UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL MANAGEMENT PROGRAM
DESIGN HANDBOOK

CHAPTER 9

ISLANDS

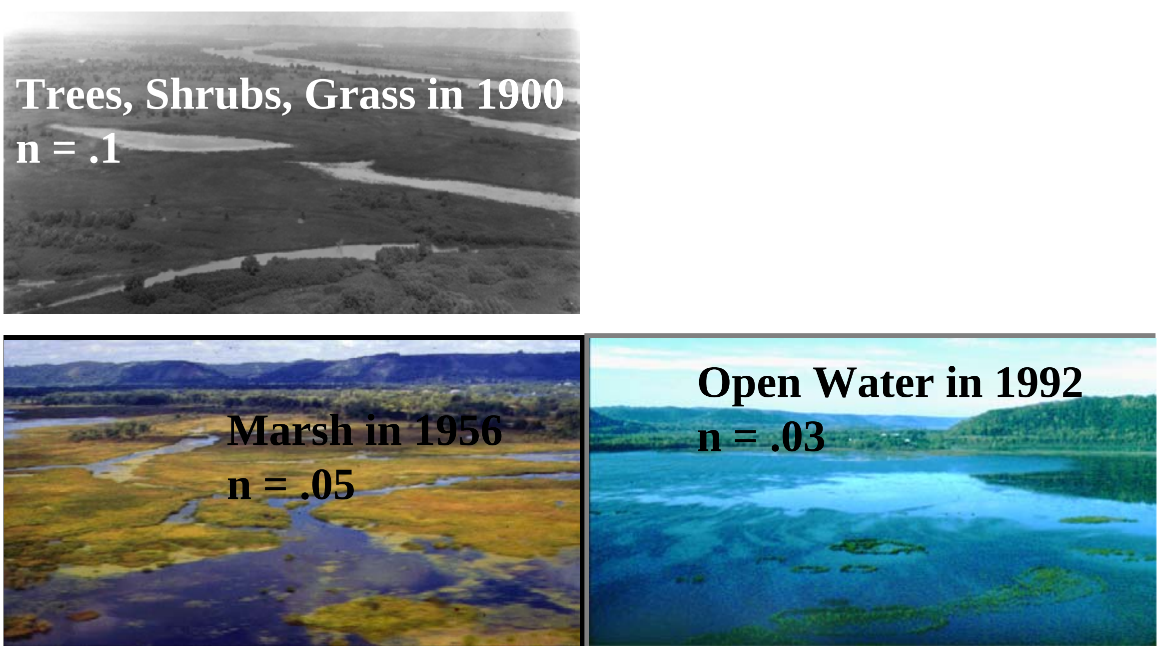
APPENDIX A
PHYSICAL RIVER ATTRIBUTES

Effects of Lock and Dams and Islands on
Hydraulics, Sediment Transport, and Geomorphology

APPENDIX A
PHYSICAL RIVER ATTRIBUTES

The Upper Mississippi River is island braided with many anastamosing side channels, sloughs, backwaters, and islands (Collins & Knox, 2003). Natural levees separate the channels from the backwaters and floodplain. In its natural state, the flow of water and sediment was confined to channels during low flow conditions. For larger floods, the natural levees were submerged resulting in water and sediment conveyance in the floodplain, however channel conveyance continued to be high since floodplain vegetation increased resistance and reduced discharge in the floodplain. The River today is a reflection of many changes that have altered the natural condition of the river (Chen & Simons, 1979, Collins & Knox, 2003). These include early attempts to create a navigation channel through the construction of river training structures, the conversion of the watershed to agricultural land-use, the urbanization of some reaches of the river, and the introduction of exotic species. However, the construction of the Locks and Dams in the 1930s is the most significant event affecting the condition of the river and most restoration efforts attempt to alter the impacts of the locks and dams.

