3.7 WATER RESOURCES

3.7.1 Introduction

This section describes existing surface water quality and groundwater resources to serve as a baseline from which the Proposed Action and alternatives will be evaluated. Section 3.7.2 discusses the relevant regulatory framework surrounding water resources. Section 3.7.3 examines multiple surface water quality parameters in the context of ongoing dredging activities and the current regulatory standards that characterize current surface water conditions in the LOMR. Existing dredging operations in the LOMR suspend sediment during dredging and during the return of slurry to the river from the dredging barge after sorting. This disturbance temporarily introduces suspended sediment, and potentially also introduces associated nutrients and contaminants, into the water column.

Section 3.7.4 describes the groundwater interactions between the LOMR and the Missouri River alluvial aquifer (alluvial aquifer) and its linkage to LOMR stage. Because of the linkage between the alluvial aquifer and river stage, long-term and short-term alterations in river stage may affect alluvial aquifer levels. Changes in alluvial aquifer levels may influence water availability for wetlands (discussed in Section 3.9) and withdrawal of water for municipal, agricultural, and commercial uses (discussed in Section 3.5)

3.7.2 Regulatory Setting

Activities that may impact waters of the United States may require various permits or authorizations under the CWA. Sections of the CWA are enforced at both the federal and state level. There are no relevant state or federal regulations pertaining to groundwater resources.

3.7.2.1 Federal

Clean Water Act – Sections 303(d) and 305 (b)

Biennially, each state is required by the CWA to submit a report to the USEPA describing the status of surface waters in the state and listing the water bodies that are not achieving water quality standards. Section 303(d) of the CWA requires a list of water bodies in the state that are impaired, and Section 305 (b) requires a report on the overall condition of water bodies in the state. Generally, these lists are provided to the USEPA in an Integrated 303(d)/305(b) Report (Integrated Report). Water body uses are classified as “fully supported,” “fully supported but threatened,” “partially supported,” or “not supported” based on achievement of relevant water quality criteria standards. A use is said to be “impaired” when it is partially supported or not supported. Section 303(d) also requires a total maximum daily load (TMDL) to be established for those waterways that do not meet their designated water quality standards for a particular pollutant. A TMDL calculates the maximum amount of a pollutant that can be allowed to enter a water body and still meet the water quality standard specified for the pollutant and allocates that pollutant load from point and non-point sources.

Clean Water Act – Section 404

Section 404 of the CWA establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Activities in waters of the United States regulated under this program include fill for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports), and mining projects. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States. State authority under Section 401 of the CWA is discussed in Section 3.7.2.2.

Under Section 404(b)(1) of the CWA, individual permit issuance requires that the USACE make a factual determination based on a written review process that evaluates short- and long-term aquatic impacts of the proposed permitted action and the proposed avoidance, minimization, and mitigation measures. This factual determination is used to determine compliance or non-compliance with discharge restrictions.

3.7.2.2 State

No high-quality or state resource waters have been designated on the LOMR in the Project area (e.g., Outstanding State Resource Water, Outstanding National Resource Water, National Wild and Scenic River, or listing in the Nationwide Rivers Inventory) (MDNR 2007a, 2007b; nationalatlas.gov 2009; NPS 2008).

Clean Water Act – Sections 401 and 402

According to the CWA, any activity requiring a federal permit that may result in a discharge to waters of the United States must obtain a state Section 401 water quality certification. The state regulatory agency evaluates applications to determine whether the proposed activity would comply with state water quality standards. If the activity is likely to violate state water quality standards, conditions for complying with the state standards will be issued with the certification or the certification will be denied.

Among other things, Section 402 under the CWA requires that direct and stormwater discharges into state waters from industrial activities be controlled by an NPDES permit. The USEPA has authorized Missouri, Kansas, and Nebraska to issue NPDES permits for activities in their respective states.

3.7.3 Surface Water Quality

The following discussion of surface water quality provides a background in the context of ongoing dredging activities and regulatory standards.

Section 303(c) of the CWA requires states to review, establish, and revise water quality standards for all surface waters in the state. Designated uses are assigned to water bodies by the states; specific water quality criteria standards are determined based on the designated use for each water body. Table 3.7-1 lists the designated uses that apply to water bodies in the Project area.

Table 3.7-1 State Designated Uses and Attainment Status in the Lower Missouri River by River Segment

Segment	Designated Use	2008 Designated Use Attainment [a,b]	Parameter of Concern	Total Maximum Daily Load (Date of USEPA Approval)
Missouri				
All segments	Irrigation	S		
	Livestock and wildlife watering	S		
	Protection of aquatic life and human health	S		Chlordane, polychlorinated biphenyls (PCBs) (2006)
	Whole body contact recreation	I[c]	Bacteria	
	Secondary contact recreation	S		
	Drinking water supply	S		
	Industrial	S		

Table 3.7-1 State Designated Uses and Attainment Status in the Lower Missouri River by River Segment

Segment	Designated Use	2008 Designated Use Attainment [a,b]	Parameter of Concern	Total Maximum Daily Load (Date of USEPA Approval)
Kansas				
St. Joseph[d] Kansas City	Aquatic life	S		
	Contact recreational	S		
	Domestic water supply	S		
	Food procurement	S		
	Groundwater recharge	S		
	Industrial water supply	S		
	Irrigation	S		
	Livestock watering	S		
Nebraska				
St. Joseph	Primary contact recreation	I	*Escherichia coli* (*E. coli*)	*E. coli* (2007)
	Aquatic life (cold and warm water)	I	Dieldrin, PCBs	
	Water supply (public drinking water, agricultural, industrial)	S		
	Aesthetics	S		

Note: USEPA = U.S. Environmental Protection Agency.

[a] S= Use supported; I = Use impaired.

[b] Impairment determined by listing in 2008 Integrated Report for the respective state.

[c] The final 2008 303(d) list does not include an impaired use designation but does list the segment as impaired for bacteria (MDNR 2009a). The draft 2010 303(d) list indicates that a portion of the Lower Missouri River crossing Missouri is impaired for whole body contact recreation due to bacteria (MDNR 2010).

[d] Only a portion of the St. Joseph segment is located in Kansas.

Sources: MDNR 2009a, 2009b, 2006c; NDEQ 2008, 2007; KDHE 2008a; USEPA 2008; Missouri 10CSR 20-7.031(C); Kansas K.A.R. 28-16-28d; Nebraska 117NAC4.

There are no 303(d) listings or TMDLs for the LOMR flowing through Kansas (KDHE 2008b, 2009). The portion of the LOMR flowing between St. Louis and Gasconade Counties in Missouri has been listed on the final, USEPA-approved Missouri 2008 303(d) list for bacteria impairment. The proposed 2010 303(d) list expands the area of the LOMR listed as impaired for bacteria (MDNR 2010). The MDNR has proposed classifying the LOMR flowing between Atchison and Jackson Counties and Gasconades and St. Charles Counties in Missouri as impaired in the proposed 2010 303(d) list. The 2008 Integrated Report also identified the LOMR as potentially impaired for habitat degradation due to channelization in Holt, Carroll, Calloway, and St. Charles Counties (MDNR 2009a). Habitat degradation due to channelization is from both historical large-scale and current minor channelization projects that have reduced the river length and the availability of aquatic habitat. TMDLs have been established for PCBs and chlordane in the LOMR in Missouri (MDNR 2006a).

