Appendix H
Part 1

Potential Impacts to Shorebirds

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HABITAT FOR MIGRATING SHOREBIRDS IN SOUTHEAST MISSOURI: Potential Impact of St. Johns-New Madrid Project

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Abstract. Shallow, seasonal floodwater on areas of non-forest land cover provides potential foraging habitat for migrating shorebirds (Charadriiformes). Historical records of river stage (elevation), from 1943 through 2009, provide insight regarding the long-term variability in flood conditions within the St. Johns and New Madrid Basins in southeastern Missouri during spring (15 March – 15 June) and fall (1 July – 30 October). I estimated the daily availability of shorebird foraging habitat associated with historical flood conditions under assumptions that shorebirds optimally forage in water depth <6 cm, also forage in water depth between 6 – 15 cm, and use mudflat habitat for 3 days after post-inundation exposure. Suitability of habitat was weighted to account for water depth, duration of mudflat exposure, temporal availability of habitat within the migration periods of shorebirds, and average planting and harvesting dates of agricultural crops. Under existing flood conditions, average daily shorebird foraging habitat within the St. Johns and New Madrid Basins, based on replicated random samples of 50 years drawn from 1943 to 2009, is 964 ha during spring and 33 ha during fall. Adjustments to account for habitat quality resulting from hydrological fluctuation (i.e., water depth and duration of mud exposure) and vegetation change (i.e., crop growth and harvest), as well as temporal coincidence with shorebird migration, suggest that the optimally equivalent area of shorebird habitat is 489 ha during spring and 12 ha during fall but varied markedly among years, from <1 ha to 1840 ha during spring and from 0 to 275 ha during fall. Implementation of the St. Johns-New Madrid Project would complete a system of levees which, when water-control gates are closed, would isolate these basins from Mississippi River floodwaters. The proposed project includes pumps to transport drainage water, which accumulates and floods land behind closed water-control gates,

across levees to maintain or lower water elevations within these basins. Hydrological changes resulting from the St. Johns-New Madrid Project would reduce the area and temporal availability of shallow floodwater habitat used by foraging shorebirds. Under authorized water-management (i.e., flood reduction) conditions, the average daily area of shorebird foraging habitat would be reduced by 80%, to 208 (107 optimally equivalent) ha during spring and 9 (<3 optimal) ha during fall. Proposed alternative water management scenarios within the New Madrid Basin would allow floodwater to fluctuate above authorized elevations. The most liberal alternative water management scenario that permits flooding of lower elevations year-round provides continuance of nearly all shorebird foraging habitat during fall and retains nearly two-thirds extant habitat during spring. More conservative of water management scenarios that afford greater flood protection during spring and summer would likely provide 186 (95 optimal) ha of shorebird foraging habitat during spring but provides no increase shorebird foraging habitat during fall.

Key Words: digital elevation model, flood control, floodwater, habitat quality, mudflat, shorebird habitat, temporal availability

INTRODUCTION

After record flooding in 1937, concerted flood control measures were implemented along the Mississippi River and its tributaries (Stevens et al. 1975). These measures included extensive earthen levees intended to confine rivers within their battures, such that >3218 km of mainline river levees are present along the 1529 km course of the lower Mississippi River (Nunnally et al. 1987). In addition, a network of canals throughout southeastern Missouri was created to facilitate drainage from croplands. Hydrological alteration from levees and canals patently alters adjacent ecosystems (Gergel et al. 2002). As such, historically forested landcover within southeastern Missouri has largely been converted to agriculture (Fig. 1).

Despite marked hydrological change in the St. Johns and New Madrid Basins, these basins remain subject to seasonal inundation (Fig. 1). In part, continuance of flooding outside the batture has been due to a gap within the levee system that surrounds the New Madrid Basin. This gap permits Mississippi River floodwater to enter the New Madrid Basin during periods of high water. Historical data suggest that an average (2-year) backwater flood in the New Madrid

Basin inundates circa 7000 ha, of which 4700 ha are in agriculture (unpublished data, U.S. Army Corps of Engineers, http://www.mvm.usace.army.mil/stjohns/overview/default.asp). Even so, during 1973 significant backwater flooding inundated over 20,000 ha in this basin. In addition, the New Madrid Floodway, authorized in 1928, was designed to convey Mississippi River water during extreme flood conditions: it served this function during floods of 1937 and 2011.

Conversely, contiguous levees protect the St. Johns Basin from Mississippi River backwater flooding but gravity-outlet, box culverts through this levee allow drainage when the Mississippi River elevation is lower than the interior water elevation. However, when culvet gates are closed, surface drainage from intra-basin precipitation accumulates and lands are inundated behind the protective levees. In the St. Johns Basin, headwater flooding after closure of culvert gates has resulted in average 2-year flood events that inundate circa 4000 ha, of which 2500 ha are in agriculture (unpublished data, U.S. Army Corps of Engineers).

Although agricultural production may be adversely affected by flooding in the New Madrid and St. Johns Basins when floods occur during the growing season, seasonal floods have many ecological benefits. Seasonal inundation of non-forested land, predominately cropland, within these basins provides shallow-water flooding and mudflats that are suitable for foraging by shorebirds (Charadriiformes). These birds comprise a diverse group of small to medium-large birds that generally forage for invertebrates in shallow water (Recher 1966, Brown et al. 2001). Away from coastal shorelines, most shorebird species forage in areas of sparse vegetation, such as those associated with harvested agricultural lands (Helmers 1992, Rottenborn 1996, Twedt et al. 1998, Isola et al. 2000, Cole et al. 2002).

Because most of southeastern Missouri was historically forested, it previously did not attract large flocks of shorebirds (Twedt and Loesch 2002, Smith et al. 1996). However, as most of the land within the New Madrid and St. Johns Basins has been converted to agriculture, these basins now have tremendous potential for providing foraging habitat for shorebirds. Even so, few shorebird species breed in this area, with only Killdeer (*Charadrius vociferus*) being a common breeding species (Missouri Breeding Bird Atlas 1986 – 1992 <http://mdc.mo.gov/nathis/birds/birdatlas/index.htm>). Similarly, few individuals and species of shorebirds are present during winter. For example, during the past 2 decades Big Oak Tree State Park Christmas Bird Counts, conducted within a 15-mile diameter circle in the New Madrid Basin, detected only 5 species of shorebird, with only Killdeer, Common Snipe

(*Gallinago gallinago*), and Least Sandpiper (*Calidris minutilla*) detected in more than 1 year. The greatest abundance and species diversity of shorebirds within this region occur during spring and fall, as en-route migrant shorebirds make "rest and refueling" stops during their northbound (spring) and southbound (fall) passages (Elliott and McKnight 2000; Skagen 1997, 2006). Based on conservation planning documents (Loesch et al. 2000; Elliott and McKnight 2000), and empirical observations of shorebird abundances reported to the Lower Mississippi Valley Joint Venture Shorebird Monitoring Program (http://www.lmvjv.org/shorebird/default.asp), shorebirds of small or medium body size comprise the preponderance of these shorebirds (Table 1).

