### 5.3.2.4 Wind and Temperature Data

Daily climatological statistics consisting of wind speed, wind direction, and air temperature were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information website (NOAA 2016a) and from data provided by Environment and Climate Change Canada's Canadian Climate Normals database (Environment Canada 2016). The preliminary climate datasets consist of three parts:

- Site information: the station location (latitude/longitude) and the month and year of the report
- Daily climatological data
- Monthly averages and totals for the month

The available data for both air temperature and wind speed between 2010 and 2015 (in the U.S.) and 1981 and 2010 (in Canada) were averaged by month. Releases scenarios were simulated under different meteorological conditions (i.e., different wind speed and air temperature for each flow condition/season), which cover the range of weather at the release locations and provide a conservative approach to assessing potential outcomes of a release (i.e., trajectories, fates and effects). Table 5-10 shows the temperatures and wind speeds used for different seasonal scenarios in the model at each release location. Because these were river simulations, salinity was assumed to be zero for all modeling locations.

**Table 5-10 Air Temperature (°C and °F) and Wind Speed (m/s) Values Used as Model Inputs for Each OILMAP Land Release Location and Seasonal Scenario**

| Case # | Release Location | Season / River Flow | Month | Air Temp. (°C) | Air Temp. (°F) | Wind Speed (m/s) |
|---|---|---|---|---|---|---|
| 1 | Mosquito Creek to Lower Rice Lake | Low | February | -11.50 | 11.30 | 4.44 |
| | | Average | July | 19.25 | 66.65 | 3.68 |
| | | High | April | 4.17 | 39.51 | 4.88 |
| 2 | Mississippi River at Ball Club | Low | March | -3.61 | 25.50 | 4.51 |
| | | Average | August | 18.92 | 66.06 | 3.51 |
| | | High | April | 5.00 | 41.00 | 4.88 |
| 3 | Sandy River | Low | March | -3.07 | 26.47 | 4.21 |
| | | Average | July | 19.96 | 67.93 | 3.50 |
| | | High | April | 5.00 | 41.0 | 4.73 |
| 4 | Shell River to Twin Lakes | Low | March | -4.65 | 23.63 | 4.58 |
| | | Average | August | 18.61 | 65.50 | 3.52 |
| | | High | April | 4.04 | 39.27 | 5.05 |
| 5 | Red River | Low | February | -14.68 | 5.54 | 5.19 |
| | | Average | August | 19.78 | 67.64 | 3.98 |

**Table 5-10 Air Temperature (°C and °F) and Wind Speed (m/s) Values Used as Model Inputs for Each OILMAP Land Release Location and Seasonal Scenario**

| Case # | Release Location | Season / River Flow | Month | Air Temp. (°C) | Air Temp. (°F) | Wind Speed (m/s) |
|---|---|---|---|---|---|---|
| | | High | April | 4.02 | 39.20 | 5.05 |

### 5.3.2.5 Snow Cover Depth

Snow cover depth was considered for only the Mosquito Creek overland scenario. Daily snow depth data are available from the NOAA National Centers for Environmental Information (NOAA 2016b). The data are compiled by NOAA from observations collected by the National Weather Service Cooperative Observer stations and First Order stations. The daily data from January 2006 to December 2014 was acquired and the snow cover depth was averaged for each month at each station. The values for the two closest stations to the Mosquito Creek site were selected and averaged, including Thorhult, Minnesota and the University of Minnesota Itasca Biological Station. The monthly average snow cover depth ranged from 0.0 to 34.8 cm (Table 5-11).

**Table 5-11 Monthly Average Daily Snow Cover Depth from 2006–2014**

| Average Daily Snow Cover Depth (cm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 29.5 | 34.8 | 29.4 | 14.7 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 2.5 | 9.3 |

During non-winter months, the groundcover is predominantly a grassland/herbaceous cover. However, the area is known for its long cold winters with periods of extensive snow cover. A snow cover of 13.5 in. (34.8 cm) was assumed for the month of February (Table 5-11). The retention of oil in snow was assumed to be 20% for the lighter Bakken Crude, corresponding to a retention depth of 2.7 in. (6.96 cm) and 40% for the heavier CLWB, corresponding to a retention depth of 5.5 in. (13.92 cm) (Allen 2015; Belore and Buist 1988; ACS 2013). While the specific retention of oil by snow will depend upon environmental parameters, the temperature of the released oils, snow cover and type, solar insolation, slope, and other factors, these values align within the expected range from previous studies (Bech and Sveum 1991; Allen 1978; Etkin et al. 2007; Fingas and Hollebone 2015). These studies all indicate that heavier oils with higher viscosities tend to spread less, forming thicker layers in the snow, than lighter oils and diesel fuel.

### 5.3.2.6 Thickness of Oil Under Ice

Ice coverage is important to consider as it may affect the ultimate trajectory and fate of oil within the winter environment. Ice may reduce the quantity or prevent oil from entering a water body altogether. Furthermore, it may affect the potential downstream transport and potential for pooling of oil under ice. Fates processes such as evaporation may be affected as well.

Ice cover was considered at each of the modeled locations. During winter conditions, complete coverage (100% ice cover) of the water surface is assumed. If a release were to originate on land (e.g., Mosquito Creek) and travel downslope towards the surface water network, it would be absorbed to some extent by the local snow cover. Any oil that made its way to the watercourse would be prevented or delayed from entering the water body due to the coverage of ice. However, if a release were to occur into the watercourse from the underground/underwater crossing (e.g., all modeled locations other than Mosquito Creek), then all oil would enter into the water column itself. For the purpose of modeling, oil is assumed to rise through the water column and be trapped by the ice cover at the surface. The model assumes that evaporation is prevented completely (0% evaporation) due to the layer of ice on the water surface. The downstream transport of oil is modeled within river sections at the local water velocity; however, oil pools under the ice in lakes. As modeled in the ice-free conditions, complete shoreline oiling occurs in the complete ice cover season as well. However, rather than referring to true shoreline oiling, this term in the winter would more appropriately be named edge-oiling. Shorelines are set to ice-edge and shoreline retention values are lower than those found in non-winter conditions. The retention of oil along the banks during winter seasons refers to the oil that would be trapped below the ice surface along the edge of the river in the narrow region between the ice and the bottom. These conservative approximations maximize the extent of potential oiling.

The equilibrium thickness of oil under ice has been measured in many environments. However, the main focus has been in the marine environment, where thicknesses may range from 1-30 cm (Dickins et al. 2008). Freshwater environments, particularly rivers, are quite different than the open ocean, notably with the level of energy within the environment (e.g., waves and other turbulent processes). Assuming that new ice formed in calm conditions and the underside was flat and smooth, the oil will spread underneath to an equilibrium based upon the balance between surface tension and buoyancy (Barnes et al. 2013). The equilibrium slick thickness may be determined using the equation of Cox et al. (1980):

$$\delta = -8.5(\rho_w - \rho_o) + 1.67$$

Where $\delta$ is the thickness of oil under ice in cm and $(\rho_w - \rho_o)$ is the density difference between oil and water. Under the smoothest ice conditions, 5.2–11.5 mm are typical for oils with densities in the range crude oils (Cox et al. 1981). The minimum stable drop thickness for crude oil under ice is approximately 8 mm (Lewis 1976). The equilibrium thickness of CLWB was determined to be 0.4 in. (1.06 cm), while the thickness for Bakken was calculated to be 0.07 in. (0.19 cm). The CLWB is thicker than the aforementioned predictions as it is a heavy crude oil. The Bakken was slightly thicker than the previous values due to the smaller density difference between oil and freshwater, as opposed to saltwater.

### 5.3.3 SIMAP

#### 5.3.3.1 Geographic and Habitat Data

For geographical reference, SIMAP uses a rectilinear grid to designate the location of the shoreline, the water depth (bathymetry), slope, bottom roughness, and the shore or habitat type. The grid is generated from a digital shoreline or other geographical information using the ESRI Arc/Info compatible Spatial Analyst program. The cells are coded for depth and habitat type; the model then identifies the shoreline using this grid. Thus, in model outputs, the land-water map is only used for visual reference; it is the habitat grid that defines the actual location of the shoreline in the model.

Geographical data including digital shoreline basemap, river geometry, and habitat mapping were obtained from the USGS NHD high-resolution dataset. This includes river polygons that were used to define river area, with slight improvements based upon aerial imagery. Variations in the water area between low/average river flow and high river flow were determined based upon aerial imagery from different seasons. The NHD data followed a high flow condition well. Areas that were regularly dry in summer, fall, or winter were excluded from the river area for the average and low flow conditions. Basemap data were used to define the land/water boundary and habitat data were used to define the types of habitats present within the study area. Habitat grids were used to define the bottom type and vegetation found in watered areas, areas of extensive mud flats and wetlands, and the shore type.

Shore types were characterized based on aerial imagery and photographs posted by Google Earth. For average river flow conditions, the shore type was based upon visible bank type. For low river flow conditions, the shore type was assumed to be ice along natural shorelines and man-made structures (e.g., ditches) where present. For high river flow conditions, the shore types were assigned based upon the land cover data above the riverbank, except for man-made structures. The bottom type was defined as silt and mud with some regions characterized as wetlands from imagery and mapping that identified wetlands.

River depth was characterized based on flood insurance studies for Palisade and Aitkin County (FEMA 1983, 1996) and the St Paul District Corps of Engineers (1980). Depths were provided at various distances from known locations along the river. These locations were mapped and assigned their corresponding depth. Depths were linearly interpolated along the river centerline between these known values. Lacking any cross sectional river profiles, a rectangular river channel was assumed. To create a rectangular shaped depth profile (i.e., constant depth from bank to bank at any cross section in the river), a grid was created based upon these centerline depths.

River depth and habitat are presented for the Mississippi River at Palisade and Little Falls in Figure 5-30 through Figure 5-37 for each of the modeled seasons.