In general, water quality in the LOMR differs substantially compared to historical conditions. As discussed in Section 3.4.5.2, the hydrology and the sediment load delivered to the LOMR have been altered through construction and operation of upstream dams, and channelization and stabilization of the LOMR banks. The resultant changes to stream flow quantity and timing have affected sediment inputs, eliminated off-channel habitats, and isolated the LOMR from its floodplain. Compared to historical levels, turbidity and TSS concentrations decreased after installation of upstream dams and channelization (Blevins 2006, MDNR 2006b). Further, due to industrial, agricultural, and residential land uses in the LOMR watershed, contaminants such as nutrients, pathogens, metals, and pesticides can be found in the water, sediment, and fish.

Integrated Reports for the respective states and USGS current water-year annual reports constitute the most comprehensive data sets available for recent water quality in the LOMR and were used to summarize recent conditions in the LOMR, as described below.

The Missouri Clean Water Commission raised concerns about the water quality impacts in the LOMR associated with adding sediment to the LOMR (MRRP 2007, Gossenauer 2009). Although USACE testing and monitoring of shallow-water habitat construction sites showed that activities were in compliance with Missouri water quality standards (USACE 2007), the Missouri Clean Water Commission issued orders in September 2007 and March 2008 to cease all shallow-water habitat construction activities that resulted in adding sediment to the LOMR (Gossenauer 2009). In response to the Missouri Clean Water Commission orders, the USACE ceased construction of in-river shallow-water habitat in Missouri and commissioned the National Academy of Science to complete an independent assessment of the impacts of adding sediment to the LOMR (MRRP 2007, Gossenauer 2009).

3.7.3.1 Nutrients

MDNR monitoring data at St. Joseph, Missouri have shown a general long-term increase in nitrate plus nitrite levels from point and non-point sources (MDNR 2006b). Nitrogen from the Mississippi River basin, into which the Missouri River basin empties, has been implicated as one of the primary causes of hypoxia in the Gulf of Mexico (USGS 2000). The role of phosphorous in Gulf of Mexico hypoxia is unclear (USACE 2007). The USGS annually predicts the extent of the Gulf of Mexico hypoxic zone based on upstream hydrologic and nutrient data. The net nutrient flux contributed by the Missouri River is modeled through data obtained from the Hermann, Missouri sampling station (USGS 2007). Typically, the Missouri River basin contributes approximately 20 percent of the total phosphorous and 15 percent of the total nitrogen loads to the Gulf of Mexico via the Mississippi River (Soballe 2009).

3.7.3.2 Temperature

Missouri State water quality requirements stipulate that water bodies not be in excess of 90 degrees Fahrenheit (°F) (32 degrees Celsius [°C]) and that no action shall raise or lower the temperature of a water body greater than 5 °F (3 °C) (Missouri 10CSR 20-7.31). Kansas water quality regulations stipulate that the temperature of receiving water shall not be increased by a total of more than 5 °F (3 °C) from natural background outside the mixing zone (Kansas K.A.R. 28-16-28e). The Nebraska maximum water temperature limit is 85°F (29°C), and regulations limit water temperature change to a maximum of 4 °F (2 °C) from natural background temperatures.

None of the LOMR segments flowing through Nebraska, Kansas, or Missouri are listed as impaired for temperature (MDNR 2009a, KDHE 2008b, NDEQ 2008). In general, summer water temperatures at Gavins Point Dam, located upstream of the Project area, range from 75.2 °F (24 °C) to 78.8 °F (26 °C) (USACE 2003). Water temperatures generally increase downstream from this point and peak near Kansas City, Missouri (USACE 2003). USGS gage data collected and compiled by the MDNR and USGS were used to determine the maximum and minimum daily temperatures at representative monitoring stations near each segment (Table 3.7-2).

Water temperature fluctuates with season, hydrology, and non-point and point source discharges into the river. Factors historically affecting water temperatures in the Missouri River include heated effluent from power plants and the contribution of water from tributaries to the LOMR (USACE 2003). The small amount of water required for dredging operations relative to the overall quantity of water in the LOMR, combined with the short duration during which water is removed, makes it unlikely that dredging measurably changes the water temperature in the LOMR.

3.7.3.3 Dissolved Oxygen

DO levels fluctuate monthly, daily, and hourly. The State of Missouri requires that constituents added to the water not reduce dissolved oxygen (DO) levels to less than 5.0 mg/l (Missouri 10CSR 20-7.31).

The State of Missouri determines water bodies to be impaired if more than 10 percent of the days monitored fail to meet the water quality standard for DO (MDNR 2009c). Nebraska requires that a 1-day minimum of not less than 5.0 mg/l for early life stages is present between April 1 and September 30, and a 1-day minimum of not less than 3.0 mg/l for all life stages other than early life stages is present from October 1 through March 31 (Nebraska 117NAC4). Kansas maintains a 5.0-mg/l DO criterion for aquatic life and stipulates that no pollutant may influence the lowering of DO levels in surface waters.

Table 3.7-2 Representative High and Low Temperatures in the Lower Missouri River by River Segment

Segment	Sampling Location	Sampling Period	Maximum Daily Temperature	Minimum Daily Temperature
St. Joseph	St. Joseph, MO[a]	2000–2006	87.3°F (30.7 °C)	32°F (0.0°C)
Kansas City	NA	NA	NA	NA
Waverly	Waverly, MO[a]	March to September 2006	89.6 °F (32°C)	43.5°F (6.4°C)[b]
Jefferson City	Booneville, MO[a]	March 2006 to September 2008	90.5 °F (32.5°C)	36.1°F (2.3°C)[b]
St. Charles	St. Charles, MO[a]	October 2007 to September 2008	77.0°F (25.0°C)	34.9°F (1.6°C)
St. Charles	Hermann, MO[a]	2000–2006	89.6 °F (32°C)	32.4°F (0.2°C)

Notes:

C = Celsius.
F = Fahrenheit.
MO = Missouri.
NA = Data not available for this river segment.

[a] Daily temperature data record has not been completed. Disruptions in temperature data availability due to freezing conditions, instrument failure, or no flow at monitoring location.

[b] Winter data were not collected for this location; therefore, the winter low water temperature was likely lower than the reported low.

Sources: MDNR 2009c; USGS 2008a, 2008b, 2008c, 2008d, 2008e, 2008f.

Table 3.7-3 depicts maximum and minimum daily DO concentrations measured at various stations along the LOMR. During summer, DO levels often measure less than 5 mg/l and can reach as low as 1 mg/l (Blevins and Fairchild 2001). DO levels for the LOMR in Missouri have dropped below the minimum DO level of 5 mg/l, the level established to protect aquatic life at multiple locations (Table 3.7-3); however, because none of the segments were impaired greater than 10 percent of the days monitored, inclusion on the 2008 303(d) list was not warranted. No segment of the LOMR in the

Project area in Missouri, Nebraska, or Kansas has been listed as impaired for DO in the USEPA-approved 2008 Integrated Reports (MDNR 2009a, KDHE 2008b, NDEQ 2008).

Table 3.7-3 Representative High and Low Dissolved Oxygen Levels in the Lower Missouri River by River Segment

Segment	Sampling Location	Sampling Period	Maximum Daily DO Concentration (mg/l)	Minimum Daily DO Concentration (mg/l)
St. Joseph	St. Joseph, MO[a]	2000–2006	15.5	3.8
Kansas City	NA	NA	NA	NA
Jefferson City	Booneville, MO[a]	February 2006 to September 2008	15.6	2.9
Waverly	Waverly, MO[a]	March 2006 to September 2008	12.9	1.9
St. Charles	Columbia Bottom, MO[a]	2004–2006	15.2	5.7
St. Charles	Hermann, MO[a]	2000–2006	16.0	2.1

Notes:

DO = Dissolved oxygen.
mg/l = Milligrams per liter.
MO = Missouri.
NA = Data not available for this river segment.