Comprehensive, long-term monitoring data that document the temporal passage of shorebirds through southeastern Missouri during migration do not exist, but Skagen et al. (1999) provide a general latitudinal quantification of the temporal distribution of abundances for small and medium sized shorebirds. An assessment of these data suggests that spring migrants are present between 15 March and 15 June, whereas fall migration may begin as early as 1 July and continue through 30 October (Skagen et al. 1999). These two time periods encompass nearly the entirety of shorebird passage through southeastern Missouri. Even so, the numbers of shorebirds migrating through this region are not uniformly distributed within these intervals, but peak abundances are expected between late April and mid-May during spring and between mid-August and mid-September during fall.

Many factors contribute to habitat selection by shorebirds (Burger 1984, Jing et al. 2002). Even so, most small and medium size shorebirds forage primarily in water depths <6 cm. Some of these shorebirds, and other less abundant shorebirds, also forage in exposed mudflat habitats and in floodwater of depth from 6-15 cm, with a few, usually larger, species foraging at greater water depth (Table 1). Despite this diversity in foraging habitats, more than 70% of shorebird species forage in water depths <10 cm and many species are restricted to water depths of <5 cm (Helmers 1992, Skagen et al. 1999, Dinsmore et al. 1999). Indeed, shallow water depth was the most important predictor of shorebird abundance within the Rainwater Basin in Nebraska (Webb et al. 2010). Similarly, in an assessment of foraging habitat use by shorebirds in the Playa Lakes Region of Texas, Davis (1996) reported shallow (<4 cm depth) flooded habitats were used by 46% of foraging flocks, moderately flooded (4-16 cm depth) habitats were used by 29%, and mudflats were used by 19%, but only 5% of foraging flocks used habitats flooded deeper than 16 cm.

Shorebirds forage within a variety of substrates that range from bare ground to >75% vegetative cover, but most species preferentially use sites with sparse (<25%) vegetative cover (Davis and Smith 1998, Dinsmore et al. 1999). Davis (1996) reported that in Texas, 95% of foraging flocks used sites with <33% vegetation. Moreover, abundance of some shorebird species was negatively correlated with vegetation height (Colwell and Dodd 1995) with most species found on sites where vegetation height was less than half of their body height.

Because prolonged duration of flooding stimulates production of aquatic invertebrates, water is often retained for long periods (weeks or months) on artificial wetlands (i.e., impoundments) that are managed for shorebird foraging habitat. However, natural wetlands and rivers harbor myriad aquatic invertebrates upon which shorebirds forage. In addition, terrestrial insects and other invertebrates found in cultivated fields in the Mississippi Alluvial Valley provide food for shorebirds when these fields are flooded. Thus, lands subjected to backwater flooding that have sparse or short vegetation (e.g., agricultural fields or grazed grasslands) may provide productive foraging sites for migrating shorebirds regardless of flood duration. Given current land use within southeastern Missouri, supplying the necessary mix of water depth and vegetative structure, within temporal windows that correspond with shorebird migration, is the most important issue for shorebird conservation in this region (Brown et al. 2001).

The U.S. Army Corps of Engineers (USACE) has proposed completion of an earthen levee to protect the New Madrid Basin and concurrent installation of water pumping facilities within both the St. Johns and New Madrid Basins (a.k.a., St. Johns-New Madrid Project). Proposed pumps would be capable of transporting headwaters, that accumulate behind closed water control gates, over the protective levees with subsequent deposition in the Mississippi River batture. Completion of the St. Johns-New Madrid Project is expected to eliminate backwater flooding from the Mississippi River and afford reduction of headwater flooding within both of these basins. Reduced flooding will likely diminish the area of habitat that is suitable for foraging shorebirds within both basis, but because the direct connection with the Mississippi River will be severed, habitat loss is anticipated to be greater within the New Madrid Basin.

To assess the effect of the St. Johns-New Madrid Project on shorebird habitat, I sought to quantify the area of shorebird habitat within the St. Johns Bayou and New Madrid Basins, and to predict the area of shorebird habitat that would be available under presumed post-flood control project conditions. Specifically, my objectives were to:

1. Develop a methodology to quantify the area of potential shorebird habitat relative to intra-basin hydrological elevations (National Geodetic Vertical Datum: NGVD) that were derived from Mississippi River elevations (a.k.a., river stages), precipitation, topograph, and land cover,
2. Estimate the area of potential shorebird habitat within the St. Johns and New Madrid Basins that is associated with each ~3 cm (0.1 foot) increment of intra-basin water elevation,
3. Quantify the availability of shorebird habitat within the St. Johns and New Madrid Basins during periods of northward and southward migration of shorebirds, based on historical intra-basin water elevations, and
4. Predict future availability of shorebird habitat during periods of northward and southward migration of shorebirds within the St. Johns and New Madrid Basins based on projected post-project intra-basin water elevations.

METHODS

Study Area

Area of investigation included 126,325 ha in the St. Johns Bayou Basin and 47,670 ha in the New Madrid Basin of southeastern Missouri that would be impacted by the St. Johns-New Madrid Project (Fig. 1). Greater than 90% (163,235 ha) of landcover in these basins is cropland, pasture, or other sparse vegetation, that if shallowly inundated could provide habitat conditions suitable for foraging shorebirds (Fig. 1).

Landcover

I considered all lands with tall or dense vegetation (e.g., forest or shrubs) unsuitable for shorebirds. Similarly, areas in permanent water (i.e., lakes and ponds) were assumed to be predominately of depths that exceed shorebird foraging limits and thus not suitable shorebird habitat. Conversely, I assumed agricultural cropland, grassland, and other open lands were suitable shorebird foraging habitat when appropriately inundated.

Initial landcover classifications within the St. Johns and New Madrid Basins were obtained at 30-m resolution from the Multi-Resolution Land Characterization Consortium's 2001 National Land Cover data (available online at: http://www.mrlc.gov/nlcd01_data.php, Homer et al. 2004, 2007). These National Land Cover data were verified using aerial imagery obtained from the U.S. Department of Agriculture, National Agricultural Imagery Program. Individual land use polygons were visually compared with aerial imagery and, where inconsistencies were identified, corrections were made to the land use data to conform with aerial imagery. Finally, land use was further verified by conducting site visits on 20% of the project area and crop types were assigned to agricultural lands (K. Pigott, personal communication).

I reclassified the USACE landcover raster into binary descriptors of shorebird habitat (suitable vs. non-suitable) where non-suitable habitat included all forest classes (including wooded wetlands), shrubland, open water, and high-density developed areas (i.e., cities). All other cover classes, including all crops, fallow fields, orchards, grassland, pasture, low- and medium density developed lands (i.e., farmsteads and suburban areas), and herbaceous or emergent wetlands, were considered potentially suitable as shorebird habitat.

