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# Analysis of naturalization alternatives for the recovery of moist-soil plants in the floodplain of the Illinois River

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## Abstract

The hydrologic regime of the Illinois River has been substantially altered by floodplain levees, navigation dams, and water diversion. Unnaturally frequent and untimely water level fluctuations, large and small, have decreased the productivity of many floodplain vegetation communities that provide important ecological services, including the moist-soil plant community. We simulated three scenarios, including two that were expected to benefit moist-soil plants: (1) existing conditions, with levees and navigation dams closed during the summer growing season; (2) levees opened to reconnect the river and its floodplain during the growing season; and (3) both the downstream navigation dam and the levees opened during the growing season. A 1-dimensional hydraulic model generated daily hydrographs of the river at three positions in the 135 km study reach: (1) near the downstream dam, (2) in the middle of the reach, and (3) near the upstream dam. These hydrographs then were used to run a model that predicts the growth of moist-soil plants at a range of floodplain elevations. As expected, the model predicted that plants would grow over a larger area with levees open during the growing season than under the existing conditions, but the outcomes showed a strong location dependency. Moist-soil plant production would increase in the upper and mid-reach locations, but there would be no change near the downstream dam despite opening the levees. Modelling revealed that the existing operation of the navigation dam permanently floods most of the floodplain zone where moist soil plants might grow for at least 15 km upstream of the dam. Trees currently grow all the way to the low water line and are likely to exclude moist soil plants from any restored portion of the floodplain. Sites for reconnecting the river with its floodplain should be carefully chosen to maximize the chances of recovering the important moist-soil plant community in this regulated river.

## Introduction

During the past 100 years, the hydrologic regime of the Illinois River has been substantially altered by locks and dams, floodplain levees, and water diversion (Sparks et al., 1998, 2000; Schneider, 2000; Koel & Sparks, 2002). The generally higher water levels and more frequent fluctuations (including fluctuations far smaller than flood stage) due to the hydrologic alterations profoundly affect many plants that thrive in the Illinois floodplain-river ecosystem, including moist-soil plants.

Moist-soil plants are typically annual grasses and forbs (though some species may live for several years under favorable conditions) that grow on mud flats exposed as seasonal floods recede. One member of this group, the decurrent false aster (*Boltonia decurrens*) is endemic to the Illinois River and is listed as an endangered species by the U.S. Fish & Wildlife Service. Productivity of moist-soil plants along the Illinois River has declined because of unnaturally frequent fluctuations that inundate these mud flats and drown the plants during the critical summer growing season. In common with other types of floodplain plant communities, including forests and submergent vegetation, the moist-soil plants perform several ecological functions. Their roots stabilize the sediments deposited along shorelines of the channels and floodplain lakes where wave action would otherwise resuspend the sediment and thereby increase the turbidity of the water. Even in death, at the end of the summer growing season, the stems and leaves of moist-soil plants contribute organic matter to detritus-based food webs. The seeds, rhizomes and tubers of these plants are an important food source for resident beaver (*Castor canadensis*) and muskrat (*Ondatra zibethicus*) and for waterfowl during their spring and fall migrations in the Mississippi Flyway, of which the Illinois River is an important part (Bellrose et al., 1979; Fredrickson & Taylor, 1982; Bellrose et al., 1983; Havera, 1999).

Currently, there are seven locks and dams on the Illinois River that create the Illinois Waterway (Demissie & Knapp, 2000). Two of these dams, on the lower 370 km of the Illinois River, are wicket dams. Wickets are lowered to the river bottom during periods of high flow; during periods of low flow the wickets are raised to maintain the required navigation depth of 2.74 m (Sparks et al., 1998).

There are also 36 levee and drainage districts, mostly on the lower Illinois River (Thompson, 2002). The levees isolate about 73,000 ha, or 57% of the floodplain, from the river (Bellrose et al., 1983). Levees that protect industrial and urban areas occupy a very small proportion of the 73,000 ha, including two small districts that provide flood protection for the towns of Liverpool and Beardstown in the La Grange Reach. By isolating large areas of the floodplain, primarily for row crop agriculture, levees reduce the area of the floodplain available to store and convey floods and the extent of the biologically rich floodplain, a biological richness and productivity that had evolved under the influence of the natural flood pulse (Junk et al., 1989). The remaining 43% of the floodplain remains "active", in the sense that it is still subject to inundation by the river.

Recently, public interest in the conservation and recovery of natural services has prompted major public and private investments in conversion of some levee and drainage districts back to functional floodplains along some rivers (Galat, 1998; Sparks et al., 2000). Restoration of native moist-soil plants is important in these conversions because they provide food for wildlife and other valuable ecological services; they are also indicators of successful restoration of the flood pulse (Ahn et al., 2004a,b). However, there are very few precedents for this type of naturalization to guide current efforts and there is a controversy regarding whether the converted levee districts should be opened to the river or isolated from the river, for reasons explained next.

