Project Title: FluEgg Modeling of Silver Carp in Upper Mississippi River Pools 1-9

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Participating Agencies: U.S. Geological Survey, UMESC

Location of Activities: Upper Mississippi River Pools 1-10

Statement of Need:
Invasive carp captures have increased in Minnesota waters of the Upper Mississippi River following a high-water event in 2019. Necropsies showed that most of the Silver Carp captured in Minnesota in 2021 and 2022 were mature (Minnesota DNR 2022). In spring 2022, there were also credible reports of Silver Carp jumping below Lock and Dam 5 (Wisconsin DNR, personal communication) and a telemetered Silver Carp was observed moving upstream to this location (Minnesota DNR 2022). In spring 2023, near-record flooding opened dam gates for several weeks. Sighting, captures, and telemetry data from Spring 2023 suggest that many invasive carp took advantage of this opportunity to move upstream into Minnesota waters (USFWS personal communication, USGS personal communication, Minnesota DNR personal communication). While no evidence of invasive carp reproduction has been found in pools 1-9 of the Mississippi River, the increased number of captures and sightings in this reach has raised concerns about the potential for reproduction to occur.

Minnesota DNR conducts ichthyoplankton trawl and light trap sampling weekly from May-August at select locations to monitor for evidence of invasive carp reproduction during potential spawning events. Additionally, we use a variety of fisheries gears and contracted commercial fishing to target adult invasive carp for removal. Deterrents on the Upper Mississippi River have been suggested as another possible management option. These monitoring and response actions are sited based on the best available information on invasive carp behavior, captures, telemetry, sightings, and eDNA detections. However, it is currently unknown where invasive carp would be able to successfully recruit in the Upper Mississippi River if a spawning event were to occur. Several pools likely have insufficient flow, length, or nursery habitat to allow for invasive carp recruitment. Knowing which locations are most likely to support recruitment would allow us to target our ichthyoplankton sampling to the most appropriate locations, and target management actions to reduce abundance in areas most likely to support recruitment

Project Objectives:
1) Determine which pools of the Upper Mississippi River in Minnesota could potentially support Silver Carp recruitment if a spawning event were to occur below the upstream dam. Use the results to inform larval monitoring and invasive carp management activities, with a goal of disrupting reproduction.
2) Write and publish an open access journal article on the results of the study.

3) Train Minnesota DNR staff (and other UMR agency staff as interested) in the use of the FluEgg model, to allow staff to conduct additional simulations in the future.

Project Highlights:

- The USGS, in cooperation with the MNDNR, is using the Fluvial Egg Drift Simulator (FluEgg) to model the drift of invasive carp eggs and larvae in pools 1-10 of the Upper Mississippi River under a variety of hypothetical spawning scenarios that represent all combinations of 10 spawning locations, 5 water temperatures, and 9 flow conditions.
- FluEgg simulations have been completed and analyzed for 495 hypothetical spawning scenarios.
- The results are being used to assess the relative risk posed by the hypothetical spawning scenarios for invasive carp recruitment in pools 1-10 of the Upper Mississippi River and are also being examined in the context of invasive carp movement data collected during the spring 2023 flood (Fritts et al., 2024).
- An interpretive peer-reviewed journal article and supporting USGS data release/model archive are in preparation.
- A FluEgg training workshop for Minnesota DNR staff is planned for winter of FY2026.

Methods:

USGS developed the Fluvial Egg Drift Simulator (FluEgg; Garcia et al. 2013, Domanski and Berutti, 2020, Domanski et al. 2021) to simulate the transport and development of invasive carp eggs and larvae in a riverine system. According to Domanski et al. (2021):

> FluEgg integrates the biological development of invasive carp eggs and larvae with a particle transport model that simulates the advection and dispersion of the eggs and larvae based on user-supplied one-dimensional hydraulic conditions. FluEgg can be used to evaluate the hydrodynamic suitability of a river for invasive carp spawning, to inform sampling and monitoring efforts, and to identify the most likely spawning areas of captured eggs or larvae.