Comparison of these 30-m data with 2007 aerial photography within these basins revealed marked discrepancies in areas deemed suitable shorebird foraging habitat. That is, some areas of forest cover were classified as 'open' habitats whereas other areas of 'open' habitat were classified as forested. Therefore, I converted this binary depiction of shorebird habitat to a vector format and subsequently employed 'heads-up' digitization to alter habitat polygons to reflect habitats identified from 2007 aerial photography. Only areas within the St. Johns and New Madrid Basins that had landcover suitable for shorebirds during 2007 were considered when estimating areas of potential shorebird foraging habitat (Table 2)

Wetland Reserve Program

Some areas deemed potentially suitable for shorebirds were known to have been previously enrolled in the U.S. Department of Agriculture's Wetland Reserve Program (WRP). As most WRP enrollments within this region are reforested or converted to semi-permanent water, these areas will likely harbor little potential shorebird habitat in the future. Thus, all lands enrolled in WRP were removed from consideration as shorebird habitat.

In addition, U.S. Department of Agriculture personnel, in cooperation with USACE personnel, estimated that WRP enrollment over the next 50 years will increase by 345 ha in the New Madrid Floodway and by 1200 ha within the St. John's Basin. Based on the area of existing WRP enrollments (i.e., average contract size: 87 ha in St. John's, 67 ha in New Madrid), enrollment of as few as 2 contracts per year would realize these WRP projections within 10 years. Therefore I assumed 10% of projected future enrollment in WRP occurred each year for 10 years and thereafter remained stable. Elevations (decifoot) of projected WRP enrollments were assumed comparable to elevations within existing WRP enrollment. Therefore proportionally equivalent areas were annually (for 10 years) removed from potential shorebird habitat. If insufficient area for removal remained within a decifoot elevation, proportional removal was increased among remaining decifoot elevations until projected area of removal was attained.

Foraging habitat

Because most shorebirds rarely forage in dry habitats, I assumed only areas that were inundated or recently exposed from inundation (i.e., mudflats) were suitable for use by foraging shorebirds. However, based on differential habitat use reported by Davis (1996), I assumed only habitats that were shallowly flooded with ≤6.1 cm (0.2 ft) of water provided optimal foraging conditions. These shallowly flooded areas were assigned maximum habitat suitability (s = 1.0). Suitability of habitats flooded at greater depths, up to 15.25 cm (0.5 ft) was assumed inversely related to water depth. Therefore I assigned reduced suitability scores to flood depths 6.1 − 9.15 cm (s = 0.8), 9.15 − 12.2 cm (s = 0.7), and 12.2 − 15.25 cm (s = 0.6). Similarly, because of relatively less use of mudflats by foraging shorebirds (Davis 1966), presumed spatial heterogeneity in mudflat habitat conditions, and uncertainty regarding the temporal stability of exposed mudflats due to variation in drainage and rates of evapo-transpiration, I assumed mudflats were less than optimal for most foraging shorebird species. Therefore, I inversely weighted suitability of mudflats relative to length of exposure after inundation as: exposed 1 day (s = 0.6), exposed 2 days (s = 0.5), and exposed 3 days (s = 0.4).

Migration Window

The quantitative distribution of shorebirds within spring and fall migration periods is not uniform, as fewer birds are present at the beginning and end of each migration period. Using temporal distribution data for small and medium shorebirds within 35^{o} – 40^{o} north latitude in North America provided by Skagen et al. (1999), I modeled abundance as a function of time (day) within each migration period. The best-fit regression models were:

Spring shorebird abundance = 1.012(day) + 0.0255(day^2) – 0.0004(day^3) and

Fall shorebird abundance = 4.2538(day) - 0.0598(day^2) + 0.0002(day^3)], where day was the interval after the presumed first day within each migration period (Fig. 2). From these regression models I estimated the intervals within each migration period wherein 50% and 90% of the migrating shorebird populations were predicted to be within the study area. Assuming the greatest benefit occurs when the greatest abundance of shorebirds have access to suitable foraging habitat, I assigned maximum value to those days wherein 50% of the population was predicted to be present ($t = 1.0$). For those remaining days of each migration period that harbored an additional 40% of the population (90% total), migration period value was reduced to 90% of maximum ($t = 0.9$). For all other days, during which only 10% of the shorebird population was predicted to be present, I reduced migration period value to 50% of maximum ($t = 0.5$). Using these migration period values, the daily area of shorebird foraging habitat equivalence, previously estimated from suitability of flood conditions in areas of suitable landcover, was modified to reflect temporal availability of habitat within each migration period.

Crops: Planting, Growth and Harvest

Suitability of inundated lands as shorebird habitat diminishes with increased density and stature of vegetation. Therefore, I evaluated the usual first and last planting and harvesting dates for crop grown in Missouri (USDA 1997). Using 9 reclassified land cover types (Table 2), I developed step-functions for each of 7 crop types that were potentially suitable as shorebird habitat to reflect a decreased suitability of habitat after planting (crop suitability; $c = 0.75$), an additional decrease in suitability upon presumed maturation ($c = 0.5$), followed by increased suitability upon initiation of harvest ($c = 0.75$), and subsequent return to maximum suitability ($c = 1.0$) upon completion of harvest (Figure 3). Land cover classified as fallow or developed (open, low density, or medium density) was assumed to be maintained in suitable condition as shorebird habitat and retained maximum suitability ($c = 1.0$), whereas land cover classes deemed unsuitable as shorebird habitat were assumed to have zero crop suitability ($c = 0.0$).

I calculated the area of each crop type class within each 3.05 cm contour elevation for each river basin and determined its proportion of all potentially suitable shorebird habitats within the respective contour elevation. For each day of the year (a.k.a., Julian day), I summed the products of proportion of crop type class (constant among days) and crop suitability index (varied among days) to determine an elevation-day crop development index. Where the elevation-day crop development index was the proportion of crop type class times the crop type class suitability index for the day, summed over 8 crop type classes (Table 2). To account for temporal change in crop status within each contour elevation, I decreased the area of optimally suitable shorebird habitat using its corresponding elevation-day crop development index. Thus for each day, the optimally equivalent area of shorebird foraging habitat was calculated as:

Optimally equivalent area = Σ (ha*s*t*CDI), summed over all elevations, where
ha = area in hectares inundated <16 cm or exposed from inundation within the previous 3 days,
s = water depth or mud exposure suitability,
t = temporal suitability within spring or fall migration window.
CDI = elevation-day crop development index.

Water Elevations

Neither St. Johns Bayou nor the New Madrid Floodway had river gage (water elevation) records suitable for direct estimation of intra-basin water levels. Therefore U.S. Army Corps of Engineers personnel derived daily intra-basin water elevations for each of these basins from 1943 through 2009 based on: 1) period of record data from New Madrid river gage (MS115, -89.53222, 36.58306, 0.2 km downstream from the mouth of St. Johns Bayou at river navigation mile 889.0, http://www.mvm.usace.army.mil/hydraulics/docs/gagtitl/ms115hdr.htm); 2) regional precipitation records from weather stations at New Madrid and Sikeston, Missouri and Cairo, Illinois; 3) topography (conventional and LiDAR); and 4) land cover. From these data, daily intra-basin water elevations were calculated for the St. Johns Basin (Appendix A1) and the New Madrid Basin (Appendix 10) using the computer program HUXRAIN (pers. com., B. J. Bruchman, Memphis District, U.S. Army Corps of Engineers).

