic costs, the economic cost associated with stream dredging and channelization is enormous when compared to the protection offered by natural flood control. Granted, major storms and hundred year flood events like Tropical Storm Irene will always cause damage to human property and infrastructure as long as we inhabit flood plains. However, flood management techniques like dredging and channelization not only add greatly to the cost of recovery and need frequent maintenance but also intensify the damage during the next major event.

[35] Nearing, 2011.

In the aftermath of Tropical Storm Irene, after floodwaters had receded, federal, state and municipal agencies spent millions of dollars to re-channelize previously straightened riverbeds in addition to channelizing natural reaches to try and protect nearby investments.[36] This work removed woody debris and boulders, straightened and deepened channels, and armored river banks, all of which destroyed critical habitat and removed structural features and floodplain connectivity that functions to dissipate flood energy. Bank armoring costs, for example, ranges from $40-100 per linear foot. Geomorphic data collected in Vermont alone indicates that a third to half of all stream and river miles have been channelized and re-channelized. It is easy to see how much money man-made flood control efforts have cost individual tax-payers and public agencies in the northeastern United States after major floods in recent decades.[37]

River management by dredging and channelization has been the norm for over a century in the northeastern United States. It is a practice engrained in local communities who believe it is necessary and practical. While it is understandable that it gives residents a sense of self efficacy and security to take action after experiencing such devastation, it is the wrong approach entirely to build flood resiliency. If this response pattern can be reversed through public education, policy changes and economic incentives, and previously modified northeastern rivers and streams can be restored to their natural dimensions and connected to their floodplains, it has been shown that natural flood control can provide superior and cost effective flood mitigation when compared to expensive and environmentally damaging man-made flood control efforts.

[36] Kline, 2011.
[37] Kline, 2011.

Table 1: Costs and Benefits of Gray vs. Green Flood Infrastructure

	Gray Infrastructure: Channelized, dredged and cleared rivers	**Green Infrastructure**: Natural rivers connected to functioning floodplains
Response to Floods	Perpetuates flood energy downstream, increasing vulnerability. Transports sediment and debris downstream. Promotes lateral incision as well as upstream and downstream erosion and downstream deposition.	Slows flood energy through boundary roughness and sinuosity. Floodplains attenuate floodwaters and release them over time leading to decreased flood peaks.
Construction and Maintenance Costs	Bank armoring alone costs between $211,000 and $528,000 per mile. Costs of dredging, gravel mining, debris removal and channel reconstruction are unknown.	None. However, initial restoration of channelized reaches is needed. Restoration costs vary between $64,000 and $354,000 per mile depending on the size of the stream and scope of the restoration needed.[38]
Effects on Fish and Wildlife	Loss of critical habitat and key river features such as riffles, deep pools and in-stream structure. Loss of shaded riparian zones and access to productive floodplains and wetlands.	Provides a diverse array of critical in-stream habitat, as well as shaded riparian zones and access to productive floodplains and wetlands.

Case Studies

After the flooding from Tropical Storm Irene receded in the days following the storm, hundreds of miles of dredging and channelization took place in northeastern streams and rivers. Some of the worst were in New York State's Catskill and Adirondack regions. Over five miles of Little Schoharie Creek, a class A wild brook trout stream (DEC classification), above the town of Middleburgh, NY was dredged, channelized and over-widened in the weeks following Tropical Storm Irene. According to Dr. John Braico, M.D., New York State Council Trout

Figure 6: Little Schoharie Creek, Middleburgh, NY. (Photo: John Braico)

[38] Bair, Brian. "Stream Restoration Cost Estimates." NOAA.gov. USDA Forest Service. Gifford-Pinchot National Forest. Web. 16 Mar. 2012. <http://www.st.nmfs.noaa.gov/st5/Salmon_Workshop/11_Bair.pdf>.

Unlimited (TU) Vice President for Resource Management, the work done on the Little Schoharie "cost $5.4 million and it is not going to function at all. It is unstable and will fall apart quickly."[39] Information from a TU Freedom of Information Act (FOIA) request indicate that the New York State Department of Environmental Conservation (DEC) and Federal Emergency Management Agency (FEMA) are requiring a $6 million restoration. If done to geomorphic standards initially, at a cost of $2 million, then a net savings of $10 million would have been realized.[40] Not only was the work on the Little Schoharie costly, but it was directly upstream of the town of Middleburgh. During the next major flood this channelization will only serve to act as a chute and direct the flood energy and flow velocity directly at the town that lies in its path at the end of these five miles of channel reconstruction.[41]

Turning to the high peak region of New York's Adirondacks, other examples of dredging and channelization in wild brook trout waters post Tropical Storm Irene can be found. Near the town of New Russia, NY, the Elizabethtown Department of Public Works channelized a 700' reach of Roaring Brook immediately upstream of the NY 9N bridge in mid-September, 2011, without proper permitting or conforming to

Figure 7: Roaring Brook, New Russia, NY. (Photo: John Braico)

---

[39] John Braico. Telephone Interview. Feb 13th, 2012.

