Restoration / Ecosystems

An Historical Perspective on the Kissimmee River Restoration Project

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Abstract

This paper reviews the events leading to the channelization of the Kissimmee River, the physical, hydrologic, and biological effects of channelization, and the restoration movement. Between 1962 and 1971, in order to provide flood control for central and southern Florida, the 166 km-long meandering Kissimmee River was transformed into a 90 km-long, 10 meter-deep, 100 meter-wide canal. Channelization and transformation of the Kissimmee River system into a series of impoundments resulted in the loss of 12,000–14,000 ha of wetland habitat, eliminated historic water level fluctuations, and greatly modified flow characteristics. As a result, the biological communities of the river and floodplain system (vegetation, invertebrate, fish, wading bird, and waterfowl) were severely damaged. Following completion of the canal, the U.S. Geological Survey released a report documenting the environmental concerns associated with channelization of the river. This action led to the 1971 Governor's Conference on Water Management in South Florida that produced a consensus to request that steps be taken to restore the fish and wildlife resources and habitat of the Kissimmee basin. In 1976, the Florida Legislature passed the Kissimmee River Restoration Act. As a result, three major restoration and planning studies (first federal feasibility study [1978–1985], the Pool B Demonstration Project [1984–1990], and the second federal feasibility study [1990–present] were initiated (1) to evaluate measures and provide recommendations for restoring floodplain wetlands and improving water quality within the Kissimmee basin, (2) to assess the feasibility of the recommended dechannelization plan, and (3) to evaluate implementation of the dechannelization plan. The recommended plan calls for the backfilling of over 35 km of C-38, recarving of 14 km of river channel, and removal of two water-control structures and associated levees. Restoration of the Kissimmee River ecosystem will result in the reestablishment of 104 km² of river-floodplain ecosystem, including 70 km of river channel and 11,000 ha of wetland habitat, which is expected to benefit over 320 species of fish and wildlife.

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Background

The Kissimmee River basin is located in central Florida between the city of Orlando and Lake Okeechobee within the Coastal Lowlands physiographic province. It consists of a 4229-km² upper basin, which includes Lake Kissimmee and 18 smaller lakes ranging in size from a few hectares to 144 km², and a 1,963-km² lower basin, which includes the tributary watersheds (excluding Lake Istokpoga) of the Kissimmee River between Lake Kissimmee and Lake Okeechobee. The physiography of the region includes the Osceola and Okeechobee Plains and the Lake Wales ridge of the Wicomico shore (U.S. Army Corps of Engineers 1992).

Prior to channelization, the Kissimmee River meandered approximately 166 km within a 1.5–3-km-wide floodplain. The river and floodplain gradually sloped to the south from an elevation of approximately 15.5 meters (51' National Geodetic Vertical Datum) at Lake Kissimmee to approximately 4.6 meters (15' NGVD) at Lake Okeechobee. The transition between the Osceola and Okeechobee plains occurs in the middle of Pool B between weirs two and three (Fig. 1), resulting in a 37% reduction in river slope (0.09 m/km along the Osceola plain and 0.057 m/km along the Okeechobee plain, respectively) over the last 130 km of river channel. Pre-channelization stage and discharge records (1929–1960) from gaging stations at the outlet of Lake Kissimmee and approximately 155 km downstream (near S-65E water control structure; Fig. 1), indicate that continuous flow and seasonal water-level fluctuations were integral hydrologic characteristics of the unmodified system. Discharge exceeded 11 m³ per second during 90%–95% of the period of record, with overbank flow generally occurring along the entire river course when flows exceeded 40 m³ per second in the upper reaches and 57 m³ per second in the lower reaches. Highest discharges typically occurred at the end of the wet season (September-November), although considerable variability existed across the years (Toth 1993) (Fig. 2).

The historic, pre-channelized Kissimmee River was hydrologically unique among North American river systems. Stage duration data and floodplain elevations adjacent to gaging stations indicate that, prior to channelization, 94% (approximately 16,920 ha) of the floodplain was inundated over 50% of the time. When inundated, water depths on the floodplain were generally 0.3–0.7 meters, with depths greater than 1 meter occurring on over 40% of the flood-

Figure 1. Location of the Kissimmee River-C-38 system showing channelized route (C-38) superimposed upon meandering river channel. The system is divided into a series of five pools (A-E) separated by water control structures (S-65s). Weirs 1-3, located in Pool B, were installed as part of the 1984 Kissimmee River Demonstration Project. The highlighted areas indicate the phased approach to restoration construction to begin in 1998.

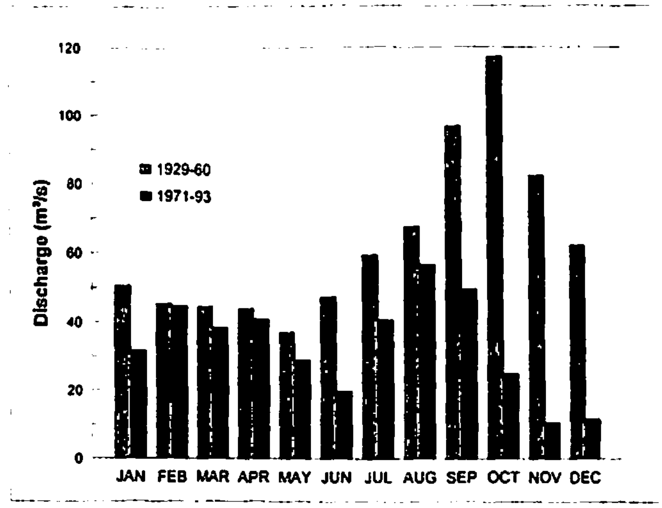

Figure 2. Mean monthly discharge for the Kissimmee River-C-38 system prior to (1929-1960) and following (1971-1993) channelization. Discharge was measured at a point near the current location of S-65E.

plain for at least one-third of the period of record (Toth 1990).