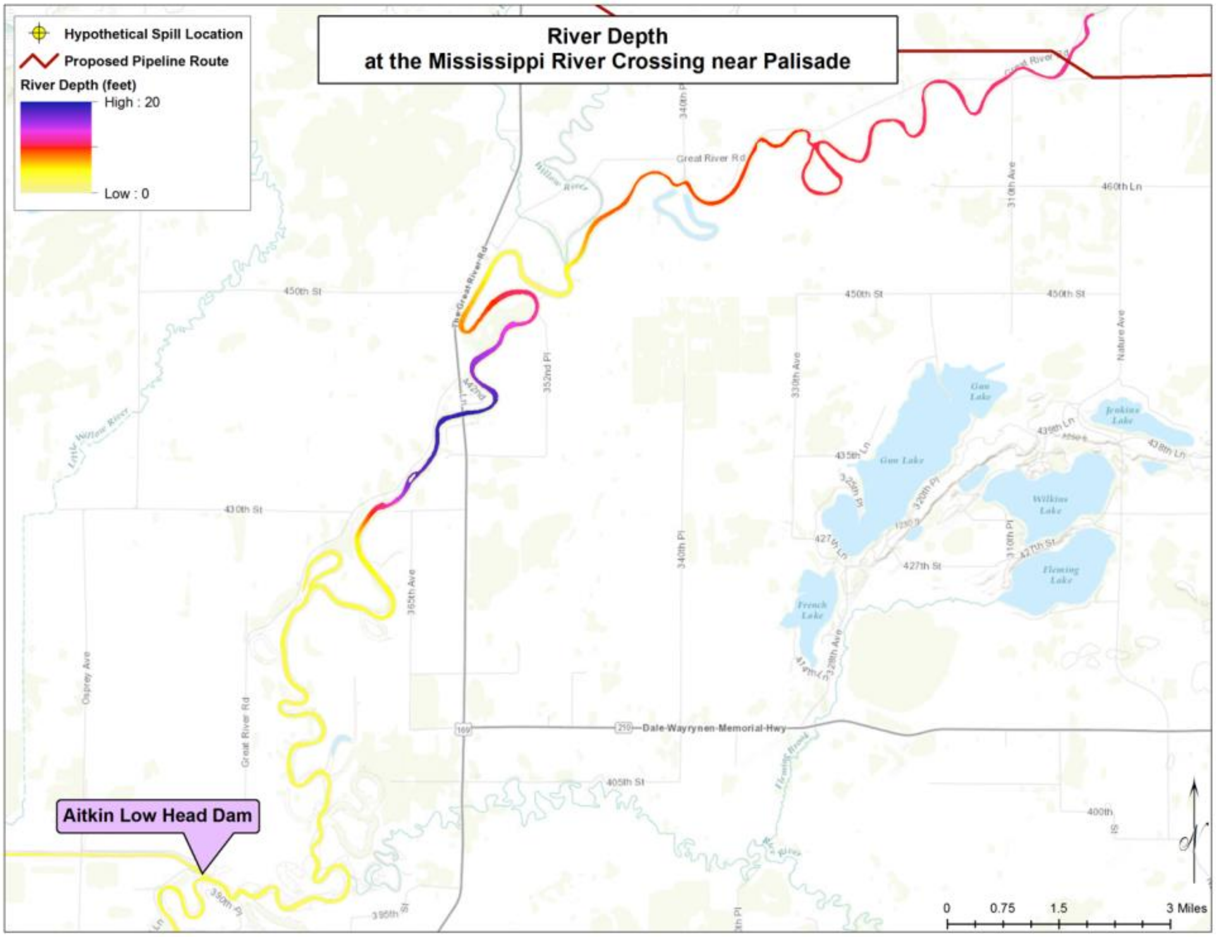


**Figure 5-30 River Depth for the Mississippi River at Palisade Release Location**

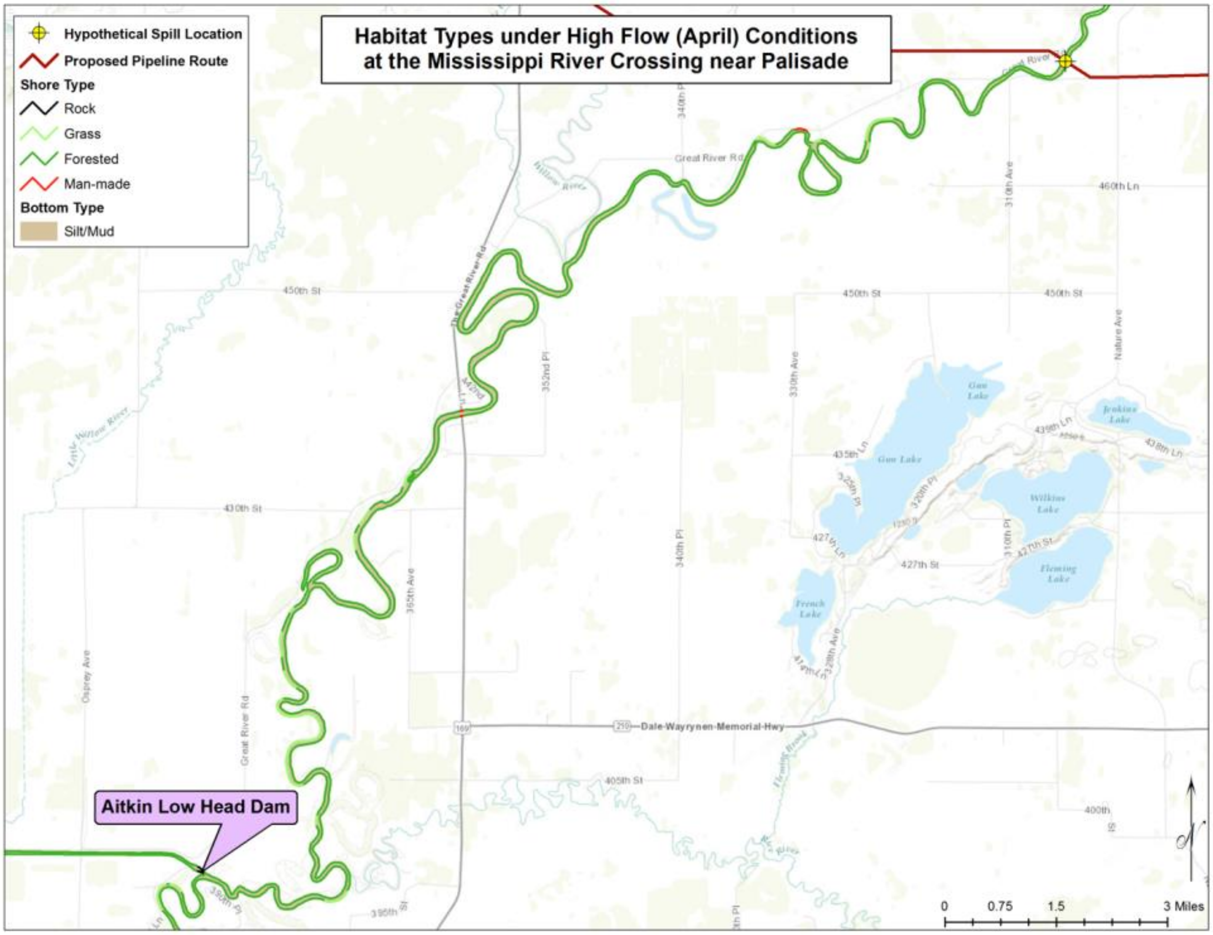


**Figure 5-31 Habitat Types for the Mississippi River at Palisade Release Location Under High Flow Conditions**

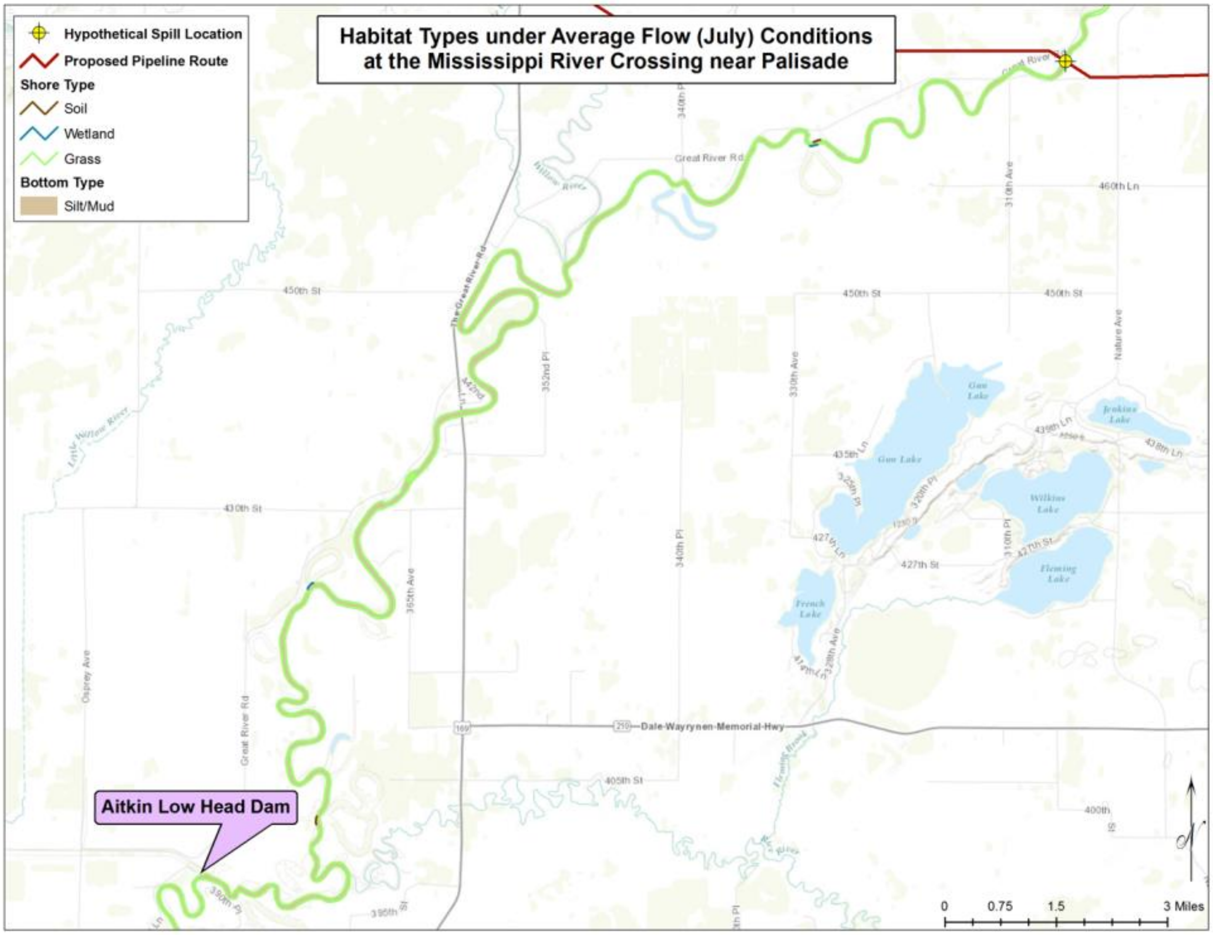


**Figure 5-32 Habitat Types for the Mississippi River at Palisade Release Location Under Average Flow Conditions**

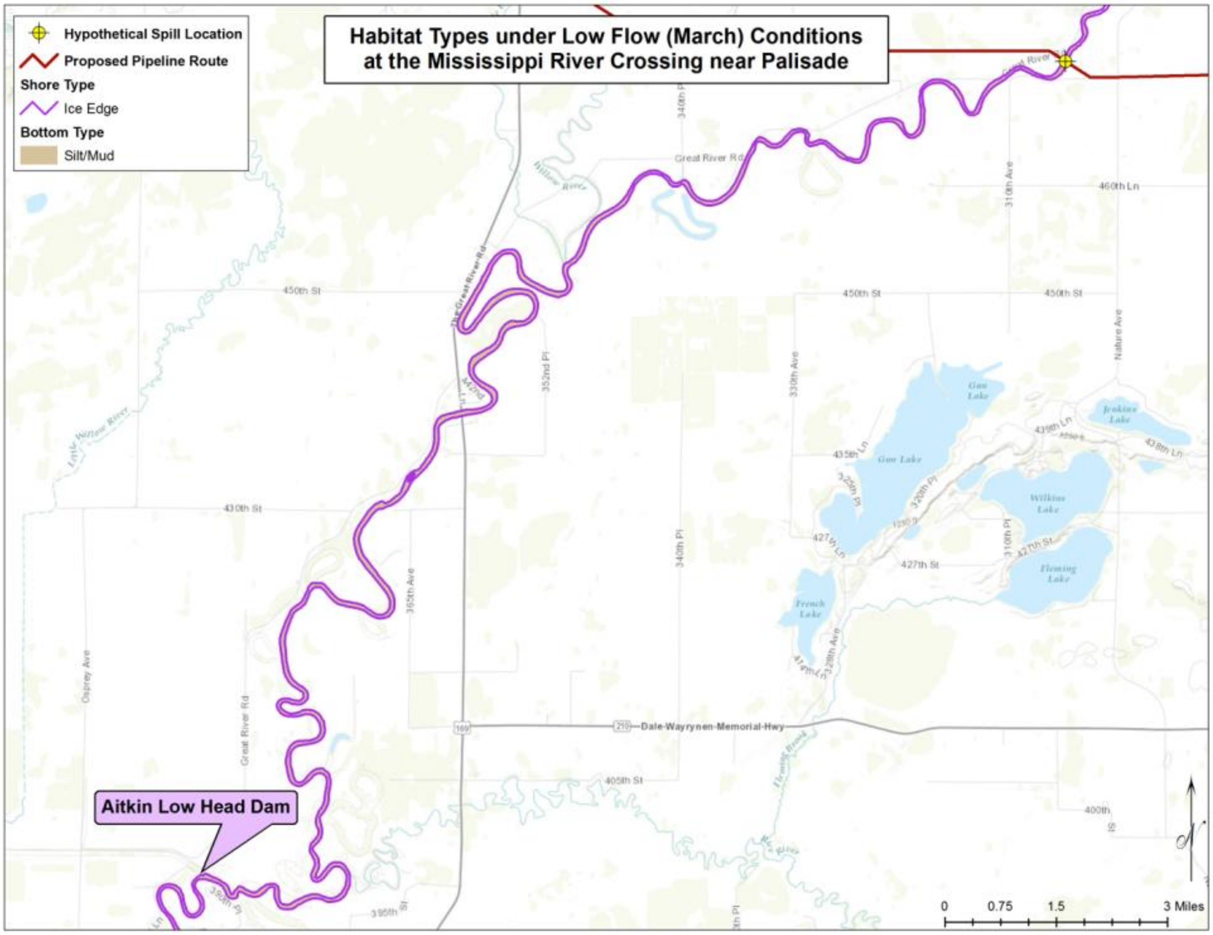


**Figure 5-33 Habitat Types for the Mississippi River at Palisade Release Location Under Low Flow Conditions**

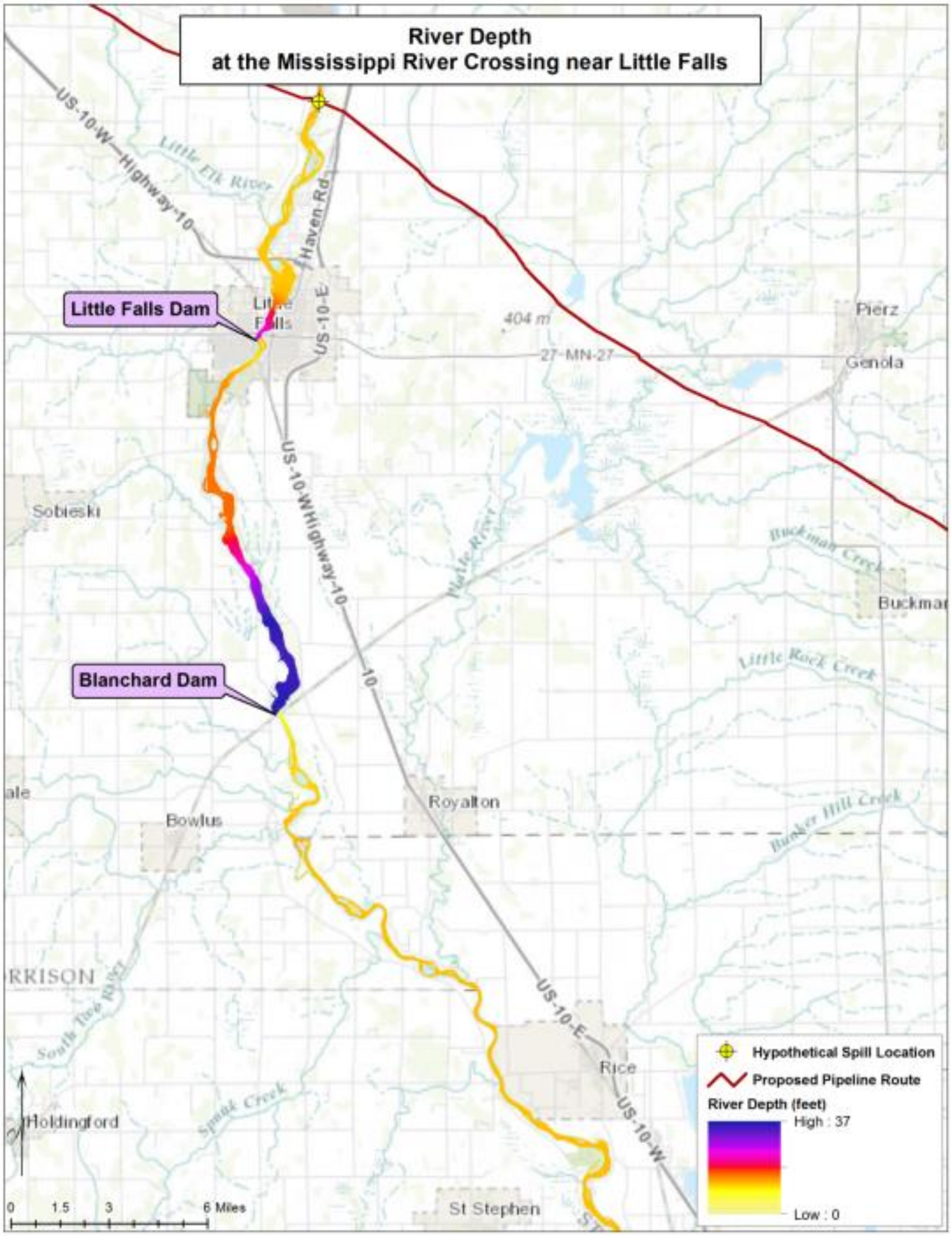


**Figure 5-34 River Depth for the Mississippi River at Little Falls Release Location**

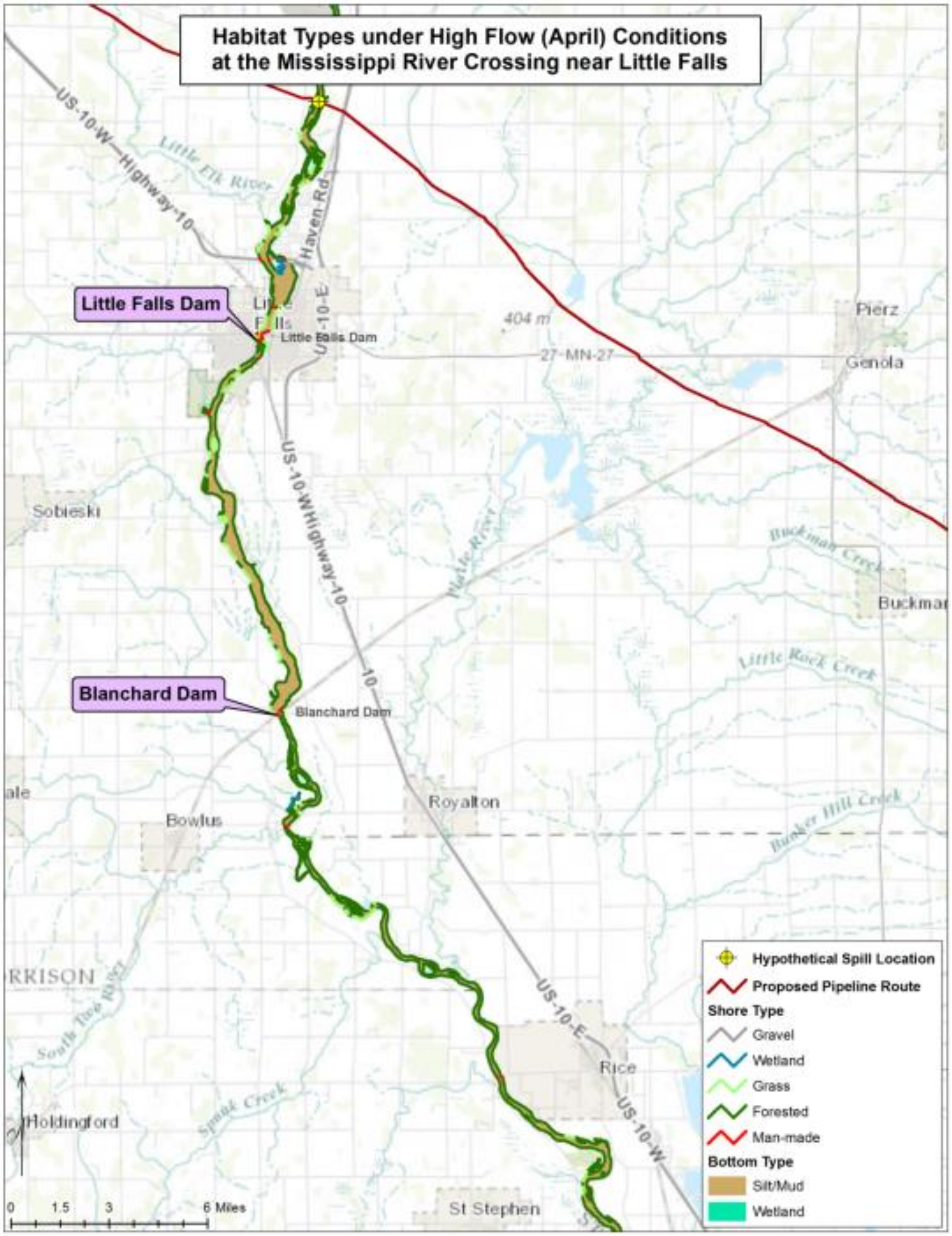


**Figure 5-35 Habitat Types for the Mississippi River at Little Falls Release Location Under High Flow Conditions**

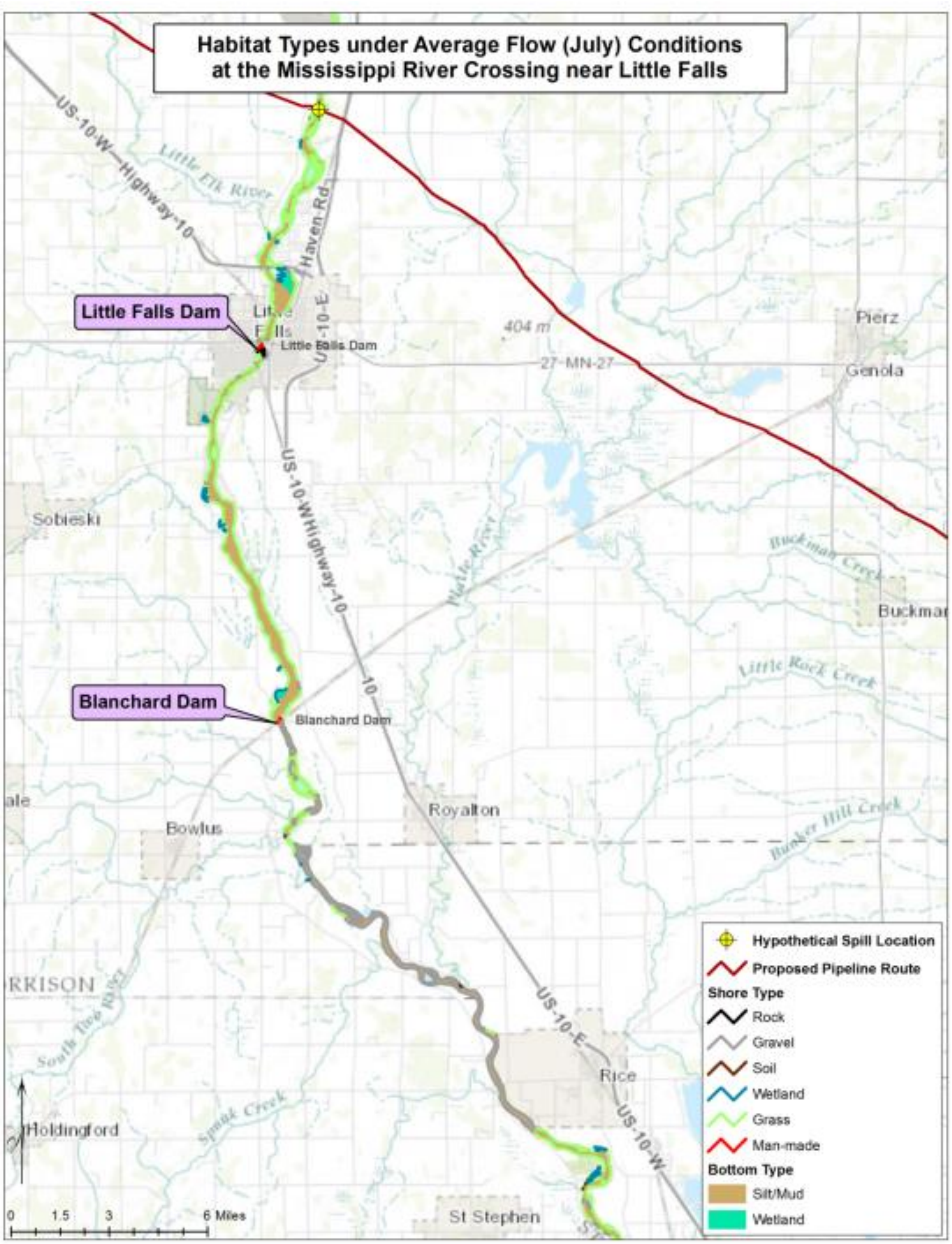


**Figure 5-36 Habitat Types for the Mississippi River at Little Falls Release Location Under Average Flow Conditions**

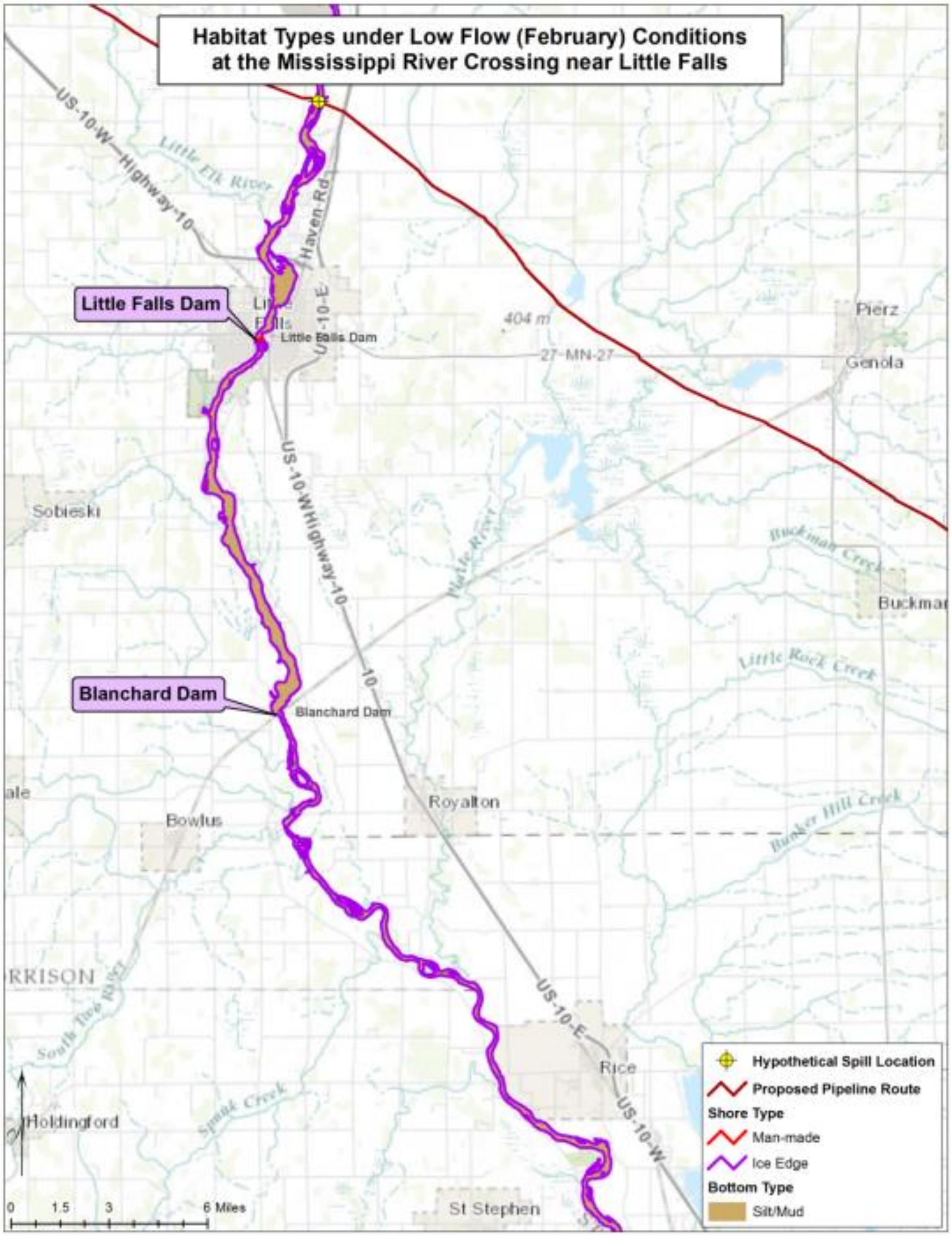


**Figure 5-37 Habitat Types for the Mississippi River at Little Falls Release Location Under Low Flow Conditions**

### 5.3.3.2 Environmental Data

#### 5.3.3.2.1 River Currents

Currents have an important influence on the trajectory and fate of the oil, and are critical data inputs. The SIMAP modeling system used spatially varying current fields throughout a gridded domain of the river within the study area to force oil throughout the domain. The current fields were generated using BFHYDRO, a hydrodynamic model created by RPS ASA. The model was used to first generate a boundary fitted grid mapped to the wetted domain, as defined by the NHD. It was then used to generate a spatially varying current field for three different environmental conditions representing low, average, and high monthly average river flows and associated current speeds.

##### *5.3.3.2.1.1 Hydrologic Analysis*

NHDPlus is a geo-spatial, hydrologic framework dataset built by the US EPA Office of Water, assisted by the USGS. The NHDPlus data set was queried to determine the variability in monthly flows and river reach speeds within the study area. NHDPlus includes an estimated monthly and annual average stream flow rate and velocity for each stream segment. Flow is estimated using EROM. This method determines river flow based on estimates of accumulated runoff based on the elevation data, evaporative loss, and various adjustments based on gages within the region. The velocities are calculated based on the estimated flow using the Jobson Method (Jobson 1996). A summary of the monthly flows and current speeds at points within the Palisade and Little Falls domains are presented in Table 5-12. Based on analysis of this data, it was determined that the months representing low river flow conditions were March for the Mississippi River at Palisade and February for the Mississippi River at Little Falls. Average river flow conditions occurred in July, with high river flow conditions in April for both locations.

**Table 5-12 Summary of Monthly River Flows and Current Speeds for SIMAP Release Sites**

| Month | Mississippi River at Palisade | | Mississippi River at Little Falls | |
|---|---|---|---|---|
| | Flow ($m^3/s$) | Current Speed (m/s) | Flow ($m^3/s$) | Current Speed (m/s) |
| January | 53.8 | 0.35 | 99.5 | 0.47 |
| February | 52.9 | 0.35 | 95.2 | 0.46 |
| March | 45.6 | 0.33 | 142.1 | 0.54 |
| April | 109.6 | 0.47 | 276.8 | 0.74 |
| May | 92.2 | 0.44 | 252.3 | 0.70 |
| June | 72.5 | 0.40 | 167.1 | 0.58 |
| July | 66.1 | 0.38 | 178.2 | 0.60 |
| August | 50.6 | 0.34 | 113.4 | 0.49 |
| September | 48.2 | 0.34 | 109.0 | 0.48 |

**Table 5-12 Summary of Monthly River Flows and Current Speeds for SIMAP Release Sites**

| Month | Mississippi River at Palisade | | Mississippi River at Little Falls | |
|---|---|---|---|---|
| | Flow ($m^3/s$) | Current Speed (m/s) | Flow ($m^3/s$) | Current Speed (m/s) |
| October | 79.5 | 0.41 | 138.7 | 0.54 |
| November | 85.2 | 0.42 | 142.0 | 0.54 |
| December | 63.0 | 0.37 | 117.5 | 0.50 |
| Low | 45.6 | 0.33 | 95.2 | 0.46 |
| Average | 68.3 | 0.38 | 152.7 | 0.55 |
| High | 109.6 | 0.47 | 276.8 | 0.74 |

### *5.3.3.2.1.2 Hydrodynamic Modeling System*

The hydrodynamic modeling was carried out using the in-house modeling tool BFHYDRO within the Water Quality Mapping and Analysis Program (WQMAP) modeling system, both of which were created by RPS ASA (Mendelsohn et al. 1995). WQMAP integrates geographic information (land use, watersheds, etc.), environmental data (water quality parameters, surface elevations and velocities, stream flows, bathymetry, etc.), and models (analytical and numerical, hydrodynamic, pollutant transport, etc.). The WQMAP computational engine is a family of general curvilinear coordinate system computer models including a boundary conforming gridding model (BFGRID) and a hydrodynamic model (BFHYDRO). This study used BFGRID to generate a grid of the model domain and BFHYDRO to perform simulations to generate current fields.

The boundary fitted grid generation model BFGRID is a tool used to build a grid of the study area on which the hydrodynamics and pollutant transport models run. The boundary-fitted coordinate system approach generates transformation functions such that all domain boundaries are coincident with coordinate lines. The grid generation is accomplished by using a set of coupled quasi-linear elliptic transformation equations to map an arbitrary horizontal multi-connected region from physical space to a rectangular mesh structure in the transformed horizontal plane (Mendelsohn et al. 1995; Spaulding 1984; Thompson et al. 1977). While the transformed set of equations is considerably more complex than the original set, the transformed boundary conditions are specified on straight lines and the coordinate spacing is uniform in the transformed plane. It should further be noted that the orthogonal and conformal curvilinear grids, as well as the simple stretched rectangular and square grids, are special cases of the general curvilinear, boundary-fitted coordinate approach used here.