[a] The daily DO data record has not been completed. Disruptions in DO data availability due to freezing conditions, instrument failure, or no flow at monitoring location. Minimum daily DO may have been lower during periods of missing records.

Sources: MDNR 2009c; USGS 2008a, 2008b, 2008c, 2008d, 2008e, 2008f.

The MDNR reports that DO levels in the LOMR generally appear to be most affected by non-point pollution sources during runoff events (MDNR 2006b). Current dredging operations temporarily suspend sediment, which may release DO-lowering nutrients into the LOMR water column. Inorganic sand, which is largely inert and does not result in a depletion of DO, typically comprises half of the suspended sediment in the LOMR (Blevins and Fairchild 2001). Phosphorous typically adsorbs to fine sediment (Soballe 2009); therefore, phosphorous is not likely released in significant quantities during disturbance of sediments. Nitrogen is typically in a dissolved state and is only indirectly linked to sediment (Soballe 2009). Further, USACE testing has found that the total phosphorous concentration of elutriate water (measuring the potential release of water-soluble constituents from sediment to the water column) at five shallow-water habitat creation sites was approximately 66 percent lower than concentrations present in the river water (USACE 2007). The USACE indicated that this was most likely due to adsorption of phosphorous to the sediment. Likewise, it is likely that remobilized sediment adsorbs total phosphorous from the river water (Soballe 2009). The disturbance of sediment during current dredging operations is not likely to greatly increase the nutrient load of the LOMR; therefore, dredging is not likely to substantially lower DO levels.

3.7.3.4 Total Suspended Solids and Turbidity

Total suspended solids (TSS) is a measure of both inorganic and organic suspended solids, while turbidity is an optical property that causes light to be scattered and absorbed (USACE 2000). Water quality standards for these parameters in the LOMR are largely qualitative. Missouri State turbidity and color standards on the LOMR require that an action shall not cause a substantial visible contrast with the natural appearance of the water body (Missouri 10CSR 20-7.31). The Missouri Clean Water Commission considers organic and inorganic sediment a contaminant because nutrients and metals are typically delivered to water bodies via sediment (MDNR 2009b). In Kansas, TSS must not interfere with the “behavior, reproduction, physical habitat, or other factors related to the survival and propagation of aquatic or semi-aquatic life or terrestrial wildlife” (Kansas K.A.R. 28-16-28e). Nebraska requires that water shall be free from human-induced pollution that causes floating, suspended, colloidal, or settleable materials that produce objectionable films, colors, turbidity, or deposits (Nebraska 117NAC4).

Factors affecting TSS loads include hydraulics, erosion, runoff, and river impoundments. Natural erosion introduces inorganic sediments and organic matter to the LOMR. Historically, the LOMR was known as the “Big Muddy” due to the high levels of sediment in the water caused by the highly erodible banks (Blevins 2006). Upstream reservoirs and bank stabilization have decreased suspended sediment and turbidity in the LOMR (Blevins 2006). The USGS estimates that median suspended sediment concentrations in the LOMR have decreased at least 70–80 percent from predevelopment conditions (Blevins 2006). For example, the USACE data collected between February 1 and October 31, 1879 at St. Charles, Missouri (St. Charles segment) showed an average suspended sediment concentration of 4,100 mg/l (Blevins 2006), which exceeds the maximum value of 3,560 mg/l recorded by the USGS at this location between 2005 and 2008 (USGS 2008f). The minimum daily suspended sediment concentration at this location between 2005 and 2008 was 82 mg/l (USGS 2008f).

The USEPA collected TSS data through grab samples collected throughout the LOMR during summer months (July, August, and September) between 2004 and 2006 as part of the Environmental Monitoring and Assessment of Great River Ecosystems program (USEPA 2009). An average TSS concentration of 203.4 mg/l was recorded for all segments of the LOMR (USEPA 2009). The highest concentration found was 1,161.7 mg/l at a sampling site in the St. Joseph segment; the lowest was 61.4 mg/l in the St. Charles segment (USEPA 2009).

The USGS primarily reports turbidity measurements, as opposed to TSS concentrations. Table 3.7-4 reports USGS turbidity measurements in the river segments from 2006 to 2008. While no historical turbidity data directly correlate with the data presented in Table 3.7-4, it is likely that a decrease in suspended sediment concentration is indicative of a decrease in current turbidity levels compared to historical levels.

Table 3.7-4 Representative High and Low Turbidity in the Lower Missouri River by River Segment

Segment	Sampling Location	Sampling Period	Maximum Daily Turbidity (FNU)	Minimum Daily Turbidity (FNU)
St. Joseph	St. Joseph, MO[a]	2006–2008	1,990 FNU	2.5 FNU
Kansas City	NA	NA	NA	NA
Waverly	Waverly, MO[a]	2006–2008	1,180 FNU	24 FNU
Jefferson City	Booneville, MO[a]	2006–2008	1,630 FNU	15 FNU
St. Charles	Hermann, MO[a]	2006–2008	1,430 FNU	15 FNU

Notes:

FNU = Formazin nephelometric unit.
MO = Missouri.
NA = Data not available for this river segment.

[a] The daily turbidity data record has not been completed. Disruptions in turbidity data availability due to freezing conditions, instrument failure, or no flow at monitoring location. Minimum and maximum daily turbidity may have been lower during periods of missing records.

Sources: USGS 2008a, 2008b, 2008c, 2008d, 2008e, 2008f.

Current dredging activities result in temporary resuspension of sediment, which increases TSS concentrations immediately downstream of the dredge head and the slurry discharge. The dissipation rate and the associated level of TSS in the water column as a result of bed disturbance and slurry discharge is dependent on multiple factors, including the hydrodynamic conditions of the dredging site, type of dredge used, operational methods, and sediment type and the associated settling rate (USACE 1986).

As described in Chapter 2, a higher proportion of bed load meets material specifications in the St. Charles and Jefferson City segments; therefore, slurry water returned to the LOMR at these locations contains a lower percentage of sediment, compared to discharge in the upper segments of the LOMR. Approximately 60–70 percent of all dredged sediment from the Kansas City and St. Joseph segments does not meet the required materials specifications and is discharged into the LOMR via the slurry water.

The USACE assessed the quantity of sediment particles in the water column that do not rapidly settle out of the water column following resuspension from various dredging activities (USACE 1986). The USACE reported that, based on studies conducted in the James River in Virginia and the Savannah River in Georgia, the cutter-head dredge removed bed sediment with a relatively small amount of suspended sediment extending beyond the immediate vicinity of the dredge (USACE 1986). The study showed that a cutter-head dredge produced between 25 and 250 mg/l of suspended solids within 100 feet of the dredge and that the quantity of suspended solids decreased to between 10 and 150 mg/l within 400 feet of the dredge (USACE 1986). As stated above, the USEPA reported an average suspended solid concentration of 203.4 mg/l in all LOMR river segments (USEPA 2009). The addition of suspended sediment levels from dredging, as reported by the USACE, would represent a small, temporary increase in suspended sediment levels above average ambient conditions in areas that are near the dredging operation. The USACE reports that elevated suspended sediment plumes from dredging in the Missouri River typically extend for less than 1,000 feet downstream of a dredge site (USACE 1990).

As discussed above, turbidity and TSS levels in the LOMR have been greatly reduced compared to historical levels. At current levels, however, the LOMR is still a relatively turbid river. A large number of studies show that dredging activity produces a temporary increase in turbidity near the dredging operation, but turbidity and suspended sediment levels quickly dissipate to background levels (USEPA 1996, Thackston et al. 2000, USACE 1990).

