Project Title: Understanding invasion risk to more effectively allocate monitoring and management.

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Participating Agencies: South Dakota Department of Game, Fish & Parks (SDGFP), South Dakota State University (SDSU), Center Nebraska Game and Parks Commission (NGPC), University of Nebraska – Lincoln, U.S. Geological Survey—Nebraska Cooperative Fisheries and Wildlife Research Unit, USGS South Dakota Water Sciences

Location of Activities: The study area includes the Missouri River, its tributaries, and waterbodies within the Missouri River watershed.

Statement of Need: Minimizing the risk of invasive carp from spreading to new areas in the Missouri River basin requires an understanding of which sites are most vulnerable to invasion. This knowledge will allow limited management resources (e.g., prevention efforts, surveillance, removal) to be prioritized to the most at-risk locations and can aid in the development of proactive response plans. A site's vulnerability to invasive carp depends on a suite of factors. Permanent or temporary connectivity to systems where invasive carp occur increases a site's invasion risk due to the potential for movement or dispersal. The Missouri River basin has a diverse network of rivers, streams, and diversion canals which connect river systems, yet information is lacking regarding the hydrological connectivity that could allow invasive carp to move among these systems, especially during high-water events. A site's invasion risk also depends on whether habitat conditions (e.g., thermal conditions, flow regime, prey availability) are suitable to allow invasive carp to grow and survive once they have become introduced, regardless of the mechanism of introduction. Past habitat suitability assessments have been conducted over a broad spatial scale using climate matching approaches (e.g., Herborg et al. 2007). Instead, fine-scale habitat suitability predictions are needed so sites can be compared and ranked based on relative risk. Additionally, understanding whether site conditions are suitable only for certain sizes or life stages can refine site relative risk comparisons and inform gears needed for surveillance efforts. Finally, a site's invasion risk depends on whether conditions are suitable for spawning. The ability of invasive carp to capitalize on environmental conditions conducive to spawning greatly contribute to their ability to invade an area and become the dominant fish species (Kolar et al. 2007; Irons et al. 2007). Applying previously developed models (e.g., Garcia et al. 2015) to quantify spawning potential will be an essential component for determining invasion risk in uninvaded rivers.

Control and mitigation of invasive carp species has largely focused on efforts to remove or divert them in an attempt to minimize short- and long-term changes in ecosystems where they are already established. Much of this work has focused on larger sub-adult and adult sized fish in an attempt to decrease populations in larger river systems. However, emerging data from otolith microchemistry analyses show that many individual carp collected in the Missouri River basin have natal origins from tributaries rather than the mainstem portion of the basin. This information suggests an unaccounted-for source-sink dynamic that could sustain carp populations even in the presence of large-scale removal efforts if successful recruitment is occurring in these tributaries on a regular basis.

We have a basic understanding of the requirements these carps need to successfully reproduce and thus survive through their early life stages (e.g., free-floating eggs to larval drift stages). For example, the FluEgg model has been used to simulate drift requirements for invasive carps in rivers characterized as a single channel (e.g., Illinois River Waterway). However, many tributaries in the Missouri River and especially those flowing through the Great Plains are characteristically shallow, braided systems (e.g., Platte River) that incorporate additional complexity that has yet to be evaluated. Therefore, understanding the dynamics of early life-stage outcomes in braided river systems may shed light on the ability of these systems to support the spawning and development of eggs and larvae as well as on new avenues to affect control measures. Better knowledge of how eggs and larvae drift in the water column in these braided systems could prove beneficial for informing prevention and innovation in population control. Specifically, being able to determine how eggs and larvae move throughout a system could identify potential habitat types and locations where young invasive carps become concentrated due to flow dynamics. These concentration habitats could then be targeted for monitoring in areas not yet invaded by invasive carp or intensive carp management practices to remove individuals in a more effective manner. Our goal is to better understand how flow and habitat dynamics in the Platte River Basin influence egg and free-floating life-stages of invasive carp. The primary goal of this project is to limit the spread of invasive carp in the Missouri River basin. Further, we will increase our understanding of their drift dynamics to identify areas to target larval and/or age-0 removal. The tasks described here will develop quantitative risk assessments that will identify site vulnerability to invasive carp in the Missouri River basin. These results will allow for the efficient use of management resources by identifying locations where movement deterrents can be placed, determining locations and life stages (eggs, juveniles, adult size classes) monitoring efforts should target and appropriate sampling gears to use, and informing or developing response plans if invasive carp are observed in new locations.

Project Objectives:

1. Assess hydrologic connectivity in the Missouri River Basin to identify locations at risk of Silver and Bighead carp movement into new areas.
2. Define relative risk based on habitat suitability for Silver and Bighead Carp invasion in uninvaded areas of the Missouri River Basin.
3. Model and evaluate drift dynamics of Invasive Carp eggs and larvae in the Platte River to assess the successful spawning potential of invasive carps under varying flow conditions and identify habitat types or locations conducive for carp population management.

Project Highlights:

- A standardized protocol was developed for identifying which uninvaded waterbodies become connected to invaded rivers during temporary flooding.
- Habitat conditions were sampled monthly at 18 locations in 2024 (50 total locations) for modeling of invasive carp habitat suitability that will ultimately be used to prioritize sites for monitoring and management based on relative invasion risk.

- A working two-dimensional HEC-RAS model has been developed for a study reach of the Platte River from Ashland to Louisville.
- A set of scripts has been written that imports HEC-RAS results into QGIS, processes the results to find velocities and depths at any location in the study reach, and tracks the motion of individual egg releases as they travel downstream.
- A large set of field data has been collected to provide accurate representation of the bathymetry of the Platte River in the computer model.
- Developed a 40-year spread model for assessing the potential range expansion of invasive carp, utilizing hydrological data to identify potential control and management areas in Nebraska waterways.
- Assessed egg drift dynamics to evaluate risk of successful bigheaded carp spawning and establish 'no-spawn zones'.
- The North Platte diversion could significantly delay upstream movement, with estimated times of 17 years under normal conditions and 1.8 years during flood events.
- The Tri-County Supply Canal is unlikely to support carp spawning or juvenile habitats due to insufficient flow and unsuitable environmental conditions.
- Ongoing studies will refine the model using real-world movement and egg drift data, with expansion to other Nebraska river systems like the Loup River.

Agency: South Dakota Department of Game, Fish and Parks, South Dakota State University

Methods:

Objective 1. This project assesses the potential for invasive carp to spread from Missouri River tributaries in South Dakota and North Dakota into currently uninvaded waterbodies through floodwater connections. Potential habitat connections were evaluated across a gradient of flooding intensities. For a given flooding event, data on the spatial extent of floodwaters was obtained from USGS's Dynamic Surface Water Extent product, which represents surface water observed from Landsat reflectance measurements. Methods for GIS analyses were being developed to identify where habitat connections occur and to calculate metrics of connectivity between rivers invaded with carp and adjacent, uninvaded waterbodies. These metrics can then be used to categorize habitat connections based on their relative risk for prioritizing monitoring and deterrent efforts. Deliverables from this work will include maps and GIS layers identifying waterbodies that are hydrologically connected to invaded habitats under 1) typical water levels, and 2) extreme low- and high-water levels.