Mean monthly stage data suggest that the Kissimmee basin underwent a seasonal wet-dry cycle, typical of subtropical regions, but that only peripheral areas of the floodplain underwent consistent annual seasonal drying. Approximately 80% of the floodplain was continuously wet in 11 of the 25 years on record. The floodplain was 100% inundated for two consecutive years during three intervals and for a period of approximately four years from 1946 to 1949. Although extensive periods of drying were uncommon, 84% of the floodplain was dry for at least five months during three separate years (1932, 1935, 1955-1956) (Toth 1990).

In general, river-floodplain systems of the southeastern United States (such as the Edisto River in the Lower Coastal Plain of South Carolina, the Ogeechee and Satilla Rivers in the Southern Coastal Plain of Georgia, and the Suwanee, Ochlockonee, Choctawhatchee, and Blackwater Rivers of Peninsular Florida) undergo a somewhat predictable seasonal wet-dry cycle. Periods of high flow and floodplain inundation generally occur in December-May after the onset of winter rains, with low flows and floodplain drying occurring in late summer and autumn (Smock & Gilinsky 1992). Seasonal periods of floodplain inundation are essential for the productivity of the biological communities associated with these river systems. As early as 1925, Forbes (1925) recognized the importance of inundated floodplains as breeding grounds and foraging areas for fish and aquatic invertebrates. More recent studies (Ross & Baker 1983) suggest that spring flooding may exert significant control over fish community structure through increased larval recruitment of flood-exploitative species. In addition, fish production on the floodplain can account for a significant proportion of total fish production, with the seasonal river-floodplain connectivity allowing for recruitment of floodplain-reared juveniles and adults back to the river channel (Halyk & Balon 1983; Bayley 1991).

Invertebrates hold a critical place in the trophic web of an aquatic ecosystem and serve as a vital link in the trophic structure of river-floodplain systems. Macroinvertebrates play a key role in organic-matter processing and nutrient cycling (Merritt et al. 1984), and they are often used as indicators of the biological health of aquatic systems (Hawkes 1979; Plafkin et al. 1989). Annual invertebrate production on the floodplain is often one to two orders of magnitude greater than stream channel production (Gladdon & Smock, 1990), with much of the invertebrate biomass produced on the floodplain being exported to the river channel during periods of declining water levels. These inputs of high-quality organic matter are readily accessible to many organisms at higher trophic levels (Eckblad et al. 1984). Although seasonal floodplain inundation is critical for the productivity of fish and invertebrate communities, the timing and duration of flood events in most North American river-floodplain systems are highly unpredictable, often resulting in large annual variation in the productivity of these biological communities.

The hydrology of the Kissimmee River is more closely associated with the large river-floodplain systems of the Southern Hemisphere, such as the Amazon in South America or the Senegal and Niger Rivers of Africa. The near-continuous connectivity of the river and floodplain is critical to the trophic structure and biological productivity of these systems. Although these systems, as well as the Kissimmee, undergo a seasonal wet-dry cycle driven by local rainfall, they differ from most North American river-floodplain systems in the extremely well-developed fringing floodplain that occurs for most of their lengths, and for the long period of time the floodplain may remain inundated (Welcomme 1979). In some cases, almost 60% of the floodplain of these tropical systems remains inundated after periods of annual floodplain drying. The long-term floodplain inundation and the diverse habitats of these tropical systems and of the Kissimmee River system are critical to the production of avian, fish, and invertebrate communities. In many cases, the life cycles of water birds (Robertson & Kushlan 1974), fish (Junk et al. 1989; Bayley 1991), and invertebrates are closely linked to flooding, with greater fish breeding success and recruitment in years with smooth increase in water level and with floods of high amplitude and long duration (Welcomme 1979; Payne 1986).

Prior to alteration of hydrologic characteristics and isolation of the river from its floodplain in the 1960s, the Kissimmee River ecosystem consisted of a mosaic of floodplain wetland habitats (Toth et al. 1995) that supported as many as 35 species of fish (Florida Game and Fresh Water Fish Commission 1957), 16 species of wading birds (Audubon 1936–1959), 16 species of waterfowl (Perrin et al. 1982), and six other species of waterbirds. The heterogeneous plant communities supported a diverse invertebrate fauna, including caddisflies, dragonflies, damselflies, water bugs, water beetles, isopods, amphipods, freshwater shrimp, midges, Sphaerid clams, Unionid Mussels, *Corbicula*, and *Pomacea* (Vannote 1971), and they provided refuge for up to 35 species of juvenile fishes (Trexler 1995).

Central and Southern Florida Flood Control Project

Prior to alteration of the Kissimmee River, flooding in the Kissimmee basin resulted from runoff accumulation within the basin and the subsequent rise of lake levels within the upper basin, which remained at high levels due to their poor outlet capacity. As a result, major flood events transformed the Kissimmee River into a system resembling a shallow, wide lake (U.S. Army Corps of Engineers 1992).

Prior to 1940, human habitation was sparse within the Kissimmee basin. Land use within the basin consisted primarily of farming and cattle ranching. Rapid growth and economic development following World War II, coupled with a severe hurricane in 1947 and a mean peak monthly discharge exceeding 170 m^3 per second from 1947 to 1949, contributed to extensive property damage within the basin. The results of mass flooding during this period (the area between Lake Cypress and Lake Kissimmee remained inundated for approximately eight months) intensified public pressure to reduce the threat of flood damage within the Kissimmee basin. As a result, the State of Florida responded with a request to the federal government to prepare a flood-control plan for central and southern Florida (U.S. Army Corps of Engineers 1992).