Therefore, for a given scenario of spawning location, water temperature, and flow conditions, FluEgg predicts the position, extent, and suspended proportion of a plume of fertilized eggs at the time of hatching. After hatching, FluEgg continues to simulate the drift of larvae until they reach the gas bladder inflation (GBI) stage, at which point the larvae no longer passively drift and can swim laterally to find nursery habitat (Chapman and George 2011). FluEgg simulations can be used to evaluate the suitability of a reach or river for spawning and recruitment based on two key assumptions: (1) that drifting fertilized eggs must be suspended in the water column until hatching to ensure viability (Garcia et al. 2013, George and Chapman 2013, 2015, George et al. 2015, George, Garcia, and Chapman 2017), and (2) that larvae must reach the GBI stage near nursery habitat for the greatest chance of survival. The FluEgg model has been applied in

the Lower St. Croix River (Kasprak et al. 2022) and the Illinois River (Murphy et al. 2016, Zhu et al. 2018), among other locations (e.g., Garcia et al. 2013, 2015, Embke et al. 2019, Smyth et al. 2023)

This project uses FluEgg to examine hypothetical spawning scenarios in pools 1-10 of the Upper Mississippi River (Figure 1). Minnesota DNR has provided project support to facilitate the analysis by USGS, providing the scope and direction for this project and local information on sites likely to elicit spawning activity, the likelihood of modeled nursery areas to support recruitment, and other interpretation of results. The USGS worked collaboratively with Minnesota DNR to define the conditions of the hypothetical spawning events based on current understanding of invasive carp spawning behaviors (e.g. Kolar et al. 2007). The hypothetical spawning events represent all combinations of 10 spawning locations, 5 water temperatures, and 9 flow conditions. The modeled spawning locations were placed in the tailwaters of Lower Saint Anthony Falls Lock and Dam and Lock and Dams 1, 2, 3, 4, 5, 5A, 6, 7, and 8, where flows are typically fast and turbulent. The water temperatures (18, 20, 22, 24, and 26 °C) span most of the typical range during invasive carp spawning. The 9 flow conditions span from approximately the annual mean flow to the 5 percent annual exceedance probability flood at USGS streamgage 05378500 Mississippi River at Winona, MN.

The USGS has completed the following modeling and analysis steps:

- Obtained and quality-checked a pre-existing unsteady-state 1D hydraulic model of the Upper Mississippi River developed by the U.S. Army Corps of Engineers (USACE) (USACE 2020; Figure 1)
- Extracted the hydraulic parameters needed to run FluEgg for the selected hypothetical spawning scenarios from the hydraulic model and formatted the data for input into FluEgg (example shown in Figure 2)
- Ran FluEgg simulations for all 495 hypothetical spawning scenarios and exported the “condensed” results files, which summarizes the position of the egg/larval plume using 101 quantiles
- Ran an additional repeat set of FluEgg simulations for a selection of 72 scenarios with spawning in the tailwaters of Lock and Dams 2 and 5 and exported the “full” results files, which records the position of each egg at every timestep and can be used for more detailed analyses
- Analyzed the results of the FluEgg simulations to determine the locations where eggs hatch into larvae, the likelihood that eggs remain suspended until hatching, and the locations where larvae reach the gas bladder inflation stage

The USGS is preparing an interpretive journal article and supporting data release/model archive for publication in an open-access format. Collaborators at Minnesota DNR will assist in drafting the interpretive journal article, lending their perspective on the management implications of the results, and will be included as co-authors.

To facilitate further simulations beyond the scope of this project (for example, using a different hydraulic model or simulating other species of invasive carp), USGS will instruct Minnesota DNR staff (and other UMR partner agency staff as interested) in the operation of the FluEgg model. This will likely be a multi-day workshop, which could be online or in-person depending on which format will best facilitate instructors and attendees. The simulations, reporting, and workshop will be completed in the winter of FY2026.

Results and Discussion:

The results of this study will be released as an interpretive journal article and supporting data release/model archive following completion of the USGS Fundamental Science Processes review and approval process.

The results of this project will be used by Minnesota DNR to assess potential management options for reducing risk of reproduction in Minnesota waters. Potential actions could include commercial fishing to reduce abundance at key locations, deterrents to prevent invasive carp from accumulating at locations where a spawn could result in recruitment, disruption of spawning aggregations at those locations, or directing spawning activities to locations where recruitment is not possible.