[40] John Braico. Telephone Interview. Feb 13th, 2012

[41] "National Management Measures to Control Nonpoint Source Pollution from Hydromodification." EPA.gov. United States Environmental Protection Agency, July 2007. Web. <http://www.epa.gov/owow/NPS/hydromod/pdf/Chapter_3_Channelization_web.pdf>.

Emergency Guidelines and without consultation with the DEC. Because of this channelization, this reach of Roaring Brook will experience upstream incision, lateral bank erosion and downstream sediment deposition to its confluence with the Bouquet River. All of these factors will lead to serious instabilities in the reach, which if left unchecked, will proceed upstream to destabilize more of the stream and pose greater dangers to communities and infrastructure.[42]

Impediments to Natural Flood Control

In 2011, Tropical Storm Irene highlighted the existing flood response and resiliency problems in the Northeastern United States. Contradictory federal, state and local policy, project funding processes, lack of a knowledgeable command and control structure, minimal capacity for oversight and enforcement, and a lack of community and stakeholder ecological understanding all played a dramatic role in the perpetuation of the dredging, channelizing and reliance on manmade flood control.

Inconsistent policy on the federal and state level regarding recovery efforts following Tropical Storm Irene demonstrated the lack of coordination between agencies and resulted in destructive in-stream work. According to Delaware County guidance, in New York, compliance with state and federal environmental permitting laws must be established before work can commence and this compliance needs to be documented prior to receiving FEMA disaster relief funds.[43] Work without the necessary permits can lead to significant fines and the need to redo the

[42] " Post Flood Emergency Stream Intervention Training Manual". Delaware County Soil and Water Conservation District. July 2011.
[43] " Post Flood Emergency Stream Intervention Training Manual". 2011.

project.[44] In New York, for example, the DEC regulates activities in and around the water resources of the state pursuant to the Environmental Conservation Law (ECL) Article 15, Title 5, Protection of Waters Program. Article 15 Permits are required for temporary and permanent disturbances to the bed or banks of a stream, including activities such as excavations of gravel, debris removal, fill placement for bank stabilization and placement of structures in or across a stream. Federal permit requirements are similar. Section 10 of the Rivers and Harbors Act requires a permit from the U.S. Army Corps of Engineers for any work in or affecting navigable waters of the United States. Section 404 of the Clean Water Act requires a permit for any activities that involve or result in the discharge of fill material into waters (navigable waters and adjacent wetlands and tributaries to navigable waters and wetlands) of the United States. Typical flood response actions that require a permit are: channel shaping, sediment removal, bank stabilization, and culvert and bridge repair or replacement.[45] Under normal circumstances, both state and federal permits are only given when the applicant has demonstrated that they have taken all action to avoid or minimize environmental damage when at all possible.

When natural disasters like Tropical Storm Irene occur, the environmental permitting process becomes very murky and as was seen across New England, free rein is essentially given to municipalities to repair their infrastructure, at whatever cost. Again, using New York as an example, after Tropical Storm Irene, Governor Andrew Cuomo announced that the DEC was waiving all permitting requirements for “any emergency project necessary in response to Tropical Storm Irene for the protection of life or property.” The waiver went on to state that “when possible, work should be undertaken in consultation with the DEC to ensure that the

---

[44] “ Post Flood Emergency Stream Intervention Training Manual”. 2011.

[45]“ Post Flood Emergency Stream Intervention Training Manual”. 2011.

project will be carried out in a manner that will cause the least adverse impact to natural resources."[46] The on-the-ground interpretations of this permitting waiver, combined with the lack of compliance with the DEC consultation mandate had devastating impacts on river and stream environments. The Governor's waiver was over-used and applied to situations that were non-emergency and that did not safeguard life and property. These circumstances allowed for a total disregard of both state and federal environmental regulations that were designed to prevent this type of damaging work. It is also important to recognize that the dredging, channelizing, and in-stream work was done largely after floodwaters receded, days, weeks and even months after the storm. It can be reasonably argued that since the flows had returned to normal, there was relatively little or often no remaining eminent "threat to life, health, property, the general welfare and natural resources" as the temporary emergency authorization required.[47] In fact, the only threat to natural resources was the dredging itself. These issues highlight the policy and statutory problems that come into play in emergency situations. There needs to be clear unambiguous guidance coupled with effective coordination, communication, and enforcement during these natural disasters to prevent misguided attempts at recovery and control of future flooding.

