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Restoring straightened rivers for sustainable flood mitigation

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Abstract

Purpose – This article aims to show how communities with severe river flooding can develop sustainable flood plans that remediate environmental problems caused by previous river straightening and other structural flood controls.

Design/methodology/approach – The article builds on a case study of the nationally recognized Napa River Flood Protection Project (USA), which incorporates an ecological living river strategy and builds on strong community participation to restore a river and its floodplain. After discussing the drawbacks of structural flood control measures, and especially of river straightening, reviews the contents of the Napa Flood Project and the public participation process necessary for its design, approval and implementation.

Findings – The key lessons learned from Napa's flood project are that: undoing past structural works is difficult but feasible; ecological criteria can and should be used to design modern flood projects; involvement of a wide and diverse group of stakeholders is crucial to developing and implementing an environmentally sustainable flood management project; and the US Army Corps of Engineers can work with communities and depart from its typical, structural flood control approaches.

Research limitations/implications – Information on straightened rivers is extremely limited. Furthermore, this study focuses on flood planning for US rivers, and may therefore be less useful elsewhere in the world where the frequency of river straightening may differ.

Originality/value – This case study provides a critique on river straightening, which is a poorly documented but fairly frequent approach to flood control. This article helps to fill gaps in the knowledge of how communities can, and are, addressing environmental concerns associated with flood controls and river straightening.

Keywords Floods, Environmental and safety engineering, Structural engineering, Environmental management, United States of America

Paper type Case study

Introduction

While floods replenish and sustain ecosystems, they also pose serious threats to the structures and people in their path. Over time, settlement patterns and the development of land and infrastructures in flood-prone areas have dramatically increased flood frequency, extent, and subsequent hazards (Blaikie *et al.*, 1994). Floods are the most costly natural disasters worldwide (Hewitt, 1997; Palm, 1990) and make up 90 percent of all disasters incidents in the USA (Federal Emergency Management Agency, 1997).

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With the annual cost of flood damages in the USA estimated at $4 billion (Siegel, 1996), flood mitigation policies are important to localities, states, and the federal government. Although cities across the country have developed and implemented flood plans, economic losses from natural disasters are still increasing (Mileti, 1999).

Traditional approaches to flood control have relied on structural works, including building floodwalls and levees or modifying river channels (e.g. widening, lining with concrete, or straightening by cutting through channel meanders to shorten the flow distance). These structural approaches, however, have failed to reduce flooding or to reduce ever-increasing economic losses from floods, as economic losses are merely postponed and continue to rise (Mileti, 1999). In addition, structural approaches are not environmentally sustainable and can cause severe environmental degradation locally and downstream (Burby *et al.*, 1988), including the loss of wetlands and animal habitat.

In contrast, non-structural approaches, such as land use and zoning regulations, land acquisition, and environmental restoration programs, can be both effective and more sustainable (Gruntfest, 2000). Sustainable flood mitigation focusing on restoring the natural functions of rivers and floodplains sometimes requires undoing pre-existing structural works. However, practical experience, established best management practices, and literature on undoing structural works and retrofitting straightened rivers are lacking from the planning and flood management literature. The Napa River Flood Protection Project illustrates how undoing structural works can play a significant role in promoting sustainable flood mitigation without forfeiting flood protection.

This article presents an in-depth analysis of the contents of the Napa Project, as well as a discussion of the key elements of this successful planning process. It illustrates how a community can undo existing structural flood control works and incorporate sustainable flood mitigation approaches into local flood planning to address flood hazards in an economically efficient and environmentally sound manner.

Structural, non-structural, and innovative flood mitigation approaches

Flood control policies adopted to manage floods have historically relied on structural public works (Gruntfest, 2000; May *et al.*, 1996; May and Williams, 1986). Structural approaches involve the use of levees, floodwalls, dams and reservoirs, as well as the channelization and straightening of selected portions of river channels to control the direction and velocity of floodwater. Such works reduce flood peak flows and flood elevations, contain flood flows within channels, and route floodwaters away from developed areas (Owen, 1981).

The goal of structural flood mitigation measures is to prevent or reduce flood damages by keeping floodwaters away from people and buildings (rather than by keeping development away from flood-prone areas). These structural flood controls provide a degree of protection from floods (Pasterick, 1998, p. 125). For instance, the Corps of Engineers estimates that they prevented $19 billion in damages during the Midwest flood of 1993 (Burby *et al.*, 1999, p. 252).

