2017 Project Abstract
For the Period Ending June 30, 2019

PROJECT TITLE: Adapting Stream Barriers to Remove Common Carp
PROJECT MANAGER: Przemyslaw Bajer
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2017, Chp. 96, Sec. 2, Subd. 06d

APPROPRIATION AMOUNT: $ 301,000
AMOUNT SPENT: $ 299,813
AMOUNT REMAINING: $ 1,187

Sound bite of Project Outcomes and Results
We developed a new, practical and largely automated technology for removing common carp during seasonal migrations with minimal human labor. The technology includes electric guidance systems to aggregate the carp and submersed conveyers to remove them. This system is ready for commercial applications to manage carp across Minnesota.

Overall Project Outcome and Results
As a result of this project, we developed a new technology for managing the invasive common carp that is currently being commercialized by the University of Minnesota. The technology is easy to implement in various field conditions, requires minimum site engineering, and can be operated by a crew of two, which substantially reduces labor costs. This project started by testing whether the Whooshh system developed for migrating salmon might be adopted for common carp removal during spring migrations. Over the course of two field seasons we determined that the Whoosh technology is not easily adaptable for carp management because it requires that carp voluntarily swim into the Whooshh through a system of fish ladders, which proved problematic. However, we developed an alternative technology that appears to be effective and practical. Our technology is comprised of a low-voltage fish guidance system (available commercially) that guides the migrating carp into a large fenced in enclosure along the bank constructed using PVC pipes that slide into the stream bottom via horizontal support beams, a system of additional low-voltage electrodes placed inside the enclosure that can be activated as needed to crowd the carp and then briefly immobilize them, and a system of partially-submersed conveyers that collect the immobilized carp and carry them on land. All elements of this technology were rigorously tested over two field seasons using over a 1,000 carp marked with electronic micro-tags. The entire system was then successfully tested in summer 2019 and spring 2020. The technology appears to be ready for management implementations. In addition to its applications for managing common carp throughout Minnesota, the technology we developed might be also applicable for managing other invasive fish, including the bighead and the silver carp that are advancing up the Mississippi and St. Croix rivers.

Project Results Use and Dissemination
The main results if a new technology for managing common carp described above. The technology is currently being commercialized by the University of Minnesota. In addition, our efforts to disseminate the results of this work include one manuscript published in peer-reviewed literature that described our early tests of the electric guidance system, another manuscript that describes the entire system and its performance during spring migrations of 2018 – 2020 that is currently in preparation, two TV interviews for local stations, three press articles including one in the New York Times, four regional or national conferences, four MAISRC presentations or publications.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2017 LCCMR Work Plan Final Report

Date of Submission: June 30, 2020

Date of Next Status Update Report: Final Report

Date of Work Plan Approval: 06/07/2017

Project Completion Date: June 30, 2020

Does this submission include an amendment request? No

PROJECT TITLE: Adapting Stream Barriers to Remove Common Carp

Project Manager: Przemyslaw Bajer

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Location: Statewide

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$301,000**
	Amount Spent:	**$299,813**
	Balance:	**$1,187**

Legal Citation: M.L. 2017, Chp. 96, Sec. 2, Subd. 06d, as extended M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 20

Appropriation Language:
$301,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to conduct field tests at existing barrier sites and laboratory experiments to adapt a technology to remove common carp from streams during carp spawning migrations in Minnesota. **Carryforward; Extension (b) The availability of the appropriations for the following projects are extended to June 30, 2020: (3) Laws 2017, chapter 96, section 2, subdivision 6, paragraph (d), Adapting Stream Barriers to Remove Common Carp**

I. PROJECT TITLE: Adapting stream barriers to remove invasive fish during their seasonal migrations

II. PROJECT STATEMENT:

The overarching goal of this proposal is to develop a system that can remove large numbers of invasive common carp during their spawning and seasonal migrations at existing barrier sites in streams. Specifically, we will focus on testing and adapting a technology recently developed for salmon in western United States to achieve this goal. This technology, called the Whooshh System, is comprised of an artificial riffle (i.e. a simple fish ladder) that the fish climb and then follow a slight downward slope (slide) into an entry chamber. Once the fish enter the front chamber, they are pneumatically pushed through a flexible plastic tube that can be hundreds of feet long. By doing so, the fish can be safely and quickly transported over dams and other man-made structures to allow their spawning migrations. In case of invasive fish, such as carp, the tube could lead to cages for removal. Thus, while Whooshh was originally designed to restore salmon populations along the west coast, we will use it to manage invasive common carp in the Midwest. Carp employ similar spawning migrations like salmon.

