ENBRIDGE LINE 5 WISCONSIN SEGMENT RELOCATION PROJECT
22-P-216493

Construction Assessment: Sediment Discharge Modeling Report

Enbridge Line 5
Segment Relocation Project
Wisconsin

22-P-216493
SEDIMENT DISCHARGE MODELING REPORT

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Preface

RPS Group PLC (RPS) was retained by Enbridge Energy, Limited Partnership (Enbridge) to prepare a construction assessment that assessed the potential for effects following hypothetical releases of sediment into waterways associated with the Line 5 Wisconsin Segment Relocation Project (L5WSRP).

Purpose

The purpose of this Sediment Discharge Modeling Report is to provide quantitative information that contextualizes the range of potential effects to watercourses associated with sediment disturbance following the L5WSRP construction. A sediment dispersion analysis using computational dispersion modeling tools was used to quantify and bound the range of potential concentrations of sediment within the water column, the downstream timing and extent, and the depositional footprint of sediments that may be caused by both planned and accidental discharges of sediment due to installation techniques of the relocated pipeline, as construction activities cross the range of water bodies within the Project Area. The pipeline installation methods considered include dry trenching methods in smaller watercourses along the pipeline routes, as well as the potential for an inadvertent return into large watercourse crossings that may require Horizontal Directional Drilling (HDD). The occurrence of an inadvertent return is unlikely given the planned drilling pressures, but has still been modeled to understand the potential consequences of such a release. These analyses bound the expected and accidental events and types of consequences that could result in a range of magnitudes and extents of potential effects during pipeline construction.

Information from this modeling will be used to bound the potential range of consequences that are predicted across the region under a range of environmental conditions. Results can be used to understand the potential for effects that may occur at other locations with similar features among and across the proposed and alternative routes.

This material was prepared to supplement the draft Environmental Impact Statement (DEIS), issued December 2021 by the Wisconsin Department of Natural Resources.

Direction on Technical Work

RPS was retained by Enbridge. RPS was responsible for identifying the preferred approach and range of hypothetical scenarios and for conducting the modeling and analysis of results. RPS undertook the technical work under its own direction.

A presentation outlining the technical work associated with this preferred approach was made to the Wisconsin Department of Natural Resources (WDNR) and the United States Army Corps of Engineers (USACE) prior to the work being undertaken. RPS then prepared this assessment, which was again presented to WDNR, USACE, the Pipeline and Hazardous Material Safety Administration (PHMSA), and the United States EPA (USEPA). Prior to this meeting, comments on the draft assessment were received by Enbridge. In response to these comments, revisions to the draft assessment were undertaken by RPS, but only where RPS deemed the changes to be appropriate. The work's technical conclusions were unchanged by the revisions accepted. A final report was prepared by RPS for final submission to WDNR and USACE.

Funding

Funding for the work undertaken by RPS was provided by Enbridge.

Authorship

This Construction Assessment was prepared by RPS. The Technical Leads for the report were as follows:

- Matt Horn, Ph.D., RPS
- Melissa Gloekler, Ph.D., RPS
- Hilary Robinson, P.E., RPS

Declaration

As the Technical Leads for the Construction Assessment (Sediment Discharge Modeling Report) associated with the Line 5 Wisconsin Segment Relocation Project, we verify that we are responsible for leading and managing the preparation of the modeling assessment and the report as described above. All technical analysis and all conclusions reflect our work and opinions. Modifications in response to verbal or written comments have not modified the technical aspects and results of our work or our conclusions.

Matt Horn, Ph.D., RPS

Melissa Gloekler, Ph.D., RPS

Hilary Robinson, P.E., RPS

Executive Summary

Enbridge Energy, Limited Partnership (Enbridge) has proposed the Line 5 Wisconsin Segment Relocation Project (L5WSRP) to relocate the existing Line 5 pipeline (Line 5) around the Bad River Reservation ("the Reservation") in northern Wisconsin. This report (the "Sediment Discharge Modeling Report") was prepared by RPS to model sediment releases resulting from pipe installation methods proposed for the L5WSRP Relocation. The modeling and results presented herein support a Construction Assessment.

Sediment releases were modeled spanning a range of representative locations, environmental conditions, and types and volumes of release. Together, these modeling assessments convey an understanding of the range of potential effects from the Relocation's installation.

KEY POINTS:

Sedimentation Impacts from Pipe Installation Are Low, Localized, and Limited in Time.

For trenched methods at water crossings, the proposed installation activities would be expected to have a lesser magnitude and more brief effect on Total Suspended Solids (TSS) in the water column than storm-related events. As compared to storm-related events that can cause TSS values to exceed hundreds to thousands of mg/L over periods of time that are longer than theses installation periods, trenched crossings would be expected to have TSS concentrations near the installation site in the low hundreds of mg/L, which would decrease below 19 mg/L by approximately 1,000 meters downstream of the crossing and last only ~4-10 hours per construction phase.

Successful horizontal directional drill (HDD) methods will have no sedimentation impacts; however, TSS concentrations resulting from hypothetical inadvertent returns were modeled. TSS concentrations near the HDD release site would be expected to be high (more than 20,000 mg/L), but would decrease to 10-300 mg/L at a point 500-1,000 meters downstream. No modeling scenario (for trenched or HDD crossings) would result in TSS levels exceeding 19 mg/L at farther downstream locations, including any portion of the Reservation.

OVERVIEW OF THE ANALYSIS

RPS used the SSFATE model to assess numerous hypothetical release scenarios during the construction process. SSFATE is a computational sediment dispersion modeling tool that was developed jointly by RPS (previously ASA) and the U.S. Army Corps of Engineers to simulate sediment resuspension and deposition. This model has been used extensively in the United States and internationally to assess the potential impacts of the release of sediments.

- Sediment dispersion modeling of 18 hypothetical release scenarios was performed in SSFATE to assess TSS within the water column from 1) installation in small-to-medium watercourses for open trench methods and 2) installation in large watercourses for potential inadvertent returns resulting from a failed HDD under a water crossing. An inadvertent return would involve releases of bentonite drilling fluid, frequently referred to as a "frac out." This modeling assessed the magnitude and timing of potential water column concentrations of TSS on top of background values (referred to as "in exceedance of") and the depositional footprint of sediments that may be caused by discharged sediment from installation of the relocated pipeline as it crosses the range of water bodies within the Project Area.

  - While dry trenching will result in sediment discharge into the water column, the occurrence of an inadvertent return is unlikely (i.e., may never occur), given the planned drilling pressures.
  - The background concentration of TSS within a watercourse can naturally vary greatly (several orders of magnitude) over the course of a year. Storm-related events can cause TSS to exceed hundreds to several thousands of mg/L over periods of time that are longer than planned installation periods.
  - While WDNR holds a water quality standard of 40 mg/L for TSS associated with construction dewatering activities, RPS calculated a more conservative (i.e., more protective) representative threshold of 19 mg/L TSS (based upon the measured relationship between turbidity and TSS within the Bad River) that correlates to the Bad River Band's water quality standard for turbidity within the exterior boundaries of the Reservation.
  - The downstream extent, duration, and magnitude of elevated TSS concentrations and resulting deposition were assessed for a matrix of 18 scenarios, which captured the variability within watercourse sizes, river flow conditions, and sediment characteristics (i.e., particle or grain sizes). The TSS plumes were expected to be temporary in any given location and would therefore not pose a permanent impact.
- Trenched installations:
  - Crossings in small and medium watercourses were expected to be completed within 20-32 hours, respectively, and would actively release sediment for a total of 4 hours (small) and 10 hours (medium). Associated increases in TSS concentrations would generally follow the same timing of the installation and removal activities, quickly attenuating after the sediment disturbances ceased.
  - The sediment loads in the watercourses produced initially larger TSS concentrations near the installation site (up to 132 mg/L) due to the conservatively large assumed amount of sediment that was resuspended and the shallow watercourse depths (1-3 ft deep).
  - TSS concentrations predicted downstream of the trenched installations (e.g., 500-1,000 m) were on the order of <1 to 30 mg/L for the small watercourse and <1 to 10 mg/L for the medium watercourse. The levels at 1,000 m distance were consistently below typical background TSS conditions in the water column for the anticipated construction period of June-August. The proposed installation activities would be expected to have a lesser magnitude and more brief effect on TSS in the water column than storm-related events, which would be expected to have a greater and more enduring effects on TSS in the water column than the proposed installation activities.
  - By 1,000 m (or 1 km) downstream, the TSS predictions were below the more conservative calculated threshold of 19 mg/L. This threshold exceedance lasted on the order of tens of minutes to hours at any specific location over the course of approximately one day as the TSS was transported downstream.
  - TSS concentrations were predicted to be well below a threshold of 19 mg/L for all watercourses represented by the simulated small and medium watercourse scenarios by the time any suspended sediments reached the Reservation boundary.

- HDD installations:
  - No sedimentation will result from a successful HDD.
  - For hypothetical inadvertent returns into a large watercourse:
    - The discharge into the watercourse produced initially large TSS concentrations near the release site (more than 20,000 mg/L) due to the large volume of drilling fluid (bentonite) that was released in a relatively short period of time. The largest concentrations were predicted for the larger release volume (Final Ream Pass) scenario under low river flow conditions, where dilution and dispersion would be the lowest.
    - TSS concentrations predicted at distances 500-1,000 m downstream were on the order of 10-300 mg/L, which is smaller or of similar magnitude to background conditions and those typically caused by storm-related events.
    - By 2,000 m (or 2 km) downstream, TSS predictions for all scenarios were below the more conservative calculated threshold of 19 mg/L. This threshold exceedance lasted on the order of hours at any specific location over the course of one to two days as the TSS was transported downstream.
    - Nearly all of the discharged bentonite eventually settled within the model domain (the Bad River), regardless of river flow rate. The greatest deposition occurred near the release location, as well as toward the center of the river channel. For the Final Ream Pass scenarios with greatest sediment loads, deposition above the thickness thresholds extended slightly further and had greater extent than the Pilot Hole scenarios. The distance and area covered by deposition above 5-10 mm thickness was greatest for the low flow scenario, particularly near the simulated release location, where deposition at this level extended up to 40 m downstream. While the model predicted very large areas of deposition less than the 0.1 mm reporting threshold, no deposition above that threshold was predicted past 400 m downstream, well upstream of the Reservation boundary.
- Because the Proposed Route crosses the various watercourses in the Project Area at distances between 2.1 km and 23.9 km (1.3 and 14.9 miles) upstream of the Reservation boundary, TSS concentrations were predicted to be below the more conservative calculated threshold of 19 mg/L by the time any suspended sediments from trenching installations (or an inadvertent return on the Bad River) reached the Reservation boundary.

Contents

Figures

Tables

List of Acronyms and Abbreviations

3D: Three dimensional, referring to the vertical and horizontal, as in x, y, and z directions

BFGRID: a boundary fitted grid using an unstructured conforming grid for modeling that was developed by RPS

BFHYDRO: Boundary Fitted Hydrodynamic model, a boundary fitted hydrodynamic model developed by RPS

cm: centimeter

DEIS: Draft Environmental Impact Statement

DEM: Digital elevation model

EIS: Environmental Impact Statement

Enbridge: Enbridge Energy Limited Partnership

EPA: Environmental Protection Agency

EROM: Extended Unit Runoff Method

ESRI: Environmental Systems Research Institute

ft: feet

GIS: Geographic Information Systems

GPM: Gallons per minute

HDD: Horizontal Directional Drill

km: kilometer

L5WSRP: Line 5 Wisconsin Segment Relocation Project

LiDAR: Light Detection and Ranging

m: meter

m^3: cubic meter

mph: miles per hour

mg/kg: milligram per kilogram

MT: Metric ton

NED: National Elevation Database

NHD: USGS National Hydrography Dataset

NHDPlus: EPA National Hydrography Plus Dataset

NLCD: The United States Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database

NOAA: United States National Oceanic and Atmospheric Administration

OHWL: Ordinary High Water Line

QA/QC: Quality Assurance / Quality Control

PHMSA: Pipeline and Hazardous Materials Safety Administration

PPM: Parts per million, as referring to concentration. Roughly equivalent to mg/L.

RA: Route Alternative

ROW: Right-of-Way

RPS: RPS Group PLC

The Tribe: Bad River Band of the Lake Superior Tribe of Chippewa Indians

TSS: Total suspended solids

µg/L: microgram per liter

USACE: United States Army Corps of Engineers

USEPA: United States Environmental Protection Agency

USCG: United States Coast Guard

USFWS: United States Fish and Wildlife Service

USGS: United States Geological Survey

WBD: National Watershed Boundary Dataset

WDNR: Wisconsin Department of Natural Resources

WQMAP: Water Quality Management and Analysis Package – a modeling package that contains the BFHYDRO gridding capabilities for hydrodynamic modeling developed by RPS.

1 INTRODUCTION

Enbridge Energy, Limited Partnership (Enbridge) is proposing the Line 5 Wisconsin Segment Relocation Project (L5WSRP), which is designed to relocate the existing Line 5 pipeline (Line 5) around the Bad River Reservation (“the Reservation”) in northern Wisconsin to a more southerly route in Ashland, Bayfield, Douglas, and Iron Counties, Wisconsin. The Proposed Route and each route alternative (RA) of the L5WSRP would divert a small portion of the Line 5 pipeline from the existing route through the Reservation and instead route the pipeline from a starting point west of the Reservation, south around the Reservation, and then back to the north to reconnect at another point farther east in Iron County. Depending on the route alternative, the relocated route would add between 50.5 km (31.4 mi) and 163.4 km (101.5 mi) of new pipeline. The pipeline would carry the same products to the same ultimate Line 5 destination in Sarnia, Ontario, Canada. The Proposed Route and alternate routes RA-01 and RA-02 would bypass the Reservation to the south and pass through the upper portions of the Bad River watershed, while RA-03 would start farther west, travel farther south, and rejoin the existing line farther east, bypassing the Bad River watershed entirely.

The draft Environmental Impact Statement (DEIS) for the proposed relocation project, which was prepared by the Wisconsin Department of Natural Resources (WDNR), discusses potential environmental impacts from the Proposed Route of the pipeline and three route alternatives (RA-01, RA-02, and RA-03). This report provides quantitative analyses of the proposed pipeline construction methods using computational sediment dispersion modeling. The goal was to assess the potential concentrations of sediment within the water column, the downstream sediment concentrations, and the depositional footprint of sediments that may be caused by both planned and accidental discharges of sediment due to installation techniques of the relocated pipeline as it crosses the range of water bodies within the Project Area.

1.1 Purpose and Scope

To construct the Proposed Route (or one of the Route Alternatives), numerous watercourses are to be crossed. Enbridge contracted RPS to provide a quantitative assessment of sediment dispersion from planned construction activities associated with these crossings. Certain installation methods (e.g., trenching) are generally used for small- or medium-size watercourses and would have expected (or known) effects on a watercourse through disturbance of the sediment bottom associated with several activities related to the pipeline installation. Larger watercourses, however, are typically crossed using Horizontal Directional Drilling (HDD), which is a trenchless method that involves underground boring beneath a watercourse, where the pipeline would be installed tens of feet below the bottom of the watercourse. An HDD would only affect the watercourse in the event of an accidental discharge, or “inadvertent return", of drilling fluid to the water body. Inadvertent returns occur when the drilling fluid travels toward the surface through pathways in fractured bedrock, surrounding sand, or unconsolidated sedimentary material, where it reaches the river bottom and enters into the water column. For this analysis, Enbridge provided RPS with a list of 138 Pipeline Right-of-Way

(ROW) crossings of waterways along the Proposed Route,[1] including planned crossing methods, and numerous geomorphological characteristics of each watercourse (Figure 1-1).

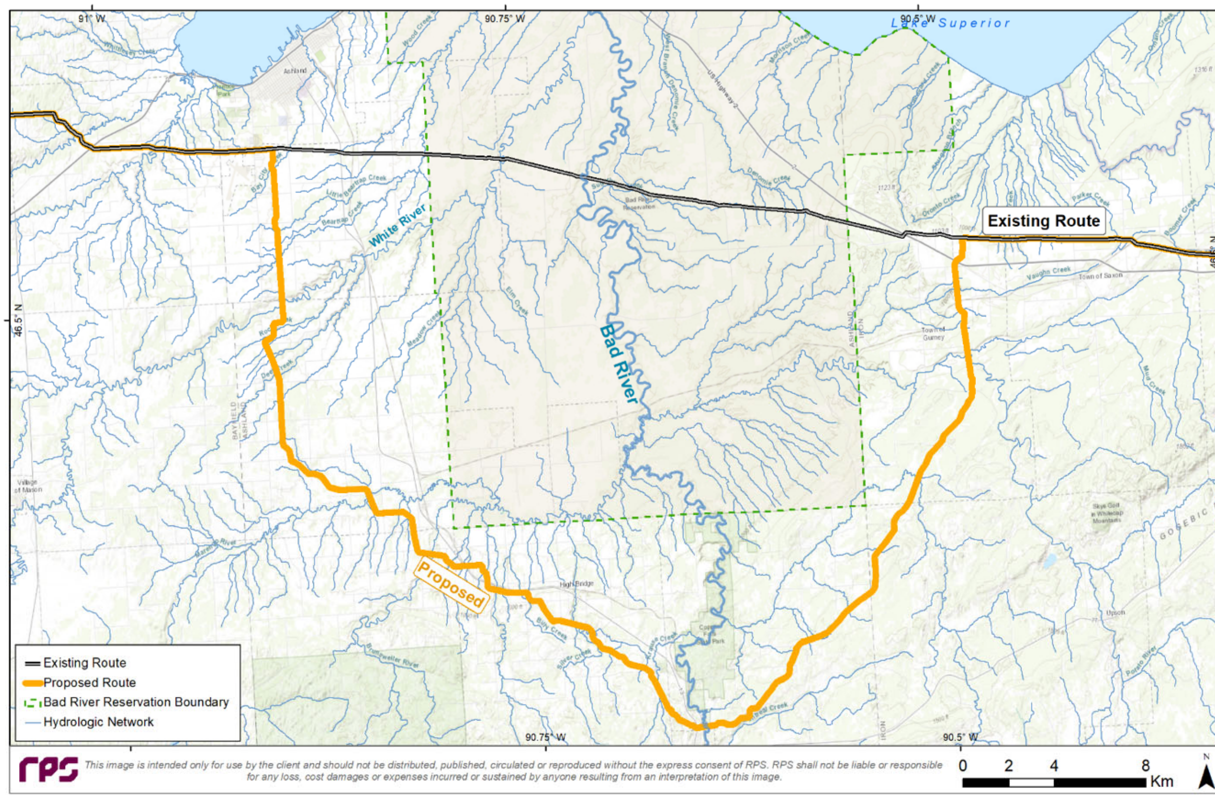


Figure 1-1. Hydrologic network crossings of the Proposed Route in the NHDPlus dataset. Note that this dataset does not include some smaller ephemeral watercourses.

[1] Enbridge developed this Pipeline ROW crossing list from surveys and observational information gathered in the planning of the Proposed Route. This Enbridge dataset is more complete (including ephemeral and intermittent streams) and contains ~35 additional crossings that are associated with only construction activities and grading, when compared to the crossing dataset from NHDPlus used in the Hydrocarbon Route Assessment and HCA Analysis (Appendix C), which provides hydrologic data for only 65 crossings on the Proposed Route. For completeness of understanding the full range of crossings that might be encountered in pipeline installation, all 138 crossings were considered in this analysis, while the smaller NHDPlus dataset was specifically used for the river flow analysis , which required monthly hydrologic data.

Proposed crossing methods ranged in their potential to result in effects based on the type of crossing method used and the site-specific characteristics of the watercourse. A dataset of all watercourses crossed was used to develop hypothetical representative watercourses for use in simulating a set of sediment discharge scenarios along the Proposed Route that bounded planned installation techniques and known sediment variability. These simulations provided a range of predicted effects and are considered representative of other crossings in the project area (i.e., along the Route Alternatives), as the ranges of modeled watercourse sizes, watercourse flow conditions, and sediment compositions within this region are similar between routes.

Enbridge has planned to install the pipeline in predominantly trenched crossings at small- and medium-size watercourses. Prior to and during trenching in flowing watercourses, the construction work area within the watercourse would be isolated from stream flow using temporary dams (e.g., sandbags or water bags) and the stream flow would be maintained by pumping water around the isolated work area or by directing stream flow into flume pipes that extend through the isolated work area. This “dry crossing” method minimizes the potential for downstream sediment transport within the watercourses while construction activities are underway. Drilled crossings using HDD have been proposed for the large-size watercourses (and other sensitive areas). Based on these plans, RPS modeled herein the installation of trenched crossings in both small and medium watercourses under varying environmental conditions. Two non-site-specific watercourses (a small, 5-ft wide channel and a medium, 25-ft wide channel) were developed to represent the many other watercourses crossing through the project area. By simulating hypothetical pipeline installations at two different size crossings, for both a generalized coarse and a fine sediment composition, a range of different potential downstream effects was able to be modeled and assessed.

RPS also modeled inadvertent returns occurring at the Proposed Route crossing of the Bad River, in order to simulate release into a large watercourse. While there are some smaller watercourses that are proposed to be installed via HDD, inadvertent returns were not simulated in these small channels because advanced computational modeling, such as that conducted here, would not be needed to determine that there would be the potential for local effects in the event of an inadvertent return (or frac-out) into a smaller watercourse (e.g., 5 ft width). Such effects would likely have higher magnitudes, but be more contained than those associated with an inadvertent return into a large watercourse, due to lower water flow and reduced velocity and turbulence. Notably, any release would occur at least 2.1 km (1.3 mi.) upstream of the Reservation, as that is the shortest downstream distance from the watercourses crossed by the Proposed Route to the Reservation boundary.[2] The ultimate goal of this study was to determine whether installation of the proposed watercourse crossings could have temporary or permanent impacts on water quality parameters of concern, specifically total suspended solids (TSS).

To assess the potential for impacts to watercourses from pipeline installation and construction activities, RPS developed a modeling approach that used RPS’ SSFATE sediment dispersion model to assess the movement and behavior of suspended sediments in the water column for a set of representative scenarios (Table 1-1).

[2] The downstream distance from the watercourses crossed by the Proposed Route to the Reservation boundary ranges from 2.1 – 23.9 km (1.3 – 14.9 mi). Most of the crossings are approximately 10-15 km (6-9 mi) from the Reservation boundary.

The scenarios reflected representative ranges of river width and depth, sediment/substrate type, and river flow conditions for the watercourses with proposed crossings. The simulations were used to assess:

- Downstream movement and timing of TSS above background value,
- Peak TSS concentrations above background value in the water column,
- Duration of exposure, and
- Depositional thickness.

The results of the suite of modeling scenarios provided an understanding of the range of effects from a planned, dry trenching installation and effects from an unlikely inadvertent release during the pipeline installation process, for any of the route alternatives. The intent was to summarize the potential levels of TSS increases, relative to background values, that could occur within the water column, the duration and downstream distance over which these effects are likely, and the depositional thickness of released sediments on the river bottom. It is important to note that baseline TSS concentrations vary naturally within waterbodies. “Background” is defined here as a range of baseline conditions, with the modeling focus on determining excess TSS concentrations above that range for whenever construction occurs.

Table 1-1. Hypothetical sediment discharge scenarios simulated for representative watercourses.

Scenario ID	Watercourse Size	Construction Method / Sediment Release Type	Sediment Type	River Flow / Hydrodynamic Condition
1	Small Watercourse	Trenching	Fine	Low / Slow
2				Avg / Typical
3				High / Fast
4			Coarse	Low / Slow
5				Avg / Typical
6				High / Fast
7	Medium Watercourse	Trenching	Fine	Low / Slow
8				Avg / Typical
9				High / Fast
10			Coarse	Low / Slow
11				Avg / Typical
12				High / Fast
13	Large Watercourse (Bad River)	Inadvertent Return (Pilot Hole)	Actual Operations (Drilling Mud)	Low / Slow
14				Avg / Typical
15				High / Fast
16		Inadvertent Return (Final Reaming Pass)	Actual Operations (Drilling Mud)	Low / Slow
17				Avg / Typical
18				High / Fast

1.2 Study Area

Line 5 originates near Superior, WI, passes through Michigan's Upper and Lower Peninsulas, and terminates in Ontario, Canada. Along this route, the pipeline transects the Bad River watershed, along the north shore of Wisconsin. The area is known to contain many sensitive aquatic receptors, including fish and wild rice that are harvested for human consumption, and areas within the watershed that include spawning grounds for fish species (TNC, 2020). The downstream reaches and mouth of the Bad River on Lake Superior provide the last remaining extensive coastal wild rice wetland in the Great Lakes Basin.

The Bad River watershed is depicted in Figure 1-2. Beartrap Creek, which drains into the Kakagon Slough, is also adjacent to the Bad River watershed (Bad River Watershed Association, 2021). To the west and east of the Bad River watershed, respectively, are the Beartrap-Nemadji and Montreal River watersheds. The Proposed Route and Route Alternatives RA-01 and RA-02 pass through portions of the Beartrap-Nemadji, Bad River, and Montreal River watersheds. RA-03 bypasses the Bad River watershed entirely, instead passing to the south through the St. Croix and Upper Chippewa basins that drain to the St. Croix and Chippewa Rivers in the greater Mississippi River watershed.

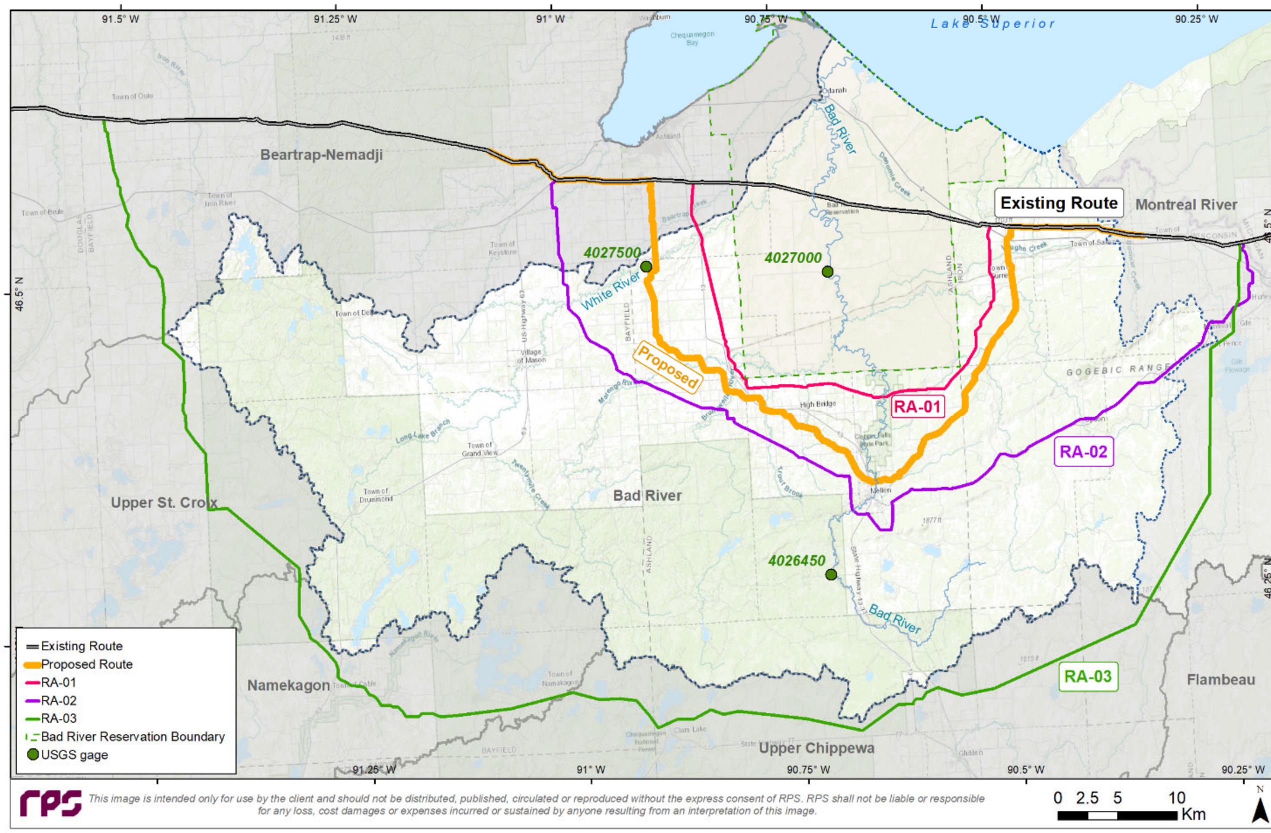


Figure 1-2. Map of proposed and alternative Enbridge Line 5 routes in the DEIS relative to the Bad River watershed.

