TECHNICAL SUPPORT OF PUBLIC DECISIONS TO RESTORE FLOODPLAIN ECOSYSTEMS: A STATUS REPORT ON THE ILLINOIS RIVER PROJECT, USA

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Abstract

The history and consequences of river alterations are similar in most of the industrialised nations, where rivers have been increasingly regulated and isolated from their floodplains to increase commercial activity, but where the flows of natural services from these river/floodplain systems have declined as a result. Now there is widespread public support in developed river basins to recover lost or diminished natural functions. In developing basins, loss of natural services may not be an inevitable consequence of commercial development, if citizens, government officials, planners, and engineers learn from previous experience in developed basins. Where long-term data have been collected, as in the upper Mississippi river system, a comparative historical approach is especially useful in identifying impacts of alterations, but such insights need to be incorporated in models to predict effects of alternative development or recovery plans. On the Illinois river, a major tributary of the upper Mississippi river, many recovery projects are being undertaken by a variety of partnerships among private landowners, non-governmental conservation and environmental organisations, and state and federal government agencies. In an effort to support these projects, inter-related hydrological, ecological, and economic models are being developed to predict what will happen to total social benefits (from both commercial and natural sources) if selected portions of the floodplain and of the annual flood cycle are restored. Similar models could be used to evaluate effects of development alternatives in other river basins. This work is in progress, but initial results indicate that the flood regime must be naturalised for full benefits to be achieved on restored floodplains. A significant problem is that low water levels that naturally occurred for several weeks in the summer season have been artificially raised (and de-stabilised) to benefit river shipping. A stable period of low flows during the summer allows floodplain soils to dry out. This seasonal drying is particularly critical to floodplain vegetation which, in turn, is critical for support of animal life, including species highly valued by people. One management solution is to maintain existing dikes or levees, or to construct new ones, so that water levels behind the levees can be artificially maintained in a pattern that is more "natural" than in the regulated river of today. Another approach is to modify the operation of

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the existing navigation dams to create a more natural water regime along the entire river, while also maintaining water depths required for navigation. The most cost-effective approach may be a hybrid of the two: managed flooding of selected parts of the floodplain as well as new operating criteria for existing dams. The cost (in terms of capital and operating costs, and impacts on commercial activity) and quality of the restoration (in terms of "naturalness," biodiversity, recovery of fisheries, and outdoor recreational opportunities) are key factors in public decisions regarding floodplain restoration. In retrospect, it would have been less expensive and more beneficial to have preserved more of the floodplain and to have included a more natural range of water level variation in the design criteria for river development projects-lessons that might be applied to current projects elsewhere.

1. Introduction

The Upper Mississippi River System (UMRS; Figure 1) represents an intermediate condition between the highly developed and regulated large rivers of Europe and the western United States (US), and largely unregulated rivers (*e.g.*, the Paraguay in Brazil and Argentina). This intermediate level of river regulation results from the rather late start in river development in the Midwestern region of the US (compared to Europe), from lack of suitable terrain for high storage dams, and from the rise of a conservation movement before the rivers were so greatly altered (Galloway 2000,

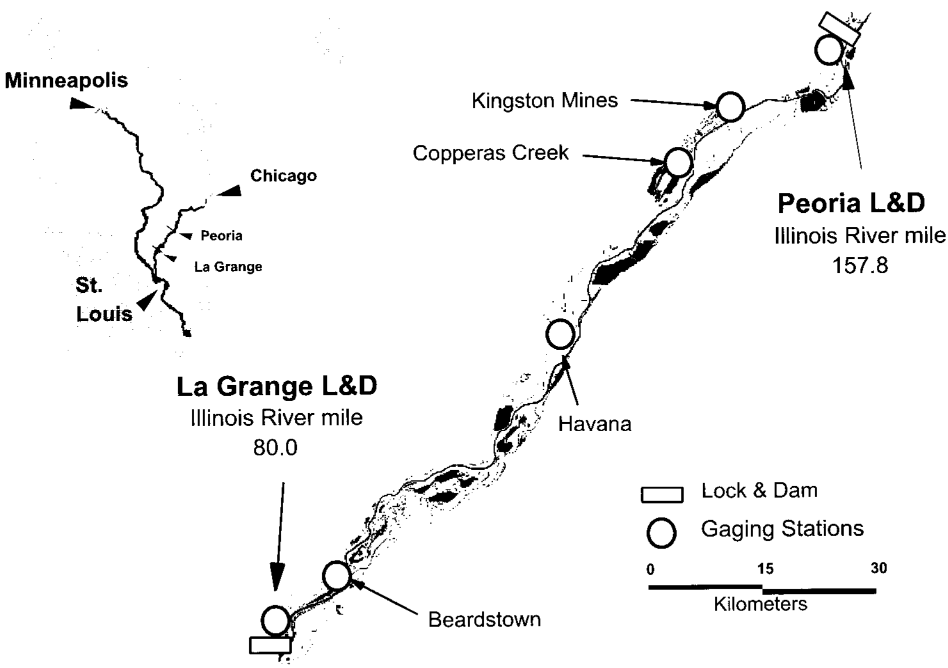

Fig. 1. The upper Mississippi river system is located in the upper Midwest of the USA. The 124 km study reach of the Illinois river is bounded upstream by the Peoria Lock and Dam (L&D) and downstream by the La Grange L&D.

Scarpino 1985). Europe had been modifying its rivers for at least 2000 years before 1818 (*cf* Havinga & Smits 2000), for example, when Illinois finally had enough residents to become a state.

This paper describes the UMRS and its comparatively brief history of commercial development and ecological decline. This history documents long term lag effects and threshold responses that led to persistent, sometimes rapid, degradation and loss of natural benefits. Effects that should now be anticipated and avoided in river development projects elsewhere (Sparks 1992). The paper describes the recent rise of public support and public involvement in river recovery, particularly along the Illinois river, a major tributary within the UMRS. Greater involvement of the public, including local stakeholders who are most directly affected by river development, appears to be a growing, world-wide phenomenon. On-going modelling efforts are described that provide a more scientific basis for choosing among alternative approaches to recovery. The same modelling techniques could be used elsewhere to predict the effects of river development.

Preliminary results indicate the importance of restoring a more natural water level regime, particularly the low flow portion of the annual flood cycle. The discussion uses naturalisation to describe the goal. Naturalisation is: the shifting of some components of an altered ecosystem (*e.g.*, floodplain vegetation) closer to a natural condition, while maintaining or enhancing existing social and economic uses of the ecosystem (Rhoads & Herricks 1996). In river basins that are being developed, a better goal might be the preservation of the ecosystem characteristics and processes that maintain desirable natural services, products, and amenities while instituting compatible commercial development. An ecosystem approach to both preservation and naturalisation involves maintaining or re-creating the water and sediment regimes that support the plants and animals, rather than attempting to maintain the biota by direct human intervention, as in fish hatcheries or botanical parks (Sparks 1995). The motivating hypothesis for our efforts in the UMRS is that the total flow of social benefits (broadly defined to include both natural and commercial services) from regulated floodplain-river ecosystems can be increased by selective re-connection of rivers to their floodplains and re-creation of more natural flooding regimes. The comparable hypothesis for developing basins is that the greatest total flow of benefits will occur from commercial development that retains critical natural processes. Essential to the evaluation of both hypotheses is identification of the critical processes and critical range of natural variation that need to be maintained.