Common carp (*Cyprinus carpio*) are the most wide-spread and damaging invasive fish in Minnesota. In the spring, up to 90% of carp migrate from lakes to marshes to spawn. Often, thousands of carp are seen moving through small streams and creeks over the course of few weeks in May and June (Fig. 1). These fish are driven to reach their destinations and are often seen trying to jump over existing stream barriers, which they can usually cross with some effort. If these carp could be removed, many populations could be managed in a sustainable way. Unfortunately, it is difficult to predict exactly when carp will migrate, most move at night, and the ones that are seen at barrier sites during the day scare easily and are difficult to capture. If whoosh systems could be incorporated into existing carp barriers, many thousands of carp could be removed from streams with relatively little effort, which would allow for sustainable management strategies in many locations. Further, Whooshh engineers are currently developing species recognition capacities, which could be used to direct invasive carp into containment while allowing native fish a safe passage across barriers. **The direct goal** of this proposal is to test and adapt the existing Whooshh system to allow for selective removal of common carp during their spawning migrations. This will be accomplished by conducting field trials during two springs and summers at sites where carp barriers already exist (or where temporary barriers could be easily built) and where spring migrations have been documented in the past. We will also conduct laboratory tests during fall and winter to optimize systems that guide carp into the Whooshh System. Finally, if species-recognition component of the Whooshh System is developed by the onset of the project, we will also conduct laboratory trials to determine if carp can be selectively distinguished from native fish, such as the northern pike (*Esox lucius*), during spring migrations to remove the former and conserve the latter.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of December 31, 2017:

The project is progressing without delays. To address Activity 1, two study sites were selected in Rice Creek in New Brighton, MN and infrastructure was installed at those sites to get them ready for Whooshh tests in the spring of 2018. At each site, we installed a portable, low-voltage electric guidance system (EGS) to guide the migrating carp into Whooshh. We also analyzed existing data on water levels, flows and carp movement through Rice Creek to anticipate when Whooshh tests should occur in spring 2018 (first field season). This data shows that Whooshh system needs to be in place by mid-March. To address Activity 2, we tested the electric guidance system (EGS) to see if it could direct carp into a mock version of Whooshh (“Gate”). These test showed that 74% of carp could be directed into the Gate within 24h. We find these results very satisfactory give the realistic conditions at the field site (large stream). The EGS has been in the stream for 6 months and appears to be handling field regime (debris, changing water levels) very well and requires minimum maintenance.

Project Status as of June 30, 2018:

The first field season is in progress. We have finalized building infrastructure at our field site which in addition to the (1) electric guidance system (EGS) installed in Fall 2017 now also includes a (2) floating fish ladder which serves as an entrance to the Whooshh System, and the (3) Whooshh System (z.umn.edu/ElectricCarpBarrier). We have also installed additional electronic PIT antennas and underwater cameras to monitor the passage of carp through the fish ladder and Whooshh. Tests of carp passage have been conducted daily since ice out, first during natural carp spawning migration, and then using carp placed within a fenced in experimental arena. The EGS performed very well and it blocked ~90% of carp passage attempts despite high water flows that occurred during natural spring migration. Field tests of the Whooshh system also went well as we showed that the Whooshh was capable of transporting carp of a broad size range (420 mm to 640 mm; these carp were manually placed into Whooshh). Tests of the floating carp ladder (which is needed to direct carp into Whooshh) have been challenging. The carp were shown to be reluctant to cross through the ladder. The goal for the rest of the season is to conduct tests of the specific ladder design, and especially the weirs that connect each step of the ladder, until a design is reached where the carp are easily able to find their way through the ladder and into the Whooshh.