Construction of the locks and dams submerged the natural levees and floodplain creating navigation pools upstream of the dams and leaving only the higher parts of the natural levees as islands. Table 9.A.1 shows the effect of submergence on parameters describing hydrodynamics, sediment transport, and geomorphology in the lower portions of navigation pools. Submergence altered habitat in the floodplain producing a robust response of aquatic plants and animals in the shallow marshes that were created. However, because a minimum pool level is maintained for navigation, the low water portion of the annual hydrologic cycle was eliminated ($\Delta \mathbf{z_w}$ decreased). This degraded habitat for many plants and animals adapted to a larger range of water level fluctuations. The shift in vegetation communities (photograph 9.A.1) decreased floodplain resistance causing increased floodplain conveyance (i.e. floodplain connectivity) with time (Q_f/Q_t increased, Qc/Q_t decreased).



Photograph 9.A.1. Weaver Bottoms, Pool 5 - Changes in Floodplain Vegetation and Roughness

For river flows near and well above bankfull, the majority of the conveyance is now in the floodplain in the lower reaches of the navigation pools. This increased the delivery of sediment to the floodplain (D_f increased). Chen and Simons, 1979, found that the water surface for a given flood discharge in the upper and middle reaches of the navigation pools was decreased after the locks and dams were constructed (Δz_w decreased). They attributed this to the destruction of overbank vegetation, which increases the riverbed area (the flow carrying portion of the river). A comparison of water surface profiles for pre- and post-lock and dam conditions indicates that the decrease in water surface elevation was as much as 1-foot in the upper portions of the pool. Combined with the increase in water surface in the lower reaches of the pools, caused by the dams, the hydraulic slope in the pools for flood conditions as been decreased as much as 20-percent. Channel velocities (v_c) decreased and the lower reach of the navigation pools became more depositional (***Qs*** decreased). Sediment deposition in the main channel (D_c) was increased adjacent secondary channels where flow enters the floodplain, requiring periodic dredging to maintain the 9-foot navigation channel. The combination of dredging and sediment flow to the floodplain through the secondary channels limits the supply of sand-size sediment to the lower portions of the navigation pools, which is a potential factor increasing shoreline erosion (E_b increased). Superimposed on this lower velocity depositional system is a high velocity reach at each lock and dam, which presents a potential barrier to migrating fish. Although a significant quantity of backwater habitat was initially created by submergence, island erosion and the continued increase in floodplain conveyance has increased velocities (v_f) in many of these areas making them less suitable for plants and animals. The width of the main channel (W_c) increased in the lower reaches of the pools due to Lock and Dam construction (Chen & Simons 1979, WEST Consultants 2000, Collins & Knox 2003).

Wind driven wave action has become a more significant factor in the floodplain affecting both the transport of sediment and morphological changes in the floodplain. Many of the islands and shallow areas in the lower pools eroded (E_f, E_b increased) due to wave action (WEST Consultants, 2000) (photograph 9.A.2) . Sediment transport in the floodplain now is affected by daily wind conditions as much as seasonal variations due to annual cycles of basin-wide runoff. This has resulted in increased suspended sediment concentrations (***SS***).

Photograph 9.A.2. Pool 8, Phase II, Stoddard Bay. Erosion, due primarily to wind driven wave action, reduced over one mile of barrier islands to this one remnant by 1995.

While project goals and objectives usually focus directly on the improvement of habitat in the floodplain, the physical impact of island construction is to partially restore riverine hydrodynamic, sediment transport, and geomorphic conditions. As Table 9.A.1 illustrates, islands reverse many of the effects of lock and dam construction. A new island essentially becomes the new natural levee, separating channel from floodplain, reducing channel-floodplain connectivity, and increasing channel flow while decreasing the amount of floodplain flow (Q_c/Q_t increases, Q_f/Q_t decreases). This increases the velocity in adjacent channels increasing the erosion and transport of sediment (v_c, E_c, increased). Wind fetch and wave action is reduced in the vicinity of islands, reducing the resuspension of bottom sediments, floodplain erosion, and shoreline erosion (F, SS, E_f, E_b decreases). In some cases, islands act primarily as wave barriers and don't alter the river-wide distribution of flow. Islands reduce the supply of sediment to the floodplain potentially decreasing floodplain sediment deposition (D_f). Constructing islands (or natural levees) is a necessary step in restoring the form, function, and habitat value in the lower portions of the navigation pools.