Given that damaging in-stream work was allowed to occur through executive interpretation and issuance of contradictory policy, the process and structure by which these projects got funded through FEMA and other state and federal disaster relief funds lacks transparency and in some instances has been subject to override of federal and state regulations. There are two types of stream work eligible for reimbursement through a FEMA Public Assistance Grant: *emergency* work and *permanent* work. *Emergency* work includes debris

---

[46] Vielkind, Jimmy. "Cuomo Suspends APA, DEC Permitting for Irene." Times Union, 30 Aug. 2011. Web. <http://blog.timesunion.com/capitol/archives/79675/cuomo-suspends-apa-dec-permitting-for-irene/>.

[47] Nearing, Brian. "Post-Hurricane Flood Control Efforts Damaging Adirondack Rivers and Streams?" Times Union, 28 Sept. 2011. Web. <http://blog.timesunion.com/green/hurricane-road-repair-efforts-damaging-adirondack-rivers-and-streams/3383/>.

removal and emergency protective measures. For debris removal to be eligible for funding, the work must be necessary to: “eliminate an immediate threat to lives, public health and safety; eliminate immediate threats of significant damage to improved public or private property; and ensure the economic recovery of the affected community to the benefit of the community-at-large.”[48] Ineligible debris removal includes “removal of debris from a natural channel unless the debris poses an immediate threat of flooding to improved property.”[49] Eligible emergency protective measures include: “construction of temporary levees; bracing/shoring damaged structures; and emergency repairs.”[50] Finally, under the *permanent* work category regarding roads and bridges, FEMA states, “Work to repair scour or erosion damage to the channel and stream banks is eligible if the repair is necessary to ensure the structural integrity of the bridge. Earthwork that is not related to the structural integrity of the bridge is not eligible.”[51]

In summary, in order to secure funding for an in-stream project by FEMA, the applicant must demonstrate *emergency* criteria of an *immediate* threat to property and life, the need to construct *temporary* levees or, for *permanent* work, that the structural integrity of a bridge is in jeopardy. After Tropical Storm Irene, dredging and channelizing with heavy equipment did not begin until floodwaters had receded, that is to say after the *immediate* threat had passed, yet often these projects were still funded. Whole sections of rivers and streams that were channelized and levied with no intention to be *temporary* were often still funded as well. Granted localized dredging and debris clearing projects upstream of bridges were eligible and entirely appropriate for FEMA funding. However, many took advantage of the ambiguity of the situation, FEMA requirements and the pot of emergency funding intended to stabilize infrastructure.

---

[48] "Categories of Work." FEMA.gov. Federal Emergency Management Agency, 11 Aug. 2010. Web. <http://www.fema.gov/government/grant/pa/re_categories.shtm>.
[49] “Categories of Work.” 2010.
[50] “Categories of Work.” 2010.
[51] “Categories of Work.” 2010.

Tropical Storm Irene's chaotic aftermath clearly demonstrated the lack of a knowledgeable and effective command and control structure to deal with flood response, as well as a limited to non-existent capacity for oversight and enforcement of environmental rules and regulations designed to protect rivers and riparian zones. The disjointed and uncoordinated efforts of federal, state and local agencies created a laissez faire environment where stakeholders, departments of transportation and other actors could dredge, channelize and destroy stream and wetland habitat in the name of recovery. While serving immediate public safety always needs to be a central priority, those responsible simply were not trained in the basics of river science or conscious of current best flood management practices, and thus were unaware of the full consequences of their actions. As John Braico, of the New York State Council of Trout Unlimited, points out, "We don't have an agreement on models. Infrastructure people have a belief and a management system that is directly contrary to everything river science says is appropriate. It is old school stuff. They look to constrain and control rivers, to move the water faster from point A to point B, not at how dynamic stream systems behave over time to imposed change. Everyone needs to buy in and be reading from the same bible."[52]

If a new comprehensive flood response strategy based on thoughtful action, and current natural flood control and river science principles was to be developed and accepted by federal, state and local agencies, the problem of oversight and enforcement still would need to be addressed. "In New York State there is no capacity to deal with this," says John Braico. "In Vermont, given their well established River Program, I thought they would have had a reasonable capacity, but, they too were overwhelmed by the magnitude of the storm. Vermont

[52] John Braico. Telephone Interview. Feb 13th, 2012.

has six or so river engineers, we [New York] have *none*."[53] After a flood like Tropical Storm Irene, the sheer numbers of recovery projects are staggering. Vermont alone had over 480 state and municipal bridges damaged, approximately 960 culverts damaged or blown out entirely and over 2,000 stream segments adversely impacted.[54] [55] To properly provide oversight for this kind of recovery, Vermont's Agency of Natural Resources (ANR) estimates needing at least eight qualified river scientists with a well developed support team available to supervise and set limits.