3.7.3.5 Sediment Quality and Toxicity

The LOMR historically received and currently receives point-source and non-point-source pollutant inputs from agricultural, urban, and industrial sources. Current and past pesticide use for agricultural applications throughout the LOMR basin has resulted in the introduction of pesticides, such as chlordane, dieldrin, and dichlorodiphenyltrichloroethane (DDT), into the LOMR water and sediment. Polychlorinated biphenyls (PCBs), which were used in industrial applications, remain at industrial sites near the LOMR and in river sediment. Depending on their chemical and physical properties, contaminants present in sediment, interstitial pore water (water contained in the spaces between sediment grains), and surface waters of the LOMR can be available for biological uptake and have the potential to bioaccumulate in aquatic organisms.

Depending on the properties of the contaminant, higher concentrations could be present in the sediment, the interstitial pore water, and/or the water column. Many organic chemicals are not water soluble (referred to as "hydrophobic") and adsorb to sediment or animal fatty tissue; therefore, these hydrophobic chemicals are highly related to sediment deposition and bioaccumulation (Blevins and Fairchild 2001). For chemicals that are not hydrophobic, interstitial pore water typically is in constant contact with sediments in which contaminants may be present for a longer period of time—compared to the water column, which results in restricted mixing with surface waters. Due to the prolonged exposure to sediment, and any associated contaminants present, pore water often has elevated concentrations of water-soluble sediment-associated contaminants (Chapman et al. 2001). The regular movement and transport of river sediments in the LOMR allows for dilution and mixing of pore water with the water column.

Sediment contamination in the LOMR has been documented in some recent studies that have shown areas with pesticide, chemical, and metal contamination; but overall, sediment contamination has had limited documentation (Jacobson, Blevins, and Bitner 2008; Echols et al. 2008). Data from fine sediment in depositional areas were analyzed for pesticides, polycyclic aromatic hydrocarbons (PAHs), and PCBs at sampling sites between Omaha, Nebraska and Jefferson City, Missouri (encompassing all river segments). In general, pesticide concentrations (DDT, chlorodanes, cyclodiene pesticides, trifluralin, diazinon, chlorpyrifos, and permethrins) were greater at sampling sites downstream and in Kansas City, Missouri (the Kansas City, Waverly, Jefferson City, and St. Charles segments) (Echols et al. 2008). For example, on average, sites downstream of Kansas City were found to have a higher mean total chlorodane concentrations (3.0 +/- 1.3 nanograms per gram [ng/g]) compared to upstream sites (1.1+/-0.3 ng/g) (Echols et al. 2008). Echols et al. (2008) compared the levels found at the sampling sites with "probable effects levels," those levels of contaminants that, if exposed, would likely cause adverse effects to an organism. For those pesticides with established probable effects levels, none of the pesticide sediment concentrations exceeded probable effect level thresholds. Similar to pesticide concentrations, all sampling sites downstream of and in Kansas City (the Kansas City, Waverly, Jefferson City, and St. Charles segments) had higher than average PCB levels, compared to upstream sites (Echols et al. 2008). Sampling sites downstream of urban areas in the St. Joseph, Jefferson City, and St. Charles segment were found to have elevated PAH levels compared to upstream sampling sites. While elevated PAH concentrations were observed, all PAH concentrations were found to be below published levels that would cause adverse effects to organisms.

As discussed in Section 3.4.3, the LOMR underwent a large flood event in 1993. Petty et al. (1998) sampled the water of the mainstem LOMR following the 1993 flooding event to determine the presence of bioavailable organochlorine pesticides (OCs), PCBs, and PAHs at sites located in the Kansas City, Jefferson City, and St. Charles segments. Contaminants were found at all sites and were found to be at higher concentrations than those observed prior to the 1993 flood event (Petty et al. 1998). Results suggested that the disturbance of OC-, PAH-, and PCB-contaminated sediment in the floodplain as a result of the 1993 flooding increased levels of these pollutants in the LOMR, as opposed to their being flushed and rapidly dissipating. The change in concentration was attributed to the mobilization of soil and sediment with OC, PCB, and PAH residues (Petty et al. 1998). While herbicide transport during the 1993 flood was not studied in the LOMR, a study by Goolsby et al. (1993) in the Mississippi River following the 1993 flood identified a similar phenomenon. Goolsby et al. (1993) identified increased levels of herbicide residues, which the authors attributed to the contribution of large quantities of soil-bound herbicide residues from the floodplain into the Mississippi River.

While limited direct sediment and water testing has occurred in the LOMR, several federal agencies (including the USFWS, USGS, and USEPA) and several state agencies conduct fish tissue and egg sampling to determine the presence of bioavailable contaminants. Sampling conducted in support of development of the Missouri 303(d) list identified elevated levels of chlordane and PCBs in fish tissue sampled at multiple sites in all river segments; consequently, the LOMR was included on Missouri's 2002 303(d) list. MDNR then developed a TMDL for chlordane and PCBs (MDNR 2006a). Subsequent review of fish tissue data for the 2004/2006 and 2008 303(d) lists indicates that chlordane and PCB levels meet current MDNR water quality guidelines.

Chlordane is an OC pesticide that was used in the United States between 1948 and 1988 that entered water bodies via runoff (MDNR 2006a). Because the United States banned use of the chemical in 1988, no additional loading of the chemical into water bodies is anticipated (MDNR 2006a). Chlordane degrades very slowly; therefore, residual quantities of the chemical are still present in Missouri River sediments. Because its use has been banned, the MDNR expects that chlordane levels will decrease over time.

PCBs are comprised of chlorinated compounds that had wide industrial applications (MDNR 2006a). Production of PCBs in the United States was halted in 1977, but approximately 60 percent of the PCBs produced in the United States are still in use (MDNR 2006a). Generally, the MDNR reports that these compounds are relatively insoluble and absorb into organic matter (MDNR 2006a).

Both chlordane and PCBs degrade slowly and are persistent in the environment. Because production of both of these pollutants has been banned in the United States, the MDNR anticipates that levels of both of these pollutants will decline in the future (MDNR 2006a). Neither pollutant is water soluble and therefore is not readily present in the water column. Both adsorb to sediments in the Missouri River and can bioaccumulate in fish tissue. Bioaccumulation of PCBs and chlordane in aquatic organisms (such as carp) is primarily driven by consumption of or exposure to sediments containing these chemical constituents (MDNR 2006a). The MDNR TMDL indicates that the presence of these compounds is “mainly a sediment issue and amounts in the water column are virtually non-detectable” (MDNR 2006a). Because of the low solubility of both of these contaminants, they would generally be prevented from reaching high concentrations in LOMR water.

Current dredging operations disturb sediments and the associated pore water, some of which may contain contaminants. The LOMR is a large river with a high potential for mixing and dispersion (USACE 1990); therefore, most elevated levels of contaminants due to dredging would quickly return to background levels. Most organic contaminants are hydrophobic; therefore, sediment resuspension (see Section 3.7.2.3) during dredging is a relative measure of the potential for contaminant release (USACE 1986). The extent of this potential desorption and dispersal of interstitial pore water would depend on the concentration and properties of the suspended contaminant and site-specific conditions. Those soluble contaminants contained within sediment pore water that are released during dredging would be quickly flushed due to the high potential for mixing.

In support of the L-385 project, the USACE conducted testing to determine the mixing zone for dilution of dissolved contaminants and for settling of suspended materials (USACE 1990). The study found that some contaminant sample concentrations exceeded receiving water concentrations, but none exceeded the water quality standards in place at the time. While elevated concentrations of contaminants were detected, the researchers concluded that the mixing would quickly reduce any elevated contaminant concentration to background levels and that no significant release of contaminants would occur due to dredging in sand bed sediments (USACE 1990).