In spite of these benefits, structural approaches to flood mitigation are extremely costly and tend to fail in the long term (Burby *et al.*, 1988), are detrimental to the natural environment (Burby *et al.*, 1988), provide a false sense of security and thereby encourage development in flood-prone areas (Pasterick, 1998; Hewitt and Burton, 1971; Montz and Gruntfest, 1986), and simply redirect floodwaters rather than increase infiltration. Although they protect the immediate area where they are located, structural works often increase downstream flooding by increasing the carrying capacity of river channels (Burby *et al.*, 1988; Owen, 1981; Beatley, 1998; US Army Corps of Engineers, 1994; US Army Corps of Engineers, 1995). They thus tend to protect a community while threatening another.

River straightening, a drastic, fairly common, and yet poorly documented type of structural flood control, deserves specific attention. River straightening, or realignment, involves modifying the channels of rivers to straighten their course. It increases the carrying capacity of rivers by shortening the flow path, but also increases the velocity of floodwaters[1]. A large number of rivers have been straightened in the USA (typically during the first three decades of the century, though some as recent at the 1960s) to control floods, such as the Chicago River, the Kissimmee River, and the Napa River (see Table I).

River straightening as a flood mitigation method has significant negative environmental impacts and has therefore come under attack by the public and environmentalists as a response to flood hazards (US Army Corps of Engineers, 1994). Straightened river channels increase the water discharge and can increase downstream flooding (US Army Corps of Engineers, 1995, p. 6-3), and degrade local environmental

River	State
Napa River	CA
Kissimmee River	FL
Chicago River	IL
Missouri River	MO
Cuyahoga River	OH
Smiths Fork River	WY
Alamosa River	CO
Mississippi River	MS
Petaluma River	CA
Duchesne River	UT
Provo River	UT
John Day River	OR
Los Angeles River	CA
Salmon River	ID
Willamette River	OR
East Two Rivers	MN
Jordan River	UT
Sammamish River	WA
Russian River	CA
Trinity River	TX
Truckee River	NV
Long Creek	MS
San Antonio River	TX
Red River	NM, TX, OK, ARK, LA
Puerco River	NM
Twenty Mile Creek	MS

Note: The US Army Corps of Engineers does not maintain a database of rivers straightened. This list is therefore incomplete
Source: Internet search

Table I.
A sample of straightened rivers in the USA

conditions by causing channel modification, bank erosion, and the incision of tributaries (US Army Corps of Engineers, 1994, pp. 3-2). Artificially straightened rivers are less stable morphologically and have a less consistent pattern of sediment routing than meandering rivers (Keller and Brookes, 1983, p. 384). In addition, straightening river channels often results in steeper slopes and higher flow velocities – ultimately increasing erosion and reducing water clarity and quality (MacBroom, 2002, p. 380). As a result, straightened rivers maintain less hydrological and biological diversity (Keller and Brookes, 1983, p. 384), with aquatic habitat being reduced by as much as 60 percent (US Army Corps of Engineers, 1989, pp. 2-6).

In sum, structural flood controls, including river straightening, are costly, often fail to mitigate floods, and negatively impact local and downstream environments. Despite the billions of dollars spent by the USA on structural flood controls, flooding remains a hazard and economic losses from flooding are increasing (May and Williams, 1986, p. 65). The exclusive use of structural controls is thus a limited and ineffective approach to flood mitigation (May and Williams, 1986, p. 65) and structural methods should thus only be utilized in conjunction with more sustainable nonstructural flood mitigation measures.

Traditional nonstructural flood measures include land acquisition programs and land-use management steering development away from floodplains, and development regulations that restrict land-uses in flood-prone areas (Hewitt and Burton, 1971; May and Williams, 1986; Burby *et al.*, 1988; Beatley and Manning, 1997; Smith and Ward, 1998). The nonstructural approaches that are currently gaining momentum include restoring wetlands and returning rivers to their natural paths to increase their capacity to absorb runoff and floodwaters (Beatley, 1998, p. 245; US Army Corps of Engineers, 1998; Gruntfest, 2000; South Florida Water Management District, n.d.). Nonstructural flood measures tend to achieve more sustainable flood mitigation because they reduce flood damages by keeping development and people away from flood hazards, and maintain and restore the environmental quality of flood-prone areas, thereby providing long-term resiliency to floods (Mileti, 1999). They can also promote local economic vitality by supporting commerce in areas previously at high-risk of flooding, and they tend to allow for more active public participation in planning processes than structural works (Mileti, 1999). Given these far-reaching environmental and social advantages, nonstructural flood mitigation methods are becoming key components of sustainable flood management.