Objective 2. Led by SDSU and SDGFP in collaboration with other states in the basin, this project assessed invasion risk of Bighead and Silver carp in the Dakotas by quantifying habitat suitability. High invasion risk will be assigned to locations where adult and young-of-year (YOY) carp can grow and survive, whereas sites with low invasion risk will be characterized by poorly suited habitat for growth and survival of adult and/or YOY. Site-specific risk is being evaluated across all sizes of fish (YOY – adults) that could become introduced, thereby assessing risk regardless of the mechanism of introduction (e.g., live bait release, dispersal of adults, or spawning). Long-term growth and survival will be quantified in uninvaded tributaries, lakes, and wetlands in the Missouri River Basin using a bioenergetics-based approach based on site-specific observations of water temperature, velocity, and plankton density. Model output will include a database listing for each location and species: percent of individuals surviving, minimum size capable of surviving, growth of surviving individuals, and YOY introduction dates resulting in survival. Model results will also indicate the locations within a waterbody where high quality habitat for bigheaded carp is located and how this changes seasonally, which informs sampling locations for surveillance monitoring or response actions. Deliverables will include maps and GIS layers indicating relative invasion risk for Bighead and Silver Carp in Missouri River tributaries. Results from this project will provide stakeholders the information they need to (1) allocate signage or outreach to prevent bait dumping in areas where YOY can survive, (2) develop monitoring plans that prioritize locations based on relative risk and focus sampling gears on the size of fish expected to survive, and (3) inform actions when a Bighead or Silver Carp is observed (e.g., support for no action if individuals are found in a low risk area). This risk assessment will be valuable for identifying suitable areas that can be prioritized for management actions and for identifying areas where low survival and negative fish growth lead to a population sink that reduces risk priority. Elements of this risk assessment are additive to ongoing risk assessments focused on hydrologic connections or spawning potential in the basin.

Results and Discussion:

Objective 1. Dates representing a gradient of flood intensities were identified using mean daily discharge measurements from 1990 – 2023 in the lower James River of South Dakota (USGS gage 06477000). These daily discharge values were sorted and divided into five equally spaced percentiles (Figure 1). Ten dates were then randomly selected within each discharge percentile which ultimately identified 100 dates representing a gradient of flood intensities for assessing floodwater connections. Surface water data (DSWE) observed from Landsat satellites were obtained for each of these 100 selected dates. A workflow for GIS analyses was developed to identify where floodwater connected the James River to currently uninvaded waterbodies. This involved removing existing waterbodies from the DSWE surface water data to produce locations of temporary floodwater. Steps were then established to identify waterbodies that become connected by a contiguous floodwater connection to the James River (Figure 2). Finally, procedures were identified to quantify metrics of habitat connectivity that can be used to prioritize habitat connections for monitoring or management actions, including 1) which waterbodies become connected to the invaded river, 2), the habitat type (e.g., wetland, lake) and size of uninvaded habitats that become connected, and 3) the amount (surface area) of floodwater connecting invaded and uninvaded waterbodies. These procedures will be applied to identify floodwater connections that occur across the entire gradient of flood intensities in the lower James River, as well as along other tributaries in the Missouri River Basin.

Objective 2: Environmental conditions (water temperature, chlorophyll concentration, zooplankton density, and water velocity) were sampled once per month from 18 waterbodies in South Dakota and North Dakota during 2024. Combined with sampling conducted in 2023, a total of 50 uninvaded waterbodies were sampled monthly and will be assessed for invasive carp habitat suitability with this project. Samples collected in the field during 2023 and 2024 were processed in the laboratory to determine chlorophyll-*a* concentrations and taxa-specific zooplankton density. These data on monthly environmental conditions act as input data to an invasive carp population model (Coulter et al., 2022) that simulates growth and survival following a hypothetical introduction. Final simulations are underway but initial model results provide an understanding of how the location of high-quality habitat patches for bigheaded carp can change seasonally for some habitats. As environmental conditions change throughout the year, the location of high-quality habitat patches within a waterbody can vary, whereas other waterbodies are more stable through time (Figure 3). Prior research has documented how the spatial distribution of bigheaded carp changes across seasons and is related to changes in the environmental conditions used in this habitat suitability modeling (Glubzinski et al., 2021). Therefore, these initial model results inform sampling protocols for early detection and response actions by identifying which waterbodies undergo changes in the location of high-quality habitat patches for bigheaded carp and should be accounted for in sampling efforts. Completed population model output for all 50 waterbodies will determine relative habitat quality for each waterbody and allow waterbodies to be prioritized based on relative invasion risk.

Tables and Figures:

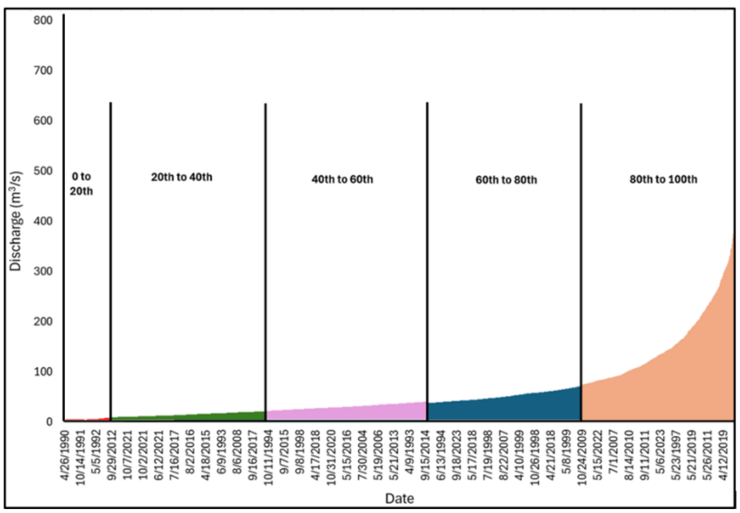

Figure 1. Mean daily discharge from 1990 – 2023 in the lower James River (USGS gage 06477000) separated into equally spaced percentiles. Dates were randomly selected within each percentile to obtain a gradient of flood intensities for identifying locations where floodwaters connect the invaded James River to adjacent, uninvaded waterbodies.

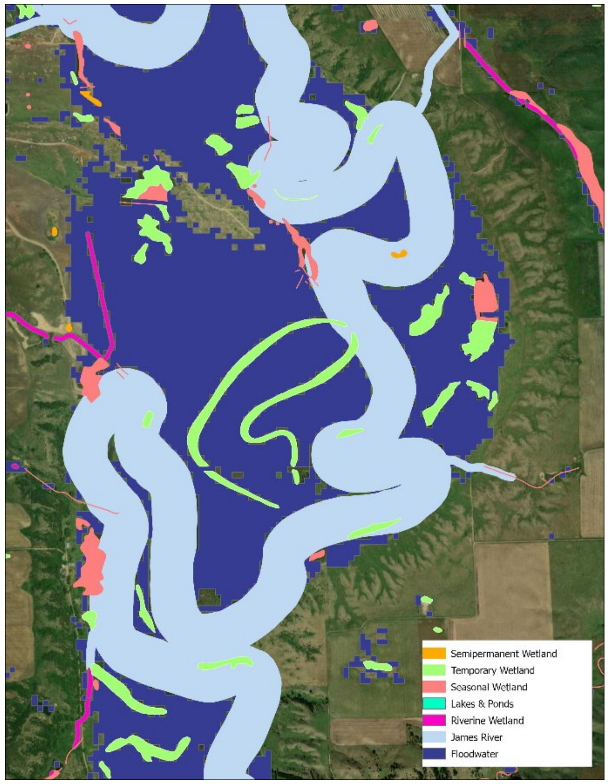

Figure 2. Example of temporary floodwaters (Landsat-observed data) and adjacent waterbodies in a reach of the lower James River in South Dakota where floodwater habitat connections will be identified.