State, federal and non-governmental agencies are currently investing significant resources to naturalize areas within the Illinois floodplain-river ecosystem (Sparks et al., 2000; Clancy, 2001). There are two distinctly different approaches to re-establishing a more natural hydrologic regime on the floodplain (Sparks et al., 1998). One is to keep the existing levees and manage the water levels on project sites independently from the river in order to produce wetland vegetation, including moist-soil plants, primarily to attract and feed migrating waterfowl. This water level management in impoundments maintained by private duck hunting clubs and government wildlife agencies mimics the natural water regime, with the mud flats intentionally flooded from late fall through winter and late spring, then exposed during the summer low flow season. Pumps are often used to pump water in or out of the impoundments, if river levels do not permit the filling or emptying of the impoundments through gates at the desired times. One former levee district that is just south of the dam at Peoria is currently not connected to the river at all. Local rainfall, groundwater and river water that seeps through or under the levees are allowed to raise water levels and pumps are used to lower the water levels. Water is pumped out into the river, but river water is not allowed directly in.

However, this option does not provide a direct connection between the river and its floodplain that is essential to many fish species that spawn and feed on the floodplains (e.g. basses and sunfishes, Family *Centrarchidae*, which are sought by sport fishermen) and to many important ecological processes (dispersal of floating seeds, nutrient cycling).

A second, more systemic approach is to reconnect the floodplain to the river either by breaching the levees or (more likely) installing gates in the levees – in either case, the levee is ''opened'' to the river, the term that will be used throughout this paper. The approach is systemic in the sense that the river itself provides the water regime in all the reconnected floodplains, instead of management staff who operate pumps and gates in each isolated floodplain compartment. Such an approach also allows fish access and promotes exchanges of nutrients, organic matter, and plant propagules (seeds, shoots, and winter buds) between the river and its floodplain, but it exposes the floodplain to the unnatural water fluctuations of the regulated river.

The Nature Conservancy, a non-governmental conservation organization, proposes to reconnect the Illinois River to a recently acquired 21.3 $km^2$ agricultural levee district in the middle section of the La Grange reach of the Illinois River (Fig. 1). Called ''Emiquon,'' the area to be naturalized once contained two large backwater lakes connected to the Illinois River during rises in the river level. The area was drained and leveed in the 1920s and was farmed for 80 years (Clancy, 2001). The model described in this paper was developed to assist in planning the Emiquon reconnection and in the selection of other potential reconnection sites. The Nature Conservancy regards Emiquon as a demonstration and learning project. If reconnection to the river promotes recovery here, then other private and government agencies might be persuaded to reconnect the floodplain compartments they manage. Rather than simply breaching the levee, The Nature Conservancy proposes to install gates, so that the reconnection can be tested and even stopped, if excessive sedimentation and water level fluctuations impede recovery.

Another systemic approach, besides opening the levees, would be to ''open'' the dams. In the case of the navigation dams at Peoria and La Grange, ''opening'' could be accomplished by lowering the wickets at the dams during the low water, growing season, to expose the floodplain that is now permanently inundated. Such an approach is unlikely because it would shorten the navigation season or require that barges be lightly loaded so that they could operate in shallow water, so we did not even model this scenario initially. However, after the simulation model predicted no moist soil plants would grow in the 15 km upstream of the dam, even if the levees were opened (Table 1), we did model the additional effect of opening the downstream dam (lowering the wickets) at La Grange during the growing season. Our interest was in better understanding the effects of the dam, after this rather surprising prediction.

Naturalization planning for the entire Illinois River is currently in progress, guided by both hydrologic and ecological models which predict the impacts of various naturalization and management scenarios on water flow, sedimentation, and vegetation. We have developed a moist-soil plant growth simulator (Ahn et al., 2004a) as part of an inter-disciplinary modelling approach linking the timing, duration and extent of flooding to the annual success and areal extent of moist-soil plants (Ahn et al., 2004b).

Here we describe how the plant model was used to assess naturalization scenarios along a representative section of the lower Illinois River, between the La Grange dam and Peoria dam (Fig. 1). We examined rather extreme scenarios involving opening the levees and the La Grange Dam. Our approach and analysis provide information and insights that are useful in selecting restoration sites and in addressing the controversy over isolating vs. connecting the converted levee districts to the river.

## Materials and methods

### *Site description: the La Grange Reach of the Illinois River*

The 135km long La Grange Reach of the Illinois River is bounded by dams at La Grange and Peoria (Fig. 1). The wickets are lowered during high flows, so that commercial barges and migratory fishes can pass directly over the structures without going