In 1948, Congress authorized the U.S. Army Corps of Engineers to initiate construction of the Central & Southern Florida Project for flood control and protection. In 1954, Congress specifically authorized the Kissimmee River portion of the project, which was planned and designed from 1954 to 1960. Between 1962 and 1971, the Kissimmee River was channelized and transformed into a series of impounded reservoirs (Pools A-E). Inflow from the upper basin was regulated by six water control structures (S-65s) (Fig. 1) along the newly created canal (C-38). Water regulation structures were built in the upper lakes region from 1964 to 1970 and resulted in a series of channels and water control features that connected and regulated water flow within and between the major lakes of the upper basin.

Effects of Channelization

The physical effects of channelization, including alteration of the system's hydrologic characteristics, largely eliminated river and floodplain wetlands and degraded fish and wildlife values of the Kissimmee River ecosystem (Toth 1993). The broad, 166-km-long meandering river was transformed into a 90-km-long, 9-meter-deep, 100-meter-wide canal. Excavation of the canal and deposition of the resulting spoil replaced approximately 56 km of river channel and 2800 ha of floodplain wetland habitat. Transformation of the river-floodplain ecosystem into a series of deep impoundments drained much of the floodplain (Toth 1995), eliminated historical water-level fluctuations, and greatly modified flow characteristics. Approximately 12,000–14,000 ha of pre-channelized floodplain wetlands were drained, covered with spoil, or converted into canal. The floodplain at the lower end of each pool remained inundated, but pre-channelization water level fluctuations were eliminated. Low- and no-flow regimes in remnant river channels resulted in encroachment of vegetation, especially floating exotics (such as *Pistia stratiotes* [water lettuce] and *Eichhornia crassipes* [water hyacinth]) to the center of the river channel. Senescence and death of encroaching vegetation covered the shifting sand substrate of the historic channel with large amounts of organic matter, greatly increasing the biological oxygen demand of the system (Toth 1990).

River channelization and degradation of the floodplain severely affected other biological components. By the early 1970s, floodplain utilization by wintering waterfowl declined by 92% (Perrin et al. 1982). Wading bird populations, a highly visible component of the historic system, declined and were largely replaced by *Bubulcus ibis* (cattle egret), a species generally associated with upland, terrestrial habitats (Toland 1990). The internationally recognized *Micropterus salmoides* (largemouth bass) fishery was severely damaged. Low- and no-flow regimes in the canal and remnant river channels resulted in depleted dissolved oxygen levels (Fig. 3). Sport fish were largely replaced by species tolerant of low dissolved oxygen regimes and reduced water quality (such as *Lepisosteus platyrhincus* [Florida gar] and *Amia calva* [bowfin]). Rheophylic invertebrate taxa typical of many large river systems (for example, hydropsychid caddisflies and heptageniid mayflies) were largely replaced by species common to lentic systems (for example, *Chaoborus*, *Pelocoris* [Hemiptera:Naucoridae], and hydrophilid beetles) (Toth 1993). Stabilized water levels and reduced flow eliminated prechannelization river-floodplain interactions. Influx of dissolved organic matter (DOM), particulate organic matter (POM), invertebrates, and forage fishes to the river from the floodplain during periods of water recession was greatly reduced. In addition, stabilized water levels largely eliminated adult spawning and foraging habitat, as well as larval and juvenile refuge sites for fish on the floodplain (Trexler 1995).

Restoration Initiative

Prior to completion of the canal in 1971, a grassroots movement to restore the Kissimmee River began to form. In 1971, the U.S. Geological Survey released a report documenting environmental concerns associated with channelization of the river. This action led to that year's Governor's Conference on Water Management in South Florida. This conference focused on the water-quality problems of South Florida and produced a consensus to request that steps be taken to restore the fish and wildlife resources and habitat of the Kissimmee basin. In 1976, in response to public concern, the Florida Legislature passed the Kissimmee River Restoration Act, which created the Kissimmee River Coordinating Council (KRCC). The council's main directives were to use the natural energies of the river system (1) to restore pre-channelized, natural, seasonal water-level fluctuations in the upper basin lakes, (2) to reestablish the natural floodplain and wetland habitat of the Kissimmee River, and (3) to re-create conditions favorable to the increase of production of wetland wildlife, vegetation, and native aquatic life. As a result, three major restoration evaluation and planning studies were initiated by the Corps of Engineers and the South Florida Water Management District (SFWMD).

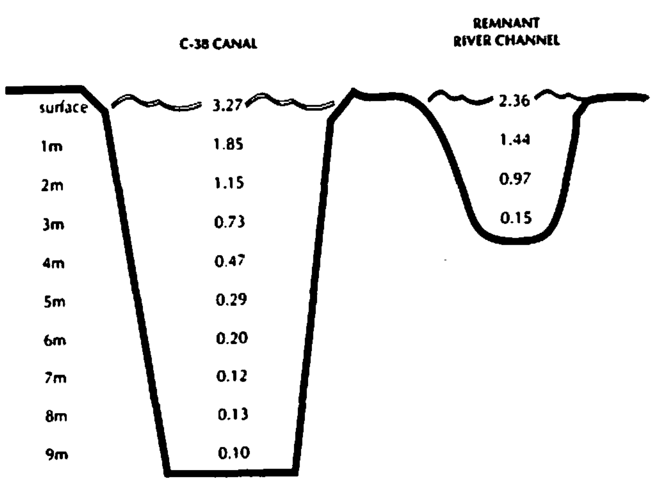

Figure 3. Typical summer-fall dissolved oxygen profiles in C-38 and remnant channels. Data represent mean dissolved oxygen concentrations (mg/liter) at six canal sites and 23 remnant river sites between July and October 1989.