The model application does not consider how large scale land use changes and climate change may affect future water elevations. Use of historic data such as water elevation data to make future projections assumes stationarity – that natural systems fluctuate within an unchanging envelope of variability. The assumption of stationarity may not be appropriate but our current understanding of future land use and climatic conditions does not afford guidance on how to address non-stationarity of water resources.

Flood assessment

I obtained digital vertical elevation (NGVD) contours at 0.305 m (1-foot), derived from light detection and ranging (LiDAR) data within the New Madrid Basin and derived from geodetic and hydrologic data within the St. Johns Basin, from U.S. Army Corps of Engineers (K. R. Pigott, Memphis District, U.S. Army Corps of Engineers; Appendix C). A fundamental underlying assumption for subsequent estimation of shorebird habitat within the St. Johns and New Madrid Basins was that these 1-foot elevation contours reasonably approximated the extent of floodwater associated with their respective intra-basin water elevations.

I used ArcMap 9.3 (ESRI, Redlands, California) geographic information system to spatially interpolate 3.05 cm (0.1-foot) interval elevations between each pair of 1-ft elevation contours. Because of computer memory limitations, separate interpolations were undertaken within subdivisions of each basin. Upon completion of interpolation, within each basin I merged all interpolated subdivisions into a unified digital elevation map (raster). Specifically for each basin I:

1. Used Hawth's Analysis Tools for ArcGIS (http://www.spatialecology.com/htools) to create grid cells (10,000 ft x 10,000 ft) which encompassed the entirety of the basin and clipped grid cells to the boundaries of each basin if cells extended beyond the boundaries of the basin.
    a. If resultant clipped grid cell was small, or lacked sufficient 1-ft contour lines for subsequent interpolation, it was merged with an adjacent cell [Analysis Tools; Overlay; Union].
2. Extracted separate pieces of the original 1-ft contour lines using each of the separate clipped grid cells as extraction boundaries [Analysis Tools; Extract; Clip].
3. Interpolated 0.1-ft elevation digital elevation model (DEM) for each extracted subdivision using ArcMap [Spatial Analyst Tools; Interpolation; Topo-to-Raster]. Interpolation was set at the default of 20 cells beyond the boundary of the grid cell extraction (i.e., overlap among subdivisions) and output cell size of resultant DEM specified at 3 ft x 3ft (0.9 m) horizontal spacing [i.e., 9 ft^2 raster pixel]. Resultant elevation models were 64-bit, floating point rasters.

   a. For a few subdivisions, Topo-to-Raster interpolation failed. In these instances, the area being interpolated was reduced through reiteration of the above methods but with smaller grid cells (5,000 ft x 10,000 ft or smaller).

4. Used ERDAS IMAGINE 2010 (Erdas Inc., Norcross, Georgia) to merge all subdivisions within each basin into a single digital elevation model (raster). Areas of overlap were assigned mean cell values.
5. Multiplied all cell values within each merged digital elevation model by 10 [Spatial Analyst Tools; Math; Timesand converted from a floating point raster to a 16-bit unsigned raster], such that each raster cell represented a 'decifoot' elevation (where 1 decifoot = 0.1 foot). For example, an original elevation of 294.823848 feet would be represented as 2948 decifeet.

The total area (ha) included in each presumed decifoot (3.05 cm) elevation, summed separately within each basin, represented the area inundated at each corresponding intra-basin water elevation.

Model Application

Within each river basin, for each day from 1 January 1943 through 30 November 2009, I projected intra-basin water elevations to estimate the area of landcover within 3.05 cm elevation intervals, and with habitat structure suitable for shorebird foraging, that was inundated with ≤15.25 cm of water. Concurrently, I projected inundations associated with water elevations for each of the previous 3 days. When inundation was greater during any of the previous 3 days (i.e., falling water levels), the area of suitable landcover exposed after inundation was estimated separately for each of these 3 days. That is, the area between the daily water-land interface contour (0 depth) and the contour representing the previous day's flood extent was summed to represent mudflat habitat exposed on each day. The total daily area of potential shorebird habitat with suitable land cover within the St. Johns and New Madrid Basins was the combined areas of inundation ≤15.25 cm in depth and mudflats exposed within the previous 3 days. For each day, this sum represented the total area (i.e., footprint) available to shorebirds for foraging.

As not all of the area available to shorebirds was considered optimal for foraging, the area of presumed suitable shorebird foraging habitat within each flood-depth interval was weighted by its depth-specified suitability (s). Similarly, the area of presumed suitable shorebird foraging habitat exposed as mudflats was weighted relative to suitability (s) associated with length of exposure (1, 2, or 3 days) after prior inundation.

All suitable habitats were also temporally weighted to account for the likelihood of migrating shorebirds being present in the study area (t), and to account for seasonal change in vegetation on croplands (CDI). Daily sums of appropriately weighted foraging areas, that accounted for presumed foraging quality and temporal suitability, provided a measure of 'optimal' habitat equivalence (i.e., the equivalent area of suitable shorebird foraging habitat if quality and temporal availability were optimal).

To determine the area of shorebird foraging habitat available during spring and during fall under existing flood conditions, I determined the mean and variance associated with 200 bootstrap samples, with each sample consisting of 50 years of intra-basin water elevation data that were randomly selected (with replacement) from years 1943 – 2009. I assessed the extent of annual variation in available shorebird foraging habitat by identifying annual minimum and maximum areas of shorebird foraging habitat during spring and during fall.

Forecast Prediction

The authorized St. Johns-New Madrid Project will ostensibly restrict floodwater elevations from spring through fall to ≤279 feet NGVD within the St. Johns Basin and ≤278 feet NGVD within the New Madrid Basin. Pumping of impounded water would commence within each basin at these prescribed maximum elevations and would continue until sump elevations were reduced to 277 feet NGVD in the St. Johns Basin and 275 feet NGVD in the New Madrid Basin. Recognizing that extreme rainfall events and pump limitations will likely prevent strict adherence to authorized flood elevation limits, and that intentional retention of sump elevation above falling river elevation is possible, U.S. Army Corps of Engineers personnel (B. Bruchman, pers. com.) generated projected estimates of water elevations under authorized project flood restrictions for the St. Johns Basin (Appendix A2) and the New Madrid Basin (Appendix B2) using methodologies similar to those used to derive historical daily water elevations. I forecast the probable area of foraging habitat for shorebirds based intra-basin water elevations using the same methods described above, but with historical daily water elevations replaced with daily water elevations projected under post-project authorized flood restrictions.

Because flood events that do not impact crop production or imperil residential areas are socio-politically acceptable and environmentally beneficial, 3 alternative water management scenarios that allow greater inundation were evaluated within the New Madrid basin (Table 3). The most liberal of these proposed alternatives would provide flood protection to elevations

≥290 feet NGVD throughout the year (Table 3). A more conservative alternative allows water elevation up to 288 feet NGVD during the early portion of spring migration, with subsequent reduction in water elevation to ≤284 feet NGVD during later spring migration, and 279.5 feet during fall (Table 3). Using the methodologies described above, daily estimates of intra-basin water elevation were projected that reflect in impact of alternative water management (Appendices B3, B4, and B5) which were subsequently used to predict the daily area of shorebird foraging habitat that would be available under proposed alternative water management scenarios.