Project Status as of December 31, 2018:
Data from previous season has been analyzed and preparation for second field season is underway. For activity one, we continued to test various fish ladder designs during the natural spawning migrations and built a PVC corral for controlled experiments of exit designs with PIT tagged carp caught in Long Lake. We tested multiple fish ladder, weir, and exit designs. Overall, carp behavior was not predictable resulting in generally low passage success and varied individual behavior. Since Carp behavior was very cautious, verified in videos, and not predicable based on design exit we have conducted extensive research into new methods to “lift” carp into Whooshh system and will focus on testing these methods in the laboratory and second field season. One method, a large net that functions as a staging (aggregation) area + mechanical lifting device into Whoosh will be our primary approach during spring 2019 tests. We will be also conducting laboratory tests of other methods, such as Archimedes screw that might be used to autonomously lift carp into Whooshh.

Project Status as of June 30, 2019:
During the 2019 spring migration of carp we tested various methods for guiding carp into devices that can be used to enter carp into the Whooshh system. For activity one, we built a large modular fence and netting system which was able to capture ~ 4500 carp. This proof of concept design showed that the net can be emptied into and carp were transported hundreds of feet via the Whooshh transport system. While this approach is not fully autonomous, it already allows for scalable management applications. For activity two, we tested the efficacy a portable EGS system. This “electric fence” was highly effective at corralling carp into a tight aggregation, making them susceptible to a transport system (e.g. Archimedes screw or conveyor belt) that would be used to load carp into the Whooshh transport system. Laboratory tests of a mini- Archimedes screw suggest that we can force carp to enter the Archimedes screw, which can then load carp into Whooshh. Plans are being made for building and field testing a large Archimedes screw. Even more promising appears to be a design that uses a partially-submersed conveyer belt that collects carp briefly stunned with electricity (after they are tightly aggregated in front of the belt) and transports them out of the stream and into Whooshh.

AMENDMENT REQUEST June 30, 2019

We are requesting funds ($23,000 overall) to be shifted from:

- Salaries will be reduced from $246,000 to $228,065
- Publishing costs reduced from $3,000 to $1,935

- Lab services reduced from $3,000 to $0
- Statistical consulting reduced from $1,000 to $0.

And $23,000 be added to :

- Supplies will be increased from $8,000 to $18,000
- A conveyor belt system be purchased; increase from $0 to $11,000
- Costs of shipping the whoosh system back to Seattle; increase from $0 to $2,000.

These changes are being requested because more supply money is needed to pay for designing and implementing entry ways into Whooshh system. Initially, we expected that carp will use the small fish ladder design but it turned out that much larger designs were needed (large fenced in areas). Also, after tests conducted this spring with portable electrode systems, we concluded that the underwater conveyor belt system is the most promising and practical element needed to transport carp into Whooshh. This system was not in the original budget. Further, we ask for $2,000 to pay for shipping the Whooshh back to Seattle at the end of the lease period.

The savings are possible because Bajer's time on the project (past June 2019) will be reduced from 34% FTE to 25% FTE. This is reasonable because a great majority of the planned tests have been accomplished during the two spawning seasons of 2018 and 2019 which are now over. Further, Dr. Hundt (postdoc on the project) shows very high degree of independence. Further, we saved on publishing costs because MAISRC now has a separate budget for publishing papers. We saved $3,000 on lab services because carp used for this work are housed together with carp used on another project which already pays for fish housing. Lastly, we will not be needing statistical consulting on this project because the results are easy to interpret using analyses we are familiar with.

Because the amendment does not change the scope of the project, there was no need to edit the already approved sections of the work plan, except for the $ on each activity.

Amendment Approved 7/9/19

Project Status as of December 31, 2019:
As a result of this project, we have developed a technology that can remove migrating carp with high efficiency and with minimal use of human labor. This can be a breakthrough in carp management because large numbers of carp can be removed with relatively low cost. The technology consists of several devices working in unison: a low-voltage electric guidance system that guides the carp into a fenced in area/enclosure, enclosure constructed using PVC fencing in which the carp aggregate, portable set of electrodes inside the enclosure area that are used to crowd the carp using electricity in front of a partially submersed conveyer, electrodes positioned directly in front of the conveyer that stun the fish which then drift onto the surface of the conveyer with water current and are removed from the water. Once out of the water, the carp can be dropped into Whooshh system or other conveyer system to carry them on land. Field tests of the prototype version of this technology were conducted in the fall of 2019. In the final iteration of the technology, 70% of carp were removed from the enclosure with minimal human assistance. The funding for this project ends, but a full-scale application of this technology is scheduled to occur in Rice Creek in spring 2020. If successful, this technology could be applied throughout Minnesota and elsewhere to manage common carp. This technology could also be used to manage other species of invasive fish that migrate seasonally.

