Environment and Natural Resources Trust Fund

Research Addendum for Peer Review

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Project Title: Blocking Bighead, Silver, and Other Invasive Carp by Optimizing Lock and Dams

Project number: 097-D

1. Abstract

Untold millions of Silver and Bighead carp (together known as 'Bigheaded carps') inhabit the Mississippi River below the Iowa border from which they threaten to invade Minnesota and cause great economic and ecological damage. These invasive fishes (and several other carp species) originally came from Asia and are also often loosely termed 'Asian carp.' This proposal focuses on silver and bighead carp (the most immediate threat) while using common carp as a surrogate for some behavior tests. Presently the only impediment to the northward invasion of Bigheaded carps is the lock and dam system maintained by the US Army Corp of Engineers (USACE), which appears to be an unutilized resource capable of protecting the Minnesota, St. Croix, and Mississippi Rivers. This proposal seeks to develop new understandings of water flow through and around key dam structures, the swimming ability of Bigheaded carps, and the behavior of these species to aversive sound stimuli to work with the USACE to modify lock and dam function in the Minnesota section of the Mississippi River to arrest the invasion of Bigheaded carps. The project has four activities. Activity #1 will immediately implement a simple 'stop-gap' deterrence strategy at Lock and Dam #8 near the Minnesota-Iowa border. This will give us time to develop basic scientific understandings of Bigheaded carp swimming and acoustical deterrence to develop an optimal integrated plan for the entire Upper Mississippi (i.e. Lock and Dams #2 through #8). Activity #1 will see the installation of a safe and acceptable acoustical deterrent (underwater transducer) in its lock chamber while we develop a three-dimensional statistical (computational fluid dynamics [CFD]) model of the velocity fields in and around its gates to work with the USACE to make recommendations to enhance, and later optimize velocity fields to stop carp upstream movement. Activity #2 will quantify the swimming capabilities of both species of adult Bigheaded carps for the first time using a one-of-a-kind mobile swim tunnel developed by the USACE. Swim performance data will later be used with CFD models to optimize gate operations that minimize scour while continuing to block Bigheaded carps. Activity #3 will develop and test the effectiveness of acoustical deterrent systems (e.g. transducers, water-guns, boomer plates) to deter carp from entering lock chambers without impeding navigational use. Field tests of deterrent systems will be carried out in the auxiliary lock chamber at Lock and Dam #1 using Common carp as a surrogate to make recommendations on new ways passage through locks can be stopped. Finally, Activity #4 will develop numeric solutions to optimize gate operation at all Minnesota lock and dams to prevent Bigheaded carp passage using swim performance data from Activity #2. Modifying lock and dam function is a safe and cost-effective solution to the Asian carp problem, which no other technology presently seems capable of addressing. The USACE (St. Paul, MN and Vicksburg,

MS offices), Minnesota Department of Natural Resources (MN DNR), Smith-Root Inc. (SRI; Vancouver, WA) and Advanced Telemetry Systems (ATS; Isanti, MN) are our partners in this ambitious but promising endeavor.

2. Background

2.1 The Bigheaded Carps and their invasion of the Mississippi River

Both the Silver carp (*Hypopthalmichthys molitrix*) and Bighead carp (*H. nobilis*) were introduced to Arkansas from China in the 1970's (Kolar et al. 2005; Chick and Pegg, 2001). Both also escaped within just a few years of their introduction, quickly established themselves and have been spreading north ever since, often becoming up to 75% of local fish biomass (Tucker et al., 1996; Kolar et al., 2005). Both species are planktivorous and cause great ecological damage by outcompeting native species for food while silver carp threaten human safety because of their habit of jumping (Buck et al. 2010). Both species now threaten to invade and establish themselves in Minnesota, where a few have already been caught. Large numbers of reproducing adults are already found in Iowa. It is imperative that action be taken immediately to stop these Bigheaded carps from entering Minnesota because once established, no useful techniques exist to either control or remove them. Of special concern are the St. Croix and Minnesota Rivers because neither can be modified to prevent fish from entering them because of their size and flows. It is the long-term goal of the P.I. to find additional funding to develop and implement an integrated and coordinated set of behavioral deterrents and dam management strategies that will both stop carp passage and allow for native fish passage (i.e. a next step might be to repeat this work for native fishes) throughout the entire portion of the Mississippi River Basin located within Minnesota. This project is a high priority of the P.I. who directs the Minnesota Aquatic Invasive Species Research Center (MAISRC).

2.2 An introduction to the lock and dam system and how it might be modified to protect the Upper Mississippi River

The Mississippi River is a large-floodplain river that is extremely productive and was extensively modified to enhance navigation in the early 1900s through the construction of 29 lock and dam structures that stretch from Minneapolis, MN to St. Louis, MO. These structures have both dams (with gates) and locks, and are presently maintained by the US Army Corps of Engineers (USACE) for the purpose of maintaining navigation. The USACE is responsible for these structures and has managed them for decades using simple operating rules and approaches that maintain minimal downstream velocity and thus minimize scour (i.e. erosion of river bed material caused by water released by the gates). However, the very characteristics that the USACE seeks to maintain are exactly those that promote carp passage. This proposal would work with the USACE to re-evaluate these operating procedures to determine if minor modifications might stop carp while continuing to allow navigation and minimizing scour. It does this by examining water flows in and around the dams while determining the minimum flows needed to impede carp passage and testing -and then implementing- acoustic deterrents in lock chambers. Of special interest are Lock and Dam structures #2, #5 and #8 which are positioned between the Iowa border and confluence of the Mississippi and Minnesota Rivers and also have high head (strong, relatively modifiable flow). The St. Paul office of the USACE has agreed to work with us on this project as a partner and has already funded some pilot work on carp swimming performance (see Sorensen LCCMR work plan). Below, we discuss the dam (e.g. gated spillways) and the lock chamber, and how carp and other fish can move through them, and thus might be stopped.

The most significant portion of the lock and dam structures is the moveable dam, or gated section, which generally consists of a series of tainter and/or roller gates to control discharge. Gates are operated by the USACE to maintain a navigable channel during low to moderate flows ('gate controlled flows'), while allowing water to pass unrestricted (all gates out of the water) during high discharges ('open-river conditions'). These dams already appear to impede upstream passage of Bigheaded carps by producing high velocities and potentially harmful turbulence immediately downstream of their gates even though they are not yet actively managed to accomplish this (Wilcox et al, 2004; Zigler et al., 2003, 2004; Tripp et al., 2013). Importantly, out pilot modeling analyses (see section 4.1.2.2.3) also strongly suggest that adult Bigheaded carp likely cannot pass during open river conditions and that passage is deterred during most gate controlled flows. These scenarios need to be rigorously explored to bring definition and to identify enhancement possibilities. Notably, all eight lock and dams located in Minnesota (#2-#8) operate under gate control most of the year, lending this venture special promise. We now seek to systemically evaluate current operating procedures and make recommendation to the USACE for improvements. Our partner, the USACE, has confirmed that that their office will consider all recommendations.

In addition to gates, all lock and dams systems also have lock chambers to permit navigation. Of course, these also allow fish passage. In Minnesota, each lock and dam structure contains one active lock chamber about 500 ft long x 110 ft wide x 10 ft deep. Water level in these chambers is controlled by miter gates located at the up- and down-stream ends of the chamber and a system of low level valves and tunnels. Locks are used for both up- and down-stream passage of boat traffic multiple times per day but are closed most of the time so there is significant opportunity for stopping carp passage if fish deterrents were tobe placed in them. We will explore acoustic technologies for this use as carp are extraordinarily sensitive to sound and these technologies are safe and relatively easy and inexpensive to deploy. Further, USACE has indicated that they are very likely to accept their use (and transducers in particular) by us, at least on experimental basis.

The overarching objective of this project is to address the possibility that Minnesota can be spared from Bigheaded carps by slightly modifying lock and dam structure and operating procedures. The project is broken down into four activities, whose ultimate goal is to make explicit recommendations with (and to) the USACE for lock and dam optimization to exclude Bigheaded carps while continuing to serve USACE needs. Activity #1 seeks to understand water flow in and around Lock and Dam #8 (the Iowa border) and then work with the USACE to immediately strengthen the ability of this structure to deter upstream passage of both Bigheaded carp species. Action will also be taken to deter carp passage through its lock chamber by immediately adding an acoustic deterrent system that we already know has special promise, yet is inexpensive and safe. Activity #2 will work with the research arm of the USACE to determine actual swimming capabilities of adult Bigheaded carps (which have never been formally studied but appear unremarkable), so that swimming performance can be factored into optimizing lock and dam function – the USACE does not want higher velocities than necessary because of safety and scour concerns. Activity #3 will test various state-of-the-art acoustic deterrent systems in a decommissioned lock chamber to determine which might be most effective at repelling carps in a manner that is both affordable and acceptable to the USACE, and then to make recommendations for their implementation.

Finally, Activity #4 will statistically model Lock and Dam #2 function and then revisit the model for #8 (also used as a surrogate for Lock and Dam #3-#7, which are similar), and include the swimming performance from Activity #2 to make recommendations to optimize their function as well. A final set of recommendations will be produced which describes exactly how to optimize all lock and dams (#2-#8) in the Minnesota section of the Mississippi River. These recommendations will be presented to our partners, the USACE and the MN DNR.

3. Hypotheses

We hypothesize that relatively minor (and administratively acceptable) modifications to the Mississippi River lock and dam structure and function can greatly enhance the capabilities of these structures to block upstream passage of Bigheaded carps. Within this overarching theme we address several hypotheses:

1) Bigheaded carps have unexceptional swimming abilities, making them susceptible to fatigue when exposed to the high velocity conditions in and around Mississippi River dams.
2) An ecohydraulic model combining three-dimensional velocity fields with a swimming fatigue model can estimate the probability of fish passage through the gated portion of the dams.
3) Modifications to the gate operation at Lock and Dams #2 through #8 that are acceptable by the USACE, can be identified and will create hydraulic conditions optimally suited to deter passage of Bigheaded carps.
4) Acoustical deterrents can be used to deter Bigheaded carps from entering an active lock chamber, preventing upstream passage.
5) The invasion of both species of Bighead carps into the state of Minnesota can be delayed for a long time if the recommendations we make are instituted.

4. Methodology

This proposal aims to develop and then combine new understandings of water flow through and around key dam structures, the swimming ability of Bigheaded carps, and the behavior of these species to aversive sound stimuli to modify lock and dam function to protect against the northward invasion of Bigheaded carps into the Mississippi, Minnesota, and St. Croix Rivers. We will accomplish this by pairing high resolution hydraulic calculations from a three dimensional computational fluid dynamics model with swimming performance data for both species of Bigheaded carps to identify weaknesses and operational modifications that increase deterrence. Additionally, controlled experiments in the auxiliary lock chamber at Lock and Dam #1 will be conducted to develop and test new low-cost acoustical deterrence systems for the purpose of excluding Bigheaded carps from passing through active locks. Because time is of the essence, we propose to first, and immediately, maximize deterrence at Lock and Dam #8 (near the Minnesota-Iowa border) using the simplest and quickest approaches available (Activity #1) while simultaneously conducting basic science on Bigheaded carps swimming performance (Activity #2) and acoustical deterrence (Activity #3) to develop, and then fine-tune, an integrated plan for optimizing deterrence at Lock and Dams #2 through #8 (Activity #4). Activity #1 does not presently address a specific, explicitly testable hypothesis other than it will block carp passage (lack of funding precluded performance monitoring but could/would be added if we locate additional funding).

4.1 Activity #1: Immediate development and implementation of a deterrent strategy for Lock and Dam #8

4.1.1 Overview and introduction to approach used for Activity #1

The goal of this activity is to immediately and safely maximize water velocity through the gates of Lock and Dam #8 while deploying a simple and safe acoustical deterrent system in its lock chamber as a stop-gap measure while we perfect technologies (Activities #2, #3 and #4). This work will proceed in several steps. First we will install acoustical deterrents within the lock chamber. Then, a 3-dimensional (3-D) statistical model (computational fluid dynamics [CFD]) will be developed on the University supercomputer and used to calculate velocities in and around the structure under a wide range of environmental (temperature, river discharge, etc.) and operational conditions. We will then identify changes to gate operation that will safely maximize velocity through the gates because we assume that high velocities are best to deter Bigheaded carps (i.e. promote dam to act as a velocity barrier). To accomplish this task we will develop a novel computational tool to search through 3-dimensional velocity data from the CFD model, identify potential passageways through the dam, and pair these data with swimming capabilities of both species of Bigheaded carps to determine if successful passage is possible under varying conditions – and if so, how to best stop it. We will work in close collaboration with the USACE (our partner) to identify and implement acceptable operational modifications to deter Bigheaded carps as quickly as possible. As soon as data on Bigheaded carp swimming are available (Activity #2), we will adjust the models to include fish data and then make recommendations to optimize operations to produce velocities that block Bigheaded carps passage while minimizing scour.