RESULTS

For each day within the spring and fall migration periods from 1943 through 2009, I estimated: (1) the total area of potential shorebird foraging habitat (i.e., open land) flooded regardless of depth, (2) total area of shorebird foraging habitat that was inundated with ≤15.25 cm or exposed from inundation for ≤3 days, (3) the equivalent area of shorebird foraging habitat after accounting for presumed quality of foraging habitat, (4) the equivalent area of shorebird foraging habitat that also accounts for temporal availability of habitat within migration periods, and (5) the optimally equivalent area of foraging habitat that accounts for habitat quality, temporal availability, as well as crop planting, growth, and harvest within the St. Johns Basin (Appendix A1) and New Madrid Basin (Appendix B1). Shorebird foraging habitat was available on >80% of days during spring but <50% of days during fall and was present on more days within the St. Johns Basin than within the New Madrid Basin (Table 4).

Despite a smaller area, the average daily available shorebird foraging habitat under existing conditions within the New Madrid Basin was markedly greater than that available within the St. Johns Basin (Table 5). Mean daily area of shorebird foraging habitat under existing conditions within both basins was 29 times greater during spring (964.3 ± 114.1 ha; x ± SD) than during fall ((33.2 ± 13.9 ha; Table 5).

After adjusting for habitat quality, temporal availability, and crop condition, mean daily ‘optimally equivalent’ area of shorebird foraging habitat under existing conditions within both basins, was >40 times more abundant during spring (488.9 ± 60.3 ha) than during fall (11.6 ± 5.3; Table 6). During an average spring day under existing flood conditions, shorebird foraging habitat was present on nearly 1000 ha of 3700 flooded ha, but habitat quality and temporal availability indicated <500 ha of optimally equivalent habitat were available for foraging. In contrast, during an average fall day under existing flood conditions, only 33 ha of shorebird foraging habitat were present, with the equivalence of <12 ha optimal foraging habitat.

Adherence to water management as authorized upon completion of the St. Johns-New Madrid Project that restricts sump elevation to ≤279 ft NGVD within the St. Johns Basin would reduce the total availability of shorebird foraging habitat within this basin by ~30% in spring and by ~38% in fall (Table 5). Authorized restriction of sump elevation to ≤278 ft NGVD within the New Madrid Basin would reduce the total availability of shorebird foraging habitat within this basin much more markedly, by >98% in both spring and fall (Table 5). The optimally equivalent area of shorebird foraging habitat within the New Madrid Basin was similarly reduced during both migration periods (Table 6).

The alternative water management scenario that affords year-round flood protection only for elevations ≥290 feet NGVD within the New Madrid Basin (alternative 4) will provide nearly all existing shorebird foraging habitat during fall and retain nearly two-thirds of the existing shorebird foraging habitat during spring (Table 6). Moreover this liberal alternative water management scenario encompasses >50% of existing annual variation in shorebird foraging habitat (Table 6). In contrast, the alternative water management scenarios proposed for the New Madrid Basin, which allow increased inundation only during spring (alternatives 1 and 2) do not mitigate loss of shorebird foraging habitat during fall, and would likely reduce the availability of total shorebird foraging habitat (Table 5) and optimally equivalent area of shorebird foraging habitat (Table 6) during spring by 70% – 85%.

DISCUSSION

I assumed that 1-foot elevation contours developed by U.S. Army Corps of Engineers' personnel provided a reasonable approximation of the ground elevation and drainages within the St. Johns and New Madrid Basins. As such, the extent of floodwater associated with each respective intra-basin water elevation was accurately depicted through conformity to these elevation contours. Interpolated 0.1 foot elevation contours between adjacent 1-foot elevation contours are undoubtedly inexact. However, this shorebird foraging habitat model assumes that variation in flooded area is unbiased within the landscape and, thus on average provides a reasonable approximation of suitably flooded areas. That is, the exact geographic distribution of areas assumed to be suitable for shorebird foraging may not be accurately depicted but the total area of suitably inundated and recently exposed (mudflat) habitat is presumed to be an accurate representation of daily conditions.

Because reduction in the area of shorebird foraging habitat associated with completion of the St. John-New Madrid Project was great within the New Madrid Basin, alternative water management scenarios were proposed to lessen loss of shorebird foraging habitat. Even though these alternatives increased the area of available shorebird foraging habitat during spring, both proposed alternatives resulted in a marked reduction (70% or 85%) in the area of shorebird foraging habitat. Furthermore, all proposed post-project management scenarios nearly eliminate shorebird foraging habitat during fall in the New Madrid Basin.

I assumed intra-basin water elevations would fluctuate with river stage but intentional retention of water within management pools, at elevations that exceed river stage, would increase the area of shorebird foraging habitat above that identified by this model. Thus, additional targeted management actions, within either of these basins, could enhance the availability of shorebird foraging habitat without increased flooding beyond proposed management scenarios.

Grassland vegetation conditions range from very short to relatively tall and rank. Grazed or hayed grasslands likely have vegetation structure during fall or spring that when flooded constitutes suitable habitat for shorebird foraging.

During the past 15 years, >2300 ha of agricultural land have been enrolled in WRP with >1500 additional ha anticipated to be enrolled within the St. Johns and New Madrid Basins. I assumed these additional enrolments would occur within the next 10 years and that the elevation distribution of future enrollment will be similar to past enrollment. Therefore, as the geo-spatial coordinates of any future WRP enrollments become known, increased precision of these predictions is possible.

These model projections assumed stationarity of future flood conditions. However, if future flood events are less frequent and of lower intensity, the area of shorebird foraging habitat will suffer reduction. The annual effects of the St. John-New Madrid Project on shorebird habitat should be lessened – but the resultant further reduction in diminished foraging area may detrimental to migrating shorebird populations. Conversely, if future flood events are more frequent and of greater intensity (i.e., higher elevation), shorebird foraging habitat would likely increase in area and duration of availability. Under these conditions, although the St. John-New

Madrid Project would likely reduce shorebird foraging habitat, the extent and availability of suitable shorebird foraging habitat may be sufficient to support migrating shorebird populations.

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Figure 1. St. Johns and New Madrid Basin study area in southeastern Missouri. Forest, open water, and urban landcover were deemed unsuitable for foraging shorebirds. Relative flood frequency was based on multi-temporal analysis of satellite imagery (Ducks Unlimited, unpublished data).

Figure 2. Predicted relative abundance of small and medium shorebirds between 35^{o} and 40^{o} N latitude in North America during a 93 day (15 March – 15 June) spring migration period and during a 122 day (1 July – 30 October) fall migration period. Polynomial approximations are based on shorebird abundances reported by Skagen et al. (1999). Assessment of the area under predicted curves indicates 50% of the spring population present 24 April – 23 May and 90% present 3 April – 8 June. During fall migration, 50% of the shorebird population occurs 5 August – 16 September and 90% present 14 July – 13 October.

Figure 3. Step functions used to characterize crop-type suitabilty for every day of year based on first and last planting and havesting dates within Missouri and a presumed 4 week period of rapid initial growth (U.S. Department of Agriculture 1997).

