ISLAND CONSTRUCTION – REBUILDING NATURAL LEVEES TO RESTORE CONNECTIVITY IN THE NORTHERN REACHES OF THE UPPER MISSISSIPPI RIVER

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INTRODUCTION

Over ten miles of islands have been constructed during the last twenty years in Pool 8 of the Upper Mississippi River (UMR) near La Crosse, Wisconsin to restore fish and wildlife habitat. Funding for this effort came through the Upper Mississippi River Environmental Management Program (EMP), which was authorized as part of the Water Resources Development Act of 1986 (WRDA 1986). When the EMP was authorized there was no blueprint for restoring the Upper Mississippi River, yet the WRDA language required that a certain amount of money be invested in habitat restoration. To meet this requirement, an interagency team including personnel from State Natural Resource Agencies, the United States Fish and Wildlife Service (USFWS), and the United States Army Corps of Engineers (USACE) worked together to plan and design these islands, which are located in the Upper Mississippi River Fish and Wildlife Refuge.

Significant changes had occurred on the UMR since the locks and dams were constructed in the 1930s, raising and stabilizing water levels. Figure 1 shows the transition that took place in lower pool 8 from 1930 (pre-lock and dam) to 1938 (one year after lock and dam 8 was constructed) to 1991 (54 years after lock and dam construction. In 1930, the two and a half mile wide river valley in this reach consisted of a few large channels with even larger floodplain areas that included secondary channels, isolated lakes, and floodplain forests. The large channels remained in 1938 after inundation by the dams, however the floodplain was now submerged and had become much more connected to the channels.

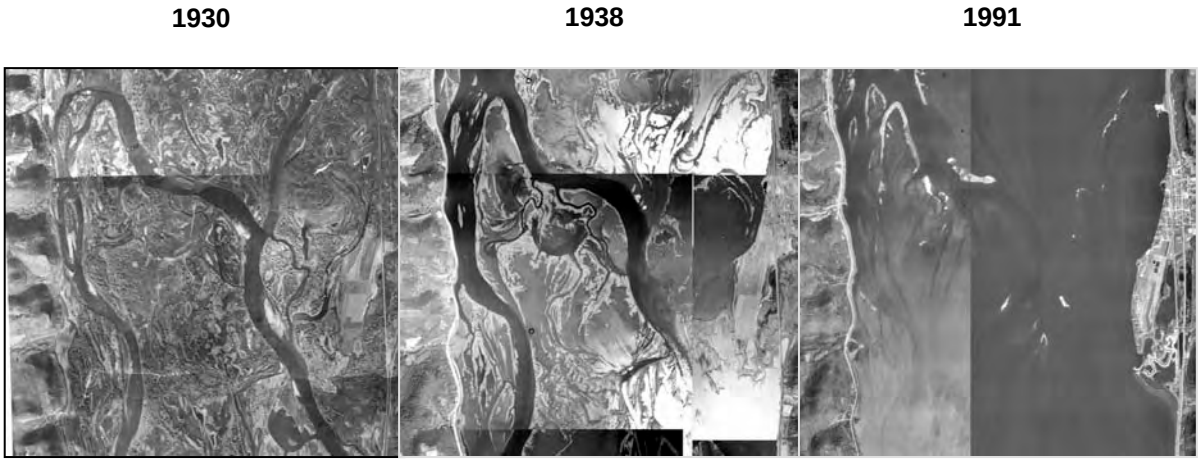

Figure 1 Hydrologic, geomorphic, and habitat changes in lower pool 8 of the Upper Mississippi River due to lock and dam construction in 1937.

Although the river had been altered significantly, the off-channel areas (now called backwaters) provided valued habitat that was enhanced by the remaining islands and vegetation beds. However, by 1991 the relentless erosion from river currents and wind driven waves had caused most of the islands and vegetation beds to disappear resulting in highly connected channels and backwaters. Over half of the total river flow was conveyed in the backwaters, by this time. Isolated areas that once provided refuge to migrating waterfowl and overwintering fish ceased to provide this need.

Because of the obvious effects the locks and dams had in raising water levels and submerging the floodplain in the lower reaches of each navigation pool, the interagency teams focused their efforts in these areas. This has been especially true in Lower Pool 8, which has one of the largest impounded areas of any pool in the system.