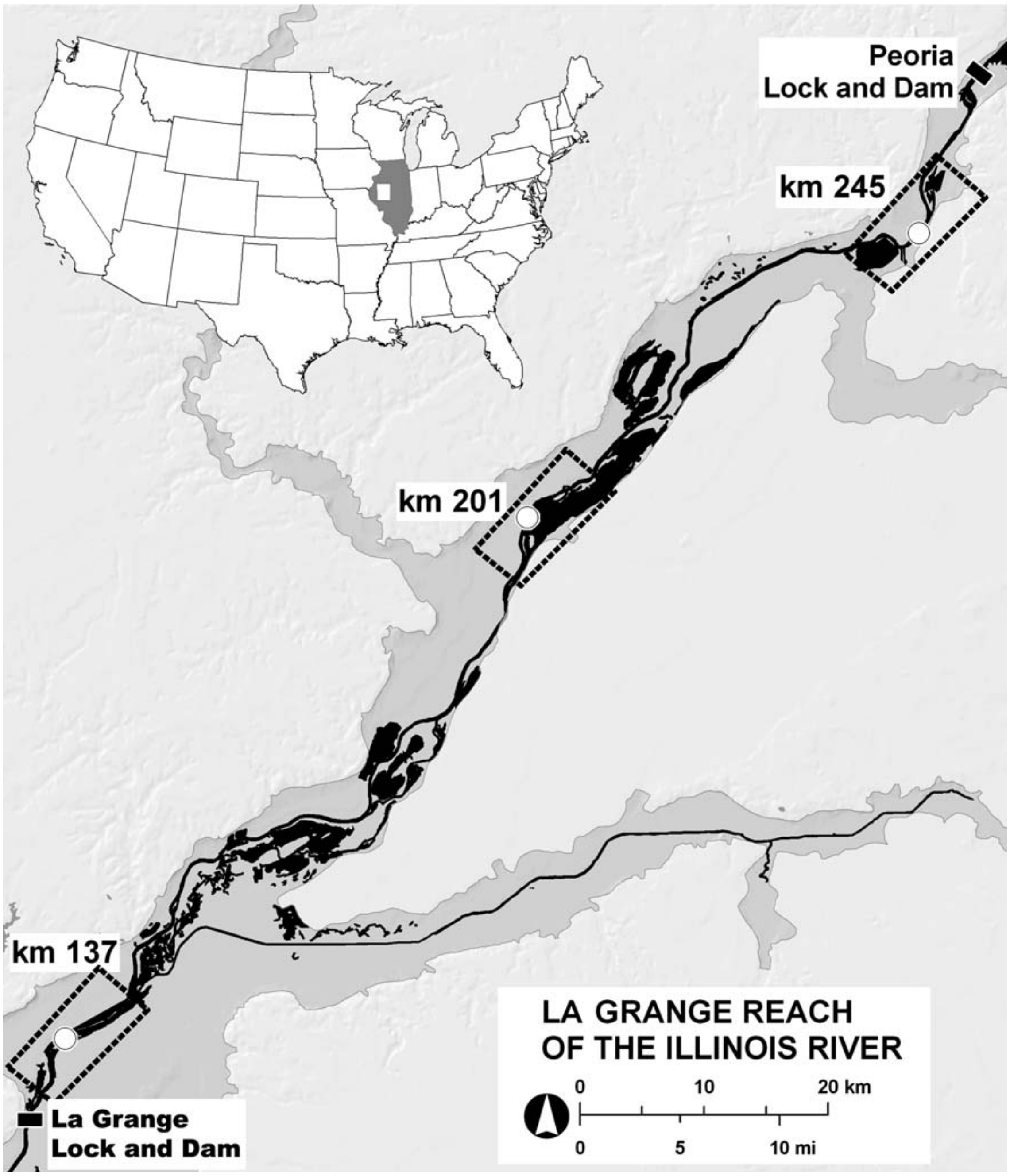


*Figure 1.* The La Grange Reach of the Illinois River. The growth of moist soil vegetation was modelled in three 15 km zones: near the upstream dam at Peoria (the center point of the zone is Illinois River km 245, measured upstream from the confluence with the Mississippi River); in mid-reach (km 201); and near the downstream dam at La Grange (km 137). The 21.3 $km^2$ Emiquon Floodplain Restoration Site, an agricultural drainage and levee district purchased by The Nature Conservancy, is in the middle zone.

through the locks. As a result, these dams have a much smaller effect on the river and its biota than high storage dams do on rivers elsewhere.

Several levee and drainage districts are located along the La Grange reach. These districts separate a total of about 33,000 ha of formerly active

*Table 1.* Variation in water levels (coefficient of variation, CV) and predicted floodplain area (km$^2$) of moist-soil plants under three scenarios at three locations in the La Grange reach of the Illinois River

| Location within navigation reach | Scenario | Variation (CV) in water levels during growing season | Area available for moist soil plants[a] (km$^2$) | Gain[b] (km$^2$) |
|---|---|---|---|---|
| Upper 15 km | Existing | 0.44 | 0.58 | |
| | Levees open | 0.37 | 5.34 | 4.76 |
| | Levees and dam open | 0.46 | 5.23 | 4.65 |
| Middle 15 km | Existing | 0.33 | 2.09 | |
| | Levees open | 0.28 | 2.44 | 0.35 |
| | Levees and dam open | 0.40 | 2.44 | 0.35 |
| Lower 15 km | Existing | 0.22 | 0.00 | |
| | Levees open | 0.19 | 0.00 | 0.00 |
| | Levees and dam open | 0.55 | 1.17 | 1.17 |

[a]The area above the low water line and below the elevation of the tree line where moist soil plants can germinate, grow and set seed in four out of ten years, on average (i.e. probability of success in any given year = 40%).
[b]Difference between the area currently available for moist soil plants and what would be available under two scenarios: (1) if levees were opened, and (2) if levees and the downstream navigation dam were opened.

floodplain from the hydrologic influence of the river, and are potential floodplain restoration sites, if the landowners are willing to sell the land or accept payments in return for flood or conservation easements.

*Hydraulic model*

We have calibrated a hydraulic model for the La Grange Reach of the river, using 61 years of daily water level elevations at three gages within the reach. The model used is UNET (HEC, 1993; United States Army Corps of Engineers, 1995). UNET is an acronym for *Un*steady Flow through a Full *Net*work of Open Channels. The 61 years encompass the period from 1940, when the modern navigation dams became operational, to the most recently available gage readings. UNET simulates one-dimensional unsteady flow through a defined, or bounded, network of open channels. We used the model to estimate river stages within the upper, middle, and lower segments of the La Grange Reach (Fig. 1) during the summer growing season under three conditions: (1) current conditions (with levees and dams in place); (2) levees opened; and (3) levees and La Grange dam opened (wickets down). The model was calibrated using historic records under current conditions (levees and dams in place) using standard engineering practices. Modeled results allow estimation of stages at locations along the reach not having recorded observations. As there are no recorded observations under the other two conditions, we must assume the model simulates river stages under these conditions.