Table 1. Shorebird species, body size, presumed foraging depth (cm), and numbers of southward (fall) migrating shorebirds detected on surveys in the 4 states (Missouri, Kentucky, Tennessee, and Arkansas) near the St. Johns-New Madrid study area that were reported to the Lower Mississippi Valley Joint Venture Shorebird Monitoring Program.

Family	Common Name	Scientific Name	Size[1]	Depth	Number[2]
Charadriidae	Piping Plover	*Charadrius melodus*	S	<3	25
Charadriidae	Semipalmated Plover	*Charadrius semipalmatus*	S	<3	1672
Charadriidae	Killdeer	*Charadrius vociferus*	M	<3	15292
Charadriidae	American Golden-Plover	*Pluvialis dominica*	M	<9	80
Charadriidae	Black-bellied Plover	*Pluvialis squatarola*	M	<9	518
Recurvirostridae	Black-necked Stilt	*Himantopus himantopus*	L	<20	4082
Recurvirostridae	American Avocet	*Recurvirostra americana*	L	<12	793
Scolopacidae	Spotted Sandpiper	*Actitis macularia*	M	<4	535
Scolopacidae	Ruddy Turnstone	*Arenaria interpres*	M	<6	10
Scolopacidae	Upland Sandpiper	*Bartramia longicauda*	M	<6	19
Scolopacidae	Sanderling	*Calidris alba*	M	<3	257
Scolopacidae	Dunlin	*Calidris alpina*	M	<6	152
Scolopacidae	Baird's Sandpiper	*Calidris bairdii*	S	<6	925
Scolopacidae	Red Knot	*Calidris canutus*	M	<6	2
Scolopacidae	White-rumped Sandpiper	*Calidris fuscicollis*	S	<6	540
Scolopacidae	Stilt Sandpiper	*Calidris himantopus*	M	<9	8785
Scolopacidae	Western Sandpiper	*Calidris mauri*	S	<6	2521
Scolopacidae	Pectoral Sandpiper	*Calidris melanotos*	M	<6	42549

Scolopacidae	Least Sandpiper	*Calidris minutilla*	S	<6	46626
Scolopacidae	Semipalmated Sandpiper	*Calidris pusilla*	S	<6	11817
Scolopacidae	Calidris spp. (peeps)	*Calidris spp.*	S	<6	4674
Scolopacidae	Willet	*Catoptrophorus semipalmatus*	L	<12	19
Scolopacidae	Common Snipe	*Gallinago gallinago*	M	<6	92
Scolopacidae	Short-billed Dowitcher	*Limnodromus griseus*	M	<12	1097
Scolopacidae	Long-billed Dowitcher	*Limnodromus scolopaceus*	M	<12	4622
Scolopacidae	Dowitcher spp.	*Limnodromus spp.*	M	<12	1377
Scolopacidae	Marbled Godwit	*Limosa fedoa*	L	<12	18
Scolopacidae	Hudsonian Godwit	*Limosa haemastica*	L	<12	0
Scolopacidae	Long-billed Curlew	*Numenius americanus*	L	<9	0
Scolopacidae	Whimbrel	*Numenius phaeopus*	L	<12	0
Scolopacidae	Red-necked Phalarope	*Phalaropus lobatus*	M	various	18
Scolopacidae	Wilson’s Phalarope	*Phalaropus tricolor*	M	various	598
Scolopacidae	Greater Yellowlegs	*Tringa melanoleuca*	M	<12	787
Scolopacidae	Solitary Sandpiper	*Tringa solitaria*	M	<6	267
Scolopacidae	Lesser Yellowlegs	*Tringa. flavipes*	M	<12	6533
Scolopacidae	Buff-breasted Sandpiper	*Tryngites subruficollis*	M	<3	371

[1] Body size: S = body length ≤190 mm, M = body length 195 - 350 mm, and L = body length > 350 mm (Skagen and Knopf 1993).

[2] Lower Mississippi Valley Joint Venture Shorebird Monitoring Program <http://www.lmvjv.org/shorebird/default.asp>.

Table 2. Circa 2007 land cover classes identified within U.S. Army Corps of Engineers (USACE) digital land cover raster and their respective crop type class and shorebird habitat class (Shorebird) used for quantitative assessment of the area of

shorebird foraging habitat within the St. Johns and New Madrid Basins in southeastern Missouri. Slight discrepancy in area between USACE and Shorebird habitat designations attributed to differences in scale (pixel size) and delineation of land enrolled in USDA Wetland Reserve Program.

<table>
<tr><th rowspan="2">Land cover class</th><th rowspan="2">Crop type class</th><th rowspan="2">Habitat class</th><th colspan="2">New Madrid Basin (ha)</th><th colspan="2">St. Johns Basin (ha)</th></tr>
<tr><th>USACE</th><th>Shorebird</th><th>USACE</th><th>Shorebird</th></tr>
<tr><td>barren</td><td>n/a</td><td>Unsuitable</td><td>0</td><td rowspan="9">4,949</td><td>1</td><td rowspan="9">10,304</td></tr>
<tr><td>deciduous forest</td><td>n/a</td><td>Unsuitable</td><td>529</td><td>2,165</td></tr>
<tr><td>developed/high intensity</td><td>n/a</td><td>Unsuitable</td><td>2</td><td>179</td></tr>
<tr><td>evergreen forest</td><td>n/a</td><td>Unsuitable</td><td>0</td><td>284</td></tr>
<tr><td>mixed forest</td><td>n/a</td><td>Unsuitable</td><td>0</td><td>17</td></tr>
<tr><td>open water</td><td>n/a</td><td>Unsuitable</td><td>492</td><td>380</td></tr>
<tr><td>shrub</td><td>n/a</td><td>Unsuitable</td><td>5</td><td>17</td></tr>
<tr><td>woody wetland</td><td>n/a</td><td>Unsuitable</td><td>3,596</td><td>5,389</td></tr>
<tr><td>Wetland Reserve Program</td><td>n/a</td><td>Unsuitable</td><td>0</td><td>0</td></tr>
<tr><td>corn</td><td>corn-sorghum</td><td>Suitable</td><td>5,228</td><td rowspan="3">6,260</td><td>23,797</td><td rowspan="3">23,897</td></tr>
<tr><td>popcorn</td><td>corn-sorghum</td><td>Suitable</td><td>1</td><td>2</td></tr>
<tr><td>sorghum</td><td>corn-sorghum</td><td>Suitable</td><td>1,158</td><td>583</td></tr>
<tr><td>cotton</td><td>cotton</td><td>Suitable</td><td>123</td><td>120</td><td>2,641</td><td>2,589</td></tr>
<tr><td>developed/low intensity</td><td>fallow</td><td>Suitable</td><td>238</td><td rowspan="4">2,721</td><td>2,536</td><td rowspan="4">11,224</td></tr>
<tr><td>developed/medium intensity</td><td>fallow</td><td>Suitable</td><td>21</td><td>719</td></tr>
<tr><td>developed/open space</td><td>fallow</td><td>Suitable</td><td>2,440</td><td>7,905</td></tr>
<tr><td>fallow</td><td>fallow</td><td>Suitable</td><td>78</td><td>292</td></tr>
<tr><td>grassland</td><td>grass-herbaceous</td><td>Suitable</td><td>1</td><td rowspan="5">329</td><td>3</td><td rowspan="5">3,707</td></tr>
<tr><td>herbaceous wetlands</td><td>grass-herbaceous</td><td>Suitable</td><td>56</td><td>112</td></tr>
<tr><td>herbs</td><td>grass-herbaceous</td><td>Suitable</td><td>33</td><td>12</td></tr>
<tr><td>pasture/hay</td><td>grass-herbaceous</td><td>Suitable</td><td>156</td><td>3,536</td></tr>
<tr><td>wetlands</td><td>grass-herbaceous</td><td>Suitable</td><td>123</td><td>120</td></tr>
<tr><td>soybean</td><td>soybean</td><td>Suitable</td><td>24,820</td><td>24,326</td><td>32,863</td><td>32,209</td></tr>
<tr><td>wheat/soybean (double)</td><td>wheat</td><td>Suitable</td><td>7,309</td><td rowspan="2">7,200</td><td>27,140</td><td rowspan="2">27,948</td></tr>
<tr><td>winter wheat</td><td>wheat</td><td>Suitable</td><td>37</td><td>1,376</td></tr>
</table>