2. Site description and history

The UMRS is defined in the Water Resources Development Act of 1986 as the navigable portions of both the Illinois river and the main stem of the upper Mississippi river (2,080 km), from Minneapolis-St. Paul in Minnesota downstream past St. Louis, Missouri to the mouth of the Ohio river. The same legislation recognises both the natural and commercial value of the UMRS by designating it as both a "nationally significant ecosystem" and "nationally significant waterway" (for commercial navigation). Short navigable portions of other tributaries are also included. The Illinois river, the primary focus of this paper, flows 523 km south-east across the state of Illinois before joining the Mississippi near St. Louis (Figure 1).

The early developments affecting the Illinois river occurred in the 19th and early 20th centuries. As part of the process of converting the prairies of the American Midwest into cropland, upland wetlands were drained and streams were channelled to improve drainage in the 1880s and 1890s. On the main rivers of the UMRS most flood protection levees were built between 1909 and 1922 (Mulvihill & Cornish 1929, Thompson 1989). A few of the agricultural levees subsequently failed during floods, the levee districts that owned them went bankrupt, and the lands were purchased for fish and wildlife refuges during the Great Depression of the 1930s (Bellrose *et al.* 1983). A conservation organisation, the Izaak Walton League, was largely responsible for building public support and persuading the US Congress to preserve natural floodplains and backwaters along the upper Mississippi. As a result, a national fish and wildlife refuge system was started in 1924 with 112,000 ha arranged in a corridor along the river (Scarpino 1985). Today, another 400,000 ha of largely unleveed floodplain in the upper Mississippi is owned by individuals, private duck hunting clubs, state natural resource agencies, conservation organisations, and local units of government, as well as by the federal government.

The Illinois river became the waste receptacle for the rapidly-growing population in Chicago in the latter half of the 19th century (Sparks 1984). In 1848, the headwaters of the Illinois were connected to Lake Michigan at Chicago by a man-made navigation canal (the Illinois and Michigan Canal, I&M Canal) that also carried wastes from the city. The canal cut through the 4 m high natural divide that separated the Mississippi drainage basin from the Great Lakes-St. Lawrence river basin. However, the I&M Canal had insufficient conveyance capacity during rain storms, so the Chicago river still carried wastes into the lake, polluting the city's water supply. Therefore, in 1900 the flow of the Chicago river was reversed and directed into the newly-completed, much larger Chicago Sanitary and Ship Canal (CSS Canal). Today an average of 91 m^3s^{-1} of lake water and effluent is released into the Illinois river via the CSS Canal.

The predominantly organic pollution (human sewage, animal wastes from the Chicago stockyards, offal from the meat packing plants) delivered by the CSS Canal initially damaged just the upstream portion of the Illinois river, creating an anoxic zone devoid of fishes and other aquatic life. However, fish yields actually increased downstream of the anoxic zone. In fact, the peak yield in the commercial fishery occurred in 1908, eight years after the opening of the CSS Canal (Sparks 1984). In 1908 2,000 commercial fishermen were employed along a 300 km reach of the Illinois river and their catch constituted 10 percent of the total US harvest of freshwater fish. The annual yield was about 10 million kg, or approximately 159 kg ha^{-1} (Lubinski *et al.* 1981).

The boost in downstream productivity was attributable to two causes; although the causes persist, the productivity boost unfortunately proved to be temporary. The first cause was the permanent rise in the downstream water levels (due to diversion of lake water and waste water), which increased the amount of permanent aquatic habitat for fish (but also drowned bottomland forests). Second, the nutrients in the wastes were mineralised in the upstream reaches and carried downstream where they fertilised the expanded aquatic habitat and increased production (Sparks 1984). After 1910, however, the increasing pollution load caused the anoxic and hypoxic zones to extend downriver, destroying the bottom fauna that served as food for many fishes and diving ducks (Sparks 1984). In the 1920s, the earlier gains in aquatic habitat resulting from the rise in water level were offset by leveeing and draining of half (81,000 ha) of the floodplain for agriculture along the Illinois river (Mulvihill & Cornish 1929, Thompson 1989).

By the 1950s the annual yield had dropped to 34 kg ha^{-1}; in the 1970s the yield reached a low of 3 kg ha^{-1}, totalling only 0.32 percent of the total US freshwater harvest (Sparks 1984). Sparks (1984) attributed declines in yield to declines in productivity, rather than to declines in prices (which remained relatively constant, or even increased, for preferred species) or over-harvest (commercial harvest has been low to non-existent on the Illinois river for decades, giving the fish populations more than enough time to recover). If regional demand for freshwater fish had fallen off, there should be comparable declines in the upper Mississippi. Instead, the commercial yield has been relatively stable on the upper Mississippi (Sparks 1984). Nutrient depletion is not the problem because nutrient concentrations remain high in the Illinois river and its backwaters. In the last 20 years, the annual fish yield from the Illinois river has recovered slightly, to about 9 kg ha^{-1}, primarily in response to improvements in water quality starting with the federal Clean Water Acts in 1972. However the most dramatic gains in water quality (improvement of dissolved oxygen levels, reduction of acute toxicity) have already been made, and water quality alone will not revive the fisheries in the Illinois river. The commercial fish yield on the upper Mississippi remained relatively stable during the decline on the Illinois suggesting that the better quality of spawning, nursery, and over-wintering habitat for fishes and better conditions for invertebrates the fishes feed upon played major roles in maintaining fish populations there (Sparks 1984).

The decline in quality of fish and wildlife habitat in the Illinois river has been blamed primarily on intensification of agriculture in upland basins and the associated increase in soil erosion and sediment delivery to the main river, although other factors (*e.g.*, fluctuating water levels) also contribute (Bellrose *et al.* 1979, 1983, Sparks *et al.* 1990). The navigation dams, in contrast to high dams for water storage, generally do not impede fish migrations that occur during the flood season, because the gates are out of the water and the river is essentially free-flowing. The gates are lowered during the low flow season to maintain water depths for navigation. The sediment certainly has filled in formerly deep backwaters and floodplain lakes and suspended sediment has reduced light penetration, thereby restricting the growth of aquatic plants, which provide substrate for invertebrates and shelter for young fishes. Sparks *et al.* (1990) point out that habitat deterioration was not gradual, but sudden, occurring between 1958 and 1961, and was associated with the loss of submersed aquatic plants and certain groups of benthic macroinvertebrates (fingernail clams, burrowing mayflies, and snails). The lakes and backwaters changed from vegetated, clear waters to turbid, plantless deserts. The plants evidently had served as biotic mediators, anchoring the sediments and shorelines with their roots, damping wind-generated waves (which resuspend bottom sediments) with their leaves and stems, and slowing entry of sediment-laden water from the main channels and tributaries into the backwaters. The pattern of decline suggests that a threshold was crossed: once aquatic plants began to weaken or die, the wind fetch increased, resulting in larger waves that uprooted more plants and increased turbidity further by resuspending bottom sediments and eroding shorelines. This positive feedback caused rapid degradation of the remaining plant beds. The loss of the plants may also be associated with an increase in toxic ammonia in the pore water of sediments and the resulting loss of burrowing macroinvertebrates (Sparks *et al.* 1993). Aquatic macrophytes oxygenate sediments around their roots and are capable of taking up nitrogen as a nutrient either in the reduced form that is very toxic to invertebrates and fish (ammonia) or in the oxidised, non-toxic form (nitrate) that exists in the root zone. Without the aquatic plants, the organic and inorganic nitrogen delivered from agricultural lands and urban sources may be deposited in the anaerobic sediments and converted by microbial processes into toxic ammonia.