4.1.1.2 Introduction to fish deterrents

The movement of carp, like all fish, can be deterred in several ways: by mechanical barriers that block, electrical fields that immobilize, or behavioral deterrents that use sensory fields to repel. Obviously, we do not have the funding or ability to consider large scale mechanical barriers. Electrical fields are also expensive and dangerous and, in any case, are already being considered by the MN DNR along with Smith-Root Inc. at Lock and Dam #1 (upstream of the Minnesota and St. Croix Rivers at St. Paul), which have yet to produce a viable and acceptable solution. Consequently, we focus on behavioral deterrents. It is assumed that if judiciously employed (i.e. in the right ways and times), even fields that are less than 100% effective in the laboratory, may be up to 100% biologically effective in the field. We define ‘success’ as being able to stop a critical number of reproductively active carp from passing and producing young (i.e. perhaps a few dozen; see DFO. 2012. Binational ecological risk assessment of the bigheaded carps (*Hypophthalmichthys spp*.) for the Great Lakes basin. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/071). Fish typically detect several types of sensory fields: 1) light (vision); 2) chemical (olfaction, taste, common chemical sense); 3) magnetic (and sometimes electrical via lateral line), 4) tactile (fluid flow via the mechanosensory lateral line); and 5) ‘sound’ (pressure and particle movement via inner ear and lateral line). We presently focus on sound because light is hard to manipulate in turbid rivers and has been shown to be ineffective, chemicals may be difficult to allow with permitting requirements, carp are not known to be sensitive to magnetic fields, and manipulating flow in the lock chamber would negatively impact lock usage. Acoustic (sound) deterrents have special promise because carps have physiological specializations that make them uniquely sensitive to sound. Sound sources are safe to humans and fish, relatively easy to mount, and relatively inexpensive to purchase and operate.

We will consider all three high-amplitude acoustic technologies that are currently commercially available and affordable:: 1) underwater transducers; 2) water- (or ‘hydro-’) guns, and 3) boomer plates. Underwater transducers contain piezoelectric materials that produce high amplitude continuous or pulsed sound pressure (up to 197 dB [ref. 1 μPa]) between 200 Hz - 9 kHz, and require minimal power supply. Deterrent systems utilizing arrays of underwater transducers have been used in the hydropower industry as a means to reduce fish impingement at underwater intakes (Noatch and Suski, 2012), and deflect salmon migrations (Perry et al., 2012). Taylor et al. (2005) found that an acoustic barrier driven by underwater transducers reduced Bighead carp passage by ~90% in an experimental channel. These devices can transmit a wide range of complex sound signals, as they function analogously to above-ground loudspeakers. Although safe and inexpensive (less than $10,000), transducers are not as loud as the other two options. Hydraulic or water guns (Smith-Root Inc., Vancouver, WA) are used for seismic exploration and generate pulsed sound waves by discharging water with a piston through a cylinder inducing cavitation of water. Upon the cavities collapse a pulsed sound pressure wave is generated. The water gun then provides two deterrent mechanisms, the water jet and large peak to peak rapid sound pressure wave. Boomer plates (Applied Acoustics, Houston, TX) produce a short-duration pulse, 4 or 6 pulses per second that contains acoustic energy from approximately 300 Hz to 3 kHz. Sound is generated using electrical energy to two spring loaded plates, which then repel and generate a small peak to peak pressure wave as acoustic energy. The frequency content varies upon the input power and the transducer placement. Water-guns are presently being evaluated to stop carp passage in Chicago and are extremely high amplitude and thus may injure aquatic organisms in close proximity to the source of the pressure wave (Gross et al., 2013). Boomer plates have not been tested before for fish. All three technologies can be operated as either a stationary or mobilized barrier as a means to deter fishes. Due to the specialized nature and high cost of water-gun and boomer plates, Smith-Root Inc., who will also be our collaborator and partner (Activity #3), will be subcontracted to conduct these tests..

4.1.1.3 Introduction to modeling as a way to understand water flows and fish response to it

Modifications to gate operation that optimize (i.e. maximize velocity while minimizing scour) will be identified using an ecohydraulic modeling approach which combines computational fluid dynamics (CFD) with swimming fatigue models. This approach has not been used to evaluate and promote fish blockage at lock and dams before. Our basic approach will be to 1) model the velocity fields carp will encounter under a range of operational and environmental conditions and then 2) determine if carp have the physical capability to traverse the dam under said conditions (i.e. does the dam act as a velocity barrier?). Recent advances in computer technology and CFD modeling have made high resolution 3-dimensional models of highly turbulent and complex flows more accessible for design of hydraulic structures (Kahn, 2006; Ge and Sotiropolis, 2005) and fish passage (Goodwin et al., 2006; Weber et al., 2006). CFD models calculate velocity vectors, and their fluctuations, across the entire computational domain, which allow for better description of hydraulic conditions encountered by fish and greater accuracy in determining passage success. These data can then be used in a swimming fatigue model (using empirical data we will generate), an approach that tests if fish have the physical capability to maintain a sufficient velocity to traverse some obstacle, to determine what gate operating conditions offer the most resistance against carp passage.

The Eularian-Lagrangian-Agent Method (ELAM) developed by Goodwin and others provides the best example of how an individual fish swimming model can integrate CFD modelling to determine how fish navigate a hydrodynamic field (Goodwin et al., 2006; Weber et al., 2006). In this method a fish surrogate (agent) follows strict movement guidelines depending on the region of flow it currently occupies (Haefner and Bowen, 2002). Swimming endurance is only accounted for in the duration that a fish may utilize high speed or avoidance swimming, rather than predict ultimate fatigue. Kahn (2006) also used a similar approach to estimate energy costs required of fish to pass through a vertical slot fishway, but used generic predetermined swimming pathways. Although both models provide insight into fish swimming behavior and energetics, neither account for ultimate swimming fatigue, a critical variable in our analysis. Rather others have developed intuitive and straightforward one-dimensional models that estimate the endurance (or time to fatigue) for fish in steady and unsteady flows (Neary 2012; Castro-Santos, 2006, 2005; Haro et al., 2003). Since the primary concern at the Mississippi River dams is whether Bigheaded carps have the capacity to pass through the gates, we propose to extend the model developed by Castro-Santos (2005, 2006) to create an unsteady swimming fatigue model to be used with 3-dimensional velocity data (see below).

4.1.2 Material and Methods for Activity #1

4.1.2.1 Installation of acoustic deterrents at Lock&Dam #8: Step 1

We will install an acoustic deterrent array of LL-1424HP piezoelectric underwater transducers (designed for military and scientific applications; Lubell Labs, Columbus, OH) below the downstream lock chamber opening at Lock and Dam #8 by mid-summer 2014 (i.e. as quickly as possible). These transducers are the highest amplitude sound devices we can afford and have already been tentatively approved by the USACE. They will be installed in the lock chamber by commercial divers whom we will hire but who will also be guided by the USACE. An LL-1424HP transducer is capable of producing a maximum sound pressure level of 197 dB (ref 1μPa) at 600 Hz. Five transducers are required to produce a sound field with sound pressure levels above 180 dB (ref 1 μPa) throughout the chamber opening. We believe this will provide adequate aversive stimulus to repel carps of all species; our calculations show at the normal lower pool elevation the sound pressure level will not drop below 160 dB (ref 1 μPa) within 300 ft of the transducer array. The transducers could be attached to the chamber floor (immediately downstream of the downstream gate sill), mounted on the downstream face of the downstream gate, or in extant stop-log slots located near the downstream gate. Attaching the transducers to the downstream gate sill will allow the sound field to have a constant upward projection (i.e. perpendicular to fish body), but leave the transducers vulnerable to damage from boat props, strong turblence, and sediment accumulation. Mounting the transducers on the gate will permit the sound field to not only project outward into the river (optimal position for sound pressure gradient) when the gate is closed, but also projected across the chamber (i.e. transducers on each gate will point towards each other) when opened. Installing the transducers in the stop-log slot would protect against boat impact, but restricts the transducers to point inwards, across the channel. The exact location of the transducers will be selected following a visual inspection of the dewatered lock chamber (January 2014) and subsequent acoustic modeling in FLUENT (ANSYS Corp., PA, USA). This system will be evaluated pending experimental results of Activity #3 and recommendations for optimizing use or possibly replacing or supplementing them with alternative technologies will be made. In the meantime, given the seemingly low numbers of Bigheaded carp near Lock and Dam #8, this system is expected to at least provide short term protection against the upstream advance of Bigheaded carp while ongoing studies perfect acoustic deterrent technologies. The USACE has agreed to work with us on installing and maintaining this deterrent array.

4.1.2.2 Modeling to identify how to modify gate function at Lock & Dam #8: Step 2

The purpose of the modeling aspect of this activity is to identify weaknesses in Lock and Dam #8 and optimize gate operation to block both Bigheaded carp species. This work will proceed in two large steps, each with its own smaller sub-steps: 1) develop a CFD model to describe velocities in and around the dam under a variety of environmental and operating conditions, validate the CFD model using field measured velocities obtained from the USACE, and then recommend changes to gate function; and 2) develop and then use a computational algorithm that searches through the 3-D velocity fields and identifies specific weaknesses (i.e. swimming pathways) so they might be blocked. The later will incorporate swimming data from both species of Bigheaded carp (Activity #2) in a swimming fatigue model to determine whether passage along these pathways is feasible, and determine the optimal operating condition that blocks the carp -and then make recommendations to optimize gate operation. This proceeds in several sub-steps as outlined below. This work will be performed by Dr. Zielinski while Dr. Voller provides assistance developing the computer models.

4.1.2.2.1 CFD modeling

A CFD model is required to describe the velocity fields in and around dams with high resolution. This step is generally comprised of 5 basic steps (Kahn, 2006): 1) software selection; 2) domain mesh/grid generation; 3) applying appropriate boundary conditions; 4) calibrate and validate model; and 5) analyzing model results. The computational model will be analyzed using FLUENT (ANSYS Corp., PA, USA), a 3-D CFD software that uses the volume of fluid method to determine the free surface and solves the Reynolds-averaged Navier Stokes (RANS) equations. The $k-\varepsilon$ turbulence model with wall functions is then solved to determine eddy viscosities and close the RANS equations (see Pope (2000) for turbulence model equations). The RANS and turbulence equations are then discretized over the computational domain using a finite volume scheme.

A computational grid of the lock and dam structures will be constructed using up-to-date plan drawings of Lock and Dam #8 along with up- and down-stream contour maps of the river bed provided by the USACE. General geometric features of Lock and Dam #8 are provided in Table 1.

Table 1. Geometrical features of Lock and Dam #8.

Feature*	**Lock and Dam #8** $^{+}$
Total Structure Height	51.5 ft
Length of moveable dam	934.5 ft
Max flow depth	30 ft

Size of Tainter Gates (WxH)	35 ft x 15 ft
Number of Tainter Gates	10
Size of Roller Gates (WxH)	80 ft x 20 ft
Number of Roller Gates	5

* All elevations are in reference to MSL – 1912 adjustment

\+ Lock and Dam #8 also features 2,275 ft of submersible earthen dams

Computational grid for the structure will have a resolution of ~1 ft^3, and extend 250 ft up- and down-stream of the structure. This way, the computational grid will contain approximately 1x10^7 nodes.

In order to apply boundary conditions to the model, the domain must initially be split into an upper zone occupied by air and a lower zone occupied by water. The interface between zones will be initially set to match the longitudinal water surface profile obtained from historical records for flows of interest (i.e. parallel to the river bottom). A symmetry boundary is applied to the interface such that velocities, pressure, and gradients within each zone at the interface are zero. At the upstream end of the model, inlet velocities will be estimated for low, medium, and high discharges. Actual discharges for each flow regime at Lock and Dam #8 is provided in Table 2. Outlet velocities will be extrapolated from internal nodes (i.e. zero diffusion condition). Surface roughness will be accounted for on all solid surface boundaries by applying the modified law-of-the-wall equations and velocity shift formulas (Fluent Inc., 2006).