(1) First Federal Feasibility Study (1978–1985). The primary objectives of the first feasibility study were to evaluate measures for restoring floodplain wetlands and improving water quality within the Kissimmee River basin. The study incorporated the concerns of many public and private groups and state and federal agencies in formulating objectives for restoring lost floodplain habitat of the Kissimmee River (Table 1).

Numerous structural and nonstructural restoration plans to meet these objectives were formulated and evaluated (Ta-

Table 1. Environmental concerns and objectives for restoration of the Kissimmee River set forth in the first Federal Feasibility Study, 1978–1985.

Environmental Concerns
Loss of naturally fluctuating water levels.
Loss of large areas of wetlands.
Deterioration of water quality in Lake Okeechobee and the Kissimmee Basin.
Changes in land use resulting in increased drainage.
Loss of natural river meanders.
Lower groundwater levels and reduced groundwater quality.
Potential need for increased flood protection.
Potential reduction in frost protection.
Potential increase in mosquito populations.
Reduced recreational navigational opportunities.
Feasibility Study Objectives for Restoration
Restore wetland areas.
Improve water quality.
Restore river meanders and oxbows.
Improve groundwater recharge.
Maintain flood protection.
Restore fluctuating water levels.
Provide surface water supply.
Maintain navigation.
Meet recreational demands.

U.S. Army Corps of Engineers (1992).

ble 2). Analyses determined that many of the plans were not feasible or did not meet restoration objectives. As a result, six alternative restoration plans were identified (Table 2) by the Corps of Engineers and distributed for public review. Comments, questions, and concerns from the public demonstrated growing support for backfilling C-38 as a means of restoring the Kissimmee River (U.S. Army Corps of Engineers 1992). Continued public support for the backfilling plan resulted in many plans being dropped from consideration, modified, or combined to create new alternative plans (Table 2). In late 1983, at the request of the Coordinating Council, the Corps of Engineers narrowed its restoration evaluation focus to two alternatives, including partial backfilling of C-38 and a combined wetlands approach that encompassed the plans for a flow-through marsh, pool stage manipulation, impounded wetland, and Paradise Run. Overall public support for dechannelization of the Kissimmee River led to the 1983 endorsement of the backfilling plan by the Coordinating Council.

Although the federal government played a critical role in the formulation of restoration objectives and the evaluation of alternative restoration plans, the first feasibility study did not recommend federal participation in the Kissimmee River restoration project. Federal policies and guidelines in effect at this time required that any recommended plan result in a net economic benefit, in which annual dollar benefits exceed annual dollar costs. When analyzed under the restrictions required by economic evaluation procedures, none of the proposed plans projected a net economic benefit (U.S. Army Corps of Engineers 1992).

(2) Kissimmee River Demonstration Project (1984–1990). As a result of the Coordinating Council's endorsement of the backfill plan, the SFWMD initiated the Kissimmee River Demonstration Project to assess the feasibility of the backfilling plan. The Demonstration Project had four major components: (1) implementation of a pool-stage fluctuation schedule to reestablish seasonal water-level fluctuations over approximately 1080 ha of floodplain, (2) construction of three notched weirs across C-38 to simulate the effects of backfilling by diverting flow through remnant river runs, (3) creation of a flow-through marsh system, and (4) hydrologic and hydraulic modeling studies to evaluate the engineering feasibility of the backfill, flood control implications, and sedimentation issues (Loftin et al. 1990). Although the demonstration project was not intended to fully restore prechannelization hydrology within the test area (Pool B) (Fig. 1), hydrologic changes were expected to play a key role in the biological response of the system (Toth 1993).

Results of the Demonstration Project

Hydrology. As expected, the demonstration project reestablished pre-channelization inundation patterns over only a limited portion of the floodplain. At the lower end of Pool B, stage fluctuations provided inundation frequencies similar to those of the pre-channelized system. Stage fluctuations and backwater effects of the weirs resulted in prolonged flooding of approximately 20% and periodic flooding of approximately 75% of the floodplain in the central portion

Table 2. Alternative restoration plans for restoring the ecological integrity of the Kissimmee River.

Alternative Restoration Plan	*Action*
No action.	Operate and maintain existing flood control and navigation systems.
Modify lake regulation schedule.	Increase flood storage in the upper basin by modifying lake regulation schedules.
Additional lake control structure.	Install structure above Lake Kissimmee to regulate Lakes Cypress, Hatchineha, and Kissimmee at different levels.
Complete backfilling.	Fill entire length of C-38 and remove structures.
*Partial backfilling.	Fill middle section of C-38, remove appropriate structures, install flow-through elements in Pools A and B.
Plugging.	Place earthen plugs at points along C-38 to divert flow to portions of remnant river channel.
*Flow-through marshes.	Construct wetlands adjacent to C-38 and below S-65A, S-65B, S-65C, S-65D.
*Pool stage manipulations.	Modify S-65A, S-65B, S-65C, S65-D, and S-65E to accommodate higher stages to increase wetlands.
*Impounded wetlands.	Create wetlands through a series of separate elements, including flow-through marshes, tributary impoundments, and pool stage manipulations.
Enhance existing system.	Remove or reshape excavated material along C-38.
*Paradise Run.	Restore Paradise Run wetlands.
*Best management practices.	Use BMPs to improve water quality and restore wetlands.
Minimum maintenance.	Restore prechannelization conditions through lack of maintenance.
Dual watercourse.	Create a riverine system adjacent to C-38.

*Plans that were advanced for further consideration.
U.S. Army Corps of Engineers (1992).

of Pool B. Backwater effects of the weirs at the northern end of Pool B resulted in historic inundation frequencies on approximately 35% of the floodplain and periodic inundation frequencies over an additional 30%–35%.