The seeds of degradation may well have been sown by a combination of factors, rather than the increased sediment loads alone. The permanent rise in water levels on the Illinois river in 1900, and again in the 1930s when modern navigation dams were installed on both the Illinois and upper Mississippi rivers, killed portions of the floodplain forests and removed an effective windbreak that was especially important in the late winter and early spring floods that were often accompanied by storms and high winds. The permanent impoundments and expanded floodplain lakes created by the dams also served as efficient sediment traps. The floodplain levees also forced the sediment-laden waters into the half of the floodplain that remained unleveed, possibly accelerating the sediment deposition. Finally, unnaturally frequent and rapid fluctuations in water levels during the summer growing season inhibit both submersed and moist soil vegetation (Bellrose *et al.* 1979). The results of hydraulic modelling reported in this paper indicate that operation of the navigation dams contribute to these excessive fluctuations.

It is ironic that the severe pollution and resulting anoxic conditions in the past were beneficial to some degree because they created a barrier that protected the Mississippi and the Great Lakes ecosystems from each other's introduced aquatic pests. Since the 1972 Clean Water Act, US$4 billion have been spent on improved municipal waste treatment in the Chicago area, water quality has improved, and aquatic organisms can survive in the Chicago canals (Stoeckel *et al.*1996). Within the last five years, the European Zebra mussel (*Dreissena polymorpha*) has spread from the Great Lakes into the Mississippi drainage through the Chicago connection and at least six other non-native pests are poised to enter. Conversely, the Asian Grass carp (*Ctenopharyngodon idella*) and an African zooplankter (*Daphnia lumholtzi*) are advancing upstream in the Illinois river and could soon enter Lake Michigan (Stoeckel *et al.* 1996). The zebra mussel can plug water intakes and has been associated with declines in populations of native mussels in the upper Mississippi (Miller, A., personal communication). The Grass carp could compete with several native species of waterfowl, because the carp and the ducks prefer to consume the same species of aquatic plants. The African zooplankter is not palatable to young fish because it has protective spines, and it may compete for food with more palatable native zooplankters.

In summary, the biological productivity and biodiversity of the UMRS diminished as commercial use of the river and its floodplain increased. This is conceptually represented in figure 2. The declines were especially acute and well documented in and along the Illinois river. Sparks *et al.* (1990) note several reasons why the dramatic changes in the Illinois river were not predicted and averted. First, when the diversions and land alterations were carried out, there was little thought given to downstream effects. The paramount concerns were protection of drinking water and

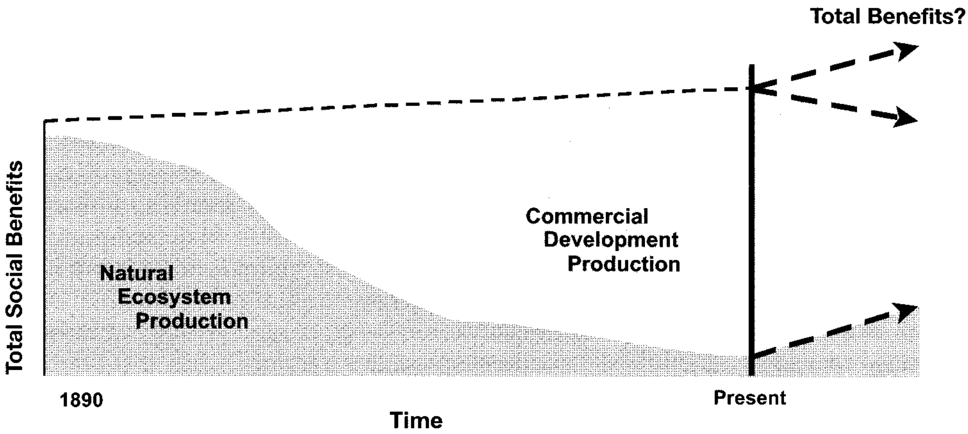

Fig. 2. The flow of social benefits from the Illinois river has shifted from predominantly natural to predominantly commercial during more than a century of development. The current policy focus is on whether natural service flows can be restored at little, or no, net cost to society.

putting land into agricultural production. The state of ecological knowledge was not sufficient to identify the variety of causative factors that acted in a complex, decompensatory way, often after time lags of decades. A major stressor, sediment loading, increased gradually until an effect threshold was reached, triggering an abrupt and persistent change in the state of the backwater and lake habitats that were critical spawning, feeding, and wintering areas for fishes. Prior to this change, the floodplain-river ecosystem produced fish in abundance and seemed to absorb the sediment without great harm, just as it had earlier absorbed the organic wastes from Chicago. The existing water quality monitoring network did not detect changes in the critical backwater habitats because all the monitoring sites were in the main channel. Moreover, only the water column was monitored. Biological monitoring used macroinvertebrates colonising artificial substrates suspended in the water column, so development of toxic ammonia concentrations in the sediments initially went undetected. One of the gravest continuing threats to the UMRS is an increasing rate of introduction of invasive species and their parasites and diseases from outside the system (via the Great Lakes and other distant points of introduction). This threat is related to expansion of world trade and, ironically, to the removal of former pollution barriers. Finally, the commercial fishermen and other river users affected by drainage of the floodplain and the increased sediment and pollution loading simply did not have the sustained political influence needed to retain public access to backwaters and to prevent conversion of the floodplain to cropland (Schneider 1996). The latter situation has changed recently.

3. Rise of public interest and public participation in recovery

There is strong public and government interest in a greater recovery of the natural productivity and services of the UMRS. Since 1988, Congress has provided

US$176 million for monitoring of biological resources and for habitat rehabilitation and enhancement in the UMRS, and the five states in the UMRS have contributed US$10.5 million (USACE 1997). The Lt. Governor of Illinois chairs the Illinois River Co-ordinating Council, which comprises leaders from government, industry, agriculture, universities, and non-governmental organisations who are charged with implementation of 33 recommendations for recovery of the Illinois river. The recommendations were developed by 150 citizens representing a diversity of interests from throughout the river basin, who worked with a professional facilitator and technical experts in hydrology, ecology, and economic development. The facilitator helped the planning group of citizens to develop operating rules for the discussions and a consensus-based approach to decision-making. In the opening workshops, participants described personal associations with the river and worked together on a shared vision for the future of the river.

The most substantial achievement to date of the Co-ordinating Council has been the commitment of nearly US$500 million in federal and state funds over the next 15 years for riparian restoration and other practices in selected tributary watersheds, practices that will reduce excessive yields of sediment, water, nutrients, and contaminants from agricultural land (the dominant land use in the Illinois river basin). Participation in the programme is entirely voluntary and the response of private landowners has been gratifying, with the number of enrolees exceeding the funds initially available during the first two years of the programme.

Citizens have other opportunities to confront issues and prepare recommendations in both state-wide programmes and programmes within the Illinois river basin. Illinois has a Conservation Congress that is modelled after a representative legislative process, with citizens from all over the state convening every two years to address natural resource issues, build public consensus, and advocate specific policies and procedures to be implemented by state agencies and the state legislature. Ecosystem partnerships are coalitions of local and regional interest groups who seek to merge natural resource stewardship (usually within individual watersheds) with compatible economic and recreational development. Both of these programmes are managed by the Illinois Department of Natural Resources. Watershed management plans are being developed by residents of watersheds throughout Illinois with funding provided by the federal and state environmental protection agencies and natural resource agencies, and technical advice furnished by the agencies, universities, consultants, and non-governmental conservation organisations. In the case of the Mackinaw river, a tributary of the Illinois river, a non-governmental conservation organisation, The Nature Conservancy (TNC), managed the watershed planning grant and facilitated the work of the watershed planning committee. TNC is also developing a conservation plan for the Illinois river itself, focusing on recovery of biodiversity. TNC has purchased a 440 ha agricultural levee district where it plans to restore the aquatic and terrestrial communities that characterised the original Illinois river floodplain. The Illinois river and most of its tributaries now have "friends" groups (*e.g.*, Friends of the Illinois River, Friends of the Chicago River), who organise clean-ups by volunteers and build consensus for political action. Some of these groups are well funded and politically effective; some have full time or part time technical staff and publish newsletters.