Based on a growing understanding of the adverse effects that past structural approaches have had on floodplains, ecosystems and communities, restoration projects have emerged throughout the country in the past decade, such as the ongoing Kissimmee River Restoration Project in Florida, the San Antonio River Improvements Project in Texas, the Bronx River Restoration Project in New York, the White River Watershed Restoration project in Vermont, and the Napa River Flood Protection Project in California. Similarly, regional agencies, such as the South Florida Water Management District for the Kissimmee River, have researched the negative effects of previous structural measures and have identified ways to correct related environmental damages.

Localities undertaking restoration projects are beginning to experiment with the potential of river and floodplain restoration and with undoing structural works as a means of flood mitigation. They also face the challenge of developing complex processes to implement innovative flood projects. These planning processes can be extremely complex as they usually involve numerous stakeholders with conflicting expectations. Napa's flood project involves river restoration and undoing past structural works. It is a model for other communities initiating sustainable flood mitigation planning, both for its approach to flood mitigation and for its successful implementation.

The Napa River Flood Protection Project

The Napa River/Napa Creek Flood Protection Project (the Project) of the County of Napa, California provides an ideal case study to illustrate how a community with a previously straightened river can develop a sustainable flood mitigation plan based on environmental restoration. The Project shows how carefully chosen and designed innovative and sustainable approaches to flood mitigation can correct past (and ineffective) structural works involving river straightening and levees, and implement an effective flood mitigation plan that protects both the community and its natural environment.

The Napa flood project is nationally recognized for its innovation and serves as a model for other communities (Larry Dacus, 2003, personal communication, 18 August; Graham Wadsworth, 2003, personal communication, 18 August). The Project has received numerous awards, such as the 1998 American Institute of Architects Award, the 1998 American Society of Landscape Architects Award, and the 1999 Governor's Environmental and Economic Leadership Award from the California Division of the Environmental Protection Agency. As a result, Napa's flood plan is currently used as a model for flood projects in other communities, such as Santa Clara County, California (Graham Wadsworth, 2003, personal communication, 18 August; John Lander, 2003, personal communication, 1 August).

Kathleen McGinty, the 1998 Chair for the President's Council on Environmental Quality, praised Napa's flood project:

> In redefining its relationship with nature, Napa exemplifies a new model of environmental decision-making. They had the courage to break with convention … and in so doing, they helped inspire new thinking in other communities and within government agencies (Napa County Flood Control and Water Conservation District, 2002).

This case study analysis of the Napa River/Napa Creek Flood Protection Project focuses both on the planning process that resulted in the plan and on the flood mitigation approach (i.e., the content of the plan). The research is based on the contents of the Supplemental General Design Memorandum (GDM) prepared by the US Army Corps of Engineers, as well as interviews with a City Council member and three project engineers.

The Napa River and its floods

The Napa River drainage basin covers 426 square miles and is located approximately 40 miles northeast of San Francisco, California. The Napa River's natural meandering channel includes a large oxbow within the city limits as well as the tidal marshlands of San Pablo Bay. Figure 1 shows the path of the river as it travels south through the City of Napa. The Napa River supports various habitat types, including emergent marsh, riparian vegetation, oak upland, and grasslands.

Source: Napa Traffic Management Plan (2003)

Figure 1.
Aerial view of the Napa River, looking south over downtown Napa at the oxbow

Napa was established in 1879, with its economic base focused on access to the river. In an early attempt to control the flooding of the Napa River and improve navigation, the Army Corps of Engineers straightened a portion of the river during the 1930s (Wadsworth, 1998). Nonetheless, since the straightening, Napa has endured 15 major floods (Wadsworth, 1999). Although the river straightening may have reduced the severity of flooding, its impact on the incision of the Napa Creek and other creeks draining into the Napa River is debated (Graham Wadsworth, 2003, personal communication, 18 August). The straightened stretch of the river south of the city (shown in Figure 2, looking east over what is locally known as Horseshoe Bend because of its shape) has decreased riparian habitat, requiring the restoration of marshland habitat (John Lander, 2003, personal communication, 1 August), although some argue that the environmental impacts may be minimal given the short length of the straightening (Larry Dacus, 2003, personal communication, 18 August).