The levees open scenario is represented in the model by removing the levees from the elevation cross-sections across the channel and floodplain. In actuality, it would be prohibitively expensive to physically remove the entire levee system; instead, levees would be opened at the upstream and downstream ends, so that flood waters could flow through the former levee and drainage districts in the old natural floodways and floodplain lakes that existed before the levees. Because the hydraulic volume of the floodplain is large in comparison to the volume of earth in the levee, the portion of the levee that would be left after breaching or installing gates at the upstream and downstream ends would have little effect on water levels. Moreover, the main levee parallels the main channel, so flood waters would pass on both the channel and floodplain side of the breached or gated levee, with little loss in conveyance capacity due to flow restriction.

The hydraulic model assumes that the topography remains the same after opening the levees or the dam. This is a reasonable assumption over a time span of at least 30 years, based on modelling the Emiquon site under five "opening" scenarios that included full connection and various operating rules for either one or two gates in the levee (Illinois State Water Survey, 2004). The most sedimentation occurs with full connection, with 3.30 cm of fill in the restoration site in 30 years. The other four scenarios, where one or two gates are opened and closed under various operating rules, lead to much less sedimentation, down to a minimum of 0.25 cm in 30 years.

*Plant growth model*

The resulting simulated hydrographs from UNET were used as input to a moist-soil plant growth model developed by Ahn et al. (2004a), which quantifies moist-soil plant "success" in terms of germination and growth. The model uses physiological parameters for millets (*Echinochloa* sp.), one group of moist soil plants. Millets are summer annual plants that grow up to 1.5 m tall and prefer wet (but not inundated) soils and warm temperatures to germinate. Although individual species of moist soil plants undoubtedly vary in their tolerances for inundation, little published information is available on species other than those, such as millets, that are important in waterfowl management.

The plants require that mudflats be exposed during the period from 10 July to 1 October (Bellrose et al., 1983). Inundation during germination or early seedling development kills the plants. They cannot tolerate flooding until the plants are at least 15 cm tall (Fredrickson & Taylor, 1982). If moist-soil plants can grow for at least 70 days without being overtopped by water, they will mature and produce seeds. The timing of the flood is critical for a successful seed crop.

The upper land elevation boundary for moist soil plants is the tree line. Above this land elevation, the annual moist-soil plants are excluded by the perennial, but less flood tolerant woody species. The land elevation of the tree line along the La Grange reach was determined from aerial photographs and topographic maps. The vertical range of the potential zone for moist-soil plants is only about 2–3 m, extending from the tree line down to the permanent water level, either the low stage in the river and its connecting channels or the low stage in floodplain lakes that are seasonally disconnected from the river.

As reported elsewhere (Ahn et al., 2004a), the plant model was validated by comparing model predictions to 19 vegetation inventories conducted in the 1930s and 1940s. The historical record included years of success and years of failure of the moist soil plants. Although the model predictions matched the historical observations in all 19 cases, the validation must be considered qualitative, because the agreement was limited to whether the plants were absent or present. Presence/absence was the only common response measure we could use because the historical observations reported plant cover (as a percentage of the total area available for moist soil plants) while the model predicts biomass density and height of the plants.

Daily water level fluctuations during the growing season determine the success of the plants in a given year at a specified land elevation. The plant model is run at a series of land elevations, starting at the tree line and decreasing at 10 cm intervals until the lowest recorded water level is reached. This step-wise process allows us to determine, for each year, the *lowest* land elevation at which moist-soil plants are successful, with success defined as producing 90% of the potential maximum biomass (Ahn et al., 2004a). The *lowest successful elevation* is an annual hydrologic parameter (analogous to "maximum daily flow," or "7-day low flow"; Ahn et al., 2004b). For example, at River km 245 the lowest land elevation in 1998 where moist soil plants germinated and grew to at least 90% of their maximum potential biomass was 132.5 m above mean sea level.

Repeating this process for the 61 years of daily river stage records since the modern dams became operational provides us with a historical distribution of the *lowest successful elevation* parameter. This distribution enables us to employ frequency analysis, a commonly used technique in hydrology (Chow, 1964), to make statements about the probability of future plant success at a given land elevation, assuming that the underlying source of variability (such as year-to-year differences in weather) remains the same. For example, a probability of 0.4 means that moist soil plants would be successful 4 out of 10 years. The purpose of this modelling is to allow us to compare alternative naturalization strategies, which requires computing a probability distribution for each scenario. We reduced the computational requirements of scenario assessment by about two-thirds while retaining the full range of historical variability, by selecting the first, last and every 5th percentile observation (21 years in all) from the historical distribution and modelling only those years.

*Scenario testing*

Using the procedure described above, we modelled three scenarios: existing conditions (neither the levees nor the dam are typically open during the growing season); levees opened; and both levees and the downstream dam open (wickets down) during the growing season. The scenarios are admittedly extreme because they assume that the entire floodplain along the study reach would be reconnected to the river. Examining such unlikely cases provides a useful check of effectiveness of the naturalization strategy. If wholesale reconnection produces no reduction in flood heights and improvements in moist-soil plants, then there would be little point in developing scenarios for less reconnection. If the extreme case *does* produce benefits, then there would be value in testing smaller scale efforts at locations where potential benefits are expected to be high or costs low, or where the land use change would be politically acceptable.