The results of recovery efforts are being assessed not only by federal and state environmental agencies in the course of their work, but also by a network of citizen volunteers who monitor habitat conditions and biological indicators in streams and rivers throughout the state as part of the Illinois River Watch Programme. A separate programme (Illinois Rivers Project) involves secondary school teachers and students who use local streams as an educational resource for science, biology, and social studies classes. The River Web Project, funded by the US National Science Foundation, involves the National Centre for Supercomputing Applications at the University of Illinois, and three museums in Illinois, Missouri and Minnesota that are co-operating in the development of computer-based exhibits and educational materials that focus on the science and social history of the river system.

Both in education and in public policy decisions, it is important to understand that many of the attributes and services of rivers and floodplains that humans value and wish to restore depend upon the master variable: the water regime (Figure 3). Floodplain services include the conveyance of floods and the reduction of flood peaks. Both stage and frequency of major floods have increased in both the upper Mississippi and the Illinois river in the last 20 years, in comparison with the previous 60 years, and flood damage has consequently increased (Leopold 1994, Singh & Ramamurthy 1990). The US Army Corps of Engineers (the federal agency in the US responsible for flood control and for navigation in the UMRS), is addressing the causes of the increases in magnitude and frequency of the big floods.

In contrast to the more typical modelling of the physical capacity of a river-floodplain system to accommodate major floods, the work reported here examines

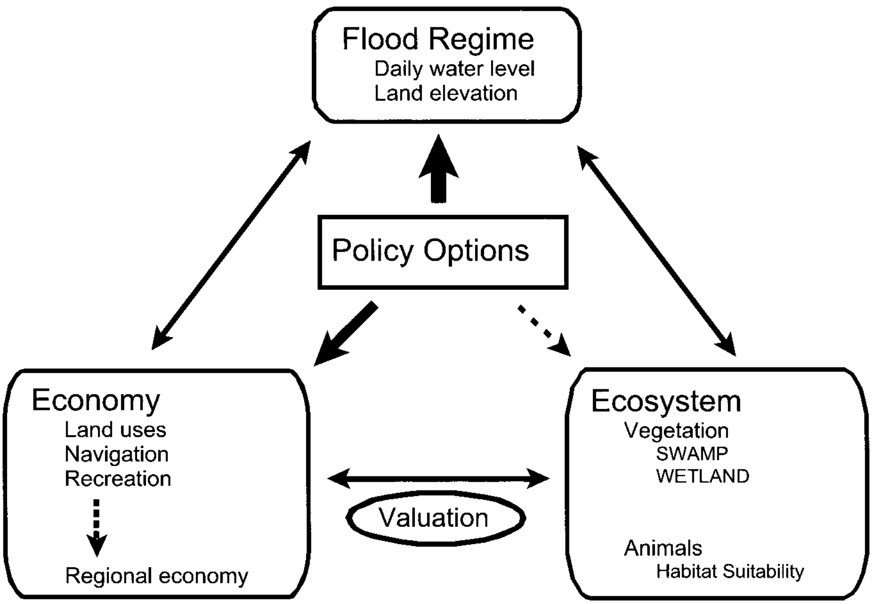

Fig. 3. Simulation of the hydrology, ecology and economy related to a section of the Illinois river involves developing a set of inter-related models. The thickness of the arrows from policy options to the other boxes indicate the expected relative cost-effectiveness of recovery options aimed at changing the river's flood regime versus efforts to protect selected plant and animal populations by isolating them from the river.

a neglected part of the seasonal flood cycle, the low water levels that occur during the summer growing season. Figure 4 illustrates the impact that development has had on the annual pattern of water levels in the Illinois river. Small fluctuations of the water level during the critical summer growing period for floodplain plants appear to have a dramatic impact on the ecology of the riparian vegetation, of the floodplain lakes and of the main river channel.

4. Hydraulic modelling and effects of operations of navigation dams

We are using UNET (Barkau 1995), an one dimensional hydraulic model, of the study reach to examine effects of dam operations on summer water levels. The 129 km study reach is divided into segments and water is routed from one segment to the next (Figure 5). In each segment, water can be added from tributaries. Water flow and elevation are affected by the size and shape of the cross-section of the segment and by factors such as flow resistance during overbank flows, caused by vegetation growing on the floodplain. Flow resistance results in higher water levels within the segment. In the summer of 1997, an unusual repetitive weekly pattern in water levels was recorded at several river gages (Figure 6). We subsequently learned that maintenance work was being performed during this period on the gates at the upstream dam. Water was being released during the week to facilitate work on the downstream side of the gates. For the weekend, the water above the dam was allowed to rise again to the normal summer elevation, to better accommodate recreationists using the lake above the dam.

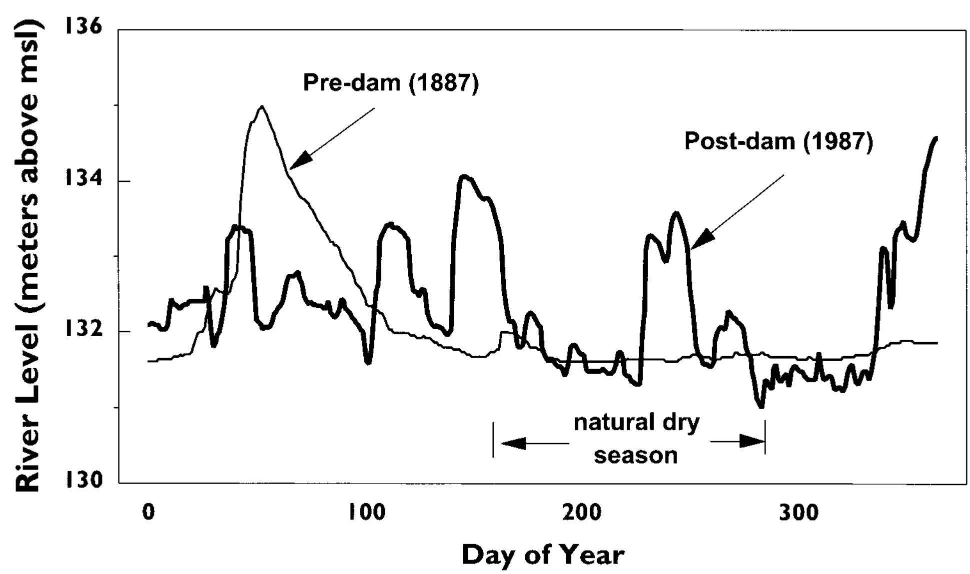

Fig. 4. Since the navigation dams have been in place on the Illinois River, the natural pattern of a spring flood pulse followed by a summer season of low flow has been replaced by an unpredictable, chaotic pattern year-round (msl: mean surface level).