Major floods have been recorded on the Napa River since 1862. The most devastating flood occurred in February 1986 after 20 inches of rainfall within a 48-hour period (the annual average rainfall is 36 inches) (US Army Corps of Engineers and Napa County Flood Control and Water Conservation District, 1997; Napa County Flood

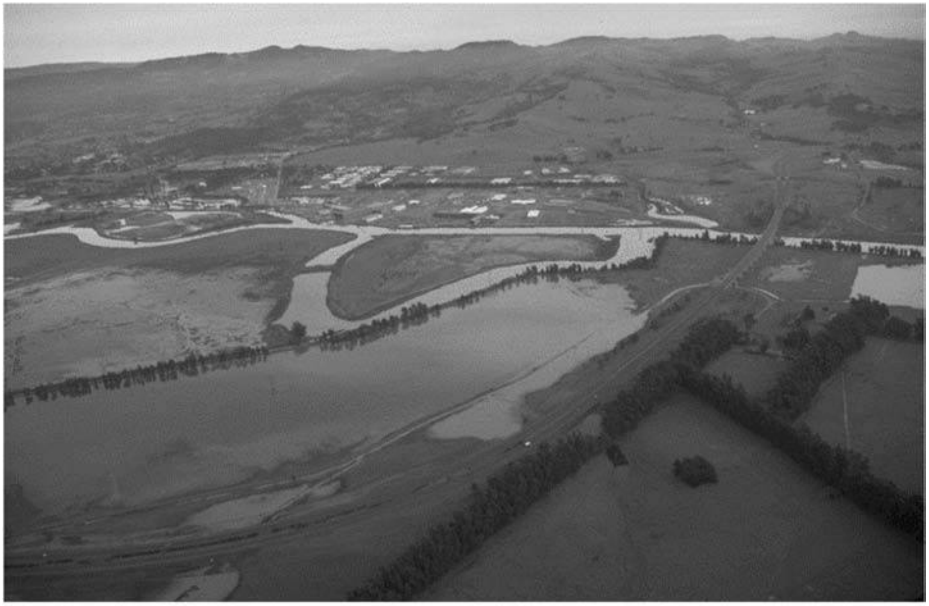

Figure 2.
Napa River at Horseshoe Bend

Source: http://www.dhigroup.com/ProjRef/Napa.gif (8/7/2003)

Control and Water Conservation District, 2002). The 1986 flood caused $100 million in damages, destroyed 250 homes, damaged 2,500 homes, and caused 27 injuries and 3 deaths (Wadsworth, 1999).

Historical context of the Napa River Flood Protection Project

In 1965 Congress gave authorization for a major flood project for Napa County, which was to be produced by the US Army Corps of Engineers. The 1965 project proposal and a 1975 General Design Memorandum (1975 GDM) submitted by the US Army Corps of Engineers did not receive a warm welcome by Napa County residents. Despite the creation of wildlife habitat, the 1975 GDM was rejected in subsequent referendum elections in 1976 and 1977 because residents were displeased with the plan's failure to address the environmental impacts of structural flood controls. This initial flood project proposal was thus shelved.

The devastating flood of 1986 triggered a new flood protection project for the Napa River. After a thorough revision of their 1975 GDM, the US Army Corps of Engineers submitted a revised proposal in 1995, referred to as the Updated 1975 GDM, only to be deemed unacceptable by residents again due the lack of environmental sensitivity. In particular, the public review process pointed out major concerns including salinity intrusion from deepening the channel, and degraded water quality in the oxbow due to the proposed wet bypass channel (US Army Corps of Engineers, 1998). The public disapproval of the Updated 1975 GDM led, two decades later, to the formulation of the Napa River/Napa Creek Flood Protection Project and its adoption in 1998.