Dredging has been an ongoing activity in the LOMR that may temporarily, slightly increase contaminant concentrations in the water column. The Missouri Department of Health and Senior Services has recommended limited fish consumption due to the presence of PCBs, chlordane, and mercury (MDHSS 2010). While current dredging potentially increases the potential number of areas where sediments with PCBs or chlordane adsorbed are redistributed through the water column and on the river bottom, it does not serve as a source of these contaminants.

3.7.3.6 Metals

The Missouri River historically had naturally high concentrations of metals such as selenium and arsenic that are related to underlying geology and soils. Metals enter the waterway via natural sources, as well as by point and non-point sources. In general, no long-term monitoring in Missouri's larger rivers (including the LOMR) has indicated any issues related to heavy metals (MDNR 2006b). Metal concentrations that exceed state water quality standards have not been detected within the Project area, and none of the Project area has been included on a state 303(d) list for metal impairment. While extensive contamination has not been documented, background sediment contamination in some locations of the LOMR is likely (Jacobson, Blevins, and Bitner 2008). In general, though, metals concentrations sampled along the LOMR were not remarkably elevated, and the acid-volatile sulfides concentration values suggest a low potential for toxicity from these metals (Poulton et al. 2005).

Echols et al. (2008) also analyzed metal (nickel, zinc, copper, cadmium, and lead) concentrations in LOMR depositional sediments. Metal concentrations in the depositional sediments of the LOMR were found to be within the following ranges: 9.4 ± 1.8 micrograms per gram (µg/g) for nickel, 6.4 ± 1.4 µg/g for copper, 28 ± 18 µg/g for zinc, 0.42 ± 0.11 µg/g for cadmium, and 13 ± 6 µg/g for lead (Echols et al. 2008). Metal concentrations tended to increase downstream of Kansas City in the Kansas City, Waverly, Jefferson City, and St. Charles segments, particularly near the Blue River confluence with the LOMR (Echols et al. 2008). Despite the increase of metal concentrations in depositional sediment downstream of Kansas City, metals concentrations found were below published levels that would cause adverse effects to organisms.

Acid-volatile sulfides typically interact with metals to render the metal biologically immobile by interacting with the metal to form a highly insoluble and stable sulfide. Echols et al. (2008) also found moderately high levels of acid-volatile sulfide in the tested depositional sediments. Testing in the LOMR that found high levels of acid-volatile sulfide concentrations relative to metals suggest a low potential toxicity and bioavailability of zinc, copper, cadmium, and lead in the tested sediments (Echols et al. 2008).

Due to the exchange of water between the alluvial aquifer and the LOMR (see Section 3.7.3), there is a potential for contaminated groundwater to enter interstitial pore water in the river, as well as the water column. A USGS study at a site located upstream of the Project area near Omaha, Nebraska found that, even with a constant influx of metal-contaminated groundwater into the sediment pore water near an abandoned lead refinery, none of the USEPA toxicity thresholds were exceeded (Chapman et al.

2001). This study suggests that, even in areas where there are known consistent metal inputs into the sediment via groundwater, pore water may not exceed USEPA toxicity thresholds.

Ongoing dredging operations disturb sediment and pore water that may contain elevated metal concentrations. The USGS study in Omaha, Nebraska suggests that, even if metal-contaminated pore water is released, waters would not be sufficiently toxic to exceed USEPA toxicity thresholds. The mobilization of fine suspended sediments during current dredging activities could alter the acid-volatile sulfides concentration, which would alter the bioavailability of any metals present in the sediment (Echols et al. 2008). Because the testing at the 19 sites in the LOMR did not identify any metal concentrations in sediments that were above probable effects level guidelines, Echols et al. (2008) concluded that any alteration of the acid-volatile sulfide content as a result of sediment mobilization would not result in the bioavailability of metals in sufficiently high concentrations to cause toxicological effects. The results of these two studies suggest that the disturbance of any sediment contaminated with metals, such as through dredging, would not result in a significant increase in toxicity.

3.7.4 Groundwater

The LOMR alluvial aquifer serves as a water source for municipal drinking water and several commercial uses; including irrigation, manufacturing, and food processing (see Section 3.5). Extending from the Iowa/Missouri border to the confluence of the LOMR with the Mississippi River, the alluvial aquifer is comprised of sediment from glacial drift and loess in the LOMR floodplain that lie atop shale, limestone, and sandstone bedrock (Miller and Appel 1997, Hedman and Jorgenson 1990, USGS 2003, Emmett and Jeffery 1970). These alluvial deposits sitting atop the bedrock form the alluvial aquifer. Figure 3.7-1 depicts an average cross section of the LOMR and the geologic composition of the alluvial aquifer. A typical alluvial deposit cross section includes several meters of fine-grained clays and silts; underlain by a thick layer of sand and gravel-sand; followed by a thin layer of sandy-gravel, gravel, and/or boulders in the deepest part of the aquifer (USGS 2003). These alluvial deposits typically increase in coarseness (from sand to cobble), with depth and sediment increases in age from recent Holocene to Wisconsinan-age alluvial deposits of glacial origin (USGS 2003, Kelly 2004). Pennsylvanian-aged shale, limestone, and sandstone bedrock form the bottom and side boundaries of the alluvial aquifer (USGS 2003).

Alluvial deposits fill the entrenched bedrock valley, which typically ranges between 4 and 15 miles in width (Hedman and Jorgenson 1990). In several locations, however, the LOMR hugs the bluff line, limiting the alluvial aquifer width to near nothing (Miller and Vandike 1997). In general, the alluvial aquifer is widest upstream of Howard County, Missouri (the St. Joseph, Kansas City, Waverly, and Jefferson City segments) (Miller and Vandike 1997). The alluvial aquifer thickness is reported as typically from 80 to 90 feet (Miller and Appel 1997, USGS 2003, Emmett and Jeffery 1970, Kelly 2004), but the thickness can locally range from 3 to 300 feet (USGS 2003, Hedman and Jorgenson 1990, USACE 2008). Locally, the alluvial aquifer can be confined or unconfined, depending on site geology and groundwater levels that typically range from 1 foot to more than 20 feet below ground surface (Miller and Vandike 1997).