The Bad River's headwaters are located at Caroline Lake, which is located approximately 40 km (24.9 mi) south of Lake Superior (straight-line distance). In total, the Bad River is approximately 125 km (77 mi) long, with a sinuous path that leads to the north, where it enters the Bad River Slough and Lake Superior. It has an average depth of 1.3 m (4.27 ft) under average river flow conditions (TNC, 2020).

For the purposes of this study, representative watercourse crossings were developed to model small and medium watercourse crossings associated with construction activities along each of the pipeline route alternatives. The Proposed Route crossing location on the Bad River was selected as a representative large waterbody crossing for analysis of accidental inadvertent returns. The study boundary was terminated 78 km (48.5 mi) downstream (north) of the crossing, at the entrance to Lake Superior. The modeled area, referred to as the model domain, for the simulations of releases into the Bad River extended between 90.61°W – 90.73°W and 46.33°N – 46.65°N.

2 MODEL DESCRIPTIONS

Several numerical approaches were used in the development of the hydrodynamic and sediment modeling tools. The hydrodynamics for the small and medium watercourses were developed using the Delft3D Flexible Mesh (FM) modeling suite (described in this section) and the hydrodynamics for the large watercourse (i.e., the Bad River) were developed using the BFHYDRO model. Details of the specific model applications used for the small and medium watercourses are in Section 4.1 and for the Bad River are in Section 4.2. The sediment dispersion modeling was carried out using RPS's SSFATE model, with that application described in Section 4.3.

2.1 D-flow FM Model Description

The current speed and direction within a watercourse define the movement and behavior of any sediment load that is released into the water column. Current speed and direction within each grid cell of the simulated watercourse channel were developed using a hydrodynamic model for use as the underlying force in the sediment dispersion model**.** Hydrodynamic modeling was performed using Delft3D FM, which is a modeling suite developed and maintained by Deltares. The Delft3D FM modeling suite includes the D-Flow FM finite volume model code that was used for this application, and an interface (Delta Shell) for handling model inputs and outputs (Deltares, 2022). Hydrodynamic outputs from the D-Flow FM model were then converted to a file format that is compatible with RPS's SSFATE model input format, and was used to determine the transport and deposition of suspended sediments in the water column.

D-Flow FM is a multi-dimensional, boundary-fitted hydrodynamic model that can operate with cartesian or spherical coordinates (Deltares, 2022). The unstructured mesh grid utilizes a boundary-fitting technique, which matches the grid coordinates with shoreline and bathymetric feature boundaries for highly accurate representations of areas with complex coastal or riverine geometries. This allows for easy development of model grids that conform well to complex shorelines and sinuous channels and can include high degrees of mesh resolution in areas only where it is desired. D-Flow FM may be applied in either two or three dimensions depending on the nature of the problem and the complexity of the study. User-specified forcing conditions (e.g., tidal, meteorological) can be applied to the model to generate water elevations, velocities, density, and/or salinity in various coastal, river, lakes, and estuarine environments. The model has undergone extensive validation for a variety of hydrodynamic conditions and water body types and has been found to perform accurately and agree well with measurements of steady and unsteady flow behavior (Gerritsen et al., 2008). A brief description of the model follows.

2.1.1 D-Flow FM Model Theory

The boundary-fitted model solves a series of non-linear shallow water equations derived from the three-dimensional Navier-Stokes equations with Boussinesq approximation for incompressible free surface flow (Deltares, 2022). In cases where non-hydrostatic modeling is required, additional components can be added to make the equations practically equivalent to the incompressible Navier-Stokes equations.

The equations solved in the modeling are conservative toward:

- Water volume (the continuity equation), and
- Linear momentum (the Reynolds-averaged Navier-Stokes equations).

Two vertical grid co-ordinate systems are available, the sigma-grid system (a more common application initially designed for atmospheric models) and the Z-grid system (for simulations of weakly forced stratified water systems). The sigma-grid has several layers bounded by two sigma-planes, which follow the bottom topography and the free surface (Figure 2-1) to obtain a smooth representation of the topography. The Z-grid has horizontal coordinate lines that are (nearly) parallel with density interfaces (isopycnals) in regions with steep bottom slopes, for modeling stratified systems with horizontal density gradient (Deltares, 2022).

The sigma-grid system was used to resolve the vertical direction in this application of the model because there are no steep bed slopes, and no strong stratifications needed to be captured in this study.

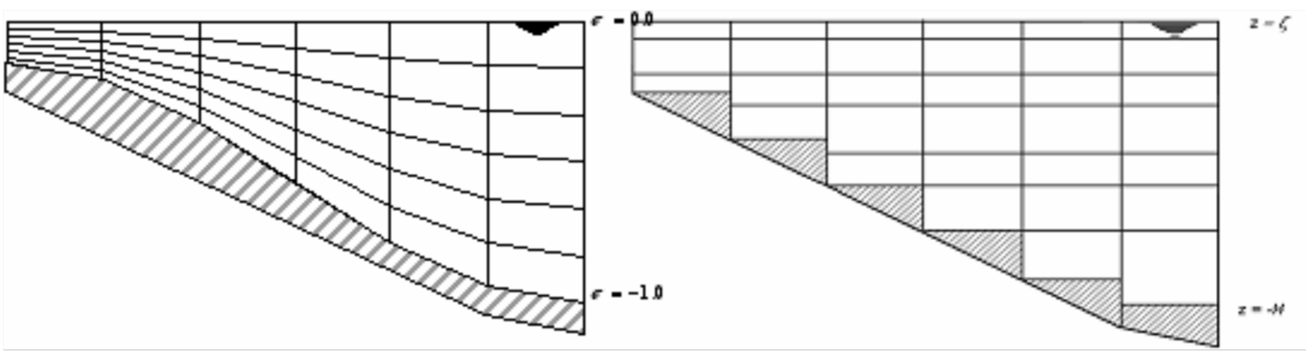


Figure 2-1: Schematic of the D-Flow FM vertical sigma (left) and vertical Z-coordinate (right) systems (Deltares, 2022).

Boundary conditions of the model can be defined as follows:

- The flux of matter through land boundaries and on the bottom is zero, thus creating a zero normal component of velocity,
- Flow and transport boundary conditions (e.g., water levels, currents, gradients, discharges) are input at open boundaries to represent influences from areas outside the model,
- Slip conditions are assumed at the bottom of the waterway, while partial-, free-, or no-slip conditions can be applied at the sides,
- Wind stress can be applied at the free surface, which generates wind-driven flow. Flow can also be driven by pressure gradients or density gradients in the watercourse, and
- Spatial and temporal outputs of velocity and water surface elevation can be obtained at the specified model output locations.

In D-Flow FM, there are various levels of complexity that can be applied to model the turbulent exchange of momentum and mass in the vertical direction. The simplest assumption is that both are constant throughout the water column, although other options are available. Iterative solvers are used for the core equations in the model, allowing for efficient solutions and adaptability to different assumptions and complexities in the system (Gerritsen et al., 2008).

2.2 BFHYDRO Model Description

Hydrodynamics for the Bad River were calculated using the RPS BFHYDRO hydrodynamic model. The BFHYDRO model is a general curvilinear coordinate, boundary-fitted hydrodynamic model (Muin and Spaulding, 1997; Mendelsohn et al., 1995; Huang and Spaulding, 1995; Swanson et al., 1989) that can be used to generate tidal or river elevations, velocities, and salinity and temperature distributions. The model uses a boundary-fitting technique, which matches the grid coordinates with shoreline and bathymetric feature boundaries for highly accurate representations of areas with complex coastal or riverine geometries, such as the Bad River. This system also allows the modeling team to adjust the model grid resolution as desired and introduce lower mesh resolution (larger cells) at locations several miles from the proposed route for computational efficiency. BFHYDRO may be applied in either two or three dimensions depending on the nature of the problem and the complexity of the study. A detailed description of the model with associated test cases is described in Muin and Spaulding (1997), and Muin (1993). The model has undergone extensive testing against analytical solutions and has been found to perform accurately and quickly. Specific model comparisons are found in Swanson et al. (2012), Mendelsohn et al. (2003), Muin and Spaulding (1997), Mendelsohn et al. (1995) and Huang and Spaulding, (1995).

A brief description of the model theory follows. The application development and hydrodynamic outputs developed for the Bad River using the BFHYDRO model are described in Section 4.2.

2.2.1 BFHYDRO Model Theory

The boundary-fitted method uses 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 (Spaulding, 1984). The three-dimensional conservation of mass and momentum equations, with approximations suitable for lakes, rivers, estuaries, and coastal oceans (Swanson, 1986; Muin, 1993) that form the basis of the model, are then solved in this transformed space. A sigma stretching system is used in the vertical to map the free surface and bottom onto coordinate surfaces to resolve bathymetric variations. The vertical mesh stretches and shrinks with the changing tidal elevation or river stage, maintaining a constant number of layers, so that no interpolation is required to simulate the surface slope or the bathymetry (Figure 2-2). The velocities are represented in their contra-variant form, on an Arakawa-C grid.

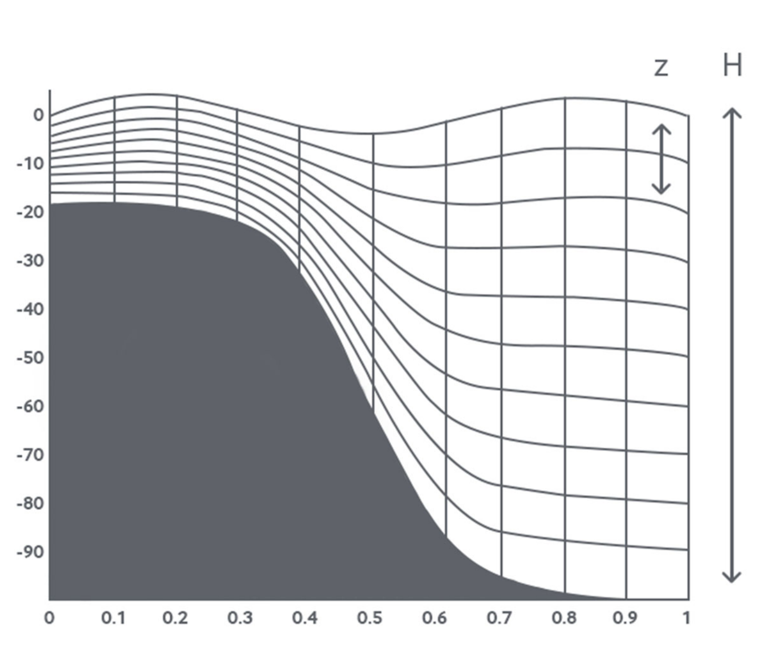


Figure 2-2. Schematic of the BFHYDRO vertical sigma coordinate system.

The basic equations are written in spherical coordinates to allow for accurate representation of large, modeled areas without distortion. The conservation equations for water mass, momentum (in three dimensions) and constituent mass (temperature [heat] and salinity) form the basis of the model and are well established. It is assumed that the discharge 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 in discharge,
- On outflow, temperature (heat) and salinity are advected out of the model domain,
- At river boundaries, the volume flux must be specified, with positive discharge into the model domain, and temperature (and occasionally salinity) must be specified,
- A bottom stress or a no slip condition can be 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, and
- A wind stress, and appropriate heat transfer terms, are applied at the water surface. The surface heat balance includes all the primary heat transfer mechanisms for environmental interaction.

There are various options for specification of vertical eddy viscosity, (for momentum) and vertical eddy diffusivity, (for constituent mass [temperature and salinity]). The simplest formulation is that both are constant throughout the water column. They can also be functions of the local Richardson number, which, in turn, is a function of the vertical density gradient and vertical gradient of horizontal velocity. A 1-equation or 2-equation turbulence closure model may also be used.

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. Vertical 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).

2.3 SSFATE Description

SSFATE is a three-dimensional Lagrangian (particle) model developed jointly by the United States (US) Army Corps of Engineers' Environmental Research and Development Center (ACE-ERDC) and Applied Science Associates (now part of RPS) to simulate sediment resuspension and deposition, originally from marine dredging operations. Model development was documented in a series of US Army Corps of Engineers' Dredging Operations and Environmental Research Program technical notes (Johnson et al., 2000; Swanson et al., 2000), at previous World Dredging Conferences (Anderson et al., 2001), and at a series of Western Dredging Association Conferences (Swanson and Isaji, 2006; Swanson et al., 2004). Following dozens of technical studies, which demonstrated successful application to dredging, SSFATE was further developed to include simulation of cable and pipeline burial operations using water jet trenchers (Swanson and Isaji, 2006) and mechanical ploughs as well as sediment dumping and dewatering operations. The tool is maintained by RPS and is used for sediment dispersion modeling studies such as this internationally. The current modeling system includes a GIS-based interface for visualization and analysis of model output.

SSFATE computes TSS concentrations above background value (i.e., above ambient conditions) in the water column and sedimentation patterns (i.e., deposition) on the riverbed above background deposition resulting from sediment disturbance and resuspension, such as the construction activities investigated here. The model uses specifications for the suspended sediment source strengths (i.e., mass flux), vertical distributions of sediments, and sediment grain-size distributions to represent loads to the water column from different construction activities such as dredging, dumping, cable and pipeline line installation, pile driving, dam installation and removal, and land reclamation. Multiple sediment types or fractions can be simulated simultaneously, as can discharges from moving sources. The model predicts the transport, dispersion, and settling of suspended sediment released to the water column. The focus of the model is on the far-field processes (i.e., meters or kilometers beyond the initial disturbance) affecting the dispersion of suspended sediment.

SSFATE has been successfully applied to a number of recent modeling studies with these studies receiving acceptance from federal and state regulatory agencies.

2.3.1 SSFATE Model Theory

SSFATE addresses the short-term movement of sediments that are disturbed during mechanical ploughing, hydraulic jetting, dredging, and other processes where sediment is resuspended into the water column. The model predicts the three-dimensional path and fate of sediment particles based on sediment properties, sediment loading characteristics, and environmental conditions (e.g., bathymetry, water density, and current flows). The computational model utilizes a Lagrangian or particle-based scheme to represent the total mass of suspended sediments over time, which provides a method to track suspended sediment without any loss of mass. This is a stronger approach as compared to Eulerian (continuous) models, which may lose mass due to the nature of the numerical approximations used for the conservation equations. Thus, the Lagrangian method is not subject to artificial diffusion near sharp concentration gradients and can easily simulate all types of sediment sources.

Sediment particles in SSFATE are divided into five size classes, each having unique behaviors for transport, dispersion, and settling (Table 3-4). For any given location (segment of the route), the sediment characterization is defined by this set of five classes, with each class representing a portion of the distribution and all five classes summing to 100%. The model determines the number of particles used per time step, depending on the model time step and overall duration, thereby ensuring an equal number of particles is used to define the source throughout the simulation. While a minimum of one particle per sediment size class per time step is enforced, typically multiple particles are used. The mass per particle varies depending on the total number of particles released, the grain size distribution, and the mass flux per time step.

Horizontal transport, settling, and turbulence-induced suspension of each particle are computed independently by the model for each time step. Particle advection is based on the relationship that a particle moves linearly, in three-dimensions, with a local velocity obtained from the hydrodynamic field, for a specified model time step. Diffusion is assumed to follow a simple random walk process, with the diffusion distance defined as the square root of the product of an input diffusion coefficient, and at each time step is decomposed into X and Y displacements via a random direction function. The vertical Z diffusion distance is scaled by a random positive or negative direction.

Particle settling rates are calculated using Stokes equations and are based on the size and density of each particle class. Settling of mixtures of particles is a complex process due to interaction of the different size classes, some of which tend to be cohesive and thus clump together to form larger particles that have different settling rates than would be expected based on their individual sizes. Enhanced settlement rates due to flocculation and scavenging are particularly important for clay and fine-silt sized particles (Swanson et al., 2004; Teeter, 1998), and these processes have been implemented in SSFATE. These processes are bound by upper and lower concentration limits, defined through empirical studies, which contribute to flocculation for each size class of particles. Above and below these limits, particle collisions are either too infrequent to promote aggregation or so numerous that the interactions hinder settling.

Deposition is calculated as a probability function of the prevailing bottom stress and local sediment concentration and size class. The bottom shear stress is based on the combined velocity due to waves (if used) and currents using the parametric approximation by Soulsby (1998). Sediment particles that are deposited may be subsequently resuspended into the lower water column if critical levels of bottom stress are exceeded, and the model employs two different resuspension algorithms. The first applies to material deposited in the last tidal cycle (Lin et al., 2003). This accounts for the fact that newly-deposited material will not have had time to consolidate and will be resuspended with less effort (lower shear force) than consolidated bottom material. The second algorithm is the established Van Rijn (1989) method and applies to all other material that has been deposited prior to the start of the last tidal cycle (if appropriate). Swanson et al. (2007) summarize the justifications and tests for each of these resuspension schemes. Particles initially released by operations are continuously tracked for the length of the simulation, whether in suspension or deposited.

For each model time step, the suspended concentration of each sediment class, as well as the total concentration, is computed on a concentration grid. The concentration grid is a uniform rectangular grid in the horizontal dimension with user-specified cell size and a uniform thickness in the vertical dimension (z-grid). The concentration grid is independent of the resolution of the hydrodynamic data used to calculate transport, thus supporting finer spatial differentiation of plume concentrations and avoiding underestimation of concentrations caused by spatial averaging over larger volumes/areas. Model outputs include:

- water-column concentrations in both horizontal and vertical dimensions,
- time-series plots of suspended sediment concentrations at points of interest, and
- thickness contours of sediment deposited on the river bottom.

Deposition is calculated as the mass of sediment particles that accumulate over a unit area and using the same grid that is used in the determination of concentration. Because the amount of water in the deposited sediment is unknown, SSFATE converts deposition mass to thickness by assuming no water content.

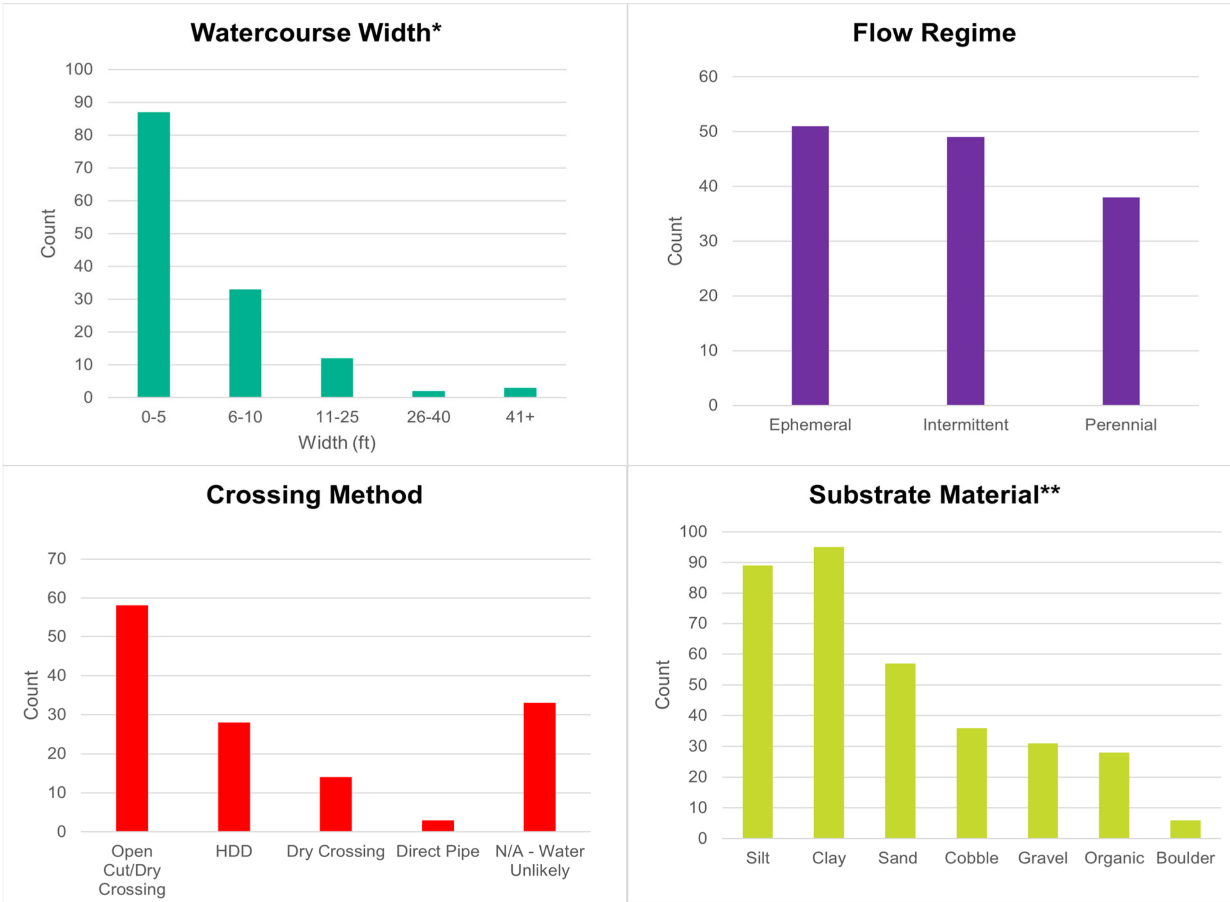
Detailed descriptions of the SSFATE model equations governing sediment transport, settling, deposition, and resuspension, are summarized in Swanson et al. (2007).

3 MODELING INPUTS

Enbridge provided RPS with a list of 138 watercourse crossings for the Proposed Route that spanned the range from small ephemeral watercourses, with a width of <1 foot and a depth of a few inches, up to well-established rivers with a maximum width of 60 feet. The data provided for these crossings (Enbridge, 2022a) included location, proposed crossing method (or construction only purpose), watercourse width (at the Ordinary High Water Mark, or OHWM), substrate material, and numerous other descriptions of the watercourses, receptors, and defining characteristics. Of note, several of these watercourses are designated as Class I, II, or III trout streams, perennial tributaries of trout streams, or Areas of Special Natural Resource Interest – Priority Navigable Waterways (ASNRI-PNW).

It would be impractical to simulate sediment dispersion for each watercourse crossing under the range of potential environmental conditions at the time of construction, which would necessitate several hundred or even thousand simulations. As would be expected, there were numerous similarities between watercourse crossings, with ~110 crossings being <10 ft across. Therefore, representative watercourses were developed with dimensions that would provide sediment dispersion modeling results that would apply to each of those watercourses. Because channel geomorphology can change the site-specific dynamics of sediment dispersion within any specific water column, a generic approach was used to develop simplified rectangular watercourse channels as a first order approximation. The idealized approach included numerous simulations of sediment dispersion under various river flow conditions in the uniform rectangular channels with fixed widths and depths. These generalized results were representative of numerous channels with similar characteristics and the sediment results would be applicable to each of the small and medium watercourses that would be crossed. For the large watercourse crossings, the actual Bad River geomorphology was used, rather than a simplified or representative channel.

The defining characteristics of each of the 138 watercourse crossings were used to determine the distribution and range of watercourse width, flow regime, substrate material, and crossing method (Figure 3-1). Based upon the analysis of each identified parameter, a number of scenarios were developed that could be used to bound the range of potential effects from each crossing installation. These included small, medium, and large watercourses where pipeline installation methods could range from dry trenching (using temporary dams) to HDD.



*OHWM used for watercourse width. (OHWM)
** Multiple substrate materials may be listed for a single watercourse. Substrate types have been broken apart for count statistics.

Figure 3-1. Distribution of width, flow regime, substrate, and crossing method for the provided list of 138 watercourse crossings.

3.1 Watercourse Width & Depth

Watercourse width and depth define the wetted channel and ultimately the volume of water contained within. The dispersion and dilution within this volume of water will control the concentration of TSS in the water column. Additionally, the watercourse width is directly correlated to the amount of sediment that could be disturbed and/or removed in the installation of a dry trench crossing (i.e., wider channels require larger temporary dams and longer trenches).

The watercourse crossings along the Proposed Route encompass a broad range of watercourse widths (<1 - 60 ft) (Enbridge, 2022a). The majority of the watercourses are skewed toward the smaller end of the distribution with narrow and shallow channels (Figure 3-1). Roughly two-thirds of the watercourse crossings are less than 5 ft across, although a portion of those crossings are on intermittent or ephemeral watercourses where dry trench methods within a watercourse may not be needed depending on the season of installation, as water may not be within the channel.

Two representative watercourse dimensions were selected to bound the size of watercourses that may be trenched, while the Bad River itself was used to characterize a third, larger watercourse where HDD installation would be applied (Table 3-1). Based upon the distribution of watercourses in the area of interest, the representative simplified watercourses developed for modeling included a small creek (5 ft width, 1 ft depth) and a medium river (25 ft width, 3 ft depth) (Figure 3-2). The small watercourse size was developed to reflect the predominant majority of crossing dimensions, while the medium watercourse represents an upper range for which dry trenching techniques might be applied for this pipeline relocation project. The small watercourse size would result in less sediment load to the water column, but would also have less water within the channel for the TSS to disperse within.

Table 3-1: Simplified watercourse crossing dimensions used in the sediment dispersion modeling.