Project Status as of June 30, 2020:

Overall Project Outcomes and Results:

As a result of this project, we developed a new technology for managing the invasive common carp that is currently being commercialized by the University of Minnesota. The technology is easy to implement in various field conditions, requires minimum site engineering, and can be operated by a crew of two, which substantially reduces labor costs. This project started by testing whether the Whooshh system developed for migrating salmon might be adopted for common carp removal during spring migrations. Over the course of two field seasons we determined that the Whoosh technology is not easily adaptable for carp management because it requires that carp voluntarily swim into the Whooshh through a system of fish ladders, which proved problematic. However, we developed an alternative technology that appears to be effective and practical. Our technology is comprised of a low-voltage fish guidance system (available commercially) that guides the migrating carp into a large fenced in enclosure along the bank constructed using PVC pipes that slide into the stream bottom via horizontal support beams, a system of additional low-voltage electrodes placed inside the enclosure that can be activated as needed to crowd the carp and then briefly immobilize them, and a system of partially-submersed conveyers that collect the immobilized carp and carry them on land. All elements of this technology were rigorously tested over two field seasons using over a 1,000 carp marked with electronic micro-tags. The entire system was then successfully tested in summer 2019 and spring 2020. The technology appears to be ready for management implementations. In addition to its applications for managing common carp throughout Minnesota, the technology we developed might be also applicable for managing other invasive fish, including the bighead and the silver carp that are advancing up the Mississippi and St. Croix rivers.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Field tests of the Whooshh System or its components during carp migrations

Description: We will select two sites with existing carp barriers, or where temporary barriers could be constructed, and where large carp migrations occur each year. We will adapt the existing or newly-built barriers by attaching specially designed entry ways that will direct fish into the Whooshh System. These entry ways will be developed in the fall of 2017, in anticipation of the first spring field season, and installed during April-August of 2018 and then again in April-August of 2019 (carp migrate predominantly in the spring and summer). The entry way to the whoosh system will be equipped with an antenna capable of detecting Passive Integrated Transponders (miniature electronic PIT tags) that we will use to quantify the efficacy with which carp enter the Whooshh System and are removed by it. Similar antennas will be also placed 5m upstream and downstream of the barrier to quantify the number of attempts and successful passages. During each season, up to 500 carp will be captured in the stream using backpack electrofishing during their migrations and released below (or above depending on the direction of movement) the barriers. This will be repeated as many times as possible during each season to increase sample size for statistical analyses. Similar numbers of native fish will also be implanted with PIT tags to assess if they are also attempting to migrate through the Whooshh System. To optimize cost-efficiency and flexibility of study site selection (testing the Whoosh System does not require full installation of all components and power supply because tests in the fall of 2015 already showed that carp will be removed with the Whooshh System if the enter the entry chamber), tests of the Whooshh System during the first field season might be conducted using only the entry chamber.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 189,935**
Amount Spent: $ 188,748
Balance: $ 1,187

Outcome	**Completion Date**
1. Study sites selected for season 1 (spring 2018)	December 31, 2017
2. Field tests of Whoosh or its components during 1st spawning migration under way	June 30, 2018

3. Tests of Whoosh or its components completed during 1st season of carp migrations	December 31, 2018
4. Field tests of Whoosh or its components during 2nd spawning migration under way	June 30, 2019
5. Tests of Whoosh or its components completed during 2nd season of carp migrations; final report written.	December 31, 2019

Activity 1 Status as of December 31, 2017:

Two study sites were selected and infrastructure installed to prep them for Whooshh tests in the spring of 2018.

Specifically, we selected two study sites located within Rice Creek Watershed district. The first site is located approximately 0.5 km upstream of Long Lake in New Brighton, MN and the second site is located approximately 0.5 km downstream of Rice Lake in Circle Pines, MN. At each site we have measured water depth, and velocity to design appropriate guidance systems to guide carp into Whooshh during spawning migrations. Due to large size of Rice Creek, using a physical barrier was not practical (debris) and too expensive. To overcome this problem, we have worked with Rice Creek watershed District (our partner on this project) to install and test a new type of fish guidance system that appears to be very effective and practical to deploy in the field. Specifically, we have worked with RCWD to install a portable, low-voltage electric guidance system at each of the two sites. The guidance systems were tested on three occasions to optimize their arrangement and to direct carp into a mock version of the Whooshh system (Activity 2).