Hydrologic connectivity was an uncommon term in the late 1980s and 1990s when the project teams were planning and designing the first EMP projects. In almost all cases though, the teams developed management actions that reduced inflows to project areas by reducing the size or number of connections between the channels and backwaters. Fisheries managers knew that over-wintering habitat for many species of fish required low flow velocities, adequate dissolved oxygen, and warmer water temperatures. Waterfowl managers understood the importance of submerged aquatic vegetation, which grew best in lower flow environments, and the need to minimize disturbance by humans. The public had observed the loss of islands and experienced the effects of sediment deposition since the locks and dams had been constructed. All of this information and knowledge pointed towards the need to reduce hydrologic connectivity. Islands were the logical choice to improve habitat for various species of fish, birds, and animals. They would result in the partial restoration of natural levee function and in a hydrologic regime that reflected more natural seasonal variation. During summer and winter low flow conditions, backwater flow was reduced enough so that water velocity, temperature, and dissolved oxygen concentration were at more desirable levels. Some sections of the islands were constructed at low elevations so that during Spring high flow conditions, floodplain conveyance was maximized. Movement of aquatic organisms into the areas sheltered by the islands was maintained by leaving openings in the islands (usually at the downstream end).

CONNECTIVITY DEFINITIONS

The term connectivity is used in different ways. Jackson and Pringle (2010) referred to hydrological connectivity in a broad ecological sense as water mediated transport of matter, energy, or organisms within or between elements of the hydrological cycle. This definition seems to recognize both the transport of constituents and organisms (e.g. nutrients and larvae) by water, and the actual movement of organisms (e.g. fish) through water. The Upper Mississippi River Conservation Committee produced a white paper on connectivity in which connectivity was defined as a dynamic natural pathway that provides a functional access for an organism (or nutrients) from one habitat type to another and/or creates a physical linkage between habitats through a natural conduit (UMRCC 2008). They went on to describe the generic term “connectivity” in the following categories: habitat connectivity, lateral flood pulse connectivity, lateral non-flood connectivity, longitudinal connectivity, main stem to tributary connectivity, linear connectivity, and sub-surface connectivity. The USACE Engineering Regulation 1105-2-

100 (USACE 2000) describes connectivity as a measure of the potential for movement and dispersal of species throughout a given area or ecosystem. Clearly the focus of this definition is on habitat and increasing the connections (or corridors) between habitats – a very meaningful objective in many situations. Others have recognized that connectivity is naturally variable and that defining this variation is critical to making good decisions regarding ecosystem restoration. Brierley and Fryirs (2008) stated that whether appraised in biophysical or social terms, landscapes, ecosystems, and communities can be relatively connected or disconnected. For river management to be successful and relevant it is important to recognize that biophysical disconnection may be natural and healthy at a given time and place. Roach et al. (2008), studying a reach of the UMRS just upstream of Pool 8, stated that extensive lateral complexity within the riverscape creates strong gradients in hydrological connectivity from the main channel through the many secondary channels that pass around wooded islands to the more isolated backwaters.

For ecosystem restoration on the UMR, hydrologic connectivity can be thought of as the exchange of water from one water body to another (channels to floodplains for instance). It can be described at different spatial scales (watershed, river reach, backwaters) and temporal scales (annual, daily). Parameters that can be used to describe hydrological connectivity include its magnitude, duration, frequency, seasonal timing, inter-annual variability, and flow sequencing. Although the EMP has been the main program for habitat restoration on the UMR, funding limits and program requirements essentially limited the scale of projects to individual backwaters rather than larger river reaches or watersheds.

HISTORIC CONDITIONS

Based on maps from the 1800s, the Upper Mississippi River in the reach between Lake Pepin and the Wisconsin River delta consisted of a main channel, secondary channels, a floodplain, and natural levees. The natural levees were one of the most important geomorphic features in the river valley. They separated flowing channels from floodplains during most of the year, they acted as visual barriers between the channels and floodplain, and they were the highest landforms in the active floodplain providing conditions for terrestrial vegetation that couldn't survive at lower elevations. Some of the early studies done to identify habitat restoration alternatives recognized the importance of natural levees. Fremling (1976) stated that "many marshes which flank the Mississippi River owe their existence to natural levees which protect them from normal river flow". He went on to explain that "such levees are formed when the river spills over its banks during flood time, loses its capacity to carry sediment, and drops much of its suspended load along the channel border".