The planning process: public participation and support for the Project

Napa's Flood Project was developed in the context of a strong public participation process and community support. Public participation in the Napa River Flood Protection Project was crucial in writing and implementing a well-supported and funded flood plan (Larry Dacus, 2003, personal communication, 18 August; John Lander, 2003, personal communication, 1 August; Graham Wadsworth, 2003, personal communication, 18 August). Interviews with Project engineers from the US Army Corps of Engineers, Napa County and the City of Napa indicate that public involvement and consensus building within the community was key to getting the Project approved (Larry Dacus, 2003, personal communication, 18 August; John Lander, 2003, personal communication, 1 August; Graham Wadsworth, 2003, personal communication, 18 August).

Given the rejection of previous versions of the plan due to strong community opposition, and acknowledging the need for community support for the flood plan, the community coalition Citizens for Napa River Flood Management (the Coalition) was created in 1996 (John Lander, 2003, personal communication, 1 August). The Coalition includes various interests and is comprised of more than 400 representatives from business and agriculture, environmental groups, the US Army Corps of Engineers, and government agencies. Although all participants may not have initially shared the same vision for the flood project, they ultimately all worked towards a common outcome (Graham Wadsworth, 2003, personal communication, 18 August).

The Coalition participants had various reasons to support the Project. From an economic standpoint, the considerable media attention to the numerous flood events drove away tourists, and businesses could not afford to rebuild after floods year after year and were eager to see an effective flood protection project and (Graham Wadsworth, 2003, personal communication, 18 August). Flooded vineyards and a slow tourist economy also impacted agricultural interests, primarily being the wine industry. Environmental groups pushed for the Project as a means to restore and improve habitat (Graham Wadsworth, 2003, personal communication, 18 August). Finally, policy makers and the general public wanted to stop flooding with a cost effective and fundable flood project (Graham Wadsworth, 2003, personal communication, 18 August).

The Coalition-driven planning process resulted in the US Army Corps of Engineers acting as an equal participant in planning decisions rather than an outside agency imposing its ideas and practices upon a community. A new operating approach by the Corps was also crucial to the integration of community input in flood planning decisions and to the success of the Project. Project manager Larry Dacus (2003, personal communication) explains that:

> In the past the Corps has often gone off by themselves and developed a plan and then told the community to take it or leave it. The Coalition process … with the Corps as an equal participant allowed the community to feel as if they owned the project. We are now constructing "their" project.

The fact that the community "owns" the Project is an important aspect of the success of this community-based planning effort. The leaders of the Coalition were also essential to the success of the Project: they were passionate about preserving the natural beauty of the river while also providing flood control.

The Coalition planning process allowed the parties to build a strong consensus about the goals and principles of the Project, to agree on a final design, and to build public support for the funding of the Project (Graham Wadsworth, 2003, personal communication, 18 August). The key contribution of this Coalition-based planning process was the adoption of the "living river" strategy, which shifted the flood mitigation approach away from structural flood control elements and toward river restoration.

The flood plan contents: "living river" strategy and emphasis on non-structural elements
Napa's Flood Project is most notably innovative for its approach based on a strong ecological framework, outlined in the "living river" strategy, and emphasizing nonstructural and environmental restoration approaches to flood mitigation, which "represents a much needed departure from past flood control efforts" (US Army Corps of Engineers and the Napa County Flood Control and Water Conservation District, 1997, p. 23). The uniqueness of this Project is based on the adoption of a "living river" strategy. This guiding framework oriented the Project toward nonstructural flood mitigation methods, although a few structural elements were necessary.

The main objective of the "living river" strategy is to "maintain or enhance the Napa River's natural processes and characteristics by integrating principles of fluvial geomorphology with river engineering and riparian wetland ecology" (US Army Corps of Engineers, 1998, pp. 5-1). The "living river" objectives (see Rippey, 2000), are based on scientific principles that have not previously guided urban flood projects (John Lander, 2003, personal communication, 1 August) and were used to guide the Project to provide flood protection while restoring the aquatic, riparian, and floodplain environments. The objectives are:

(1) Maintain natural slope of river (river should not be altered by straightening or dredging).
(2) Maintain natural width.
(3) Maintain natural width/depth ratio.
(4) Maintain and restore connection of river to its floodplain (accommodating natural meandering).
(5) Provide setbacks to allow natural meandering.
(6) Maintain channel features such as mudflats, shallows, sandbars and a naturally uneven bottom.