The natural resource managers and scientists involved in the Habitat Needs Assessment (Theiling et al. 2000) indicated that the future river should be characterized by: improved habitat quality, habitat diversity, and a closer approximation of pre-development hydrologic variability. In fact, the subject of restoring natural conditions is frequently discussed at all levels of planning and design. However, the relationships between the flow of water, the transport of sediment, and the biota in a natural system are not always well defined. Habitat goals are developed first and then the physical conditions that will most likely achieve those goals are determined. While this will continue to be the case, HREP design teams will benefit if the physical condition of the natural river is defined. The Pool 8 Islands, Phase III project was the first to incorporate processes as an objective.

In table 9.A.2, the first column lists river attributes as defined by McBain and Trush (1997). These attributes describe the fluvial geomorphic processes that sustain ecosystem integrity. They were developed for cobble and gravel-bedded rivers in the Western United States, however they apply, with some modification, to the Upper Mississippi River (column 2). All of these attributes describe the relationship between the hydrologic regime and sediment transport, and the resulting geomorphic and biologic condition of a river. Restoring these attributes on a river reach will help achieve the broad goals stated in the habitat needs assessment of improved habitat quality and diversity, and more natural hydrology. These attributes along with habitat parameters, engineering considerations, and lessons learned, form the basis for design criteria and project design once goals and objectives are defined.

Table 9.A.1. Effects of Lock and Dams and Island on Parameters Describing Hydrodynamic, Sediment Transport, and Geomorphic Regimes in the Lower Reaches of Pools in Pools 1 Through 13 of the UMRS

Parameter	Definition	Lock and Dam Effects in Lower Reaches of Pools	Island Effects
Q_c	Channel discharge including secondary channels	- [1]	+ [2]
Q_f	Floodplain discharge	+	-
Q_t	Total river discharge		
Q_c/Q_t	Ratio of channel discharge to total discharge	-	+
Q_f/Q_t	Ratio of floodplain discharge to total discharge	+	-
v_c	Channel velocity	-	+
v_f	Floodplain velocity	+	-
W_c	Channel width including secondary channels	+	-
z_c	Channel elevation	+	-
z_f	Floodplain elevation	+, -	+, -
Δz_w	Difference in elevation between the two-year flood and low flow	-	
F	Wind fetch in floodplain	+	-
Q_s	Sediment load	-	+
SS	Suspended sediment concentration	+	-
D_c	Sediment deposition rate in channels	+, -	-
D_f	Sediment deposition Rate in floodplains	+	-
E_c	Channel bed erosion rate	-	+
E_b	Bankline erosion rate	+	-
E_f	Floodplain erosion rate	+	-
d_{50}	Sediment particle size in channels	-	+

[1] + indicates that magnitude of parameter increased
[2] - indicates that magnitude of parameter decreased

Table 9.A.2. Attributes of Alluvial River Ecosystems and the Condition of Those Attributes for the Lower Reaches of Pools on the UMR, Pools 1-10