Along with top down concerns that include policy issues, insufficient funding and command and control problems; serious bottom up concerns regarding community, stakeholder and contractor education needs to be provided. A basic understanding of stream mechanics is needed along with training about both the perils of dredging, channelization and floodplain disconnection, and the contrasting financial and environmental benefits of enacting natural flood attenuation measures. Historically dredging and channelizing rivers has been standard, even routine practice by communities in the Northeast. While acknowledging short-term benefits to the immediate vicinity, invariably channelization in one locale causes destabilization elsewhere. In contrast, a watershed scale approach to flood control does not pass the buck to downstream users and is essential to building flood resiliency in the system. As time passes, higher flows erode and wash away efforts at constraining and controlling the river bed and floodplains, resulting in yet more costly and environmentally damaging in-stream work. It is a self perpetuating, costly and vicious cycle. In stark contrast, naturally stable streams with adequate access to a flood corridor fared very well in the Northeast – experiencing very minor flood damage post Irene and no flood repair costs. "Healthy natural ecosystems just do a better job

[53] John Braico. Telephone Interview. Feb 13th, 2012.
[54] Pealer, Sacha. "Lessons from Irene: Building resiliency as we rebuild." Vermont Agency of Natural Resources. Jan 4th, 2012.
[55] Nemethy, 2011.

controlling costs and reducing flood hazards," says John Braico, "It's very hard for people to see that when they feel threatened."[56]

Successes in Natural Flood Control

In the Northeast, the value of natural flood control is slowly beginning to be recognized. In the town of Bennington, Vermont, for the last 150 years or more, the municipality and its residents have battled against the Roaring Branch, which flows through their town, by attempting to confine and control it through a system of berms and levees. Records show that damaging floods take place about every 20 years on the Roaring Branch and, each time, the river has been re-dredged and berms reconstructed leaving the "protected" property behind the failure-prone berms and next to the dredged channels increasingly vulnerable to successive floods.[57] Finally, in 2008, the Town of Bennington and the Vermont Department of Environmental Conservation partnered to find ways of

Figure 7: Construction of a new floodplain for the Roaring Branch, pre-Irene, above the Park Street Bridge in Bennington Vermont. (Kline, 2011)

[56] John Braico. Telephone Interview. Feb 13th, 2012.
[57] Kline, M. and Schiff, R. "Flood Resiliency in Bennington". Report. 2011

reducing flood and erosion hazards associated with the Roaring Branch. The town passed bylaws to limit further encroachment to the river and designed a major floodplain restoration project to re-connect historic floodplain areas to the channel.

Although only a portion of the proposed floodplain reconnection had taken place when Tropical Storm Irene hit, the partially expanded floodplain likely helped save the Park Street Bridge.[58] The flood deposited approximately 500,000 cubic yards (over 35,000 dump truck loads) of sediment along 3.5 miles of the Roaring Branch in Bennington. Despite the damages, town officials, recognizing the value of this approach, chose to complete the floodplain restoration project as a part of the flood recovery work. This science-based approach with continuing state-town partnership in river corridor protection and flood resiliency provides an excellent model for other Vermont and Northeast municipalities.[59]

Elsewhere in Vermont, the federally administered Green Mountain National Forest, which uses the larger, fish friendly and more natural bottomless arched culvert standard, found that all of their culverts survived Tropical Storm Irene unscathed – a marked contrast to the nearly 1000 culverts blown out across the state.[60] [61] The key to the success of the bottomless open arch culvert lies in preserving natural stream bed continuity with unimpeded sediment transport via peak flow scouring followed by redeposition as flows recede.[62] Clearly the adaptability of bottomless culverts to all flows and sediment loads is a significant long term cost advantage that needs to be considered in all flood prone stream crossings.