## Results

Under existing conditions, the spring flood and smaller rises in water levels are moderated as they move down the La Grange reach, because of the well-known dampening effects of flow resistance and hydraulic storage capacity in the channel itself and in the floodplain and its associated channels and backwaters that remain open to the river (compare panels a, b and c in Fig. 2). The coefficients of variation in water levels under existing conditions are greatest upstream, intermediate in the middle segment, and lowest in the downstream segment (Table 1). Also, the wickets at the downstream dam are raised as the spring flood recedes, so the river is not allowed to get as low as it once did naturally (Fig. 2c). The effects of the dam diminish with distance upstream from the dam.

Opening the levees would reduce flood heights during the spring and early growing season (Fig. 2). The reduction would be over 0.5 m for the upper 15 km segment of the reach (Fig. 2a) and somewhat less in the mid-reach segment (Fig. 2b). However, the reduction in the water level accompanying levee removal would be negligible along the lower segment because the dam maintains the water levels (Fig. 2c).

Opening the downstream dam would have the greatest effect on the downstream segment (Fig. 2c). As expected, water levels would drop markedly close to the dam, but progressively less upstream (Fig. 2a,b).

*Predicted effects of opening levees and dams on moist soil plants*

The predicted response of moist soil plants varied dramatically by location within the navigation reach (Table 1, Fig. 3). In the upper 15 km of the navigation reach (in the vicinity of River km 245; Fig. 1), the model predicted that moist soil plants would do well if the floodplains were reconnected to the river by opening the levees. The area available for moist soil plants would increase substantially, from 0.58 to 5.34 $km^2$ (Table 1). Lowering of the wickets at the downstream navigation dam would have little additional effect on area (Fig. 3a).

In the mid-reach segment (in the vicinity of River km 201, including Emiquon, Fig. 1), the probability of moist-soil plant success would increase with levee removal, as would the predicted area covered by moist-soil plants (a gain of 0.35 $km^2$; Table 1 and Fig. 3b).

However, in the downstream segment (River km 137 vicinity) no moist soil plants are produced under existing conditions and the model predicted none would be produced even if more floodplain were provided by opening the levees (Table 1; Fig. 3c). At this location, it would be necessary to open the downstream (La Grange) dam to provide areas (a total of 1.17 $km^2$, Table 1) where moist-soil plants could potentially grow.