Key boundary points are specified by the user and the structure of computational grid (I,J coordinates) is defined interactively on a map using a graphical user interface. After specifying key grid nodes (grid corners) along the domain boundary, the model interpolates the remaining boundary node locations and then solves the transformed equations to locate the interior nodes. The resulting non-orthogonal grid contains quadrilaterals of various sizes and orientation to both resolve fine detail where needed, and cover large areas with coarse resolution where resolution is not required. The hydrodynamic and water quality models then use this grid in their numerical solution of the appropriate conservation equations.

BFHYDRO is a three dimensional, general curvilinear coordinate, boundary-fitted computer model (Mendelsohn 1998; Muin and Spaulding 1997; Huang and Spaulding 1995; Muin 1993) and is used to predict elevations, and current velocities within the gridded domain. The boundary-fitted model matches the model coordinates with the shoreline boundaries of the water body, accurately representing the study area. This system also allows the user to adjust the model grid resolution as desired. This approach is consistent with the variable geometry of the riverine shoreline. The model may be applied in either two or three dimensions, depending on the nature of the inquiry and its complexity. The hydrodynamic model uses the boundary fitted method and grid system as described above. The three dimensional conservation of mass and momentum equations, with approximations suitable for lakes, rivers, and estuaries (Swanson 1986; Muin 1993) that form the basis of the model, are then solved in this transformed space. In addition, a sigma stretching system is used in the vertical dimension to map the free surface and bottom onto coordinate surfaces to resolve variable surface elevations and bathymetric variations. The resulting equations are solved using an efficient semi-implicit finite difference algorithm for the exterior mode (two dimensional vertically averaged), and by an explicit finite difference leveled algorithm for the vertical structure of the interior mode (three dimensional) (Swanson 1986). The velocities are represented in their contra-variant form.

The basic equations are written in spherical coordinates to allow for accurate representation of large modeled areas. The conservation equations for water mass and momentum (in three dimensions) form the basis of the model, and are well established. It is assumed that the flow is incompressible, that the fluid is in hydrostatic balance, the horizontal friction is not significant, and the Boussinesq approximation applies all customary assumptions.

The boundary conditions are as follows:

- At land, the normal component of velocity is zero
- At open boundaries, the free surface elevation must be specified, and temperature (and salinity for estuarine and coastal applications) specified on inflow
- A bottom stress or a no slip condition is applied at the bottom. No temperature (heat) is assumed to transfer to or from the bottom, a conservative assumption as some transfer of heat to the bottom is expected to occur.
- A wind stress and appropriate heat transfer terms are applied at the surface

The set of governing equations with dependent and independent variables transformed from spherical to curvilinear coordinates, in concert with the boundary conditions, is solved by a semi-implicit, split mode finite difference procedure (Swanson 1986). The equations of motion are vertically integrated and, through simple algebraic manipulation, are recast in terms of a single

Helmholtz equation in surface elevation. This equation is solved using a sparse matrix solution technique to predict the spatial distribution of surface elevation for each grid.

The vertically averaged velocity is then determined explicitly using the momentum equation. This step constitutes the external or vertically averaged mode. Deviations of the velocity field from this vertically averaged value are then calculated, using a tridiagonal matrix technique. The deviations are added to the vertically averaged values to obtain the vertical profile of velocity at each grid cell, thereby generating the complete current patterns. This constitutes the internal mode. The methodology allows time steps based on the advective, rather than the gravity, wave speed (as in conventional explicit finite difference methods) and, therefore, results in a computationally efficient solution procedure (Swanson 1986; Muin 1993).

##### *5.3.3.2.1.3 Hydrodynamic Solution*

Hydrodynamic modeling was performed to generate river current speeds that matched the average reach speeds in the NHDPlus data set for the designated months. The BFHYDRO model was used to generate current fields that matched the NHDPlus average reach estimates. The NHDPlus estimates are simplifications that assign constant current speeds for a reach. In reality, there are variations across and along each reach due to bottom elevation changes, river cross-section changes, and other local features. The BFHYDRO model was used to simulate this variability, while representing the NHDPlus average reach speed. A summary of the range of river current speeds (10th, 50th and 90th percentile) for each representative season for both the Mississippi River at Palisade and the Mississippi River at Little Falls domains are summarized in Table 5-13. Illustrations of the spatial variability of current speeds location for low, average and high flow seasons are presented in Figure 5-38 through Figure 5-40 for the Mississippi River at Palisade release location and in Figure 5-41 through Figure 5-43 for the Mississippi River at Little Falls release, respectively.

**Table 5-13 Mean River Velocity Modeled for Each SIMAP Release Site and Season**

| Case # | Release Site | Season / River Flow | Month | River Velocity (m/s) |
|---|---|---|---|---|
| 6 | Mississippi River at Palisade | Low | March | 0.33 |
| | | Average | July | 0.38 |
| | | High | April | 0.47 |
| 7 | Mississippi River at Little Falls | Low | February | 0.46 |
| | | Average | July | 0.60 |
| | | High | April | 0.74 |

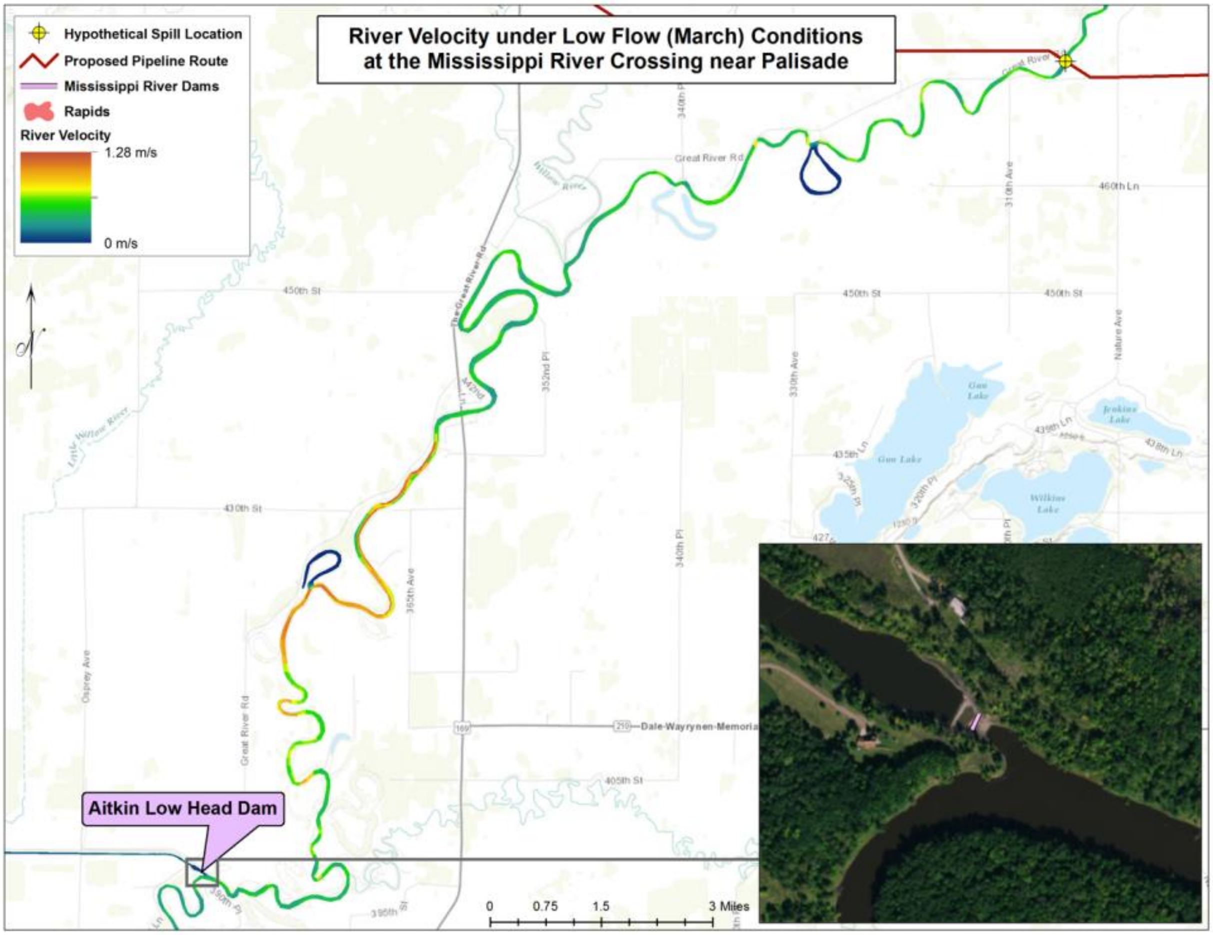


**Figure 5-38 Spatial Variability of Downstream Current Speeds for Low Flow Conditions at the Mississippi River Crossing Near Palisade**

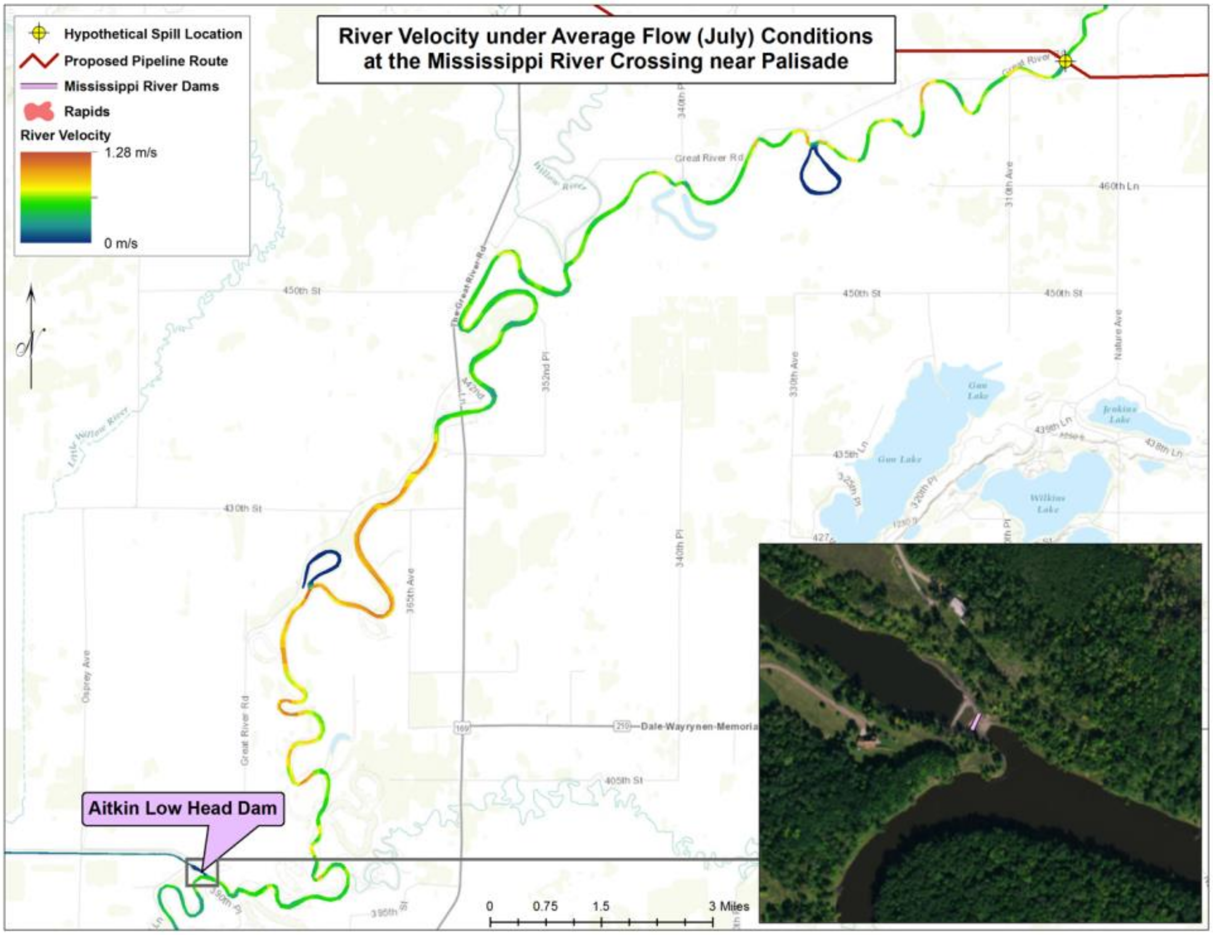


**Figure 5-39 Spatial Variability of Downstream Current Speeds for Average Flow Conditions at the Mississippi River Crossing Near Palisade**