Tables and Figures:

Figure 1. *Map of the study area and hydraulic model domain (from USACE, 2020).*

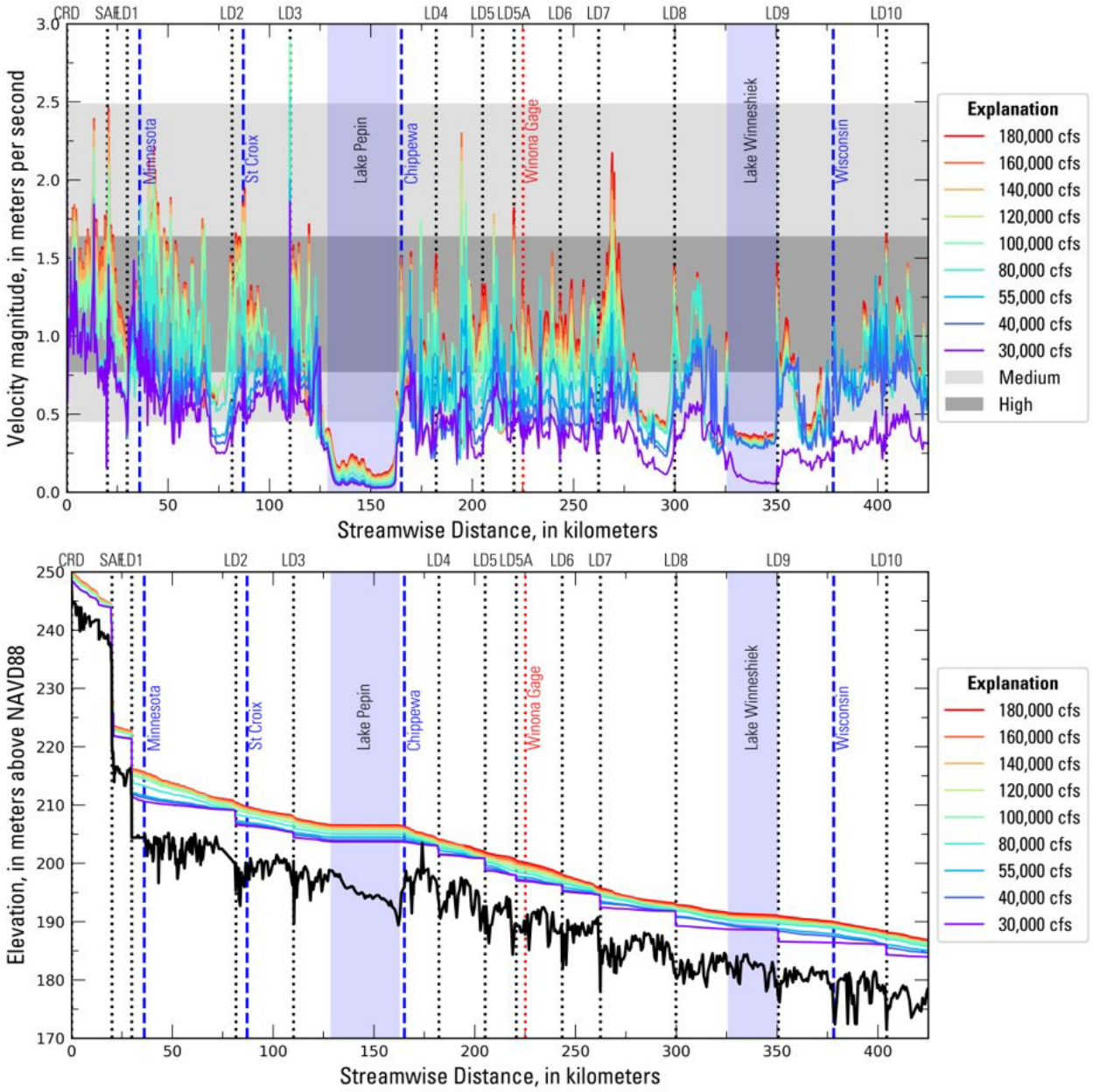

Figure 2. *Longitudinal profiles of simulated velocity (top) and water surface elevation (bottom) in the Upper Mississippi River for 9 flow conditions (specified by streamflow at USGS streamgage 05378500 Mississippi River at Winona, MN) extracted from the USACE (2020) hydraulic model. The black dotted lines show the locations of lock and dams, the blue dashed line shows the locations of major tributary confluences, the red dotted line shows the location of USGS streamgage 05378500 ("Winona Gage"), and the blue shading shows the locations of Lake Pepin and Lake Winneshiek.*

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