---

[58] Kline, and Schiff. 2011
[59] Kline, and Schiff. 2011
[60] Gram, Dave. "Vt. Officials Look to Bigger Culverts Post-Irene." Boston.com. The Boston Globe, 16 Nov. 2011. Web.<http://www.boston.com/news/local/vermont/articles/2011/11/16/vt_officials_look_to_bigger_culverts_post_irene/>.
[61] Pealer. 2012.
[62] John Braico. Telephone Interview. Feb 13th, 2012.

Across the United States, the recognition of the true value of natural flood mitigation is beginning to be understood and adopted. In Napa, California, residents designed a flood mitigation plan in the late 1990's to reconnect the Napa River to its historic floodplain. Culverts and levees would be complemented by hundreds of acres of restored tidal wetlands. Citizens approved a ½ percent sales tax increase to underwrite their portion of the project but the project has yet to be completed as federal and state funding have continued to come up short as promised levels of funding have been cut due to the economic downturn. The partially completed project was put to the test on New Year's Eve 2005 when the Napa River overflowed its banks to reach a 20-50 year flood stage. While the incomplete project was unable to entirely prevent damage, many areas normally flooded in high waters stayed dry and floodwaters receded much more rapidly due to the wetland restoration downstream. Heather Stanton, project manager at the Napa Flood and Water Conservation District, said that had the project been finished, it would "absolutely" have controlled the flooding that occurred.[63]

Another example of the recognition of the strengths of natural flood control followed the Mississippi River floods of 1993 and 2008. These floods were two of the costliest natural disasters in U.S. history ($16+ billion for 1993, around $9 billion for 2008).[64] Ecological analysis after the 1993 flood revealed that the economic damage was largely driven by land use choices and reduced flood buffering historically provided by the Mississippi's surrounding wetlands ecosystems – and that restoration of the original wetlands habitats could significantly reduce economic and societal losses if a flood of this magnitude were to recur.[65] A few key cities

[63] Brauman, Kate. "Napa River Flood Project Put to Test." Ecosystem Marketplace, 3 Feb. 2006. Web. <http://www.ecosystemmarketplace.com/pages/dynamic/article.page.php?page_id=4125>.
[64] "Ecosystem Services Case Study: The Mississippi River Floods of 1993 and 2008." *Landenconsulting.com*. Landen Consulting, 2009. Web. <http://www.landenconsulting.com/downloads/LC-Case-study--large-scale-impacts-of-wetlands-degradation.pdf>.
[65] "Ecosystem Services Case Study: The Mississippi River Floods of 1993 and 2008." 2009.

enacted these ecological and land use planning recommendations before the 2008 flood and were credited for reducing the ultimate impact of the flood – an estimated $304 million damage savings.[66] A separate analysis conducted by an interdisciplinary team (led by The University of Missouri-Columbia, The Audubon Society, and The Wetlands Initiative, with participation by multiple state and federal agencies), determined that the bulk of the flood damage from the 1993 flood was driven by the degradation and destruction of the region's native riparian and wetland ecosystems, and if those ecosystems had remained intact, the full volume of the floodwaters could have been contained and regulated with minimal impacts to industry and society.[67] Another study by the Illinois State Water Survey found that for every 1% increase in protected wetlands along a stream corridor, peak stream flows decrease by 3.7%.[68]

Turning back to Tropical Storm Irene and areas of New York and Vermont that shared in the torrential rains and historic flood flows, a number of healthy streams with intact flood corridors and ample wetlands had no appreciable damage and no associated flood repair costs. Specifically, the entire 35 miles of the Battenkill River in New York's Washington County and Vermont's Otter Creek in Addison County were both unaffected by flood waters that in some places were half a miles wide.[69] This is a marked contrast to nearby watersheds with constrained streams that suffered catastrophic impacts. These examples of the successes of natural flood control provide telling examples of the advantages natural river and riparian ecosystems combined with connected functioning floodplains can provide, in contrast to manmade flood control measures that creates a costly and losing battle while trying to constrain and control natural systems.

---

[66] "Ecosystem Services Case Study: The Mississippi River Floods of 1993 and 2008." 2009.
[67] "Ecosystem Services Case Study: The Mississippi River Floods of 1993 and 2008." 2009.
[68] "Ecosystem Services Case Study: The Mississippi River Floods of 1993 and 2008." 2009.
[69] John Braico. Telephone Interview. Feb 13th, 2012.