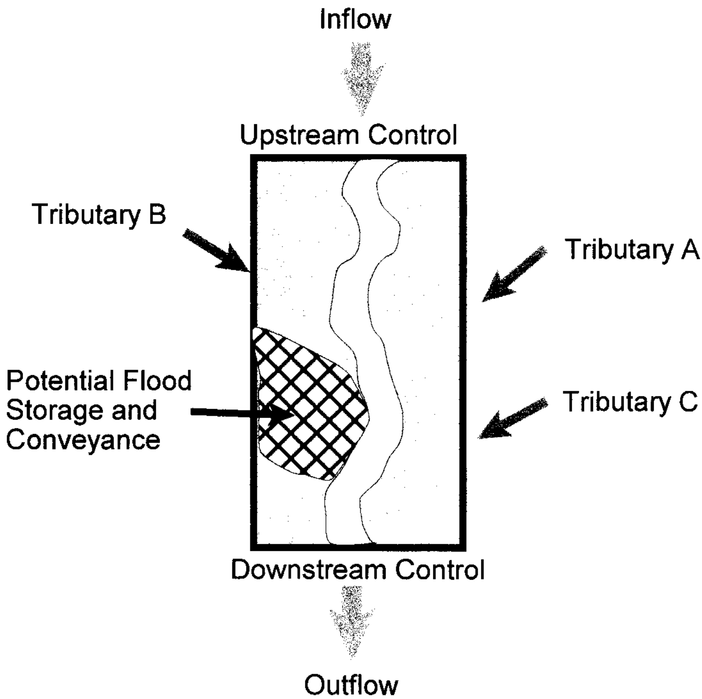

Fig. 5. Modelling the hydraulics of the river is key to simulating the behaviour of the river/floodplain system.

When we included these dam operations in our model, the model predicted the measured water level changes very accurately (Figure 6). Opening the gates caused relatively small changes upstream of the dam, because of the significant storage volume of the upstream channel, which broadens into a mainstem lake. Downstream, however, where the river is more constricted, the water releases caused maximum water fluctuations of 2.5 m immediately below the dam and fluctuations of nearly 2 m at Havana, 54 km below the dam (Figure 6). The Chautauqua National Wildlife Refuge is located at Havana, as are several state conservation areas, public hunting and fishing areas, and private duck clubs. The moist soil plants that supply food for migratory waterfowl are drowned by short term water fluctuations of this magnitude or even much lesser magnitudes, thereby decreasing waterfowl use, hunting opportunities, and income to local communities that service the hunters. The fluctuations gradually dampened out further downstream. Near the La Grange dam, 124 km below the upstream dam, the fluctuations were scarcely measurable (Figure 6).

Some of the harmful water level fluctuations in the Illinois river and its floodplain are probably attributable to unnaturally rapid drainage of stormwater from urban areas and from agricultural areas where artificial drainage systems have been installed beneath the soil surface and where streams have been channelled. The higher and faster flowing water erodes soil from the fields and from the upland channels, and carries it to the main river where it is deposited as sediment in flood-

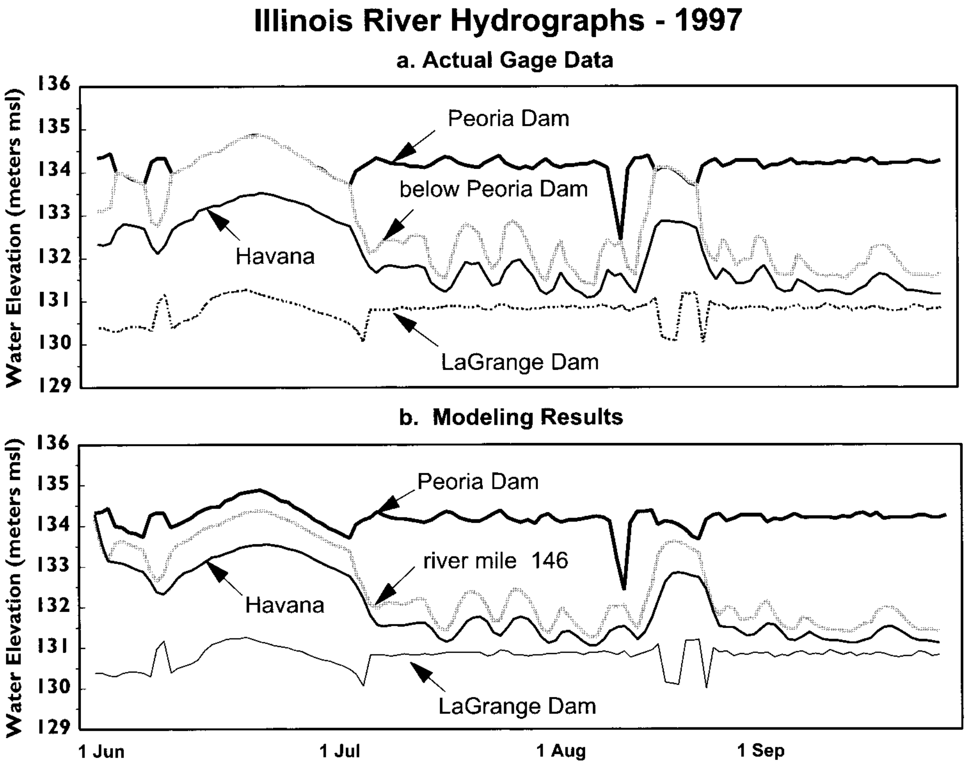

Fig. 6. a: Water releases associated with maintenance work on the Peoria Dam produced stage fluctuations ideal for calibrating our hydraulic models; b: Simulation results agreed closely with the measured water levels (msl: mean surface level).

plain lakes and backwater areas during overbank flows. This sedimentation is another dimension of river hydrology threatening the health of the river-floodplain system. The filling and resulting degradation of the floodplain lakes has been well documented (Bellrose *et al.* 1983).

Incorporating the upland processes impacting the main stem of the Illinois river is beyond the scope of the modelling project, to date. Future hydraulic model development is intended to assess sediment impacts by modelling the routing and deposition of various sediment loads assumed to be entering the boundary of the river-floodplain system. This effort will require the development of a two dimensional hydraulic model, at least for selected sites. The feasibility of modelling at this level of detail has been preliminarily tested using the TABS modelling system developed by the USACE (Thomas & McAnally 1991, Brigham Young University 1992).

5. Vegetation modelling and effects of unnatural water regimes

Since species of plants vary in their tolerance of flooding and of saturated soil, the flood regime determines what vegetation will occupy a floodplain site. Therefore, floodplain vegetation models require either an actual water level record or simulated record generated by a hydraulic model. Another critical piece of information is the elevation of the site: the lower the site and the higher the flood, the longer the site will be inundated. Eventually our models will include both a floodplain forest model and an herbaceous wetland model (Figure 7). We have chosen to run the floodplain forest model first, because the effects of altered water regimes on forests are not so obvious to decision-makers and local residents as the more immediate effect of unnatural floods on herbaceous duck food plants. An unnatural flood in the summer kills some moist soil plants in a matter of days and the losses are immediately noted by duck hunters and refuge managers. In the case of the forest, however, it may take decades before unnatural water levels change the composition of the forest through death and replacement of species. The forests also provide habitat for wildlife (hence, forest attributes are required input variables for the wildlife models we will eventually use) and woody debris that furnishes a solid substrate for many invertebrates that fish feed upon.