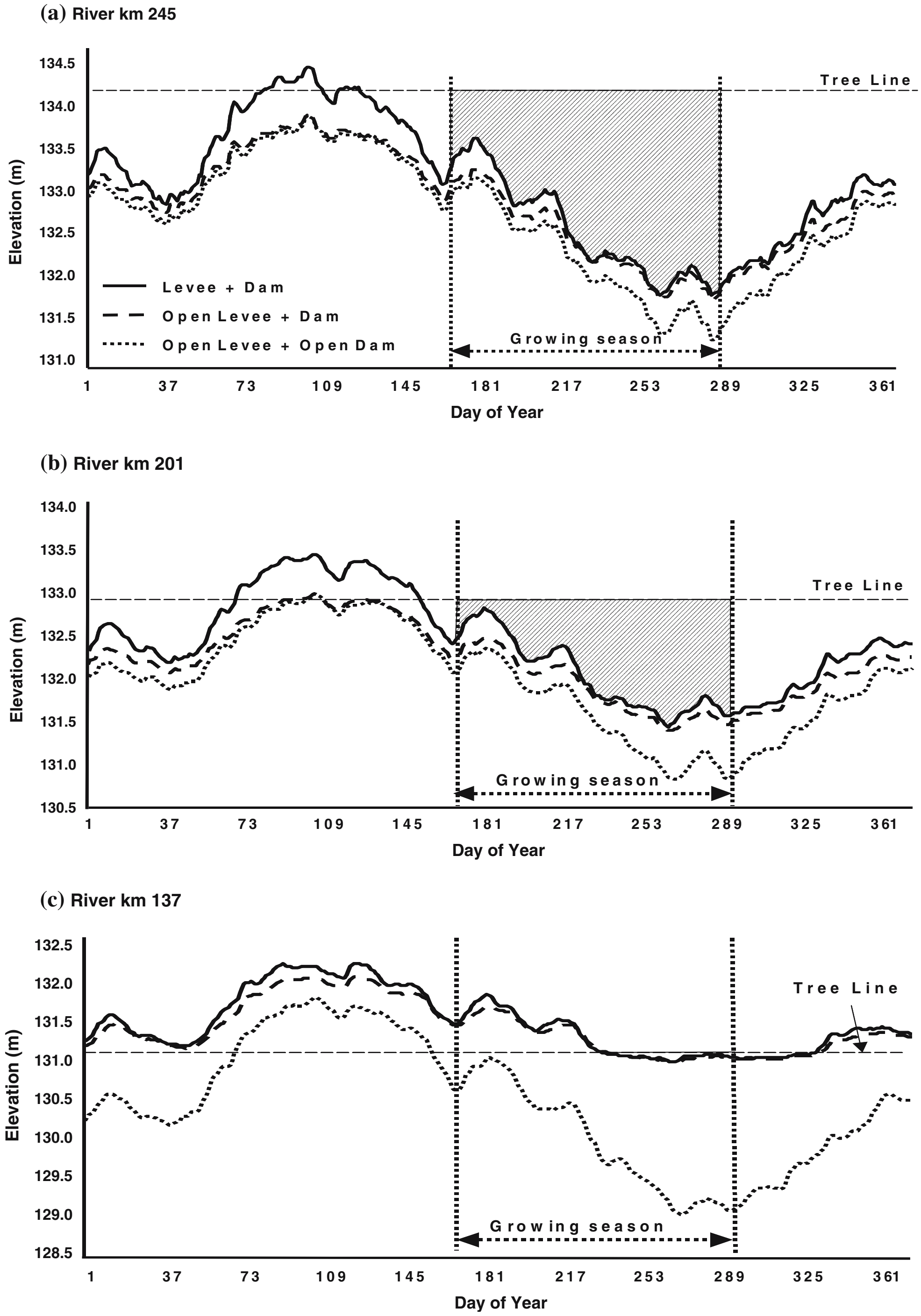


*Figure 2.* Simulated mean daily water levels at three locations, (a) km 245; (b) km 201; (c) km 137, representing three 15 km zones within the La Grange Reach of the Illinois River, under three scenarios: (1) existing conditions, with levees and locks and dams; (2) with levees open; and (3) with levees and the water level control wickets lowered at the downstream navigation dam (dam open). Vertical dotted lines bracket the growing season for moist-soil plants. The shaded grey area represents the elevation zone, bounded by the tree line at the upper end and by the average daily low water elevation at the low end, where moist soil plants could grow. See text for details about the determination of the tree line and low water elevations.

## Discussion

The effects of levees and navigation dams on water levels vary significantly from one location to the next, depending on proximity to the dams and the characteristics of the adjoining floodplain. Under regulation, the Illinois River has: (1) greater and more frequent water level fluctuations below the upstream dam during the growing season, and (2) permanently higher, but more stable water levels near the downstream dam. This upstream–downstream pattern in the water level regime is generally characteristic of navigation reaches in the Illinois and Upper Mississippi rivers (Sparks et al., 1990). Under existing conditions, the upstream fluctuations reduce the success of and the area covered by moist soil plants in most years by preventing germination or drowning plants that do germinate. In some downstream segments, including the downstream portion of La Grange reach, there is no moist soil zone at all under existing conditions, because this zone is now permanently inundated by the navigation dam during the summer low water season and the tree line begins at the margin of the water (Fig. 2c).

Opening the levees would have the expected effect of increasing the area available for moist soil plants in the middle and upper segments of the navigation reach, although the increase is much greater in the upper than in the middle segment (Table 1 and Fig. 3a,b). The increased hydraulic storage capacity would have the additional beneficial effect of damping the harmful, mid-summer water level fluctuations. If recovery of moist soil vegetation and reconnection of the floodplains to the river are management goals, our results indicate that acquisition of flood easements or outright purchases of levee and drainage districts would be most effective in the upper segments of La Grange Reach and probably in other navigation reaches as well. Having found a positive result with the extreme scenario of opening all the levees, the next step will be to simulate the effects of opening only those levees in the upstream half of the Reach, where the moist soil plants have the greatest probabilities of success. The increased success for moist soil plants occurred despite the detrimental water level fluctuations during the 61-year record used for modelling. If the water fluctuations in the main river were reduced by altering dam operations and increasing the water retention of the tributary watersheds the gains should be much greater.

In contrast to the upstream segments, opening the levees in the downstream segment would have no beneficial effect on moist soil plants. This seemingly anomalous result is explained by examining the results from the simulation where the navigation dam was opened during the growing season. Normally, the dam is closed during the summer low flow season and the water level never drops below the tree line (Fig. 2c).

Like the moist-soil plants, many of the floodplain trees will only germinate on moist soil, not under water. Likewise, both seedling trees and moist-soil plants can be drowned by untimely floods. However, trees can become established if they have a few flood-free years in which to grow taller than the depth of the next flood. Many floodplain-adapted tree species can tolerate short-duration floods that do not overtop their upper branches and leaves but do kill plants of shorter stature. The moist-soil plants thus depend on a flood pattern that will exclude trees, but not exclude them. Since trees have life spans measured in decades or centuries and produce propagules nearly every year when mature, they have opportunities to become established at unusually low elevations in the floodplain during rare events, such as prolonged droughts, when floods may not occur at all or may recede exceptionally early. Trees may then persist in what would ordinarily be the moist soil plant zone until they are cut down, die of old age or are killed by rare floods that extend through the growing season (Sparks et al., 1998). The tree lines in our study were determined from observation of aerial photographs. While moist soil plants currently cannot grow higher than the existing tree lines, the tree lines are not a permanent natural boundary, and would change in response to deforestation by humans and/or large herbivores, droughts, protracted floods, or naturalization schemes that change the existing water level patterns. Although a germination and growth model for floodplain forests was beyond the scope of our study, it would certainly be useful to develop such a model to support site selection and planning for naturalization.