Recommendations

Despite the complexity and enormity of the challenge, there are steps that can be taken to move from costly and environmentally damaging man-made flood control to cost effective, safer and environmentally friendly natural flood control. First and foremost, natural rivers and streams need to be left alone, and more focus needs to be placed on recovering the natural resiliency and flood management benefits of healthy, properly functioning rivers. Wasting millions of dollars after every flood on counterproductive dredging and channelizing projects that decrease safety, flood resiliency and aquatic habitat simply does not make sense. When bridges, culverts, and riverside roads are washed out and need to be repaired, it should be done with the utmost haste to allow for the flow of people and commerce to re-open but should not be done at the expense of the safety of downstream individuals and property, the taxpayers or the environment.

A great deal of emphasis should also be placed on community and stakeholder education. Despite Northeast communities historical dependence on dredging and channelization as methods of flood control, the benefits of natural flood control are simply too numerous to ignore. In today's economy, where wasteful government spending has become a target of public dissent, millions of taxpayer dollars spent on failure-prone gray infrastructure to ineffectively control and constrain floodwaters provides a compelling narrative. In addition to engendering an endless flood-damage-repair cycle, river science has shown that dredging and channelizing destabilizes streams' dynamic equilibrium, reduces public safety by propagating and increasing damage downstream. The debate ultimately needs to shift from a misconstrued "fish versus people" perspective to an understanding of how natural flood corridors and wetlands provide a safer, cost effective and flood resilient environment.

To accomplish these community education goals, the public must be engaged with training seminars and workshops that are conducted and sponsored by various groups including: university outreach programs, NGO's, and county, state and federal agencies like FEMA, NRCS, NY DEC and VT ANR. The best way to win the hearts and minds of the public will be to publicize and demonstrate the successes and low cost of protecting and restoring natural flood control measures, contrasted to the repeated failures and unsustainable costs of man-made flood infrastructure.

To complement community education, decision makers from the top down also need to be well informed. A knowledgeable command and control structure, similar to forestry's incident command program for forest fires, would prevent the emergence of a perceived laissez faire environment such as existed in states like New York after the flooding of Tropical Storms Irene and Lee – where dredging and channelization occurred unregulated and unsupervised due to the Governor's waiver of CWA and DEC regulations. Clear guidance is needed on which activities qualify as "emergencies" and what constitutes an "immediate" threat to life, property and natural resources. Elected government officials at federal, state and local levels need to acknowledge and support sound river management practices and be able to provide vital agencies with adequate funding and staffing to provide the necessary disaster planning, oversight and enforcement of cost effective best management plans that correspond with environmental regulations in times of critical need.

Along with a knowledgeable command and control structure, more personnel with expertise in hydrology and geomorphology need to be brought in to state, county and local highway, transportation and public works departments. These groups are usually the first to respond after floods to rebuild roads, maintain infrastructure and deal with channel obstructions. As was seen in the response to Tropical Storm Irene, road crews and contractors dredged and channelized hundreds of miles of northeastern streams without oversight, advice or knowledge of the long-term consequences of their actions. When floods do occur, it is important to act as quickly as possible to fix washed out roads and stream crossings but it should not be done without the assistance and guidance of qualified river scientists and engineers. In the aftermath of major storms and flooding when the amount of in-stream projects overwhelm the capacity for oversight for state and local river engineers, non-profit groups and individuals with hydrologic and geomorphic qualifications should coordinate to form action teams and work with state and local agencies using current evidence based best management practices to make sure in-stream activities allow for recovery as well as the maintenance of environmental stability.

FEMA’s funding policies for emergency work need to be consistent as well as transparent. Projects that do not comply with FEMA requirements or adhere to laws designed to reduce flooding and protect the environment, should not be funded with taxpayer dollars. FEMA also should take advantage of cost-savings associated with improved disaster preparedness by restricting the use of available funding for counterproductive, non-emergency projects and shifting more resources into preparedness – with the aims of saving money while achieving better outcomes.

Overall, a comprehensive flood response strategy is needed that includes a preventative medicine approach. An educated community and leadership along with clear and consistent guidance from informed government agencies is a strong foundation for an effective flood disaster response system. But, for greatest effect, an emphasis should also be placed on restoring streams and rivers with appropriate natural floodplain function during times of normal flows. This proactive flood planning approach will pay the greatest societal and environmental dividends while avoiding the regrettable responses so common in disasters lacking adequate planning. Increased funding through FEMA's Hazard Mitigation Program, combined with better utilization of government programs like the Land and Water Conservation Fund to acquire and protect floodplain habitat from willing sellers are both promising avenues to build flood resiliency. Completing projects that bring natural character and full functionality back to northeastern rivers and streams before major storms will, in the long run, reduce damages, costs and cleanup, save lives, *and* provide trout and the myriad of other species dependent on healthy riparian environments the critical habitat they need to survive.