Table 2. River discharges to be evaluated with CFD models

Flow Regime	Lock and Dam #8
Low[1]	23,000 cfs
Medium[2]	28,000 – 50,000 cfs
High[3]	95,000 cfs

[1] Maximum flow under primary gate control (per USACE Water Control Manual)

[2] Flow representing ~50% discharge capacity of gate controlled flows

[3] Minimum flow at which open-gate conditions exist.

4.1.2.2.1.1 Model calibration and testing

Calibration of the model will be accomplished by comparing solutions to a benchmark problem. A simplified model of a Tainter gate section under low flow conditions, such that submerged orifice flow controls, will be compared with benchmark solutions for submerged orifice flow through a gated spillway (USBR, 1987). Next, the full scale model of Lock and Dam #8 will be constructed. Model validation will be achieved using 3-D velocity measurements obtained by the USACE up- and down-stream of the dam. The resultant model will be marched through time to achieve an unsteady solution, as Spalart (2000) noted that unsteady RANS modeling is one of the only feasible means to model high Reynolds number flows in complex flows of interest. Furthermore, an unsteady solution is required to quantify the turbulent fluctuations which are likely to influence fish passage through the gates. Initially the steady state solution of the model will be calculated, and used as the initial conditions for the unsteady solution. Following the procedures of Ge and Sotiroplous (2005), the unsteady solution will be considered to have converged once the difference between instantaneous velocity fluctuations and the mean are an order of magnitude less than the mean. As a result, the mean velocity, U, V, W and distribution of turbulent fluctuations u', v', w' will be obtained for all nodes throughout the computational domain. From this, relevant flow characteristics that potentially influence fish swimming (i.e. Reynolds stresses and strain) can be readily obtained.

4.1.2.2.1.2 Initial set of recommendations

Using the aforementioned results, we will meet with USACE engineers and develop a set of preliminary recommendations of operating procedures that will consistently enhance velocity through Lock and Dam #8 that we believe are safe, operationally acceptable, block carp movement in predictable ways while not increasing scour. We will help them implement these recommendations if appropriate.

4.1.2.2.2 Pathway selection and swimming fatigue model to optimize gate operations

The second portion of this activity involves integrating silver and bighead carp swimming performance data with hydrodynamic data from 3-dimensional CFD models to predict fish passage. We aim to extend the percent endurance model (Castro-Santos, 2005, 2006) to develop a three-dimensional unsteady swimming fatigue model that can predict the ability of Bigheaded carps to pass through the dam and be used to determine how gate operation can be modified to improve blockage. The following steps must be taken in order to accomplish this task: 1) develop efficient algorithm to search through 3-D velocity fields and find specific weaknesses (i.e. swimming pathways) through the dam; 2) use velocities along each pathway in the swimming fatigue model to determine if carp can traverse the dam; 3) use a stochastic model that accounts for variations in performance among individuals and flow conditions to predict the percentage of fish passage under different operating conditions; and 4) consult with USACE to identify acceptable gate operation modifications that decrease potential passage of Bigheaded carps as determined by steps #1-3.

Potential pathways through the dam will be identified from the 3-D velocity data by assuming fish are able to select a path requiring the lowest energy expenditure (i.e. lowest velocity) and results in traveling the greatest distance, rather than force fish to abide by strict behavioral rules. We also assume fish are optimally motivated (perpetual forward motion) and positioned to attempt an upstream passage. Fish movement will also be restricted from moving backwards. This way, we consider a ‘worst case’ scenario in that only the physical ability of the fish, not the behavioral drive, is used to determine if a carp can pass through the dam. As an example, assuming a surrogate fish is superimposed onto a two-dimensional structured grid starting at node (I,J), the fish would have 5 potential nodes to progress to (Figure 1).

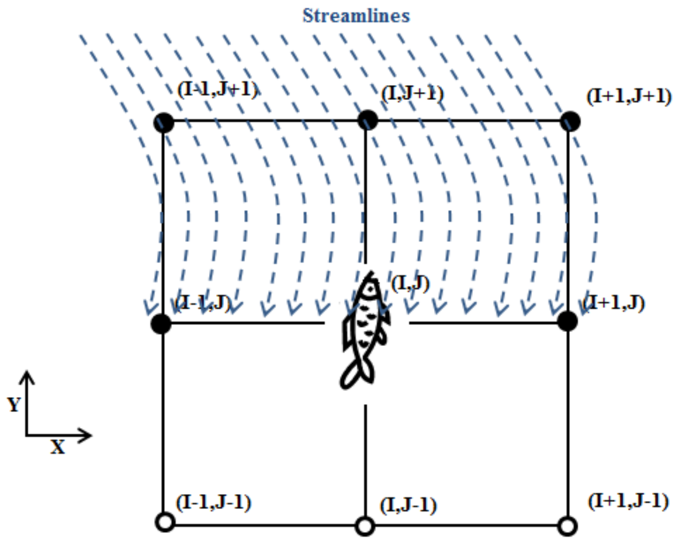

Figure 1. Two-dimensional view of fish pathway selection on structured grid. Filled circles indicate possible locations for the fish to move to, while empty circle indicate past locations. Dashed lines are velocity streamlines in the same plane as the fish. Selection of the next node is based on the lowest energy expenditure based on velocities at neighboring nodes.

In this way, a structured 3-dimensional grid would provide 12 potential locations to move to. Selecting the fish pathway using the lowest energy expenditure at the level of neighboring nodes does not necessarily locate the most vulnerable pathway (i.e. higher initial energetic costs may lead to lower total costs along an entire pathway). In order to resolve this, our pathway generating algorithm will be designed to iteratively search through the flow fields, so that multiple potential pathways for fish passage are identified and analyzed.

Binary fish passage models (i.e. one-dimensional models that estimates the maximum velocity needed to prevent passage of a fish over a certain distance) are viewed as the best available practice for determining fish passage rates through culverts and for designing fishways (Neary, 2012). Since most hydraulic conditions of any interest rarely involve uniform flows, Castro-Santos (2005, 2006) developed a percent endurance model that accounts for unsteady swimming speeds and flow velocities. Rather than estimate the maximum distance traveled, the percent endurance model tracks the percent reduction in a fish's total fatigue time, $\%F$, as it move through the water. Fatigue time is the total time a fish can maintain a given swimming speed (i.e. a sub-adult Bighead carp can maintain a swim speed of 1.5 m/s for 0.1 min, here 0.1 min is the fatigue time for a Bighead carp swimming 1.5 m/s). If a fish exceeds 100% of its fatigue time before reaching slower moving water, the fish will reach exhaustion and cannot continue. Fish are assumed to employ a zero-gradient strategy where they maintain a distance-maximizing ground speed, U_{gopt}, for a given flow velocity, U_f (Castro-Santos, 2005; Neary, 2012). Based on the following relationship

$$U_{gopt} = U_s - U_f \tag{1}$$

Where U_s is the swimming speed, a fish's swimming speed changes accordingly with changes in the flow velocity to maintain a constant ground speed. The distance-maximizing ground speed differs for each swimming regime (i.e. prolonged and burst), and is easily obtained from the slope of the swimming performance curves within each regime (Castro-Santos, 2005). Using the unsteady swimming fatigue time equations developed by Castro-Santos (2006) along with swimming performance curves from Activity #2 and velocity fields from the CFD models, we can estimate how both Bigheaded carp species may fatigue when swimming through the dams. The time for Bigheaded carps to recover from complete exhaustion is likely an order of magnitude greater than the time needed for them to potentially traverse the dams. Thus, once a fish reaches 100% of their fatigue time, they are assumed to be pushed downstream by the river and must re-start any passage attempt.

A Monte Carlo scheme will be employed, similar to Neary (2012), to account for individual variation in fish swimming performance and turbulent fluctuations. This stochastic approach will allow for estimating the percent effectiveness of each operational condition to block Bigheaded carps. This will be accomplished by generating a large number of surrogate fish (N>1000) of varying size and swimming capabilities. The swimming characteristics will be generated using the normalized swimming curves form Activity #2 (i.e. actual prolonged and burst swimming speeds will be determined from fish size and swimming speeds normalized by body lengths per second). The fish will then be released from randomly selected points at the downstream boundary, and allowed to move upstream following unique pathways. The unsteady nature of the flow field will be incorporated by modifying the mean velocities, U, V, W, at each node by randomly selecting velocity fluctuations, u', v', w', from the distributions generated by the CFD model. This way, each fish surrogate will encounter unique flow conditions along the pathway determined by:

$$\begin{aligned} u(x,y,z) &= U + u' \\ v(x,y,z) &= V + v' \\ z(x,y,z) &= W + w' \end{aligned} \tag{2}$$

Ultimately the effectiveness of a given operating condition will be calculated as the percent of fish surrogates that successfully pass through the dam.

4.1.2.2.2.1 Model implementation to optimize Lock and Dam #8 operations

Once these models are complete, we will again meet with USACE engineers to improve and revise our operational recommendation for gates at Lock and Dam #8. New recommendations will seek to optimize operations so that velocities are not more then they need to be to safely stop all carp while minimizing scour. These will be presented to the local St. Paul office of the USACE (Russ Snyder) for consideration

4.1.2.2.3 Pilot modeling data have suggested promise

We have already preformed a preliminary assessment of sub-adult and adult Bigheaded carps passage through Lock and Dam #2 under low (6,000 cfs), medium (21,000 cfs), and high (56,000 cfs) flow conditions. The results are promising so we share them, briefly. Spatially averaged flow velocities, extending 10 m upstream and 40 m downstream of the gate, were provided by the USACE based on discharge rating curves for Lock and Dam #2 (Figure 2A). Although useful in a preliminary analysis, the velocity profiles are an over-simplification of flow conditions at Lock and Dam #2. Spatially averaged velocity profiles cannot capture the impact of turbulence or non-uniform velocity distributions. Furthermore, higher resolution velocity data is necessary to assess whether any gate modifications would pose a risk to downstream scour. Using swimming performance data extrapolated from juvenile Bigheaded carps swim tests (Hoover et al., 2012) and the unsteady swimming fatigue time method, we estimated the percent fatigue of sub-adult and adult Bighead and Silver carp swimming through Lock and Dam #2 under three flow conditions (Figure 2B&C). Although these calculations roughly estimated the swim performance of adult Bigheaded carps and used coarse velocity data, the results suggested that the dams likely impede Bigheaded carp passage. More detailed analysis and high resolution velocity data are now urgently needed to better estimate how much Bigheaded carp passage can be blocked by modifying gate operations.

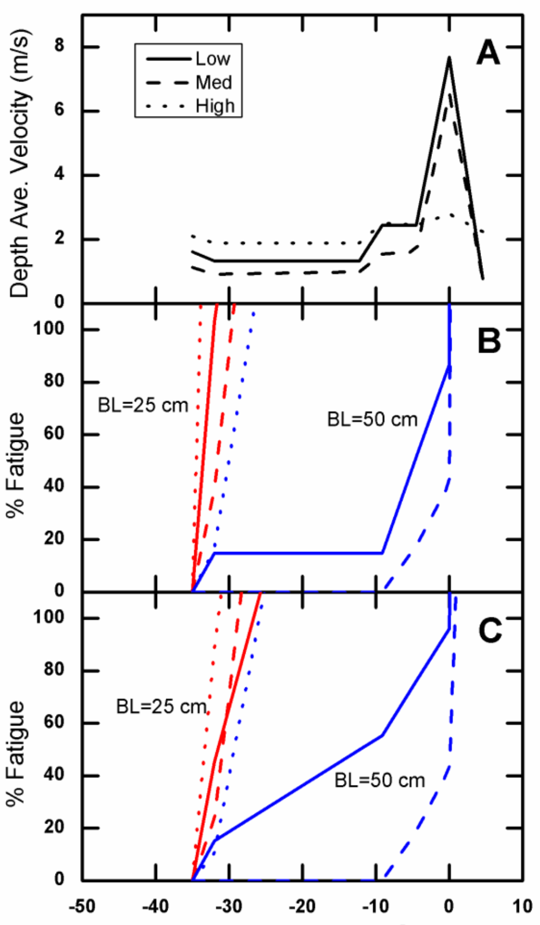

Figure 2. Panel (A) shows the depth averaged velocity through Lock and Dam 2 under low (6,000 cfs), medium (21,000 cfs), and high (56,000 cfs) flow conditions. The gate is located at distance 0 m. The gates are completely out of the water for the high flow event. Remaining panels show the expected percent fatigue for a BL=25 cm (red lines) and BL=50 cm (blue lines) Bighead carp (B) and Silver carp (C) at distance-maximizing swim speeds.