We have also analyzed existing data on the movement of common carp within Rice Creek to determine the timing for our tests in 2018. It showed that movement may occur as early as March (Figure 1), thus our goal is to have equipment on site by early march 2018. We are currently finalizing formal agreements with Whooshh to deliver the equipment by end of February. We have also formalized agreements with RCWD so that the installation of the Whooshh system and in-kind support (power source, site access) will occur as needed in the Spring 2018.

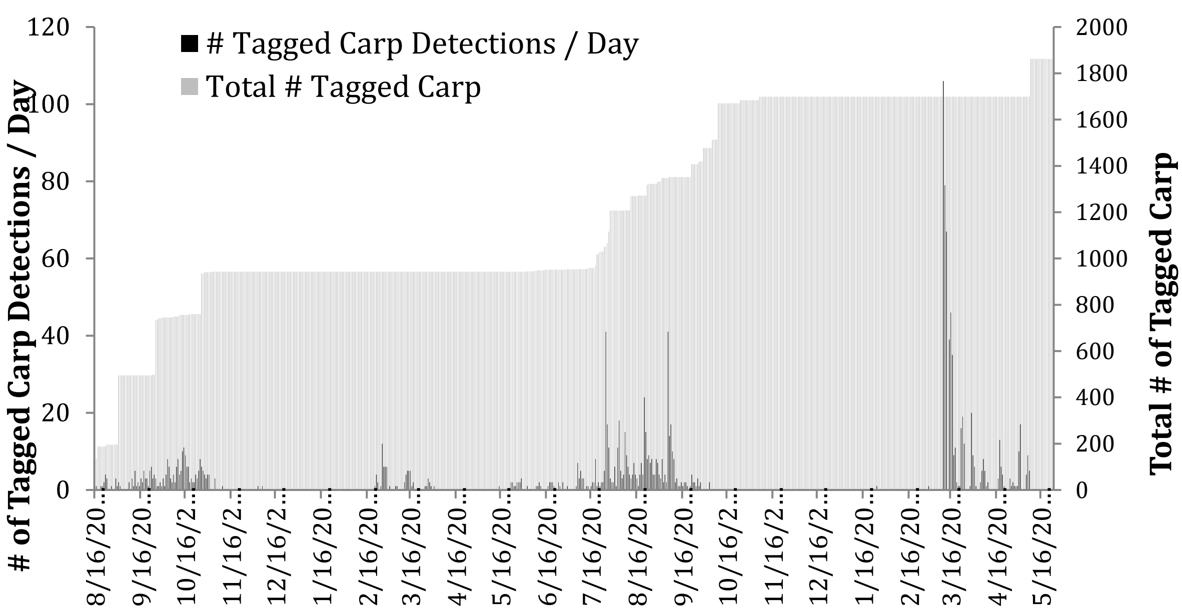


Figure 1. Movement of adult carp within Rice Creek. Data from Matt Kocian, Rice Creek Watershed District, our partner on this project.

Activity 1 Status as of June 30, 2018:

Field tests of the adaptive carp barrier and the Whooshh system have been under way since ice-out. First, we focused on testing the floating carp ladder, which is an entry way into Whooshh we developed under Activity 2 – see below. These tests were conducted during natural carp migration season. The overall approach and study design was: block the migrating carp using the EGS (electric guidance system) and direct them into a funnel-shaped PVC fence, the fence led directly into the ladder, the ladder led to Whooshh entrance (Fig. 1, 2, 3; z.umn.edu/ElectricCarpBarrier). Electronic antennas were used to monitor passage of carp implanted with PIT tags at each step. Our main focus was to test the performance of EGS and ladder, since these two components were needed to direct carp into Whooshh and we already knew that the Whooshh would perform well if carp were directed into it.