The floodplain forest model is an adaptation and extension of the SWAMP model originally developed by Phipps (1979) and Phipps & Applegate (1983). The model simulates the germination, growth and death of individual trees within a forest stand. The model accounts for individual growth factors, such as flood tolerance, and for competitive interactions among trees, such as growth reduction of small trees as they are shaded by other taller trees. The model has been calibrated using 130 years of river stage records, floodplain forest descriptions from early 19th

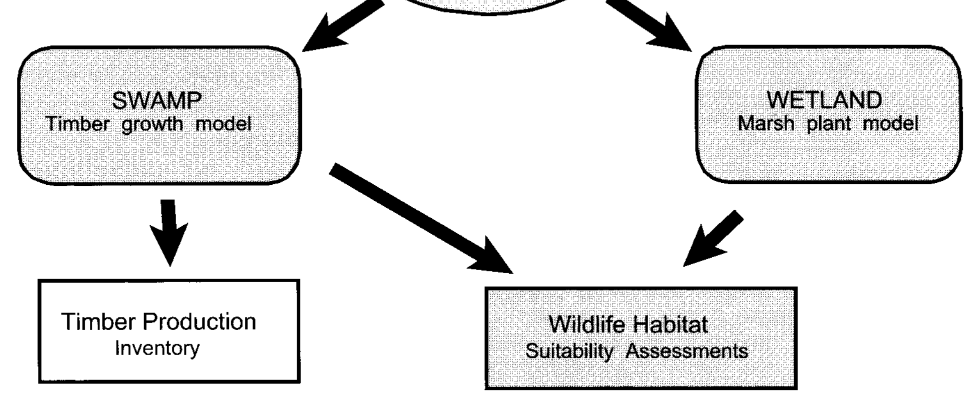

Fig. 7. Site elevation and the water level of the river determine the inundation pattern at the floodplain site. The inundation pattern in turn determines the type of vegetation (woody or herbaceous) and its rate of growth.

century surveyor notes, and information from present-day vegetation surveys. The model was initialised with a forest stand having the species composition that existed between 1817 and the 1830s, and then that stand was subjected to the historical pattern of changing water levels that has been recorded over the last 130 years. The model predicted correctly that the contemporary forest is dominated by flood-tolerant Willow (*Salix niger*). In contrast, Pin oak (*Quercus palustris*) was most abundant in the presettlement forest, with many other valuable species also present in substantial numbers, *i.e.*, relative abundance among tree species was much more even in 1817 than it is now (Figure 8).

The most important variable in the forest growth model is the period of inundation during the growing season. One refinement made to the original SWAMP model was to allow the inundation period to vary from year to year. In the original version of SWAMP the inundation period is a constant (an average computed for the period of record: 130 years in our case). We refer to this as the "static" form of the model. When we replaced the average inundation with the actual inundation recorded each year (a more realistic approach that we term the "dynamic" form of the model), the model still predicted a willow-dominated contemporary forest, but with more species present (Figure 9).

The importance of year-to-year variations in maintaining forest diversity is even more evident in recent model runs over spans of 500-1,000 years. We created an artificial 500 or 1,000 year water level record by randomly selecting years from the pre-1900 hydrographic record. If major floods are excluded, the forests become monocultures, dominated first by a single pioneer species that is eventually replaced by a single overstory species. A greater number of species are maintained if infrequent, great floods occur. These preliminary results support the "intermediate disturbance" hypothesis of Connell (1975, 1978): an intermediate level of

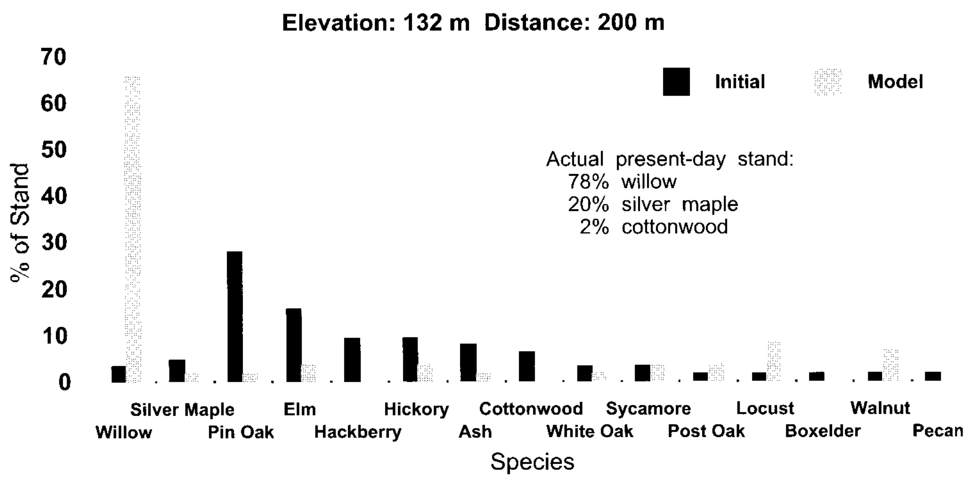

Fig. 8. In response to the actual pattern of river level fluctuations over the last century, the floodplain forest simulation model converted a pre-settlement forest composition into a less diverse forest typical of today.

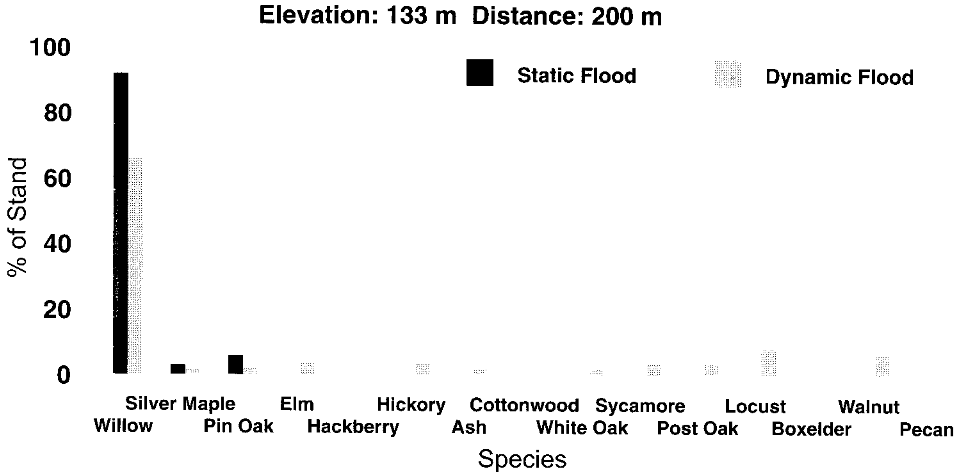

Fig. 9. A floodplain forest model that is sensitive to year-to-year differences in inundation produces stands with more species diversity (dynamic flood) than does a model using a single average inundation computed for an entire simulation period (static flood).

disturbance allows more species to co-exist, whereas only a few superior competitors will ultimately dominate a static environment and only pioneer species can survive in frequently-disturbed environments.