rice	rice	Suitable	257	252	1,440	1,412
oats	other crops	Suitable	0		7	
other small grains	other crops	Suitable	18		272	
peaches	other crops	Suitable	0	20	0	340
potatoes	other crops	Suitable	0		58	
watermelon	other crops	Suitable	2		11	
Totals			46,723	46,178	113,857	113,630

Table 3. Water elevations (feet NGVD) proposed for alternative water management scenarios to be implemented upon completion of contiguous Mississippi River levee and installation of pumps to remove water from the New Madrid Basin, compared to authorized intra-basin water elevations of 278.0 feet attained before starting to pump water from inside levees, with continued pumping until an elevation of 275.0 feet is achieved.

	Close Gate			Start Pump			Stop Pump		
Dates	Alt. 1	Alt. 2	Alt. 4	Alt.1	Alt. 2	Alt. 4	Alt.1	Alt. 2	Alt. 4
15 November – 28 February	287.5	287.5	287.5	289.5	289.5	289.5	288	288	288
1 March – 15 April	286	284	287.5	288	286	2289.5	287	285	288
16 April – 30 May	284	282	287.5	284	282	289.5	282	280	288
1 June – 14 November	278.5	278.5	287.5	279.5	279.5	289.5	278.5	278.5	288

Table 4. Annual number of days during which shorebird foraging habitat was available during spring (93 days) or fall (122 days) migration periods within the New Madrid and St. John's Basins in Missouri, 1943 to 2009 (n = 67).

Basin	Migration	Mean	SE	Minimum	Maximum
New Madrid	Spring	77.6	2.1	20	93
	Fall	23.5	2.7	0	122
St. John's	Spring	90.4	0.8	51	93
	Fall	60.7	3.6	4	122

Table 5. Daily area (ha) of shorebird habitat, irrespective of presumed habitat quality and temporal availability (i.e., total 'footprint' of foraging habitat regardless of suitability or date within migration window), during spring (15 March - 15 June) and fall (1 July - 30 October) migration periods within the St. Johns and New Madrid Basins in southeastern Missouri. Based on 200 bootstrap samples, each of 50 years, randomly selected (with replacement) from daily intra-basin water elevations, 1943 – 2009, assuming current flood conditions (existing), presumed intra-basin water elevations under conditions authorized upon completion of levees and operation of pumps associated with the St. John-New Madrid Flood Control Project (authorized), and 3 alternative water management scenarios wherein intra-basin water elevations exceed authorized elevations.

			50 year projections						Annual variation	
Basin	Migration	Conditions	Mean	SD	95% lcl	95% ucl	Min	Max	Low	High
St. John's	Fall	Existing	13.0	3.0	7.1	18.9	6.6	21.7	0.0	158.0
St. John's	Fall	Authorized	8.1	2.1	4.1	12.1	2.9	15.5	0.0	91.9
St. John's	Spring	Existing	278.8	35.7	208.9	348.7	195.1	374.4	0.9	1242.4
St. John's	Spring	Authorized	196.9	29.0	140.0	253.8	136.6	281.2	0.4	775.1
New Madrid	Fall	Existing	20.2	10.9	0.0	41.5	1.0	55.0	0.0	532.0
New Madrid	Fall	Authorized	0.4	0.1	0.2	0.7	0.2	0.9	0.0	7.1
New Madrid	Fall	Alternative 1	0.7	0.2	0.3	1.0	0.3	1.2	0.0	15.9
New Madrid	Fall	Alternative 2	0.7	0.2	0.3	1.0	0.3	1.4	0.0	15.9
New Madrid	Fall	Alternative 4	19.2	10.0	0.0	38.7	3.3	50.6	0.0	471.7
New Madrid	Spring	Existing	685.5	78.4	531.8	839.2	478.6	870.6	0.0	2082.7
New Madrid	Spring	Authorized	11.5	4.9	1.9	21.1	4.0	28.4	0.0	286.4
New Madrid	Spring	Alternative 1	197.9	23.6	151.6	244.1	135.1	252.6	0.0	601.9
New Madrid	Spring	Alternative 2	103.4	11.2	81.5	125.3	78.0	131.0	0.0	428.3
New Madrid	Spring	Alternative 4	388.5	43.4	303.4	473.6	267.2	518.5	0.0	928.0

Table 6. Daily area (ha) of 'optimally equivalent' shorebird habitat during spring (15 March - 15 June) and fall (1 July - 30 October) migration periods within the St. Johns and New Madrid Basins in southeastern Missouri. Equivalency was based on reduced suitability due to presumed sub-optimal foraging conditions: 1) on habitats flooded at depth >6 cm; 2) with increased duration of mudflat exposure; and 3) associated with increased vegetation height and density related to crop planting, growth, and harvest dates; as well as the presumed abundance of shorebirds within migration periods. Based on 200 bootstrap samples, each of 50 years, randomly selected (with replacement) from daily intra-basin water elevations, 1943 – 2009, assuming current flood conditions (existing), presumed intra-basin water elevations under conditions authorized upon completion of levees and operation of pumps associated with the St. John-New Madrid Flood Control Project (authorized), and 3 alternative water management scenarios wherein intra-basin water elevations exceed authorized elevations.