The carp spring spawning migration ran from April 22 – May 30, 2018. During this time, the EGS performed exceptionally well, even under high water conditions of early spring. During April 22 - May 1, 2018 carp were continuously challenging the EGS, with up to 206 unique PIT-tagged carp challenging the barrier per day (Fig. 4). Overall, during that week we recorded 753 unique PIT tag x day combinations of carp attempting to cross the EGS site. While only 73 were detected at an antenna located 1 km upstream. This suggests ~ 90% barrier efficiency during a week of continuous attempts by carp to cross the barrier (Fig. 3). This result gives us confidence that the EGS can be used to direct carp into the ladder and Whooshh even under high water spring conditions.

Tests of the ladder were less successful. During natural spawning migrations (April 22, May 30) no PIT-tagged carp successfully navigated through the ladder, despite many fish aggregating at the entrance to the ladder (Fig. 3). This was surprising because the weir designs (20 cm wide and 10 cm deep, V shaped) provided seemingly easy passage for carp. Adding or removing ladder chambers or increasing or decreasing water flow through the ladder did not improve its performance. Visual observations and camera recordings showed that the carp would approach the weir, partially swim through it and back out downstream. We suspect that the end weir (which was only 2 cm deep) that functioned as the entrance to the Whooshh was the reason for low passage rates.

We then changed our approach by conducing detailed daily tests of various weir designs and added underwater cameras to observe how carp navigate through the weirs. To allow these tests, we modified the field site by creating a fenced-in experimental area into which we release 20 PIT-tagged carp at a time. PIT antennas were placed at the entrance and exit of the weir to document passage attempts/success. The goal is to produce a weir that carp are not reluctant to use. We are testing weir dimensions (width, depth), and placement (surface, or bottom) of the weir. Preliminary results show that ~ 60% of carp pass through a V-shaped weir that is 30 cm wide and 20 cm deep within the first 3 hours post release. These tests will continue through the summer.

We also tested the capacity of Whooshh to transport carp of various sizes that are commonly seen in lakes in Minnesota. We deployed the Whooshh system at the study site and collected carp that ranged from 420 mm to 640 mm. The Whooshh system was shown to easily pass all of those carp (z.umn.edu/TestingWhooshh).