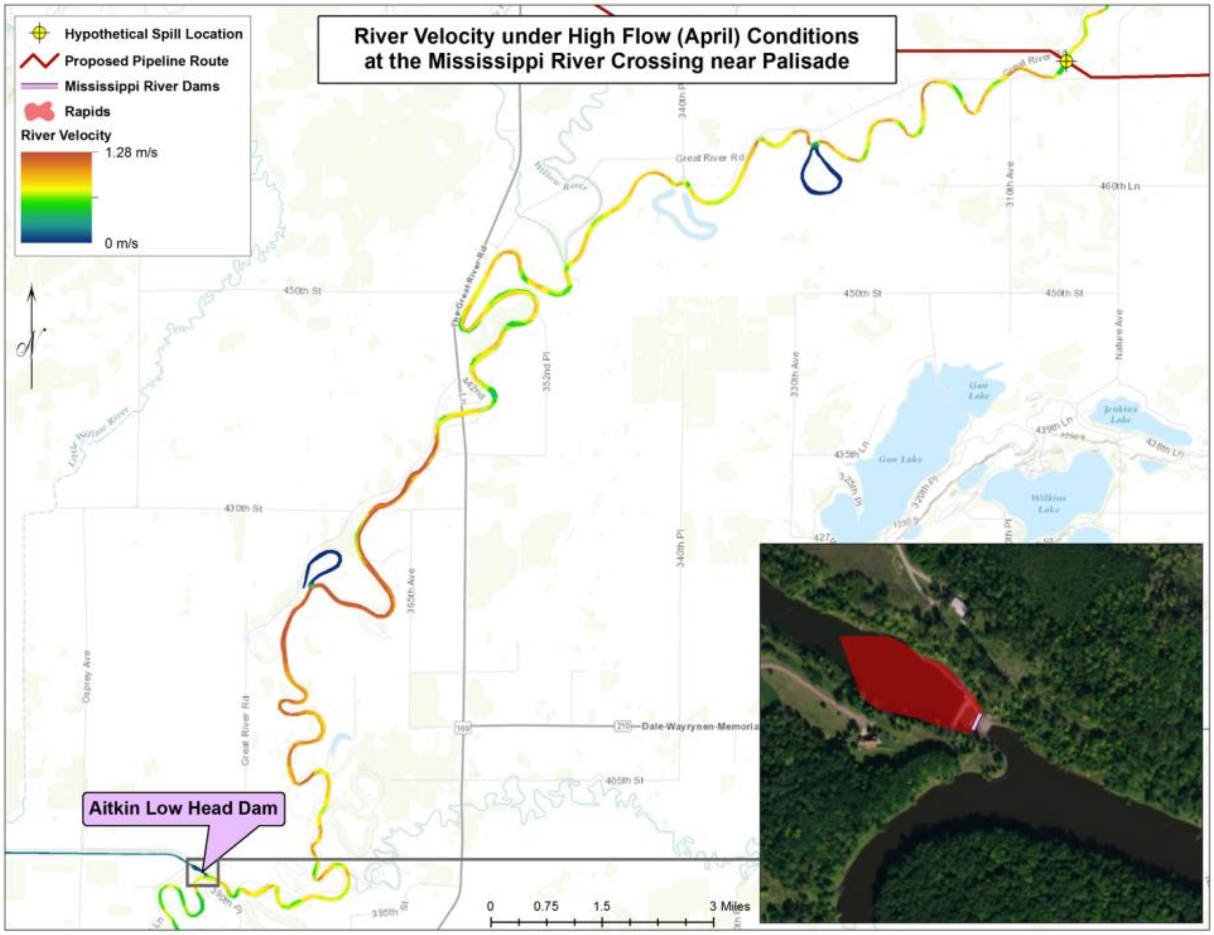


**Figure 5-40 Spatial Variability of Downstream Current Speeds for High Flow Conditions at the Mississippi River Crossing Near Palisade**

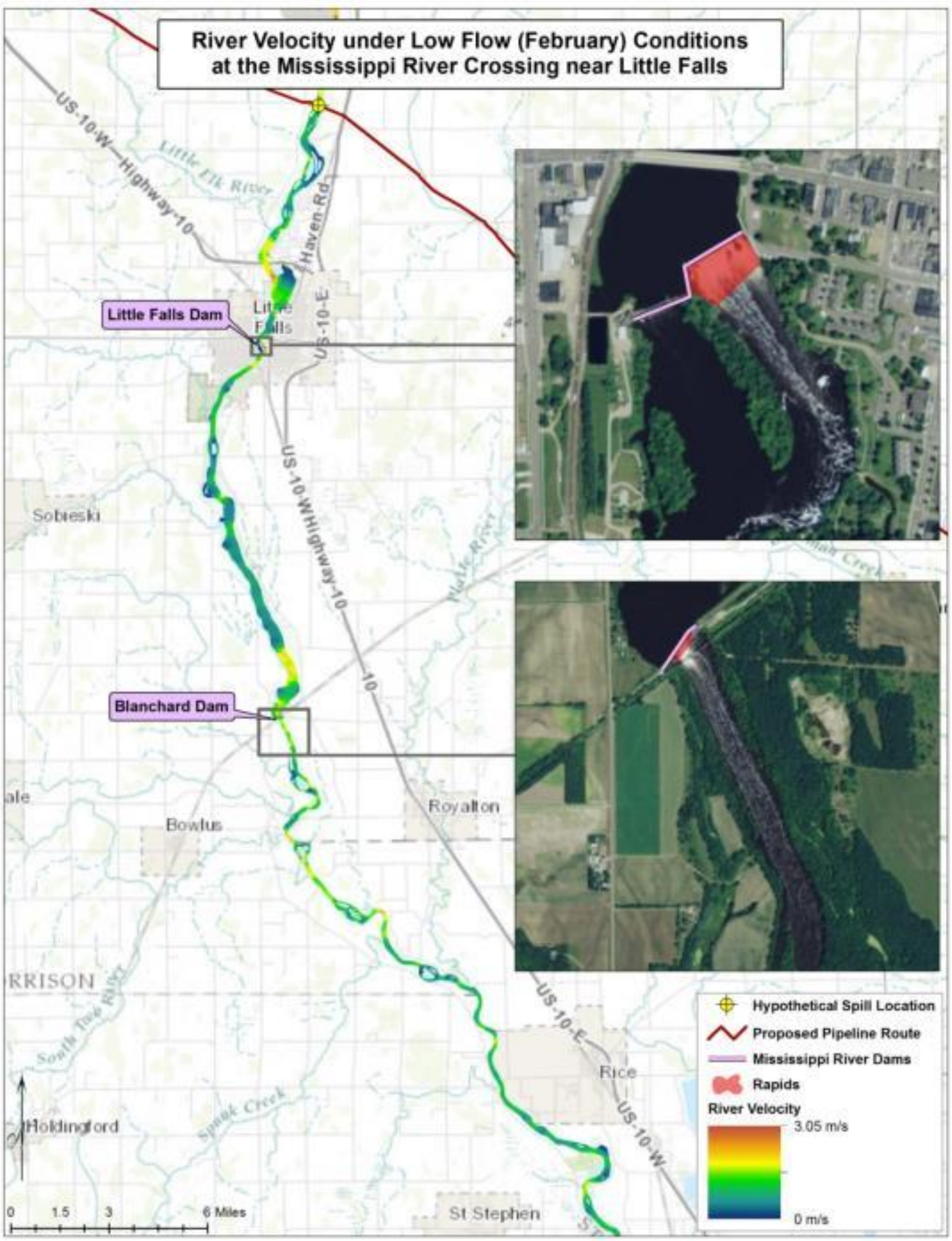


**Figure 5-41 Spatial Variability of Downstream Current Speeds for Low Flow Conditions at the Mississippi River Crossing Near Little Falls**

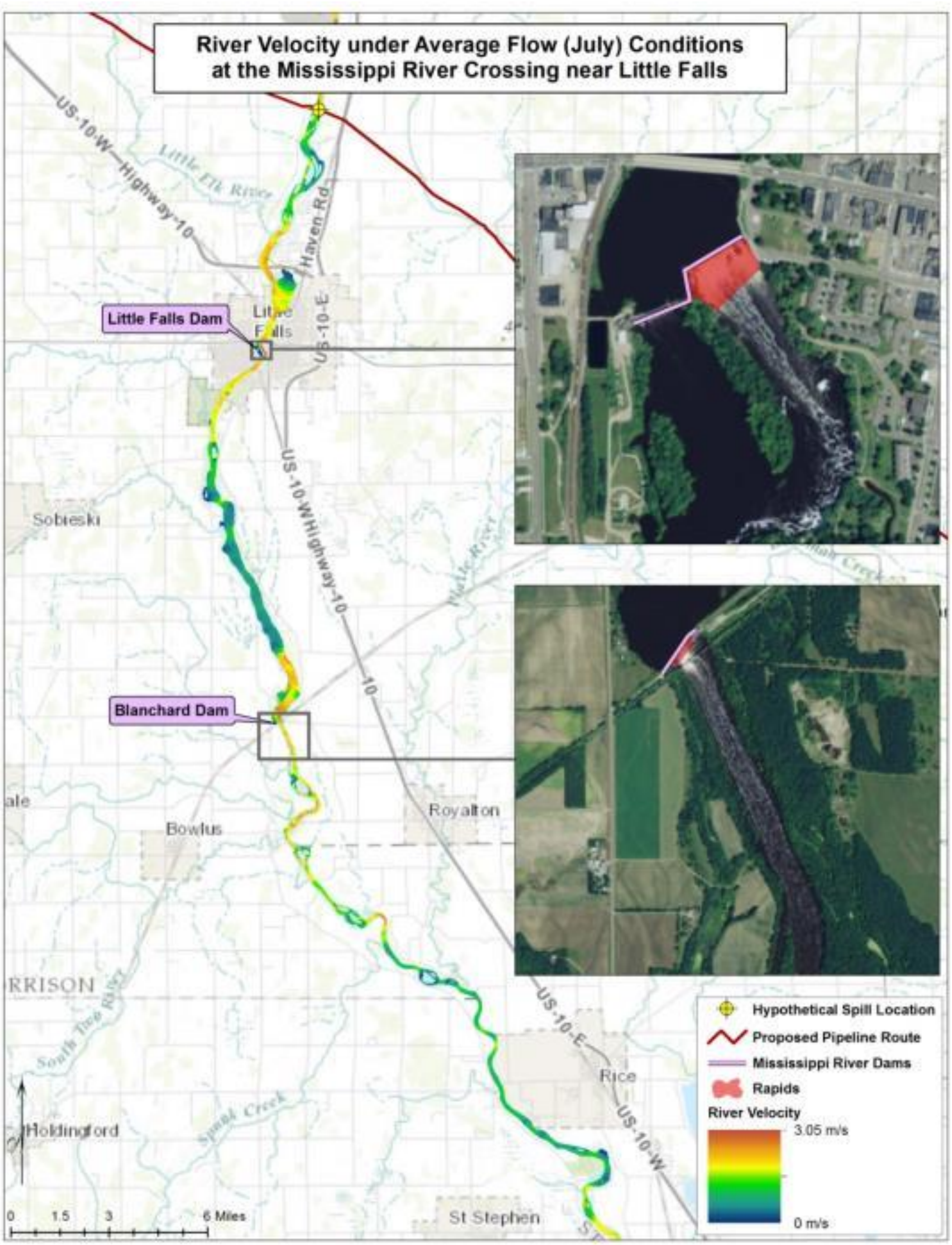


**Figure 5-42 Spatial Variability of Downstream Current Speeds for Average Flow Conditions at the Mississippi River Crossing Near Little Falls**

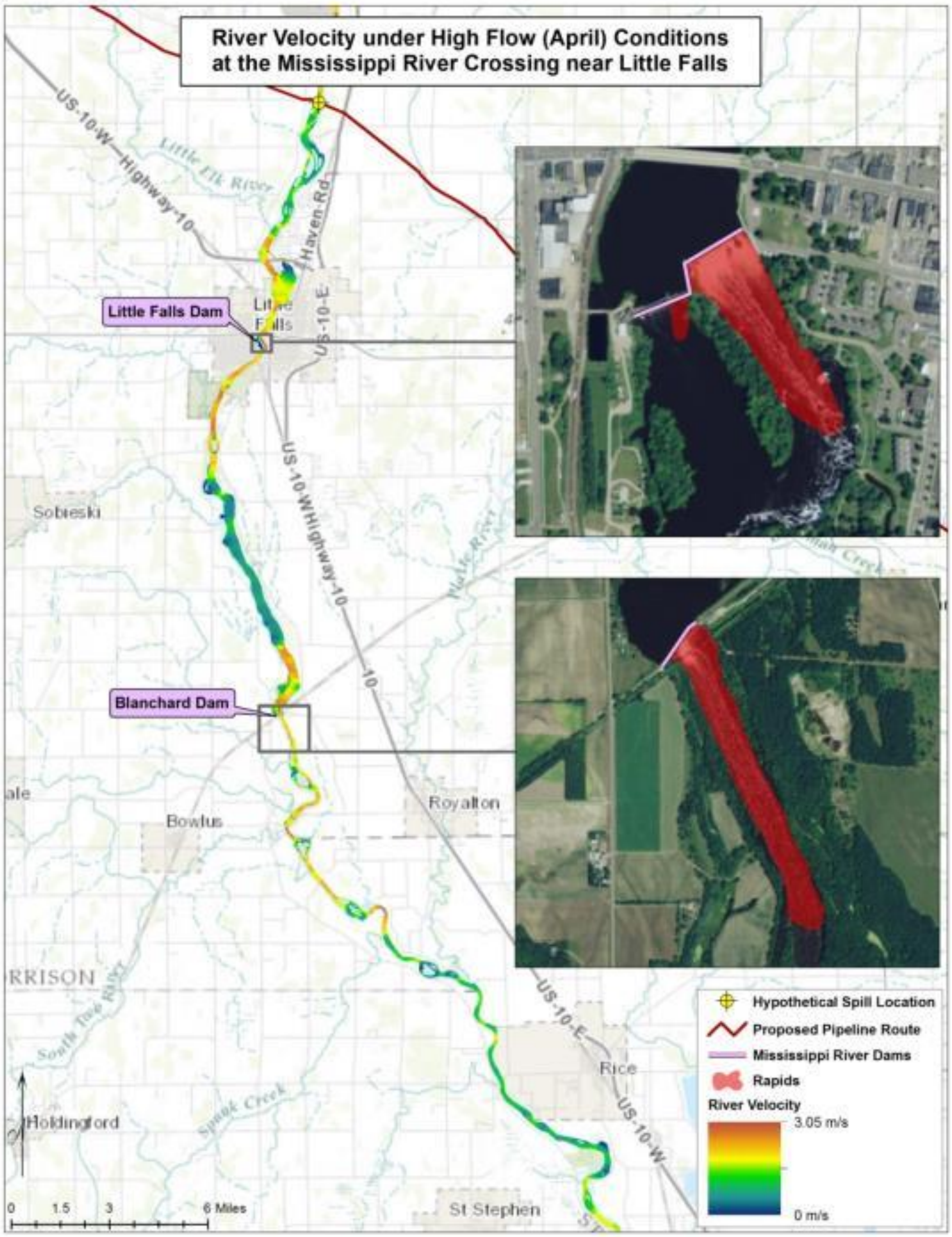


**Figure 5-43 Spatial Variability of Downstream Current Speeds for High Flow Conditions at the Mississippi River Crossing Near Little Falls**

#### 5.3.3.2.2 Wind and Temperature

The same wind and temperature data sources for that were used as inputs for the OILMAP Land scenarios (Section 5.3.2.4) were also used to develop wind and temperature information for the two Mississippi River SIMAP scenarios. Daily climatological statistics from 2000 to 2015 consisting of wind speed, wind direction, and air temperature were obtained from the NOAA National Centers for Environmental Information website (NOAA 2016a) and were averaged by month. Table 5-14 depicts the temperatures and wind speeds used for each seasonal scenario at each release location. Because these were river simulations, salinity was assumed to be zero for all modeling locations.

**Table 5-14 Air Temperature and Wind Speed Values Used as Model Inputs for Each SIMAP Release Location and Seasonal Scenario**

| Case # | Release Location | Season / River Flow | Month | Air Temp. (°C) | Air Temp. (°F) | Wind Speed (m/s) |
|---|---|---|---|---|---|---|
| 6 | Mississippi River at Palisade | Low | March | -3.19 | 26.26 | 4.78 |
| | | Average | July | 20.19 | 68.34 | 3.95 |
| | | High | April | 5.03 | 41.05 | 5.24 |
| 7 | Mississippi River at Little Falls | Low | February | -8.33 | 17.01 | 4.30 |
| | | Average | July | 22.06 | 71.71 | 3.47 |
| | | High | April | 7.06 | 44.71 | 4.85 |

Winds may physically transport oil on the water surface and wind speed and direction at the water surface may make a difference between limited (especially in windy sections of river) or extensive transport. The wind data available is for open areas at some distance from the release sites examined, as opposed to in the forested stream areas modeled; thus, local winds at each point downstream from the release location may be different than the reported wind speed and direction. Because of these uncertainties and the expected variability in direction, the SIMAP model conservatively assumed wind drift transport as zero (i.e., winds did not laterally transport oil or push it ashore) for each of the modeling locations. The modeled wind was therefore not a true vector as it had magnitude, but no direction. Because of this assumption, winds may add to the evaporation of surface oil in the model output, and could enhance the vertical mixing of the surface water, in some instances keeping subsurface oil entrained or entraining more oil under higher wind speeds.