Lock and dam construction in the 1930s raised and stabilized water surface elevations, permanently submerged most of the natural levees in the lower reaches of each navigation pool, leaving only their highest portions as islands. Submergence and subsequent island erosion increased the number and size of connections and transformed them to permanent connections, rather than seasonal ones corresponding to a certain flood event (Figure 1). Wind driven wave action became a much more significant factor in the floodplain of the lower pools also, causing even more erosion and further increasing connections. The altered conditions initially produced unique and productive habitat, however the seasonal variability in physical, chemical, and

biologic properties of the submerged floodplains, which were now called backwaters was greatly reduced. This created a number of problems including elimination of the wet-dry cycles needed for many aquatic plants, reduced light penetration, loss of over-wintering fish habitat, altered patterns of sediment deposition, and reduced flow in adjacent channels.

PROJECT PLANNING AND DESIGN

Objectives

Islands were designed and constructed to achieve a set of objectives and criteria that were developed by the interagency teams based on the habitat needs of various species of fish, birds, and animals. Essentially, during low flow conditions, floodplain conveyance had to be low enough so that water velocity, temperature, and dissolved oxygen concentration were at optimum levels for winter fish habitat. However, during high flow conditions, floodplain conveyance had to be high enough so that effects on water surface elevation were minimized. Although it wasn't explicitly stated as an objective, a more riverine sediment transport regime resulted, one that probably more closely resembles historic conditions.

Future without project conditions

In pool 8, the observed changes since the locks and dams were constructed, suggested a condition that would not improve during a reasonable planning horizon. Emergent and submergent aquatic vegetation had disappeared from many areas. Islands had eroded and because of the altered hydrologic connectivity, the river had lost its ability to transport coarse grained (or sand size) sediment to the project area. Operation of the navigation dams resulted in a condition where the bankfull water surface elevation was less than a foot higher than the average annual water surface. This meant that the ability for the river to build islands on its own through geomorphic processes was gone.

Monitoring and Modeling

Hydrologic monitoring was initiated early in the study process to quantify the flow distribution in lower pool 8. Although the number and size of connections between channels and backwaters had increased significantly over time due to island erosion, the rate of change in the early 1990s had slowed down considerably. This made it possible to collect 3 or 4 sets of measurements at each measurement site for different river flow conditions that could be used to develop rating curves for each site. Bathymetric data had been collected in lower pool 8 by the United States Geologic Survey (USGS) using funds from the Long Term Resource Monitoring Program (LTRMP). The LTRMP is funded through the EMP also. A two-dimensional hydraulic model (RMA-2V) was calibrated to these rating curves and used to simulate flow exchange between the main channel and the floodplain. This information was used to estimate ecosystem outputs for various alternatives. GIS was used to develop elevation models for historic and existing conditions. These elevation models were used to quantify sediment deposition in the area and along with the hydraulic models were used to assess sediment transport.

Selected alternatives

During the planning and design of these islands, factors considered included constructability, cost, shoreline stability, and ecosystem outputs. Although connectivity wasn't explicitly listed as a design criterion, both hydraulic and habitat connectivity in the project area were changed. Figure 2 shows pre-project conditions (1991 aerial photo), island layout (2003 aerial photo) and simulated flow velocities from the hydraulic model. Island layout was based on the historic location of islands shown earlier in figure 1, with adjustments made based on opportunities to maximize ecosystem output. In all cases, there was a desire to separate backwater areas from flowing channels. Islands were positioned along channels and island remnants to rebuild the natural levees that were submerged by dam construction and eroded by wave action. This reduced backwater flows in the target backwater areas that were analyzed for ecosystem outputs.

Because of the raised and stabilized water levels in lower pool 8, island elevations usually were set higher than the original natural levees. The lower islands in pool 8 were set at the 2.5-year flood, while the higher islands were set at the 4-year flood. Rock spillways replaced earth islands in several locations to provide floodplain flow when river discharge exceeds the 1.5-year flood event.