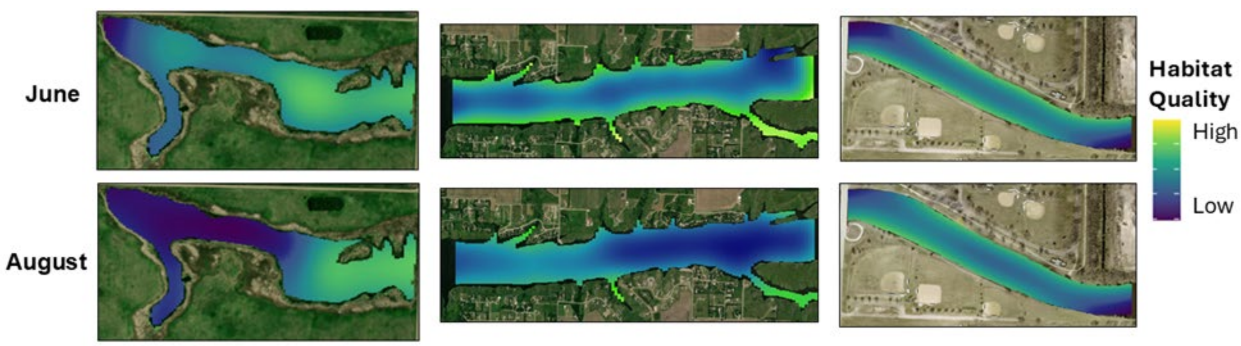

Figure 3. Example of spatial patterns in the location of predicted high quality habitat for bigheaded carp in three currently uninvaded waterbodies in South Dakota and North Dakota. Sampling protocols for early detection or response actions may need to account for seasonal changes in the location of high-quality habitat patches in highly variable habitats to ensure sampling or removal effectiveness (left panel). However, this might not be necessary for habitats undergoing moderate (middle panel) or minimal (right panel) change in habitat conditions through time.

Agency: Nebraska Game and Parks Commission (NGPC), University of Nebraska – Lincoln, U.S. Geological Survey—Nebraska Cooperative Fisheries and Wildlife Research Unit

Methods:

Objective 1.
Modeling
Since our goal is to create an egg tracking methodology that allows us to accurately predict egg dispersion for a variety of flow conditions and in different locations, we are using widely available software so that our approach can be more easily replicated. The Platte and other alluvial rivers in Nebraska are wide and shallow with multiple sub-channels, and a one-dimensional model will not adequately capture flow behavior or consequent egg dispersion behavior. Three-dimensional modeling for egg-dispersion has been reported for the Missouri River (Li et al., 2022), and although feasible for short reaches, it would be difficult to implement for the large area that we are studying. Moreover, two-dimensional modeling provides a good representation of most of our study area due to the wide, shallow planform of the river.
Our modeling methodology is divided into two distinct parts: (1) flow modeling and (2) egg dispersion tracking. Separating the process into two steps makes it simpler to utilize existing software. The required assumption of this quasi-steady approach is that the flow channel does not change significantly over the duration of the dispersion event. Although some changes to the bed do occur during an egg release, the changes are slow compared to the flow velocities, and their effects will be ignored in the current project. If bed changes were important, the approach would require that flow modeling and egg dispersion tracking be simultaneously modeled. There are ways of doing this with the software that we are using, but the approach is much more complex and unnecessary for the flows we are investigating.

Objective 2. The greatest determining factor in carp movement is behavioral choice. Adult carp could move several dozen kilometers upstream in a single day, only to backtrack even further downstream the next. Work to inform the range and extent of carp movements will begin in 2025. However, we used information from published literature to predict the behavioral baseline for prototype modeling. High rates of flow also likely create additional, physiological costs where a modifier was applied to upstream movement in extreme flow events. Water elevations (e.g., Monthly Mean Gage Height) can also modify carp movement, where high water likely indicates increased potential for movement and lessen restriction on movement in some situations. These data were incorporated into a spread model using input from parameters in Figure 9. Figure 9 also shows the general approach and flow of model development to estimate potential range expansion over a 40 year time period. The 40-year spread estimate model represents permanent movement of carp populations, rather than temporary appearances of individual fish. It uses Supply Canal Norms, water table height and discharge data from multiple river gages, and rainfall estimates per watershed to generate approximate stream conditions for each polyline. This model was further assessed using conditions to model "normal" or median flow ranges as well as flooding events to predict time to moving through a particular location (Days To Infestation; DTI). Here, those locations were often potential impediment points to identify where additional control and management activities may be warranted.

The basis of the network itself comes from the United States Geological Survey, specifically the National Hydrology Dataset (NHD). This dataset contains polylines which represent the centerlines of rivers and streams, with points placed in an order that matches direction of flow, known as flowlines. This model removed non-permanent and underground flowlines from the wider NHD flowline package and used the remaining areas to determine major hydrological systems (named for their primary stream or river). The NHD Waterbodies dataset was also used to determine low-flow water areas, useful in the egg drift studies. The NHD Flowlines dataset includes the centerlines of these static waterbodies for the purpose of network continuity. The NHD Lines dataset provided several polylines representing types of artificial construction (i.e., dams, locks, gates, etc.) to establish blocking points along the hydrological network. Once the acceptable hydrological network of flowlines, static areas, and water blocks is finished, the model will also establish test points to predict passage at specific locations using currently known information.

Current research is underway to assess egg drift in braided river systems like most of those found in Nebraska's waters that also hold invasive carp (FY 2023 funding). However, currently available data suggest the invasive carp need a period of 40-60 hours in the drift of moving water before a gas bladder inflates to keep them afloat. Eggs that become static before the bladder inflates will sink and be buried, never to hatch. Therefore, we used this information to form the basis of the 'no-spawn zone' portion of this study model. The model used stream discharge rates to infer a rate of drift from an assumed norm, since the true rate of drift and the hydrodynamic properties of the carp eggs are still being studied. The model assumes that eggs drift at a rate of 1km per day, solely downstream, given average conditions. Monthly rate-of-discharge gage data were compared to annual rate-of-discharge gage data to produce a monthly modifier to this movement rate, which will be used in network analysis via ArcGIS. Eggs also require a water temperature of at least 17 C, so the egg drift modeling was only conducted for May to September, when water temperature averages are above 17 C.

Intensive assessment of the potential for range expansion in the Central Platte River (Figure 10) was the primary focus for analyses following initial identification of potential connections via canals and other waterways, potential barriers to movement, and compiling biological and physical attributes of the ecosystems in Nebraska during 2022-2023. The potential barrier to movement near North Platte, Nebraska was of special importance because it may preclude further upstream movement as well as movement into the canal network associated with the Tri-County Canal (Figure 10). The following highlights model results with the available data. Additional revisions will be made as the movement and egg drift studies provide input.

Results and Discussion:

Objective 1. The study reach is shown in Figure 1. This reach is from Ashland, NE to Louisville, NE. The upstream and downstream locations have USGS stream gages, which will aid in calibration of the models that we develop.

We selected HEC-RAS for flow modeling because it is versatile, widely used, and produces results that are reliable when properly applied. Figure 2 shows our original computational mesh, which extends from the mouth of Salt Creek to Platte River State Park. We have recently extended our model to cover from the State Highway 6 bridge to the State Highway 50 bridge, which are the locations of two stream gauges on the Platte River. The current model has a channel mesh size of 15m by 15m. We have used a very coarse mesh (80m by 80m) in the floodplain since summer flows are not high enough to enter the floodplain. As we close in on a solution, we intend to increase channel resolution to improve results, but the current resolution is good for initial testing of our methodology because it reduces computational time, allowing us to make more rapid adjustments as we work on the model.