#### 5.3.3.2.3 Total Suspended Solids

The amount of sediment transport can change by several orders of magnitude based on location and flow conditions, with extensive of sediment transport during high river flow conditions (especially storm events), and very low sediment transport and clear water during low river flow conditions (e.g., under winter ice cover). During peak storm events, it is not uncommon to have values exceeding 1,000 mg/L in some locations. Oil droplets may stick to suspended sediments and settle out to the bottom. The sedimentation rate was set to 1 mm/day for high flow scenarios and 0.1 mm/day for low flow scenarios. At suspended sediment concentration of about 100 mg/L, sedimentation of oil and PAHs becomes substantial. Sediment loads were assumed to be 99, 25, and 10 mg/l for the high, average, and low river flow conditions, respectively.

#### 5.3.3.2.4 Ice Cover

Oil interactions with mobile and immobile ice involve several processes that affect the transport and fate of the oil. Oil released under water may become trapped under the ice in ridges and keels, or build up along and become trapped (Drozdowski et al. 2011). Many of these interactions and processes are at a finer scale than can be captured in oil spill models using inputs from the available large scale meteorological, hydrodynamic and coupled hydrodynamic-ice models. SIMAP simulates the influence of ice on net transport and fate processes by considering potential reduction in the surface area of the oil and the water in contact with the atmosphere, which changes the effects of the wave environment, spreading, movements, dissolution, volatilization, and mixing on the released oil.

In SIMAP, when oil encounters ice at the surface of the river, it is assumed to trap along the ice edge and remain immobile until ice retreats. In areas deep enough for ice to have subsurface open channels (i.e., where the ice sheet may not extend completely to the riverbed in all areas), SIMAP allows entrained oil to circulate underneath the surface ice using subsurface current data for transport. The 100% ice coverage on the rivers during the winter was assumed to have a thickness of ice of 0.5 m. Therefore, subsurface oil spillets continued to move downstream with currents, until the spillets reached the water-ice interface, at which point they "stick."

The presence of ice can shelter oil from the wind and waves (Drozdowski et al. 2011). Thus, weathering processes such as evaporation and emulsification, and behaviors such as spreading and entrainment are slowed (Spaulding 1988). Field data show evaporation, dispersion, and emulsification s slowed substantially in ice leads, contrary to some laboratory experiments. Wave-damping, the limitations on spreading dictated by the presence of sea ice, and temperature appear to be the primary factors governing observed spreading and weathering rates (Sørstrøm et al. 2010).

During the low flow river conditions, corresponding with the winter months, ice cover was assumed to be 100%. With 100% ice coverage, SIMAP stops the processes of evaporation, emulsification, entrainment, volatilization, and spreading.

# 6.0 TRAJECTORY AND FATE RESULTS FOR MODELING LOCATIONS

## 6.1 DESCRIPTION OF OILMAP LAND MODEL OUTPUTS

This section provides modeled predictions of expected downstream transport and mass balance information for CLB (either Winter or Summer) and Bakken Crude oil under high, average, and low river flow conditions at five hypothetical release locations modeled in OILMAP Land.

As described in Section 5.1.1, OILMAP Land predicts the trajectory and fate of released oil. The model includes a land component that predicts how much oil will adhere to vegetation and soils and remain in depressions in the landscape, as well as the quantity that would be lost to evaporation during overland flow. Overland trajectory and fate were modeled only for the Mosquito Creek site (Section 6.2), as the other four sites assumed that oil was released directly into a watercourse. OILMAP Land also predicts the downstream trajectory and fate of released oil in water. The model calculates the amount of released oil that would evaporate, adhere to the shoreline, and remain on the water surface. In an actual oil release, other processes such as dissolution and dispersion would come into play (Section 7.1.2).

Figures are provided for each of the five modeling locations and two oil types in Sections 6.1.1 through 6.1.5. Each figure includes each of the three modeled seasons that correspond with high, average, and low river flow. In these figures, symbols with different color/shape combinations denote the location and time in hours of the farthest downstream movement of released crude oil for each set of scenarios at a given location. The mass balances are also provided, summarizing how much of the oil remained on the river surface, evaporated to the atmosphere, or stranded on the riverbanks. The model was run for 24 hours, or until no further oil remained on the river surface (i.e., all oil had evaporated or adhered to shorelines). If there was oil on the river surface after 24-hours, it would continue downstream, further oiling shorelines, until it either evaporated and stranded, or was captured by emergency response operations.

### 6.1.1 Unmitigated Hypothetical Release Case 1—Mosquito Creek to Lower Rice Lake

Mosquito Creek is a small stream located approximately 6 miles (9.7 km) south of Bagley, Minnesota. The pipeline does not actually cross Mosquito Creek; however, the simulated release location is located approximately 2,000 ft (610 m) to the northeast from the head of the creek and at a higher elevation. Based on local topography, oil would need to travel overland approximately 3,300 ft (1,006 m) before entering Mosquito Creek. Mosquito Creek flows to the southwest for approximately 12 miles (19.3 km) before entering Lower Rice Lake. Mosquito Creek is the smallest stream of the sites investigated with an average width of approximately 15 ft (5 m). At the widest points around its entrance into Lower Rice Lake, it is approximately 30 ft

(10 m) across, while the upper portions of the creek are much less ranging from approximately 3–15 ft (1–5 m) wide. Expected environmental and river flow conditions throughout the year for Mosquito Creek are provided in Table 5-6. In all release scenarios, spills were not predicted to enter Lower Rice Lake before all of the oil had either evaporated or adhered to the land cover or stream shorelines. Maps of the predicted downstream trajectory and mass balance tables of CLB (Figure 6-1) and Bakken Crude (Figure 6-2) seasonal scenarios for the Mosquito Creek release site are provided at the beginning of the following subsections.

#### 6.1.1.1 Cold Lake Blend Scenarios

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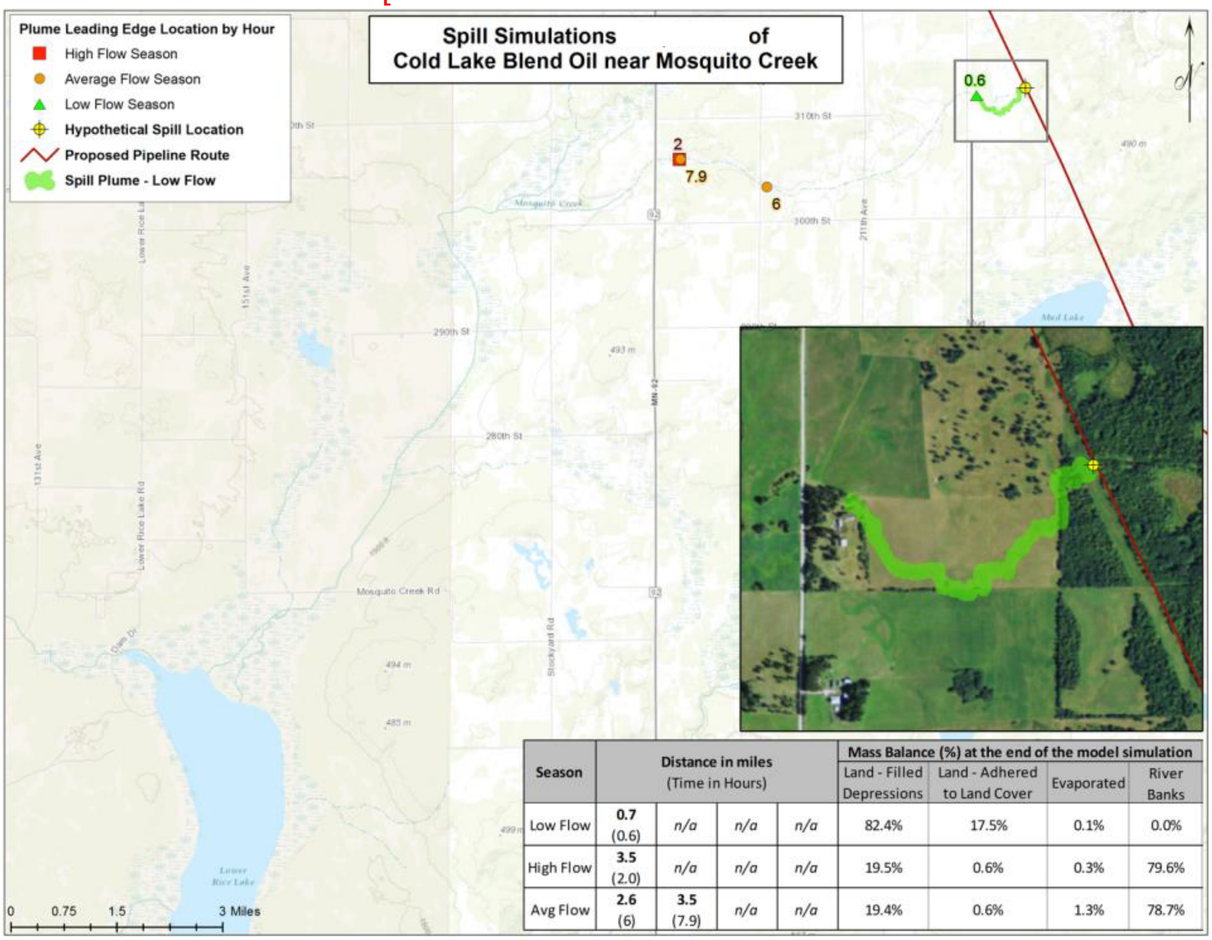


| Season | Distance in miles (Time in Hours) | | | | Mass Balance (%) at the end of the model simulation | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Land - Filled Depressions | Land - Adhered to Land Cover | Evaporated | River Banks |
| Low Flow | 0.7 (0.6) | n/a | n/a | n/a | 82.4% | 17.5% | 0.1% | 0.0% |
| High Flow | 3.5 (2.0) | n/a | n/a | n/a | 19.5% | 0.6% | 0.3% | 79.6% |
| Avg Flow | 2.6 (6) | 3.5 (7.9) | n/a | n/a | 19.4% | 0.6% | 1.3% | 78.7% |

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**Figure 6-1 Predicted Downstream Transport of CLB Oil Near Mosquito Creek**

#### 6.1.1.1.1 Trajectory and Fate Results for High River Flow (Spring)

Flow rates on Mosquito Creek during the spring season (April) resulted in peak average river velocities ranging from 1.67 to 2.30 miles per hour (mph) (0.75 to 1.03 m/s). Under high river flow, CLSB was predicted to travel approximately 3.5 miles (5.6 km) downstream. After 2.0 hours, approximately 0.3% of the CLSB evaporated to the atmosphere, 20.1% filled depressions on land or adhered to land cover, and the remaining 79.6% oiled shorelines. Note that the model predicts that no CLSB would remain on the water surface after 2.0 hours since all of the released oil would have been retained in depressions, adhered to land cover, or evaporated by that point in time.

#### 6.1.1.1.2 Trajectory and Fate Results for Average River Flow (Summer-Fall)

Flow rates on Mosquito Creek during the summer (July) and fall resulted in average river velocities ranging between 0.43 to 0.47 mph (0.19 and 0.21 m/s). These velocities were significantly slower than the high river flow conditions during the spring. As in the high flow condition, all of the released CLSB was predicted to adhere to the land cover, adhere to the shorelines, or evaporate to the atmosphere within the same 3.5 miles from the release site. However, under average river flow conditions with lower velocities, it took approximately 7.9 hours to reach that same distance. After 7.9 hours, approximately 1.3% of the CLSB evaporated to the atmosphere, 20.0% filled depressions on land or adhered to land cover, and the remaining 78.7% oiled shorelines. Note that the model predicted that there would be no CLSB on the water surface after 7.9 hours.

Under the average river flow condition (i.e., summer), more of the CLSB was predicted to evaporate, when compared to the high flow conditions (i.e., spring). This is partially due to the higher temperatures in this summer scenario, however, the main factor in the increased evaporation was the longer time required for the CLSB to move downstream due to the slower stream velocities. The longer time allowed for more complete evaporation of the CLSB.

#### 6.1.1.1.3 Trajectory and Fate Results for Low River Flow (Winter)

Under winter (February) conditions, the region near the Mosquito Creek release location was assumed to be covered in snow at a depth of 34.8 cm. In addition, it was assumed that Mosquito Creek would be frozen over (100% coverage of ice), with a layer of snow on top. Therefore, a release of CLWB from the pipeline onto land would result in a spill traveling over the snow surface and onto Mosquito Creek, but the oil would not enter the water.

Under winter conditions, CLWB was predicted to travel approximately 0.7 miles (1.13 km) over the land surface. Approximately 82.4% of the CLWB filled depressions in the land surface, 17.5% adhered to the land cover, and only 0.1% evaporated. After 0.6 hours, all of the released CLWB evaporated, adhered to the land cover, or filled depressions in the land surface; therefore, the model simulation stopped at that time.

Considerably more CLWB was predicted to adhere to the land cover in winter conditions due to the holding capacity of the snow cover, which is over 35 times greater than that of the typical land cover in this area for CLWB (Table 5-9). With Mosquito Creek frozen over, additional depressions were created in surface of the stream that allowed more CLWB to form pools on the ice surface.

Very little evaporation was predicted to occur under winter conditions due to the very short (0.6 hour) duration of the simulation. Lower air temperatures also slow evaporation. Additionally, a reduced surface area for exchange was predicted due to less spreading of oil and no downstream transport. This resulted in a smaller surface area over which evaporation could occur.

#### 6.1.1.1 Bakken Crude Scenarios

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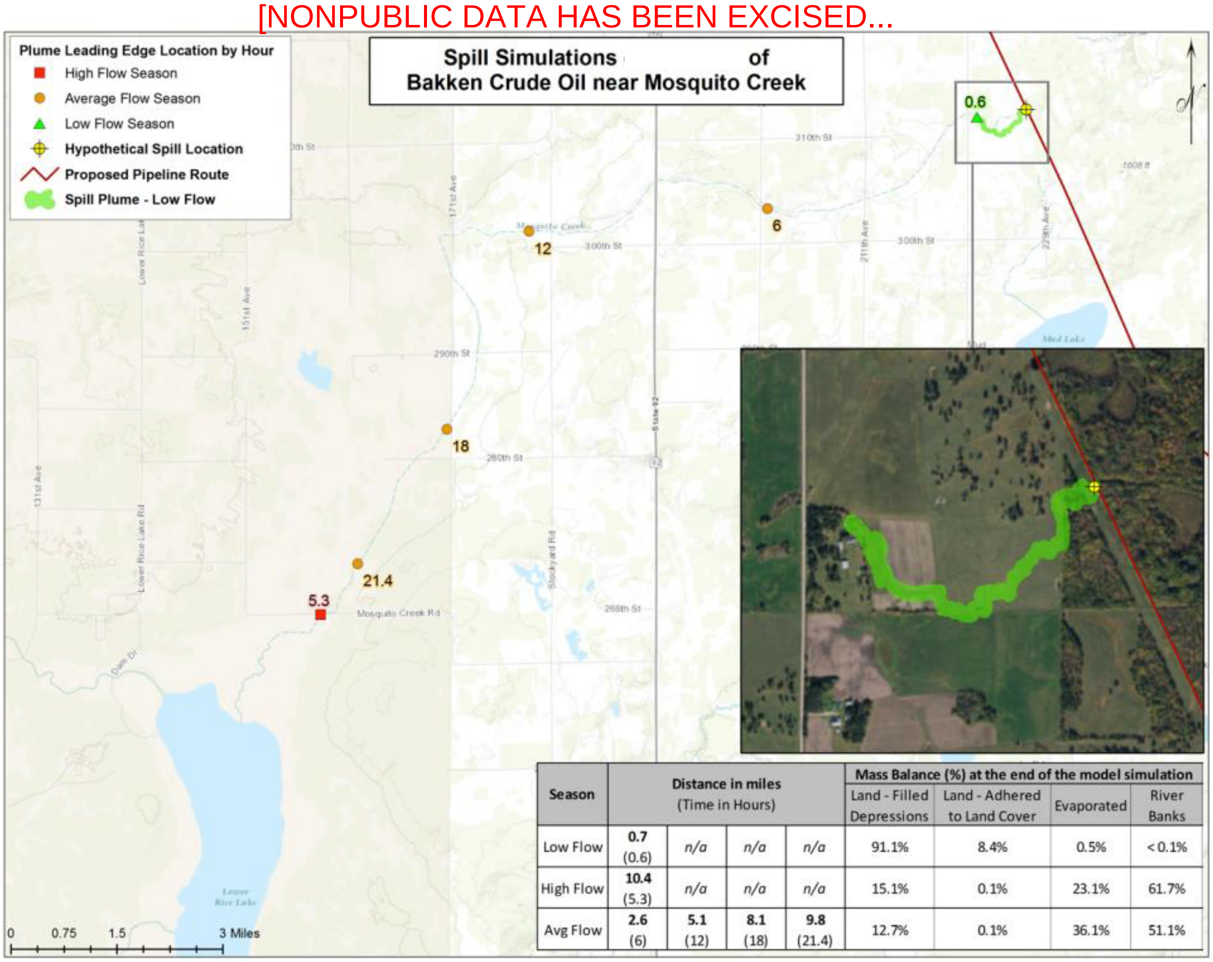


| Season | Distance in miles (Time in Hours) | | | | Mass Balance (%) at the end of the model simulation | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Land - Filled Depressions | Land - Adhered to Land Cover | Evaporated | River Banks |
| Low Flow | **0.7** (0.6) | *n/a* | *n/a* | *n/a* | 91.1% | 8.4% | 0.5% | < 0.1% |
| High Flow | **10.4** (5.3) | *n/a* | *n/a* | *n/a* | 15.1% | 0.1% | 23.1% | 61.7% |
| Avg Flow | **2.6** (6) | **5.1** (12) | **8.1** (18) | **9.8** (21.4) | 12.7% | 0.1% | 36.1% | 51.1% |

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**Figure 6-2 Predicted Downstream Transport of Bakken Crude Oil Near Mosquito Creek**

### 6.1.1.1.4 Trajectory and Fate Results for High Flow (Spring)

Under high river flow conditions (April), Bakken crude traveled approximately 10.4 miles (16.7 km) downstream. After 5.3 hours, approximately 23.1% of the Bakken crude had evaporated to the atmosphere, 15.2% filled depressions on land or adhered to land cover, and the remaining 61.7% oiled shorelines. Note that there was no Bakken crude remaining on the water surface after 5.3 hours, as the model predicted that all of the oil would have been lost from the water surface by that point.