To further examine the effects of the modern water level regime on forests, we compared two additional simulations. One simulation used the actual water levels during the past 100 years. The other made 100 random draws from 25 years of late 19th century hydrographs to approximate a 100-year record of conditions that might have occurred in the absence of dams, levees, and releases of water from Lake Michigan. The more natural, simulated flood regime supports a more even distribution of species (Figure 10); *i.e.*, the forest is not dominated by willow, but includes substantial percentages of Silver maple (*Acer saccharinum*), Elm (*Ulmus americana*), Ash (*Fraxinus*), Boxelder (*Acer negundo*), Walnut (*Juglans nigra*) and Pecan (*Carya illinoensis).*

In the near future, we intend to extend our modelling to non-forest vegetation, particularly the moist soil plants that provide food for migratory waterfowl. In the case of herbaceous plants, the approach will be analogous to the physically-driven models used to simulate marsh succession in the Mississippi delta (Costanza *et al.* 1990, Sklar *et al.* 1985). The flooding tolerances of the moist soil plants are so well documented that manuals have been developed for waterfowl managers who grow moist soil plants in leveed compartments on the floodplain (Fredrickson & Taylor 1982). Water levels within the compartments are controlled with gates and pumps. One goal of our modelling is to determine whether the navigation dams could be operated to recreate the stable low water levels that characterised the summer growing season prior to 1900, thereby encouraging the growth of moist soil plants over much larger areas and perhaps at lower costs than can be achieved in the floodplain compartments (Sparks *et al.* 1998). The output from the hydraulic models and

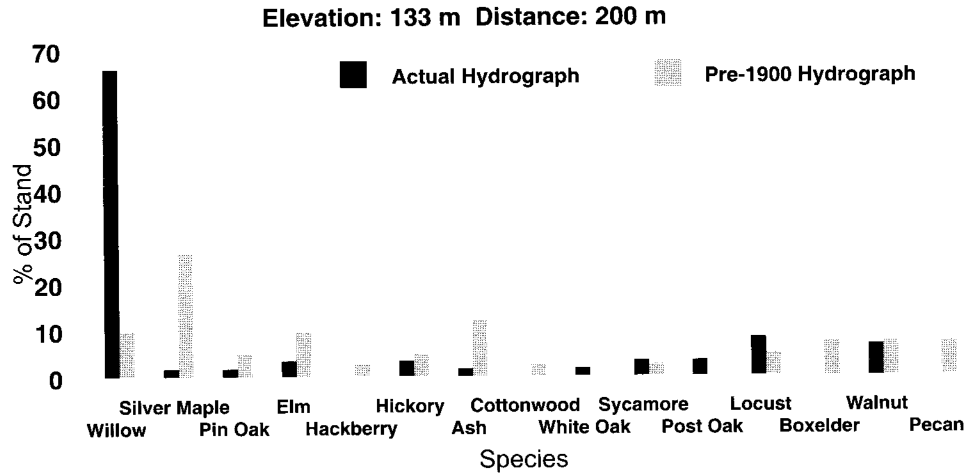

Fig. 10. Comparing the simulated response of a floodplain forest to a regulated (actual hydrograph) and to an unregulated (pre-1900 hydrograph) river indicates that regulation results in dominance by one species (Willow). Abundance among species is much more even with an unregulated river.

vegetation models will be used in existing habitat suitability models for selected fishes, birds, and mammals (Fig. 7). Although each of the intermediate steps in the modelling process provides useful information and insights (such as the importance of flood dynamics in maintaining forest diversity), our ultimate goal is to assess the net effects of alternative floodplain naturalisation strategies on both the economy and the ecosystem. The broader interdisciplinary framework shown in Figure 4 will enable comparison of alternatives in terms that are understandable and useful, both to the public and to public officials.

6. Economics of flood easements

The physical and biological modelling reported here has not progressed sufficiently to directly support assessment of the economic impacts of reconnecting floodplains to the Illinois river. However, members of the research team have been involved in a related study of the economics of flood easements; specifically, flood easements in sparsely settled agricultural levee districts in order to protect populous urban areas (Hirschi 1999). This research provides some useful insights into how land use is affected by government subsidies and how current land use would be affected by changes in flood risk (*e.g.*, if a levee was to be lowered or breached).

Hirschi (1999) used a constrained, non-linear optimisation model to examine profit maximising farming decisions as the level of flood risk varied from a 1 in 200 chance (or 0.5% probability) to a 1 in 2 chance (or 50% probability). The management alternatives available to the optimising model included a range of crops and production practices common to the agriculture of the region (including a more flood-tolerant crop of hay), the ability to delay planting as needed to accommodate spring floods, and current government agricultural support programmes. The government programmes examined were subsidised crop insurance, and annual government land rent payments paid to farmers who convert crop land to some perennial vegetation for at least 10 years. Such rent payments are available through either the Conservation Reserve Programme (CRP), for highly erodible land, or the Wetland Reserve Programme (WRP), for wetland areas.

Results from the model are summarised in Table 1. These results, for a risk-neutral farmer, suggest that when the annual risk of flooding increases to the level of 1 year in 25 (or a 4% probability), enrolling the land in crop insurance becomes necessary to maximise the expected profit. At lower flood risks, expected loss to flooding does not justify paying the crop insurance premium, even at the government subsidised rate (Hirschi 1999). As one would expect, the availability and the subsidised cost of insurance increases the level of flood risk the farmer is willing to face by choosing to produce a row crop rather than to put the land into CRP/WRP, in which case the returns would be assured.

Another interesting aspect of the optimisation is that the currently preferred crops (corn/maize and soybeans) remained preferred as the flood risk increased until the risk rose to the frequency of one year out of two (a 50% probability of flooding in any given year), at which point all of the land was converted to the CRP/WRP conservation programme. The results suggest that the cropping decision is an "all or nothing" choice. Either the land is used to raise conventional crop of corn or soybeans or, when the risk gets too high, it is put into the conservation programme. At least as modelled, no circumstance justified a risk management strategy of putting some land in CRP/WRP, while continuing to farm the rest; or of growing more flood tolerant crops (Hirschi 1999).

The expected net incomes shown in Table 1 can be interpreted as the level of compensation that the farmer would require to choose some cropping pattern or land use other than the one generating the returns. These results are for a decision-maker with a neutral attitude about risk, neither averse to nor preferring to take risks. Since farmers are by and large risk averse, Hirschi (1999) also examined the influence of risk aversion on these results. As one would expect, increasing the reluctance to assume risk caused the decision-maker to become more cautious and to convert more land to CRP/WRP at lower flood risk, and/or accept less compensation for the conversion.

The modelling work by Hirschi (1999) provides useful insights into the decision-making process of floodplain landowners. More lessons are being learned in the real world. A major new government programme similar to the CRP/WRP has been created to benefit the Illinois river. The Conservation Reserve Enhancement Programme (CREP), begun in 1998, is targeted specifically within the Illinois river watershed, providing US$459 million in federal and state funds over 15 years for conversion of highly erodible and flood-prone land from cropland to permanent vegetation. CREP targets riparian zones, with a goal of enrolling 206,500 ha, or 2.5% of the entire 8,341,000-ha drainage basin. Partly as a result of the currently low corn and soybean prices, voluntary requests for enrolment in the CREP programme in 1998 and 1999 have exceeded the funds available (Bruce, D., personal communication).

Table 1. Expected net income and optimal land use percentages (from Hirschi 1999).

Probability of Flooding (% Chance)	Crop Insurance Coverage (% Yield)	ExpectedZ Net Returns (US$)	Percentage of land area				
			Late April Corn	Early May Corn	Early May Beans	Late May Beans	CRP/ WRP
0.5	0	094.24	22.75	22.25	31.50	18.50	0
1	0	191.57	22.75	22.25	31.50	18.50	0
2	0	186.04	22.75	22.25	31.50	18.50	0
4	50	176.42	22.75	22.25	31.50	18.50	0
10	65	152.52	22.75	22.25	31.50	18.50	0
20	50	94.13	22.75	22.25	31.50	18.50	0
50	n.a.	67.34	0	0	0	0	100

CRP/WRP: Conservation Reserve Programme or Wetland Reserve Programme; n.a.: not applicable.