The modelling approach described in this paper can be useful in predicting responses of moist soil

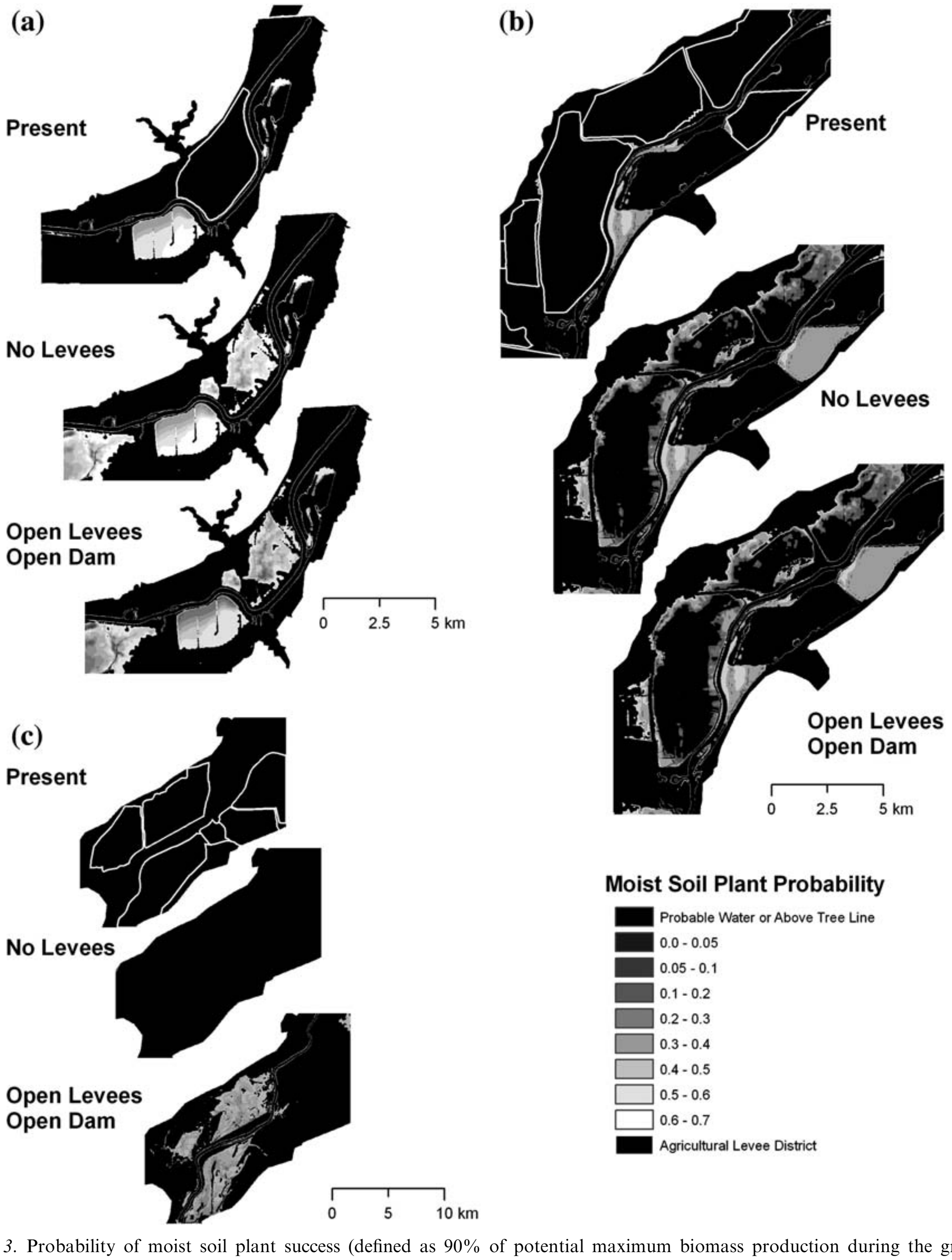


*Figure 3*. Probability of moist soil plant success (defined as 90% of potential maximum biomass production during the growing season) in three zones: (a) upper 15 km; (b) mid 15 km; and (c) lower 15 km in the La Grange Reach of the Illinois River, under three scenarios: (1) existing conditions, with levees and locks and dams; (2) levees open; and (3) levees and the downstream navigation dam open. At a floodplain elevation where the probability of successful germination and growth of the moist soil plants is 0.50, moist soil plants are replaced by trees. No moist soil plants grow at low elevations in permanent water (probability of success = 0.00). White lines designate levees.

plants to *any* water level fluctuations at any location proposed for naturalization, including: (1) natural fluctuations; (2) dam operations on the main-stem river that might be altered to benefit floodplain vegetation; (3) moderating effects of conservation practices in tributary watersheds; or (4) combinations of approaches. Since moist-soil plants are a good food source for muskrats, beaver, and migratory waterfowl, there is also a link between the success of these plants, used by wildlife, and value to humans who hunt, fish, or view wildlife. Moist soil vegetation provides ecological services, including stabilization of shorelines that are otherwise subject to wave erosion. These linkages could be incorporated in evaluations of probable benefits and costs of river management alternatives.

## Conclusion

The framework and approach of linking hydrological and ecological models in this study enabled us to predict and compare consequences of alternative naturalization scenarios for the Illinois floodplain–river system. The models are well grounded in their respective literature and reflect the current state of knowledge of river hydraulics and moist-soil plant ecology. However, not all of the factors involved in moist-soil plant success are fully understood and factors such as nutrient levels, sedimentation rates, and competition with woody vegetation were not included in our modelling, and may prove important. In addition, the choice of indicators or key ecosystem components to model may be critical in examining each floodplain–river system, and any model must be parameterized for the particular system that is to be modelled.