Under high river flow conditions, the Bakken crude resulted in oiling of shorelines nearly 3 times farther downstream (10.4 miles) than the CLSB (3.5 miles). The difference in the extent of downstream transport was primarily due to differences in the shoreline oil retention between the two oils. Because of its higher viscosity and other parameters, CLSB stranded upon shorelines more thickly than Bakken Crude oil, resulting in larger amounts of CLSB along the same length of shoreline. In contrast, the same amount of Bakken Crude oiled longer lengths of shoreline with a reduced thickness. While this result is logical, it is based upon the assumption of 100% shoreline oiling coverage (i.e., all shoreline up to that point was oiled to its maximum holding capacity) as oil made its way downstream. In the event of an actual release, the downstream extents of CLSB and Bakken Crude may be more similar, and the effects of CLSB may extend farther downstream than presented, with patchy coverage.

Due to its lighter nature and higher volatile content, Bakken Crude was predicted to evaporate more completely (23.1%) than the CLSB (0.3%) oil. The Bakken Crude oiled farther downstream, which also took more time. The additional time for downstream transport allowed for more time over which the oil evaporated to the atmosphere.

### 6.1.1.1.5 Trajectory and Fate Results for Average Flow (Summer-Fall)

Under average river flow conditions (July), the Bakken Crude traveled approximately 9.8 miles downstream. At that point, approximately 36.1% of the Bakken Crude had evaporated to the atmosphere, 12.7% filled depressions on land or adhered to land cover, and the remaining 51.1% would have adhered to shorelines. The model predicted that no Bakken Crude would remain on the water surface after 21.4 hours.

Under average flow conditions, the Bakken Crude was predicted to oil 0.6 fewer miles (0.97 km) of shoreline than during high river flow conditions. Under average river flow conditions, the Bakken Crude was transported downstream at a slower velocity than that of the high river flow conditions. Since this allowed more time for evaporation from the stream surface, less oil was available for shoreline retention. Although the land surface retained the same volume of oil under high flow and average flow conditions, more of the released oil evaporated over the 21.4 hours of the average flow simulation, than during the 5.3 hour high flow simulation. This resulted in less oil remaining on the land surface at the end of the simulation.

#### 6.1.1.1.6 Trajectory and Fate Results for Low Flow (Winter)

Under winter conditions (February) Bakken crude traveled approximately 0.7 miles over the land surface. At that point, approximately 91.1% of the oil filled depressions in the land surface, 8.4% adhered to the land cover, and only 0.5% evaporated. After 0.6 hours, all of the released Bakken Crude evaporated, adhered to the land cover, or filled depressions in the land surface; therefore, the model simulation stopped.

Considerably more Bakken Crude adhered to the land cover during low flow (winter) conditions than during high or average river flow conditions, due to the holding capacity of snow cover. The holding capacity of snow for Bakken Crude was over 100 times the retention values of the typical land cover in this area (Table 5-9). However, the holding capacity on snow for Bakken Crude is about half of that for CLWB; therefore, a release of Bakken will create a footprint that is nearly double the areal extent of CLWB. The model predicts that very little evaporation will occur over the 0.6 hours of the simulation under winter conditions, since lower air temperatures slowed evaporative losses. Additionally, the smaller surface area, due to reduced spreading of either type of oil without entering the creek, resulted in a smaller surface area for evaporation.

### 6.1.2 Unmitigated Hypothetical Release Case 2—Mississippi River at Ball Club

The Mississippi River passes to the south and west of the town of Ball Club, Minnesota. The pipeline route crosses the Mississippi River 1.25 miles (2.01 km) to the west of Ball Club, and 400 ft (122 m) south of U.S. Highway 2. At this location the Mississippi River flows to the east through an extensively marshy area. Approximately 12.2 miles (19.6 km) downstream, the river passes through the southern end of White Oak Lake, and then turns to the south. Under low or average river flow conditions the main channel of the Mississippi River passes to the south of White Oak Lake, with only small marshy streams connecting them. Under high river flow conditions, hydraulic connections are present between the river and lake; therefore, it was assumed that under high river flow conditions that the main pathway of the Mississippi River could transport oil into White Oak Lake. The width of the Mississippi River averages approximately 160 ft (48.8 m) in this area. Expected environmental and flow conditions throughout the year for Mississippi River near Ball Club are provided in Table 5-6.

The shore type for the majority of the Mississippi River in this region is marsh. An initial set of scenarios was run using this marsh shore type. However, the high retention value for marsh shore types (120 $m^3$/km of river for Bakken crude and 800 $m^3$ for CLB (Table 5-8) resulted in minimal transport of oil down the Mississippi River. Due to the uncertainty of how much oil would be able to infiltrate the marshy shoreline, based on the water level, a second set of scenarios were run assuming that the marsh shoreline was instead grass, with a lower oil retention capacity. Both sets of results are presented. It is anticipated that if an actual release were to occur that downstream oil transport may be somewhere between the two predicted downstream distances.

The predicted downstream trajectory and mass balance tables for CLB (Figure 6-3) and Bakken Crude (Figure 6-5) seasonal scenarios for the Mississippi River near Ball Club release site with marsh shore type are provided. Results for an assumed grass shore type for CLB (Figure 6-4) and Bakken Crude (Figure 6-6) are also provided.

### 6.1.2.1 Cold Lake Blend Scenarios

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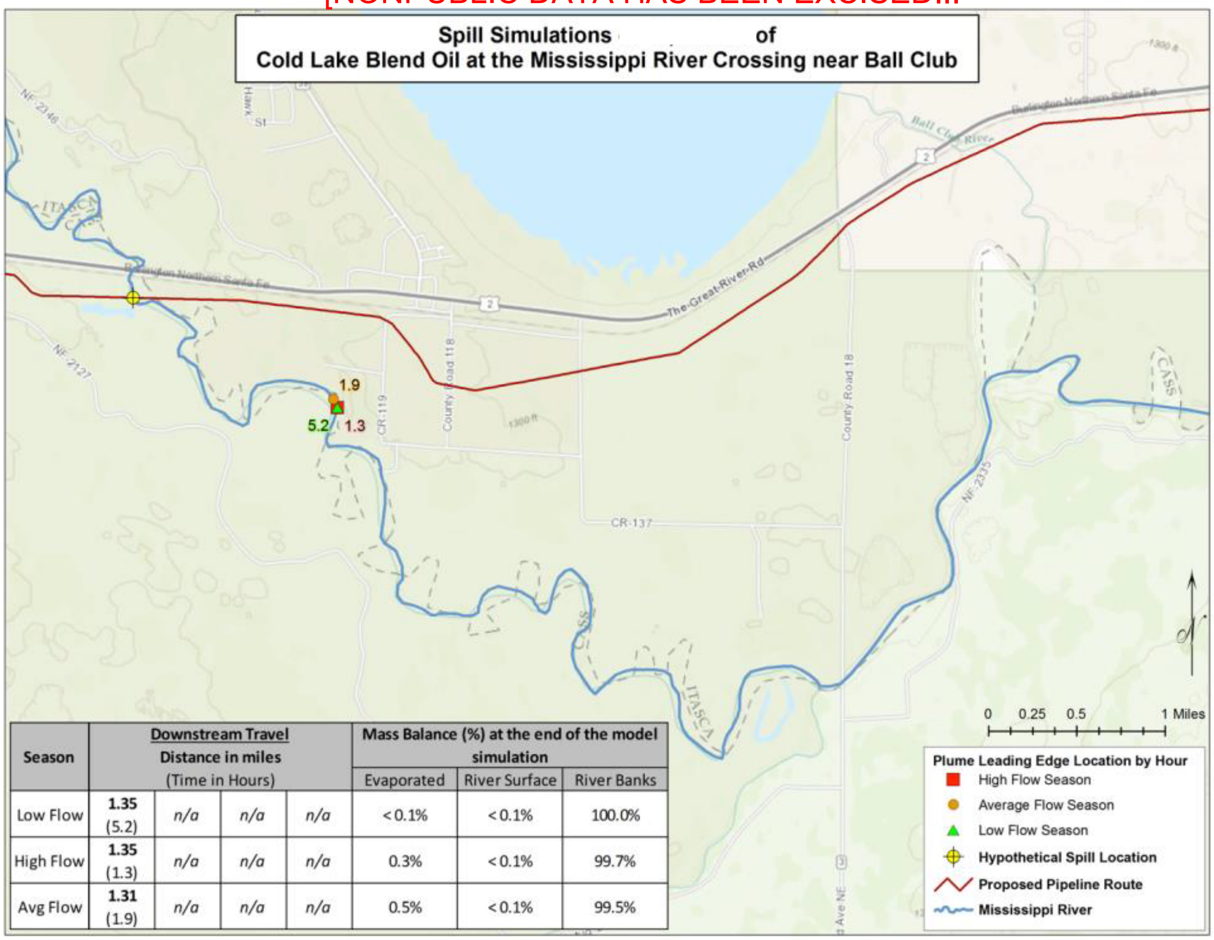


| Season | Downstream Travel Distance in miles (Time in Hours) | | | | Mass Balance (%) at the end of the model simulation: Evaporated | River Surface | River Banks |
|---|---|---|---|---|---|---|---|
| Low Flow | 1.35 (5.2) | n/a | n/a | n/a | < 0.1% | < 0.1% | 100.0% |
| High Flow | 1.35 (1.3) | n/a | n/a | n/a | 0.3% | < 0.1% | 99.7% |
| Avg Flow | 1.31 (1.9) | n/a | n/a | n/a | 0.5% | < 0.1% | 99.5% |

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**Figure 6-3 Predicted Downstream Transport of CLB at the Mississippi River at Ball Club Release Location with Marsh Shoreline**

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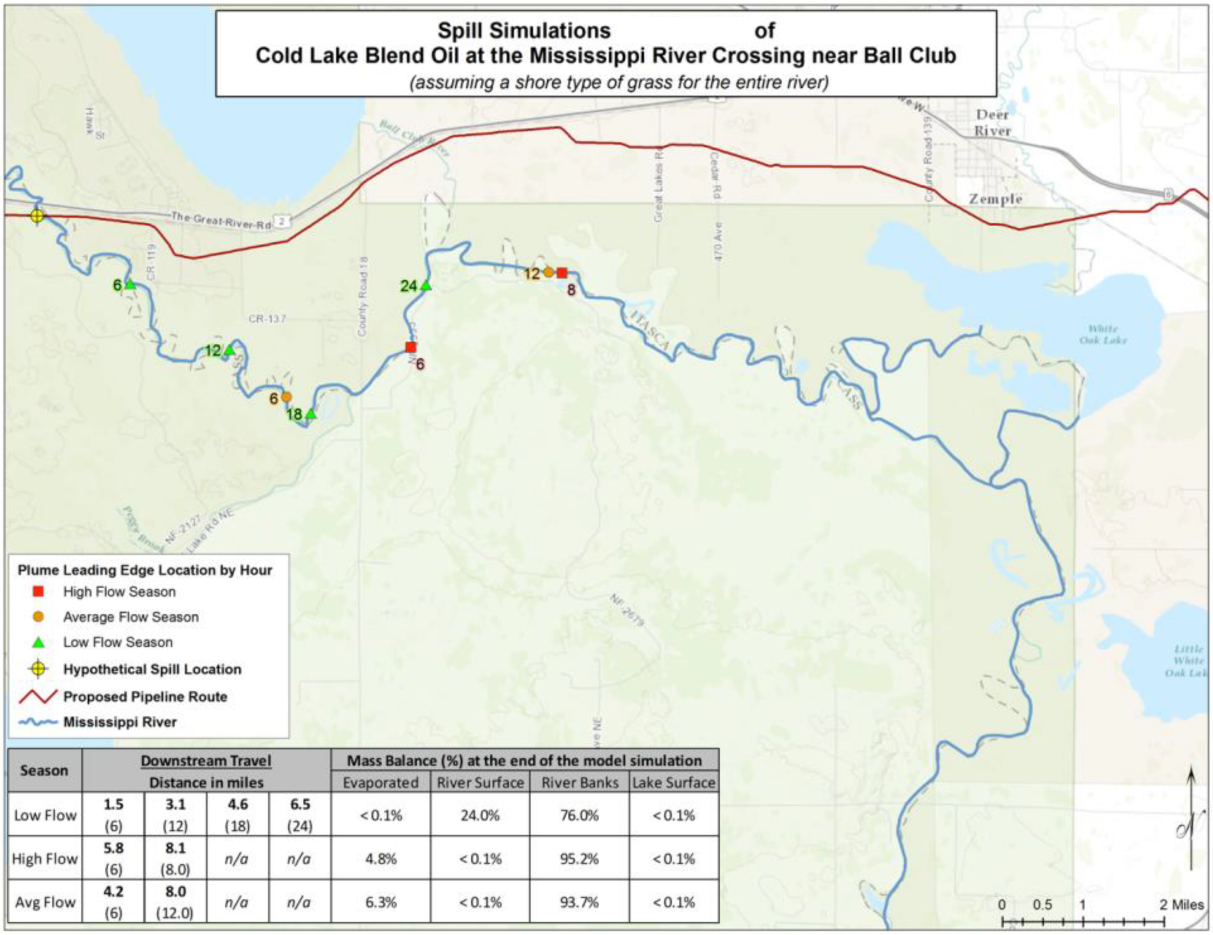


| Season | Downstream Travel Distance in miles | | | | Mass Balance (%) at the end of the model simulation | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Evaporated | River Surface | River Banks | Lake Surface |
| Low Flow | 1.5 (6) | 3.1 (12) | 4.6 (18) | 6.5 (24) | < 0.1% | 24.0% | 76.0% | < 0.1% |
| High Flow | 5.8 (6) | 8.1 (8.0) | n/a | n/a | 4.8% | < 0.1% | 95.2% | < 0.1% |
| Avg Flow | 4.2 (6) | 8.0 (12.0) | n/a | n/a | 6.3% | < 0.1% | 93.7% | < 0.1% |

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**Figure 6-4 Predicted Downstream Transport of CLB oil at the Mississippi River at Ball Club Release Location With Assumed Grass Shoreline**

### 6.1.2.1.1 Trajectory and Fate Results for High Flow (Spring)

Flow rates for the Mississippi River during the spring (April) resulted in peak average river velocities during April. Velocities ranged between 0.34 to 1.25 mph (0.15 and 0.56 m/s) for the portion of the river modeled in the marsh shoreline scenario runs and between 0.27 and 1.28 mph (0.12 and 0.57 m/s) for the longer portion of river modeled in the grass shoreline runs. The OILMAP Land model transported oil downstream with these velocities to a point where all oil had evaporated and/or adhered to the shoreline.

Under high river flow for marsh shorelines, CLSB was predicted to travel a total of approximately 1.35 miles (2.17 km) downstream, within 1.3 hours of the release. At this time, the model predicts that no CLSB would remain on the water surface. Approximately 99.7% of the CLSB was predicted to oil the shorelines of the Mississippi River, and 0.3% would have evaporated into the atmosphere.

Under high river flow conditions with grass shorelines, CLSB was predicted to travel a total of approximately 8.1 miles (13.0 km) downstream, within 8.0 hours of the release. At this time, the model predicted that all of the oil would have been lost from the water surface. Approximately 95.2% of the CLSB was predicted to oil shorelines of the Mississippi River, and 4.8% would have evaporated into the atmosphere.

#### 6.1.2.1.2 Trajectory and Fate Results for Average Flow (Summer-Fall)

Average flow rates for Mississippi River occurred during the summer (August) with river velocities ranging between 0.27 to 0.72 mph (0.12 and 0.32 m/s) for the portion of river modeled in the marsh runs and between 0.22 and 0.72 mph (0.10 and 0.32 m/s) for the longer portion of river modeled in the grass shoreline runs. These river velocities were approximately 58–67% of those that would occur under the modeled high flow conditions.

Similar to the high river flow conditions with marsh shorelines, CLSB was predicted to travel a total of approximately 1.31 miles (2.11 km) downstream, under average river flow. However, under average river flow conditions, it would take approximately 1.9 hours to reach this same distance due to the lower stream velocities. At this time, there would be no remaining CLSB on the river surface; approximately 99.5% of the CLSB was predicted to be on the shorelines, while the remainder (0.5%) would have evaporated into the atmosphere.

Under average river flow with grass shorelines, CLSB was predicted to travel a total of approximately 8.0 miles (12.9 km) downstream. However, with lower stream velocities, it took approximately 12.0 hours to reach this distance. At this time the model predicted that there would be no CLSB on the river surface; approximately 93.7% of the CLSB would have adhered to the shorelines of the Mississippi River, and 6.3% would have evaporated into the atmosphere.

Relative to the high river flow condition, more of the CLSB was predicted to evaporate. This is mainly due to the longer time required for the CLSB to move down stream, due to the lower stream velocities. In addition, the higher temperatures during the summer conditions results in more evaporation. The slight reduction in oil remaining on the river shoreline in the average river flow condition was the result of this increase in evaporation.

#### 6.1.2.1.3 Trajectory and Fate Results for Low Flow (Winter)

Under winter conditions (March), it was assumed that Mississippi River would be frozen over completely (100% coverage of ice). It was also assumed that CLWB would be released directly into the river from the pipeline, which is located under the riverbed. Oil released into the water would remain in the water or be trapped under the ice. The ice cover would prevent any evaporation to the atmosphere. Flow rates for the Mississippi River during these winter conditions resulted in minimum river velocities during March, which ranged between 0.22 to 0.34 mph (0.10 and 0.15 m/s). These river velocities were approximately 30% of the high river flow conditions.

Under low river flow conditions with marsh shorelines, CLWB was predicted to travel a total of approximately 1.35 miles (2.17 km) downstream. However, under low river flow conditions with the lowest stream velocities, it took approximately 5.2 hours to reach this same distance. At this time there was no CLWB on the river surface, as the model predicts that all of the CLWB (100%) would have adhered to the shoreline. In an actual spill, the released oil would collect in pockets under the ice, as well as dissolve and disperse in the water column. Some released oil might also collect in openings in the ice where a small portion of the oil would evaporate.

Under low river flow with grass shorelines, CLWB was predicted to travel a total of approximately 6.5 miles (10.5 km) downstream, over the full 24-hour modeled period. Approximately 76.0% of the CLWB was predicted to adhere to the shorelines of the Mississippi River, and the remaining 24.0% would remain in the river, below the ice, at the end of the 24 hour simulation. If left unmitigated, it is expected that the remaining CLWB would continue downstream, oiling shorelines until all of the oil was removed from the water.

Relative to the average and high river flow conditions, the CLWB is predicted to travel approximately the same distance downstream before all of the oil had adhered to the marsh or grass shoreline.