Reintroduction of flow through remnant river channels was also a major feature of the Demonstration Project. The notched weirs diverted up to 60% of the flow of C-38 through adjacent floodplain and river runs during high discharge periods (28 m^3/sec). Weirs diverted considerably less flow when C-38 discharge fell below 0.8 m^3/per second.

Vegetation. Plant community responses during the demonstration project indicated that reestablishment of appropriate hydrologic conditions led to rapid restoration of historic vegetation characteristics in river and floodplain habitats (Toth 1990). River channel and floodplain plant communities responded to subtle as well as major changes in flow, water depth, and inundation frequencies. Reintroduction of flow through remnant river channels reduced encroachment by vegetation into the center of the channel and restricted growth of emergent and floating hydrophytes to the littoral fringe. In addition, accumulations of dead and decaying organic matter were washed into C-38, restoring the historic shifting sand substrate in the remnant channels. The restored frequencies of floodplain inundation resulted in reductions of mesophytic and xerophytic species (for example, *Centella asiatica* [coinwort], *Paspalum conjugatum* [sour paspalum], and *Sambucus canadensis* [elderberry]) and replacement by hydrophytic species (for example *Panicum hemitomon* [maidencane], *Polygonum punctatum* [smartweed], and *Alternanthera philoxeroides* [alligatorweed]), typical of the pre-channelized ecosystem. These results indicate that many of the remaining species associations on the channelized floodplain are sensitive to hydrologic change and have the reproductive potential, including a viable seek bank or propagule source, to rapidly colonize habitats once favorable hydrology is restored (Toth 1990).

Invertebrates. Reintroduction of flow through remnant river channels resulted in colonization by invertebrate taxa characteristic of river communities rather than lentic ecosystems. Rheophilic taxa including *Stenacron* (Ephemeroptera: Heptageniidae), *Cheumatopsyche* (Trichoptera: Hydropsychidae), and *Rheotanytarsus* (Diptera: Chironomidae) replaced *Chaoborus* (Diptera: Chaoboridae) and other more lentic taxa. These replacements verified the importance of continuous flow in reestablishment of a more typical river invertebrate community (Toth 1993).

Invertebrate colonization of the reinundated floodplain illustrated that the critical trophic link between floodplain invertebrate production, serving as a food base for higher trophic level predators (wading birds, waterfowl, and fishes), could be reestablished quickly. Representative densities of most common floodplain invertebrate taxa were attained after only 40 days of inundation. The trophic importance of the continuous, open hydraulic connectivity between the river channel and floodplain was illustrated by invertebrate export rates from the floodplain during periods of water recession. Very small channels (less than one meter wide) carried as many as 4800 fish and invertebrates per hour to adjoining river habitats, reestablishing a key link in the trophic web of this system (Toth 1993). Although the importance of river channel-floodplain interactions was illustrated by fish and invertebrate export rates from the floodplain, the directional movement of fish and invertebrates between the river channel and floodplain depends on seasonal hydrology.

Fishes. A total of 25 and 16 fish species were collected from Pool B and Pool E (control area), respectively. Fish community response was reflected in an increase in abundance of *Lepomis punctatus* and *Lepomis auritus* (spotted and red-breasted sunfish, respectively) in river runs with reintroduced flow. These and other game fish (including largemouth bass, *Lepomis macrochirus* [bluegill], *Lepomis microlophus* [redear sunfish], and *Lepomis gulosus* [warmouth]) represented 58.5% of total biomass and 39.3% of total electrofishing catch in areas with increased flow. Game fish accounted for 43.7% and 20.0% of biomass and total numbers, respectively, in control areas located in Pool E (Wullschleger et al. 1990; Bull et al. 1991).

Wading Birds and Waterfowl. Reinundation of the floodplain, with subsequent positive response of other biological communities, led to increased utilization of the floodplain by wading birds and waterfowl. Pool B had the highest density of ducks and highest species diversity and richness of wading birds and waterfowl of any of the five pools within the Kissimmee River/C-38 system (Toland 1990). Wading bird densities were two times higher at the end of the demonstration project than densities in a previous 1978–1980 survey (Perrin et al. 1982). Much of the increased wading bird and waterfowl utilization of the floodplain occurred in the flow-through marsh, where inundation patterns were similar to those of the pre-channelized system. Although this area comprised less than 40% of the floodplain area in Pool B, it supported 70% of the waterfowl and 66% of the wading birds and had the highest wading bird density in the Kissimmee River/C-38 system (Toth 1993).

Consequences of the Demonstration Project. Results of the demonstration project confirmed the feasibility of restoring the structure and function of the Kissimmee River ecosystem. Reestablishment of two components of pre-channelized hydrology, water level fluctuations and reintroduction of flow, increased floodplain inundation and reestablished biological communities similar to those of the pre-channelized system (Toth 1993). Largely based on these findings, environmental restoration goals and objectives for the Kissimmee River were formulated at the Kissimmee River Restoration Symposium conducted by the SFWMD in 1988. The symposium emphasized an ecosystem approach to restoration with a single objective: to restore the ecological integrity of the Kissimmee River (Toth 1993).

It was proposed that the ecological integrity of systems like the Kissimmee River be determined by five classes of variables (Karr et al. 1983):

(1) source of energy: type, amount and size of allochthonous inputs, primary production, and the seasonality of available energy;
(2) water quality parameters: temperature, turbidity, dissolved oxygen, nutrient inputs, organic and inorganic chemicals, heavy metals, and pH;
(3) habitat quality: substrate, water depth, current velocity, availability of habitat for all life-history needs, and habitat diversity;
(4) hydrologic conditions: water volume and temporal variability of discharge.
(5) biotic interactions: competition, predation, disease, and parasitism.