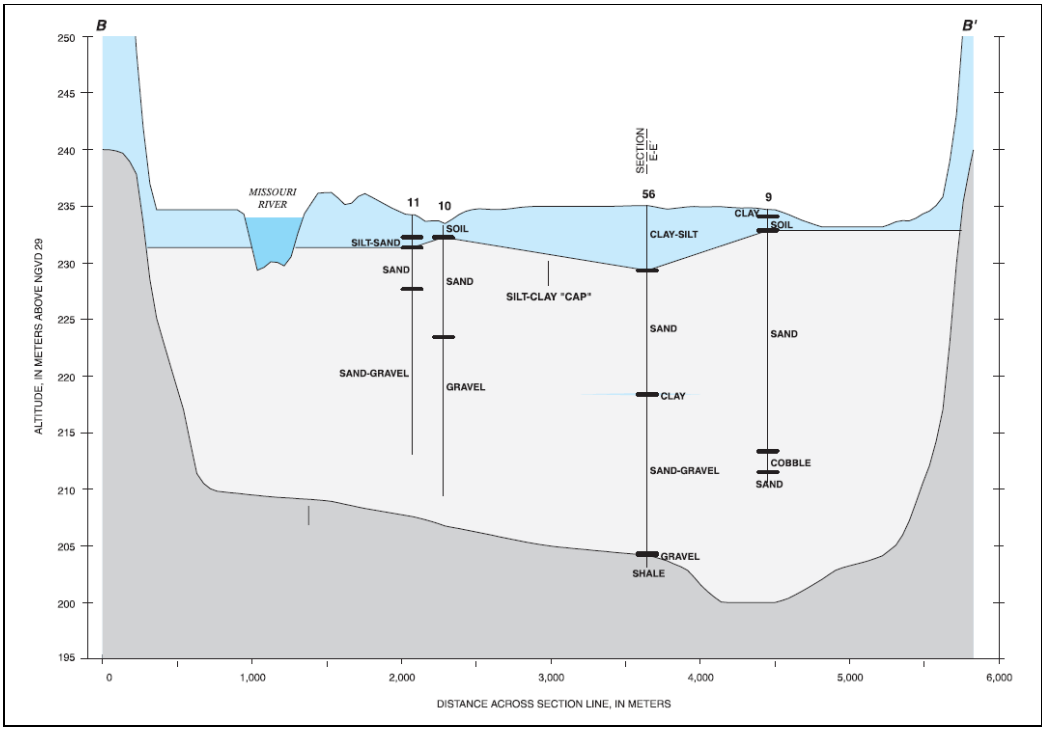

Figure 3.7-1 Cross Section of the Missouri River Alluvial Aquifer

Source: Kelly 2004.

Recharge of the alluvial aquifer can vary locally, depending on specific hydrologic characteristics of the alluvial material (Miller and Vandike 1997). In general, recharge is driven by water exchange from the LOMR during high stream flow, precipitation, and groundwater inflow from underlying, permeable bedrock aquifers (Miller and Appel 1997). The rate of exchange between bedrock aquifers and the alluvial aquifer have largely not been quantified, but the rate is believed to be negligible compared to the rate of exchange between the LOMR and the alluvial aquifer (USGS 2003). Similarly, the alluvial aquifer does not respond appreciably to precipitation (Miller and Vandike 1997). Because the LOMR stream bed has a high hydraulic conductivity and the bottom of the river channel is below the top of the groundwater potentiometric surface (the level to which groundwater would rise if not trapped in a confined aquifer) in most areas, the LOMR is hydraulically linked to the alluvial aquifer, which results in the river stage having a large impact on the alluvial aquifer (Hedman and Jorgenson 1990, Miller and Vandike 1997, Kelly 2004). Because of the hydrologic connection between the LOMR and the alluvial aquifer, increases in LOMR stage—with respect to the potentiometric surface—result in water flow from the LOMR to the alluvial aquifer (Kelly 2004). Conversely, decreased river stage results in water flowing from the alluvial aquifer to the LOMR (Kelly 2004).

The magnitude of change in the potentiometric surface altitude and the associated response in groundwater levels at a particular location are controlled by multiple factors, including the magnitude of river stage change, the length of time the river maintains a particular stage, the localized hydraulic properties of the aquifer materials, and distance from the river (Kelly 2004). Flood pulse simulations indicate that groundwater levels show little response to small, temporary river stage fluctuations; but large river-stage increases of long duration affect groundwater levels (Kelly 2000). Groundwater flow modeling conducted by Kelly (2000, 2001) indicated that groundwater changes rose during flood pulses at shorter distances from the river and then continued through the alluvium at a delay as distance from the river increased. Groundwater levels continued to rise at distances farther from the river after the flood pulse. Because the groundwater changes associated with river stage lag behind the actual changes in river stage, the rate that groundwater responds with increasing distance from the river is less in magnitude (Kelly 2000, 2001). Typically, due to the delayed response of groundwater at greater distances from the LOMR, changes to river stage that occur over a short duration have an effect (or more dramatic effect) on groundwater levels close to the river, compared to areas close to the outer periphery of the aquifer (Kelly 2004).

The USACE, in coordination with the USGS, operates several alluvial aquifer groundwater monitoring wells along the LOMR (near Forest City, Atherton, and Hermann). Initial data were collected in support of the Master Manual Review and Update EIS (USACE 2004). Three of the five monitoring wells are located within the Project area (at RM 96, RM 345, and RM 471) and are used to conduct annual monitoring of groundwater responses to river stage (USACE 2008). All monitoring wells were installed within 1,000 feet of the LOMR to capture groundwater-level responses to changes in river stages (USACE 2008). Of these three monitoring wells, two (located near Atherton and Hermann) were very responsive to river stage. Figure 3.7-2 depicts the 2008 groundwater response at Atherton, Missouri compared to river stage at the Kansas City, Missouri river gage. As shown in Figure 3.7-2, the maximum groundwater change over the monitoring period was approximately 13 feet, while the maximum change in river stage was 17 feet (USACE 2008).

Several localized conditions may alter groundwater well production with river stage, including the localized hydraulic properties of the aquifer near a well field, the pumping rate from the field, and the proximity to other pumping wells (USGS 2003). As described above, typically, increased river stage results in a lowering of the regional groundwater gradient between the alluvial aquifer and the river (Kelly 2004). As can be seen with the USACE monitoring wells described above, depending on site-specific factors, this connection between the LOMR stage and groundwater levels does not occur uniformly.

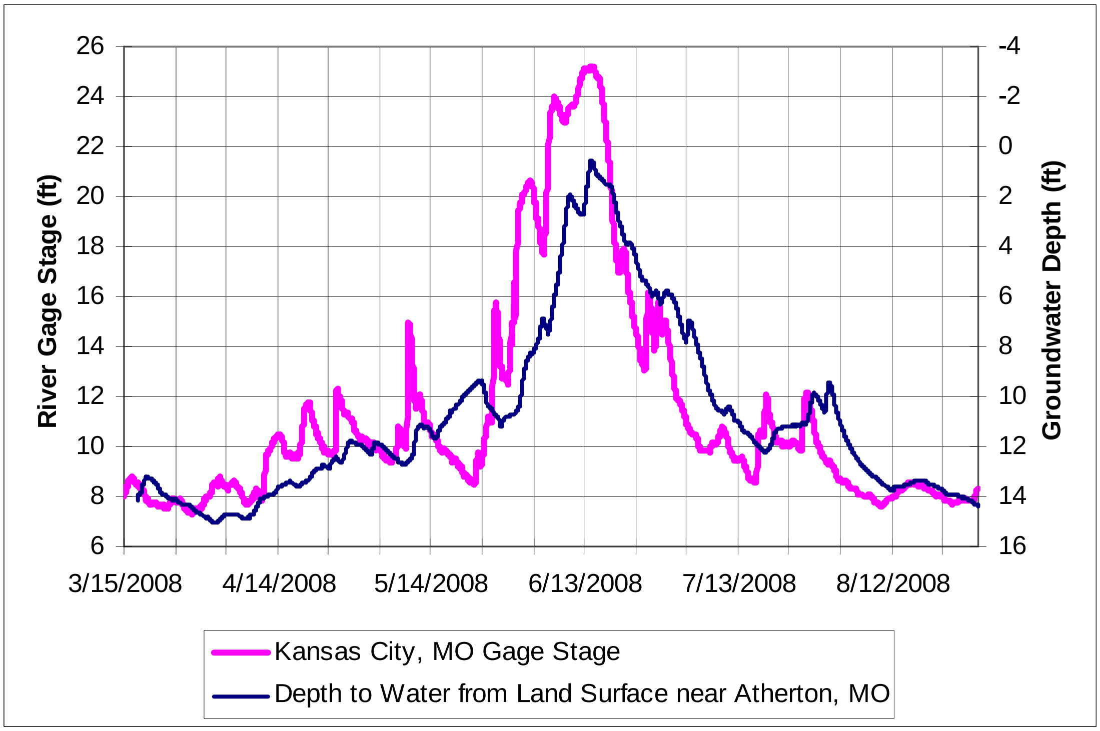

Figure 3.7-2 Depth to Groundwater at a Monitoring Well in Atherton, Missouri and River Stage Data at Kansas City, Missouri (March 15 to August 28, 2008)

Source: USACE 2008.