Restoring the natural course of the river and avoiding straightening and dredging is thus a major component of the "living river" objectives. This emphasis on promoting geomorphic stability is evident not only in the limited amount of channel modification provided for in the Project design, but also in the construction of a dry bypass channel, as opposed to the originally proposed wet bypass channel (see below). The geomorphic stability of the river is also protected by maintaining the natural width and width-depth ratio of the river, by restoring the connections between the river and the floodplain, by allowing natural meandering, and by maintaining other natural channel features such as mudflats, shallow sandbars, and a naturally uneven bottom. This aspect of the "living river" strategy illustrates the possibility of returning rivers to their natural meandering course, in lieu of artificial river straightening.

To carry out the "living river" objectives, the Project relies mainly on nonstructural approaches, although it integrates a few necessary structural elements. The nonstructural elements of the Project include the removal of existing levees and dikes, and the restoration of wetlands (i.e., marsh plain) and the floodplain. The structural elements include the reconstruction of bridges and the creation of a dry-bypass channel and a few levees.

While the concept of increasing the land area of a river and its floodplain is not unique to Napa, the Project's approach of setting back and removing levees and dikes is receiving national attention and awards (Graham Wadsworth, 2003, personal communication, 18 August). Levees along the southern stretch of the river known as Horseshoe Bend (Figure 3) were removed. These levees previously prevented tidal cycles from inundating the wetlands and their removal and setback will allow the Napa River to return to its natural historic course. It will also restore and re-create 600 acres of wetland and marshland habitat (Napa County Flood Control and Water Conservation District, 2002).

In addition, wetland and floodplain terraces have been constructed to increase flood conveyance (thus increasing stormwater infiltration) and restore habitat. Wetland terraces are excavated at the mean tide level (Larry Dacus, 2003, personal communication, 18 August) and submerge twice daily during high tides, thereby re-creating wetland habitat (US Army Corps of Engineers and the Napa County Flood Control and Water Conservation District, 1997). The floodplain terraces are slightly elevated from the wetland terraces, and are excavated at the two-year flood level (Larry Dacus, 2003, personal communication, 18 August). They will be inundated every few years and can be utilized for recreation and bird watching during dry periods (US Army Corps of Engineers and the Napa County Flood Control and Water Conservation District, 1997).

Source: Napa County Flood Control and Water Conservation District (2003)

Figure 3.
In 2002 the wetlands are reborn with the removal of levees

The dry bypass channel was constructed to serve as a route for floodwaters bypassing the oxbow, which inevitably floods with heavy rainfall[2]. The dry bypass allows floodwaters to pass through downtown without decreasing the already low summer flows in the oxbow. The raised bed of the dry bypass channel will carry floodwaters only when the river reaches flood levels. It thus mitigates flooding without decreasing the low summer water levels in the oxbow, and avoids the adverse impacts to water quality and riparian habitat of a wet bypass (i.e. straightening), thereby protecting fish and wildlife. This dry bypass channel method was selected as an alternative to the US Army Corps of Engineers' proposal to excavate and straighten a portion of the river at the oxbow to provide a wet bypass flood channel. Local decision makers and residents deemed this proposal unacceptable because of the environmental consequences of straightening even such a small length of the river.

Funding for the Project

In response to more than a century of devastating flood events and millions of dollars in damage throughout Napa County, and as a result of the strong community-wide support for the Napa River Flood Protection Project, voters approved a 1998 sales tax increase of a half-cent for 20 years to fund the Project. The sales tax increase is expected to raise $8-10 million per year, and will fund the 50 percent of the total Project costs that Napa County Flood Control and Water Conservation District is responsible for. The total capital cost of the Project is $155.5 million and the estimated cost for construction over a 20-year period is $238 million. Although the price tag for the project is high, it will save $20.9 million a year in avoided property damage.