4.2 Activity #2: Quantify adult Bigheaded carps swimming capabilities

4.2.1 Overview of Activity #2

Swimming performance data for both species of Bigheaded carps is needed to determine exactly what velocities are needed to prevent passage through the gated section of the dam (Activities #1 and #4). Further, we need to understand the complete set of swimming behaviors carp might exhibit because we do not know exactly how they might approach dam structures. Swimming performance is generally classified into three distinct swimming regimes: sustained, prolonged, and burst (Beamish, 1978). Sustained swimming speeds are those fueled aerobically and maintained for long periods (> 200 min). Prolonged swimming consists of speeds fueled aerobically, but for shorter periods (> 1min) and produce fatigue. Burst swimming is the maximum speed of which the fish is capable, can be maintained for very short periods (< 1min), and is fueled anaerobically. We are specifically interested in upper prolonged and burst swim speeds rather than sustained swimming speeds because the objective of this study is to identify impassable water velocities (i.e. speeds that cause fatigue). Although these data exist for juvenile and small adult Bigheaded carps (Hoover et al., 2012), they are not currently available for large adults – the worst case scenario and our concern. The USACE research facility in Vicksburg, MS is the only U.S. laboratory with the equipment (large swim tunnels) and expertise (Dr. Jan Hoover) needed to address this critical data gap. We will partner with Dr. Hoover and his laboratory to perform swimming performance tests in their one-of-a-kind mobile swim tunnel. Swim speed-fatigue curves for a range of velocities, adult Bigheaded carp sizes, and temperatures (summer [high] and winter [low]) will be generated. These experiments will provide essential relationships for modeling hypothetical Bigheaded carp passage through lock and dam structures (last step in Activity #1 and Activity #4), and thus how to block it. We have already started working with Dr. Hoover using a small amount of seed funding ($12,000) provided by the USACE St. Paul office and have produced the analysis shown Figure 2.

4.2.2 Materials and Methods

4.2.2.1 Experimental Design

Swimming performance tests will be conducted on adult Bigheaded carps of both species using an extraordinarily large, mobile swim tunnel at the USACE laboratory in Vicksburg, MS. Swim tunnel testing entails subjecting fish to increasing velocities until they become fatigued. Trials will be conducted in the field in the winter during cool water temperatures (10±2° C) and autumn during warm water temperatures (25 ± 2° C), as performance varies with water temperature. Data for performers (i.e. fish exhibiting positive rheotaxis - head first orientation into the current) will consist of time-to-fatigue and corresponding measurements of water quality, fish behavior, morphology, size, gender, age, and reproductive stage. Predictive models relating water velocity (independent or predictor variable) to endurance (dependent or response variable) will be developed. These data will be compiled into standardized swimming fatigue-time curves that will be used in our comprehensive swimming fatigue models to estimate the percent reduction in a fish's total fatigue time (theoretical metric which quantifies swimming endurance) as fish move through the water.

4.2.2.2 General Materials and Methods

Swimming performance will be measured in a swim tunnel designed for large riverine fishes. The tunnel is a Brett-type test chamber (Brett, 1964), with a design modified from a recent laboratory precursor constructed and used to evaluate fish swimming performance in rectilinear, boundary layer, or turbulent flows (Hoover et al., 2011). The mobile swim tunnel differs from traditional lab tunnels in several respects: i) total water volume is large - 2900 liters (vs 1200 liters); ii) tank size is very large - 2000 liters (vs 823 liters); iii) water moves through a single stainless steel loop attached at each end of the test chamber (vs. separate propulsion pipe, return pipe, and cubical reservoirs); and iv) the tunnel is mounted to a heavy duty trailer with leveling jacks (vs. a frame with coasters). Modifications in design make it possible to test larger fish (> 1000 mm, > 20 kg), under greater flow (> 180 cm/s), at remote locations.

Swim trials will be conducted on the shore of the Mississippi River (near Vicksburg, MS) or near-by backwater adjacent to a boat ramp using wild fish. The tunnel will be set up in advance of fish collections and filled with de-chlorinated tap water, well water, or filtered river water depending on available water sources and problems with turbidity. Pure oxygen will be used as needed to maintain dissolved oxygen levels in the tunnel > 6.0 mg/L. Fish will tested in summer (warm) and fall (cold) because performance is temperature dependent. This work will be subcontracted with Dr. Hoover (USACE) who will be our partner and co-author for reports and publications. Dr. Sorensen will visit Dr. Hoover to coordinate work which will occur in the first year of the project.

Fish will be collected using 4-6” stretch monofilament gill nets that are monitored continuously. Upon capture, fish will be transferred to an aerated live well, driven to the ramp, and transferred expeditiously to the swim tunnel. Adult carp will be acclimated in the swim tunnel to gradually increasing increments of slowly flowing water over a 30-min period, then subjected to a randomly chosen test velocity for which endurance will be determined. Because the objective of this study is to identify impassable water velocities, upper prolonged and burst swim speeds will be emphasized over low water velocities (<< 1 body length per second) representing sustained swim speeds. The range of tested swim speeds cannot be accurately forecasted, but will be determined largely from responses observed during the course of the experiments. Individual water velocities tested will be randomly ordered to minimize likelihood of temporal effects on swimming performance. Fish that do not exhibit positive rheotaxis during acclimation will not be used for swimming trials and will be removed from the tank for processing. Each fish will be timed using a stopwatch until it is impinged on the downstream grid of the tunnel for 5 sec or after 200 min have elapsed (whichever occurs first). During the test, water quality (i.e., water temperature, dissolved oxygen, pH, conductivity, and turbidity) will be continuously recorded using a YSI-multiparameter meter. Behavior will be video recorded. Tail beat frequency and ventilation will be determined at set intervals during the test when endurance > 5 min. The same data will be determined post-test from reviewing videotapes when endurance < 5 min. Test velocities will emphasize medium to high prolonged swim speeds (equivalent to endurances of 10 to 0.5 min) and burst speeds (equivalent to endurances < 0.5 min).

Following completion of swim trials, fish will be removed from the tank and euthanized by MS-222 overdose. They will be photographed (left lateral aspect) with a reference scale (meter stick marked in mm) and identification tag. Morphological measurements will be taken of structures associated with swimming performance (e.g., length of keel, head depth, pectoral fin size). Gill rakers will be removed and examined for evidence of hybridization (Lamer et al., 2010). Length and mass of the fish will be recorded and a tissue sample preserved in ethanol for subsequent genotyping. Pectoral ray will be removed for age determination. Fish will be dissected so that gender and reproductive condition can be established.

4.2.2.3 Data Analysis

Sustained swim speeds (equivalent to endurances of > 200 min), if obtained, will be excluded from subsequent analyses. Predictive models relating water velocity (independent or predictor variable) to endurance (dependent or response variable) will be developed by regression analysis which is standard for such data (Videler and Wardle, 1991) and has been applied to juvenile and sub-adult of both Bigheaded carp species (Hoover et al., 2012). Linear and curvilinear relationships will be explored and the model with greatest predictive value (i.e., highest r^2, lowest P) will be used as the representative model. The role of potentially confounding variables, extrinsic (e.g., water quality, time of day) and intrinsic (e.g., fish size, gender, condition), will be determined using multivariate techniques (e.g., multiple regression, ordination).

4.2.3 Pilot swim performance test data have suggested promise

Dr. Hoover and his lab have already conducted feasibility studies with the mobile swim tunnel at Forest Home Chute near Vicksburg, MS in 2013. The data are promising so are shared here. Briefly, large silver carp responded poorly to confinement in a tube insert (used to maintain rectilinear flow) therefore, tests were conducted using no tank inserts (turbulent flow). Dr. Hoover collected data on Bigheaded carps (9 silver, 1 bighead) in September 2013. Silver carp acclimated well to the open tank, were consistently rheotactic at the acclimation velocities (7, 28, and 42 cm/s mean tank velocity) and exhibited a linear decrease in endurance with flow speeds between 110-151 cm/s mean tank velocity and 163-226 cm/s maximum tank velocity. Preliminary data thus suggested that Bigheaded carps swimming endurance is rather ordinary when compared with other relevant species (Figure 3).

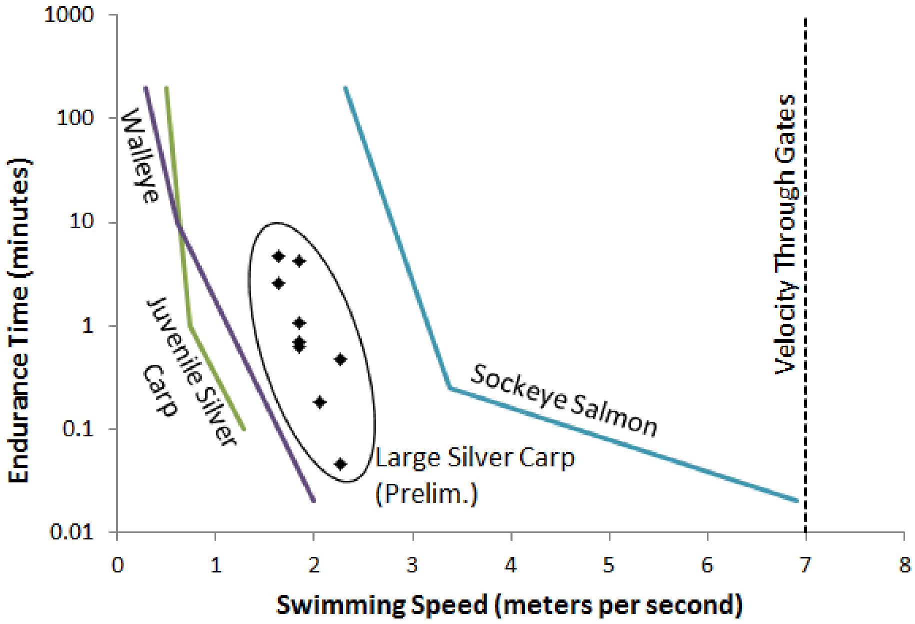

Figure 3. Pilot swimming performance data for juvenile Silver carp from Hoover et al., (2013) and adult Silver carp obtained from preliminary testing in September 2013 by Hoover et al. Note swimming speeds of Silver carp are well below the expected velocity through the gates at Lock and Dam #2 under gate controlled flow (~7m/s).

4.3 Activity #3: Test and develop new acoustical deterrent systems for locks

4.3.1 Overview of Activity #3

Independent of dam function, lock chambers represent a potential pathway for upstream passage for Bigheaded carps. New, low cost acoustic deterrent technologies including water guns, boomer plates (both derived from seismic exploration technologies), and underwater transducers will be investigated as ways to exclude fish from the lock chambers without negatively impacting lock structures or navigation. In collaboration with Dr. Jackson Gross of the research arm of Smith-Root Inc. (developer of water-gun and boomer plate concept and our partner), we will test these technologies in the auxiliary lock chamber at Lock and Dam #1 (permission for use has already been granted by USACE) to determine, and then optimize, the effectiveness of these systems. We use Common carp, *Cyprinus carpio*, for these tests because their hearing capabilities and swimming abilities and behaviors are very similar to those of bigheaded carps and because they are already readily available in the river. Results from the transducer tests will be used to optimize function at Lock and Dam #8 while other data on water-guns and boomer plates will together be used to make recommendations to USACE and MN DNR (and possibly others) about how they might optimize deterrence in all locks.

4.3.2 Material and Methods

4.3.2.1 Experimental Design

Tests will be conducted in two steps. In 2014, we will conduct a proof-of-concept test using underwater transducers (like those installed at Lock and Dam #8) to evaluate the potential of this technology while developing experimental protocols (ex. fish capture and tracking). An initial feasibility report will be prepared by us and Smith-Root Inc. In 2015, rigorous tests of the most promising acoustic technology(ies) will be conducted using recommendations from the 2014 feasibility report. Very likely these tests will involve tracking the distribution and movement of small groups of either radio-or acoustically tagged adult common carp. All studies will be conducted in the auxiliary chamber of Lock and Dam #1, which the USACE has already made available for our exclusive use. The MN DNR will provide assistance with fish capture and ATS Inc. (a local telemetry company) has kindly offered to help develop and identify appropriate fish tracking technologies (radio and acoustic) in the lock in 2014 *gratis*. Tests to evaluate the efficacy of underwater transducer arrays as deterrents will be performed by a Post-doctoral researcher from the University of Minnesota. Tests to evaluate water-gun and boomer plate arrays as deterrents will be carried out by Dr. Jackson Gross who is our partner and has unique expertise in the development and use of the water-gun and boomer plates. All studies will be collaborative (co-authored) and will evaluate array configurations and locations to determine which operating parameter best repels and excludes fish. A set of reports and publications will be produced on the promise of sound deterrence at the study's conclusion. Dr. Sorensen will supervise this study along with a new postdoctoral fellow while Dr. Zielinski will provide technical assistance as time permits.