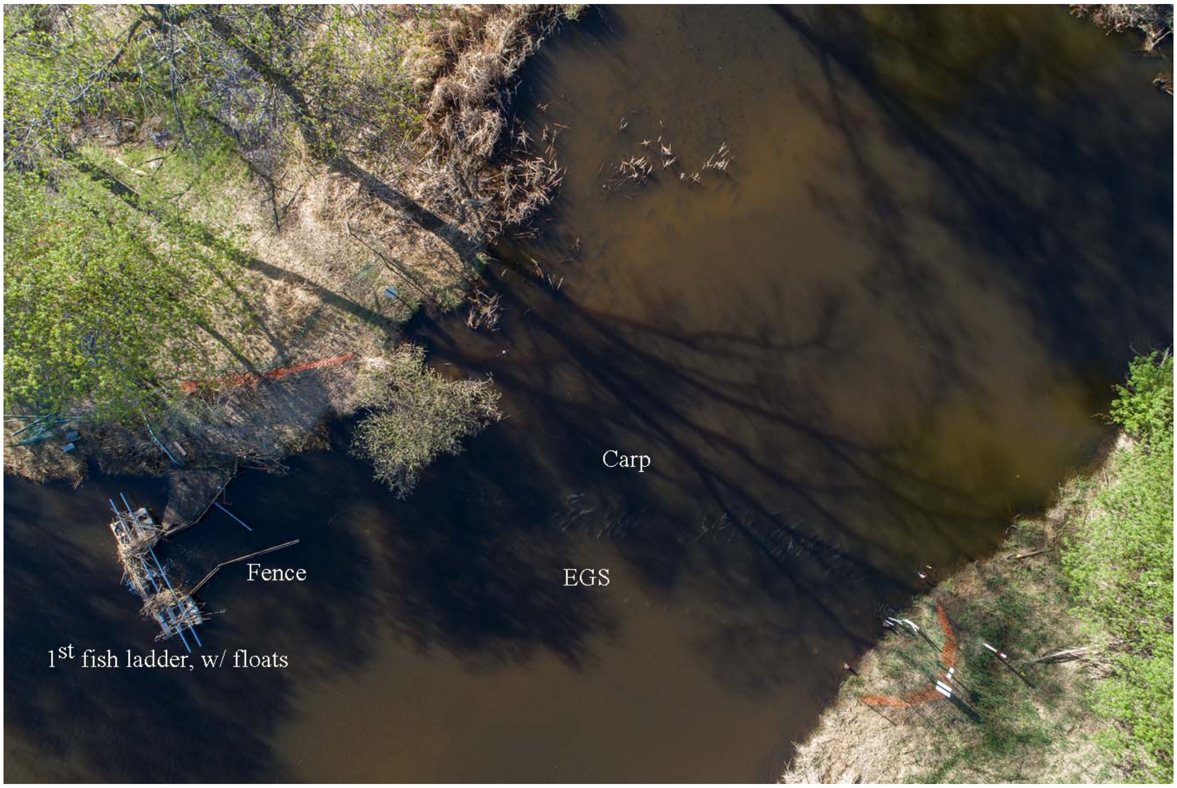


Figure 1. Electronic guidance system (EGS) directing fish moving upstream (bottom of photo) into fenced in area. Once in fenced in area fish proceed into floating fish ladder (only 1st fish ladder shown). The floating ladder leads into the entrance into Whooshh (metal weir).

Figure 2. Common carp being prevented from migrating upstream by electric guidance system (EGS).