In addition to revenues from the tax increase, other sources have granted funds for the Project. The Governor's Office of Emergency Services awarded $7 million in FEMA Hazard Mitigation Grant Program funds to the City of Napa to acquire land and seven houses along the Napa Creek (Napa County Flood Control and Water Conservation District, 2002). The Napa County Flood Control and Water Conservation District has been allocated approximately $35 million from the State Revolving Loan Fund and $15 million from the State Subvention Fund to cover the local costs of the Project (Napa County Flood Control and Water Conservation District, 2002). The CalFed Bay-Delta Program and Coastal Conservancy has also provided funding for the purpose of removing levees and acquiring land (Napa County Flood Control and Water Conservation District, 2002).

Because of its high cost, especially for land acquisition in the floodplain (Larry Dacus, 2003, personal communication, 18 August; John Lander, 2003, personal communication, 1 August), the Napa River/Napa Creek Flood Protection Project planning model may not be applicable to communities who may not be able or willing to approve the similar tax increases or the use of funding for land acquisition. Furthermore, since the Napa Project has not yet been completed in its entirety, it is difficult to determine its overall effectiveness and environmental outcomes.

Conclusions

Given the serious drawbacks of traditional structural adjustments, nonstructural environmentally sustainable approaches (e.g. floodplain management, open space conservation, and river restoration) are on the forefront of contemporary flood mitigation techniques. After years of attempting to dominate nature and control flooding, increasing attention is thus devoted to returning rivers to their natural state and to restoring the natural functions of floodplains.

The Napa flood project is becoming a river restoration model for other cities and counties, such as the City of St Helena and Santa Clara County, California (Dickson, 2003; John, Lander 2003, personal communication, 1 August; Graham Wadsworth, 2003, personal communication, 18 August) because of its innovative sustainable flood mitigation, the strengths of its approach to community involvement, and its successful funding process.

The following key lessons learned from the Napa Project study are applicable to other communities. First, the case study of the Napa River/Napa Creek Flood Protection Project illustrates how sustainable flood management can be achieved by returning previously straightened rivers to their natural state. Systems of levees can be undone to mitigate flooding while at the same time restoring fish and wildlife habitat and increasing the capacity of a region to infiltrate stormwater.

Second, the Napa Project shows that a set of scientific, or ecological, criteria for flood management efforts, in this case the "living river" strategy, can be effectively used to guide flood mitigation planning. The ecological criteria utilized in Napa's Project were crucial to addressing the public's growing concern about the environmental impacts of traditional flood control measures. Such criteria enabled the public to participate and ultimately approve a flood plan that addressed the environmental concerns that had been neglected in past flood project proposals.

Third, the study of Napa's Project shows that such an innovative approach to flood planning can gain support from a broad and diverse community coalition. The Napa flood project owes its success to the impressive community involvement in the planning process. From its disapproval of numerous past flood projects drafted by the US Army Corps of Engineers, to its leading role in the design, approval, and implementation of the Napa River/Napa Creek Flood Protection Project, the community was the driving force in creating this model flood plan.

Finally, and perhaps most surprisingly, this Project shows that the US Army Corps of Engineers can successfully participate in nonstructurally-driven projects despite their historical preference for, and experience with, structural flood control works. The community coalition process illustrates that communities need not remain passive while waiting for the US Army Corps of Engineers to design a flood plan. Napa's flood project represents a paradigm shift in which local residents became the driving force behind designing an environmentally sustainable and locally supported flood plan that would be carried out by the US Army Corps of Engineers. This essentially shifted flood management away from typical flood control approach of the US Army Corps of Engineers. The Napa Project thereby shows that a community can successfully change the Corps' approach to flood control.

These findings support various policy recommendations. First, the US Army Corps of Engineers does not maintain a database or records of the rivers they have straightened, although such a database would be necessary to systematically assess the impacts of river straightening. It would also allow flood planners to pinpoint the rivers and their communities that may benefit from returning straightened rivers to their natural course, and may ultimately guide future policy on regulating river straightening practices.

Second, local planners should discourage or limit the US Army Corps of Engineers' ability to straighten rivers as a means of flood control. The Environmental Impact Statements required under the National Environmental Policy Act of 1969 are not sufficient to avoid the artificial modifications that the US Army Corps of Engineers has imposed upon America's rivers. New federal or state policy, or the adoption of Best Management Practices at the local level, could specifically regulate the straightening or channelization of rivers to avoid further detrimental impacts of river modifications.

Notes

1. Historically, river straightening has also been used to improve navigation.
2. The dry bypass channel is the local term for a raised bed oxbow cutoff channel.

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