#### 6.1.1.2 Bakken Crude Scenarios

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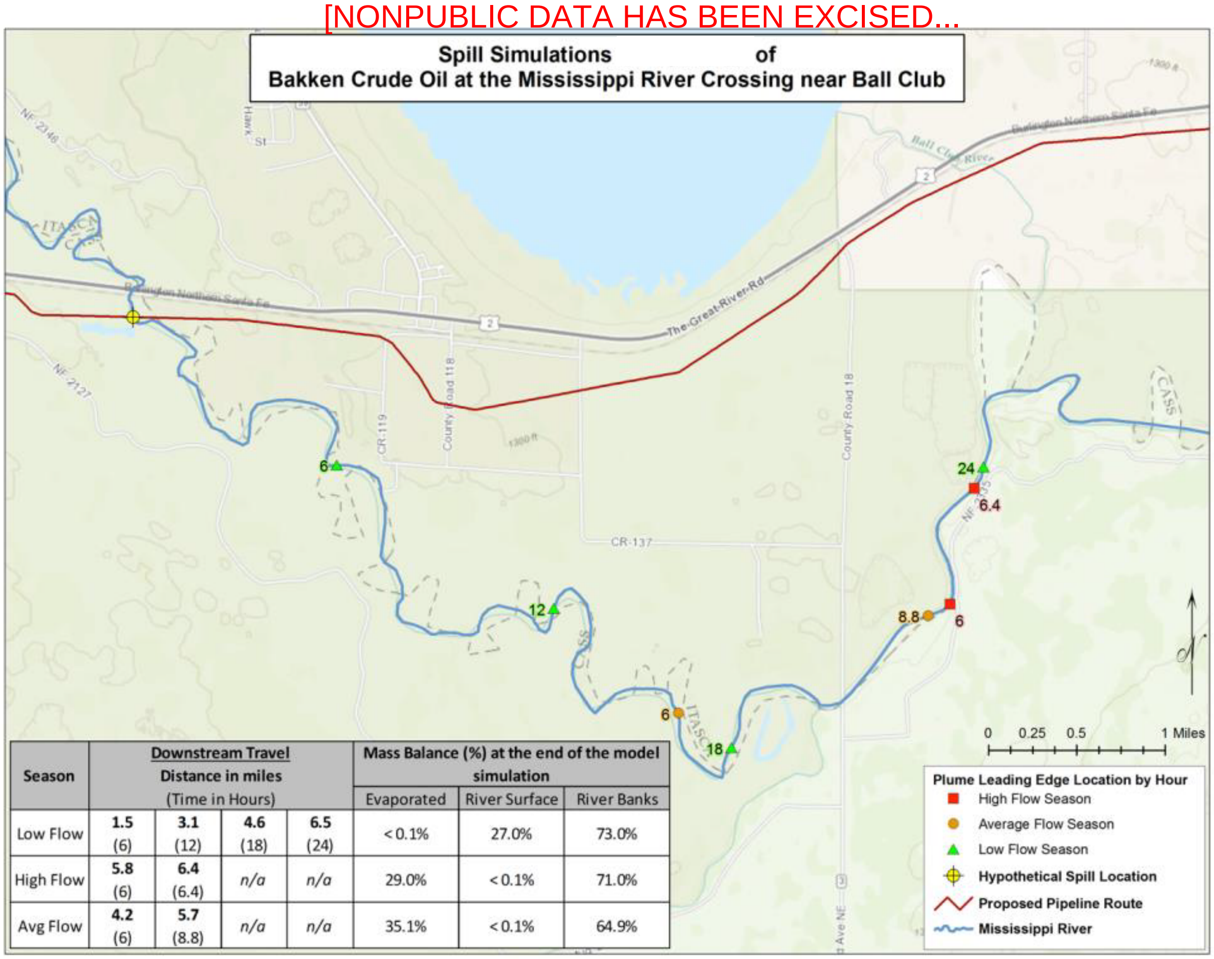


| Season | Downstream Travel Distance in miles (Time in Hours) | | | | Mass Balance (%) at the end of the model simulation | | |
|---|---|---|---|---|---|---|---|
| | | | | | Evaporated | River Surface | River Banks |
| Low Flow | 1.5 (6) | 3.1 (12) | 4.6 (18) | 6.5 (24) | < 0.1% | 27.0% | 73.0% |
| High Flow | 5.8 (6) | 6.4 (6.4) | n/a | n/a | 29.0% | < 0.1% | 71.0% |
| Avg Flow | 4.2 (6) | 5.7 (8.8) | n/a | n/a | 35.1% | < 0.1% | 64.9% |

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**Figure 6-5 Predicted Downstream Transport of Bakken Crude at the Mississippi River at Ball Club Release Location With Marsh Shoreline**

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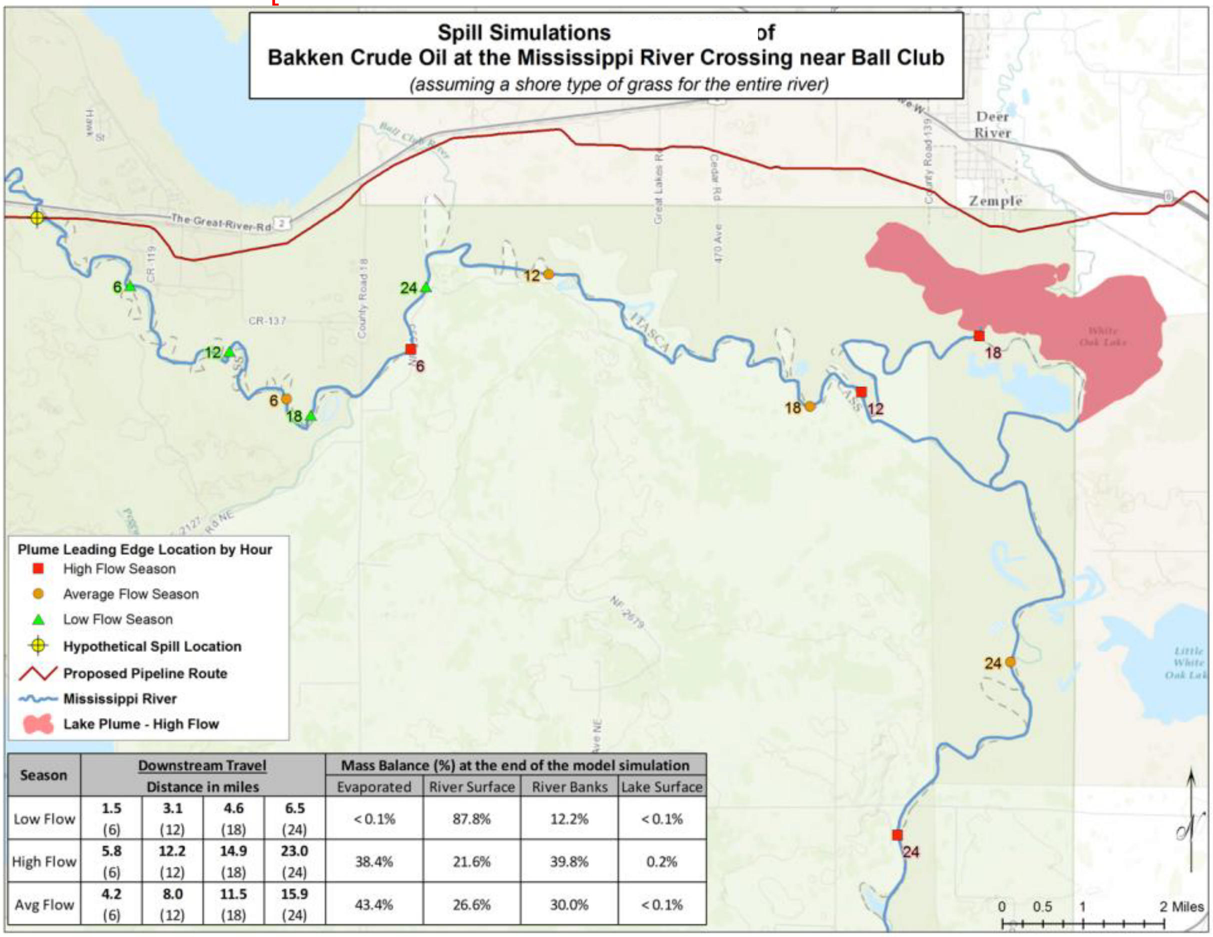


| Season | Downstream Travel Distance in miles | | | | Mass Balance (%) at the end of the model simulation | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Evaporated | River Surface | River Banks | Lake Surface |
| Low Flow | 1.5 (6) | 3.1 (12) | 4.6 (18) | 6.5 (24) | < 0.1% | 87.8% | 12.2% | < 0.1% |
| High Flow | 5.8 (6) | 12.2 (12) | 14.9 (18) | 23.0 (24) | 38.4% | 21.6% | 39.8% | 0.2% |
| Avg Flow | 4.2 (6) | 8.0 (12) | 11.5 (18) | 15.9 (24) | 43.4% | 26.6% | 30.0% | < 0.1% |

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**Figure 6-6 Predicted Downstream Transport of Bakken Crude Oil at the Mississippi River at Ball Club Release Location with Assumed Grass Shoreline**

### 6.1.2.1.4 Trajectory and Fate Results for High Flow (Spring)

Under high river flow for marsh shorelines, Bakken crude was predicted to travel a total of approximately 6.4 miles (10.3 km) downstream, within 6.4 hours of the release. At this time, the model predicts that all of the oil would have been lost from the water surface; approximately 71.0% of the Bakken crude was predicted to adhere to the shorelines of the Mississippi River, and 29.0% would have evaporated into the atmosphere.

Under high river flow for the grass shorelines, Bakken crude was predicted to travel a total of approximately 23.0 miles (37.0 km) downstream, over the full 24 hour modeled period. The Bakken crude was predicted to be transported down the Mississippi River for approximately 14.9 miles (24.0 km), before reaching White Oak Lake. Bakken was allowed to spread over the surface of the White Oak Lake (for total area of 1.47 $miles^2$) to a thickness of 0.001 mm. The remaining surface oil was then able to continue downstream another 6.9 miles (11.1 km). Approximately 39.8% of the Bakken crude was predicted to oil the shorelines of the Mississippi River, 0.2% would have spread over the surface of White Oak Lake, 38.4% would have evaporated into the atmosphere, and 21.6% to remain on the river surface at the end of the 24 hour simulation. If left unmitigated, the remaining Bakken crude on the river surface after 24 hours was expected to continue downstream, with weathering and oiling of shorelines continuing until all the oil was removed from the water surface.

The Bakken crude was predicted to result in oiling of marsh shorelines that extended 5.05 miles (8.13 km) further downstream than the CLSB scenario under high flow river conditions, which only oiled 1.35 miles (2.17 km). For grass shorelines, the Bakken crude was predicted to result in oiling 14.9 miles (24.0 km) further downstream then the CLSB (8.1 miles) under high flow river conditions.

The difference in the extent of downstream transport was primarily the result of the difference in the shoreline oil retention between the two oils. Because of its higher viscosity and other parameters, CLSB is expected to strand upon shorelines more thickly (Table 5-8) than Bakken crude oil, resulting in larger amounts of CLSB along the same length of shore. In contrast, the same amount of Bakken crude would oil longer lengths of shoreline with a reduced thickness. While this result is logical, it is based on the assumption of 100% shoreline oiling coverage (i.e., all shoreline up to that point is oiled to its maximum holding capacity) as oil made its way downstream. In the event of an actual release, the downstream extents of CLSB and Bakken crude may be more similar, and the effects of CLSB may extend farther downstream than presented, with patchy coverage.

Bakken crude was predicted to evaporate much more completely (29% for marsh and 38.4% for grass) than the CLSB (0.3% for marsh and 4.8% for grass). This was partially due to the lighter nature and higher volatile content of the Bakken crude, when compared to CLSB. Additionally, the Bakken crude was predicted to oil further downstream for marsh shorelines and spread over White Oak Lake for grass shorelines, which took more time reach and also resulted in a larger surface area over which the oil could evaporate.

#### 6.1.2.1.5 Trajectory and Fate Results for Average Flow (Summer-Fall)

Under average river flow conditions (August), Bakken crude was predicted to be transported approximately 5.7 miles (9.17 km) downstream, within 8.8 hours of the release for the marsh shorelines and approximately 15.9 miles (25.6 km) downstream, over the full 24-hour modeled period for the grass shorelines. At this time no Bakken crude was predicted to remain on the river surface; approximately 64.9% of the Bakken crude was predicted to adhere to the shorelines of the Mississippi River, and 35.1% would have evaporated into the atmosphere.

Under average river flow (August) and grass shorelines, Bakken crude was predicted to be transported approximately 15.9 miles (25.6 km) downstream, over the full 24-hour modeled period. The Bakken crude was predicted to be transported down the Mississippi River, past White

Oak Lake and stop just west of Little White Oak Lake. Approximately 30.0% of the Bakken crude was predicted to adhere to the shorelines of the Mississippi River, 43.4% to have evaporated into the atmosphere, and 26.6% to remain on the river surface at the end of the 24 hour simulation. If left unmitigated, the remaining Bakken crude on the river surface after 24 hours would be expected to continue downstream, with weathering and oiling of shorelines continuing until all the oil was removed from the water surface.

The Bakken crude for marsh shorelines was predicted to be transported 0.7 miles (1.13 km) less under average river flow conditions, when compared to the high river flow conditions. For grass shorelines Bakken crude was predicted to be transported 7.1 miles (11.4 km) less under average river flow conditions, when compared to the high river flow conditions. The lower river velocities of the average river flow condition, compared to the high river flow, transported the oil over less distance. The Bakken crude evaporated more completely under the average flow condition (35.1% for marsh and 43.4% for grass) when compared to the high river flow conditions (29.0% for marsh and 38.4% for grass). This difference is mainly due to the longer length of the simulation, for the average river flow conditions, as opposed to the high river flow conditions, that allowed for more time to evaporate before the end of the simulation. Additionally, the higher air temperatures during August enhanced evaporation.

When compared to the CLSB under average river flow conditions for marsh shorelines, the Bakken crude was transported 4.4 miles (7.08 km) further downstream (Bakken crude 5.7 miles, CLSB 1.31 miles). When compared to the CLSB under average river flow conditions for grass shorelines, the Bakken crude was transported 7.9 miles (12.7 km) further downstream before reaching the 24 hour model limit, with 26.6% of the Bakken crude still remaining on the river surface at the end of the simulation. The Bakken crude was able to travel further downstream than the CLSB scenario under the same river velocities due to the differences in the viscosity of the two oils and the greater adherence of CLSB to shorelines than Bakken Crude. For grass shorelines, the Bakken crude was able to travel further downstream, under the same river velocities due to the lower shoreline oil retention for the Bakken, when compared to the CLSB.

#### 6.1.2.1.6 Trajectory and Fate Results for Low Flow (Winter)

Under low river flow (March) conditions, where oil was released underwater with 100% ice cover, Bakken crude was predicted to be transported approximately 6.5 miles (10.5 km) downstream, over the full 24-hour modeled period. Approximately 73.0% of the Bakken crude was predicted to oil the shorelines of the Mississippi River, and the remaining 27.0% would remain in the river below the ice at the end of the 24 hour simulation for marsh shorelines. Approximately 12.2% of the Bakken crude for grass shorelines was predicted to adhere to the shorelines of the Mississippi River, and the remaining 87.8% would remain in the river, below the ice at the end of the 24 hour simulation. If left unmitigated, it is expected that the remaining Bakken crude in the river after 24 hours would continue to move downstream and oil shorelines, until all the oil was removed from the water surface (i.e., under the ice).

Relative to the high river flow conditions, the Bakken crude for the marsh shorelines was predicted to be transported 0.1 miles (0.16 km) further downstream. Relative to the average river flow conditions, the Bakken crude was predicted to be transported 0.8 miles (1.29 km) further downstream. Under low river flow conditions the shore types were conservatively assumed to be the same as the average flow condition. Retention of oil under ice conditions may be lower or higher in reality, but is expected to be variable due to irregularities in the ice and the ice/shoreline interface Rather than having an extent controlled by the loss of all surface oil, this scenario reached the 24 hour modeled time limit.

Relative to the high river flow condition, the Bakken crude for grass shorelines was predicted to be transported 16.5 miles (26.6 km) less downstream. Relative to the average river flow condition, the Bakken crude was predicted to be transported 9.4 miles (15.1 km) less downstream. Due to the winter conditions, the oil was transported at a slower velocity and therefore traveled a shorter distance then than the average and high river flow conditions. Because the Bakken crude was released below the ice of the river, no oil is lost to the atmosphere through evaporating. This further extended the potential downstream transport. With the oil being transported at a slower velocity, the 24 hour modeled time limit was reached before oil was lost to shorelines or evaporation. Additionally, with the Bakken crude below the ice of the river, no oil is lost to the atmosphere through evaporating.

The Bakken crude for grass shorelines under low flow river conditions was transported 5.15 miles (8.29 km) further downstream than the CLWB for the same conditions. The Bakken crude was able to travel further downstream, under the same river velocities due to the lower shoreline oil retention for Bakken, compared to CLWB. For this reason 27% more oil can be transported downstream under the ice.

### 6.1.3 Unmitigated Hypothetical Release Case 3—Sandy River

The Sandy River is located approximately 1 mile (1.6 km) north of McGregor, Minnesota. The pipeline route crosses the Sandy River approximately 3.3 miles (5.3 km) north east of McGregor, and 0.2 miles (0.32 km) north of Highway 210. The Sandy River flows to the west for approximately 6 miles (9.7 km) before reaching Steamboat Lake and Davis Lake. This stretch of the river is fairly narrow (approximately 40 ft wide, or 12.2 m, on average), and travels through several marshy areas. From there, the Sandy River flows to the north an additional 3.5 miles (5.6 km) where it enters Flowage Lake. The Sandy River for this stretch can average 53 ft (16.2 m) wide during low river flow conditions, and average 270 ft (82.3 m) wide during high flow conditions.

The seasonal extent of Steamboat, Davis, and Flowage Lakes also vary from low to high river flow conditions. During low and average river flow conditions, the area of Steamboat Lake is 0.036 miles$^2$ (0.093 km$^2$), and during high river flow conditions the area is typically 0.065 miles$^2$ (0.168 km$^2$). During low and average river flow conditions, the area of Davis Lake is 0.07 miles$^2$ (0.181 km$^2$), and during high river flow conditions the area is typically 0.117 miles$^2$ (0.303 km$^2$). During low river flow conditions, Sandy River does not join Flowage Lake until approximately

7 miles (11.3 km) north of Davis Lake. Under high river flow conditions, Sandy River transitions to Flowage Lake after approximately 3.5 miles (5.63 km). Expected environmental and flow conditions throughout the year for Sandy River are provided in Table 5-6.

Maps depicting the predicted downstream trajectory and mass balance tables of CLB (Figure 6-7) and Bakken Crude (Figure 6-8) seasonal scenarios for the Sandy River release site are provided at the beginning of the following subsections.