4.3.2.2 General Materials and Methods

Specific methodologies will be determined by pilot tests in 2014, so we describe general approaches here. Adult common carp will be collected using electrofishing operations upstream of the study site by University of Minnesota personnel and MN DNR staff. These adult carp will be sedated using 0.05% buffered MS-222 and fitted with appropriate tags (initially we will test radio-transmitters (ATS, MN), but we likely will aso test acoustical tags (ATS, MN) and perhaps PIT tags (Oregon RFID) - each technique has its own set of advantages and disadvantages). Fish will be given a minimum of 7 days to recover in holding pens prior to being used. All tests will be conducted in the auxiliary lock chamber at Lock and Dam #1, St. Paul, MN. This lock chamber is approximately 400 ft long by 56 ft wide with an average depth of 7 ft and we have exclusive access to it – giving us great flexibility.

Experiments in 2014 will start by identifying a suitable fish tracking and analysis system before the transducer is activated and tested. We anticipate that it may be challenging to accurately track groups of fast moving carp in turbid water with possible echo from lock walls, so we will initially consider several options with the assistance of ATS Inc. (a local telemetry company and partner). Our tentative plan is to first monitor carp movements and distribution using radio-telemetry (ATS, Minneapolis, MN) with antennas spaced equidistantly within the netted off chamber. Although this system probably will not provide great resolution or allow for testing of more than perhaps a dozen carp, it is relatively simple and should be adequate so we will (to be conservative) evaluate it first. Each radio antenna's placement will be predetermined to ensure overlapping read radius in collaboration with ATS engineers (Figure 4). ATS will customize these antennas and radio-tags to reduce read range and thus possible echo. Each read radius would serve as an occupancy zone. Within each zone a single radio-tag will be suspended by a float and serve as positive control characterizing detection probability. The effectiveness of the radio tag system will be assessed during the pilot studies (visual confirmation from lock walls may be possible in spite of poor visibility). Data will be fed into several ATS data loggers and analyzed offline for distribution and final analysis. Depending on results, we may or may not test acoustical tags, also provided by ATS *gratis.* This local company believes that they likely can provide us with a 3-D recording array that will work in real time in the lock system. Obviously, this would be highly desirable but we will have to overcome challenges with echo and analysis of large datasets. A last possible fallback option would be to explore the use of passive integrated transponders (PIT tags), whose utility could be greatly constrained by the need to construct multiple loop antennas, and read range is typically only a half meter. As part of these tests, we will also test different numbers of tagged carp to determine which is optimal (we want to test as many as possible [to simulate natural groups of about half a dozen] but the data logger associated with each option must also be capable of recording the data; we tentatively aim for groups of 5-10 adult carp). We have budgeted for these possibilities.

Once a tracking system and scenario has been identified, we will test the ability of sound to deter groups of tagged carp. Initial testing late summer 2014 will use a pair of underwater transducers placed at the upstream end of the chamber (which is permanently shut), while the downstream exit of the chamber (near the downstream miter gate, and which is permanently open) will be fitted with a barrier net to ensure fish remain within the experimental zone during tests. We anticipate monitoring the distribution of small groups of tagged common carp in the lock each day for a week while this sound stimulus is repeatedly activated in different manners. New groups would be used each week and the old fish sacrificed and their tags removed for reuse. We will consider at least two potential experimental designs for these tests. In the first design, the sound source will be operated continuously (likely for 2 h) then alternated with a 2 h shutdown; this will be repeated three times. The second proposed design will expose fish to sound for over a 24 h period to evaluate potential differences in day- and night-time swimming behaviors. Fish behavior with and without the sound source will be monitored for 12 h for this design which will be replicated over a 3-5 day interval. In 2015, this work could (if promising) be expanded to include more complex sound signals and water-guns and boomer plates. Tagged carp movement would be monitored in ways that complement the tracking device chosen (radio-telemetry can determine relative distribution while acoustics could conceivably provide detailed information on movements to determine if fish challenge the sound barrier). The auxiliary lock is only 6-7 feet deep, so it can be monitored (for confirmation) from above and we can use an electrofishing boat to be able to remove all test fishes when and as needed. It is our hope /expectation we can run through all possible scenarios in 2014 but we are prepared to extend this work into 2015 if and as needed. Dr. Gross will also visit in 2014 to help us develop these protocols and design his experiments for 2015. He will describe this in a report.

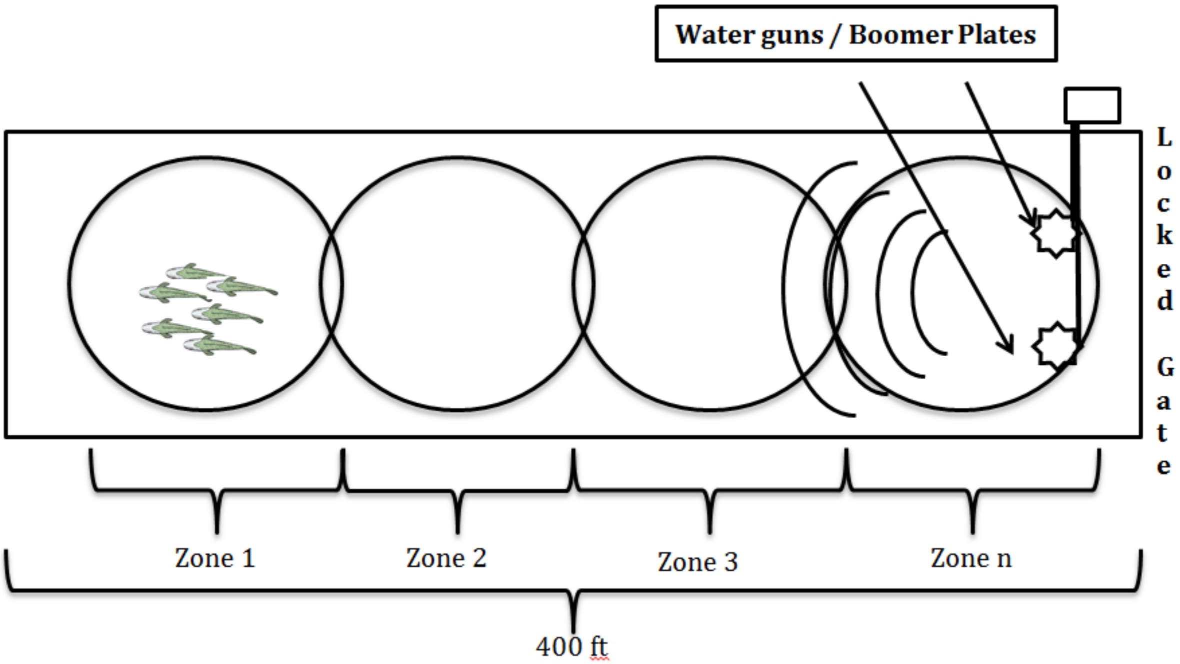

Figure 4. Side view of likely experimental area (lock chamber) for testing acoustic deterrents using radio-telemetry. Occupany zones are located equidistant along the chamber. Position of radio tagged fish within occupancy zones is monitored by the antennas (large circles). The downstream end (left side) of the chamber is barricaded by a full depth net.

Details of the 2015 tests will be determined by the 2014 test results but we expect these tests to start by using the underwater transducers by the University of Minnesota in mid-summer (when water levels are optimal, something we will also find out in 2014). Frequencies found promising in 2014 would be tested. Tests of water-guns and boomer plates are then scheduled. Different firing rates would be tested using different groups of fish. Studies in 2015 will also include detailed evaluation of acoustic energy levels associated with each location and device using hydrophones and blast sensors.

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4.3.2.3 Data Analysis

Carp avoidance will likely be evaluated for both individual and group endpoints with specific approaches being determined in consultation with a University statistician depending on tracking technology chosen and 2014 results. However, individual endpoints will likely include distance from source and percent occupancy correlated with received acoustic energy levels (sound pressure levels [SPL], sound exposure level [SEL], and power spectrum analysis). Group endpoints will include fish schooling behavior in relation to sound source position and pulsing, such as percent solidarity and percent occupancy. Data will be generated on the relative proximity of common carp to the sound sources before, during, and after sound production. The difference in distance from the source and occupancy of experimental zones between control (no sound) and test (sound on) periods will at a minimum be compared using a Chi-squared test. If significant ($P<0.05$), a Mantel-Haenzel Chi-squared test for significance of the overall degree of association will be used to determine if fish avoidance of a sound source is constant over time.

More sophisticated and interesting analyses may be possible if we adopt the use of a 3-D acoustic tracking system. A final report will identity ways to improve transducer operations at Lock & Dam #8, make new suggestions for how an effective acoustical deterrent might be added to other locks, and identify possible new research needs. We would include the USCAE in our report writing process and if interest is expressed, other parties such as the MN DNR could join (the DNR has not expressed specific interest in experimental design and analysis at this time).

4.4 Activity #4: Develop solutions to address weaknesses in Lock and Dam #2 and then optimize gate operation for Lock and Dams #2 through #7: completing the plan.

4.4.1 Overview of Activity #4

This final activity addresses water flow at Lock and Dam #2 which differs from the other structures, and then retroactively analyzes and makes recommendations on how to modify all locks and dams including Lock and Dam #2 using swim performance data. (Notably, Lock and Dam #8 will already have been addressed in Activity #1). The initial objective of this activity is to uncover potential weakness in Lock and Dam #2 by modeling and then developing an optimized solution. The second objective is to retroactively apply the model parameters developed earlier for Lock &Dam #8 to analogous structures (#3,#4, #5, #5A, #6, and #7), which have significant operational and geometrical similarities. Lock and Dam #2 must be modeled separately because it has a unique stilling basin, tailrace geometry, and gate operation plan while maintaining higher velocities than other dams (i.e. it warrants special effort). Results of the entire set of analyses will then be used to work with the USACE to develop new gate operation plans for the entire set of lock and dam structures that both stop carp and minimize scour, and thus can be implemented. This work will be accomplished in several steps.

4.4.1.1 Modeling to modify and then optimize gate function at Lock and Dam #2: Step 1

In this initial step, we will use the modeling approach described in Activity #1 to calculate velocity fields, identify weaknesses, and then include swimming performance (as we did for Lock and Dam #8 models) to optimize gate operation to minimize scour while continuing to block carp. Lock and Dam #2 lacks roller gates and is approximately 200 ft shorter than Lock & Dam #8 so it needs its own model (Table 3). River discharges also differ based on the hydraulic capacity of the dam. River discharges for low, medium, and high flows at Lock and Dam #2 are available (Table 4) as are estimated velocities near the dam structure from a physical model study (Ellis and Stefan, 1987). This way we can estimate the Reynolds number for flows we aim to model. The average upstream velocity during a high discharge event at Lock and Dam #2 is ~1.5m/s (Ellis and Stefan, 1987), which leads to a Reynolds number of $\mathrm{R} = 3.8\mathrm{x}10^{6}$ using the average velocity and pier thickness (2.5 m) between tainter gates. A separate technical report will be written on this set of procedures and recommendations. This work will be performed by Dr. Zielinski.

Table 3. Geometrical features of Lock and Dam #2.

Feature*	Lock and Dam #2
Total Structure Height	55 ft

Length of moveable dam	622 ft
Max flow depth	30 ft
Size of Tainter Gates (WxH)	30 ft x 20 ft
Number of Tainter Gates	18 (1 permanently closed gate)
Size of Roller Gates (WxH)	None
Number of Roller Gates	None

* All elevations are in reference to MSL – 1912 adjustment

Table 4. River discharges to be evaluated with CFD models

Flow Regime	Lock and Dam #2
Low[1]	6,000 cfs
Medium[2]	13,000 – 30,000 cfs
High[3]	61,000 cfs

[1] Maximum flow under primary gate control (per USACE Water Control Manual)

[2] Flow representing ~50% discharge capacity of gate controlled flows

[3] Minimum flow at which open-gate conditions exist.