The main output of the flow model is an array of flow velocities and water surface elevations for the entire study reach. These data are output into an HDF file as time series data, so we can record both steady and unsteady flows. We are starting with a steady flow model because it is less difficult to implement. Once the complete model is up and running, including both the flow model and the egg tracking subroutines, we can assess if an unsteady model is needed. Flows in the Platte River do vary substantially daily, but whether or not this impacts model predictions depends on the travel times of eggs through the study reach.

Egg dispersion tracking is being modeled using Python scripts in QGIS. Flow results are directly imported from HEC-RAS HDF files into QGIS using a set of custom scripts. Once imported, the flow data are used for Lagrangian tracking of eggs. The flow chart in Figure 3 shows the necessary workflow for doing the Lagrangian tracking. The first part of the figure shows preprocessing steps. All the calculated velocities and depths from HEC-RAS are read into NumPy arrays in QGIS. The velocities and depths are then interpolated to produce rasters that have depth-averaged velocities and flow depths at every point in the flow area of the study reach. It is a complex process to interpolate HEC-RAS velocity and depth results into raster values, because the mesh element data in HEC-RAS 2D are very irregularly located and the depth data has sub-grid resolution. But the process is important because it makes the egg tracking routine much more efficient if all data are in a grid instead of at irregularly spaced points. The other complexity is that HEC-RAS velocity interpolation requires information about bank proximity since banks must have velocities that go to zero. This requirement appears to be relaxed within HEC-RAS, but it is more important for egg transport modeling to properly identify locations of egg deposition.

Once velocity and depth rasters are found, egg tracking follows the second half of the flow chart in Figure 3. For each egg position, the velocity of the egg is determined from the velocity raster, the depth raster, and a logarithmic model of the vertical velocity profile. Although we have not completed integrating the log model and the diffusivity subroutines with our other scripts, these steps are not difficult. There is a choice between having an explicit or an implicit model for egg velocities. If time steps are small, the path steps will be small, and an explicit model will likely be sufficient. The implicit model depicted in Figure 3 will be more difficult because it requires iteration to convergence, and since diffusivity movements are random, convergence may become an issue. This is something we need to think about a little more before finalizing the model.

Field Work

One difficulty of the modelling effort is establishing accurate bathymetry to produce good results. The Platte River (and all braided alluvial rivers) have complex bathymetry that changes from year to year. To produce an accurate prediction of egg drift, the model bathymetry must be a good representation of the true bathymetry at the time of release. For the study reach, 1m by 1m Digital Elevation Model (DEM) data are available from the USGS. We also have 1yd by 1yd terrain data that Platte River Recovery Implementation Program (PRRIP) has shared with us. Both sets of data have advantages and limitations.

The USGS DEMs provide a good measure of the channel slope and excellent information about the floodplain and unsubmerged parts of the river. A big advantage of these DEMs is that they are widely available for other rivers in Nebraska. However, these DEMs do not provide bathymetry because the LiDAR used to collect elevations does not penetrate water surfaces. In locations where there is a water surface reflection, the LiDAR provides the water surface elevation at the time of collection. In some locations, where adjacent DEMs were collected at different times, adjacent water surface elevations have discontinuities, creating a problem for even a simple HEC-RAS model. Thus, to use the data for HEC-RAS models, regions with active water surfaces will need to be repaired with reasonable representations of the bathymetry.

The PRRIP terrain data are better and may be more suitable for our effort because they were collected using bathymetric LiDAR, which is intended to provide the actual bed elevations. Bathymetric LiDAR penetrates the water to get reflections of the bed. Unfortunately, bathymetric LiDAR is limited by turbidity, and the Platte River is quite turbid. The result is that the PRRIP terrain data are erroneous in some locations, due to light penetration issues. The most evident issue is the presence of long, narrow gullies that are excessively deep in parts of the riverbed. We did not observe these features when we collected field data, and it is highly unlikely that they exist (at least not at the depths reported).

The obvious conclusion is that field measurements will do a lot to improve modeling of the river bathymetry. Our approach is to simultaneously collect high-resolution imagery with an Uncrewed Aerial Survey drone and detailed cross-section data with a hand-held GPS unit. At 18 km, the model reach is much too large for us to sample with the drone. Instead, we sampled a 4 km sub-reach near Schramm State Park. The information collected in the sub-reach will be used to prepare a representative bathymetry for the entire model reach.

Figure 4 is an ortho-mosaic of the sub-reach images collected in the field. The ortho-mosaic consists of hundreds of high-definition images collected with our UAS that are stitched together. This composite image alone is valuable for understanding the meanders and sub-channels of the river and can be used to improve bathymetry representations in the computer model. The data have also been used to generate a point cloud that gives land surface elevations of all parts of the image that are solid land surfaces. While much of the image is water, there are also numerous sand bars and banks where we will be able determine elevations for the flow model. This is particularly important because summer flows in the Platte River have diurnal cycles. The UAS imagery in Figure 4 is for the low flow, and as depths increase, some of the sandbars will become submerged. Thus, knowing their elevations is beneficial.

In concert with the UAS imagery, bed elevations were measured at four cross sections using a hand-held RTK GPS unit. The locations of these cross sections are shown in Figure 5. A total of about 2000 GPS points were collected.

The cross sections, shown in Figure 6, provide information useful for representing the bathymetry of the computer model reach. For example, none of the cross sections had depths greater than one meter, and most of the flow areas were wide and shallow with relatively uniform depth. The exception might be the presence of dunes and point bars in some parts of the reach. This type of information will help us to create a reasonable representation of the actual bathymetry.

We have taken the GPS data one step further and have correlated measured depths with colors/brightnesses of the ortho-mosaic imagery. Doing this allows us to assess the depth in other parts of the image where no hand-held data were collected. Figure 7 is a comparison of the depth measured with hand-held GPS and the hue of the images collected with the UAS drone. The ortho-mosaic resolution is 1.6 cm, and some spatial filtering is done to prevent reflections from interfering with the correlation. The result is a good correlation between image hue and depth for submerged parts of the image. The blue dots in Figure 7 are a logarithmic curve fit of the correlation between depth and hue. While the correlation is good, at depths above 0.2 to 0.3 meters the reliability of depth predictions using the curve fit decreases substantially because of the turbidity of the flow. Figure 8 shows how the correlation performs when applied to a sub-image from the ortho-mosaic. Depths above point bars and dunes on the point bar are reasonably estimated by the correlation. The correlation clearly does not work as well in the deeper areas, where red and orange dots indicate noise. We still have work to do, but with some filtering and rules based on the hand-held measurements, we expect to be able to reproduce the bathymetry in the ortho-mosaic with a realistic representation.

The final step in the process will be to extend our assessment of the study reach to correct for bathymetry in the remainder of the computer model reach. We plan to use aerial imagery (from the National Agriculture Inventory Program) and subchannel models developed from our field study to correct bathymetry in existing DEMs or terrain models of the entire computer model reach. As pointed out earlier, subchannels change from year to year and we will have a better idea of how the model from this year represents typical years after we collect additional field data in 2025.

Objective 2. The time it would take for invasive carp to move upstream over the North Platte diversion was about 6,200 days (~17 years) from their current distribution under median conditions (Figure 11). However, the flood stage model predicted similar movement in 667 days (~1.8 years) primarily due to the higher water elevations that could facilitate passage over the structure (Figure 12). Future work will physically assess this structure and others with low DTI values to verify NHD and other data are accurately representing current conditions.