The symposium also led to the definition of five hydrologic criteria to be met in order to restore the ecological integrity of the Kissimmee River:

(1) Continuous flow with duration and variability characteristics comparable to the pre-channelized system. This includes re-establishment of continuous flow from July to October, with highest discharges in September-November and lowest discharge in March-May. Discharge variability should be comparable to the prechannelized hydrograph (Fig. 4).
(2) Average velocities between 0.3 and 0.6 m^3 per second when flows are contained within channel banks.
(3) A stage-discharge relationship that results in overbank flow along most of the floodplain when discharges exceed 40–57 m^3 per second.
(4) Stage recession rates that typically do not exceed 0.3 meters per month.
(5) Stage hydrographs that will result in floodplain inundation frequencies comparable to pre-channelization hydroperiods, including seasonal and long-term variability patterns (U.S. Army Corps of Engineers 1992).

Kissimmee River Modeling

A three-year physical and mathematical modeling study on the physical and hydrologic characteristics of the Kissimmee River, conducted by the University of California at Berkeley, indicated that backfill material (predominantly returned spoil) could be stabilized to resist erosion by major flood flows (Shen et al. 1994). Mass transport of these

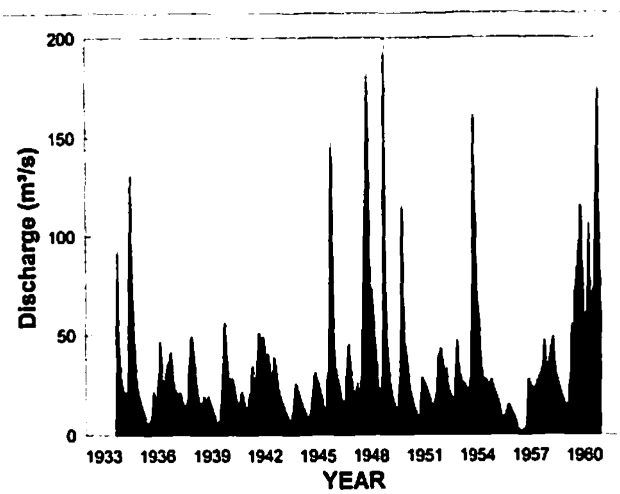

Figure 4. Mean monthly discharge for the period of record prior to channelization. Discharge was recorded at the outlet of Lake Kissimmee.

sediments to Lake Okeechobee would not occur. In addition, these studies indicated that unfilled sections of C-38 within the area to be restored would severely limit restoration efforts by causing high velocities in remnant river channels, rapid recession of floodplain water levels, and inadequate floodplain inundation (Loftin et al. 1990). This study suggested that hydrologic restoration of the Kissimmee River was feasible, but current restoration alternatives did not meet the hydrologic criteria necessary to restore the ecological integrity of the Kissimmee ecosystem.

Alternative Restoration Plans. Results of the demonstration project, the Kissimmee River Restoration Symposium, and the Berkeley hydrologic modeling study were used to formulate alternative restoration plans that focused on redirecting flow through remnant river channels and across the historic floodplain. The most important constraint in the restoration planning and modeling efforts was flood control. Flood control constraints specified that all plans for restoration must prevent flood damages beyond the present level of flood protection. Alternative plans included

(1) The *Weir Plan* included the installation of ten fixed weirs, identical to those used in the demonstration project, along C-38 to divert flow into adjacent river channels.
(2) The *Plugging Plan* was similar to the Weir Plan but utilized ten permanent plugs consisting of material originally dredged during construction of C-38 that would be placed in the same location as the proposed weirs to divert flow into remnant river sections.
(3) The *Level I Backfilling Plan* included backfilling of ten sections of C-38 to divert flow to remnant river runs, while retaining water control structures S-65B, S-65C, and S-65D.

(4) The *Level II Backfilling Plan* would result in the continuous backfilling of C-38 from the middle reaches of Pool B to two miles north of S-65E. This plan would eliminate S-65B, S-65C, and S-65D and related structures, including spillways, locks, auxiliary structures, and tieback levees (U.S. Army Corps of Engineers 1992).

In the final analysis, only the Level II Backfill Plan met the hydrologic criteria for restoration, which provided for flow, seasonal discharge patterns, floodplain inundation frequencies, and stage recession rates comparable to the prechannelized Kissimmee River ecosystem (Table 3). Therefore, this plan was accepted as the only alternative for restoration of the Kissimmee River ecosystem.

Restoration recommendations were subsequently endorsed by the State of Florida in early 1990. As a result, the U.S. Congress authorized a second feasibility study to evaluate the continuous backfilling plan and to provide a comprehensive plan for environmental restoration of the Kissimmee River ecosystem (U.S. Army Corps of Engineers 1992).

(3) Second Federal Feasibility Study (1990 to Present). A second feasibility study by the Corps of Engineers focused on implementing the continuous backfilling plan. This study was designed to determine the extent of federal participation in the restoration project. Design assumptions, structures, construction methodologies, and operational procedures were reviewed to identify ways to improve engineering design, reduce financial cost, and increase benefits to fish and wildlife. These analyses resulted in a modified Level II Backfilling Plan, which became the recommended plan for restoration by the Corps of Engineers. This plan would result in the continuous backfilling of C-38 from the middle reaches of Pool B to the lower reaches of Pool D and would eliminate S-65B and S-65C and related structures. This plan mandated analysis of additional actions, including land acquisition, mitigation of tributary effects as a result of increased flooding, structural modifications to water control structures and tieback levees, and degradation of existing floodplain levees. Evaluation of all restoration alternatives and the results of the SFWMD's demonstration project indicated that the modified backfilling plan is the most appropriate means for reestablishing ecological integrity, as defined above, of the Kissimmee River ecosystem (U.S. Army Corps of Engineers 1992).