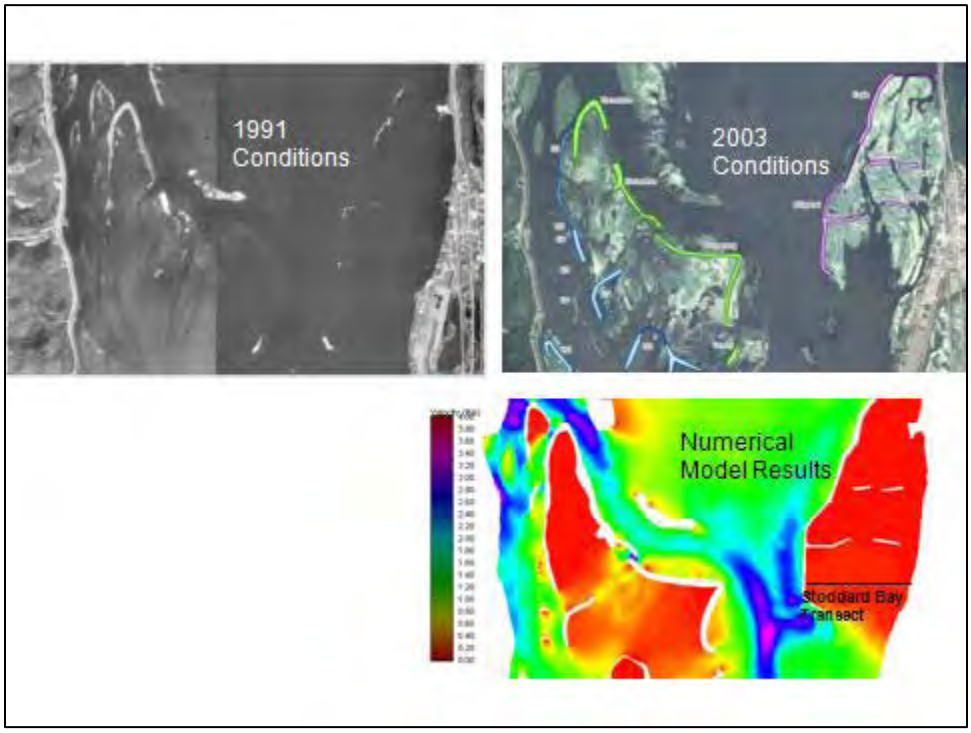

Figure 2. Images showing pre-project conditions (1991 aerial photo), proposed islands (2003 Conditions), and the effects of the proposed islands on flow velocity based on the results of a two-dimensional numerical model.

HYDROLOGIC CONNECTIVITY CHANGES IN STODDARD BAY DUE TO ISLAND CONSTRUCTION

Although, historic data on hydrologic connectivity in Stoddard Bay doesn't exist, historic maps and photographs suggest that inflows to this area were minimal for low flow conditions. Following lock and dam construction, the number of hydraulic connections increased, however a chain of islands around Stoddard Bay and within the bay limited flows. As the islands eroded, the amount of flow entering the bay increased. Figure 3 is a comparison of pre-project and post-project hydrologic connectivity at the Stoddard Bay transect that is depicted on Figure 2. Here hydrologic connectivity is defined as the amount of flow conveyed through Stoddard Bay divided by the total river flow measured at Lock and Dam 8. For pre-project conditions hydrologic connectivity varied from 10- to 20-percent depending on the total river discharge condition. For post-project conditions, hydrologic connectivity was greatly reduced for low flow conditions, with significant increases occurring for higher flows once islands and rock sills are overtopped. The two dimensional hydraulic model indicates that as total river flows approach the 10-year flood, flow conveyance through Stoddard Bay approaches pre-project conditions.