Moist-soil plants are a good indicator for a naturalistic water level regime but not for river-floodplain connectivity, because the flooding pattern these plants require can be created by regulated flooding within leveed areas of the floodplain. These areas can be inundated using local water, including rainwater, ground water and water from small local tributaries, and then dewatered with pumps or gravity drains. Other organisms, such as fish species that migrate between the river and the floodplain, are better indicators for connectivity.

The analytical framework in our study should also be viewed as part of an iterative process of adaptive management, including: modelling (as part of planning), implementing, monitoring, analysis and modelling again. Collecting more experimental and field-oriented information on the response of moist-soil plants, as naturalization efforts proceed, is critical to this adaptive management process. It is also important to have fine-scale elevation data for floodplain sites proposed for restoration because plants respond to elevational differences on the scale of 10–15 cm.

A clear result of this study is that location does matter. Even if the entire floodplain were reconnected to the river near the downstream dam in our study reach, moist soil plants are unlikely to grow there because of the effects of the dam on the water levels. Success is much more likely at locations farther upstream. Modelling approaches like those described in this paper can help with the critical step of site selection for naturalization.

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## References

Ahn, C., R. E. Sparks & D. C. White, 2004a. A dynamic model to predict responses of millets (*Echinochloa* sp.) to different hydrologic conditions for the Illinois floodplain-river. River Research and Applications 20: 485–498.

Ahn, C., D. C. White & R. E. Sparks, 2004b. Moist-soil plants as ecohydrologic indicators to recover the flood pulse in the Illinois River. Restoration Ecology 12: 207–213.

Bellrose, F. C., S. P. Havera, F. L. Paveglio & D. W. Steffeck, 1983. The fate of lakes in the Illinois River Valley. Illinois Natural History Survey Biological Notes 119: 1–27.

Bellrose, F. C., F. L. Paveglio & D. W. Steffeck, 1979. Waterfowl populations and the changing environment of the Illinois River Valley. Illinois Natural History Survey Bulletin 32: 1–54.

Chow, V. T., 1964. Statistical and Probability Analysis of Hydrologic Data, Section 8-I. In Chow, V. T. (ed.), Handbook of Applied Hydrology. McGraw-Hill Inc, New York: 1–42.

Clancy, P., 2001. Restoring the Illinois River. Nature Conservancy 51: 12–19.

Demissie, M. & V. Knapp, 2000. Hydrology and hydraulics of the Illinois River. Proceedings of the 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management. In Hotchkiss, R. H. & M. Glade (eds). Environmental and Water Resources Institute of the American Society of Civil Engineers, Reston, VA. CD-ROM.

Fredrickson L. H. & T. S. Taylor, 1982. Management of Seasonally Flooded Impoundments for Wildlife. Publication 148, United States Department of the Interior, Fish and Wildlife Service, Washington, DC.

Galat, D. L., 1998. Flooding to restore connectivity of regulated, large-river wetlands. BioScience 48: 721–733.

Havera S. P., 1999. Waterfowl of Illinois. Special Publication No. 21, Illinois Natural History Survey, Champaign, IL.

HEC, 1993. One-dimensional Unsteady Flow through a Full Network of Open Channels. User's Manual. U.S. Army Corps of Engineers, Hydraulic Engineering Center, Davis CA.

Illinois State Water Survey, 2004. Predicted sedimentation in Emiquon. Report to the Emiquon science advisory council of the nature conservancy, April 2004. http://ilrdss.sws.uiuc.edu/search/search_results.asp?pr = 500&strSearch = emiquon.

Junk, W. J., P. B. Bayley & R. E. Sparks, 1989. The flood pulse concept in river-floodplain systems. In Dodge D. P. (ed.), Proceedings of the International Large River Symposium. Vol. 106. Canadian Special Publication of Fisheries and Aquatic Sciences: 110–127.

Koel, T. M. & R. E. Sparks, 2002. Historical patterns of river stage and fish communities as criteria for operations of dams on the Illinois River. River Research and Applications 18: 2–19.

Schneider, D. W., 2000. Backwater lakes: history shows their values to Illinois. Wetland Matters 5: 1–11.

Sparks, R. E., J. C. Nelson & Y. Yin, 1998. Naturalization of the flood regime in regulated rivers. BioScience 48: 706–720.

Sparks, R. E., P. B. Bayley, S. L. Kohler & L. L. Osborne, 1990. Disturbance and recovery of large floodplain rivers. Environmental Management 14: 699–709.

Sparks R. E., J. B. Braden, M. Demissie, P. Mitra, D. W. Schneider, D. C. White & R. Xia, 2000. Technical Support of Public Decisions to Restore Floodplain Ecosystems: A Status Report on the Illinois River Project, USA. In Smits A. J. M., P. H. Nienhuis & R. S. E. W. Leuven, (eds), New Approaches to River Management. Backhuys Publishers, Leiden: 225–247.

Thompson, J., 2002. Wetlands Drainage, River Modification, and Sectoral Conflict in the Lower Illinois Valley, 1890–1930. Southern Illinois University Press, Carbondale, IL.

United States Army Corps of Engineers, 1995. Floodplain Management Assessment of the Upper Mississippi River and Lower Missouri Rivers and Tributaries Main Report, United States Army Corps of Engineers, Rock Island, IL.