Restoration Plan

Restoration of the Kissimmee River and floodplain will have two major components: (1) the Headwaters Revitalization Project in the upper basin; and (2) the Modified Level II Backfilling Plan in the lower basin. The Headwaters Revitalization Plan will provide for modification of water regulation schedules for the upper chain of lakes and thereby provide for greater and more natural fluctuations of water levels in the lakes. These modifications will assist the reestablishment of pre-channelization seasonal inflow characteristics from Lake Kissimmee to the lower basin. The revised schedule will increase water-level elevations from 14.9 meters to 16.5 meters (~54.0 NGVD), and will be zoned to provide

Table 3. Performance evaluation summary for alternative restoration plans.

Criteria	*Weirs and Plugging Plan*	*Level I Backfilling*	*Level II Backfilling*
Discharge Characteristics	continuous flow and seasonal patterns reestablished	continuous flow and seasonal patterns reestablished	continuous flow and seasonal patterns reestablished
Flow Velocities	greater than prechannelization maximum along 42% of river channel with restored flow	greater than prechannelization maximum along 40% of river channel with restored flow	less than 55 cm/sec along 95% of river channel with restored flow
Overbank flow Threshold	overbank flow at prechannelizaiton threshold along 62% of the floodplain adjacent weirs	overbank flow at prechannelization threshold along 63% of the floodplain adjacent backfilled canal	overbank flow at prechannelization threshold along 64% of the floodplain adjacent backfilled canal
Stage Recession Rates	potentially very rapid, particulary in upper 50% of each pool	potentially very rapid, particularly in upper 50% of each pool	slow, rarely greater than 30 cm/month
Floodplain Inundation Frequencies	significantly less than prechannelization on at least 50% of floodplain	significantly less than prechannelization on at least 50% of floodplain	comparable to prechannelization

U.S. Army Corps of Engineers (1992).

·arying discharges based on season and water level (Fig.). The revised schedule is expected to increase seasonal vater storage capacity in the upper lakes by approximately 2,350 hectare-meters (the equivalent of 12,350 ha flooded o a depth of 1 meter; U.S. Army Corps of Engineers 1992). ⁄lodifications to the S-65 structure will provide higher dis- :harge capacity. Acquisition of over 6882 ha of land within he upper basin (for water storage below an elevation of .6.5 m) will allow return to hydrologic characteristics crit- cal to the success of the lower basin project.

The lower basin plan calls for continuous backfilling of :-38 canal from the middle of Pool B to the lower end of Pool D, recarving of 14 km of obliterated river channel, and ·emoval of the S-65B and S-65C water control structures ınd tieback levees. These measures will result in restora- :ion of 104 km^2 of river-floodplain ecosystem, including 70 km of contiguous river channel and 11,000 ha of flood- plain wetlands (Toth 1993).

Backfilling of C-38 is slated to begin in 1998 and will be implemented in a series of construction phases. Phase one, which is expected to be completed in approximately four years, will begin at the lower end of Pool C and extend to a point below the S-65B water control structure (Fig. 1). At the completion of phase one, the S-65B water control structure will be removed. Phases two and three will extend from the lower end of Pool D to the downstream limit of phase one (the lower end of Pool C). S-65C will be removed at the completion of phase three. Phase four will begin at the upstream limit of phase one (at S-65B) and proceed northward, through Pool B, to a point south of weir three of the demonstration project. Original river channel eliminated by the excavation of the C-38 structure will be reexcavated as each phase progresses and will be connected to existing remnant river channels. Final completion of construction is projected for 2011.

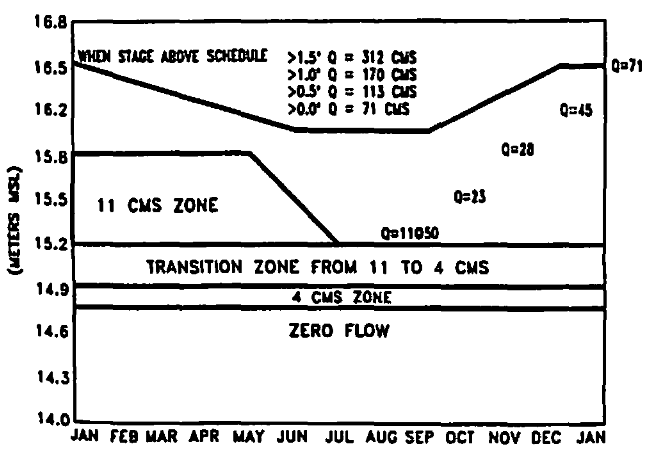

Figure 5. Proposed Lake Kissimmee discharge regulation schedule. Discharges from Lake Kissimmee are based on stage levels and are zoned to provide variable, continuous flow to the lower basin.

Prior to the initiation of full-scale construction in 1998, a test fill of C-38 has been conducted to assess construction methodologies. Approximately 300 meters of C-38, located in Pool B, were filled with adjacent soil (material originally dredged to form C-38). Elevations in the degraded spoil area and backfilled section of canal were returned to pre-channelization levels. The test fill was intended primarily to evaluate fill consolidation and construction methodologies, but it provided the opportunity for limited environmental assessments that will be used to fine-tune the restoration plan. The test fill began in March 1994 and was completed in August 1994.

Design of a Restoration Evaluation Program

The Kissimmee River restoration project will attract attention from national and international environmental and scientific communities and will serve as a template for future ecosystem restoration projects. Detection, documentation, and understanding of physical, chemical, and biological changes resulting from the project are essential to the success of restoration. The areal extent of the project and the ecological complexity of the system give rise to numerous challenging questions regarding selection of appropriate biological and ecological metrics to be used in evaluating ecosystem response as a result of restoration efforts.