Crossing Size	Watercourse Width (ft)	Watercourse Depth (ft)
Small	5	1
Medium	25	3
Large (Bad River)	Variable	Variable

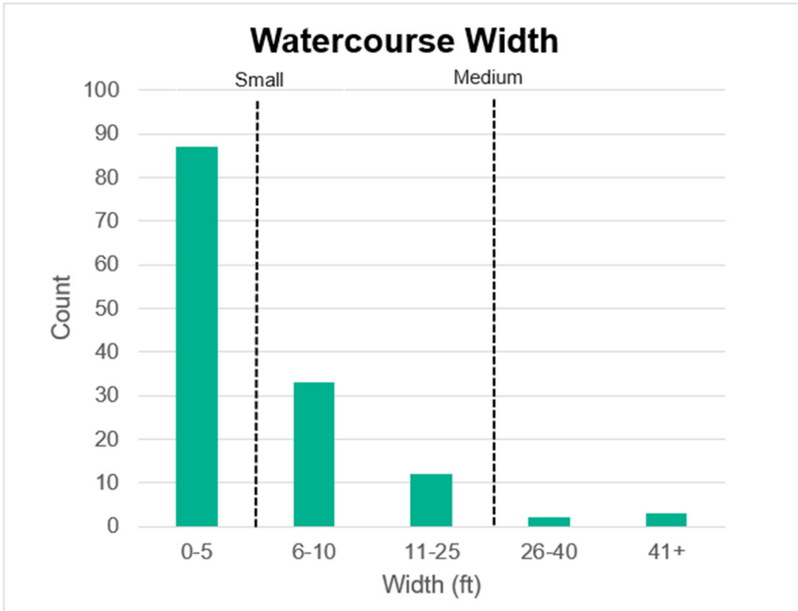


Figure 3-2: Width distributions for watercourses crossed by Proposed Route with representative size parameters used in the sediment dispersion modeling marked by the black lines.

The actual dimensions for the Bad River were used to simulate the large watercourse, including the variable width and depth along the channel and resulting hydrodynamics modeled within. Bathymetry data define the water depths within the study area. Gridded bathymetry for the Bad River was not available; therefore, bathymetry data were derived from point data from field surveys conducted by Enbridge in 2019 for the purpose of control point investigation. River depth was determined for each river flow condition (low – January; average – June; and high – April), throughout the model domain. Depths generally ranged from 2-6 ft in upstream sections and 4-10 ft in downstream sections of the Bad River, depending on the location and flow conditions (maps of model bathymetry were provided in Horn et al., 2022).

It is understood that the location of the land/water boundary and the depth of the Bad River would shift under different river flow conditions. There is the potential for a wider river with deeper depths under higher river flow conditions, when compared to the narrower widths, shallower depths, and potential for small islands to form under low river flow conditions. However, detailed imagery and mapped field data of the three-dimensional structure of the entire Bad River was not available. Therefore, a simplifying assumption was made. A single shoreline location was used in this study for each of the three modeled river flow conditions. Because river flow (volume of water moving through the channel) and cross-sectional area (river width and depth) was used to define the velocity of the river, the assumption of a fixed river width would tend to underestimate the velocity of the water under low river flow conditions (low flow volume moving through a wider channel). Similarly, maintaining the river width would tend to overestimate velocity under high river flow conditions. Therefore, the conservative assumption of a fixed river width under low, average, and high river flow conditions resulted in a wider band of predicted results, which further bounded the potential conditions that may exist within the Bad River.

3.2 River Flow and Water Velocity

A range of river flow rates and water velocities would be expected throughout the year at the 138 watercourse crossings along the Proposed Route, as well as other crossings of the alternative routes. River flow is a measure of the volume of water moving through a given cross section of the watercourse over a period of time. Typically, larger flows correspond with larger river velocities, with the potential for enhanced dispersion and dilution, but reduced deposition or even resuspension. This river flow analysis narrowed the scope to exclude watercourses of an ephemeral or intermittent nature that did not have available hydrologic flow estimates.

River flow rates and velocities were assessed at each of the watercourse crossings with available data in the USGS National Hydrography Dataset Plus V2 (NHDPlus). These data include an average river flow and velocity for each month, as well as the mean annual values. Flow and velocity values were calculated by the USGS for NHDPlus based on the Enhanced Unit RunOff Method (EROM), which uses a runoff grid produced as part of the US Global Change Research Program (USGCRP) based on a water balance approach and observation data from reference gauges (McKay, 2012). These computed monthly average river flow and velocity values *do not* encompass the extreme minimum nor maximum flow values that could be experienced at these crossings over a one- or two-day period (e.g., intense thunderstorm). However, they do provide a wide range of river flow rates over the course of a year, based upon multiple years of data.

The river flow data for all crossings categorized as Small (<10 ft) or Medium (10-40 ft) were interrogated using a shapefile of NHDPlus streamlines that was cross referenced to each watercourse crossing location. Aerial photography was used to check the accuracy of the identified stream segment. Out of 138 identified watercourse crossing points, 23 small crossings and 11 medium crossings (34 total[3]) were associated with NHDPlus streamlines with monthly flow data. The remaining watercourse crossings (except for the largest rivers) were too small or ephemeral to be classified as a watercourse in NHDPlus.

The minimum, mean, and maximum average river flow conditions were determined across all months. The largest flow rates generally occurred in April, associated with the spring freshet, followed by October. Minimum river flows tended to occur between December and March, with freezing wintertime conditions, and late summer (July-August) due to warmer temperatures and lower precipitation. Representative watercourses were identified to provide a visual example of monthly flow rates throughout the year (Figure 3-3).

[3] Note that there were more Proposed Route crossings in the NHD HR dataset, which was used in the Hydrocarbon Route Assessment and HCA Analysis (Appendix C) to identify potential release locations in the OILMAPLand modeling. However, the NHDPlus dataset used here contains only 40 crossings with enough statistical data needed to determine average flow conditions, of which 34 were categorized as small or medium for this sediment discharge assessment.

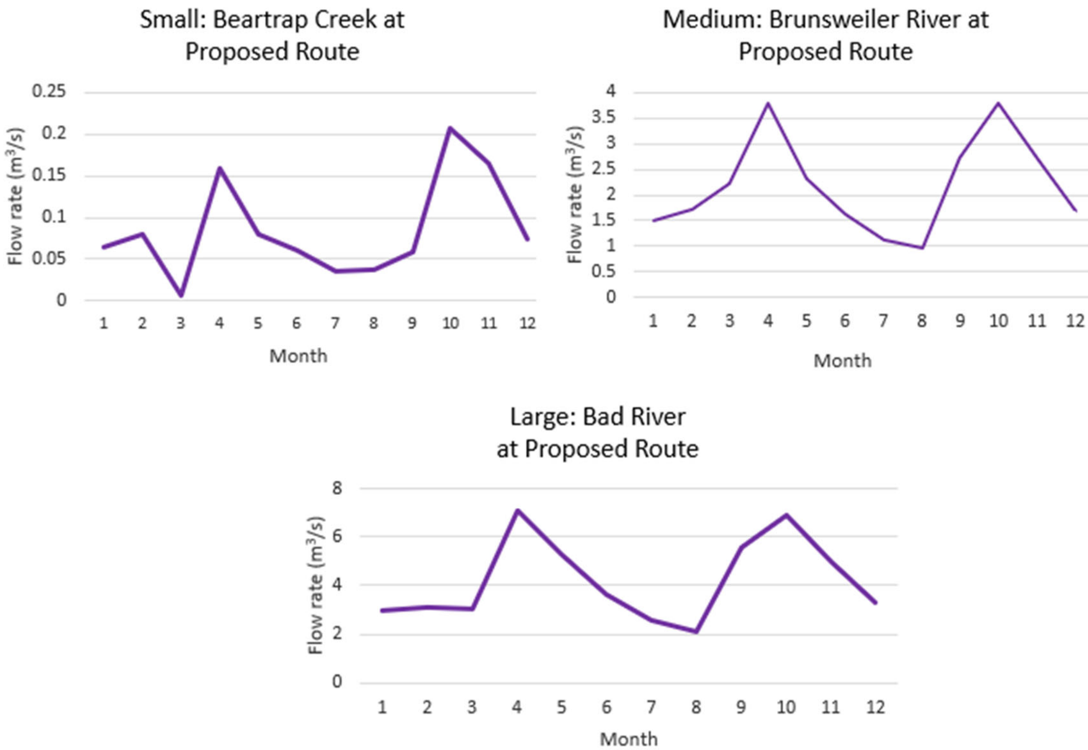


Figure 3-3: Monthly river flow rates for an example small (left), medium (right) and large (bottom) watercourse. Note that the scale of the vertical axis (i.e., flow rate) is different between the three figures.

River flow characteristics for the representative small and medium watercourse crossings needed to be identified for use as hydrodynamic inputs in the sediment dispersion modeling. The range and average river flow values were computed for all 34 NHDPlus crossing points on the Proposed Route annually, as well as specifically for the summertime period (June-August) when the construction phase of the pipeline would be likely to occur (Table 3-2). All crossings with NHDPlus data that had widths less than 10 feet (categorized as small), or 10-40 feet (categorized as medium) were included in the statistical analysis. In addition to river flow, the associated river velocities for these watercourse crossing sizes were also calculated (Table 3-3).

Table 3-2: Summary of NHDPlus river flow data for the 34 watercourse crossings.

River Flow (m^3/s)			
	Stat	Jun-Aug	All Months
Small Watercourse	Min	0.003	0.001
	Avg	0.03	0.06
	Max	0.11	0.32
Medium Watercourse	Min	0.01	0.001
	Avg	1.06	1.33
	Max	7.65	15.24

Table 3-3: Summary of NHDPlus velocity data for the 34 watercourse crossings.

River Velocity (cm/s)			
	Stat	Jun-Aug	All Months
Small Watercourse	Min	16	12
	Avg	22	25
	Max	31	48
Medium Watercourse	Min	17	13
	Avg	26	30
	Max	39	54

The June-August river flow conditions for each sized watercourse (small and medium) were used to capture the range of potential stream conditions that may occur during the construction phase. Specifically, the water velocities associated with the respective watercourse sizes were used as hydrodynamic inputs to the sediment dispersion modeling. To capture the widest range of river flow conditions during the construction phase, the input velocities used in the modeling included:

- Low river flow conditions targeting the lowest value from the minimum monthly velocities in June-August,
- Mean river flow conditions targeting the average mean velocity in June-August, and
- High river flow conditions targeting the highest value from the maximum monthly velocities in June-August.

The selected river velocities values used ranged from 16 – 31 cm/s for the small watercourse and 17 – 39 cm/s for the medium (Table 3-3). As noted earlier, these monthly velocity values are less extreme than the daily minimum and maximum values; thus, this approach ensures that the modelling represents the variation in stream velocity, while not focusing on the extreme low and high values that may be experienced less frequently and for shorter periods of time. This is an appropriate assumption, as it is unlikely that construction activities would be undertaken during extreme weather events or even potentially under high watercourse conditions.

Site-specific hydrodynamics from the 3D hydrodynamic modeling of the Bad River were used for the large watercourse (see Section 4.2 for details). For that modeling, mean monthly flow rates from representative months were used to define low (January), average (June), and high (April) river flow conditions, which were then used as inputs to develop 3D, spatially-varying hydrodynamic currents throughout the Bad River model domain. These multi-seasonal river flow conditions (rather than only a June-August construction period) were used for the present modeling, because there is greater seasonal flexibility for HDD installation, which would occur outside the waterway.

3.3 Substrate Types

The substrate material of each watercourse is one of the key variables in question for trenched crossings, due to this being the material that would become resuspended during construction activities with the potential to be transported downstream in the water column. There are several different particle size classifications that may be used for different purposes. However, the most common system in the United States is the Wentworth scale (Wentworth, 1922; reproduced in Williams et al., 2006; Figure 3-4). The International Organization for Standardization also publishes a scale commonly used to assess engineering properties of soils (ISO 2002, ISO 2013, ISO 2017). For the sediment dispersion modeling, sediment size classes were defined based on particle transport behavior, with each size class behaving uniquely in the SSFATE model (Swanson et al., 2007; Figure 3-4; Table 3-4).

Substrate material for the 138 watercourse crossings ranged from very large particle sizes (e.g., cobbles, gravel, and sand) down to small particles (e.g., silt, clay, muck) (Figure 3-1). The most common substrate types for the crossings were silt/clay and sand. Large particle sizes settle out of the water column rapidly. Even the smallest end of the large particle spectrum (i.e., small sand) sinks at approximately 0.5 cm/sec, which corresponds with a settling rate of approximately 1 ft/min. Essentially, even if the sediment were released at the top of the water column, all of the material would settle in stagnant waters within one minute for the simulated small watercourse and 5 min for the large watercourse. However, if one considered the smaller particles, with settling rates of approximately 0.0001 - 0.01 cm/s, it may take many hours-weeks to settle under stagnant conditions. Therefore, even small amounts of turbulence within the moving waters has the potential to keep these fine-grained materials in suspension for longer periods of time.

Table 3-4: Sediment particle size classification used in the SSFATE model.

Description	Class	Type	Size Range (microns)
Fine	1	Clay	0 - 7
↓	2	Fine silt	8 - 35
	3	Coarse silt	36 - 74
	4	Fine sand	75 - 130
Coarse	5	Coarse sand	>130

Two particle size groups were chosen to represent potential substrate types in the watercourse crossings that had a higher potential to remain in suspension. Based on the substrate textural categories of the watercourse crossings (Figure 3-1), fine and medium grained particles were selected for use in the modeling (for simplicity noted fine and coarse). The fine particle size group was selected to represent sediments that maximized the potential for in-water concentrations and longer durations of exposure. The small size class was defined as 50% clay (0 - 7 µm) and 50% fine silt (8 - 35µm). The coarse particle size group (actually composed of medium-sized grains) was selected to represent sediments that maximized the potential for sedimentation (i.e., depositional thickness) that may occur tens to hundreds of meters downstream and the size class was defined as 50% coarse silt (35 - 74 µm) and 50% fine sand (75 - 130 µm). The largest particles, such as gravel, cobbles, and coarse sand were not modeled in SSFATE and would be expected to settle out immediately (at the point of disturbance downstream to a few feet) and not contribute to downstream sedimentation and potential for impacts.

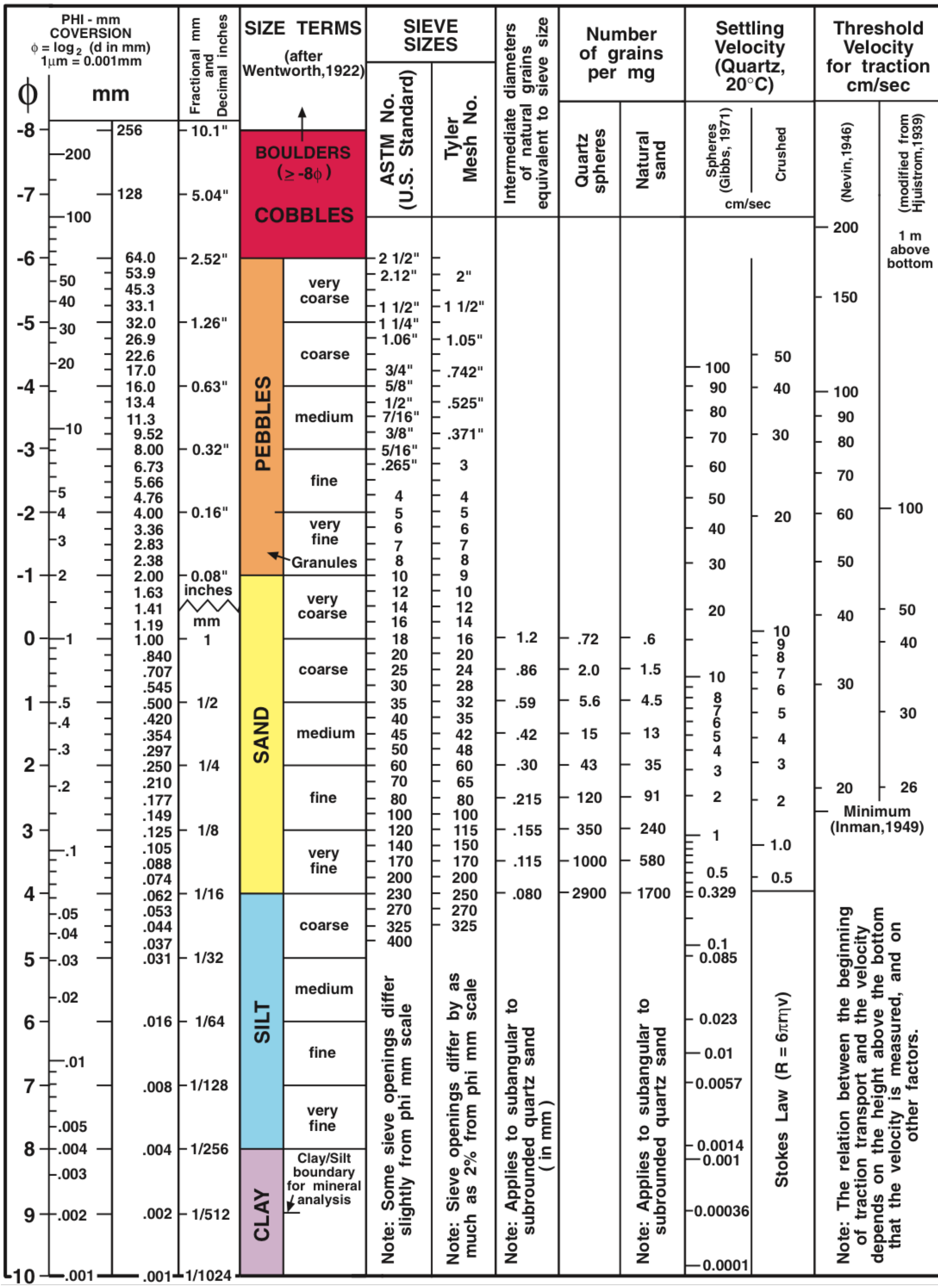


Figure 3-4: Wentworth grain size chart and associated relevant parameters. (Reproduced by Williams et al., 2006)

3.4 Suspended Sediments

3.4.1 Background TSS Concentrations

TSS is regulated as a conventional pollutant in the US Clean Water Act, however, like heat, it is one that is naturally occurring. In watercourses throughout the world, suspended solids are those materials that are carried by runoff from rain events, as well as those bedload materials that are resuspended into the water column during periods of enhanced turbulence from increased flow. The background concentration of TSS within a watercourse can naturally vary greatly (several orders of magnitude) over the course of a year, and down to timescales on the order of minutes.

Historical observations of TSS were analyzed to determine the ranges and seasonality of values that may be present in watercourses in the Bad River watershed (Table 3-5). Data were available from three USGS gages on the White River and Bad River (04027000, 04027500, 04026450), with more than 1,000 total measurements collectively across the gages (USGS 2022). Most measurements were collected at the Bad River near Odanah and the White River near Ashland gages. In total, 19 to 351 measurements are available per month across the three gages. These data demonstrate the variability in natural TSS as well as the variability between watercourses. Minimum values were generally less than 5 mg/L, whereas maximum values often exceeded 1,000 mg/L, with the highest observed value at 9,810 mg/L. TSS concentrations have been shown to vary seasonally with flow fluctuations and primary production (MPCA, 2020; Ellison et al., 2014; Lenhart et al., 2010). Concentrations are lowest during the winter months, when river flows are low and watercourses may be frozen. High spring flow periods from snowmelt runoff generally result in peak TSS levels. Runoff from summer storms, while creating large flows, may have slightly reduced TSS peaks as a result of the increased plant cover, which stabilizes the watershed soil and thus reduces sediment loading to streams (Lenhart et al., 2010). Summer plant growth and transpiration also decrease runoff and sediment delivery to streams.

Table 3-5: Statistics of TSS (mg/L) from USGS gages in the Bad River watershed. The planned construction period of June through August is highlighted in grey.

Month	No. of Obs.	Min	Max	Mean	Median
January	21	1	223	17	6
February	19	1	25	7	4
March	46	1	2,170	131	25
April	90	4	2,210	258	101
May	87	0	4,670	355	90
June	83	0	2,440	133	14
July	133	0	1,060	34	16
August	351	5	9,810	456	249
September	65	5	484	83	38
October	47	0	1,270	43	11
November	39	1	8,220	330	17
December	25	1	40	9	5

In the June-August period, which aligns with the planned construction phase, approximately one third of observations were less than 20 mg/L, but otherwise ranged in the 100s of mg/L, with a maximum value of 9,810 mg/L (Figure 3-5). The higher values likely correspond with summer storm events and higher river flow periods that carried sediment into the watercourses and/or resuspended sediments from the river bottom. Based on the above analysis, a value of 20 mg/L was identified to be a reasonable approximation of background TSS during non-storm conditions. This value also corresponds to the TSS used in the Operations Assessment (Oil Spill Report, Appendix B) for average river flow conditions (June).

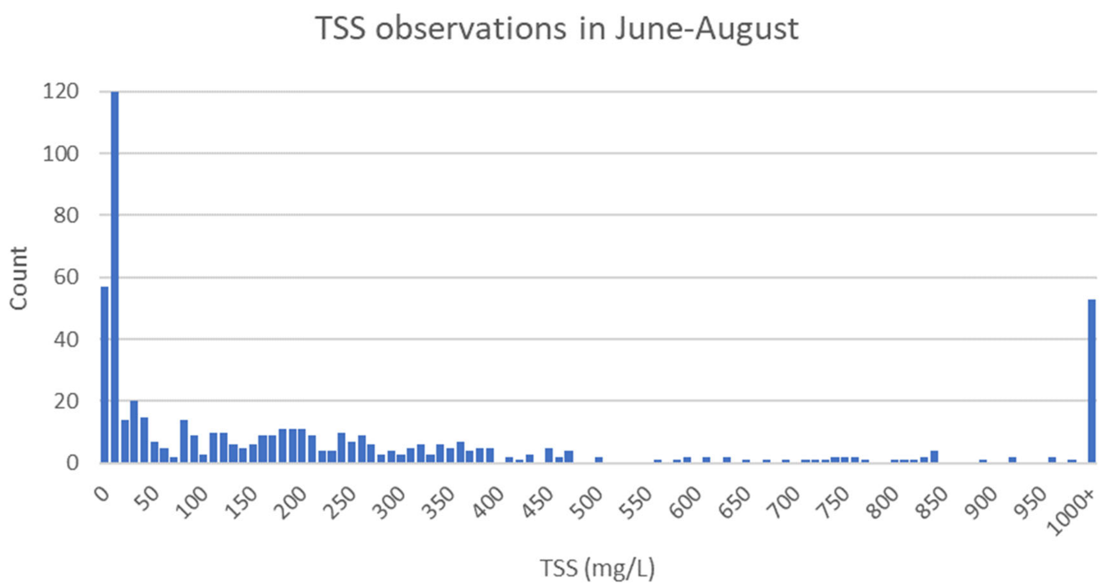


Figure 3-5. Histogram of TSS observations (mg/L) during June-August from USGS gages in the Bad River watershed.

3.4.2 Thresholds

The predicted TSS concentrations, downstream distances, and durations of exposure (time) from the SSFATE sediment discharge modeling were evaluated in the context of a contaminant of concern. The threshold of concern and any regulated values were also compared to historical natural variations in TSS due to different river flow conditions. WDNR holds a water quality standard of 40 mg/L for TSS associated with construction dewatering. In addition, Total Maximum Daily Loads (TMDLs) have been developed for other watersheds in Wisconsin (with urban pollutant issues), for example at 12 mg/L above ambient/background. EPA has also approved water quality standards for waters within the exterior boundaries of the Reservation[4], as described in the Tribe's application for water quality standards (EPA, 2014). These standards note that turbidity “Shall not exceed 5 NTU[5] over natural background turbidity when the background turbidity is 50 NTU or less, or turbidity shall not increase more than 10 percent when the background turbidity is more than 50 NTU.” While TSS is not specifically regulated under these standards, there is a correlation between turbidity and TSS that can be used to assess the equivalent concentration of TSS that might be applied as a potential exceedance.

A simple statistical analysis of turbidity and TSS was conducted using 34 available historical observations of collocated turbidity and TSS measurements at the Bad River gage near Odanah, Wisconsin between 1987 and 1993 (Figure 3-6). TSS concentrations ranged from approximately 1 to 200 mg/L between 0 to 50 NTU, with a strong general trend (r^2 = 88.06%) of greater TSS corresponding with higher levels of turbidity. The linear fit of the data was then used to determine that an increase of 5 NTU over natural background (at 50 NTU), as specified in the Reservation water quality standard for turbidity, would correlate to an increase of approximately 19.3 mg/L TSS.

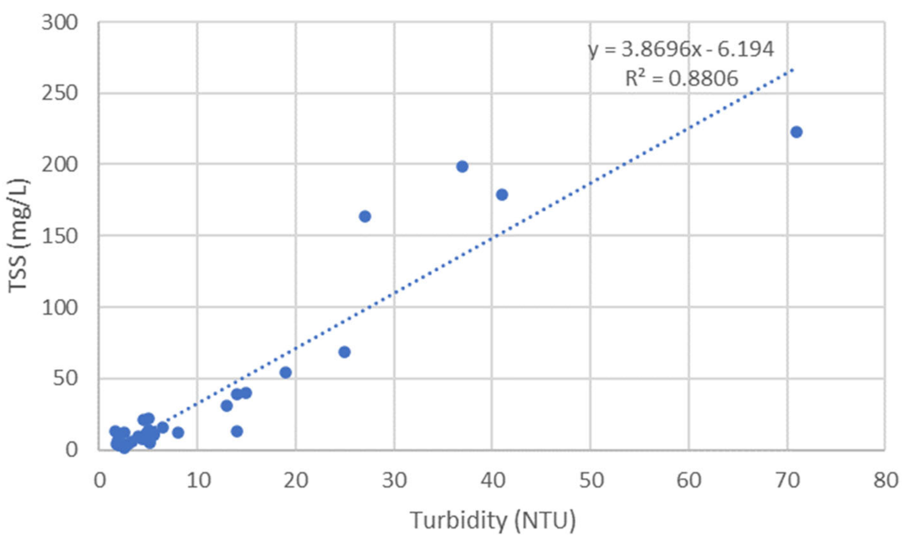


Figure 3-6. Turbidity to TSS relationship based on the limited collocated observation data set, for the Bad River near Odanah, WI.

[4] The downstream distance from the watercourses crossed by the Proposed Route to the Reservation boundary ranges from 2.1 – 23.9 km (1.3 – 14.9 mi). Most of the crossings are approximately 10-15 km (6-9 mi) from the Reservation boundary.

[5] A Nephelometric Turbidity Unit (NTU) is a measure of the opaqueness of a fluid due to the presence of suspended solids (inorganic or biological). The higher the concentration of suspended solids in the water is, the dirtier it looks and the higher the turbidity is.

Based on the above analysis, a **representative calculated TSS threshold of 19 mg/L** above background was used as one reporting threshold within the Reservation to denote a potential exceedance by the Tribe's water quality standards, which would be more conservative (i.e., more protective) than the other identified limits. Additional TSS concentrations of 1 mg/L, 100 mg/L, and 200 mg/L above background were also used as reporting thresholds to interpret model predicted results over greater distances (not only in the Reservation) and to inform comparisons among scenarios and with background values.