### 6.1.3.1 Cold Lake Blend Scenarios

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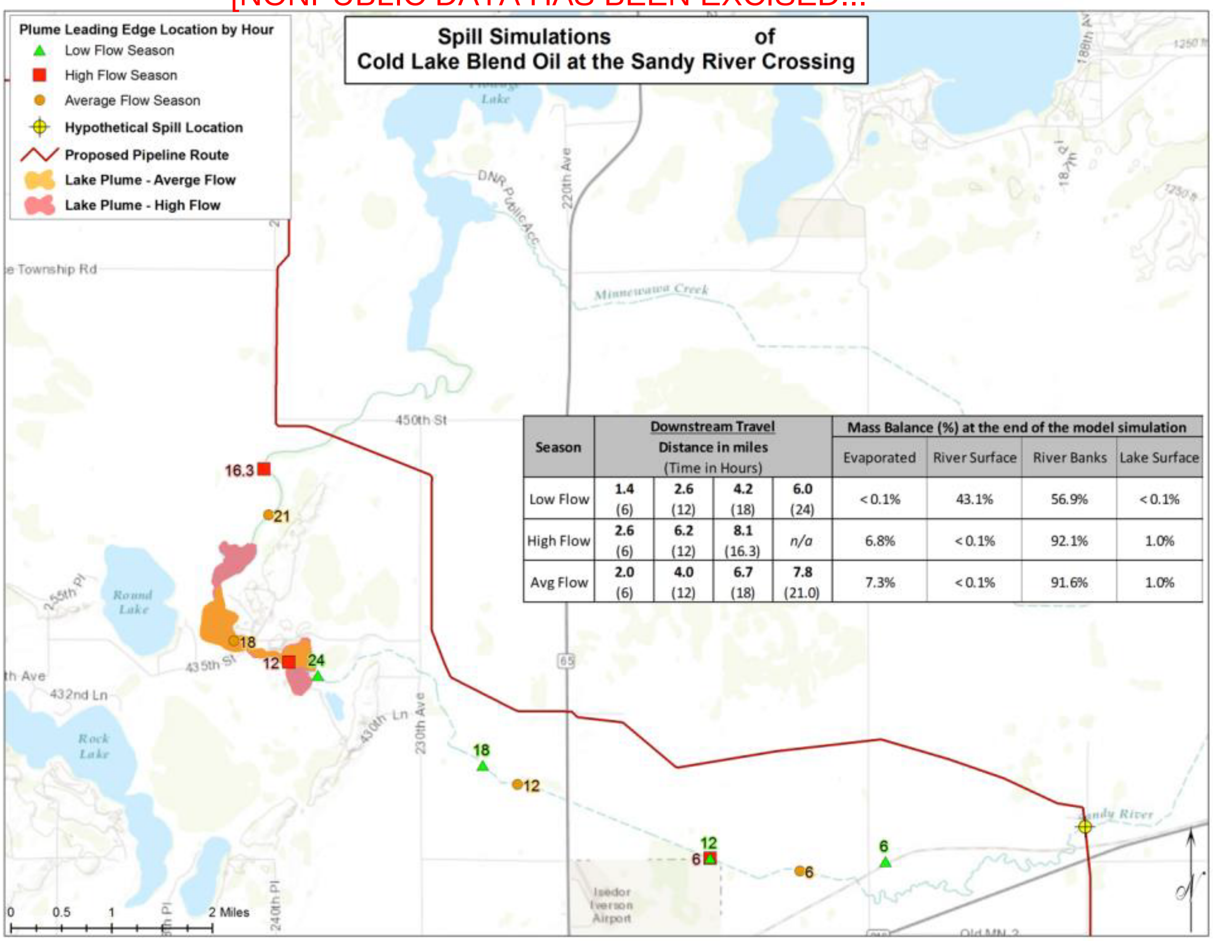


| Season | Downstream Travel Distance in miles (Time in Hours) | | | | Mass Balance (%) at the end of the model simulation | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Evaporated | River Surface | River Banks | Lake Surface |
| Low Flow | 1.4 (6) | 2.6 (12) | 4.2 (18) | 6.0 (24) | < 0.1% | 43.1% | 56.9% | < 0.1% |
| High Flow | 2.6 (6) | 6.2 (12) | 8.1 (16.3) | n/a | 6.8% | < 0.1% | 92.1% | 1.0% |
| Avg Flow | 2.0 (6) | 4.0 (12) | 6.7 (18) | 7.8 (21.0) | 7.3% | < 0.1% | 91.6% | 1.0% |

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**Figure 6-7 Predicted Downstream Transport of CLB Oil at the Sandy River Release Location**

#### 6.1.3.1.1 Trajectory and Fate Results for High River Flow (Spring)

Flow rates for Sandy River during the spring resulted in peak average river velocities during April ranging between 0.35 and 0.89 mph (0.16 and 0.4 m/s). The OILMAP Land model transported oil downstream with these velocities to a point where all oil had evaporated and/or adhered to the shoreline.

Under high river flow conditions, CLSB was predicted to travel a total of approximately 8.1 miles (13.0 km) downstream, within 16.3 hours of the release. At this time, there was no CLSB on the water surface, as the model had predicted that the oil would have been lost completely from the water surface by this point in time. The CLSB was predicted to be transported down the Sandy River, then spread covering the surfaces of both Steamboat Lake and Davis Lake (for a total area of 0.182 miles$^2$ or 0.471 km$^2$), and then continue another 0.7 miles (1.12 km) down Sandy River. Approximately 92.1% of the CLSB was predicted to oil the shorelines of Sandy River, 1.0% to have spread over the surface of Steamboat and Davis Lakes, and 6.8% to have evaporated into the atmosphere.

#### 6.1.3.1.2 Trajectory and Fate Results for Average River Flow (Summer-Fall)

Flow rates for Sandy River during the summer and fall result in average river velocities during July ranging between 0.27 and 0.60 mph (0.12 and 0.27 m/s). These river velocities were approximately 70% of those in the high flow conditions.

Under average river flow conditions, CLSB was predicted to travel a total of 7.8 miles (12.6 km) downstream, within 21 hours of the release. At this time, there was no CLSB on the water surface, as the model predicted that the oil would have been lost from the water surface by this point in time. The CLSB was predicted to be transported down the Sandy River, then spread covering the surfaces of both Steamboat Lake and Davis Lake (for total area of 0.106 miles$^2$ or 0.275 km$^2$), and then continue another 0.7 miles (1.12 km) in Sandy River. Approximately 91.6% of the CLSB was predicted to adhere to the shorelines of Sandy River, 1.0% to have spread over the surface of Steamboat and Davis Lakes, and 7.3% to have evaporated into the atmosphere.

Relative to the high river flow condition, the CLSB was predicted to be transported less distance downstream (0.3 miles or 0.48 km). This was predominantly due to the length of the scenario which allowed for more evaporation due to the longer time required for the CLSB to move down stream due to the lower stream velocities. Under both high and average flow conditions, oil spread over the entire surface of both Davis and Steamboat Lakes, however the area of the lakes was smaller in the average flow condition. The slightly reduced area of the lakes only accounts for approximately 0.01% difference in the volume remaining on the lakes.

#### 6.1.3.1.3 Trajectory and Fate Results for Low River Flow (Winter)

Under winter conditions (March), it was assumed that the Sandy River and all lakes would be frozen over completely (100% coverage of ice). It was assumed that CLWB would be released directly into the river from the pipeline under the riverbed, and that all oil would remain trapped under the ice. The ice cover would prevent any evaporation to the atmosphere. Flow rates for

Sandy River during these winter conditions resulted in minimum river velocities during March ranging between 0.20 and 0.31 mph (0.09 and 0.14 m/s). These river velocities were approximately 50% of that of the high flow condition.

Under low river flow conditions, CLWB was predicted to be transported a total of 6.0 miles (9.7 km) downstream, over the full 24-hour modeled period. The CLWB was predicted to stop just before reaching Steamboat Lake. Approximately 43.1% of the CLWB was predicted to remain in the river below the ice, and the remaining 56.9% would have oiled the shorelines of Sandy River. Any CLWB remaining in the river after 24 hours would continue to move downstream, oiling shorelines and Steamboat Lake, if not intercepted by emergency response teams.

Relative to the high and average river flow conditions, the CLWB was predicted to be transported over a shorter distance, stopping before reaching Steamboat Lake. This was due to the reduced river velocities under the low river flow conditions.

### 6.1.3.2 Bakken Crude Scenarios

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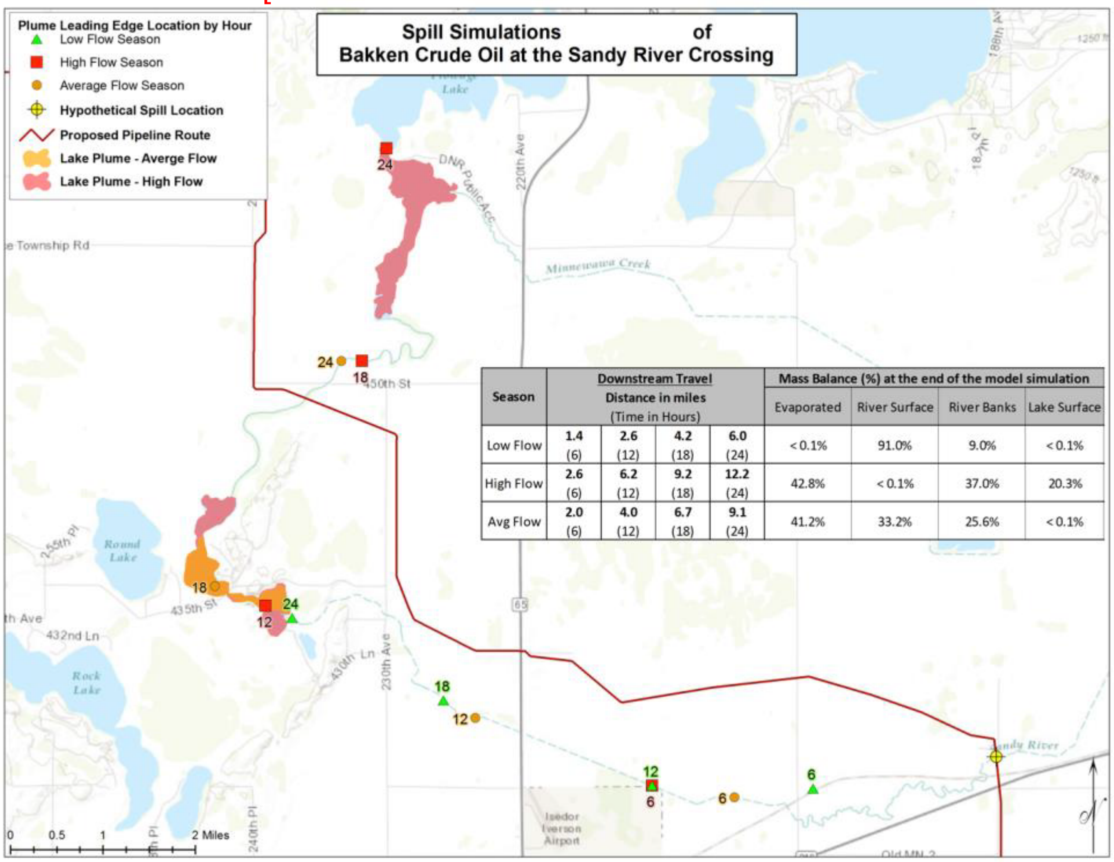


| Season | Downstream Travel Distance in miles (Time in Hours) | | | | Mass Balance (%) at the end of the model simulation | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Evaporated | River Surface | River Banks | Lake Surface |
| Low Flow | **1.4** (6) | **2.6** (12) | **4.2** (18) | **6.0** (24) | < 0.1% | 91.0% | 9.0% | < 0.1% |
| High Flow | **2.6** (6) | **6.2** (12) | **9.2** (18) | **12.2** (24) | 42.8% | < 0.1% | 37.0% | 20.3% |
| Avg Flow | **2.0** (6) | **4.0** (12) | **6.7** (18) | **9.1** (24) | 41.2% | 33.2% | 25.6% | < 0.1% |

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**Figure 6-8 Predicted Downstream Transport of Bakken Crude Oil at the Sandy River Release Location**

#### 6.1.3.2.1 Trajectory and Fate Results for High River Flow (Spring)

Under high river flow (April), Bakken crude was predicted to be transported approximately 12.2 miles (19.6 km) downstream, over the full 24-hour modeled period. The Bakken crude was predicted to be transported down the Sandy River, and then spread covering the surfaces of both Steamboat Lake and Davis Lake (for total area of 0.182 miles$^2$ or 0.471 km$^2$). It was then able to continue another 3.5 miles (5.6 km) in Sandy River, before reaching Flowage Lake. Oil was predicted to spread over the surface of Flowage Lake covering an area of approximately 0.22 miles$^2$ or 0.570 km$^2$. Approximately 37.0% of the Bakken crude was predicted to adhere to the shorelines of Sandy River, 20.3% would have spread over the surface of Steamboat, Davis, and Flowage Lakes, and 42.8% would have evaporated into the atmosphere.

OILMAP Land spreads the mass of oil entering the lake radially upon the lake surface until the specified minimum slick thickness is reached, or the simulation duration is reached. This modeling tool is used to characterize regions of potential effects on relatively short time scales (i.e., hours to days). After 24 hours, the Bakken crude oil did not yet spread in Flowage Lake to the defined minimum thickness of 0.001 mm (Table 5-9). If left unmitigated, it is expected that this spreading would continue to occur after 24 hours, covering a larger surface area of the lake.

The Bakken crude was predicted to result in oiling 4.1 miles (6.6 km) further downstream, then the CLSB (8.1 miles or 13.0 km) under high flow river conditions. The difference in the extent of downstream transport was primarily the result of the differences in the shoreline and lake surface oil retention between the two oil types. Because of its higher viscosity and other parameters, CLSB would be expected to strand upon shorelines and spread on a lake surface more thickly than Bakken crude oil, resulting in larger amounts of CLSB along the same area. In contrast, the same amount of Bakken crude would oil longer lengths of shoreline and more lake surface, but with a reduced thickness. While this result is logical, it is based upon the assumption of 100% shoreline oiling coverage (i.e., all shoreline up to that point is oiled to its maximum holding capacity) as oil makes its way downstream, and the assumption that oil would spread evenly within lake. In the event of an actual release, the downstream extents of CLSB and Bakken crude may be more similar, and the effects of CLSB may extend farther downstream than presented, with patchy coverage.

Due mostly to the lighter nature and higher volatile content, Bakken crude was predicted to evaporate over 6 times more (42.8%) than the CLSB (6.8%). The Bakken crude was predicted to oil further downstream, which took more time and resulted in a larger surface area over which the oil would evaporate.

###### 6.1.3.2.2 Trajectory and Fate Results for Average River Flow (Summer-Fall)

Under average river flow (July), Bakken crude was predicted to be transported approximately 9.1 miles (14.6 km) downstream, over the full 24-hour modeled period. The Bakken crude was predicted to be transported down the Sandy River, and then spread covering the surfaces of both Steamboat Lake and Davis Lake (for total area of 0.106 miles$^2$ or 0.274 km$^2$). It was then able to continue another 2.05 miles (3.3 km) down Sandy River. Approximately 25.6% of the Bakken crude was predicted to adhere to the shorelines of Sandy River, less than 0.1% would have spread over the surface of Steamboat and Davis Lakes, 41.2% would have evaporated into the atmosphere, and 33.2% would remain on the river surface at the end of the 24 hour simulation. If left unmitigated, it is expected that the remaining Bakken crude on the river surface would continue downstream, with weathering and oiling of shorelines continuing until all the oil is removed from the water surface.

The Bakken crude was predicted to be transported 3.1 miles (5.0 km) less when compared to the high river flow conditions. The lower river velocities of the average river flow condition prevented the oil from being transported as far downstream within the 24 hour simulation period. The Bakken crude evaporated less in the average flow condition (41.2 %) than the high flow condition (42.8%) due to the reduced surface area oiled. This was a result of smaller area of Steamboat and Davis Lakes, and the reduced downstream transport.

When compared to the CLSB under average river flow conditions, the Bakken crude was transported 3 miles (4.8 km) further downstream before reaching the 24 hour model limit. Approximately 33.2% of the Bakken crude was still remaining on the river surface at the end of the simulation. The Bakken crude was able to travel further downstream, under the same river velocities due to the differences in the shoreline and lake surface oil retention between the two oil types.

#### 6.1.3.2.3 Trajectory and Fate Results for Low River Flow (Winter)

Under low river flow conditions (March), released under 100% ice cover, Bakken crude was predicted to be transported a total of 6.0 miles (9.7 km) downstream, over the full 24-hour modeled period to a point just before Steamboat Lake. Approximately 91.0% of the Bakken crude was predicted to remain in the river below the ice, and the remaining 9.0% to adhere to the shorelines of Sandy River. If not intercepted by emergency response teams, the remaining Bakken crude in the river after 24 hours would be expected to move downstream, oiling shorelines and Steamboat Lake.

Relative to the high river flow conditions, the Bakken crude under low river flow was predicted to be transported 6.2 miles (10.0 km) less downstream. Relative to the average river flow condition, the Bakken crude was predicted to be transported 3.1 miles (5.0 km) less downstream. Under low river flow conditions, the shore types were conservatively assumed to be the same as the average flow condition. Retention of oil under ice conditions may be lower or higher in reality, but is expected to be variable due to irregularities in the ice and the ice/shoreline interface With the oil being transported at a slower speed, the 24 hour modeled time limit was reached at a distance that was shorter than that of the average river flow condition with oil remaining on the surface. With the Bakken crude below the ice of the river, no oil was allowed to evaporate from the surface.

When compared to the CLWB under low river flow conditions, 47.9% more of the Bakken crude remained in the river and under the ice. This was due to the lower shoreline oil retention for Bakken, relative to the CLWB.

### 6.1.4 Unmitigated Hypothetical Release Case 4—Shell River to Twin Lakes

Shell River is located approximately 7.4 miles (11.9 km) south of Park Rapids, Minnesota. The pipeline route crosses the Shell River and Crow Wing River at four locations. The crossing used for this release location is the eastern crossing of the Shell River located 0.6 miles (0.97 km) north of Twin Lakes and 0.75 miles (1.21 km) southeast of Arbor Road. At this location the Shell River flows directly south where it reaches the Twin Lakes (Upper Twin Lake and Lower Twin Lake). This section of the Shell River passes through a large marshy area, north of the lakes and is approximately 95 ft (29 m) wide. The Twin Lakes cover a total area of approximately 0.75 miles$^2$ (1.94 km$^2$). The outlet from Lower Twin Lake is located at the northeastern edge of the lake. From there Shell River flows to the west for approximately 9 miles (14.5) before flowing into the Crow Wing River. This stretch of river has an average width of 223 ft (68 m). From there, the Crow Wing