Conclusion

In the fall of 2011, the floodwaters of Tropical Storm Irene destroyed thousands of roads, buildings, bridges and homes, led to 18 deaths across New England, and devastated communities that have made their homes around these beautiful northeastern streams and rivers for generations.[70] This damage offers a powerful and sobering lesson in the limitations and hazards of over reliance upon man-made flood control projects aimed to constrain and control rivers and disconnect them from their floodplains. For decades, the Northeast has depended on dredging and channelizing streams and rivers as the preferred method of flood control. Now, through

[70] "Hurricane Irene Death Toll Rises to at Least 44." Msnbc.com. Msnbc Digital Network, 30 Aug. 2011. Web. 02 Mar. 2012. <http://www.msnbc.msn.com/id/44314551/ns/weather/t/hurricane-irene-death-toll-rises-least/>.

advances in the understanding of river science and geomorphology, it has been shown that the best way to control floodwaters are to let the natural systems perform the services provide naturally. Floodplains attenuate floodwaters and flood energy by absorbing excess flows, feeding groundwater aquifers, and releasing water when flood peaks have subsided. Natural sinuosity in rivers slows down flows and allows for sediment deposition while natural debris and boulders provide key boundary roughness, further absorbing flood energy.

In light of our changing climate and the likelihood of increasing numbers of major storm events, spending millions of dollars on dredging and channelization after every flood—which has been shown to reduce the safety of both life and property and severely degrade critical fish and wildlife habitat—simply does not make sense. The steps to building flood resiliency through natural flood control include: educating communities and stakeholders of the successes of natural flood control projects; informing elected officials and government and state agencies on best management practices; providing state agencies with the manpower to provide oversight for in-stream projects; decreasing or eliminating funding for dredging and channelization projects completed in violation of guidance; and increasing funding for proactive state and federal flood corridor restoration programs.

If the numerous altered northeastern rivers and streams are systematically restored to their natural condition with connected floodplains, all evidence indicates that flood damage will decrease even as the frequency of major storm events continue to increase. In addition to flood control, the ecosystem services healthy rivers and floodplains provide like clean water, groundwater recharge, recreation, and fish and wildlife habitat create incalculable value to human society. In order to realize this immense value, reactionary dredging, channelization and floodplain disconnection need to be reversed where present, and prevented after major flooding events. Although communities have depended on these methods for many decades, the damage induced by these measures greatly outweighs the perceived benefits, and by continuing these practices, future generations of people, as well as fish and wildlife, are placed in harm's way.

Appendix

Information from " Post Flood Emergency Stream Intervention Training Manual". Delaware County Soil and Water Conservation District. July 2011

Exhibit A

Immediate Effects of Dredging

Dredging is often proposed as a means of increasing channel capacity after a flood. On the previous page we have shown the evolutionary sequence that the stream must go through when channelization occurs. The immediate consequences of dredging are illustrated below:

Figure 2.11 (after R. Hey, 2003) shows a stream in profile view that has just been dredged. This corresponds to Simon and Hupp's Class II in **Figure 2.10**.

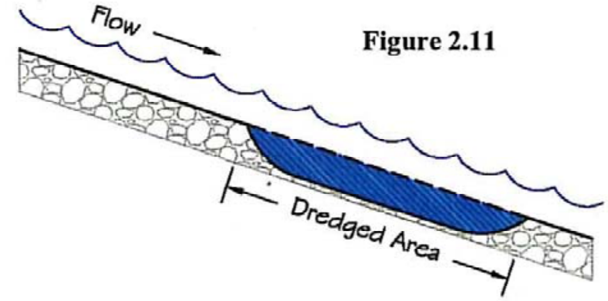
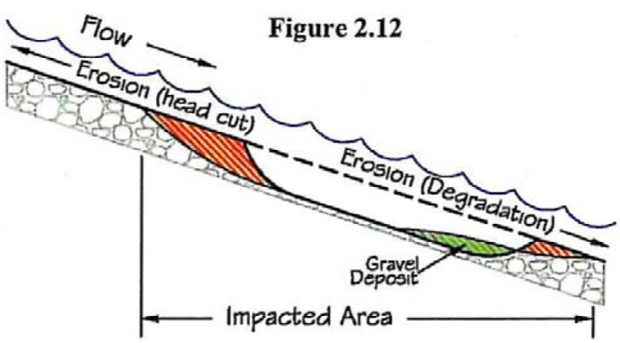


Figure 2.11

Figure 2.12



Within days, certainly no longer than weeks, the disturbances illustrated in **Figure 2.12** (after R. Hey, 2003) will be seen on the dredged stream.