4.4.1.2 Modifying and optimizing gate operation at Lock and Dam #3-#7: Step 2

We will use the optimized operating conditions determined in Activity #1 for Lock and Dam #8 to identify generalized operating rules for Lock and Dam #3-#7. This is possible because these dams all share significant operational and geometrical similarities to Lock and Dam #8. In fact, the operating rules currently set by the USACE at Lock and Dam #3-#7 are based on findings of a scour study using a physical model of Lock and Dam #8. An important distinction between these dams; however, is the range of river discharges that each dam is able to pass under gate control. For example, Lock and Dam #5 maintains gate control up to 115,000 cfs while the dam immediately downstream, #5A, only maintains gate control up to 61,000 cfs (USACE spreadsheet). In this instance, although Lock and Dam #5A can utilize the optimized operating rules up to 61,000 cfs, the dam will have less impact on carp passage than #5 at flows beyond. During this activity we will also evaluate any ancillary discharge structures (overflow spillways and low level outlets located at a few of the dams) that may allow fish passage; however, most of these structures have geometries and functions that make fish passage unlikely. We anticipate that simplified one-dimensional swimming fatigue models (Castro-Santos, 2005, 2006) will be sufficient to evaluate the need for any modifications. Once these models are complete, we will again meet with the USACE engineers to develop a set of recommendations for operating procedures that will optimize velocities to block Bigheaded carps while minimizing scour at Lock and Dams #3 though #7. We will work with the USACE to implement these recommendations if necessary. Although Lock and Dam #2, #5, and #8 may be best suited for implementation due to their hydraulic conditions (i.e. maintain higher head for longer periods of time), operational changes require little to no cost so that modifying gate operation throughout the entire system would provide a high level of efficiency and redundancy.

5. Results and Deliverables

The deliverables of the project will be:

- Implementation of a Bigheaded carp deterrence system at Lock and Dam #8,
- An understanding of adult Bigheaded carp swimming performance that can and will be used to inform barrier design and operations across the basin,
- An understanding of acoustical deterrents for carps and how they can be used,
- Development of an ecohydraulic model capable of predicting the passage of Bigheaded carps through the gated portion of a dam,
- A scheme to keep silver and bighead carp from establishing themselves in Minnesota for many decades,
- A scheme to move forward with possible future enhancements of native fishes in the Mississippi River.

Ultimately our findings on acoustical deterrents and modifications to gate operation will be submitted as formal recommendations to the USACE which we understand will consider for implementation at Lock and Dams #2 through #8. The MN DNR will also be offered these documents. This proposal offers a safe and cost-effective plan to protect Minnesota waters against Bigheaded carps with minimal impact on navigation or native fishes while answering an urgent need that no other technology seems capable of addressing. Although ambitious and frankly minimally funded, we believe this work can be accomplished because we have carefully and strategically created a partnership which has identified key, achievable first steps but which also now hope can be expanded to hopefully attract more support and funding.

6. Timetable

Activity #1 Immediate Development and Implementation of a Deterrent Strategy for Lock and Dam #8

Date	Milestones/Deliverables
July 2014	Project Begins
August 2014	Install experimental acoustic deterrent array in lock chamber
February 2015	Develop and validate computer model of Lock and Dam #8
August 2015	Make recommendations to USACE to improve gate operation at #8
February 2016	Make recommendations to USACE to optimize gate operation at #8

Activity #2: Quantify Adult Bigheaded Carps Swimming Capabilities

Date	Milestones/Deliverables
July 2014	Project Begins
February 2014	Evaluate swimming ability of large Bigheaded carps at high temperatures
August 2015	Evaluate swimming ability of large Bigheaded carps at low temperatures

Activity #3: Test and Develop New Acoustical Deterrent Systems for Locks

Date	**Milestones/Deliverables**
July 2014	Project Begins
February 2015	Pilot tests and evaluation of a variety of acoustical technologies including transducers and a report /decision on the most promising one(s)
August 2015	Testing and documentation of effectiveness of at least one technology (likely water-gun) to repel carp within lock chamber #1
February 2016	Testing and documentation of effectiveness of another promising technology (likely boomer plates) to repel carp from lock chamber #1
August 2016	Report on the best technology to repel and exclude carp provided to USACE

Activity #4: Develop Solutions to Address Weaknesses in Lock and Dam #2 and then Optimize Gate Operation for Lock and Dams #2 through #7

Date	**Milestones/Deliverables**
February 2016	Project Begins
August 2016	Develop and validate CFD model of Lock and Dam #2
February 2017	Identify weakness at Lock and Dam #2 and develop solutions to optimize gate operation based on Bigheaded carps swimming ability (Activity #2), report
June 2017	Identify weaknesses at Lock and Dams #7 through #3 and develop solutions to optimize gate operation based on Bigheaded carps swimming, report

7. Budget

TOTAL ENRTF REQUEST BUDGET 3 years

BUDGET ITEM	**AMOUNT**
Personnel:	$ 353,992
Professor: Peter Sorensen 2 weeks $6600 (80.17%Salary, 19.83% benefits, 0.04 FTE [1 wk Activity 2, 1 wk Activity 3]	
Professor: Vaughan Voller 4 weeks * 1 yr $12,000 (80.17%Salary, 19.83% benefits, 0.08 FTE [4 weeks Activity 1]	
Professional & Admin: $ + $65,654 x 1 yr ((66.4 %Salary, 33.6% benefits, 1 FTE) [Activity 4]	
Post Doctoral Fellow: Dan Zielinski $60,600 x. 1.5 yr; (79.25 % salary, 20.75% benefits) 1.5 FTE [Activity 1]	
Post Doctoral Fellow: $43,000 x 2.17yr (79.25% salary, 20.75% benefits) 2.167 FTE [Activity 3]	
Undergraduate Student: $2000 (93% salary, 7% benefits) 0.09 FTE [Activity 1]	
Undergraduate Student: $15,360 (20h/wk x 64 wk x $12/h) (93% salary, 7% benefits) 0.62 FTE [Activity 3]	
Undergraduate Student: $1000 (93% salary, 7% benefits) 0.05 FTE [Activity 4]	
Professional/Technical/Service Contracts:	
Services- office & gen oper. (printing/duplication, mailing, etc.)	$ 300.00
Services- lab & medical (Super-computing Intsitute (MSI) Resources)	$ 2,000.00
Professional Services & contracts- Activity 1: (Divers to install speakers)	$ 8,000.00

Professional Services & contracts- Activity 2: (US Army Corps of Engineers, Swimming performance tests of adult Bigheaded carp at Engineer Research and Development Center in Vicksburg, MS (Activity #2): Jan Hoover (Research Fisheries Biologist). Cost includes: Personnel (91%), Travel to field site (5%), Misc. equip. for swim tunnel (4%))	$ 150,000.00
Professional Services & contracts- Activity 3: DNR: 1 field technician and electrofishing boat(8 mo over 2 summers)	$ 20,000.00
Professional Services & contracts- Activity 3: Smith Root Inc Pilot hydrogun test and predesign report (Snr biologist and travel)	$ 17,658.00
Professional Services & contracts- Activity 3: Smith-Root water gun and boomer plate tests with report (6 wk equipment, supplies, biologist, technician; or UofMn Hydro)	$ 130,993.00
Repairs- lab & field ACTIVITY 1: speaker repair, ACTIVITY 3: various repair	$ 2,000.00
Equipment/Tools/Supplies:	
Supplies- office & gen oper. (Software - modeling, misc. office supplies)	$ 881.00
Supplies- lab & field ACTIVITY 1: (5 x 200ft of 14/3 SO Cable for transducers- implementation, Sub-surface attachment supplies- implementation, Field Supplies - implementation)	$ 11,667.00
Supplies- lab & field ACTIVITY 3: (2 x 200ft of 14/3 SO Cable for transducers, 2 Pontoon floats and supplies ($1000 ea)- for transducers, 150 radiotags (ATS F1835C)- fish radio tracking, 1 receiver case (ATS)- fish radio tracking, AC-DC power supply (ATS)- fish radio tracking, coaxial cable for antennas-fish radio tracking, surgical supplies for implanting tags (sutures, scalpels, anethestec), misc field supplies)	$ 36,557.00
Equipment- non capital lab & field ACTIVITY 1: (Computer (high powered desktop)-modeling, Equipment Rack - implementation, Controller and Amplifier Housing - implementation, MP3 Player - implementation, Sensaphone IMS-1000 Remote alarm system -implementation, 5 x current, 1 x temp, and 1x water sensors for alarm system, 5 CDi2000 amplifiers to drive transducers - implementation)	$ 16,650.00
Equipment- non capital lab & field ACTIVITY 3: 11x Ant switchbox (x11) (14219 ATS)- fish radio tracking, 2 divider nets (12 x 60ft), Laptop Computer - for data collection, 2 CDi2000 amplifiers to drive transducers - implimentation, C75 Hydrophone and calibration- accoustical measurement for transducers)	$ 9,050.00
Capital Expenditures over $5000:	
ACTIVITY 1: (5 LL1424HP under water transducers ($8200 ea) - implementation)	$ 41,000.00
ACTIVITY 3: 2 LL1424HP under water transducers ($8200 ea) - implimentation, 3 Coded receiver datalogger- fish radio tracking ($5800ea)	$ 33,800.00
Travel:	
Travel - MN ACTIVITY 1: (12 trips (LD 8) x 350 miles/trip x 0.56/mi), Lodging (200/person/wk x 2days x 2), Conference (Travel and Lodging)	$ 3,652.00
Travel - MN ACTIVITY 3: 38 wks x 100miles/wk x 0.56/mi), Conference Travel and Lodging (x2)	$ 2,628.00
Travel - MN ACTIVITY 4: 6 trips (LD 2) x 200miles/trip x 0.56/mi)	$ 672.00
Travel - Domestic ACTIVITY 1 Conference (Travel and Lodging)	$ 2,500.00
Travel - Domestic ACTIVITY 2 (Airfare to Vicksburg, MS (2 x 600), Travel in Vicksburg, MS (a car x 1 wks), Lodging (1000/person/wk x 4 days))	$ 2,500.00
Travel - Domestic ACTIVITY 3 Conference (Travel and Lodging)	$ 5,000.00
Travel - Domestic ACTIVITY 4 Conference (Travel and Lodging)	$ 2,500.00

TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 854,000

V. OTHER FUNDS

SOURCE OF FUNDS	**AMOUNT**	**Status**
n/a	*n/a*	*n/a*

7. Credentials

Dr. Peter Sorensen, P.I., coordination of overall project fish swimming and deterrence in particular
Professor and Scientific Director of Minnesota AIS Research Center
Department of Fisheries, Wildlife & Conservation Biology, University of Minnesota

Education:
Bates College (Maine), Biology, B.A. 1976
University of Rhode Island, Biological Oceanography, Ph.D., 1984

Professional History:
Postdoctoral Fellow, University of Alberta 1984-1988
Assistant Professor, University of Minnesota 1988- 1993
Associate professor, University of Minnesota 1993-1997
Professor, University of Minnesota 1997-

Research Interests
Peter is interested in the physiological basis of fish behavior and its ramifications for controlling invasive fish. Pheromones, chemical signals that pass between members of the same species, are of special interest as is their influence of fish movement and distribution. He has been studying invasive fish since 1989.

Grant management:
Dr. Sorensen has received over 60 competitive grants while at the University of Minnesota and over 15 million dollars.

Publications:
Dr. Sorensen has authored over 125 peer-reviewed publications, 1 book (in press) 20 book chapters, 1 patent (sea lamprey pheromone identification and its use in control), and 25+ non-peer reviewed publications. A few are listed below:

1. Bajer, P.G, and P.W. Sorensen. 2010. The superabundance of common carp in interconnected lakes in Midwestern North America can be attributed to the propensity of adults to reproduce in outlying habitats that experience winter hypoxia. Biological Invasions 12: 1101-1112.
2. Fine, J.M., and P.W. Sorensen. 2010. Production and fate of the sea lamprey migratory pheromone. Fish Physiology and Biochemistry. 36: 1013-1020.
3. Bajer, P.G, H.K. .Lim, M. J. Travaline, B.D. Miller, and P.W. Sorensen. 2010 Cognitive aspects of food searching behavior in free-ranging wild common carp. Environmental Biology of Fishes. 88: 295-300.
4. Garcia-Reyero. N., C.M. Lavelle, B.L. Escalon, D. Martinović, K.J. Kroll, P.W. Sorensen, and N.D. Denslow, N.D. 2011. Behavioral and genomic impacts of a wastewater effluent on the fathead minnow. Aquatic Toxicology 101: 38-48.