General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)	Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10
Attribute No. 1. Spatially complex channel morphology. No single segment of the channel bed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities	Submergence of the natural levees and floodplain and subsequent island erosion has decreased main channel flow and velocity creating a more depositional condition. Dredging and sediment deposition in the middle reaches of pools limits the amount of coarse sediment transported to the lower reaches. The increased fine and course sediment transport to the backwater areas occurs at most times during the year, compared to being flood event driven prior to impoundment. With the limited supply of coarse sediment, the lower reaches of pools have remained fairly deep through time. However, there has be a simplification of the bathymetry in these lower sections of the pools as wave action erodes "high" spots and sedimentation fills in the historic floodplain depressions that are now permanently inundated (see pool 13 bathymetric comparison by USGS and the pre and post bathymetric analysis for Phase II). These factors limit the formation of complex morphological features such as point bars, longitudinal bars, and riffles with coarser sediments. The minimum water surface elevation that is maintained for navigation usually submerges sand bars that form. Wing dams create flow and substrate diversity in some reaches.
Attribute No. 2. Flows and water quality are predictably variable. Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentrations, are similar to regional unregulated rivers and fluctuate seasonally. This temporal " predictable unpredictability" is the foundation for river ecosystem integrity.	Variability occurs at frequencies associated with inter-annual, seasonal, and storm event time scales. However wind-driven wave action causes daily and diurnal changes in water quality, especially turbidity and suspended sediment concentration in the lower reaches of pools. The increased turbidity reduces light penetration decreasing the growth of aquatic plants and affects other aquatic organisms.
Attribute No. 3. Frequently mobilized channelbed surface. Channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years.	Channelbed sediments consist of sands that are mobilized by discharges much lower than the bankfull discharge. Measurements in lower pool 8 by personnel from ERDC indicated significant bed load movement for a discharge of 50,000 cfs, which is about 60-percent of the bankfull discharge (Abraham et al. 2003). However, due to submergence of the floodplain and island erosion, floodplain conveyance in the lower reaches of navigation pools exceeds 50-percent of the total river discharge at the bankfull flow condition. Flow velocities and the potential to mobilize and transport sand-size sediments are decreased because of this. Normally this would result in rapid aggradation of the channel bed, but dredging and floodplain deposition in the middle reaches of navigation pools limits the supply of coarse sediments. Sand that enters the floodplain deposits in deltas, on natural levees, and in other features with little chance for remobilization.
Attribute No. 4. Periodic channelbed scour and fill. Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5- year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal.	The UMR is a sand-bed river and so there generally is not an armor layer that is scoured. Because of submergence and island erosion, the floodplain conveyance in the lower reaches of navigation pools is high and velocities for the 3 to 5 year floods are not significantly greater than those for the bankfull discharge.

Table 9.A.2. Attributes of Alluvial River Ecosystems and the Condition of Those Attributes for the Lower Reaches of Pools on the UMR, Pools 1-10

General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)	Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10
Attribute No. 5. Balanced fine and coarse sediment budgets. River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuate, but also sustain channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity; most particle sizes of the channelbed must be transported through the river reach	A bed material (ie. coarse material) sediment budget developed for the St. Paul District reach of the UMR (Hendrickson, 2003) indicates a decrease in the sediment load from the upper to the lower reach of the navigation pools. The only exception to this is where tributaries entered and caused a spike in the sediment load. This decrease is due to hydrodynamic changes and dredging. Main Channel conveyance changes from 80-percent of the total river discharge in the upper reaches of the navigation pools to less than 50-percent of the total river discharge in the lower reaches at the bankfull flow condition. As flow leaves the channel and enters the floodplain it carries coarse sediment, which is trapped in deltas or on the natural levees. Channel velocities and the potential to mobilize and transport sand-size sediments is decreased as the amount of main channel flow decreases, leading to coarse sediment deposition in channels and the floodplain. The lack of a balanced coarse sediment budget leads to dredging in the navigation channel, which reduces the bed material load to a level that the lower reaches can transport. Sediment budget studies in Pool 13 (Gaugush, 1997), Weaver Bottoms in Pool 5 (Nelson et al., 1998), and Peterson Lake in Pool 4 (Unpublished St. Paul District Data, 1995) indicate a balance between fine sediment input and output. However, transect measurements in Pools 4, 8, and 13 indicate a net accumulation of sediments and a gradual increase in the bed elevation of backwater areas (Rogala, 2003). Also, Collins and Knox (2003) found net accumulation of fine and coarse sediments on natural levees in pool 10. These were areas that are only inundated during floods. It is probable that the Upper Mississippi River traps more of the fine sediment load than it exports, however there certainly are reaches where there may be some type of quasi-equilibrium.
Attribute No. 6. Periodic channel migration. The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers having similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber.	Most geomorphic studies of the UMR indicate a relatively stable main channel through time. Knox (2002), using radiocarbon dating of deep cores representing floodplain sites in Pools 9 and 10, found long term stability of major island and floodplain landforms. Exceptions to this stability occurred where large tributaries enter the main channel, supplying a large amount of coarse sediment. Archaeological studies of the Mississippi floodplain in Pool 10 have found campsites and artifacts, dating back 1300 to 2000 years, buried on lateral accretion deposits adjacent present day channels. This evidence suggests that channel position has changed little in the last 2,000 years (Stoltman et al. 1982, Church 1985). Additional archaeological data provides evidence that the position of some landforms within the valley have not changed in 8,000 years Development of the UMR for navigation, aimed to stabilize the main channel even more. Chen and Simons (1979), using a combination of river surveys and aerial photographs, found that the position of the river did not change appreciably in lower pool 4 with the construction of training structures and locks and dams. However, a recent study indicates that in some areas secondary channels may have been much more dynamic, at least since the locks and dams were constructed. Carson (unpublished thesis 2004) found significant migration and expansion of secondary channels at his study sites in the Goose Island backwater in the middle reach of pool 8. Secondary channels in the middle reaches typically have hydraulic slopes higher than .0001. This is because there is often a significant water surface differential between backwaters, which might have their main connection with the river miles downstream, and the adjacent main channel. Additional factors contributing to these mid-pool dynamics induced by impoundment may also include changes in vegetation coverage (from forest to grasses) that reduced floodplain roughness, alteration of the floodplain for urban development upstream of this location and island dissection. In the lower reaches of pools, the submergence of natural levees and the floodplain has decreased the hydraulic slope to .0001 or less and current velocities in secondary channels are well below the threshold for major channel migration.