Three things are occurring in the stream when it is dredged:

- A headcut occurs as a steep abrupt change in elevation in the stream bottom which forms upstream of the dredged area. The headcut will continue to move upstream releasing a huge amount of sediment supply from the bed and banks.
- This new sediment will be deposited at the location shown in the sketch labeled gravel deposit.
- Since the headcut is in effect lowering the elevation of the channel, erosion will occur downstream of the gravel deposit and outside of the area dredged. This occurs because the stream is trying to achieve equilibrium with a new bottom elevation and slope. In short, it is trying to match downstream with what is happening upstream.

All of this leads to serious instabilities in the reach. Unfortunately, that is not all that can happen. The headcut, if left unchecked, will proceed upstream and destabilize more of the stream. The erosion and gravel deposition will proceed downstream and destabilize the downstream reach. If the upstream and downstream reaches are stable then they will become unstable. If the reach that was dredged was already unstable, it has been further destabilized and will be greater nuisance and danger to human activity.

Exhibit B

Channel Disturbance – Evolutionary Sequence

Channels that have been disturbed by dredging, incision, or channelization follow a systematic path to recovery. This process has been documented in six classes described by Simon and Hupp (1992) in **Figure 2.10**. This process can happen naturally.

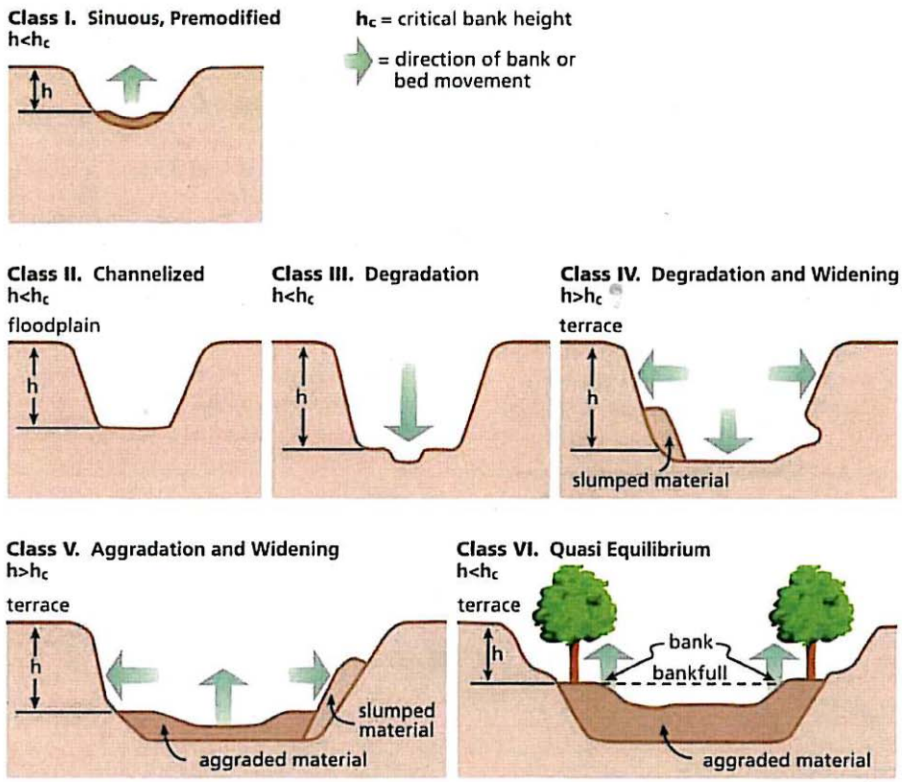


Figure 2.10 Stream Evolutionary Sequence (Simon and Hupp, 1992)

- Class I, is the channel in its natural pre-disturbed state.
- Class II, is the channel immediately after being disturbed (in this case, channelized, presumably straightened and steepened in addition to over-widened).
- Class III, is the channel eroding down (degrading) due to the flood waters being confined because channel is lower and out of contact with the former floodplain.
- Class IV, the channel continues to degrade, the banks become unstable, and the channel erodes laterally.
- Class V, the channel begins to deposit eroded material in the over-wide channel, and the newly developing floodplain continues to widen.
- Class VI, and a new channel is established and becomes relatively stable. A new floodplain is established within the original channel, and the former floodplain becomes a terrace (abandoned or inactive floodplain).