			50 year projections						Annual variation	
Basin	Migration	Conditions	Mean	SD	95% lcl	95% ucl	Min	Max	Low	High
St. John's	Fall	Existing	4.2	1.1	2.0	6.4	1.9	7.5	0.0	61.1
St. John's	Fall	Authorized	2.6	0.7	1.2	4.0	0.8	5.4	0.0	33.1
St. John's	Spring	Existing	147.8	20.0	108.6	187.0	100.9	202.9	0.5	741.6
St. John's	Spring	Authorized	102.0	15.8	71.0	133.0	66.9	151.4	0.2	442.9
New Madrid	Fall	Existing	7.4	4.2	0.0	15.6	0.3	21.7	0.0	213.5
New Madrid	Fall	Authorized	0.2	0.0	0.1	0.2	0.1	0.3	0.0	2.7
New Madrid	Fall	Alternative 1	0.2	0.1	0.1	0.4	0.1	0.5	0.0	6.4
New Madrid	Fall	Alternative 2	0.2	0.1	0.1	0.4	0.1	0.5	0.0	6.4
New Madrid	Fall	Alternative 4	7.1	4.1	0.0	15.2	0.9	19.6	0.0	203.8
New Madrid	Spring	Existing	341.1	40.3	262.0	420.1	236.1	436.6	0.0	1098.7
New Madrid	Spring	Authorized	5.0	1.9	1.4	8.7	1.9	10.9	0.0	99.0
New Madrid	Spring	Alternative 1	100.3	12.2	76.3	124.3	67.5	128.7	0.0	339.2
New Madrid	Spring	Alternative 2	48.8	5.3	38.4	59.3	36.8	64.3	0.0	164.5
New Madrid	Spring	Alternative 4	218.0	25.5	167.9	268.0	147.2	292.4	0.0	560.4

Appendix A1 [Shorebird_Habitat_SJ_Existing_Appendix_A1_20110810.xlsx]. Daily intra-basin water elevations (feet NGVD) for St. Johns Basin derived from river elevations at the New Madrid gage (MS115; navigation mile 889.0) on the Mississippi River, regional precipitation, topography, and land cover under current flood conditions (existing) and projected areas of potential shorebird foraging habitat associated with these intra-basin water elevations.

Appendix A2 [Shorebird_Habitat_SJ_Authorized_Appendix_A2_20110810.xlsx]. Daily intra-basin water elevations (feet NGVD) for St. Johns Basin derived from river elevations at the New Madrid gage (MS115; navigation mile 889.0) on the Mississippi River, regional precipitation, topography, and land cover predicted under authorized flood reduction conditions presumed upon completion of the St. Johns-New Madrid Project (Authorized) and projected areas of potential shorebird foraging habitat associated with these intra-basin water elevations.

Variables within Appendices A1, A2, B1, B2, B3, B4, and B5.

Date = day/month/year; 1/Jan/1943.

River_stage = intra-basin water elevation in feet (NGVD).

Total_open_flood = total area of open land (potential shorebird foraging habitat) inundated, regardless of depth.

All_suitable = total area of suitable shorebird foraging habitat (i.e., total area of open land inundated at depth $\leq$15.25 cm and total area of open land exposed from inundation within the previous 3 days).

Quality_adjusted = Total ‘equivalent’ area of shorebird foraging habitat, adjusted for habitat quality by lowing quality of lands inundated $>$6.1 cm and mudflats.

Time_adjusted = Total ‘equivalent’ area of shorebird foraging habitat, adjusted for habitat quality and reduced suitability during migration when fewer shorebirds are presumed to be present.

Crop_type_adjusted = Total ‘optimally equivalent’ area of shorebird foraging habitat, adjusted for habitat quality, with reduced suitability during migration when fewer shorebirds are presumed to be present, and with decreased suitability on lands with more mature crops.

Appendix B1 [Shorebird_Habitat_NM_Existing_Appendix_B1_20110810.xlsx]. Daily intra-basin water elevations (feet NGVD) for New Madrid Basin derived from river elevations at the New Madrid gage (MS115; navigation mile 889.0) on the Mississippi River, regional precipitation, topography, and land cover under current flood conditions (existing) and projected areas of potential shorebird foraging habitat associated with these intra-basin water elevations.

Appendix B2 [Shorebird_Habitat_NM_Authorized_Appendix_B2_20110810.xlsx]. Daily intra-basin water elevations (feet NGVD) for New Madrid Basin derived from river elevations at the New Madrid gage (MS115; navigation mile 889.0) on the Mississippi River, regional precipitation, topography, and land cover predicted under authorized flood reduction conditions presumed upon completion of the St. Johns-New Madrid Project (Authorized) and projected areas of potential shorebird foraging habitat associated with these intra-basin water elevations.

Appendix B3 [Shorebird_Habitat_NM_Alternative1_Appendix_B3_20110810.xlsx]. Daily intra-basin water elevations (feet NGVD) for New Madrid Basin derived from river elevations at the New Madrid gage (MS115; navigation mile 889.0) on the Mississippi River, regional precipitation, topography, and land cover predicted upon completion of the St. Johns-New Madrid Project but with water elevations allowed to exceed authorized elevations (Alternative 1; Table 3) and projected areas of potential shorebird foraging habitat associated with these intra-basin water elevations.

Appendix B4 [Shorebird_Habitat_NM_Alternative2_Appendix_B4_20110810.xlsx]. Daily intra-basin water elevations (feet NGVD) for New Madrid Basin derived from river elevations at the New Madrid gage (MS115; navigation mile 889.0) on the Mississippi River, regional precipitation, topography, and land cover predicted upon completion of the St. Johns-New Madrid Project but with water elevations allowed to exceed authorized elevations (Alternative 2; Table 3) and projected areas of potential shorebird foraging habitat associated with these intra-basin water elevations.

Appendix B5 [Shorebird_Habitat_NM_Alternative4_Appendix_B5_20120613.xlsx]. Daily intra-basin water elevations (feet NGVD) for New Madrid Basin derived from river elevations at the New Madrid gage (MS115; navigation mile 889.0) on the Mississippi River, regional precipitation, topography, and land cover predicted upon completion of the St. Johns-New Madrid Project but with water elevations allowed to exceed authorized elevations (Alternative 4; Table 3) and projected areas of potential shorebird foraging habitat associated with these intra-basin water elevations.

Appendix C: Descriptors of contour shapefiles (.shp) of digital vertical elevation (NGVD) contours at 1-foot (0.305 m) elevation intervals obtained from U.S. Army Corps of Engineers (K. R. Pigott, Memphis District, U.S. Army Corps of Engineers). Data for the New Madrid Basin (2 files) were derived from light detection and ranging (LiDAR) data. Data for the St. John's Basin were derived from geodetic and hydrologic data.

Geographic Coordinate System:	GCS_North_American_1983
Datum:	D_North_American_1983
Prime Meridian:	Greenwich
Angular Unit:	Degree
Projected Coordinate System:	NAD_1983_UTM_Zone_16N
Projection:	Transverse_Mercator
False_Easting:	1640416.66666667
False_Northing:	0.00000000
Central_Meridian:	-87.00000000
Scale_Factor:	0.99960000
Latitude_Of_Origin:	0.00000000
Linear Unit:	Foot_US

File Name:	SJ_Contours.shp (St. John's Basin)
Geometry Type:	Line
Contour Values range:	260 – 601 (1-foot interval elevation contour lines)

File Name:	SJNM_Elevation_1.shp (Northern New Madrid Basin)
Geometry Type:	Polygon
GridCode Values	217 – 362 (1-foot interval elevation lines)

File Name:	SJNM_Elevation_1.shp (Southern New Madrid Basin)
Geometry Type:	Polygon
GridCode Values	221 – 326 (1-foot interval elevation lines)