Water control and management structures along the Tri-County Supply Canal, combined with actively maintained flat bottoms, mean that the canal is unlikely to generate sufficient flow to trigger carp spawning or sustain carp egg suspension in most scenarios modelled. However, should a successful spawn occur, there are limited locations with sufficient drift distances to support larval fish survival given our current knowledge of the invasive carp life history needs (Figure 13). Similarly, juvenile invasive carp habitats were evaluated based on three criteria: depth, stream velocity, and vegetation. Shallow waters with low (but not zero) flow and substantial vegetation made the best juvenile environment. Generally, suitable juvenile habitat does not exist within the canal network itself. However, information gathering efforts on life-history plasticity, connection to potential nursery areas, and egg/juvenile drift dynamics are ongoing and will provide further insight into the threat the invasive carp present to the canal network and beyond.

Tables and Figures:

Figure 1. Modeled reach of the Platte River extending from Ashland (State Highway 6) to Louisville (State Highway 50).

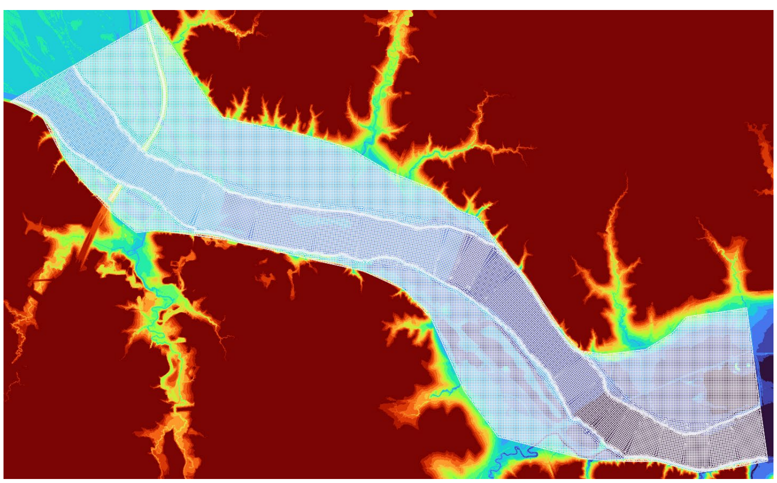

Figure 2. Original computational mesh from the mouth of Salt Creek to Platte River State Park.

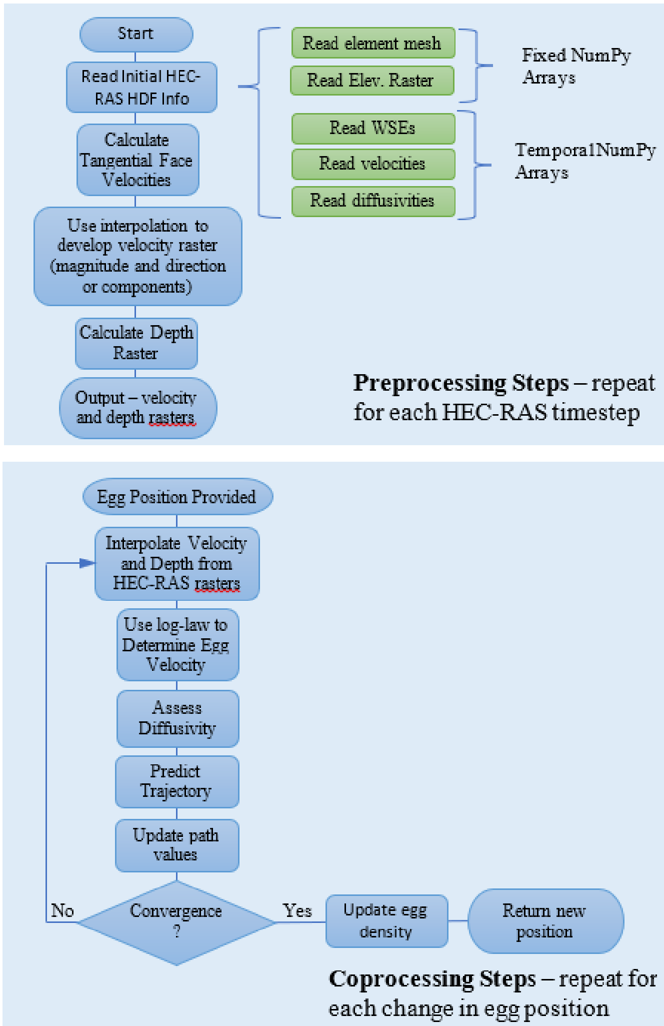

Figure 3. Flow chart showing processing steps required for tracking individual eggs.

Figure 4. High resolution orthomosaic of data collection reach. Data were collected September 26, 2024.