3.4.3 Effects of Pipeline Installation

Different crossing methods have the potential to influence the total loading, or amount of sediment that is resuspended into the water column at each watercourse crossing during installation and construction. Suspended sediment concentrations downstream of open-cut pipeline watercourse crossings have been observed at levels from <1 to 11,000 mg/L (Reid and Anderson, 1999). However, changes to streambed conditions were generally short-term. Sediment concentrations downstream of dry trenched crossings, which use dams (e.g., sandbags, coffer dams, steel plate) to isolate the trench, are generally much lower; typically, only 3 - 20 mg/L above upstream (background) levels (Reid et al., 2002). Comparing these values to the observations of monitored TSS concentrations at the three USGS gages resulted in the conclusion that dry trenched crossings using dams may result in detectable elevations during minimum and median TSS periods. However, it is likely that the added TSS from dry trenched crossings would be of the same magnitude or less than the natural variability of each system during periods of time with higher TSS and would be well below natural TSS concentrations associated with spring freshets and summer storm events.

Suspended sediment levels were monitored during construction of pipeline watercourse crossings for the Guardian pipeline from Ixonia to Green Bay Wisconsin in 2008, including upstream and downstream locations, before, during, and after construction (Table 3-6). Pre-construction water testing occurred for all crossings in June of 2008, crossings were constructed from July to November of that year, and post-construction monitoring included water testing conducted between 1 and 11 days after construction (average of 5.4 days post-construction). Peak elevations during construction activities were short lived, with concentrations typically falling to background values or below by the post-construction monitoring period (Natural Resource Group, 2010).

Table 3-6: TSS monitoring results before, during, and after the construction of the Guardian Pipeline (Natural Resource Group, 2010).

		Suspended Sediments (mg/L)														
		Baker Creek	Rock River	Rubicon River	Woodland Creek	Lentz Creek	East Branch of the Rock River	Kummel Creek	West Branch of the Milwaukee River	Sheboygan River	Stony Brook	Killsnake River	North Branch of the Manitowoc River	Plum Creek	Fox River	Duck Creek
Pre-construction	Upstream	20	52	42	160	27	30	41	18	32	13	<4[a]	1	27	n/a	16
	Downstream	21	44	66	160	31	33	42	20	28	18	<4	1	22	n/a	4
Construction	Upstream	88	55	60	30	20	21	4	45	29	13	<4	6	9	8.5	<4
	Downstream	117	55	66	168	82	23	48	45	n/a	27	9	8	12	8.4	7
Post-construction	Upstream	88	55	88	<4	22	18	9	6	62	7	<4	6	14	7.7	<4
	Downstream	68	67	88	<4	35	20	13	23	n/a	6	6	49	13	6.8	<4

[a] The practical lower range of determination for the suspended sediment is 4 mg/L

3.5 Scenarios Modeled

Sediment dispersion modeling was conducted to determine whether the proposed watercourse crossing construction and installation methods would have temporary or permanent impacts on water quality parameters of concern (i.e., TSS). A set of 18 scenarios was developed to encompass the variation in watercourse crossings along the proposed route, as well as the variable environmental and geological conditions that may be present (Table 3-7). These investigated variations included different watercourse crossing sizes, installation methods, river flow/velocity regimes, and sediment types. The scenarios with trenched crossing types were modeled specifically for the summertime period of June-August, when the construction phase of the pipeline would be likely to occur. The HDD scenarios in a large watercourse (i.e., the Bad River) were modeled using representative river flows from throughout the year (January – low, June – average, and April – high) because there is the potential for greater seasonal flexibility for HDD installation, which would occur outside (i.e., adjacent to) the waterway. Very high or flood conditions were not considered in this modeling, as these conditions would not be conducive to installation operations.

All small and medium watercourse scenarios were simulated as dry crossings. Channel width and depth were assumed to be uniform for the entire length of the river, with no catchment basins, such as a pond or a lake, at any point along the channel. As part of the dry crossing installation method, upstream and downstream barriers (i.e., dams) would be constructed in order to dewater the watercourse while the trench was dug. Thus, no sediment loading would be expected during the trenching process itself. Instead, sediment loading is based upon the disturbance of the watercourse substrate during the process of constructing and removing the barriers. Both "fine" and "coarse" sediment types were simulated within the representative small and medium watercourse crossings in the SSFATE model to represent the resuspension of sediments on the river bottom from installation and removal of the dams (Table 3-8 and Section 3.3).

Table 3-7: Hypothetical sediment discharge scenarios used to model the watercourse crossings.

Scenario ID	Watercourse Size (width x depth)	Construction Method / Sediment Release Type	Sediment Type	River Flow / Hydrodynamic Condition
1	Small Watercourse (5 ft x 1 ft)	Trenching	Fine	Low / Slow
2				Avg / Typical
3				High / Fast
4			Coarse	Low / Slow
5				Avg / Typical
6				High / Fast
7	Medium Watercourse (25 ft x 3 ft)	Trenching	Fine	Low / Slow
8				Avg / Typical
9				High / Fast
10			Coarse	Low / Slow
11				Avg / Typical
12				High / Fast
13	Large Watercourse (actual geomorphology of Bad River)	Inadvertent Return (Pilot Hole)	Actual Operations (Drilling Mud)	Low / Slow
14				Avg / Typical
15				High / Fast
16		Inadvertent Return (Final Ream Pass)	Actual Operations (Drilling Mud)	Low / Slow
17				Avg / Typical
18				High / Fast

Table 3-8: Sediment type simulated in SSFATE for each representative watercourse sediment type.

Representative Watercourse Sediment Type	Percent Clay	Percent Fine Silt	Percent Coarse Silt	Percent Fine Sand	Percent Coarse Sand
Fine	50	50	0	0	0
Coarse	0	0	50	50	0

3.6 Sediment Load Development

The determination of the sediment loading rate between the small, medium, and large watercourse crossing scenarios varied in accordance with the anticipated construction activities for each. Construction activities were assumed to be similar for the small- and medium-sized watercourse crossings, in that there would be an upstream and downstream dam installed that would allow for the isolation of the pipeline crossing to enable dry trenching. Following dewatering between the dams, water would be pumped from the upstream dam around the trenched area and down to a point below the downstream dam, during which time pipeline trenching would occur. Note that any sediment suspended during the dewatering period between the upstream and downstream dam was anticipated to captured by a dewatering structure (e.g., straw bales) in an upland well vegetated area prior to release.

The exact method of dam installation differed for the two crossing sizes. For the small watercourse crossings, the sediment load was based on the installation and removal of sandbag dams, while the medium watercourse crossings would involve the installation and removal of water bags (e.g., AquaDams^{TM}) that are capable of holding back larger flows of water. For each method, a sediment loading rate (per meter width of dam) was calculated based on the maximum amount of displaced sediment that might occur, applying a disturbed depth of 6 inches either under the sandbags or for 2 feet in front and 1 foot in back of the AquaDam^{TM}. Based on prior projects, these are conservative, upper end predictions for disturbed volume. Other mitigative measures such as silt screens could be used if disturbances of this degree were anticipated.

The evaluated methods of dam installation for small to medium watercourse crossings (i.e., sandbags and AquaDams^{TM}) considered conservatively large estimates for the sediment load that could be discharged into the watercourse. Other methods of dam installation, such as sheet piles, are anticipated to release roughly equivalent or smaller volumes of sediment during any particular installation or removal phase. In addition, the sediment load would be spread over a longer period of time, further reducing the potential sediment load to the water column. Therefore, similar or lesser effects than those modeled here would be predicted for alternative installation methods. For example, for the first installation phase (12 hours) of an upstream dam across a 25-foot medium watercourse, the total disturbance volume would be 0.66 m^3 for a sheet pile barrier assumed to be completely embedded below the riverbed[6]. The resulting sediment load is smaller than for the modeled AquaDam^{TM} installation (Section 3.6.2), both in magnitude and rate of resuspension.

Construction activities for the large watercourse crossings would involve drilling (utilizing HDD) underneath the watercourse from one side of the watercourse to the other, from points on land that were away from the riverbank, thereby bypassing the waterway entirely. While HDD eliminates any trenching or disturbance from installation of water bags, there is a limited risk of an inadvertent return, whereby pressurized drilling fluids are released through a void or weak point in the overburden. To conservatively model the possibility

[6] The total sediment disturbance of 0.66 m^3 is calculated based upon an assumed 30-foot-deep installation, using sheet pile with a thickness of 0.75 inch, and a watercourse width of 12.5 ft. A barrier of this length is likely to require a two-phase installation over two operational periods during daylight hours with an assumed 12-hour break during nighttime hours.

of such events, scenarios were developed assuming that the entire volume of drilling mud (drilling fluid) exiting the drill hole would enter the water column from either the pilot hole phase (smaller volume) or final ream pass phase (larger volume). The total loading rate was calculated based on the total volume of fluid discharged and the percentage (and density) of bentonite/clay in the drilling mud.

3.6.1 Small Watercourse Sediment Load

The entire construction and installation of the pipeline for the representative small watercourse crossing is anticipated to take place within a single day, within a roughly 20-hour period. The simulated sediment load is based upon the installation and removal of both dams within the first two hours and last two hours of construction activity (Table 3-9, Figure 3-7). For the small watercourse, the magnitude of the sediment load during installation and removal of the upstream dam was based on an assumption that each sandbag was 2 ft wide with a depth of disturbance of 6” (0.5 ft) depth. Thus, a maximum footprint of 2 ft^2 could be disturbed, resuspending 1 ft^3 of sediment for every foot of dam constructed. This value is conservatively high, as it is unlikely that the whole 6” would be disturbed with placement and adjustment of the sandbags. The installation rate for a sandbag dam was assumed to be 5 ft of dam constructed over the 2-hour installation (or removal) time period. Therefore, a total of 5 cubic feet, which is equivalent to 0.141 m^3, of sediment disturbance (i.e., total sediment load) was simulated for both the installation and removal phases of the dam, with a grand total of 0.282 m^3 of sediment simulated as resuspended (Table 3-9). This installation approach is identical to the one used in the Line 3 replacement program in Minnesota.

Table 3-9: Proposed construction activities and resulting sediment load that was simulated in SSFATE for the Small Watercourse scenarios.

Stage	Dam Width (ft)	Duration (hr)	Sediment Discharged	Sediment Loading (m^3 sediment / ft of dam)	Installation Rate (ft of dam / s)	Total Sediment Load (m^3)
Upstream dam installation	2	2	Yes	0.028	0.00069	0.141
Downstream dam installation	-	2	No			
Trenching	-	12	No			
Downstream dam removal	-	2	No			
Upstream dam removal	2	2	Yes	0.028	0.00069	0.141
Total Time:		20			**Total Load:**	**0.282**

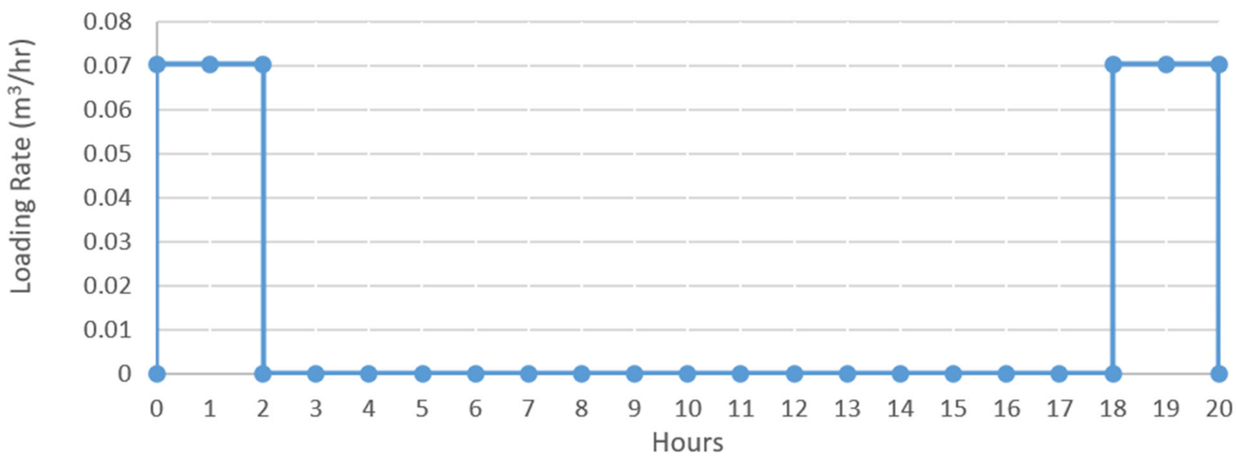


Figure 3-7: Model construction timing for sediment load calculation for small watercourse crossings.

3.6.2 Medium Watercourse Sediment Load

The entire construction and installation of the pipeline for the representative medium watercourse crossing is anticipated to take place over approximately 32 hours. The simulated sediment load is based upon the installation and removal of both dams within the first five hours and last five hours of construction activity (Table 3-10, Figure 3-8). For the medium watercourse, the magnitude of the sediment load during installation and removal of the upstream dam was based on a 9-ft wide AquaDam™, as required for a water control depth of 3 ft (AquaDam, 2004). The assumption was made that a disturbance of up to 6" (0.5 ft) depth could occur over 3 ft of the dam (2 ft downstream and 1 ft upstream distance), which represents placement and stabilization activities that might be performed along the dam during its installation, as well as displacement of sediment at the upstream/downstream edges of the dam where it meets water. Thus, a maximum footprint of 3 ft^2 could be disturbed, resuspending 1.5 ft^3 of sediment for every foot of dam constructed. This value is conservatively high, as it is unlikely that the whole 6" of sediment would be resuspended during placement and adjustment of the AquaDam™. The installation rate for an AquaDam™ was assumed to be 25 ft of dam constructed over the 5-hour installation (or removal) time period. Therefore, a total of 37.5 cubic feet, which is equivalent to 1.06 m^3, of sediment disturbance (i.e., total sediment load) was simulated for both the installation and removal phases of the dam, with a grand total of 2.12 m^3 of sediment simulated as resuspended (Table 3-10).

Table 3-10. Proposed construction activities and resulting sediment load that was simulated in SSFATE for the Medium Watercourse scenarios.

Stage	Dam Width (ft)	Duration (hr)	Sediment Discharged	Sediment Loading (m^3 sediment / ft of dam)	Installation Rate (ft of dam / s)	Total Sediment Load (m^3)
Upstream dam installation	9	5	Yes	0.042	0.0014	1.06
Downstream dam installation	-	5	No			
Trenching	-	12	No			
Downstream dam removal	-	5	No			
Upstream dam removal	9	5	Yes	0.042	0.0014	1.06
Total Time:		**32**			**Total Load:**	**2.12**

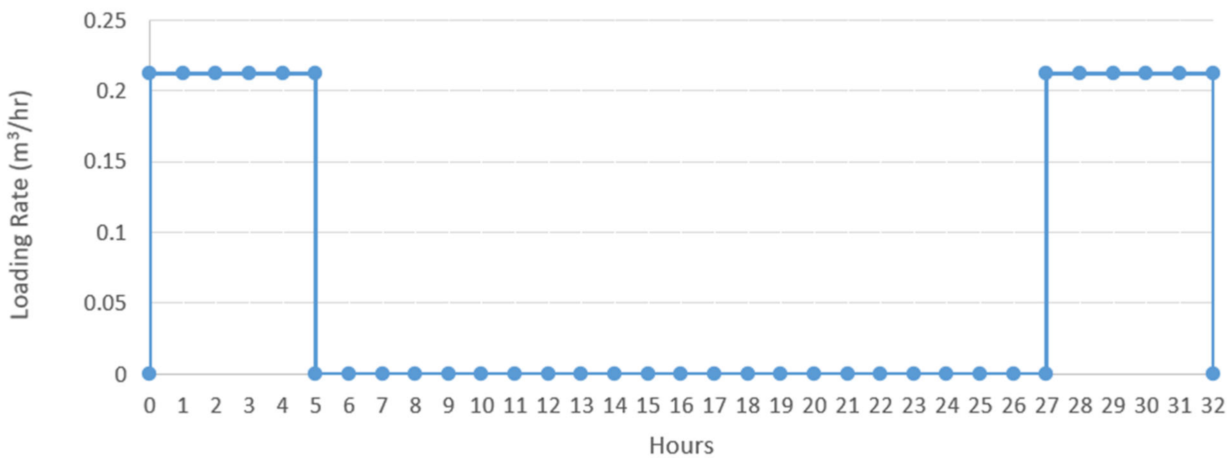


Figure 3-8: Model construction timing for sediment load calculation for medium watercourse crossings.

3.6.3 Large Watercourse Sediment Load

The specifications of an inadvertent return for an HDD crossing construction on a large watercourse (here modeled at the Proposed Route crossing of the Bad River) were obtained from Enbridge (Enbridge, 2022b). There are four possible drilling activities that could result in an inadvertent return including: the initial pilot hole boring, the ream pass and swab passes that expand the initial hole, and the pipeline pullback. The initial pilot hole was selected for simulating the smaller potential volume of an inadvertent release of drilling fluid, as the diameter of the hole and resulting volume of drilling fluid would be smallest (Table 3-11). The final ream pass captures the largest amount of drilling mud used (largest diameter and highest pump rate) and therefore represents the greatest potential release volume in the event of an inadvertent return. The release rate for each inadvertent return is defined by the pump rate through the borehole at 2 m^3/min for the pilot hole and 4 m^3/min for the final ream pass. The duration (1 hour for both) was provided by Enbridge, based on a conservatively large amount of time it may take to recognize and confirm that an advertent return to the surface was occurring, shut down HDD operations, and install secondary controls to contain and stop the discharge of drilling fluid. The calculated total drilling fluid discharge volumes for the pilot hole and the final ream pass were conservatively maximized as 120 m^3 and 240 m^3, respectively, which would assume that the pump continued to run at 2 m^3/min or 4 m^3/min for 60 minutes after the inadvertent return began (an unrealistically long period of time that conservatively maximized the volume), or a shorter period of time with subsequent release of drilling fluid within the HDD borehole (i.e., drain down). In the actual event of a complete (100%) inadvertent return into the water column, observers would likely spot the release within minutes, initiating a complete shut-down of drilling operations, thus reducing the total volume potentially released into the environment.

Table 3-11. Proposed construction activities for the Large Watercourse scenarios.

Release Site	HDD Operation	Total Volume of Drilling Fluid (m^3)	Bentonite Load (MT)	Total Release Duration (hr)[c]	Bentonite Load Rate (MT/hr)
Large Watercourse	Pilot Hole[a]	120	5.52	1.0	5.52
Large Watercourse	Final Ream Pass[b]	240	11.04	1.0	11.04

Notes: a) Installation details for the pilot scenarios were as follows: Diameter = 12"; Duration = 1 hour; Production Rate = 2 m^3/min; Volume of fluid = 2 m^3/min * 1 hours = 120 m^3.

b) Reaming scenarios were assumed to follow the largest production rate (i.e., the ream pass with the greatest amount of sediment produced). Installation details for the final pass reaming scenarios were as follows: Diameter = 48"; Duration = 1 hour; Production Rate = 4 m^3/min; Volume of fluid = 4 m^3/min * 1 hour = 240 m^3.

The volume of bentonite hypothetically released for each construction activity was calculated as a function of the percentage of bentonite in the drilling fluid (Table 3-12). The bentonite was assumed to be fully distributed in the drilling fluid, with no consideration for clumping and no need for additives. These modeling assumptions maximized the potential for particles to remain in the water column, disperse, and therefore settle over a wider area. The volume was converted to mass using an assumed drilling fluid density (1,150 kg/m^3) and an estimate for bentonite particle density (2,650 kg/m^3) from Clays and Clay Minerals, Technical Note (1988) and Kiviranta and Kumpulainen (2011). With the total mass calculated and the release duration specified, the bentonite load rate (in MT/hr) was able to be specified for input to the sediment transport model (Table 3-11). For all scenarios, the hypothetical site of each inadvertent return was modeled in the center of the Proposed Route crossing of the Bad River.

Table 3-12. Drilling mud composition and sediment details simulated in SSFATE for the Large Watercourse scenarios.

Activity	Drilling Fluid Bulk Density (kg/m^3)	Bentonite Bulk Density (kg/m^3)	Percentage of Water (%)	Percentage of Clay (%)
Pilot Hole	1,150	2,650	96	4
Reaming	1,150	2,650	96	4

4 MODELING APPLICATIONS

4.1 Small and Medium Watercourse Model Applications

The D-FLOW FM model was used to develop hydrodynamic model applications and datasets for different watercourse size and flow combinations that were used as sediment dispersion modeling inputs (Table 3-7). These applications included the development of uniform rectilinear grids for the representative small and medium watercourses that reflected the appropriate channel size (fixed width and depth). The model was forced at the open boundary with a volumetric flow of water, and tuned until the model predicted current speeds matched the established targeted speeds for each river flow condition (Table 3-7) based on the analysis described in Section 3.2. The resulting current datasets of uniform and constant velocity (i.e., steady state) were used as inputs to the sediment dispersion modeling scenarios.

For the purposes of this model application, it was assumed that the river flow was incompressible, the depth was small compared to horizontal length scales (the shallow water assumption), and the fluid was in hydrostatic balance.

The boundary conditions specified for the model applications were as follows:

- The flux of water through channel sides and the bottom was zero.
- The flow boundary condition was provided as input at one end of the channel, while the outflow exiting through the other end was defined as an open boundary (Figure 4-1).
- Free-slip conditions were assumed at the sides.

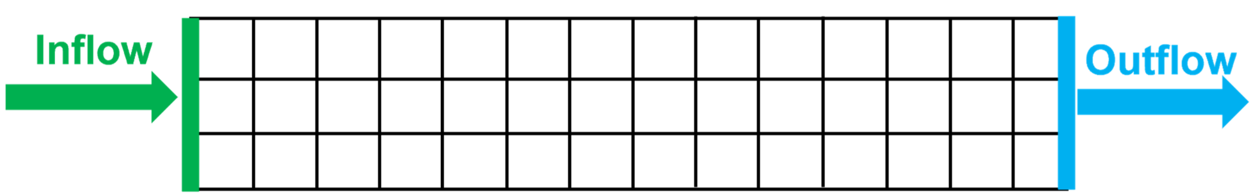


Figure 4-1: Simplified schematic of the hydrodynamic model grid for a rectangular channel.

4.2 Bad River Model Application

4.2.1 River Grid

Two hydrodynamic model grids were created to capture the Bad River flow conditions (one grid for low and average flow conditions and another for high flow conditions). The high river flow gridding included additional current vectors through an open oxbow downstream of the Existing Route crossing (Horn et al., 2022). That oxbow was closed off in the low and average river flow grid. Each Bad River grid extended from more than 10 km (6.2 mi) upstream (i.e., south) of the Proposed Route crossing to approximately 78 km (48.5 mi) downstream (i.e., north) of the Proposed Route crossing at the entrance of Lake Superior and included the

Bad River Slough. Note that the hydrodynamic grids were larger than the model domain. Different size grid cells were used to characterize the hydrodynamics, as higher resolution grid cells are required to capture smaller scale differences in the speed and direction of currents in portions of the river that were more variable (especially at river bends and narrow sections). The higher resolution gridding ensured that there were multiple grid cells spanning the channel, allowing for variable flow (i.e., higher river flow in the center of the channel or near the outer bank). Lower resolution, larger grid cells were used in regions where the river was fairly straight and where the river was wider. Grid cell resolution in the Bad River varied from approximately 6 m x 6 m (20 ft x 20 ft) to 100 m x 20 m (328 ft x 66 ft) within the study area (detailed maps available in Horn et al., 2022).

4.2.2 Boundary Conditions

The edges of the BFHYDRO model grid were designated as either closed boundaries for land or open boundaries to allow the model to be driven by volume flow from upstream and contributing tributaries. The model application was developed assuming that fluid was in hydrostatic balance and the discharge was incompressible.

The boundary conditions specified for the model applications were as follows:

- The flux of water through the channel sides and bottom was zero,
- Bottom friction was negligible,
- The upstream White River discharge rate was used for the inflow boundary at the start of the model domain. For the high flow scenario, additional inflow from the White River was integrated at that junction, and
- The outflow exited through the end of the modeling domain (at Lake Superior), which was defined as an open boundary.

4.2.3 Flow Inputs

Flow information for the Bad River was obtained from the USGS NHDPlus dataset (USGS, 2020b). The NHDPlus dataset includes information for each segment of the watercourse. The data were then compared with USGS stream gage data at two points along the Bad River near Odanah, WI and Mellen, WI (USGS, 2020a, 2022). It was determined that the NHDPlus dataset provided a more complete set of data (i.e., along the entire river, by segment/reach) to use as inputs to the BFHYDRO model, when compared to the USGS gage data at two points. The hydrodynamic model was therefore tuned to the NHDPlus river flow (low, average, and high) throughout the river, with the USGS gage data used to validate the current velocity. The current speeds predicted for the high, average, and low river flow conditions are depicted for the first half of the modeled extent to highlight the variability in river current by season and location (Figure 4-2 through Figure 4-4). Additional figures depicting current velocities for the lower half of the model extent, including the existing Line 5 crossing of the Bad River (at “the meander”) downstream to Lake Superior, are provided in Horn et al. (2022).

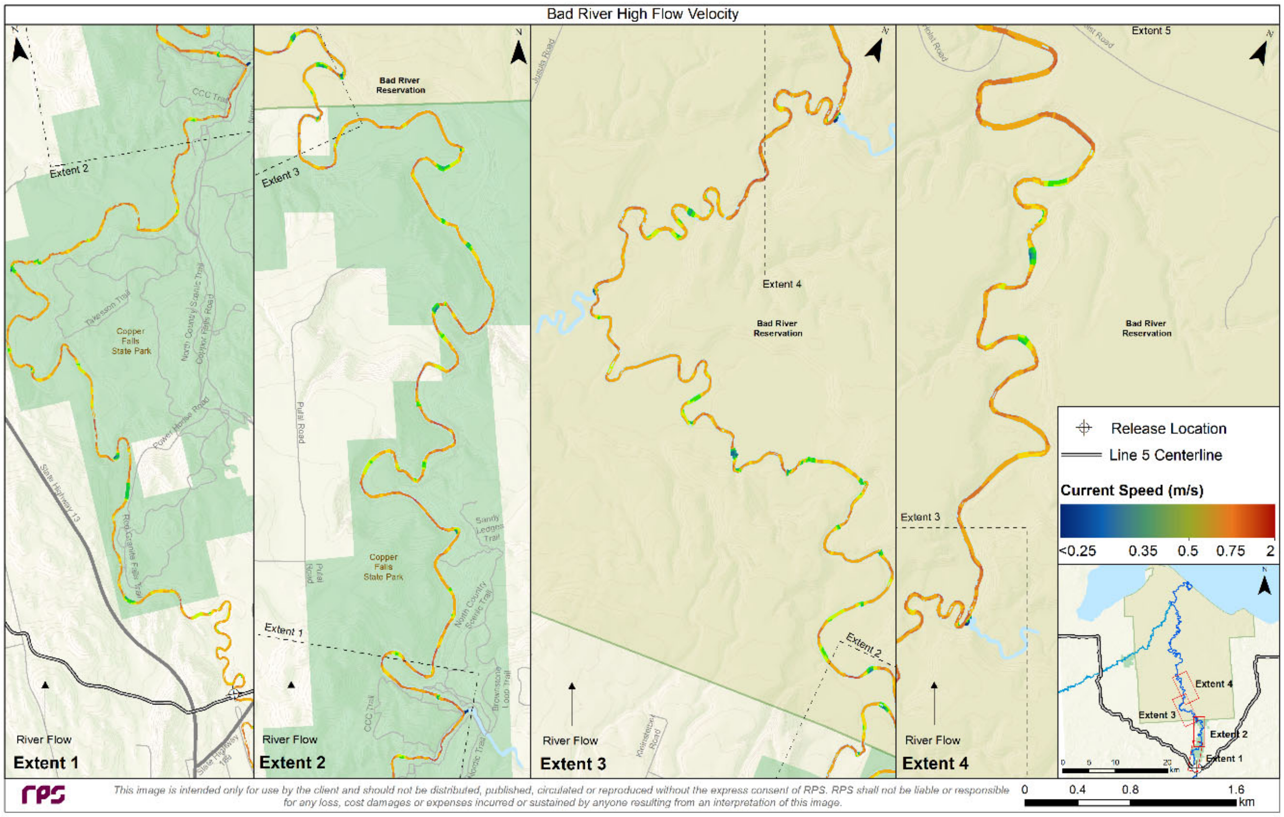


Figure 4-2. Model-predicted current speeds in the first half of the Bad River study area under the high river flow conditions. The inset depicts the full model extent, while the red boxes highlight the segmentation into Extents 1-4 that are provided in the larger panels.