5. Lavelle, C.A. and P.W. Sorensen. 2011. Behavioral responses of adult male and female fathead minnows to a model estrogenic effluent and its effects on exposure regime and reproductive success. Aquatic Toxicology 101: 521-528.
6. Burns, A.C., P.W. Sorensen, and T. R. Hoye. 2011. Synthesis and olfactory activity of unnatural, sulfated 5β-bile acid derivatives in the sea lamprey (*Petromyzon marinus*). Steroids 76: 291-296.
7. Levesque, H., D. Scaffidi, C.A. Polkinghorne, and P.W. Sorensen 2011. A multi-component species identifying pheromone in the goldfish. Journal of Chemical Ecology 37(2): 219-227 (DOI 10.1007/s10886-011-9907-6)
8. Vrieze, L.A., R.A. Bergstedt, and P.W. Sorensen. 2011. Olfactory-mediated stream finding behavior of migratory adult sea lamprey (*Petromyzon marinus*). Canadian Journal of Fisheries and Aquatic Science 68: 523–533 (doi:10.1139/F10-169)
9. Bajer, P.G., C.J. Chizinski, and P.W. Sorensen. 2011. Using the Judas technique to locate and remove wintertime aggregations of invasive common carp. Fisheries Management and Ecology 18: 497-505. (doi: 10.1111/j.1365-2400.2011.00805.x)
10. Lim, H.K. and P.W. Sorensen. 2011. Polar metabolites synergize the activity of prostaglandin $F_{\square\square}$ in a species-specific hormonal sex pheromone released by ovulated common carp. Journal of Chemical Ecology 37: 695-704. (DOI 10.1007/s10886-011-9976-6)
11. Lim, H.K. and P.W. Sorensen. 2012. Common carp implanted with prostaglandin $F_{2\alpha}$ release a sex pheromone complex that attracts conspecific males in both the laboratory and field. Journal of Chemical Ecology 38: 127-134. (DOI: 10.1007/s10886-012-0062-5)
12. Bajer, P.G., C.J. Chizinski, J.J. Silbernagel, and P.W. Sorensen. 2012. Variation in native micro-predator abundance explains recruitment of a mobile invasive fish, the common carp, in a naturally unstable environment. Biological Invasions 14: 1919-1929. (DOI: 10.1007/s10530-012-0203-3)
13. Bajer, P.G. and P.W. Sorensen. 2012. Estimating the abundance of invasive common carp in small Midwestern lakes using boat electrofishing. North American Journal of Fisheries Management 32: 817-822.
14. Vander Hook, J., P. Tokekar, E. Branson, P.G. Bajer, P.W. Sorensen, and V. Isler. 2012. Local-Search Strategy for Multi-Modal, Multi-Target, Active Localization of Invasive Fish. 13th International Symposium on Experimental Robotics 2012. 1787-1792.
15. Silbernagel, J.J. and P.W. Sorensen. 2013. Direct field and laboratory evidence that a combination of egg and larval predation controls recruitment of common carp in many lakes of the upper Mississippi Basin. Transactions of the American Fisheries Society 142(4): 1134-1140.

Dr. Daniel Zielinski, Modelling, fish passage analysis, and coordination

Post-Doctoral Associate
Department of Fisheries, Wildlife, and Conservation Biology (FWCB)
Minnesota Aquatic Invasive Species Research Center
University of Minnesota

Education

2013 Ph.D Civil Engineering, *University of Minnesota*
2011 M.S. Civil Engineering, *University of Minnesota*
2007 B.S. Civil Engineering, *University of Wisconsin - Platteville*

Professional History

Post-doctoral Associate, University of Minnesota, 2013-present
Research Assistant, FWCB, University of Minnesota, 2012-2013

Research Assistant, Civil Enigneering, University of Minnesota, 2009-2013
Water Resources Engineer, Ayres Associate, 2007-2009

Research Interests

Dr. Zielinski's research is focused on developing quantitative and empirical tools to support the design and evaluation of engineering solutions for water resources issues. He has applied this interest towards acoustical deterrent systems (including bubble curtains) for invasive carp and numerical modelling of fish movement near such deterrent systems.

Selected Publications

1. Zielinski, D.P., Hondzo, M., and Voller, V.R. (2013) Mathematical evaluation of behavioral deterrent systems to disrupt fish movement, Ecological Modeling, 272, 150-159.
2. Zielinski, D.P. and Voller, V.R. (2012) A random walk solution for fractional diffusion equations, International Journal of Numerical Methods for Heat and Fluid Flow, 23 (1).
3. Voller, V.R., Paola, C. and Zielinski, D.P. (2011), The Control Volume Weighted Flux Scheme (CVWFS) for non-local diffusion and its relationship to fractional calculus, Numerical Heat Transfer B, 59, 421-441.
4. Zielinski, D.P., Voller, V.R. The Control Volume Weighted Flux Scheme (CVWFS) for two-dimensional, two-sided Caputo fractional diffusion equations, International Journal of Advances in Engineering Software. **In Review.**
5. Zielinski D.P., Voller, V.R., Svendsen, J.C., Hondzo, M., Mensinger, A.F., and Sorensen, P., Laboratory experiments demonstrate that bubble curtains can effectively inhibit movement of common carp, Ecological Engineering. **In Review.**

Dr. Vaughan Voller, Support model development in Activity #1

Professor and Interim Associate Head
Department of Civil Engineering
University of Minnesota
E-mail: volle001@umn.edu

Education

1980 Ph.D. Applied Mathematics, *Sunderland University* (UK)
1976 M.Sc. Continuum Mechanics, *University of East Anglia* (UK)
1975 B.Sc. Mathematics, *University of East Anglia* (UK)

Professional History

Professor, Civil Engineering, University of Minnesota, 1997-present
Associate Professor, Civil Engineering, University of Minnesota, 1987-1997
Assistant Professor, Civil Engineering, University of Minnesota, 1985-1987
Senior Lecturer, Mathematics, Greenwich University (UK), 1982-1985
Post Doctoral Fellow, MRRC, University of Minnesota, 1980-1983
Research Assistant, Sunderland University, 1977-1980

Research Interests

Dr. Voller's research is focused on the development of computational models for fluid, heat, and mass transfer. He has applied such models to a range of systems including among others, solidification of metal alloys, the formation of river mouth deltas, and fish passage. According to the web of science his work has been cited over 4000 times in the literature.

Selected Publications

1. D.P. Zielinski, M. Hondzo, V.R. Voller, Mathematical evaluation of behavioral deterrent systesm to disrupt fish movement, *Ecological Modeling*, 272, 150-159, 2014
2. F. Falcinni, E. Foufoula-Georgiou, V. Ganti, C. Paola, V.R. Voller, A combined non-linear and non-local model for topographic evolution in channelized depositional systems, *JGR Earth Surface,*DOI: 10.1002/jgrf.20108, 2013.
3. J. Lorenzo-Trueba, V.R. Voller, C. Paola, A geometric model for the dynamics of a fluvially dominated deltaic system under base-level change, *Computers and Geosciences*, 53, 29-47, 2013.
4. V.R. Voller, On a fractional derivative form of the Green-Ampt infiltration model, *Advance in Water resources***,** 34, 257-262, 2011.
5. J. Lorenzo Trueba , V.R. Voller, C. Paola, T. Muto, J. Swenson, and W. Kim, A similarity solution for a dual moving boundary problem associated with a coastal depositional system, *Journal of Fluid Mechanics*, 628, 427-443, 2009.

Dr. Jan Hoover, Swim Tests in Activity #2

Research Fishery Biologist
U.S. Army Engineer Research and Development Center
Waterways Experiment Station, Vicksburg, MS

Education

University of Oklahoma – Ph.D., Zoology (1988)
University of South Florida – M.A., Zoology (1981)
Florida Atlantic University - B.S., Biology (1976)

Research Interests

Dr. Hoover has worked with Asian carp since 2005. His research includes studies in the field (demography and bioenergetic modeling) and laboratory (behavior). Relevant collaborative studies include swimming performance models of juveniles and sub-adults (with three undergraduate students – preliminary report published), critical swim speeds of adults (with team members- unpublished), and morphological correlates of critical swim speeds in juveniles (with a graduate student – in review). In addition, he is collaborating on a field study of swimming performance and metabolism of adult paddlefish.

Selected Publications

1. Hoover, J.J., S.G. George, and K.J. Killgore. 2013. A Paddlefish Entrained by the 2011 Mississippi River Flood: Rescue, Recapture, and Inferred Swim Speed. Southeastern Naturalist
2. Hoover, J.J., L.W. Southern, A. W. Katzenmeyer, and N.M. Hahn. 2012. Asian carp swimming performance. Aquatic Nuisance Species Research Program Tech Note, US Army Engineer

Research and development Center, Vicksburg, MS. Available at: http://el.erdc.usace.army.mil/elpubs/pdf/ansrp12-3.pdf

3. Hoover, J.J., J.A. Collins, K.A. Boysen, A.W. Katzenmeyer, and K.J. Killgore. 2011. Critical swim speeds of adult shovelnose sturgeon in rectilinear and boundary layer flow. Journal of Applied Ichthyology 27: 226-230.
4. Hoover, J.J., K.A. Boysen, J.A. Beard, and H. Smith. 2011. Assessing the risk of entrainment by cutterhead dredges to juvenile lake sturgeon (*Acipenser fulvescens*) and juvenile pallid sturgeon (*Scaphirhynchus albus*). Journal of Applied Ichthyology 27: 369-379.
5. Killgore, K. Jack , Miranda, L. E. , Murphy, Catherine E. , Wolff, Douglas M. , Hoover, Jan Jeffrey, Keevin, Thomas M. , Maynord, Steven T. and Cornish, Mark A. 2011. Fish Entrainment Rates through Towboat Propellers in the Upper Mississippi and Illinois Rivers, Transactions of the American Fisheries Society, 140 (3): 570 — 581.
6. Pongruktham, O., C. Ochs, and J.J. Hoover. 2010. Observations of silver carp (*Hypophthalmichthys molitrix*) planktivory in a floodplain lake of the lower Mississippi River basin. Journal of Freshwater Ecology 25(1): 85-93.
7. Hoover, J.J. and K.J. Killgore. 2009. Catfish, carp, and caviar: fisheries of the Danube and Mississippi Rivers. Danube Watch 10(1): 16-19.
8. Hoover, J.J., A. Turnage, and K.J. Killgore. 2009. Swimming performance of juvenile paddlefish: quantifying risk of entrainment. Pages 141-155 in Paukert, C. P., and G. Scholten (eds). Paddlefish Management, Propagation, and Conservation in the 21st Century: Building from 20 years of Research and Management. American Fisheries Society, Bethesda, Maryland.
9. Boysen, K.A. and J.J. Hoover. 2009. Swimming performance of juvenile white sturgeon (*Acipenser transmontanus*): training and the probability of entrainment due to dredging. Journal of Applied Ichthyology 25(Suppl 2): 54-59.
10. Adams, S.R., G.L. Adams, J.J. Hoover. 2003. Oral grasping: a distinctive behavior of cyprinids for maintaining station in flowing water. Copeia 2003(4): 851-857.
11. Parsons, G.R., J.J. Hoover, and K.J. Killgore. 2003. Effect of pectoral fin ray removal on station-holding ability of shovelnose sturgeon. North American Journal Fisheries Management 23: 742-747.
12. Hoover, J.J. 2003. Keeping out unwanted fish. Science 19 Sep 2003 (Letter)
13. Adams, S.R., J.J. Hoover, and K.J. Killgore. 2000. Swimming performance of the Topeka shiner (*Notropis topeka*) an endangered midwestern minnow. Am. Midl. Nat. 144: 178-186.
14. Adams, S.R., J.J. Hoover, and K.J. Killgore. 1999. Swimming performance of juvenile pallid sturgeon, *Scaphirhynchus albus*. Copeia 1999: 802-807.
15. Adams, S.R., G.R. Parsons, J.J. Hoover, and K.J. Killgore. 1997. Observations of swimming ability in shovelnose sturgeon (*Scaphirhynchus albus*). J. Freshwater Ecol. 12: 631-633.

Dr. Jackson Gross, Acoustic Deterrent Testing in Activity #3
Research Scientist/Aquatic Nuisance Species Division Manager
Smith Root Inc.
Vancouver, WA

Education

Ph.D. Animal Sciences, *University of Wisconsin-Madison*

M.S. Public Health, *San Diego State University*
B.S. Biology, *San Diego State University*

Years of Experience: 17

Summary of Experience
Jackson Gross transitioned to Smith-Root, Inc. in 2012 and helped to establish the Aquatic Nuisance Species Division. Jackson has a background as an ecological toxicologist with expertise in reproductive and developmental biology and previously worked for the U.S. Geological Survey's Northern Rocky Mountain Science Center (NRMSC) in Bozeman, Montana.