Table 9.A.2. Attributes of Alluvial River Ecosystems and the Condition of Those Attributes for the Lower Reaches of Pools on the UMR, Pools 1-10

<table>
<tr><th>General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)</th><th>Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10</th></tr>
<tr><td>Attribute No. 7. A functional floodplain. On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terrace.</td><td> The floodplain and natural levees in the lower reaches of navigation pools were permanently submerged by Lock and Dam construction. Subsequent island erosion (i.e. natural levee erosion) and a shift in vegetation communities, which decreased floodplain resistance, resulted in a trend of increasing floodplain conveyance and decreased channel conveyance with time. Channel-floodplain connectivity, whether measured in terms of number of connections or the amount of water conveyed in the floodplain increased. In many pools this trend continues today as islands erode and secondary channels get wider. One of the impacts of this is degraded conditions for backwater fish. Measurements at secondary channels in Pool 7 in 1980 (Pavlou et al., 1982) and in 1991 (Hendrickson et al., 1994) indicated a 10-percent increase in the amount of water conveyed through Lake Onalaska. For river flows below bankfull, 20 to 70-percent of the total river flow is conveyed in the floodplain in the lower reaches of pools. For flood conditions, floodplain conveyance is even higher (see table below). This increases the delivery of sediment to the floodplain causing sediment deposition. In the submerged lower reaches of navigation pools, velocities often are too high to provide sheltered habitat to fish and other organisms.
Percent of the Total River Discharge Conveyed in the Floodplain in the Lower Reach of Navigation Pools Where Islands Have Been Constructed for Below Bankfull and Flood Conditions
<table>
<tr><th>Pool</th><th>River Mile</th><th>Below Bankfull</th><th>Flood</th></tr>
<tr><td>5</td><td>744</td><td>58</td><td>72</td></tr>
<tr><td>5A</td><td>730</td><td>27</td><td>46</td></tr>
<tr><td>7</td><td>704</td><td>62</td><td>74</td></tr>
<tr><td>8</td><td>687</td><td>73</td><td>88</td></tr>
<tr><td>9</td><td>656</td><td>52</td><td>-</td></tr>
</table>
Sediment transport in the floodplain now is affected by daily wind-driven wave action as much as seasonal variations due to annual cycles of basin-wide runoff. The bottom shear stress generated by waves exceeds the critical shear stress for sediment resuspension in shallow backwater areas. This can result in daily spikes in suspended sediment concentrations (SS) to levels that can be several times greater than background levels. Fine sediment export from backwaters occurs throughout the year due to wave action.
The processes of sediment deposition in deeper permanently submerged areas of the floodplain and erosion of islands due to wave action in the pools has decreased the bathymetric complexity and habitat diversity in these areas. </td></tr>
</table>