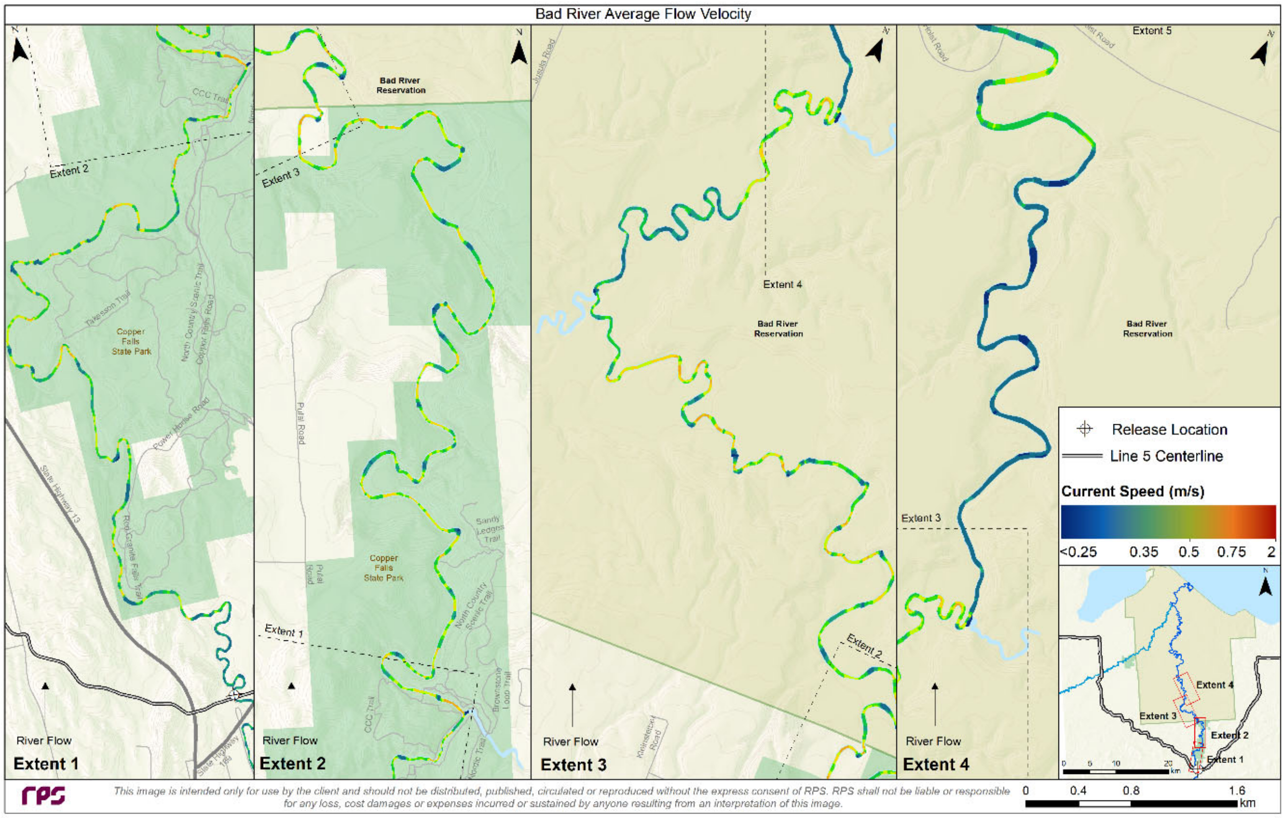


Figure 4-3. Model-predicted current speeds in the first half of the Bad River study area under the average river flow conditions. The inset depicts the full model extent, while the red boxes highlight the segmentation into Extents 1-4 that are provided in the larger panels.

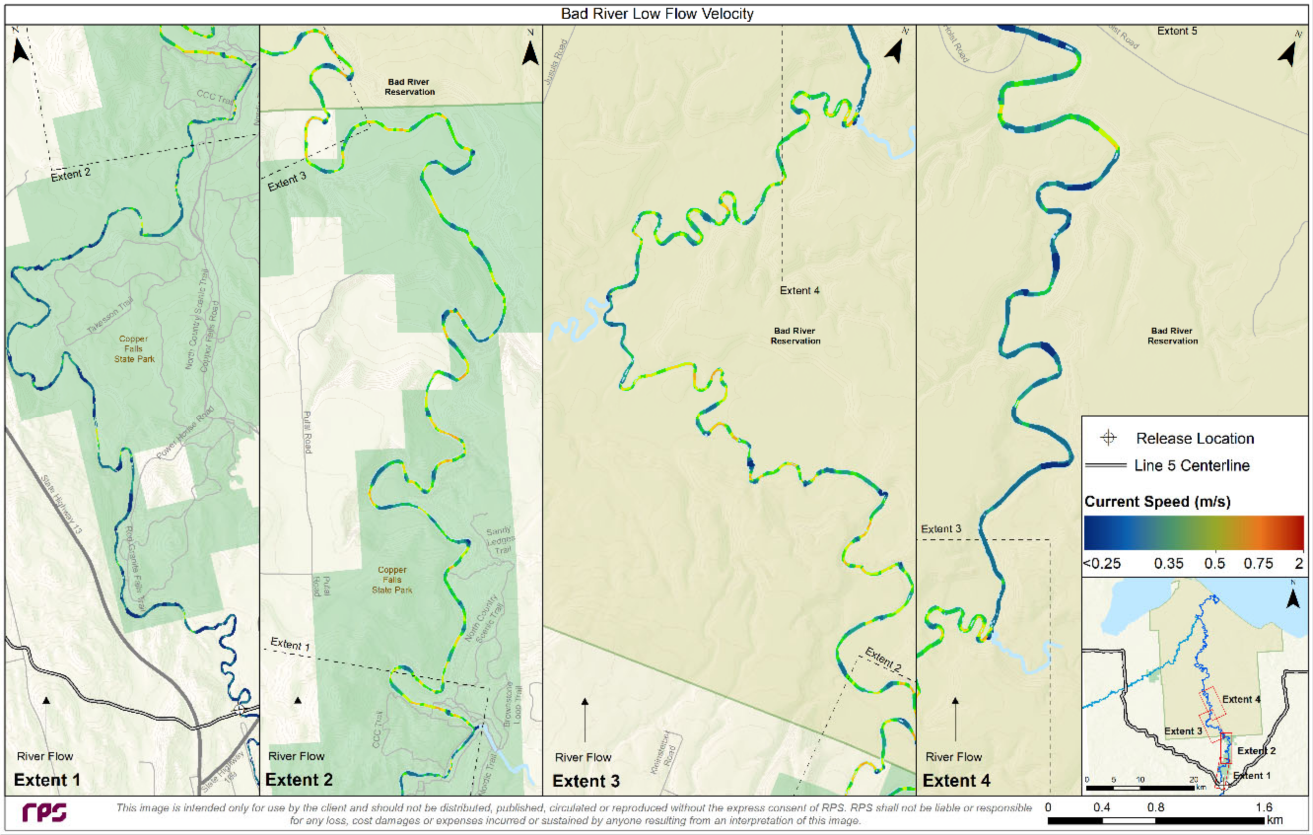


Figure 4-4. Model-predicted current speeds in the first half of the Bad River study area under the low river flow conditions. The inset depicts the full model extent, while the red boxes highlight the segmentation into Extents 1-4 that are provided in the larger panels.

4.3 SSFATE Model Application

Setup of an SSFATE model application scenario consists of defining environmental, operational, and numerical parameters. For the applications in the small and medium watercourses, the characterization of environmental conditions included the definition of the uniform rectangular channel and associated current velocity data for the specific river flow condition described in Table 3-7. For the application in the large watercourse, environmental conditions and river currents from the 3D hydrodynamic modeling of the Bad River (described in Section 4.2) were used.

The operational definition included the specification of the sediment source for each scenario. Generally, the sediment source definition describes:

- The geographic extent of the activity (point release versus line source [route]),
- Spatially varying sediment characteristics including sediment grain size and moisture content,
- Timing and duration of construction activities,
- Sediment volumes associated with the activity,
- Loss (resuspension) rates for the activity, and
- The vertical distribution of sediments as they are initially released to the water column.

For this study, the sediment source was defined as a time-varying moving flux along a line, with the flux intensity defined by the installation or removal rate as defined in Table 3-9 for the small watercourse, Table Table 3-10 for the medium watercourse, and Table 3-11 for the large watercourse. All of the sediment that was disturbed was assumed to be resuspended uniformly within the bottom 1 ft of the small and medium watercourses and uniformly within the bottom ~3 ft of the large watercourse.

5 SEDIMENT MODELING RESULTS

Sediment modeling was performed to assess the potential impacts to watercourses from pipeline installation construction activities. A total of eighteen model scenarios were simulated (Table 3-7). The model simulations were run with a 6-second time step and produced time-varying gridded predictions of TSS above background values as well as the thickness of sediment deposition. While calculated at 6-second intervals, the predicted output was provided at 2-minute intervals to provide the following data for each scenario:

- Downstream movement and timing of TSS above background value,
- Peak TSS concentrations above background value in the water column,
- Duration of exposure, and
- Depositional thickness.

While the model predicts TSS above ambient conditions, for brevity herein the predicted levels will be referred to simply as TSS. Predictions of TSS were queried at six different locations within each watercourse at varying distances from the construction activity (source) for each scenario. The results were queried from the center of the river channel near the source and at distances of approximately 50 m, 100 m, 250 m, 500 m, and 1,000 m downstream. In each case, the presented time series reflects the maximum concentration predicted in the entire vertical water column, though in all cases the plume became well mixed vertically within a short distance from the source.

5.1 Small Watercourse

The predicted plume concentrations for the small watercourse simulations were directly related to the timing of the sandbag dam installation and removal activities, with two distinct pulses of TSS aligning with dam installation and then removal (Figure 5-1). Because the watercourse was so small and well mixed, the predicted plume concentrations were essentially uniform across the narrow channel. TSS concentrations were greatest near the source, attenuating as downstream distance increased (Figure 5-1, Table 5-1). This attenuation correspondingly resulted in larger cumulative areas exceeding the 1 mg/L and 19 mg/L reporting thresholds (up to 1,269 m^2) and very small areas (less than 1 m^2) exceeding the higher reporting thresholds (100 mg/L, and 200 mg/L) (Table 5-2). The magnitudes of TSS concentrations were generally highest for the low flow scenarios and lowest for the high flow scenarios (e.g., fine sediment scenarios in Figure 5-1). This trend reflected greater dispersion potential in faster waterways of the same size, resulting from increased water velocity and turbulence. The majority of the coarse material settled to the riverbed in those scenarios because it settles more rapidly than fine material. Therefore, downstream TSS concentrations in the average and low flow scenarios with coarse sediment were quite low because most of the sediment had already settled out near the release location. The start and end times of the elevated TSS were predicted to arrive at successively later times at each downstream location, as downstream transport was defined by the velocity of the watercourse, but the dilution, dispersion, and deposition also resulted in concentrations rapidly decreasing so that the predicted duration above the 19 mg/L threshold became shorter with increasing distance downstream (Table 5-3).

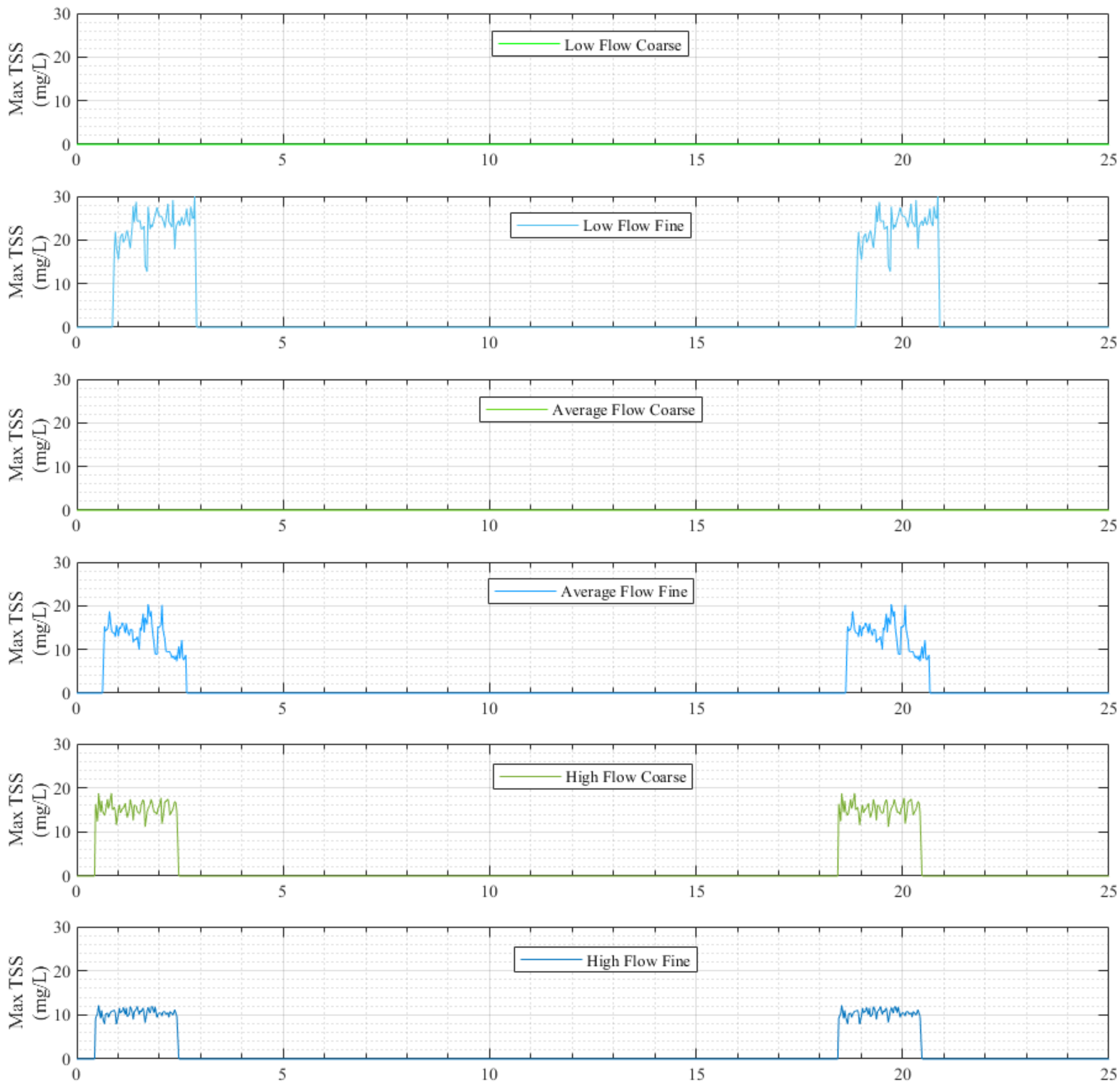


Figure 5-1: Time series data of predicted maximum TSS concentrations above background at 500 m distance from the source for the small watercourse scenarios (from top to bottom): Low Flow – Coarse, Low Flow – Fine, Average Flow – Coarse, Average Flow – Fine, High Flow – Coarse, and High Flow – Fine.

Table 5-1: Maximum predicted TSS concentrations as a function of distance from the source for all small watercourse scenarios.

Distance From Upstream Dam (m)	Maximum TSS (mg/L) – Small Watercourse					
	Low Flow		Average Flow		High Flow	
	Coarse	Fine	Coarse	Fine	Coarse	Fine
0-5	18.6	46	34	35	24	29
50	<1	39	<1	33	24	18
100	<1	39	<1	27	23	14
250	<1	30	<1	25	21	15
500	<1	30	<1	20	19	12
1,000	<1	<1	<1	<1	<1	<1

Table 5-2: Cumulative area exceeding specified TSS reporting thresholds for all small watercourse scenarios.

TSS reporting threshold (mg/L)	Cumulative Area exceeding threshold (m^2) – Small Watercourse					
	Low Flow		Average Flow		High Flow	
	Coarse	Fine	Coarse	Fine	Coarse	Fine
1	26	1,269	38	1,269	1,268	1,269
19	6	1,268	3	1,106	542	408
100	<1	<1	<1	<1	<1	<1
200	<1	<1	<1	<1	<1	<1

Table 5-3: Hours TSS predicted to be >19 mg/L as a function of distance from the source for all small watercourse scenarios.

Distance From Upstream Dam (m)	Hours TSS is over 19 mg/L – Small Watercourse					
	Low Flow		Average Flow		High Flow	
	Coarse	Fine	Coarse	Fine	Coarse	Fine
0	<0.1	4.1	4.1	4.1	4.1	4.1
50	<0.1	4.1	<0.1	4.1	4.1	<0.1
100	<0.1	3.9	<0.1	4.0	4.1	<0.1
250	<0.1	3.9	<0.1	3.1	1.2	<0.1
500	<0.1	3.5	<0.1	0.2	<0.1	<0.1
1,000	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

In the coarse sediment simulations, peak TSS concentrations of approximately 20-35 mg/L were predicted near the source, with concentrations rapidly decreasing to below the 1 mg/L reporting limit (Figure 5-1). TSS was predicted to attenuate as the coarser (larger) sediment settled out of the water column, depositing on the river bottom near the release point before reaching the downstream locations (Figure 5-2).

For the coarse sediment scenarios, the depositional area decreased as the specified thresholds increased and as a function of distance downstream. Depositional thickness exceeding 1 mm was predicted to extend up to 5 m downstream, totaling 1-2 m^2 of area, while deposition exceeding the 0.1 mm thickness threshold was predicted down to 13 m distance, covering an area of approximately 13 m^2 (Table 5-4, Table 5-5). In a natural watercourse with spatially- and time-varying flows, complex geomorphology, and non-uniform sediment compositions, the settling rate and depositional footprints may result in pockets of higher and lower deposition than modeled may occur, which would result in variations in TSS in the water column as well.

Attenuation of the TSS in the fine sediment simulations was less than that of the coarse sediment simulations (Figure 5-2). The slow settling rates of the small particles and the turbulence within the water column kept the fine sediments in suspension for a longer period of time. Peak concentrations of similar magnitude to the coarse sediment scenarios (29-46 mg/L) were predicted near the source, with slightly decreased concentrations of 12-30 mg/L at the 500 m downstream (Figure 5-1). The lower concentrations at further downstream points in the fine sediment simulation were the result of dispersion and dilution of TSS throughout the water column, as opposed to deposition. The attenuation of peak concentrations as a function of distance from the source is presented in Figure 5-2. Within this modeled channel with uniform velocity, deposition of finer sediment on the river bottom was not predicted to occur above the specified thresholds (Table 5-4) and therefore resulted in no predicted depositional footprint above the thresholds (Table 5-5). However, deposition below the 0.1 mm threshold was predicted throughout the model domain.

The durations of exposure >19 mg/L near the source were predicted to be very similar for the fine sediment scenarios at approximately 4 hours of exposure, dropping abruptly to less than <0.1 hr when the in-water concentrations fell below that threshold due to dispersion, dilution, and deposition below the 0.1 mm threshold (Table 5-3).

Table 5-4: Maximum predicted distance downstream of depositional thickness above specified thresholds for all small watercourse scenarios.

Small Watercourse Scenario		Downstream Distance to Threshold (m)				
Flow*	Sediment	0.1 mm	1 mm	2 mm	5 mm	10 mm
Low	Coarse	10	5	3	-	-
	Fine	-	-	-	-	-
Average	Coarse	13	-	-	-	-
	Fine	-	-	-	-	-
High	Coarse	-	-	-	-	-
	Fine	-	-	-	-	-

* The modeled velocities in the fine sediment scenarios and the coarse sediment, high flow scenarios, were large enough to prevent significant deposition due to the shear stress on the watercourse bottom (turbulence), keeping sediments suspended in the water column.

Table 5-5: Area of predicted deposition over specified thresholds for all small watercourse scenarios.

Small Watercourse Scenario		Total Area over Threshold (m^2)				
Flow	Sediment	0.1 mm	1 mm	2 mm	5 mm	10 mm
Low	Coarse	10	2	1	<1	<1
	Fine	<1	<1	<1	<1	<1
Average	Coarse	13	<1	<1	<1	<1
	Fine	<1	<1	<1	<1	<1
High	Coarse	<1	<1	<1	<1	<1
	Fine	<1	<1	<1	<1	<1

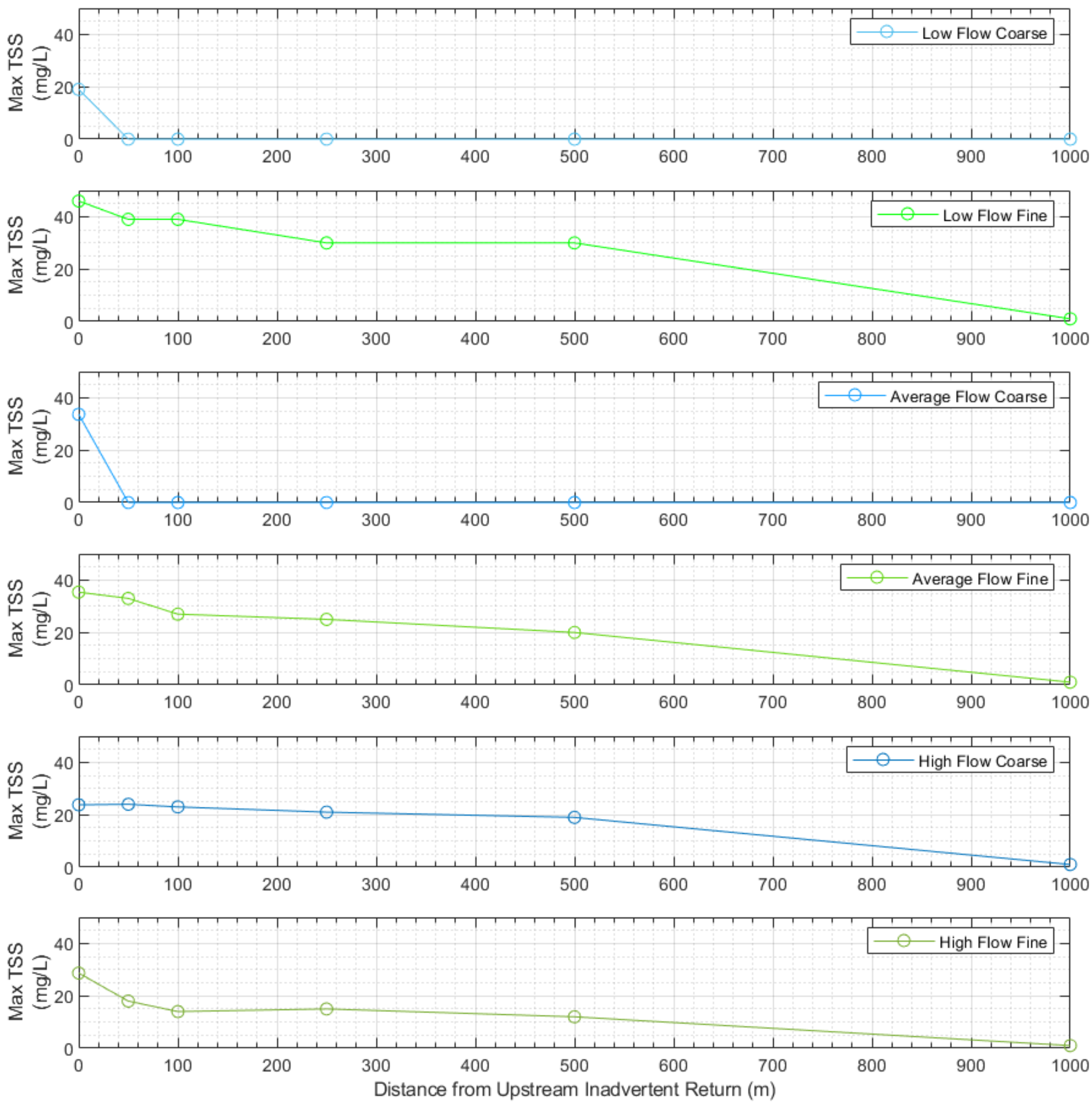


Figure 5-2: Maximum predicted TSS above background as a function of distance from the source for the small watercourse scenarios (from top to bottom): Low Flow – Coarse, Low Flow – Fine, Average Flow – Coarse, Average Flow – Fine, High Flow – Coarse, and High Flow – Fine.

5.2 Medium Watercourse

The predicted plume concentrations for the medium watercourse simulations were directly related to the timing of the water dam installation and removal activities, with two distinct pulses of TSS aligning with dam installation and then removal (Figure 5-3). As with the small watercourse, the medium watercourse is also small enough to be relatively well mixed horizontally, with the predicted plume concentrations nearly uniform across the narrow channel beginning a few tens of meters downstream. TSS concentrations were greatest near the source, attenuating as downstream distance increased (Table 5-6). This attenuation correspondingly resulted in larger cumulative areas exceeding the 1 mg/L reporting threshold (up to 30,000 m^2) and smaller areas (less than 140 m^2) exceeding the higher reporting thresholds (19 mg/L, 100 mg/L, and 200 mg/L) (Table 5-7). The magnitudes of TSS concentrations were generally highest for the low flow scenarios and lowest for the high flow scenarios, which reflected greater dilution potential with increasing water velocity and turbulence, although deposition would also reduce in-water concentrations for some scenarios. The period of elevated TSS above 19 mg/L near the source was predicted to last approximately the duration of active sediment discharge (two 5-hr periods), but dilution and deposition resulted in concentrations downstream rapidly decreasing below this threshold and not enduring in the model (Table 5-8).