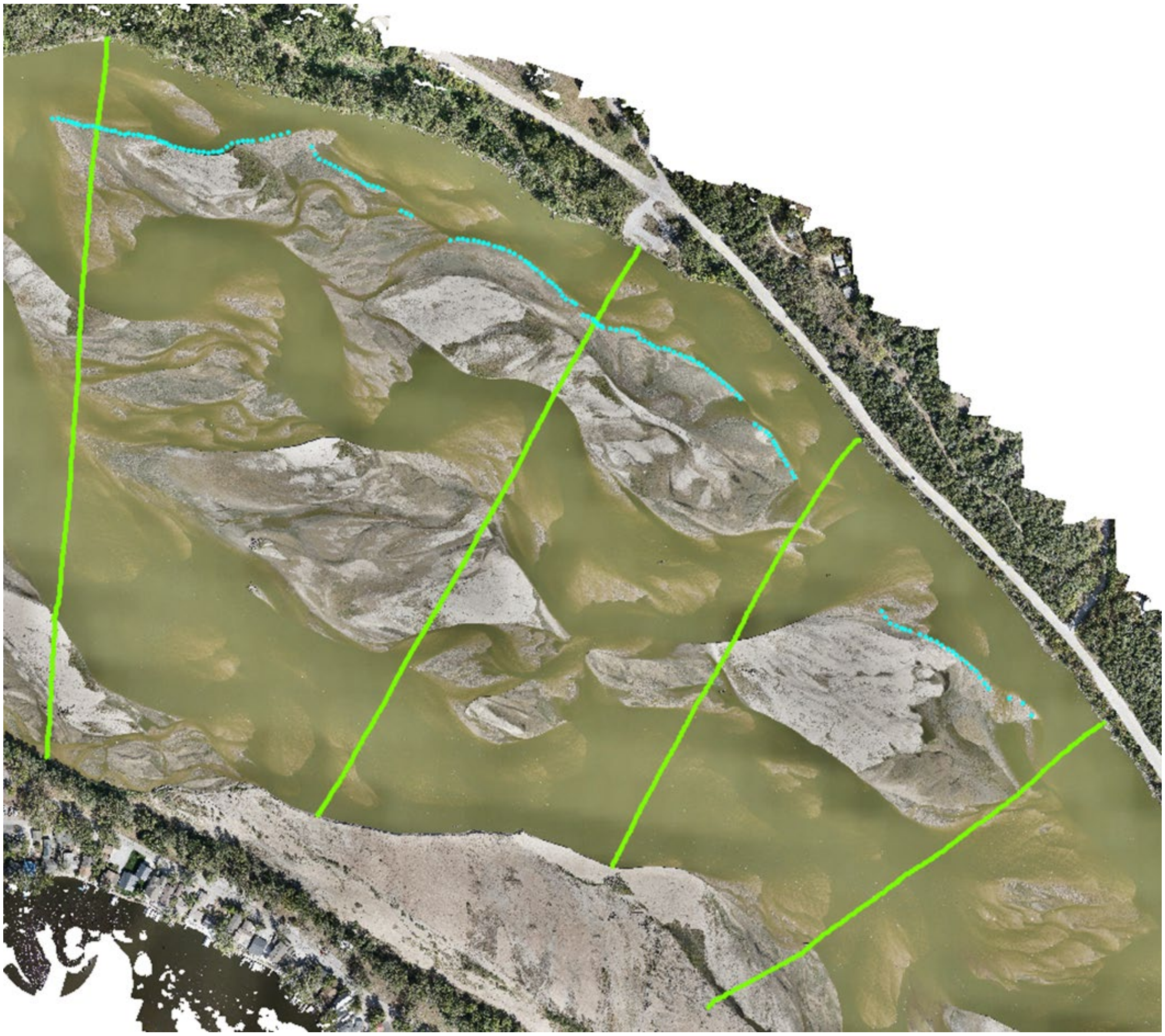

Figure 5. Locations of high-resolution, hand-collected survey data. Green shows transects A – D from left to right, respectively. Blue shows longitudinal water surface elevation data.

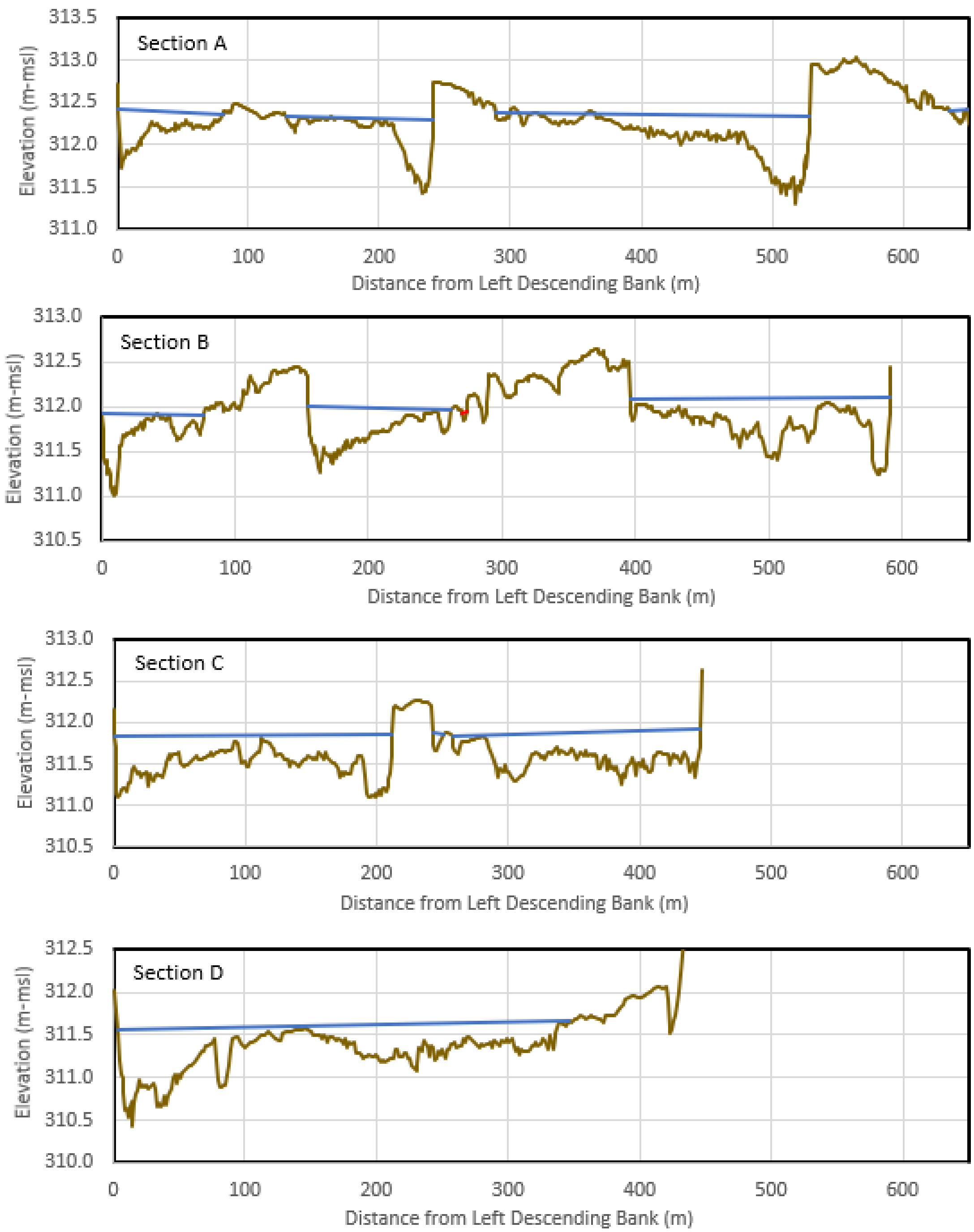

Figure 6. Hand-collected survey data of bed elevations. Water surface elevations were identified at banks while collecting the data and straight lines connecting these points are also shown.

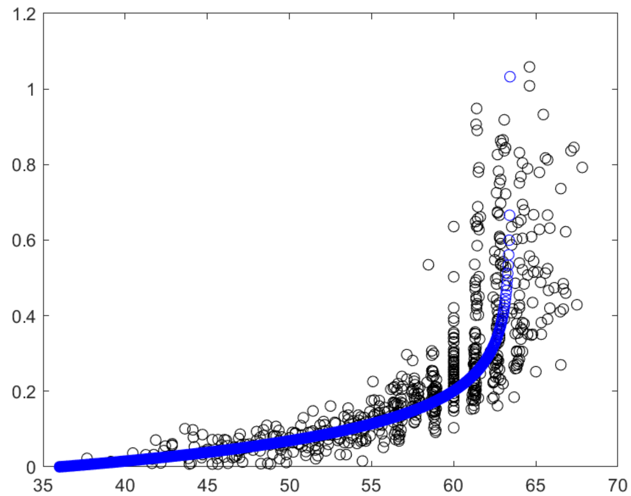

Figure 7. Depth (y axis - meters) as a function of Hue (x axis).

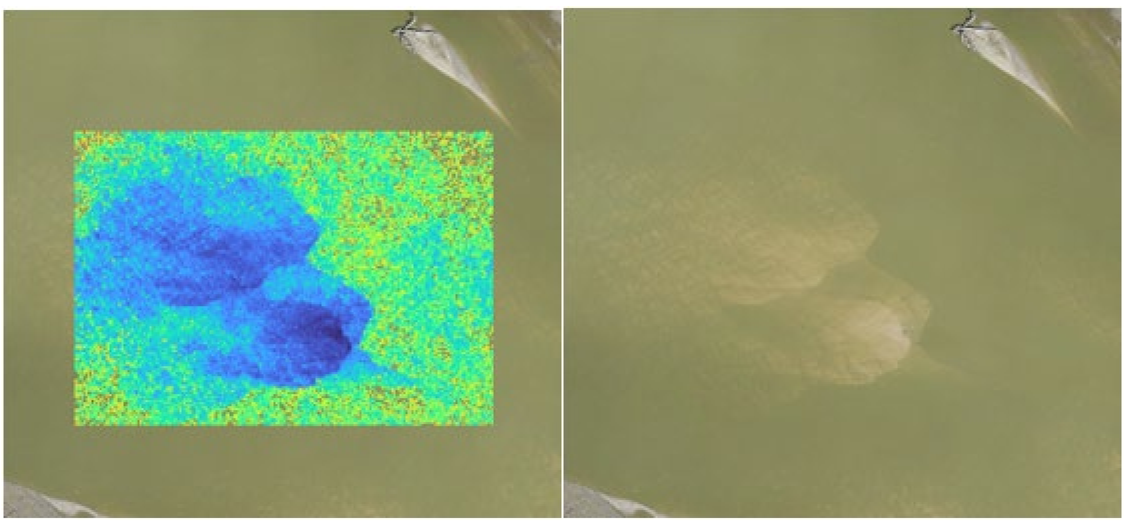

Figure 8. Comparison of raster depths with image provided by ortho-mosaic.