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<table>
<tr><th>General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)</th><th>Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10</th></tr>
<tr><td>Attribute No. 8. Infrequent channel resetting floods. Single large floods (e.g. exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenation of mature riparian stands to early-successional stages, side channel formation and maintenance, and create off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods.</td><td>Most geomorphic studies of the Upper Mississippi River indicate a relatively stable main channel through geologic time.

In the lower reaches of pools, the submergence of natural levees and the floodplain has decreased the hydraulic slope to .0001 or less and current velocities in secondary channels are well below the threshold for major channel migration. Wind driven wave action eroded many of the natural levees (i.e. islands) decreasing channel velocity even more. Sand that does enter the floodplain, deposits and forms deltas with little chance for remobilization. In a few locations, coarse sediment transport has resulted in the formation of emerged sand deposits following recent floods. These deposits are colonized by terrestrial vegetation and become semi-permanent land features in the lower pools. While this process is encouraging, it is extremely small scale, and even if the rate of deposition increased, two questions remain. First, will on-going depositional processes occur at an adequate rate to replace desirable floodplain habitat lost over the last 70 years? Second, will the quality of the terrestrial habitat on these low elevation features, be of equal value to the higher elevation features that are eroded? The answer to both of these is probably no, and so construction of artificial islands is necessary to achieve the goals and objectives that have been set for the UMRS.

Sediment deposits in deltas and sand bars are colonized by woody vegetation representing early successional stages of forest development.</td></tr>
<tr><td>Attribute No. 9. Self-sustaining diverse riparian plant communities. Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early and late successional stand structures and species diversities (canopy and understory) characteristics of self-sustaining riparian communities common to regional unregulated river corridors.</td><td>Water surface elevations in the lower reaches of pools are maintained at a high and very stable elevation. There is very little difference between low flow conditions and flood conditions, and in some cases the water surface actually drops due to the operation of the Locks and Dams (see table below). Because of this, species diversity has decreased with time. Non-native Canary grass and mono-cultures of silver maple are the dominant species on many of the remaining landforms.

Water Surface Elevations for Low Flow and Bankfull Flow Conditions at Lock and Dams 4 Through 10.

<table>
<tr><th>Pool</th><th>Low Flow
Water Surface
75% Exceedance</th><th>Bankfull Flow
Water Surface
1.5 yr flood</th><th>Difference
(feet)</th></tr>
<tr><td>4</td><td>667.0</td><td>666.5</td><td>-.5</td></tr>
<tr><td>5</td><td>659.8</td><td>659.5</td><td>-.3</td></tr>
<tr><td>5A</td><td>650.8</td><td>650.8</td><td>0</td></tr>
<tr><td>6</td><td>645.4</td><td>644.5</td><td>-.9</td></tr>
<tr><td>7</td><td>639.0</td><td>639.0</td><td>0</td></tr>
<tr><td>8</td><td>630.7</td><td>630.0</td><td>-.7</td></tr>
<tr><td>9</td><td>619.5</td><td>620.0</td><td>.5</td></tr>
<tr><td>10</td><td>611.0</td><td>612.6</td><td>1.6</td></tr>
</table></td></tr>
<tr><td>Attribute No. 10. Naturally fluctuating groundwater table. Inter-annual and seasonal groundwater fluctuations in floodplains, terraces, sloughs, and adjacent wetlands occur similarly to regional unregulated river corridors.</td><td>Water surface elevations in the lower reaches of pools are maintained at high and stable elevation (see table above). This has elevated the groundwater table in these reaches.</td></tr>
</table>