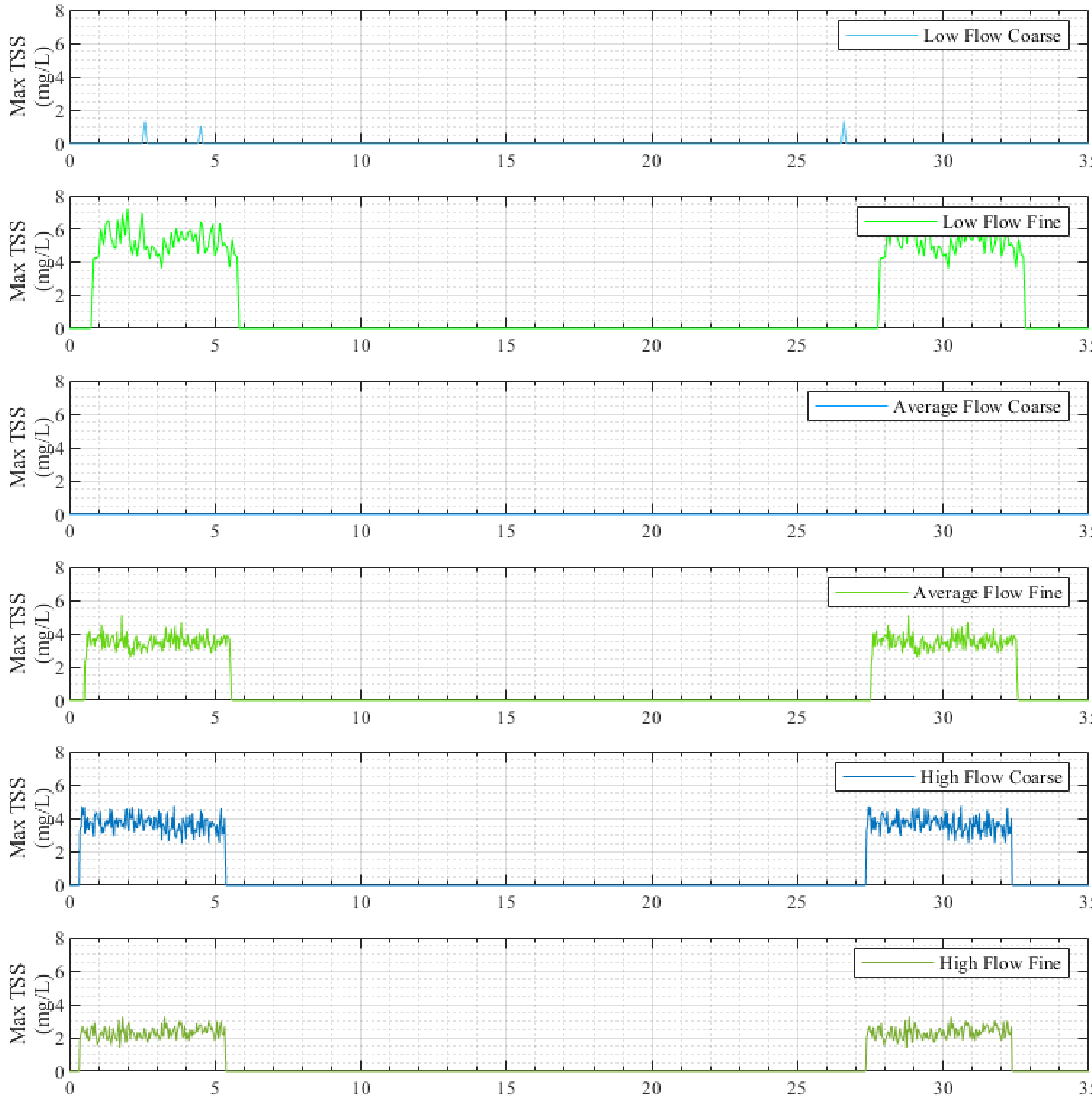


Figure 5-3: Time series data of predicted maximum TSS concentrations above background at 500m distance from the source for the medium watercourse scenarios (from top to bottom): low flow Low Flow – Coarse, Low Flow – Fine, Average Flow – Coarse, Average Flow – Fine, High Flow – Coarse, and High Flow – Fine.

Table 5-6: Maximum predicted TSS concentrations as a function of distance from the source for all medium watercourse scenarios.

Distance From Upstream Dam (m)	Maximum TSS (mg/L) – Medium Watercourse					
	Low Flow		Average Flow		High Flow	
	Coarse	Fine	Coarse	Fine	Coarse	Fine
0-5	127	132	125	128	117	116
50	6	16	6	8	12	9
100	4	15	1	5	9	4
250	2	11	<1	5	6	3
500	1	7	<1	5	5	3
1,000	1	7	<1	4	4	3

Table 5-7: Cumulative area exceeding specified TSS reporting thresholds for all medium watercourse scenarios.

TSS reporting threshold (mg/L)	Cumulative Area exceeding threshold (m^2) – Medium Watercourse					
	Low Flow		Average Flow		High Flow	
	Coarse	Fine	Coarse	Fine	Coarse	Fine
1	5,854	29,890	2,140	30,000	29,870	29,760
19	9	136	25	33	46	31
100	1	1	1	1	1	1
200	<1	<1	<1	<1	<1	<1

Table 5-8: Hours TSS predicted to be >19 mg/L as a function of distance from the source for all medium watercourse scenarios.

Distance From Upstream Dam (m)	Hours TSS is over 19 mg/L – Medium Watercourse					
	Low Flow		Average Flow		High Flow	
	Coarse	Fine	Coarse	Fine	Coarse	Fine
0	10.0	10.0	10.0	10.0	10.0	10.0
50	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
100	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
250	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
500	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1,000	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

In the coarse sediment simulations, peak TSS concentrations of 117-127 mg/L were predicted near the source, with concentrations decreasing quickly below background (20 mg/L) by the 50 m downstream location (Table 5-6). This initial attenuation was due to dispersion and dilution occurring across the waterway and also vertically, as the released sediment was assumed to be resuspended uniformly in the bottom 1 ft of the watercourse. TSS was predicted to continue attenuating (down to <1-4 mg/L by 1,000 m distance downstream) as the large sediment grains were predicted to drop out of the water column, settling on the river bottom over the time it took to reach the downstream locations (Figure 5-4). For the coarse sediment simulations, the depositional area decreased as the specified thresholds increased and as a function of distance downstream. Depositional thickness exceeding 10 mm was predicted to extend 2 m downstream, totaling ~1 m^2 of area, while deposition exceeding the 0.1 mm thickness threshold was predicted down to 30 m, covering an area of approximately 70 m^2 (Table 5-9, Table 5-10). The model predicted a very large area of deposition less than the 0.1 mm reporting threshold, throughout the model domain. In a watercourse with more variable flows and complex geomorphology, there may be pockets of higher and lower deposition than modeled here.

Attenuation of the TSS in the fine sediment simulations was less than that of the coarse sediment (Figure 5-4). The slow settling rates of the small particles and the turbulence within the water column kept the fine sediments in suspension for a longer period of time. Peak concentrations of similar magnitude to the coarse sediment scenarios (116-132 mg/L) were predicted near the source, with significant attenuation in the first 50 m due to dilution and dispersion throughout the water column, as opposed to deposition (Table 5-6, Figure 5-4). Less attenuation occurred at distances farther downstream (beyond 50 m), reaching 3-7 mg/L at 1,000 m downstream. Within this modeled channel, with uniform constant velocity, deposition of finer sediment on the river bottom was not predicted to occur above the specified thresholds (Table 5-9) and therefore resulted in no predicted depositional footprint above the thresholds (Table 5-10). However, deposition below the 0.1 mm threshold was predicted throughout the model domain. Fine sediment particles were predicted to spread out slightly more than the coarse sediment particles due to dispersion and diffusion. The durations of exposure >19 mg/L near the source were predicted to be very similar for the fine sediment scenarios at approximately 10 hours of exposure, dropping abruptly to less than <0.1 hr when the in-water concentrations fell below that threshold due to dispersion, dilution, and deposition below the 0.1 mm threshold (Table 5-8).

Table 5-9: Maximum predicted distance downstream of depositional thickness above specified thresholds for all medium watercourse scenarios.

Medium Watercourse Scenario		Downstream Distance to Threshold (m)				
Flow*	**Sediment**	**0.1 mm**	**1 mm**	**2 mm**	**5 mm**	**10 mm**
Low	Coarse	30	11	7	3	2
	Fine	-	-	-	-	-
Average	Coarse	30	5	3	-	-
	Fine	-	-	-	-	-
High	Coarse	-	-	-	-	-
	Fine	-	-	-	-	-

* The modeled velocities in the fine sediment scenarios and the coarse sediment, high flow scenarios, were large enough to prevent significant deposition due to the shear stress on the watercourse bottom (turbulence), keeping sediments suspended in the water column.

Table 5-10: Area of predicted deposition over specified thresholds for all medium watercourse scenarios.

Medium Watercourse Scenario		Total Area over Threshold (m^2)				
Flow	**Sediment**	**0.1 mm**	**1 mm**	**2 mm**	**5 mm**	**10 mm**
Low	Coarse	70	18	9	2	1
	Fine	<1	<1	<1	<1	<1
Average	Coarse	72	10	3	<1	<1
	Fine	<1	<1	<1	<1	<1
High	Coarse	<1	<1	<1	<1	<1
	Fine	<1	<1	<1	<1	<1

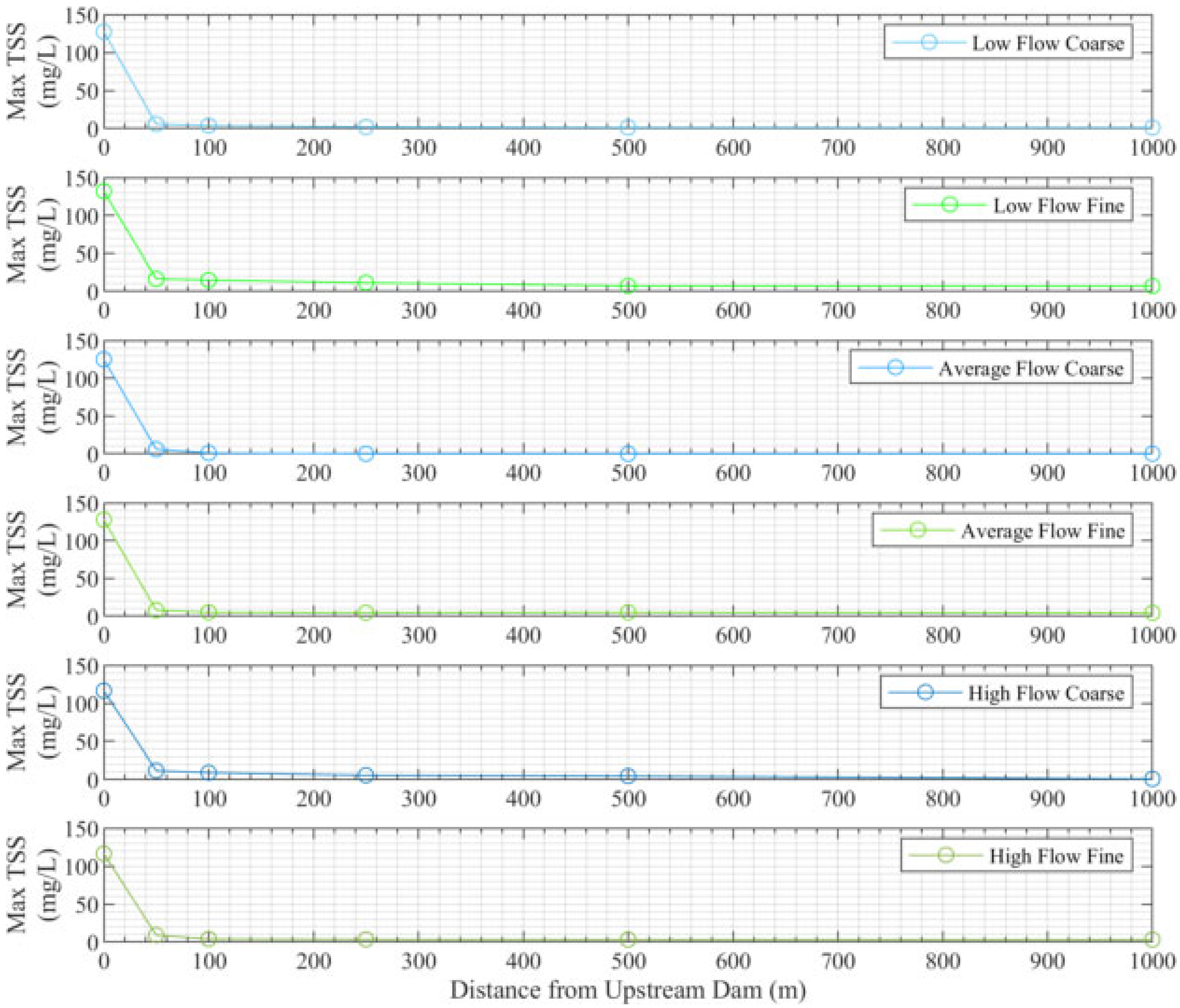


Figure 5-4: Maximum predicted TSS above background as a function of distance from the source for the medium watercourse scenarios (from top to bottom): Low Flow – Coarse, Low Flow – Fine, Average Flow – Coarse, Average Flow – Fine, High Flow – Coarse, and High Flow – Fine.

5.3 Large Watercourse – Bad River

The predicted plume concentrations in the event of an inadvertent return into the Bad River at the Proposed Route (i.e., for a large watercourse crossing) varied based upon the sediment load rate and watercourse flow conditions. The bentonite load rate for the final reaming pass (11.0 MT/h) was twice that of the pilot hole (5.5 MT/h), with each assumed to occur as a uniform release from the bottom ~3ft of the watercourse, over a 1-hour duration (Table 3-11). Similar to the small and medium watercourse scenarios, the time series data of TSS plume concentrations were directly related to sediment release timing. The TSS pulse following the simulated inadvertent return arrived most quickly to downstream locations (e.g., 500 m) in the high flow scenarios, followed by average flow, and then the low flow. However, while the small watercourse was predicted to have uniform concentrations across the river channel from the source, the large watercourse did not (Figure 5-5 through Figure 5-10). Maximum TSS concentrations were greatest near the source and generally attenuated as downstream distance increased (Table 5-11), but they varied spatially throughout the Bad River based on the varying velocity, channel morphology, and depth, with the highest concentrations toward the center of the watercourse (Figure 5-5 through Figure 5-10). TSS concentrations were generally also higher for the Final Ream Pass scenarios than the Pilot Hole scenarios, due to the higher bentonite loading rate. In addition, low flow scenarios had the highest in water concentrations due to reduced dilution from lower water velocity and turbulence. Due to TSS concentrations attenuating with downstream distance, larger cumulative areas predicted to exceed the lowest (1 mg/L) reporting threshold (~11,000 to ~27,000 m^2) than exceeded the highest (200 mg/L) reporting threshold (~400-4,000 m^2) (Table 5-12). The period of elevated TSS above 19 mg/L near the source was predicted to last approximately as long as the active sediment discharge (1-hr), but dilution, dispersion, and deposition resulted in concentrations downstream decreasing below this threshold and not enduring in the model (Table 5-13).

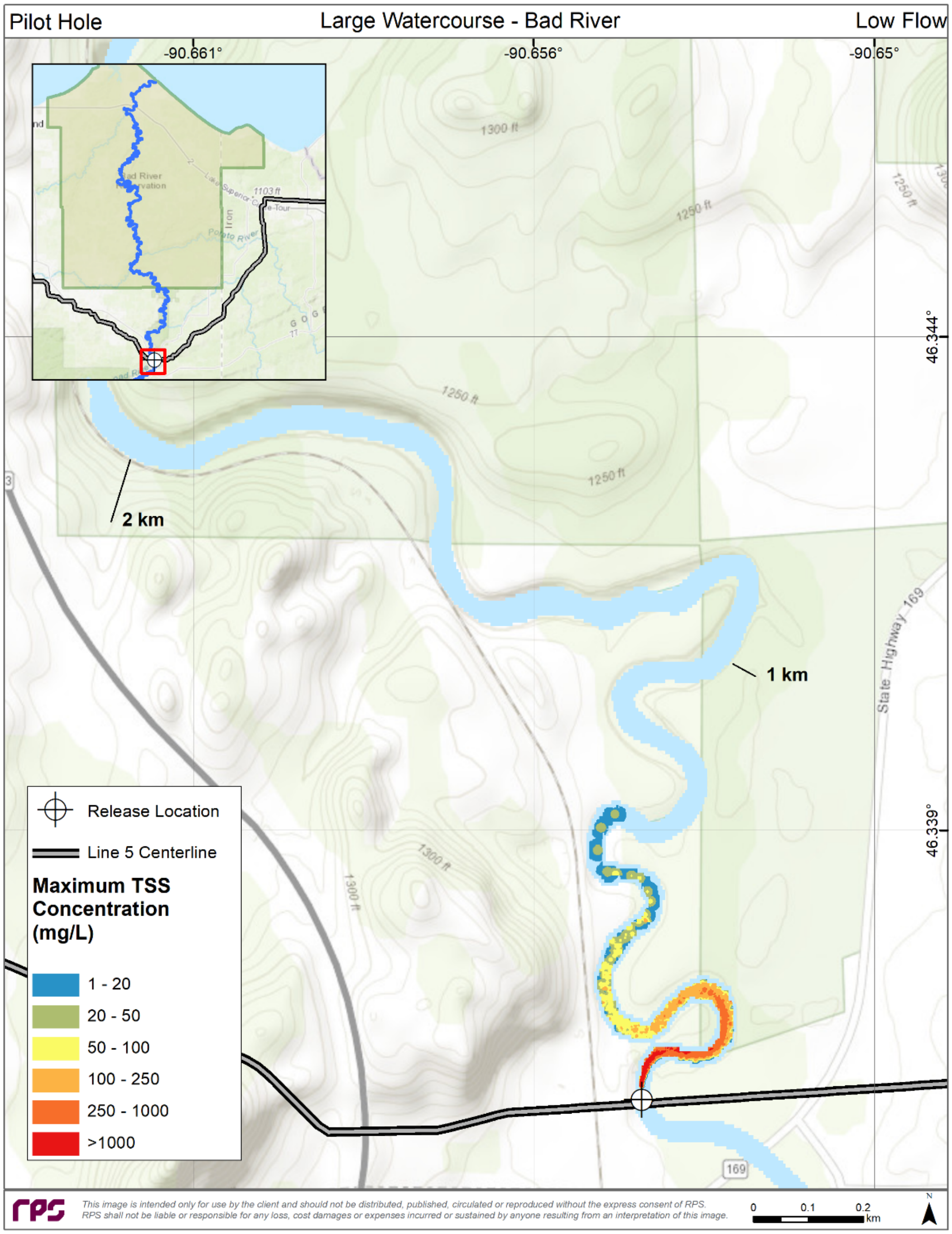


Figure 5-5. Maximum TSS concentrations above background predicted at any time in the simulation for the Pilot Hole scenario in low flow conditions. Downstream distance is provided on the map for reference (1 km = 0.62 miles; 2 km = 1.24 miles).

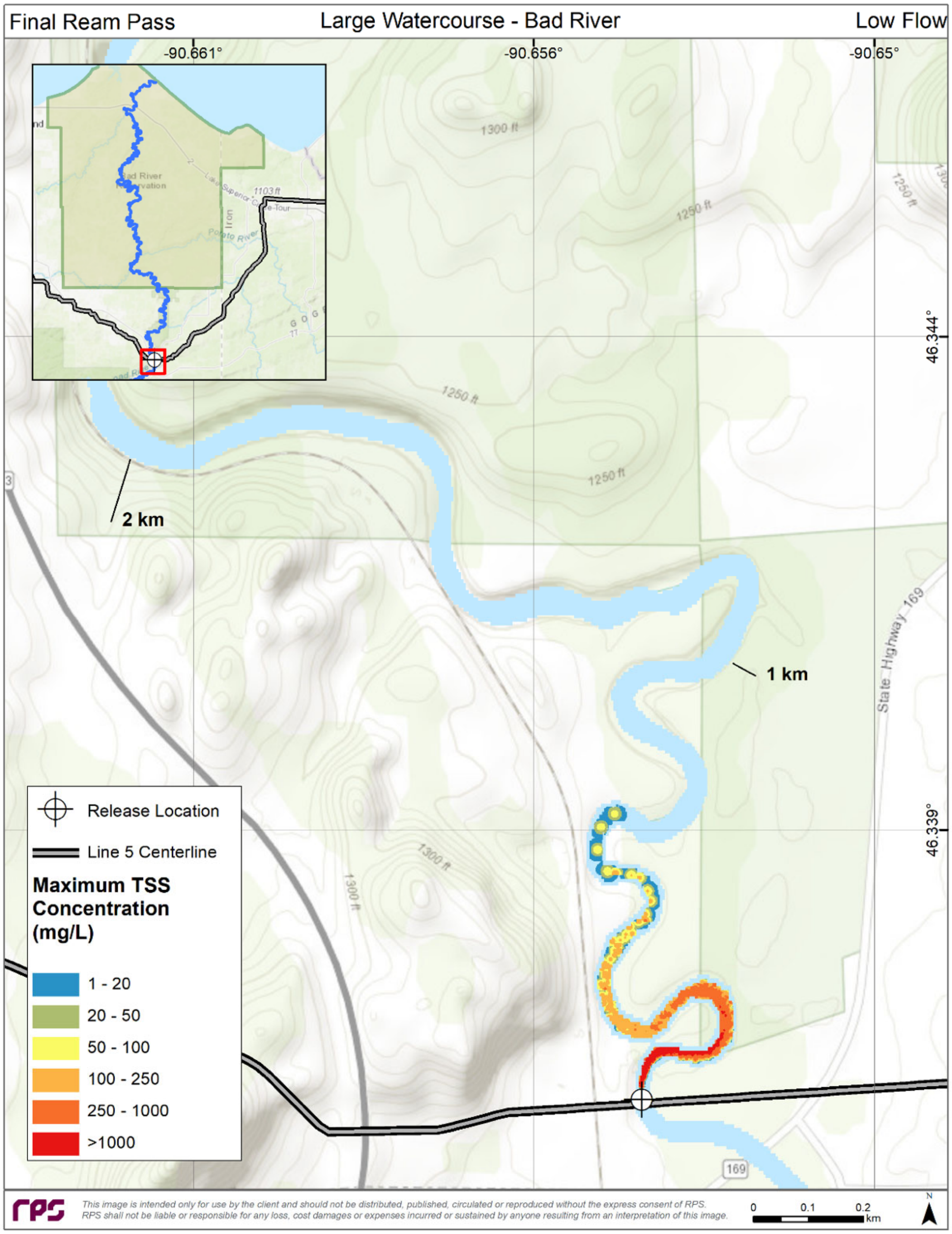


Figure 5-6. Maximum TSS concentrations above background predicted at any time in the simulation for the Final Ream scenario in low flow conditions. Downstream distance is provided on the map for reference (1 km = 0.62 miles; 2 km = 1.24 miles).

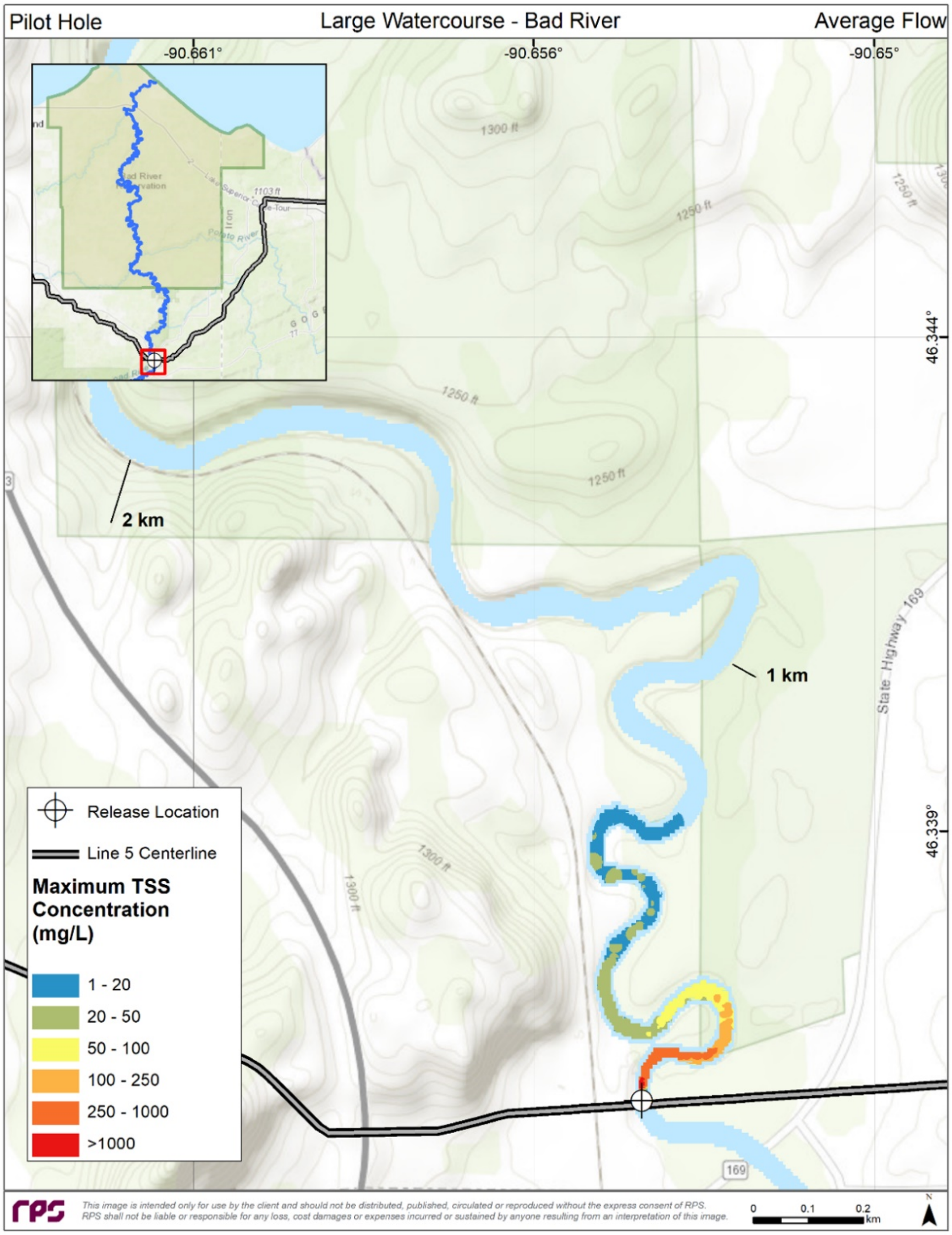


Figure 5-7. Maximum TSS concentrations above background predicted at any time in the simulation for the Pilot Hole scenario in average flow conditions. Downstream distance is provided on the map for reference (1 km = 0.62 miles; 2 km = 1.24 miles).