Jackson is expanding Smith-Root, Inc.'s research base for fisheries projects. He is supporting Smith-Root, Inc.'s effort to provide expertise for partners, corporations and various state and federal agencies to evaluate the use of electrical fields and alternate conservation technology such as gasses and pulse pressure sound energy for assessment, deterrence and suppression of aquatic species. Jackson has considerable experience working on invasive species issues and conservation of endangered and threatened fish.

Selected Publications:

1. Jackson A. Gross, Kathryn M. Irvine, Siri Wilmoth, Tristany L. Wagner, Patrick A. Shields, and Jeffrey R. Fox, (2013), The Effects of Pulse Pressure from Seismic Water Gun Technology on Northern Pike Transactions of the American Fisheries Society 142:1335–1346
2. Sepulveda, A. J., Rutz, D. S., Ivey, S. S., Dunker, K. J. and Gross, J. A. (2013), Introduced northern pike predation on salmonids in southcentral Alaska. Ecology of Freshwater Fish, 22: 268–279. doi: 10.1111/eff.12024
3. Sepulveda, Adam, Andrew Ray, Robert Al-Chokhachy, Clint Muhlfeld, Robert Gresswell, Jackson Gross and Jeff Kershner. (2012). Aquatic Invasive Species: Lessons from Cancer Research. American Scientist. 100 (234-242).
4. Gross, J. A., Johnson, P.T.J., Prahl, L. K., and Karasov, W.H. (2009) Critical period for effects of chronic cadmium exposure on growth and development in northern leopard frog (Rana pipiens) tadpoles. Environmental Toxicology and Chemistry. 28:1227-1232
5. Chen, T-H, Gross, J. A., and Karasov, W.H. (2009) Chronic exposure to pentavalent arsenic of larval leopard frogs (Rana pipiens): bioaccumulation and reduced swimming performance. Ecotoxicology. 18(5):587-593
6. Johnson, P. T. J., Chase, J. M., Dosch, K. L., Hartson, R. B, Gross, J. A.,Larson, D., Sutherland, D. R. and S. R. Carpenter. (2007) Aquatic eutrophication promotes pathogenic disease in amphibians. Proceedings of the National Academy of Science 104 (40):15781-15786.,
7. Gross, J. A., Chen, T-H, and Karasov, W.H. (2007) Effects of cadmium on development in northern leopard frog (Rana pipiens) tadpoles. Environmental Toxicology and Chemistry, 26:1192-1197.,
8. Chen, T-H, Gross, J. A., and Karasov, W.H. (2007) Adverse effects of chronic copper exposure in larval northern leopard frogs (Rana pipiens). Environmental Toxicology and Chemistry, 26:1470-1475.,
9. Chen, T-H, Gross, J. A., and Karasov, W.H. (2005). Sublethal effects of lead on northern leopard

frog (Rana pipiens) tadpoles. Environmental Toxicology and Chemistry, 25:1383-2389.,

10. Gross, J. A., Johnson, P.T.J., Prahl, L. K., and Karasov, W.H. Critical period for effects of chronic cadmium exposure on growth and development in northern leopard frog (Rana pipiens) tadpoles (2008, In Review Environmental Toxicology and Chemistry).,
11. Gross, J. A., Chen, T-H, and Karasov, W.H. Lethal and sublethal effects of chronic dietary methylmercury exposure on development in northern leopard frog (Rana pipiens) tadpoles (In Revision: Environmental Toxicology and Chemistry).

Technical Reports:

1. Gross J.A., Farokhkish B., Gresswell R.E., Webb M.A.H., Guy C.S., and Zale A.V. (2010) Techniques for Suppressing Invasive Fishes in Lacustrine Systems: A Literature Review. Draft Final Report to the National Park Service, Yellowstone National Park, Wyoming RM-CESU H1200040001

Additional pulse pressure related experimentation

1. 2010 Conducted studies on the impacts of seismic airguns on juvenile endangered pallid sturgeon (USFWS – Bismark ND, Garrison Dam National Fish Hatchery ND) Contact Steve Krentz USFWS 701-471-6605

2. 2012 Conducted studies on the impacts of seismic airguns on juvenile endangered pallid sturgeon, paddle fish and walleye (USFWS – Bismark ND, Garrison Dam National Fish Hatchery ND) Contact Steve Krentz USFWS 701-471-6605

Russ Snyder, USACE Project Manager

Russel Snyder has 33 years experience with the St. Paul District Corps of Engineers; 11 years as a landscape architect and 22 years as a project manager. In addition to being a project manager for engineering planning and design teams, Mr. Snyder is the districts outreach coordinator and manager of the districts interagency support efforts. He is the district's general liaison with the Minnesota DNR and specifically coordinates support and coordination related to Asian carp. Mr. Snyder has a Bachelor of Science degree in landscape architecture from Iowa State University.

8. Dissemination and Use

The primary use of our results will be for documenting our recommendations for gate operation changes and use of acoustical deterrents in active locks which will be submitted to the USACE for review and/or implementation. Results will also be disseminated through scholarly publications in peer-reviewed journals such as *Fisheries Management and Ecology*, *Water Resources Research*, and *Ecological Modeling*. Results from the research project will be presented at regional and national conferences such the *American Fisheries Society* and *Engineering and Ecohydrology for Fish Passage* conferences. Results will be posted on MAISRC's website and Facebook.

9. References for the research addendum

Beamish, F.W.H. 1978. Swimming capacity. In: Hoar, W.S., Randall, J.D.Z. (eds.) *Fish Physiology*, Vol. 7, Academic Press Inc. New York, pp. 101-187.

Brett, J.R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. J. Fish. Res. Bd. Can. 21, 1522-1529.

Buck, E.H, Upton, H.F., Stern, C.V., and Nicols, J.E. 2010. Bigheaded carps and the great lakes region. *Congressional Research Service Reports*. Paper 12. http://digitalcommons.edu/crsdocs/12

Castro-Santos, T. 2005. Optimal swim speeds for traversing velocity barriers: an analysis of volitional high-speed swimming behavior of migratory fishes. J. Exp. Biol. 208, 421-432.

Castro-Santos, T. 2006. Modeling the effect of varying swim speeds on fish passage through velocity barriers. Trans. Am. Fish. Soc. 135, 1230-1237.

Chick, J. H., and Pegg, M. A. 2001. Invasive carp in the Mississippi River basin. Science, 292(5525), 2250-2251.

Ellis, C.R. and Stefan, H.G. 1987. Navigation conditions and flood conveyance at Lock and Dam No. 2, Mississippi River, before and after construction of proposed hydropower plant: hydraulic model investigations. Saint Anthony Falls Hydraulic Laboratory.

Fluent Inc. 2006. Fluent 6.3: User’s Guide. USA.

Ge, L., and Sotiropoulos, F. 2005. 3D unsteady RANS modeling of complex hydraulic engineering flows. I: Numerical model. J. Hydraulic Eng. 131(9), 800-808.

Goodwin, R. A., Nestler, J. M., Anderson, J. J., Weber, L. J., and Loucks, D. P. 2006. Forecasting 3-D fish movement behavior using a Eulerian–Lagrangian–agent method (ELAM). Ecol. Model. 192(1), 197-223.

Gross, J.A., Irvine, K.M., Wilmoth, S., Wagner, T.L., Shileds, P.A., and Fox, J.R. 2013. The Effects of Pulse Pressure from Seismic Water Gun Technology on Northern Pike. Trans. Am. Fish. Soc. 142, 1335-1346.

Haefner, J. W., and Bowen, M. D. 2002. Physical-based model of fish movement in fish extraction facilities. Ecol. Model. 152(2), 227-245.

Haro, A., Castro-Santos, T., Noreika, J., and Odeh, M. 2004. Swimming performance of upstream migrant fishes in open-channel flow: a new approach to predicting passage through velocity barriers. Canadian. J. Fish. Aqua. Sci. 61(9), 1590-1601.

Hoover, J.J., J. Collins, K.A. Boysen, A.W. Katzenmeyer, and K.J. Killgore. 2011. Critical wimming speeds of adult shovelnose sturgeon in rectilinear and boundary-layer flow. Journal of Applied Ichthyology 27, 226-230.

Hoover, J. J., W. Southern, A. W. Katzenmeyer, and N. M. Hahn. 2012. Swimming performance of bighead carp and silver carp: Methodology, metrics, and management applications. ANSRP Technical Notes Collection. ERDC/TN ANSRP-12-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center. Available at: http://www.dtic.mil/dtic/tr/fulltext/u2/a571258.pdf

Khan, L. A. 2006. A three-dimensional computational fluid dynamics (CFD) model analysis of free surface hydrodynamics and fish passage energetics in a vertical-slot fishway. N. Am. J. Fish. Manage. 26(2), 255-267.

Kolar, C. S., Chapman, D. C., Courtenay Jr, W. R., Housel, C. M., Williams, J. D., and Jennings, D. P. 2005. Bigheaded carps of the Genus Hypophthalmichthys (Pisces, Cyprinidae)—A Biological Synopsis and Environmental Risk Assessment.

Lamer J.T., Dolan C.R., Petersen J.L., Chick J.H., and Epifanio J.M. 2010. Introgressive Hybridization between Bighead Carp and Silver Carp in the Mississippi and Illinois Rivers. N Am J Fish Manag 30, 1452–1461. doi: 10.1577/M10-053.1

Neary, V. S. 2012. Binary fish passage models for uniform and nonuniform flows. River Res. Appl. 28(4), 418-428.

Noatch, M.R., and Suski, C.D., 2012. Non-physical barriers to deter fish movements. Environ. Rev. 20(1), 71-82.

Perry, R.W., Romine, J.G., Adams, N.S., Blake, A.R., Burau, J.R., Johnston, S.V., and Liedtke, T.L., 2012. Using a non-physical behavioral barrier to alter migration routing of juvenile Chinook salmon in the Sacramento-San Joaquin River Delta. River Res. Appl. doi: 10.1002/rra.2628.

Pope, S. B. 2000. *Turbulent flows*. Cambridge university press. Cambridge, UK, pp. 359-382.

Spalart, P. R. 2000. Strategies for turbulence modelling and simulations. Int. J. Heat Fluid Flow. 21(3), 252-263.

Taylor, R.M., Pegg, M.A., and Chick, J.H., 2005. Response of bighead carp to a bioacoustic behavioral fish guidance system, Fish. Manage. Ecol. 12, 283-286.

Tripp, S., Brooks, R., Herzog, D., and Garvey, J. 2013. Patterns of fish passage in the Upper Mississippi River. River Res. Appl. DOI: 10.1002/rra.2696.

Tucker, J. K., Cronin, F. A., Hrabik, R. A., Petersen, M. D., and Herzog, D. P. 1996. The bighead carp (Hypophthalmichthys nobilis) in the Mississippi River. J. Fresh. Ecol. 11(2), 241-243.

Videler, J.J. and C.S. Wardler. 1991. Fish swimming stride by stride: speed limits and endurance. Rev. Fish Biol. and Fisheries 1, 23-40.

Weber, L. J., Goodwin, R. A., Li, S., Nestler, J. M., and Anderson, J. J. 2006. Application of an Eulerian-Lagrangian-Agent method (ELAM) to rank alternative designs of a juvenile fish passage facility. J. Hydroinformatics. 8(4), 271.

Wilcox, D. B., Stefanik, E. L., Kelner, D. E., Cornish, M. A., Johnson, D. J., Hodgins, I. J., and Johnson, B. L. 2004. Improving fish passage through navigation dams on the Upper Mississippi River System. USACE. ENV Report 54.

U.S. Bureau of Reclaimation (USBR). 1987. *Design of small dams*. U.S. Government Printing Office, Washington, D.C (1965)

Zigler, S. J., Dewey, M. R., Knights, B. C., Runstrom, A. L., and Steingraeber, M. T. 2003. Movement and habitat use by radio-tagged paddlefish in the upper Mississippi River and tributaries. N. Am. J. Fish. Manage. 23(1), 189-205.

Zigler, S. J., Dewey, M. R., Knights, B. C., Runstrom, A. L., and Steingraeber, M. T. 2004. Hydrologic and hydraulic factors affecting passage of paddlefish through dams in the upper Mississippi River.Trans. Am. Fish. Soc. 133(1), 160-172.