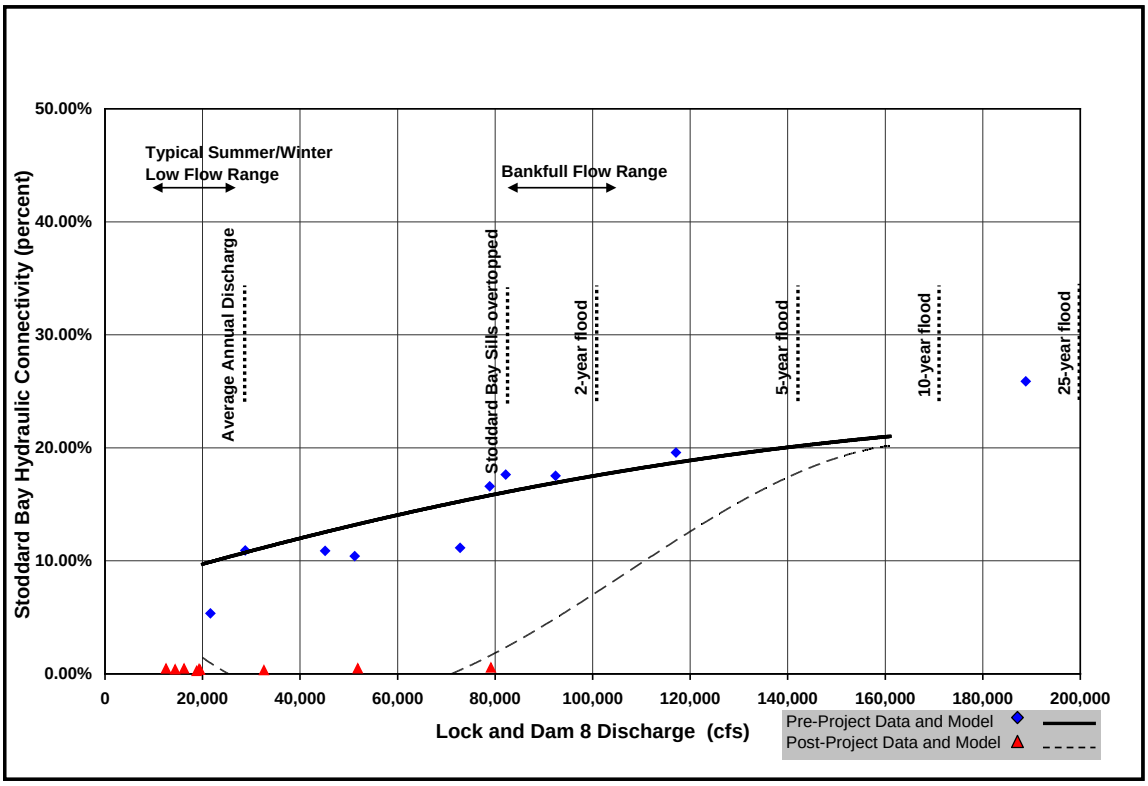

Figure 3. Stoddard Bay hydrologic connectivity for pre-project and post-project conditions. Hydrologic connectivity is given as percent of the total river flow that is conveyed through Stoddard Bay. The river discharges at Lock and Dam 8 represented here vary from low discharge conditions to a 25-year flood event.

The interagency team had developed hydrologic criteria for improving habitat conditions in Stoddard Bay. During winter low flow conditions, the inflows had to be extremely low so that temperature and velocity conditions would be suitable for overwintering fish. During floods, flow through the bay had to be high enough to minimize flood impacts. To maintain flood conveyance, over two-thousand feet of rock sills were constructed at approximately the bankfull flood event. The bankfull discharge is commonly used to describe the flow condition when the natural levees (or river banks) are overtopped. This discharge is considered to have morphological significance because it represents the breakpoint between the process of channel formation and floodplain formation (Copeland, 2001). Ecologically, this breakpoint and the increase in the number and size of the hydrologic connections between the river and its floodplain, also increases the flux of sediments, nutrients, and organisms. Figure 4 shows the 1999 to 2003 inflow hydrograph to Stoddard Bay for post-project conditions, and for a hypothetical "No Island" condition that would have existed if islands had not been constructed. These hydrographs were developed based on the flow relationships from Figure 3. Island construction has established a spring-time flood pulse with lower flows occurring during the remainder of the year. There was no major spring flood in the year 2000, thus there wasn't an observed pulse. Major flooding occurred in 2001 resulting in significant inflows through Stoddard Bay.