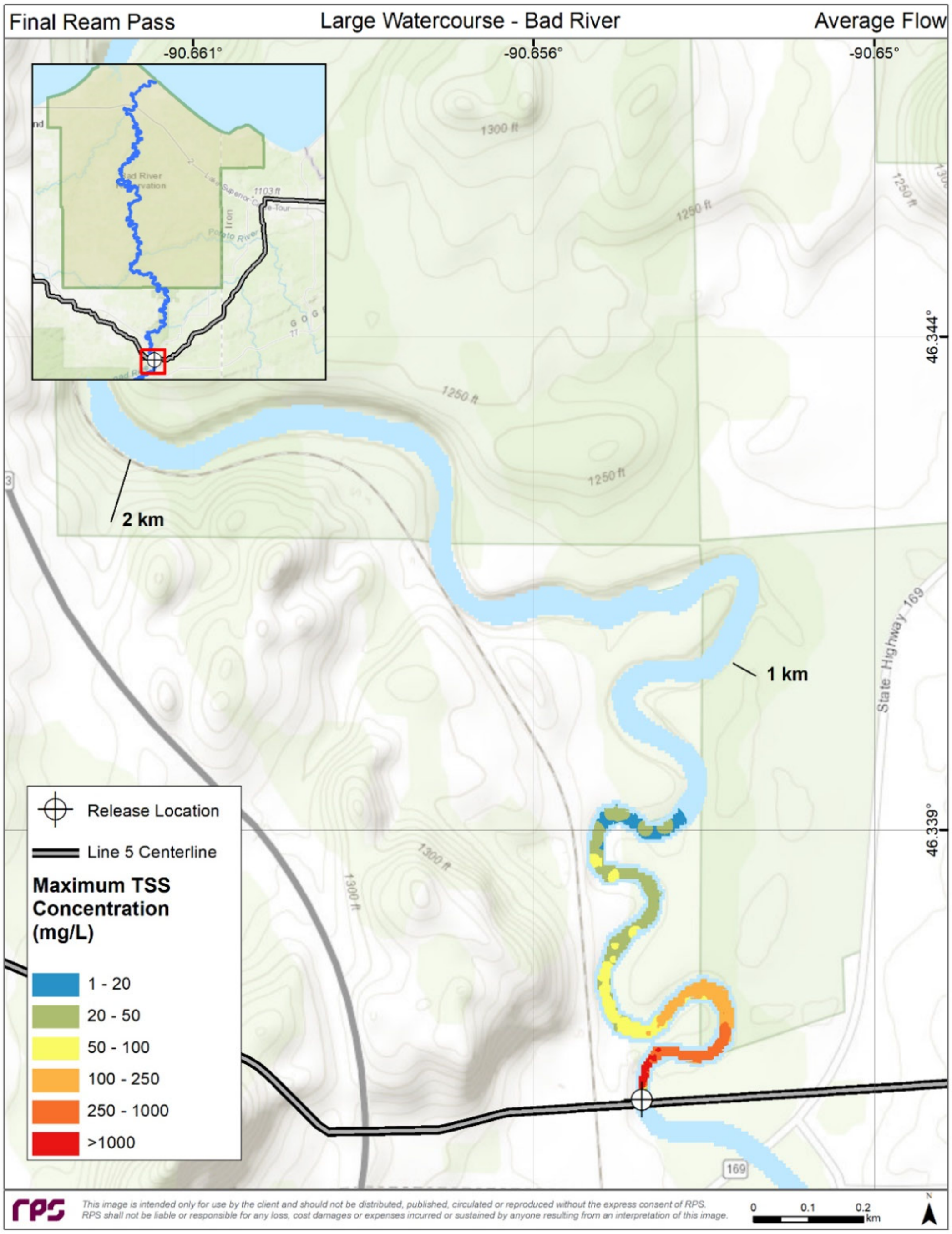


Figure 5-8. Maximum TSS concentrations above background predicted at any time in the simulation for the Final Ream scenario in average flow conditions. Downstream distance is provided on the map for reference (1 km = 0.62 miles; 2 km = 1.24 miles).

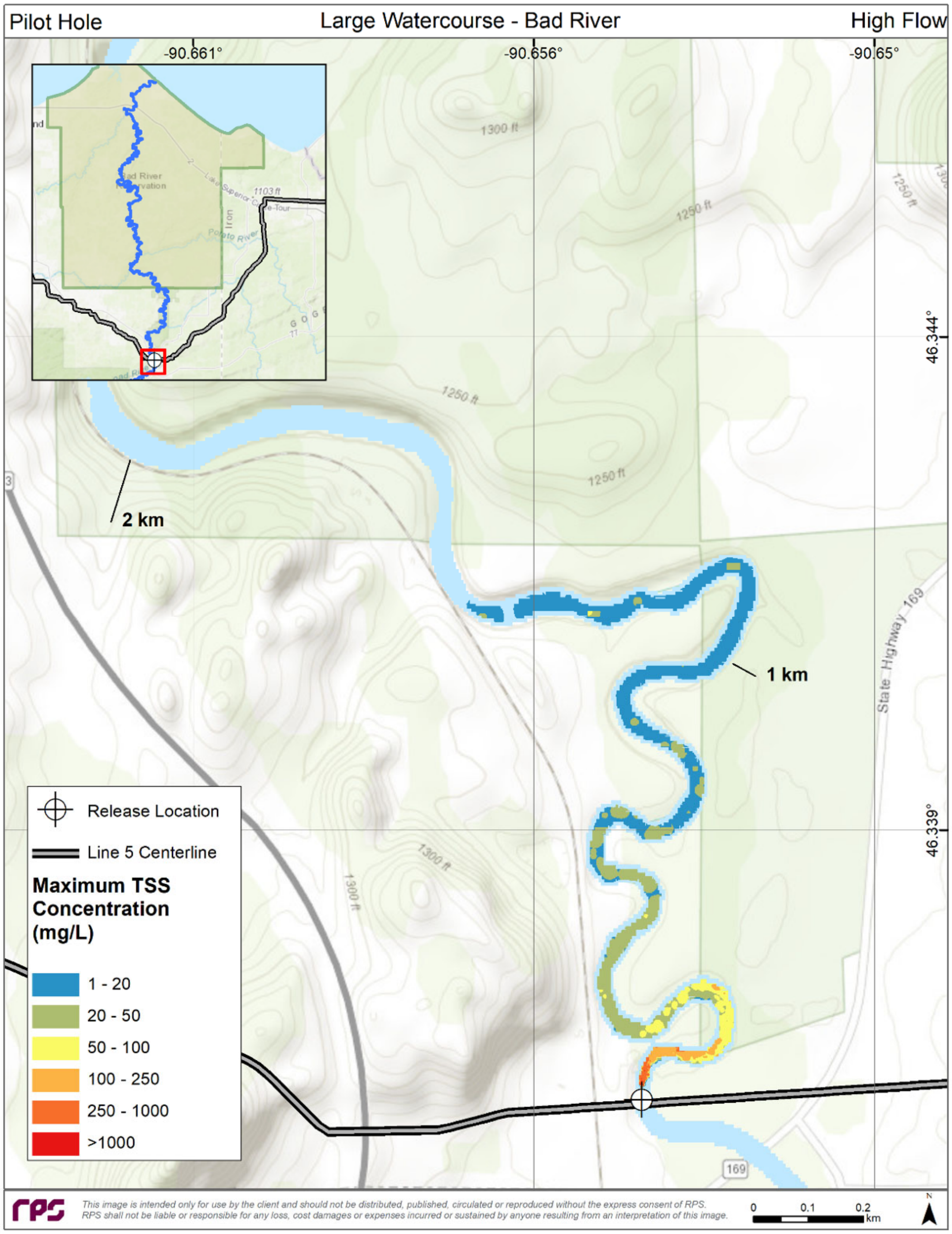


Figure 5-9. Maximum TSS concentrations above background predicted at any time in the simulation for the Pilot Hole scenario in high flow conditions. Downstream distance is provided on the map for reference (1 km = 0.62 miles; 2 km = 1.24 miles).

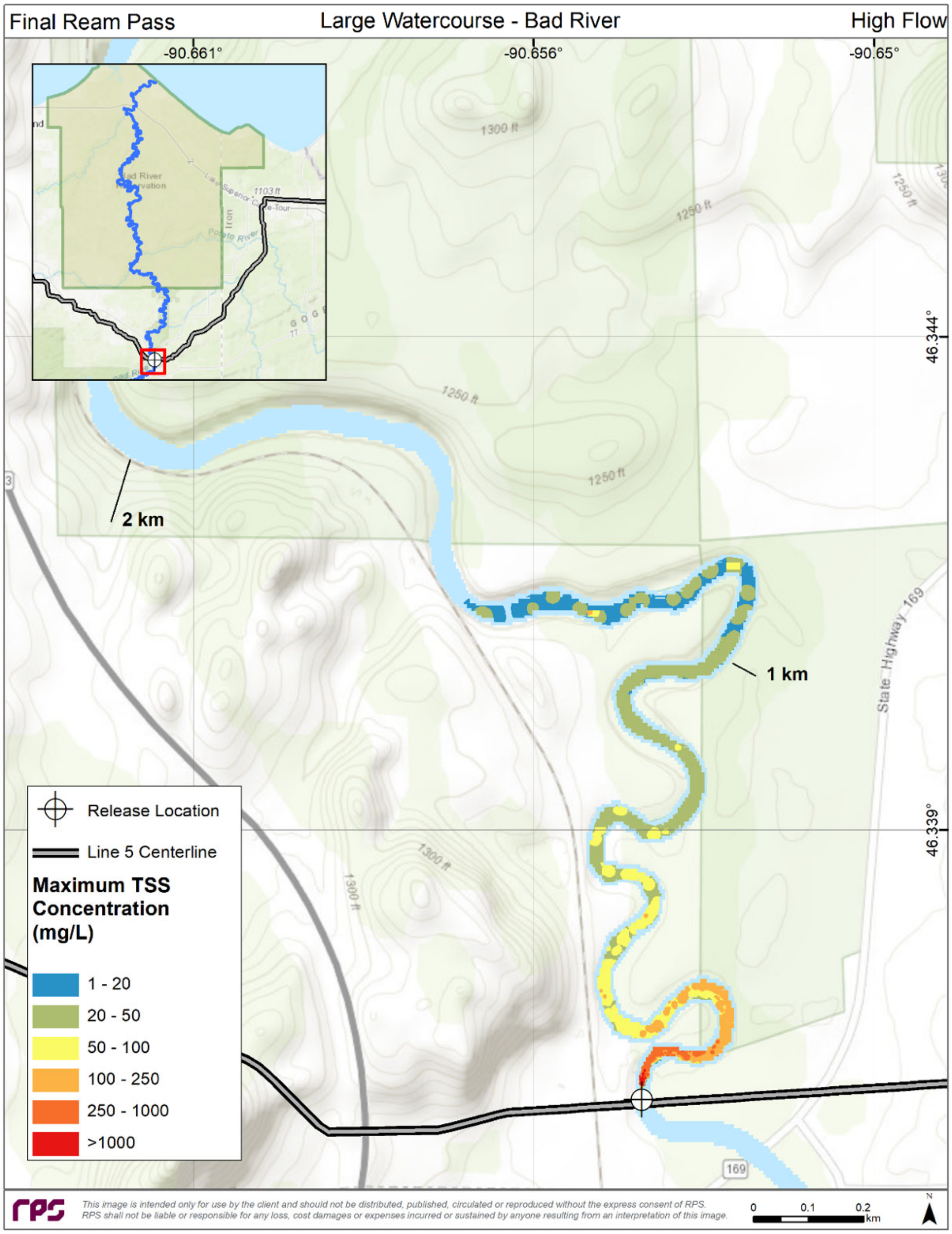


Figure 5-10. Maximum TSS concentrations above background predicted at any time in the simulation for the Final Ream scenario in high flow conditions. Downstream distance is provided on the map for reference (1 km = 0.62 miles; 2 km = 1.24 miles).

Table 5-11: Maximum predicted concentration as a function of distance for all large watercourse scenarios.

Distance From Upstream Dam (m)	Maximum TSS (mg/L) - Large Watercourse					
	Low Flow		Average Flow		High Flow	
	Pilot Hole	Final Ream	Pilot Hole	Final Ream	Pilot Hole	Final Ream
0-5	28,500	57,200	20,729	41,558	20,462	41,023
50	1,085	2,090	587	1,121	207	389
100	427	682	306	620	140	191
250	275	567	93	189	65	119
500	129	338	17	34	38	75
1,000	<1	<1	<1	<1	11	23
2,000	<1	<1	<1	<1	<1	<1

Table 5-12: Maximum predicted area exceeding specified TSS reporting thresholds for all large watercourse scenarios.

TSS reporting threshold (mg/L)	Area exceeding threshold (m^2) - Large Watercourse					
	Low Flow		Average Flow		High Flow	
	Pilot Hole	Final Ream	Pilot Hole	Final Ream	Pilot Hole	Final Ream
1	10,812	10,877	12,828	12,889	26,883	27,063
19	8,628	9,492	8,791	11,830	12,401	22,997
100	4,081	6,580	2,592	4,552	1,357	3,949
200	2,393	4,089	1,623	2,598	419	1,364

Table 5-13: Hours TSS is predicted to be >19 mg/L as a function of distance for all large watercourse scenarios.

Distance From Upstream Dam (m)	Hours TSS is over 19 mg/L – Large Watercourse					
	Low Flow		Average Flow		High Flow	
	Pilot Hole	Final Ream	Pilot Hole	Final Ream	Pilot Hole	Final Ream
0	1.0	1.0	1.0	1.0	1.0	1.0
50	1.0	1.0	1.0	1.0	1.0	1.0
100	1.0	1.0	1.0	1.0	1.0	1.0
250	0.9	0.9	1.0	1.0	1.0	1.0
500	0.1	0.1	<0.1	0.3	0.3	0.3
1,000	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

The deposition for each scenario was also assessed in terms of the maximum distance downstream above specific thickness thresholds (Table 5-14) and the total area over which that threshold was exceeded (Table 5-15). For the Final Ream Pass scenarios, with greater sediment loads, deposition above the thresholds extended slightly further and had slightly greater extent than the Pilot Hole scenarios. Nearly all of the sediment settled within the model domain for all of the scenarios, regardless of flow rate. For the low flow scenarios, exceedances of the thicker thresholds (e.g., > 5 mm deposition) extended farther downstream (up to 40 m) and over greater areas (covering up to 82 m^2) than other flow scenarios, due to the slower velocity allowing for greater deposition near the release location (Table 5-14). For the inverse reason, the high flow scenarios were predicted to exceed the 0.1 mm threshold over the shortest downstream distance (less than 140 m) and covering the smallest area (less than 471 m^2). In the high river flow cases, the water was moving too quickly for significant deposition of the suspended bentonite to occur in any given location. However, deposition below the 0.1 mm threshold was predicted throughout the model domain. The average river flow scenarios had greater downstream transport and dispersive forces than the low flow scenarios, yet moved slowly enough for lighter deposition to occur, resulting in the longest deposition footprints above the lowest threshold (0.1 mm).

Plots of predicted depositional thicknesses in the Bad River depict this pattern of greater deposition near the release location, as well as toward the center of the river channel (Figure 5-11 through Figure 5-16). Generally, the deposition coverage and thickness was greater for the Final Ream scenarios than the corresponding Pilot Hole scenarios. In all scenarios, the thinner depositional thresholds were predicted to extend the furthest and have the greatest areas of coverage. The model also predicted very large areas of deposition less than the 0.1 mm reporting threshold, throughout the model domain.

Table 5-14: Maximum predicted distance downstream of depositional thickness above specified thresholds for all large watercourse scenarios.

Large Watercourse Scenario		Downstream Distance to Threshold (m)				
Flow	**Activity**	**0.1 mm**	**1 mm**	**2 mm**	**5 mm**	**10 mm**
Low	Pilot Hole	300	138	77	40	20
	Final Ream	303	179	138	40	38
Average	Pilot Hole	330	42	8	7	6
	Final Ream	385	140	43	8	7
High	Pilot Hole	83	24	23	7	7
	Final Ream	140	25	24	22	7

Note: Small, isolated pockets of deposition at greater distance than reported here were predicted in some scenarios. The associated figures displaying deposition thickness (Figure 5-11 through Figure 5-16) show these results in greater detail.

Table 5-15: Area of predicted deposition over specified thresholds for all large watercourse scenarios.

Large Watercourse Scenario		Total Area over Threshold (m^2)				
Flow	**Activity**	**0.1 mm**	**1 mm**	**2 mm**	**5 mm**	**10 mm**
Low	Pilot Hole	1,298	180	103	38	21
	Final Ream	2,037	349	181	82	38
Average	Pilot Hole	1,884	108	42	33	26
	Final Ream	2,996	338	108	40	33
High	Pilot Hole	272	45	36	28	22
	Final Ream	471	63	45	33	28

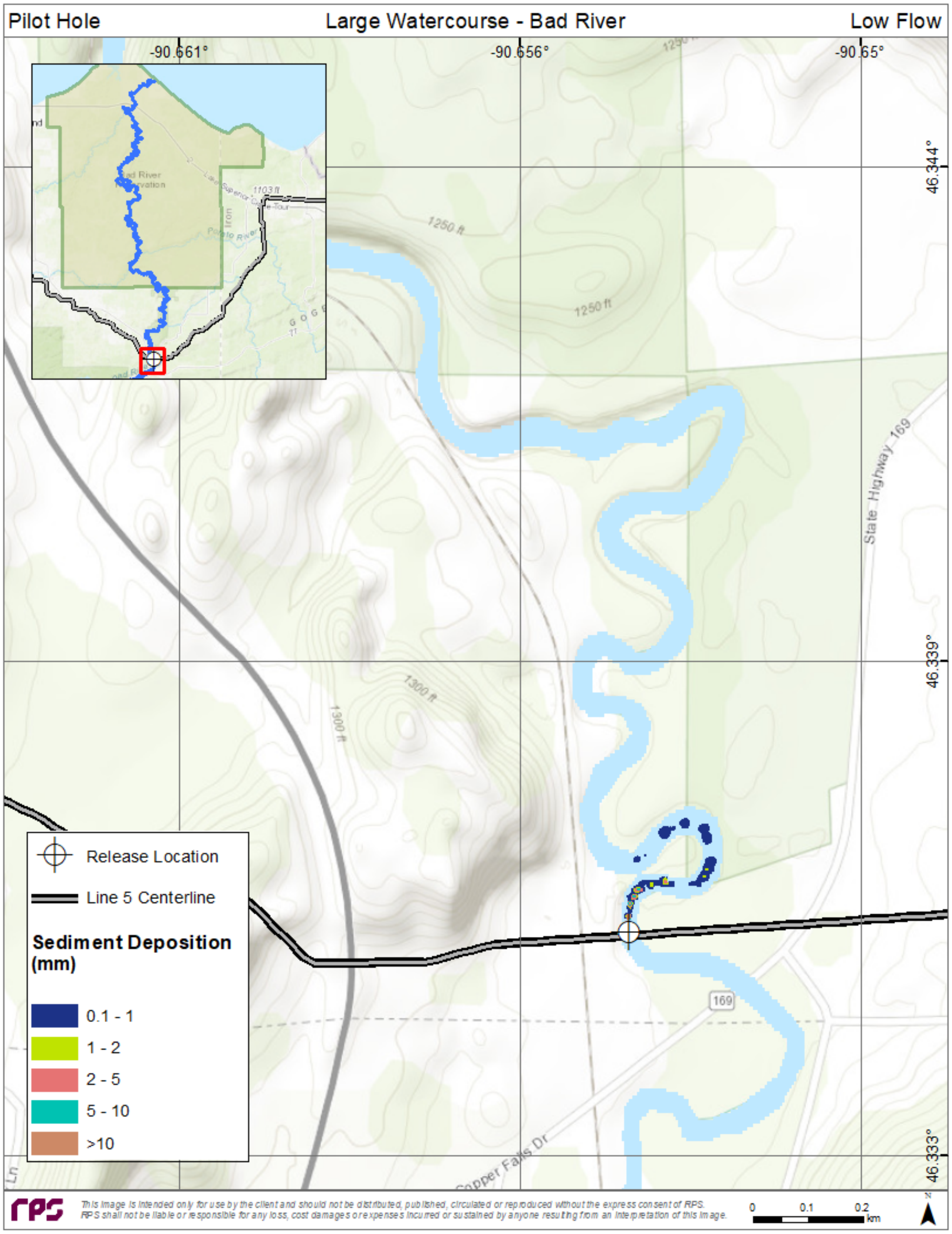


Figure 5-11. Sediment deposition predicted for the Pilot Hole scenario in low flow conditions.

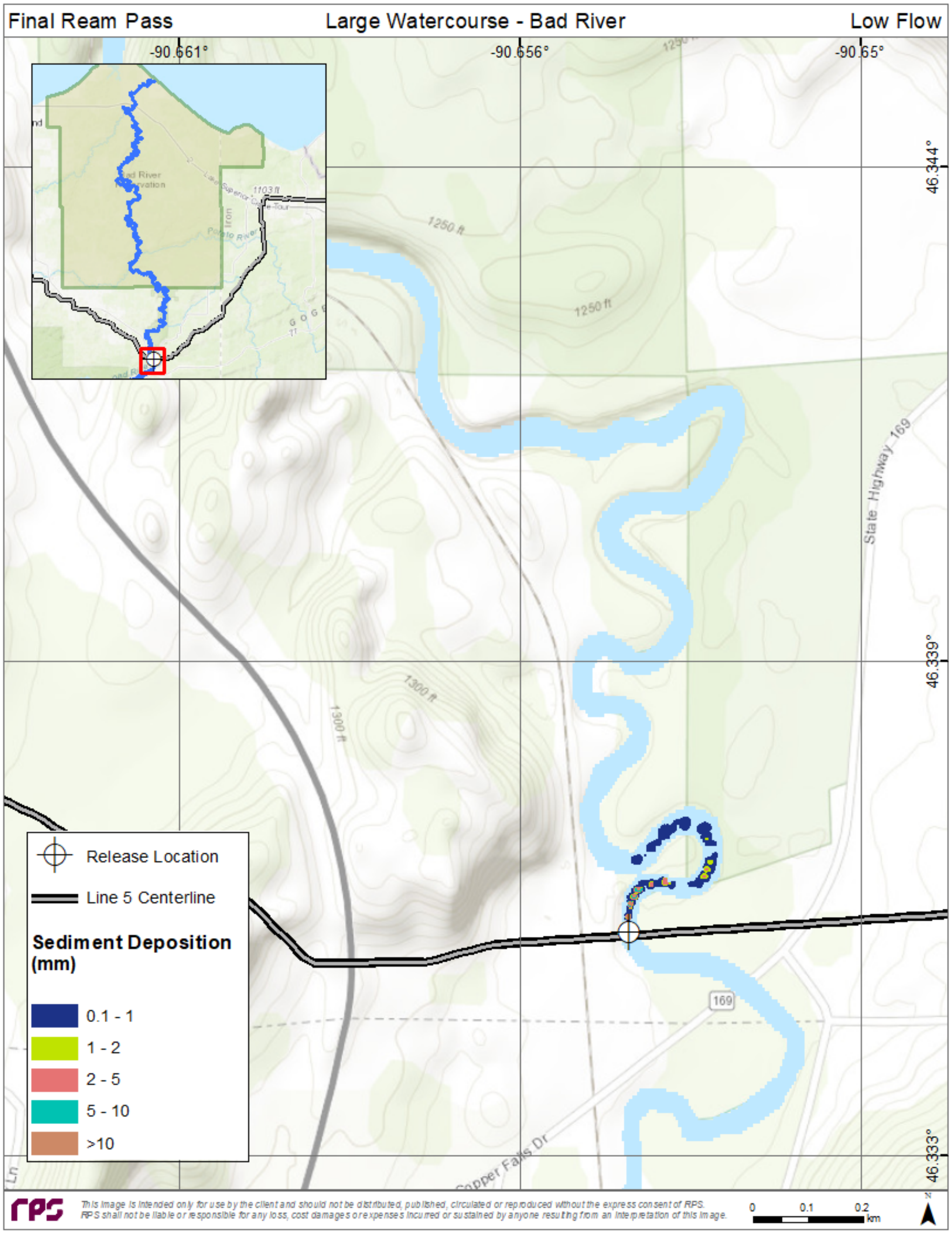


Figure 5-12. Sediment deposition predicted for the Final Ream scenario in low flow conditions.