Anecdotal evidence indicates that a market may be developing for lands that are eligible for CREP, WRP, and CRP. Advertisements seeking property which includes land that is eligible for these vegetative conversion programmes have been placed in local newspapers by individuals and groups who apparently are interested in hunting, fishing, or other outdoor recreation associated with riparian areas. The full effect of the CREP programme on land use, land values and local taxes have yet to be modelled or assessed.

7. Discussion

There are several lessons that might be taken from the history of river development and river regulation in the UMRS and applied to less developed basins elsewhere. First, there should be an effort to account for the natural services provided by the existing system, so that loss or replacement of these services can be accounted for as well as the benefits provided by commercial development. Such an analysis includes social issues, because the benefits of the natural system may accrue to middle- and low-income local people (*e.g.*, artisanal fishers who supply local markets) who may not benefit from commercial development (*e.g.*, cheap long-distance water transportation to world markets) that favours an entirely different scale and type of economic activity. Draining and leveeing of the floodplain, particularly along the Illinois river, replaced fish, wildlife and timber production with production of dry land commodity crops. In the US, meat can be easily and cheaply substituted for fish, or fish once caught locally in the river can be replaced with fish shipped from aquaculture centres or from the sea. A well known fish market on the Illinois river in the city of Peoria shifted from locally-caught fish to salt water fish and channel catfish produced in aquaculture centres in the states of Arkansas and Mississippi. In some parts of the world, however, it may not be so easy for local people to find or pay for substitutes for fish protein. Along the Illinois river, it appears that local economies became less diverse and self-sufficient and more dependent on world commodity markets which are subject to sharp price fluctuations. To our knowledge, there is no information on whether fishers who formerly derived their income from the Illinois river found jobs in the new economy. In general, commodity agriculture and commodity storage and shipping (*e.g.*, river terminals) are highly mechanised and not labour-intensive. Although agricultural machinery, fuel, and fertiliser used in commodity agriculture are sold in the river towns, these items are produced elsewhere.

In the case of the UMRS, it would probably have been cheaper to preserve natural services than it is to recover them after development. For example, some drainage and levee districts in the floodplains of the Illinois river are being purchased from private landowners by conservation organisations and state and federal natural resource agencies at prices that reflect the current use for row crop agriculture. The intent is to restore floodplain wetlands and backwaters for native plants and animals. In addition to purchase costs, there will be expenses for reshaping the interior basins of the levee districts (which were levelled for agriculture, in many cases) and in providing a natural water level cycle that benefits native biota (with gates to the river, or water pumps). It would have been cheaper to have preserved more of the undeveloped floodplain in the 1920s, when the state of Illinois initially considered the backwaters that were connected to the river as public lands, or a commons, and before court decisions that favoured private ownership and development (Schneider 1996).

In the developed river basins of the world, a key question for the public and for policy-makers is whether the total flow of social benefits (both natural and commercial) from a regulated floodplain-river ecosystem can be increased by selective re-connection of rivers with their floodplains and re-establishment of more natural flooding regimes. The communities along the rivers are particularly concerned about the quality of the naturalised environment that is achieved and the impact it will have on the local economy and quality of life. Attractive natural environments could attract outdoor recreationists and offer an alternative to the agriculture-dependent economy that may be increasingly subject to boom-or-bust cycles governed by world market prices. As recently as the 1950s, many river towns along the Illinois river had more diverse economies that included greater shares of tourism and outdoor recreation.

Preliminary results of efforts to model the river/floodplain system indicate that mere re-connection of the river with its floodplain will not be sufficient to restore high quality native forests and wetlands that attract migratory waterfowl (and hunters and bird watchers!). The water regime of our regulated river is subject to unnatural fluctuations during the summer growing season that limit native plants on the hydraulically connected floodplains. It is encouraging that some of the fluctuations appear to be attributable to operation of the navigation dams, indicating that modification of dam operations alone might improve conditions for native vegetation over extensive portions of the floodplain not currently protected by levees. The US Corps of Engineers has already modified dam operations at several locations on an experimental basis, and early results indicate that the production of wetland vegetation can be increased without adversely affecting commercial navigation. Such operational modifications probably would be inexpensive, compared to costs of artificially reproducing needed flood regimes behind low levees with the aid of gates and pumps, which is another naturalisation approach being used at a number of sites within the UMRS as part of a state-federal Habitat Rehabilitation and Enhancement Programme.

The potential to naturalise the river/floodplain systemically cannot be fully realised just by restoration actions in the mainstem river and its floodplain. Rivers are products of their watersheds, so actions are also needed in tributaries and uplands. A rising tide of public interest in protecting and restoring rivers and floodplains has stimulated expansion of existing government conservation programmes in the American Midwest to encourage farmers to convert erodible and flood prone land that is near streams from crop production into permanent vegetation. The new generations of these programmes concentrate on riparian zones and on specific problem watersheds that deliver excessive amounts of sediment and water. The scope of these watershed restoration efforts represent a tremendous challenge to efforts to model their cumulative impacts on downstream channels and floodplains.

Predictive models that are used in assessing effects of river development and river naturalisation need to be verified by measurements recorded as projects are instituted, to improve the models and to provide a more scientific basis for both preservation and naturalisation. Some development and naturalisation projects should incorporate hypothesis-testing and experiments and the potential yield of information should be considered as one factor in the cost-benefit analysis: an Adaptive Environmental Assessment and Management (AEAM) approach (Holling 1978). AEAM has begun to be applied in the US and around the world, including the Columbia river, Chesapeake Bay, south Florida, and the upper Mississippi river, where shippers, conservationists, transportation and natural resource agencies from five states, the US Corps of Engineers, the US Fish and Wildlife Service, the US Geological Survey, and several technical experts from outside the region, are currently exploring ways of improving the navigation system while maintaining or restoring the river-floodplain ecosystem (Gunderson *et al.* 1995, Holling 1978, Adaptive Environmental Assessment Steering Committee 1997). AEAM includes use of existing data and simulation models to inform stakeholders and to support decisions regarding restoration and conservation of natural resources. AEAM represents a middle ground between the 1950s US model of comprehensive river basin planning by technical experts in development agencies, and the socio-political realities of the 1990s in the US, where power is devolving from the federal to state and local levels, partnerships are necessitated by budget constraints, and there is a public demand for environmental preservation and restoration. In the US greater attention is now paid to in-stream uses of water, including fish production, protection of endangered species, and recreational uses, and at least 465 dams have been removed since 1912 to recover native fish populations, alleviate dam safety concerns, or revitalise local communities (American Rivers *et al.* 1999). There is increasing awareness that the structure and function of natural and restored rivers vary across space and time; indeed, that variation (disturbance regime) is required to maintain many ecosystems (Poff *et al.* 1997). Planning and engineering to incorporate this variability requires change on the part of the development agencies, whose historic missions have generally involved reducing variability (in water supply, shoreline configurations, channel positions of rivers, etc.).

Finally, we end with a plea for scientific monitoring and evaluation of both river recovery and river development programmes, for the sake of improving both science and policy. Management cannot be adaptive without information about the current status and trends in the key physical driving variables (*e.g.*, the sediment and water regimes), biological interactions, and indicators of interest (*e.g.*, population status of key species). A management experiment is worthless without data to show whether the hypotheses were rejected or accepted. Failure is instructive, as long as sufficient information was gathered to understand why the failure occurred. Similarly, little is gained by success if the reasons for success are not known; it may be impossible to extend the results to another site, or even to repeat them at the same site. Worse, there may be little confidence that the success was triggered by the management practice, rather than by some natural change that was unaccounted for.

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