As discussed in Section 3.4.5.4, several factors contribute to river bed degradation in the LOMR, including commercial dredging for sand and aggregate. River stage at various flows is determined by a number of channel geometry and hydraulic factors. At lower flows, when most of the flow of the

Missouri River is through the navigation channel, the bottom elevation of the general area of the navigation channel has a direct effect on river stage. At higher flows, the entire cross-sectional geometry of the river, including elevations and confinement of the channel by the banks, revetments, and dikes, becomes the controlling hydraulic feature; and the importance of the bottom elevation of the navigation channel decreases substantially. For this reason, degradation has a greater effect on water surface elevation at lower flows and less effect on river stage at higher flows. As discussed above, river stage is one of the primary drivers of alluvial aquifer levels in most locations along the LOMR.

Due to the interaction between the alluvial aquifer and the river stage, it can be inferred that river bed degradation that affects river stage would affect water levels in the alluvial aquifer. But river stages at lower flows are not the only factor determining alluvial aquifer levels (Kelly 2000). The influences of river stage on alluvial aquifer levels are complex. They depend on the magnitude and duration of medium to high flows as well as low-flow conditions, and they change seasonally and annually. To date, no definitive studies have been completed that document the dynamic interaction between river bed degradation and alluvial aquifer levels (Kelly pers. comm.). Correspondence with the USGS has indicated that a study evaluating the changes in groundwater levels in the alluvial aquifer associated with river bed degradation between St. Joseph and Waverly, Missouri will commence in summer 2010 (Kelly pers. comm.).

3.7.5 References

Blevins, D. 2006. The Response of Suspended Sediment, Turbidity, and Velocity to Historical Alterations of the Missouri River. (U.S. Geological Survey Circular 1301.)

Blevins, D. and J. Fairchild. 2001. Applicability of NASQAN Data for Ecosystem Assessments on the Missouri River. Hydrological Processes 15: 1347–1362.

Chapman, D. C., A. L. Allert, J. F. Fairchild, T. W. May, C. J. Schmitt, and E. V. Callahan. 2001. Toxicity and Bioavailability of Metals in the Missouri River Adjacent to a Lead Refinery. (USGS/BRD/BSR – 2001-0004.) Website (http://www.cerc.usgs.gov/pubs/center/pdfDocs/BSR2001-0004.pdf) accessed on May 10, 2010.

Echols, K. R., W. G. Brumbaugh, C. E. Orazio, T. W. May, B. C. Poulton, and P. H. Peterman. 2008. Distribution of Pesticides, PAHs, PCBs, and Bioavailable Metals in Depositional Sediments of the Lower Missouri River, USA. Arch. Environ. Contam. Toxicol. 55:161–172.

Emmett, L. R. and H. G. Jeffery. 1970. Reconnaissance of the Ground-Water Resources of the Missouri River Alluvium between Miami and Kansas City, Missouri. (U.S. Geological Survey Hydrologic Investigations Atlas HA-344.)

Goolsby, D. A. 1993. Occurrence and Transport of Agricultural Chemicals in the Mississippi River Basin July through August 1993. (U.S. Geological Survey Circular 1120-C.)

Gossenauer, M. 2009. Progress and Challenges in Creating Shallow Water Habitat for the Endangered Pallid Sturgeon. Website (http://www.awra.org/seattle2009/presentations/Session%2051/2009%20AWRA%20presentation%20-%20Gossenauer1.pdf) accessed on May 3, 2010.

Hedman, E. R. and D. G. Jorgenson. 1990. Surface- and Ground-Water Interaction and Hydrologic Budget of the Missouri River Valley Aquifer Between Yankton, South Dakota, and St. Louis, Missouri. (U.S. Geological Survey Hydrologic Investigations Atlas HA-721.)

Jacobson, R. B., D. W. Blevins, and C. J. Bitner. 2008. Sediment Regime Constraints on River Restoration – An Example from the Lower Missouri River. In L. A. James, S. L. Rathburn, and G. R. Whittecar (eds.), Management and Restoration of Fluvial Systems with Broad Historical Changes and Human Impacts. Denver, CO.

KDHE (Kansas Department of Health and Environment). 2009. TMDLs for the Missouri Basin. Website (http://www.kdheks.gov/tmdl/motmdl.htm) accessed on May 3, 2010.

KDHE (Kansas Department of Health and Environment). 2008a. Final Kansas Integrated Water Quality Assessment – 2008. Website (http://www.kdheks.gov/befs/download/2008IR_040108FINAL.pdf) accessed on May 3, 2010.

KDHE (Kansas Department of Health and Environment). 2008b. 303(d) List – Approved December 18, 2008. Website (http://www.kdheks.gov/tmdl/download/2008_303d_List.pdf) accessed on May 3, 2010.

Kelly, B. P. 2004. Simulation of Ground-Water Flow, Contributing Recharge Areas, and Ground-Water Travel Time in the Missouri River Alluvial Aquifer near Ft. Leavenworth, Kansas.

Kelly, B. P. 2001. Relations among River Stage, Rainfall, Groundwater Levels, and Stage at Two Missouri River Flood-Plain Wetlands. (U.S. Geological Survey Water-Resources Investigations Report 01-4123.) Website (http://mo.water.usgs.gov/Reports/01-4123-kelly/index.htm) accessed on May 3, 2010.

Kelly, B. P. 2000. Effects of Alternative River Management Plans on Ground-Water Levels in the Lower Missouri River Flood Plain. (U.S. Geological Survey Water-Resources Investigations Report 00-4052.) Website (http://mo.water.usgs.gov/Reports/00-4052-kelly/index.htm) accessed on May 3, 2010.

MDHSS (Missouri Department of Health and Senior Services). 2010. Missouri Fish Advisory. Website (http://www.dhss.mo.gov/fishadvisory/10FishAdvisory.pdf) accessed on May 3, 2010.

MDNR (Missouri Department of Natural Resources). 2010. Proposed 2010 Missouri 303(d) List. Website (http://www.dnr.mo.gov/env/wpp/waterquality/303d/2010-proposed-303d-list.pdf) accessed on May 3, 2010.

MDNR (Missouri Department of Natural Resources). 2009a. Final Consolidated 2008 Missouri 303(d) List. Approved by the USEPA on December 19, 2009. Website (http://www.dnr.mo.gov/env/wpp/waterquality/303d/2008/2008-303d-final.pdf) accessed on May 3, 2010.

MDNR (Missouri Department of Natural Resources). 2009b. 2008 Missouri Water Quality Report (Section 305[b] Report). Water Protection Program. July, 18 2009.

MDNR (Missouri Department of Natural Resources). 2009c. Water Quality Data for the Proposed 2008 303(d) List. Website (http://www.dnr.mo.gov/ENV/wpp/waterquality/303d/2008/proposed-2008-303d-list-data.htm) accessed on May 3, 2010.

MDNR (Missouri Department of Natural Resources). 2007a. Missouri Outstanding National Resource Waters. GIS data. Website (http://www.msdis.missouri.edu/datasearch/VectQueryPage.jsp) accessed on May 3, 2010.

MDNR (Missouri Department of Natural Resources). 2007b. Missouri Outstanding State Resource Waters – Rivers and Streams. GIS data. Website (http://www.msdis.missouri.edu/datasearch/VectQueryPage.jsp) accessed on May 3, 2010.