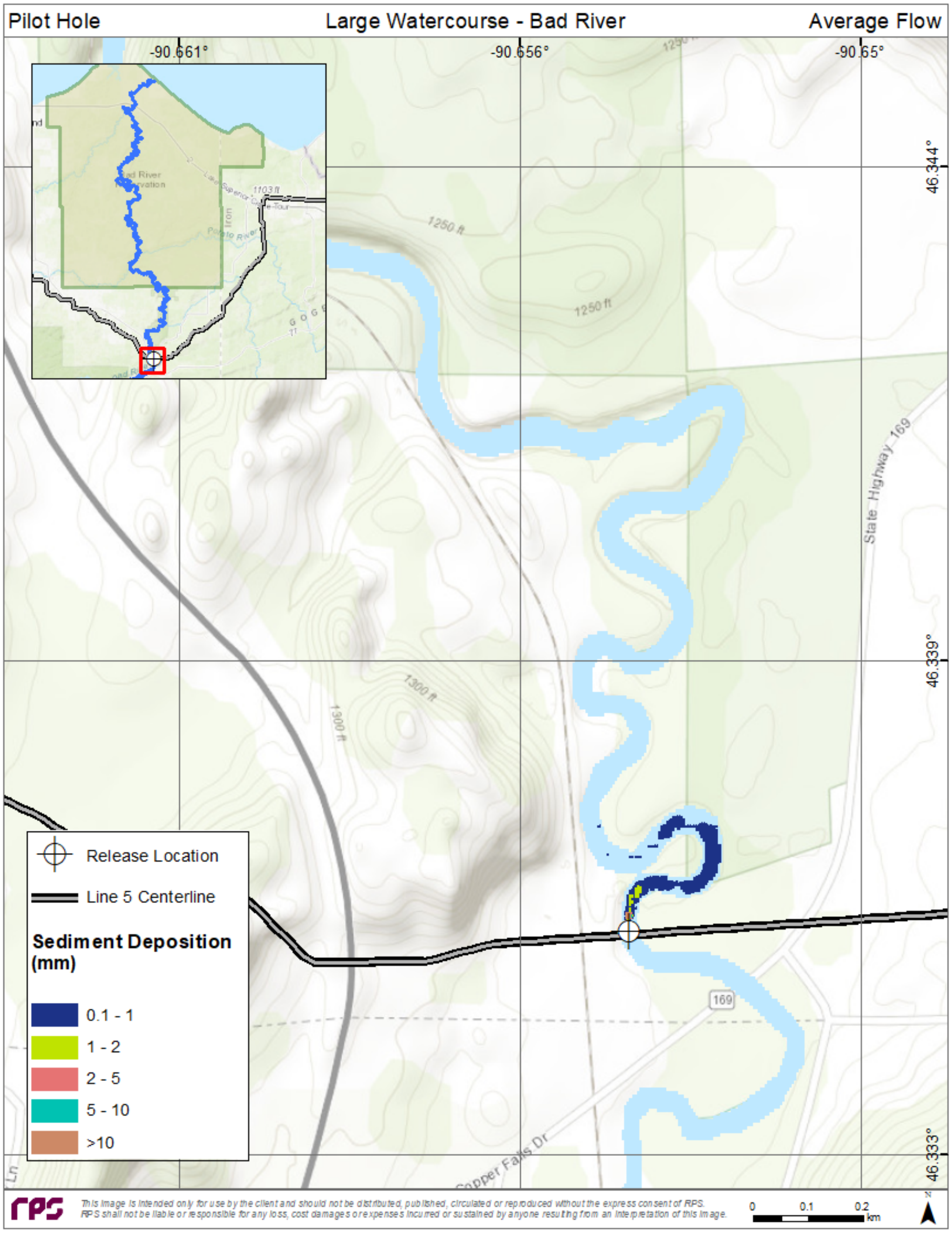


Figure 5-13. Sediment deposition predicted for the Pilot Hole scenario in average flow conditions

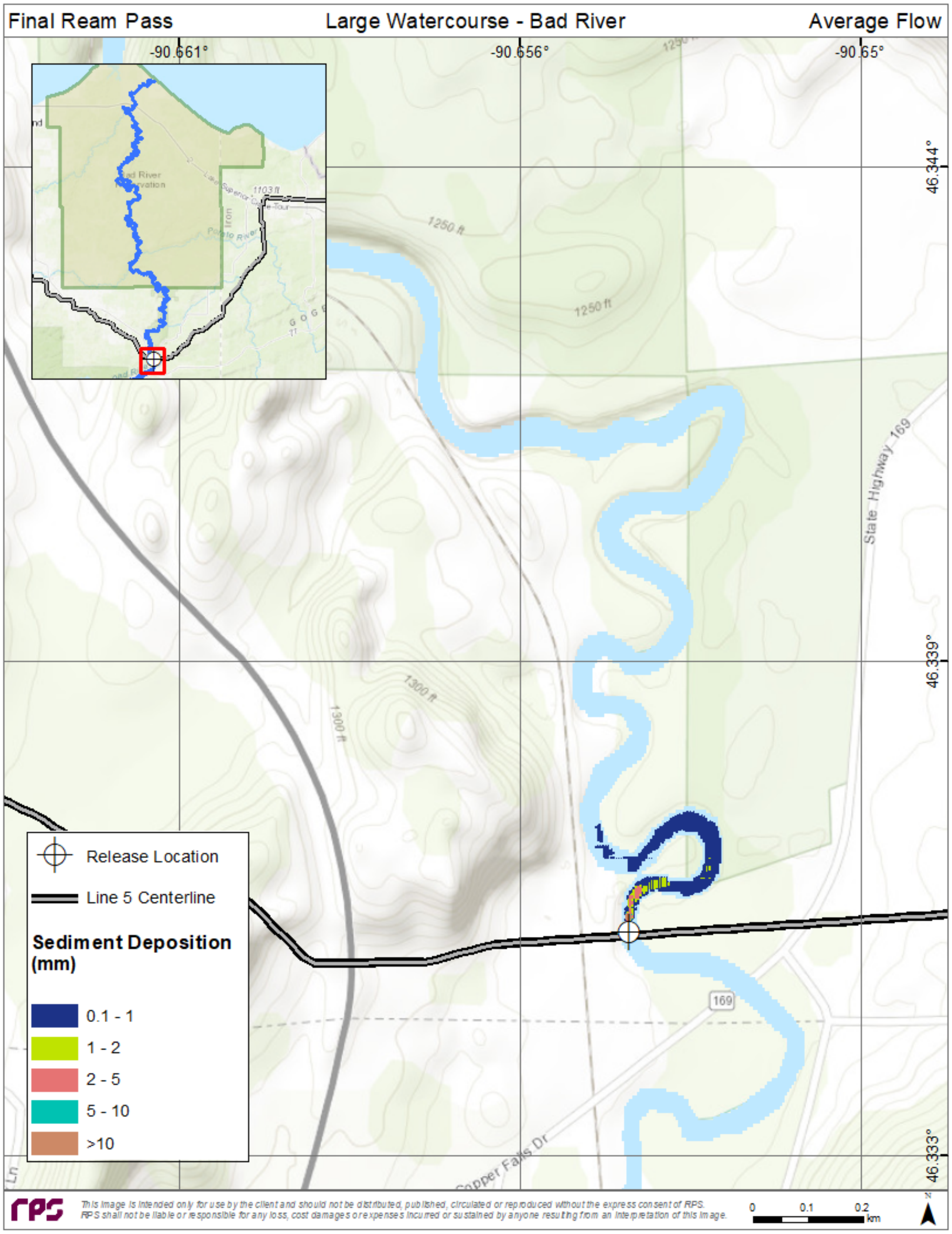


Figure 5-14. Sediment deposition predicted for the Final Ream scenario in average flow conditions

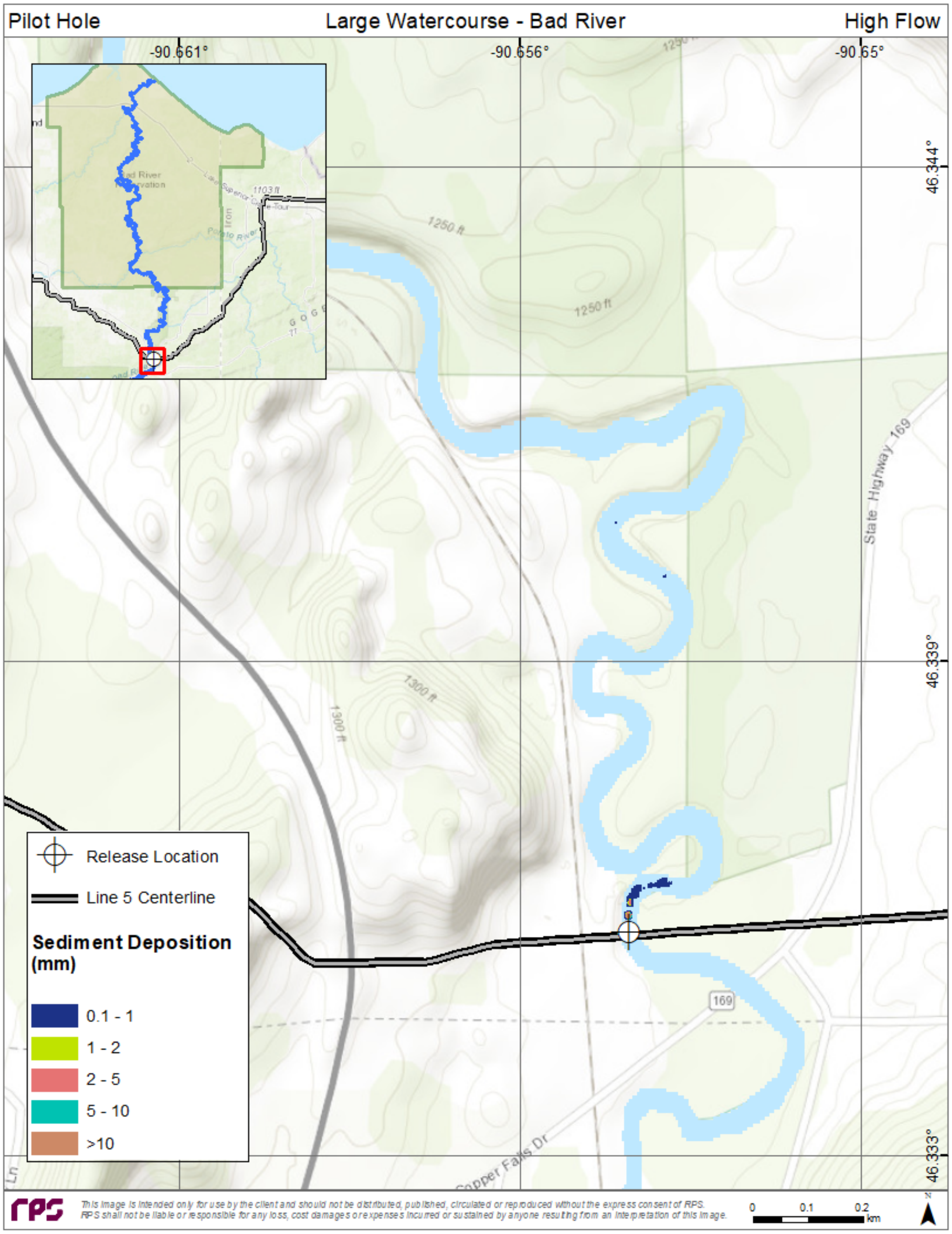


Figure 5-15. Sediment deposition predicted for the Pilot Hole scenario in high flow conditions

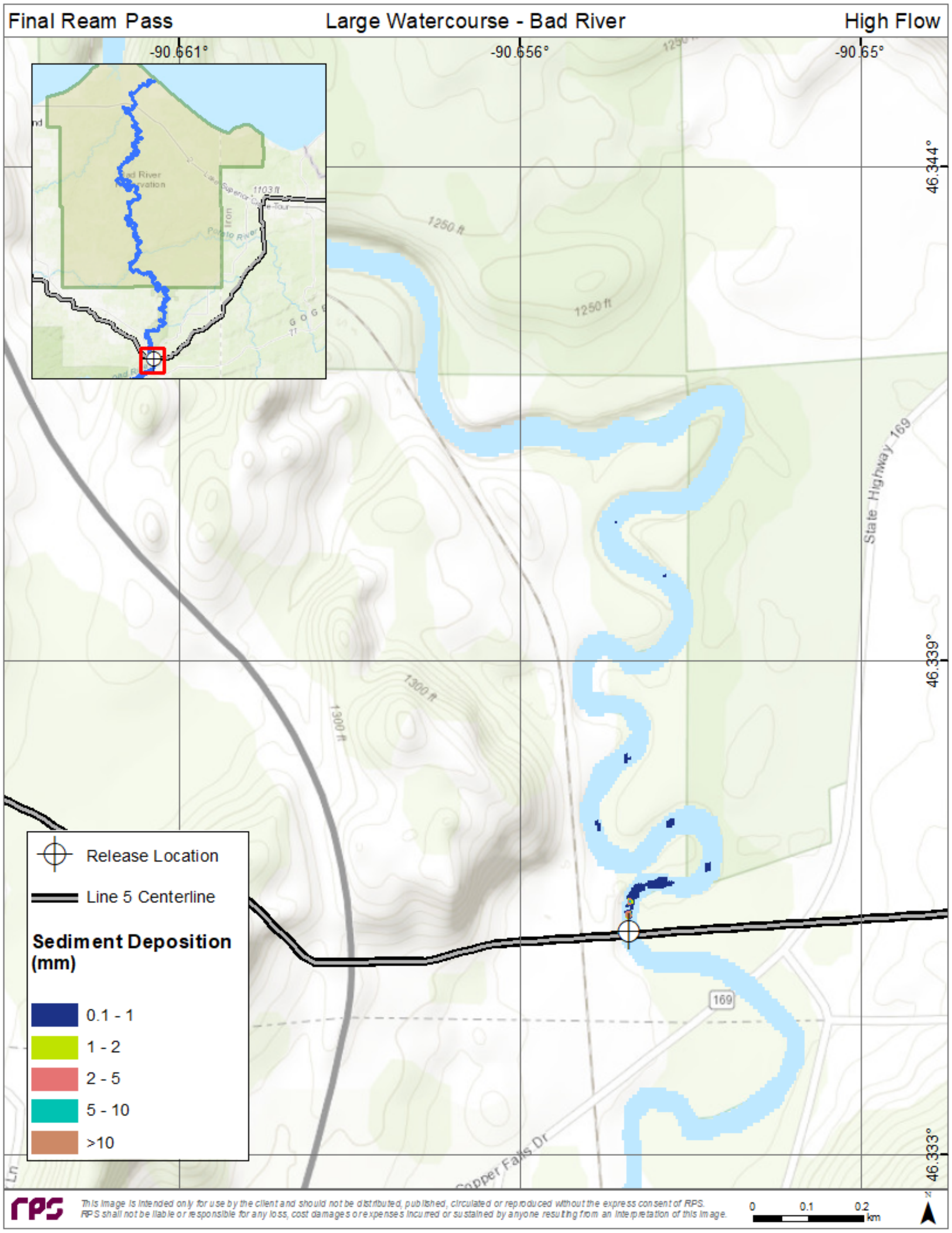


Figure 5-16. Sediment deposition predicted for the Final Ream scenario in high flow conditions

6 CONCLUSIONS

This sediment dispersion assessment was performed to provide insights regarding the potential impacts of proposed trenching and HDD pipeline installation methods for various size watercourse crossings. The analysis was focused on addressing the question as to whether the trenching methods would have temporary or permanent impacts on water quality parameters of concern (TSS), and to understand the magnitude of potential downstream impacts and deposition that could occur in the event of an inadvertent return. A matrix of 18 scenarios was simulated, which sampled the environmental and operational variability of the potential crossings. The scenarios captured the range of variability within watercourse sizes, river speeds (reflecting various flow conditions), and assumed substrate (sediment) characteristics. The operational variability for trenching methods was captured through the definition of the sediment load to the water column based on different dam installation and removal operations that would be conducted for each type of watercourse crossing (i.e., small through medium watercourses). The evaluated installation methods and assumptions were considered to be conservatively large, thus intending to maximize the potential sediment load that could be discharged into the watercourse, as compared with other methods of dam installation. Similar or lesser effects than those modeled here would be predicted for alternative construction methods such as sheet piles. The operational variability for an HDD installation was captured through two different types of frac-out events: Pilot Hole (smaller volume release) and Final Ream Pass (larger volume release) drilling activities. The following conclusions can be made from review of the inputs and outputs of the modeling.

Trenching of small or medium watercourse:

- Small watercourses of 5 ft (1.5 m) width and 1 ft (0.3 m) depth and medium watercourses of 25 ft (7.6 m) width) and 3 ft (0.9 m) depth were simulated under a range of river flow conditions representative of the June-August construction period (ranging from 0.16 to 0.39 m/s),
- Crossings in small and medium watercourses were expected to be completed within 20 and 32 hours, respectively, and would actively release sediment for a total of 4 hours (small) and 10 hours (medium). Associated increases in TSS concentrations would generally follow the same timing of the installation and removal activities, quickly attenuating after the sediment disturbances ceased,
- The sediment loads in the watercourses produced initially larger TSS concentrations near the installation site (up to 132 mg/L) due to the conservatively large assumed amount of sediment that was resuspended and the shallow watercourse depths (1-3 ft deep),
- TSS concentrations predicted farther downstream of the installations (e.g., 500-1,000 m) were on the order of <1 to 30 mg/L for the small watercourse and <1 to 10 mg/L for the medium watercourse, which was consistent with the magnitude of TSS exceedances observed in actual measurements collected during installation of the Guardian pipeline in 2008 (Section 3.4.3). Notably, the TSS predictions at 1,000 m distance downstream were consistently below background conditions for this seasonal period (20 mg/L, Section 3.4.1) The proposed installation activities would be expected to have a lesser magnitude and more brief effect on TSS in the water column than storm-related events, which can cause TSS values to exceed hundreds to thousands of mg/L over periods of time that are longer than these installation periods.

- By 1,000 m (or 1 km) downstream, the TSS predictions were below the calculated threshold of 19 mg/L identified for this study, based on the Reservation's water quality standards (Section 3.4.2). TSS consistently fell below this threshold in a shorter downstream distance than the range of distances from the various watercourse crossings of the Proposed Route to the Reservation border (2.1 to 23.9 km). Therefore, TSS concentrations were predicted to be well below the calculated threshold for all watercourses represented by the simulated small and medium watercourse scenarios by the time any suspended sediments reached the Reservation boundary.

- The TSS plumes were expected to be ephemeral in any given location and would therefore not pose a permanent impact,
- Coarser sediments were predicted to almost fully settle under both low and average river flow conditions, while the fine sediments generally remained in suspension for longer periods of time. It is expected that any actual river channel would have variable speeds across the river and downstream as channel geomorphology varied. This would result in slower regions or stilling ponds which would have a greater potential for sediments to settle out. Therefore, while it was not captured with the model, it is expected that gradual and thin deposition would occur until reaching an area with reduced currents, which may allow for greater deposition and thicker sedimentation. It is reasonable to expect that the finer sediments would eventually settle in quiescent waters. The largest (coarse) particles were not modeled because they would be expected to settle out immediately (within a few feet of the release location) and not contribute to downstream sedimentation and potential for impacts, and
- In all scenarios with deposition, the thinner deposition thresholds were predicted to extend the furthest and have the greatest areas of coverage. No deposition above 5 mm was predicted for the small watercourse scenarios, with deposition above thinner thresholds only reaching up to 13 m downstream of the installation site. For the medium watercourse scenarios, deposition above 5 mm was predicted to extend, at most, 3 m downstream, with deposition above thinner thresholds reaching up to 30 m. However, in a natural watercourse with spatially- and time-varying flows and complex geomorphology, pockets of higher and lower deposition than modeled may occur.

HDD in large watercourse (Bad River):

- The actual geomorphology and hydrodynamics of the Bad River crossing of the Proposed Route was used to simulate an accidental, inadvertent return occurring in a large watercourse during HDD installation. A range of scenarios with differing drilling fluid release volumes (Pilot Hole vs. Final Ream Pass) and seasonally-appropriate river flow conditions (low, average, and high) were modeled, each conservatively assuming a 1-hour release duration before the discharge was stopped. In the actual event of a complete (100%) inadvertent return into the water column, observers would likely spot the release within minutes, thus reducing the total volume potentially released into the environment. Associated increases in TSS concentrations would generally follow the same timing, attenuating after the sediment disturbance ceased,
- The discharge into the watercourse produced initially large TSS concentrations near the release site (more than 20,000 mg/L) due to the large volume of drilling fluid (bentonite) that was released in a relatively short period of time. The largest concentrations were predicted for

the larger release volume (Final Ream Pass) scenario under low river flow conditions, where dilution and dispersion would be lowest.

- TSS concentrations predicted farther downstream (e.g., 500-1,000 m) were on the order of 10-300 mg/L. These concentrations would be smaller or of similar magnitude to that typically caused by storm-related events, which can cause TSS to exceed hundreds to thousands of mg/L over longer periods of time that are longer than these installation periods.
- By 2,000 m (or 2 km) downstream, TSS predictions for all scenarios were below the calculated threshold of 19 mg/L identified for this study. Therefore, TSS concentrations would likely fall below this threshold by the time suspended sediments reached the Reservation boundary (approximately 19.5 km downstream from the Proposed Route crossing).
- Nearly all of the discharged bentonite eventually settled within the model domain, regardless of river flow rate. The greatest deposition occurred near the release location, as well as toward the center of the river channel. For the Final Ream Pass scenarios with greatest sediment loads, deposition above the thickness thresholds extended slightly further and had greater extent than the Pilot Hole scenarios. The distance and area covered by deposition above 5-10 mm thickness was greatest for the low flow scenario, particularly near the simulated release location, where deposition at this level extended up to 40 m downstream. While the model predicted very large areas of deposition less than the 0.1 mm reporting threshold, no deposition above that threshold was predicted past 400 m downstream, well upstream of the Bad River Reservation boundary.

7 REFERENCES

Anderson, E., Johnson, B., Isaji, T., & Howlett, E. 2001. SSFATE (Suspended Sediment FATE), a model of sediment movement from dredging operations. In WODCON XVI World Dredging Congress, pp. 2-5.

AquaDam. 2004. AquaDam User's Guide ~2004. "Water Controlling Water." 26 pm

Bad River Watershed Association. 2021. Bad River Watershed Description. Available: http://www.badriverwatershed.org/index.php/bad-river-watershed. Accessed May 2021

Clays and Clay (CCM). 1988. Density and Compressibility of Wyoming Bentonite Particles. Technical Note. Clays and Clay Minerals, Vol. 36, No. 1, pp 94-95, 1988.

Deltares, D. 2022. D-Flow FM user manual. Deltares Delft, The Netherlands, 330 p.

Ellison, C.A., Savage, B. E., and Johnson, G.D. 2014. Suspended-sediment concentrations, loads, total suspended solids, turbidity, and particle-size fractions for selected rivers in Minnesota, 2007 through 2011. U.S. Geological Survey Scientific Investigations Report 2013–5205, 43 p. Retrieved from *http://dx.doi.org/10.3133/sir20135205*.

Enbridge. 2022a. Excel file: Wetland Waterbody Crossing Table_20220516_Waterbodies only. Received by Matt Horn, RPS, from Joe McGaver, Enbridge. May 16.

Enbridge. 2022b. Email re: Sediment Dispersion Modeling: Input finalization. Received by Matt Horn, RPS, from Joe McGaver, Enbridge. June 3.

Gerritsen, H., Gerritsen, de Goede, E.D., Platzek, F.W., van Kester, J.A., Genseberger, M., & Uittenbogaard, R.E. 2008. Validation Document Delft3D-FLOW; a software system for 3D flow Simulations. Technical Report. X0356, M3470. September.

Horn, M., Robinson, H., McStay, L., Frediani, M., 2022. Rebuttal Report – Enbridge Line 5. Redesignated version. April 8. 339 p.

International Organization for Standardization. (2002). Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description (ISO Standard No. 14688-1:2002). Retrieved from https://www.iso.org/standard/25260.html

International Organization for Standardization (ISO). 2013. Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description (ISO Standard No. 14688-1:2002/AMD 1: 2013). Retrieved from https://www.iso.org/standard/57690.html.

International Organization for Standardization (ISO). 2017. Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description (ISO Standard No. 14688-1:2017). Retrieved from https://www.iso.org/standard/66345.html.

Johnson, B. H., Andersen, E., Isaji, T., Teeter, A. M., & Clarke, D. G. 2000. Description of the SSFATE numerical modeling system (No. ERDC-TN-DOER-E10). Army Engineer Waterways Experiment Station Vicksburg MS Engineer Research and Development Center.

Kiviranta, L. and S. Kumpulainen. 2011. Quality Control and Characterization of Bentonite Materials. Working Report 2011-84. Posiva Oy, Olkiluoto, Fi-27160 Eurajoki, Finland.

Lenhart, C.F., Brooks, K.N., Heneley, D., and Magner, J.A. 2010. Spatial and temporal variation in suspended sediment, organic matter, and turbidity in a Minnesota prairie river: implications for TMDLs. Environ. Monit. Assess, Vol. 165, No. 1-4, pp 435–447. Retrieved from https://doi.org/10.1007/s10661-009-0957-y.

Lin, J., Wang, H. V., Oh, J. H., Park, K., Kim, S. C., Shen, J., & Kuo, A. Y. 2003. A new approach to model sediment resuspension in tidal estuaries. Journal of coastal research, Vol. 19, No. 1, pp 76-88.

McKay, L., Bondelid, T., Dewald, T., Johnston, J., Moore, R., and Rea, A. 2012. "NHDPlus Version 2: User Guide."

Minnesota Pollution Control Agency (MPCA). 2020. Surface water data. Retrieved from https://webapp.pca.state.mn.us/surface-water/search. Accessed July 2020.

Natural Resource Group. 2010. Guardian Expansion Pipeline and Extension Project Water Quality Report.

Reid, S.M., and P.G. Anderson. 1999. Effects of Sediment Released During Open-cut Pipeline Water Crossings. Canadian Water Resources Journal. Vol. 24, No. 3, pp 235-251.

Reid, S.M., Stoklosar, S., Metikosh, S., and J. Evans. 2002. Effectiveness of Isolated Pipeline Crossing Techniques to Mitigate Sediment Impacts on Brook Trout Streams. Water Quality Research Journal of Canada, Vol. 37, No. 2, pp 473-488.

Soulsby, R.L. 1998. Dynamics of Marine Sands. Thomas Telford, England.

Swanson, J. C., Isaji, T., Ward, M., Johnson, B. H., Teeter, A., & Clarke, D. G. 2000. Demonstration of the SSFATE numerical modeling system. DOER Technical Notes Collection (TN DOER-E12). US Army Engineer Research and Development Center, Vicksburg, MS. Retrieved from http://www.wes.army.mil/el/dots/doer/pdf/doere12. pdf.

Swanson, J. C., Isaji, T., Clarke, D., & Dickerson, C. 2004. Simulations of dredging and dredged material disposal operations in Chesapeake Bay, Maryland and Saint Andrew Bay, Florida. In WEDA XXIV/36th TAMU Dredging Seminar, pp. 7-9.

Swanson, J. C., & Isaji, T. 2006. Modeling dredge-induced suspended sediment transport and deposition in the Taunton River and Mt. Hope Bay, Massachusetts. In WEDA XXVI/38th TAMU Dredging Seminar, June, pp. 25-28.

Swanson, J. C., Isaji, T., & Galagan, C. 2007. Modeling the ultimate transport and fate of dredge-induced suspended sediment transport and deposition. Proceedings of the WODCON XVIII, 27.

Teeter, A. M. 1998.Cohesive sediment modeling using multiple grain classes, Part I: settling and deposition. Proceedings of INTERCOH.

The Nature Conservancy (TNC), 2020. Wisconsin: Caroline Lake Preserve. Available: https://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/wisconsin/placesweprotect/caroline-lake-preserve.xml. Accessed: August 2020

United States Environmental Protection Agency (USEPA). 2014. Retrieved from https://www.epa.gov/sites/default/files/2014-12/documents/bad_river_band_wqs.pdf.

U.S. Geological Survey (USGS), 2020a. Surface water data for USA: USGS Surface-Water Monthly Statistics for USGS 04027000 BAD RIVER NEAR ODANAH, WI Available: https://waterdata.usgs.gov/usa/nwis/uv?04027000.
and for USGS 04026450 BAD RIVER NEAR MELLEN, WI Available: https://waterdata.usgs.gov/usa/nwis/uv?04026450
Accessed: June 2020.

U.S. Geological Survey (USGS), 2020b. The National Map – National Hydrography Dataset. Available: http://nhd.usgs.gov/

U.S. Geological Survey (USGS). 2022. Surface water data for USA: USGS Surface-Water Monthly Statistics for USGS 04027000 BAD RIVER NEAR ODANAH, WI Available: https://waterdata.usgs.gov/usa/nwis/uv?04027000. for USGS 04026450 BAD RIVER NEAR MELLEN, WI Available: https://waterdata.usgs.gov/usa/nwis/uv?04026450 and for USGS 04027500 WHITE RIVER NEAR ASHLAND, WI Available: https://waterdata.usgs.gov/usa/nwis/uv?04027500.

Van Rijn, L. C. 1989. Handbook sediment transport by currents and waves. Delft Hydraulics Laboratory.

Wentworth, C.K. 1922. A Scale of Grade and Class Terms for Clastic Sediments. The Journal of Geology, Vol. 30, No. 5, pp 377-392.

Williams, S.J., Arsenault, M.A., Buczkowski, B.J., Reid, J.A., Flocks, J.G., Kulp, M.A., Penland, S., and Jenkins, C.J. 2006. Surficial sediment character of the Louisiana offshore Continental Shelf region: a GIS Compilation, U.S. Geological Survey Open-File Report 2006-1195. Retrieved from https://pubs.usgs.gov/of/2006/1195/htmldocs/nomenclature.htm).