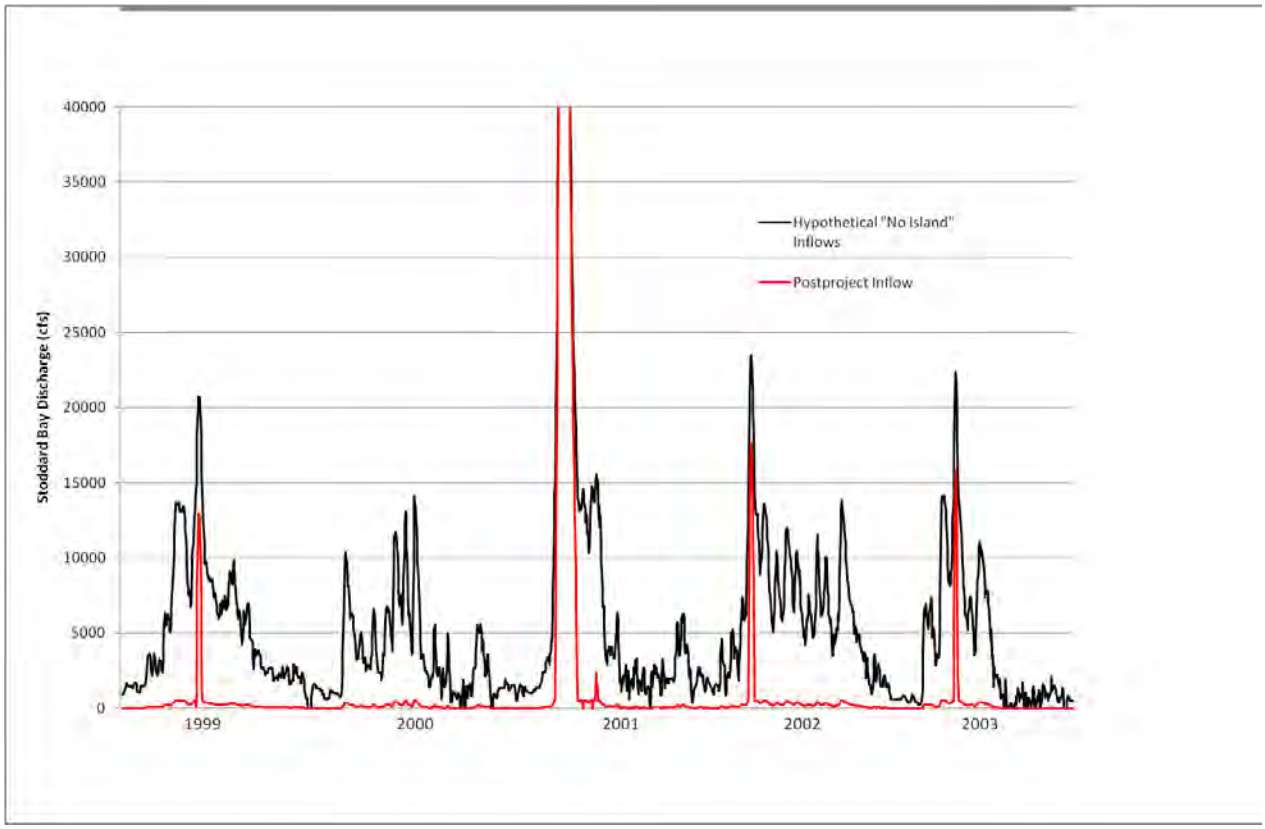

Figure 4. Inflow hydrographs to Stoddard Bay for the years 1999 to 2003 for post-project conditions and for a hypothetical "No Island" condition which would have occurred if the islands had not been constructed.

CONCLUSION

Island construction in lower pool 8 has restored natural levee function, decreased hydrologic connectivity between channels and backwaters, and partially restored a more natural seasonal flow regime in backwaters. Islands were designed so that inflows to these backwaters were reduced significantly for low flow conditions, while maintaining flow conveyance during flood conditions. Monitoring indicates that the physical, chemical, and biological characteristics of backwaters have been improved. Only a partial restoration of hydrological conditions is possible since a minimum water surface elevation is maintained for commercial navigation.

In most ecosystem restoration scenarios a common objective is to increase connectivity. However in the northern reaches of the Upper Mississippi River, the effect of lock and dam construction was to permanently raise water surface elevations and increase hydrologic connectivity to levels that degraded habitat. In order to improve backwater habitat, hydrologic connectivity had to be reduced. Island construction is one of the management actions that can be done to reverse this effect. These projects have significant support from the natural resource agencies managing the river and from the public.

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