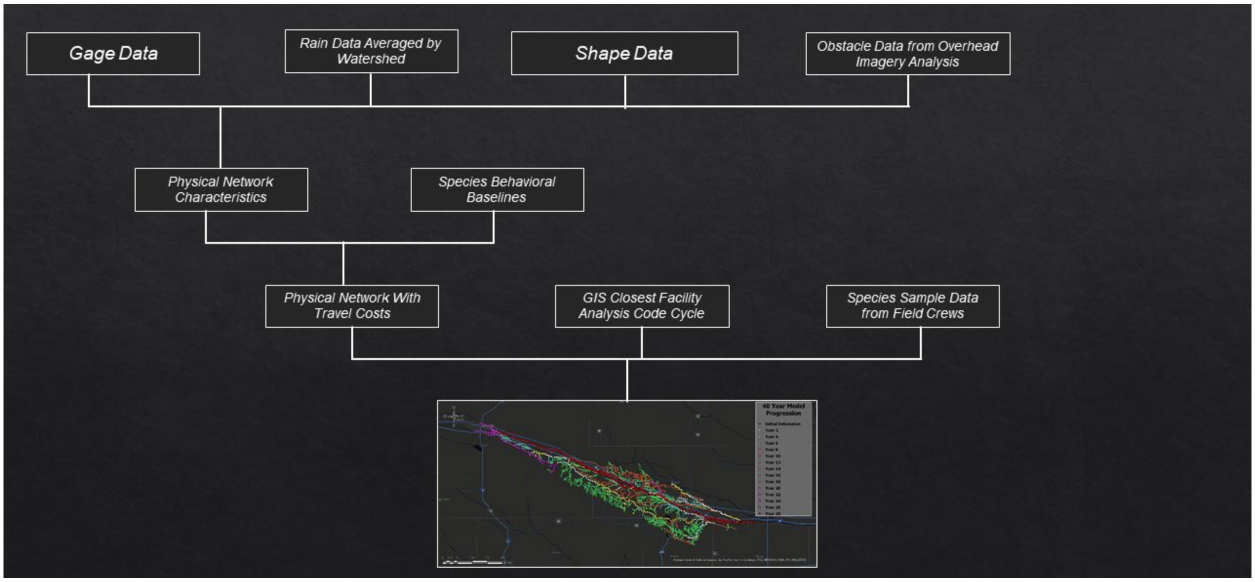

Figure 9. Predominant input data and flow of work for modelling potential spread of invasive carp in the Central Platte River.

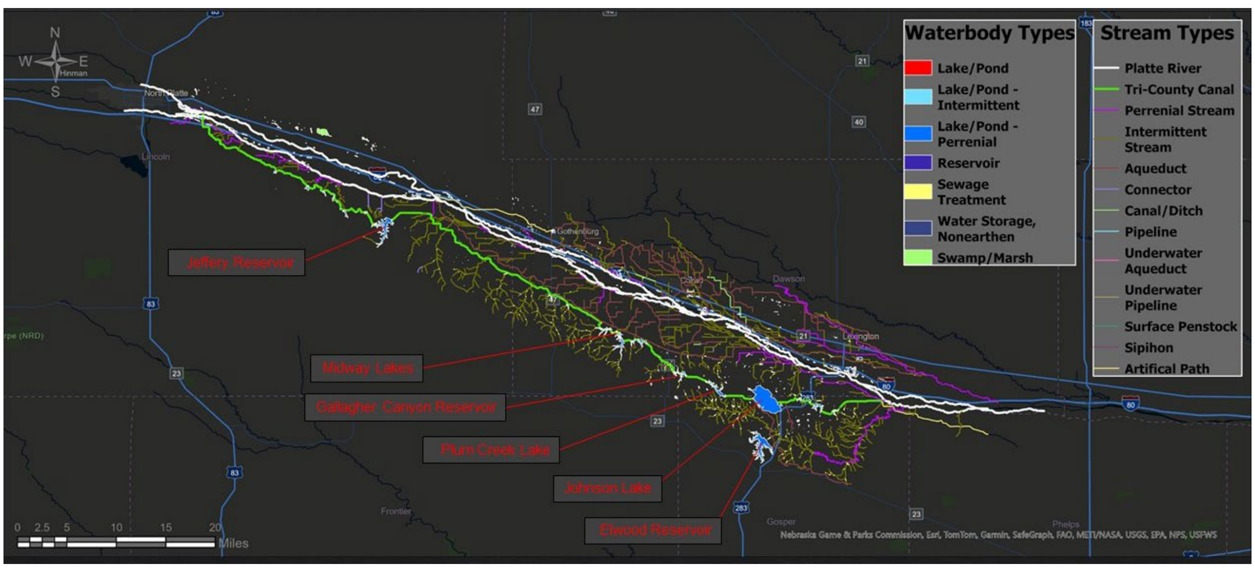

Figure 10. Central Platte River focal area for risk assessment analyses. Labelled systems (red) indicate suspected points of transition or potential holding areas should invasive carp become established. Circled area on upper left indicates the focal point for potential movement further upstream and into the canal system in the Platte River near North Platte, Nebraska.

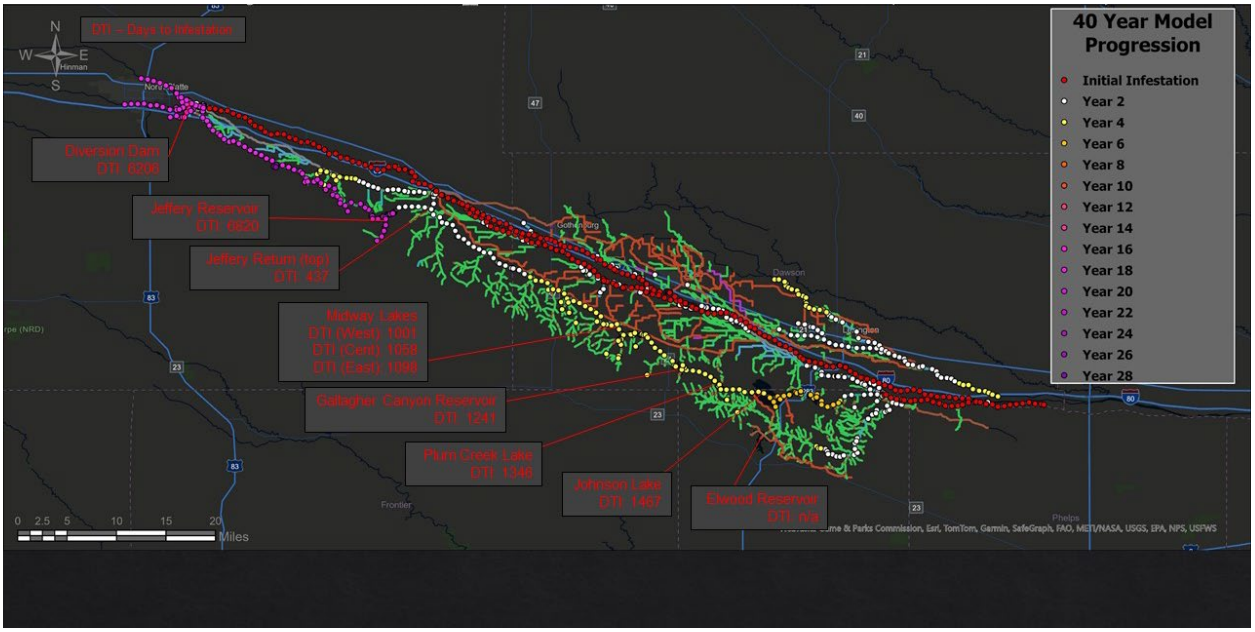

Figure 11. Model predictions of invasive carp population spread over 40 years of environmental conditions centered around their medians. Days to infestation (DTI) were predicted as the time to move past a point from their current (2024) known distribution.