Past trends in restoration evaluation have often focused on single-species responses to restoration efforts. These studies, while providing an understanding of certain life-history requirements of individual species, rarely add to our understanding of ecosystem processes and the complex web of biotic and abiotic interactions that shape and maintain biological communities.

In July 1991, the South Florida Water Management District commissioned a scientific advisory panel to provide recommendations for development of a comprehensive ecological evaluation program. The panel consisted of seven select scientists with expertise in a range of ecological disciplines relevant to the restoration project. After a thorough review of available background material and three days of technical meetings, the advisory panel submitted a series of recommendations for evaluating the Kissimmee River restoration (Karr et al. 1991). The Kissimmee River restoration evaluation program will integrate taxonomic, habitat, functional, structural, and conceptual approaches to achieve three general objectives:

(1) To determine if the restored channel and floodplain meet the required hydrologic criteria outlined in the Plan Evaluation and Design Report (Karr et al. 1991).
(2) To determine if rigorously selected biological and ecological attributes have been restored.

(3) To implement an adaptive management plan to improve and direct the restoration trajectory based on analyses of objectives 1 and 2.

The panel recommended five major phases to the evaluation program. These include:

(1) *Establishing reference conditions.* Reference conditions define realistic expectations for restoration and will include those factors (physical, chemical, and biological) that most likely contributed to the establishment, interaction, and persistence of the biological communities prior to channelization. Reference conditions can be established in three ways: (a) by establishing an unaffected reference site with similar chemical, physical, and land-use conditions as the pre-channelized system, (b) by using pre-channelization data, and (c) by using theoretical approaches.
(2) *Establish baseline conditions.* Baseline conditions define the current state of the biological communities and allow for comparisons with realistic expectations (reference conditions) for restoration, as well as actual conditions resulting from restoration.
(3) *Construction impact assessment.* Assessment of construction impact will allow for the minimization or alleviation of any short-term or incidental environmental impacts occurring over the course of the construction phase.
(4) *Post-construction restoration assessment.* Long-term restoration response evaluations will be the most complex of the evaluation program. Assessment of short- and long-term responses of all biological communities is critical in determining restoration success and is crucial to the adaptive management phase.
(5) *Adaptive management.* Adaptive management will involve the use of data collected in restoration response evaluations to provide continuous, scientifically sound fine-tuning of restoration efforts, with particular reference to the hydrologic component of the project.

The advisory panel also identified five critical biological communities to be used in the restoration evaluation program as tools to assess restoration success. These include river channel-floodplain plant communities, wading birds, waterfowl, fishes, and invertebrates. This first meeting of the advisory panel laid the framework for the evaluation program. Subsequent meetings have been held and will continue to be held on an annual basis for peer review of research plans, proposals, and manuscripts pertaining to Kissimmee River restoration. This rigorous review process will ensure that statistical designs and methods for establishing and comparing reference, baseline, and post-restoration ecosystem response—particularly biological community structure and function—are scientifically sound and sufficient to show direct cause-and-effect relationships between the physical restoration and ecological responses.

Restoration Evaluation Program

The restoration evaluation program is the mechanism by which restoration success will be measured; it will be conducted from an ecosystem perspective. An ecosystem perspective requires evaluation of biotic and abiotic conditions within the Kissimmee basin and must consider interactions among physical, chemical, and biological components of the system. In order to accurately assess the effects of restoration, therefore, an evaluation program must include (1) a detailed evaluation of ecosystem structure and function that will allow for the prediction of ecosystem responses, before and after restoration; (2) establishing cause-and-effect relationships between restoration measures and ecosystem response; (3) quantitative measures of biological responses, and (4) documentation of ecosystem changes and their social effects (Toth 1993).

The comprehensive evaluation program for the Kissimmee River restoration project will include taxonomic (vegetation, invertebrate, fish, and waterbirds), habitat (river and floodplain), functional (river-floodplain, predator-prey, food web, and competitive interactions), structural (vegetation, invertebrate, fish, and waterbird communities), and conceptual components—the structure of the pre-channelized biological community and the attributes of structure and function that will best elicit restoration responses by all biological communities. The evaluation program will focus on changes in hydrologic regime, spatial distribution and composition of vegetation, and community structure of aquatic invertebrates, fish, and waterbirds that accompany the restoration program. In addition, climatic, physical, and chemical variables such as stage height, discharge, temperature, dissolved oxygen, and water-quality parameters will be measured. Detailed recommendations for specific components of the restoration evaluation program are presented in subsequent papers in this issue of the journal.

In order to develop conceptual models for vegetation, aquatic invertebrates, fishes, and waterbirds of the Kissimmee River and floodplain, we must identify the ecological processes, factors, and relationships that govern these groups of organisms, consider how these communities interact, and predict how these organisms are expected to respond to the restoration program.

This issue of *Restoration Ecology* presents conceptual models for vegetation, aquatic invertebrate, fish, and waterbirds of the Kissimmee River. Emphasis is placed throughout on predicting the responses of these various biological communities to restoration. Ecosystem restoration at the scale proposed for the Kissimmee River has rarely, if ever, been undertaken. One hundred four square kilometers of land, including 70 km of river channel and 11,000 ha of floodplain wetlands, are planned for restoration. In an endeavor of this magnitude it is important to define what is to be expected from this effort and to design a comprehensive evaluation program for assessing the outcome for the various biological communities and the ecosystem as a whole. This series of papers attempts to accomplish this goal and to stimulate thought and discussion concerning large-scale ecosystem restoration.

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