MDNR (Missouri Department of Natural Resources). 2006a. Total Maximum Daily Loads (TMDLs) for Chlordane and Polychlorinated Biphenyls in the Missouri River. Website (http://www.dnr.mo.gov/env/wpp/tmdl/0226-0356-0701-1604-missouri-r-tmdl.pdf) accessed on May 3, 2010.

MDNR (Missouri Department of Natural Resources). 2006b. Water Quality in Missouri's Larger Rivers. Website (http://www.dnr.mo.gov/pubs/pub2020.pdf) accessed on May 3, 2010.

MRRP (Missouri River Recovery Program). 2007. Shallow Water Habitat. Website (http://im4.nwo.usace.army.mil/mrrp/f?p=136:131:2617391003726013::NO) accessed on May 3, 2010.

Miller, D. E. and J. E. Vandike. 1997. Groundwater Resources of Missouri.

Miller, J. A. and C. L. Appel. 1997. Ground Water Atlas of the United States: Kansas, Missouri, and Nebraska. (U.S. Geological Survey HA 730-D.) Website (http://pubs.usgs.gov/ha/ha730/ch_d/index.html) accessed on May 3, 2010.

Nationalatlas.gov. 2009. Federal Land Features of the United States – Parkways and Scenic Rivers. GIS data. Website (http://www.nationalatlas.gov/mld/fedlanl.html) accessed on May 3, 2010.

NPS (National Park Service). 2008. Nationwide Rivers Inventory. Website (http://www.nps.gov/ncrc/programs/rtca/nri/) accessed on May 3, 2010.

NDEQ (Nebraska Department of Environmental Quality). 2008. 2008 Water Quality Integrated Report. Website (http://www.deq.state.ne.us/Publica.nsf/23e5e39594c064ee852564ae004fa010/9d72c74655475f658625741700741ad3/$FILE/2008%20final%20IR.pdf) accessed on May 3, 2010.

NDEQ (Nebraska Department of Environmental Quality). 2007. Total Maximum Daily Loads for the Nemaha River Basin (NE1-10000, NE2-10000, NE-10600, NE2-12100, NE2-12130, NE2012200, NE2-12330, NE2-12500, and NE3-10000). Parameters of concern: *E. coli* and Atrazine (NE2-10000 only). Website (http://www.deq.state.ne.us/SurfaceW.nsf/23e5e39594c064ee852564ae004fa010/ec394c9991e83e1d8625742d005f8f6b/$FILE/nemaha%20basin.pdf) accessed on May 3, 2010.

Petty, J., B. Poulton, C. Charbonneau, J. Huckins, S. Jones, J. Cameron, and H. Prest. 1998. Determination of bioavailable contaminants in the Lower Missouri River following the flood of 1993. Environmental Science and Technology. 32(7): 837-842.

Poulton, B. C., A. L. Allert, K. R. Echols, and W. G. Brumbaugh. 2005. Validation of Aquatic Macroinvertebrate Community Endpoints for Assessment of Biological Condition in the Lower Missouri River. USGS Columbia Environmental Research Center. August.

Soballe, D. M. 2009. Influence of USACE Restoration Activities on Missouri River Nutrient Regimes. Presentation to the Committee on Missouri River Recovery and Associated Sediment Management Issues. Second Meeting January 21–23, 2009.

USACE (U.S. Army Corps of Engineers). 2008. 2008 Groundwater Monitoring and Evaluation Report: Missouri River Recovery, Integrated Science Program Report.

USACE (U.S. Army Corps of Engineers). 2007. Missouri River Recovery Program Fact Sheet: Sediment Deposition and Water Quality. Website (http://www.mostreamteam.org/Documents/Research/BigRiver/SedimentWaterQuality.pdf) accessed on May 3, 2010.

USACE (U.S. Army Corps of Engineers). 2004. Missouri River Master Water Control Manual: Review and Update. Website (http://www.nwd-mr.usace.army.mil/mmanual/feis/Index.htm) accessed on May 3, 2010.

USACE (U.S. Army Corps of Engineers). 2003. Missouri River Fish and Wildlife Mitigation Project Final Supplemental Environmental Impact Statement. USACE Kansas City and Omaha Districts. March.

USACE (U.S. Army Corps of Engineers). 2000. Improved Methods for Correlating Turbidity and Suspended Solids for Monitoring. (ERDC-TN-DOER-E8.) Website (http://el.erdc.usace.army.mil/elpubs/pdf/doere8.pdf) accessed on May 3, 2010.

USACE (U.S. Army Corps of Engineers). 1990. Memorandum through Chief, Operations Division: L-385 Elutriate Re-Evaluation and Mixing Zone Determination for Renewal of Missouri River Commercial Dredging Permits. (CEMRK-ED-HR.) May 9, 1990.

USACE (U.S. Army Corps of Engineers). 1986. Environmental Effects of Dredging Technical Notes. (EEDP-09-1.) Website (http://el.erdc.usace.army.mil/elpubs/pdf/eedp09-1.pdf) accessed on May 3, 2010.

USEPA (U.S. Environmental Protection Agency). 2009. STORET Database Data for HUCs 10300200, 10300102, 10300101, 10240011, and 1024005. Website (http://iaspub.epa.gov/storpubl/DW_resultcriteria_geo) accessed on May 3, 2010.

USEPA (U.S. Environmental Protection Agency). 2008. Kansas Surface Water Register. Website (http://www.epa.gov/waterscience/standards/wqslibrary/ks/ks_7_kswr.pdf) accessed on May 3, 2010.

U.S. Geological Survey (USGS). 2008a. Water-Data Report 2008: 06895500 Missouri River at Waverly, MO. Website (http://wdr.water.usgs.gov/wy2008/pdfs/06895500.2008.pdf) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2008b. Water-Data Report 2008: 06910450 Missouri River at Jefferson City, MO. Website (http://wdr.water.usgs.gov/wy2008/pdfs/06910450.2008.pdf) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2008c. Water-Data Report 2008: 06909000 Missouri River at Booneville, MO. Website (http://wdr.water.usgs.gov/wy2008/pdfs/06909000.2008.pdf) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2008d. Water-Data Report 2008: 06934500 Missouri River at Hermann, MO. Website (http://wdr.water.usgs.gov/wy2008/pdfs/06934500.2008.pdf) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2008e. Water-Data Report 2008: 06818000 Missouri River at St. Joseph, MO. Website (http://wdr.water.usgs.gov/wy2008/pdfs/06818000.2008.pdf) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2008f. Water-Data Report 2008: 06935965 Missouri River at St. Charles, MO. Website (http://wdr.water.usgs.gov/wy2008/pdfs/06935965.2008.pdf) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2007. Streamflow and Nutrient Fluxes of the Mississippi-Atchafalaya River Basin and Subbasins for the Period of Record through 2005. (USGS Open-File Report 2007-1080.) Website (http://toxics.usgs.gov/pubs/of-2007-1080/large_subbasins_flux.html) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2003. Missouri River Alluvial Aquifer Ground-Water Protection. Website (http://mo.water.usgs.gov/indep/kelly/mo-alluvial-gw/index.htm) accessed on May 3, 2010.

USGS (U.S. Geological Survey). 2000. Nitrogen in the Mississippi Basin Estimating Sources and Predicting Flux to the Gulf of Mexico. Website (http://ks.water.usgs.gov/pubs/fact-sheets/fs.135-00.pdf) accessed on May 3, 2010.

3.7.5.1 Personal Communication

Kelly, B. P. U.S. Geological Survey. Telephone conversation between B. Kelly and Katey Grange (ENTRIX) regarding the linkage between river bed degradation and alluvial aquifer levels on the Lower Missouri River. February 2, 2010.