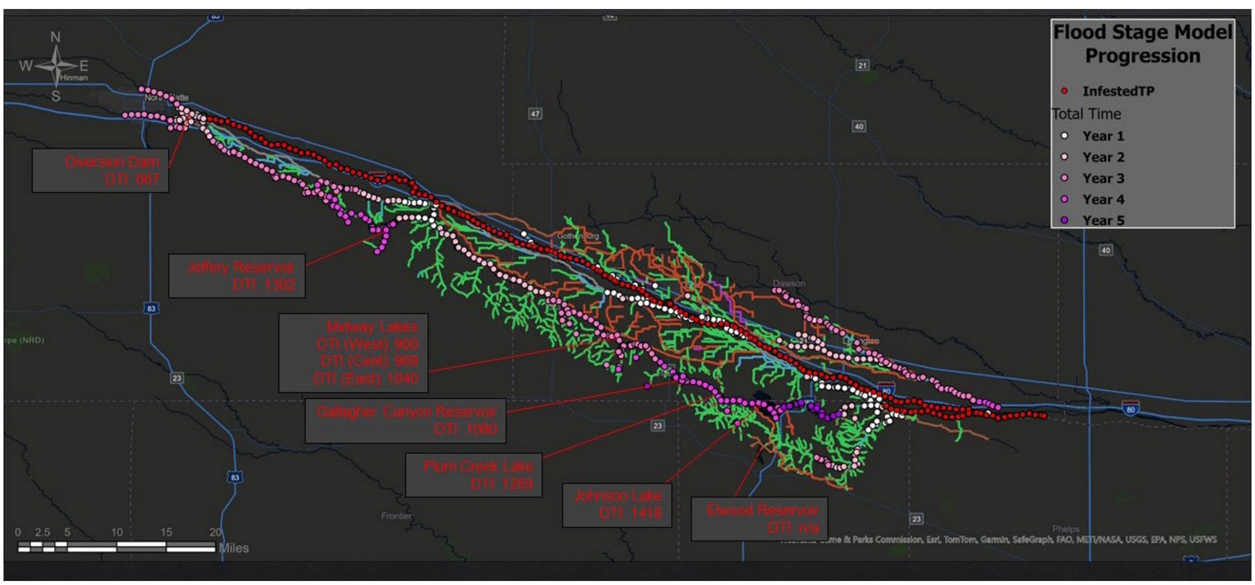

Figure 12. Model predictions of invasive carp population spread over 40 years of environmental conditions where discharge was allowed to exceed flood stage. Days to infestation (DTI) were predicted as the time to move past a point from their current (2024) known distribution.

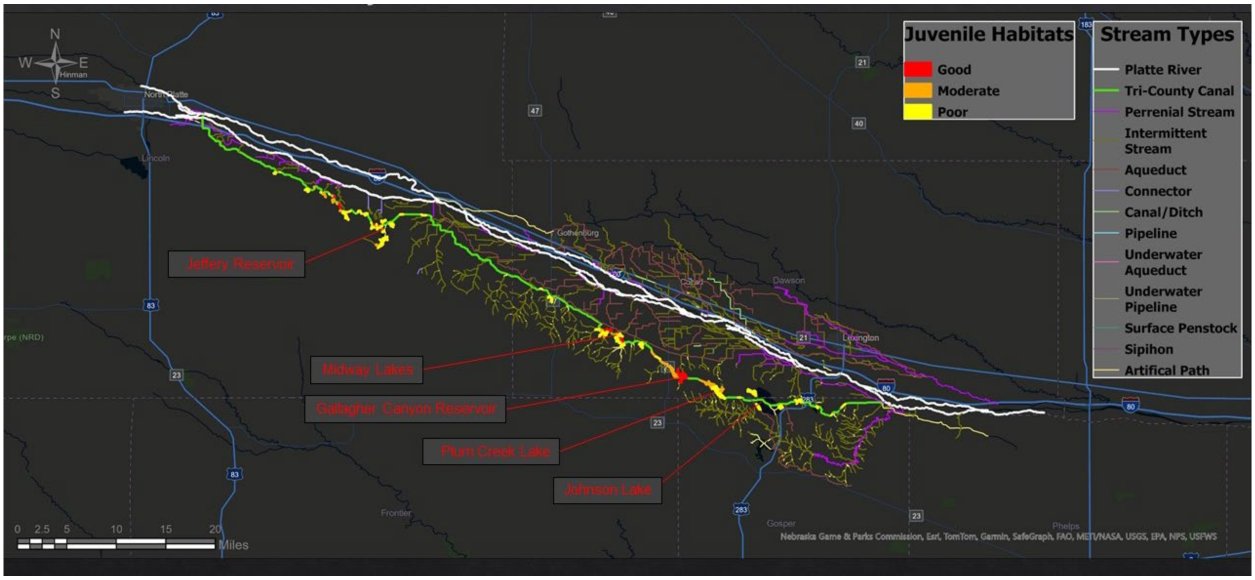

Figure 13. Canal and associated systems that may provide suitable conditions (i.e., adequate drift distance, available settling habitat, etc.) to allow successful reproduction if invasive carp become established. Red areas indicate most likely locations for success; whereas yellow areas indicate successful reproduction could happen but with lower probability. All other areas are not believed to provide conditions where successful spawning can occur.

Recommendation:

- Managers should be cautious of areas with frequent and widespread flooding which may allow invasive carp to circumvent typical barriers (i.e., watershed boundaries, dams).
- Some habitats undergo seasonal changes in environmental conditions that could result in differences in the spatial distribution of bigheaded carp through time. Sampling protocols for early detection or response actions in these habitats may need to account for these seasonal patterns to maintain the effectiveness of sampling or removal efforts.
- Finish processing field data to develop a more accurate bathymetric map for the study reach
- Incorporate the new bathymetric map into the two-dimensional HEC-RAS model.
- Complete egg-tracking scripts – these are mostly done, but we need to incorporate log-law and diffusion subroutines and a subroutine for temporal changes in egg density. Testing the scripts also requires a good bathymetric map.
- Complete the statistical analysis of egg tracks.
- Collect additional field data to verify velocities in the computer model and to evaluate the effects of year-to-year changes in bathymetry on model performance.
- Additional models of invasive carp spread are currently being developed for other river basins in Nebraska. Specifically, the Loup River system has a markedly complex network of rivers, streams, canals, and other potential waterways that may allow invasive carp access to reservoirs within the system. We are currently fleshing out the likelihood of invasive carp reaching these reservoirs and establishing populations to weigh the need for management or control actions.

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