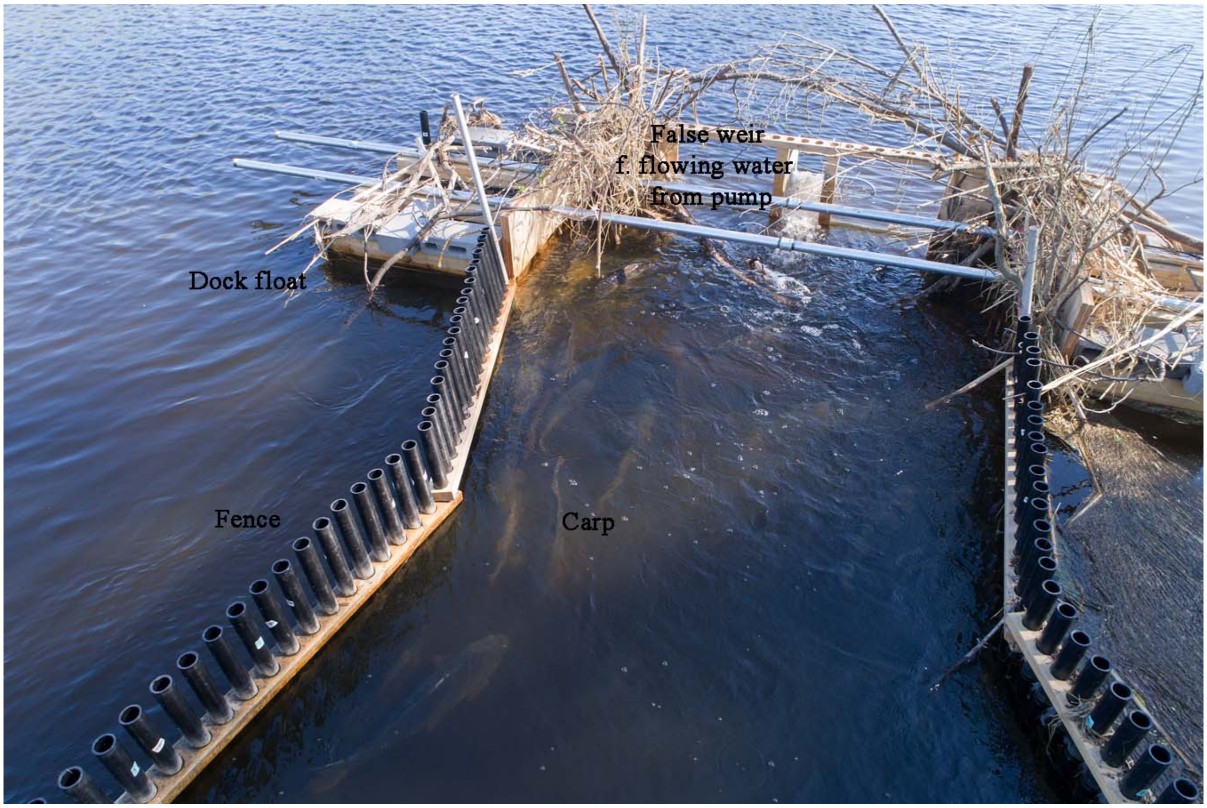


Figure 3. Fenced area and floating fish ladder, with carp being directed toward false weir, which is the entrance to the Whooshh system. Water pump is attached to the bottom of the weir to provide flow through the fish ladder. This serves as an attract for migrating fish. Subsequent boxes (not shown) hold water ~3-6 inches (depends on size of weir opening and water flow) higher than previous downstream box. Note: in this particular design, back wall is mostly made of clear acrylic glass to create the illusion of open passage way for the carp.

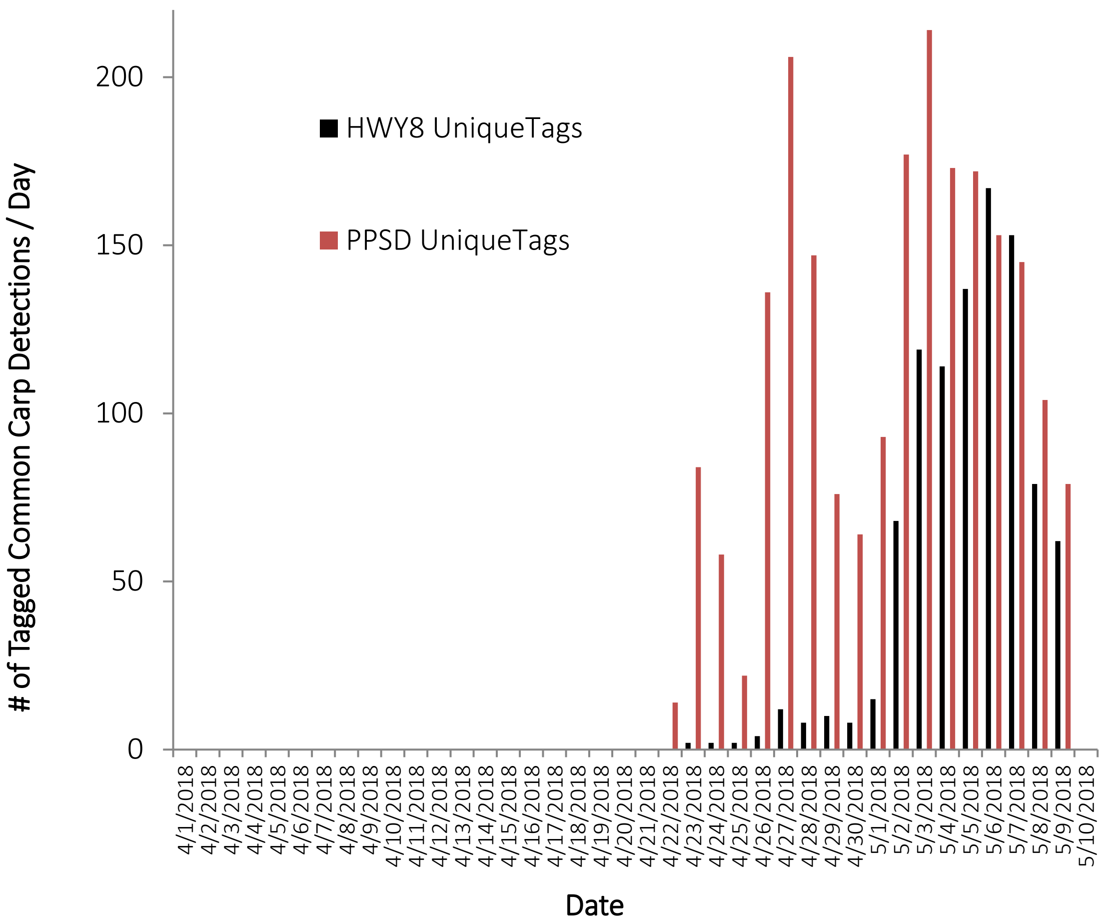


Figure 4. Total number of PIT-tagged carp detected by an antenna at the EGS (red bars; Poppyseed Drive; PPSD), and by an antenna 1 km upstream (black bars; Highway 8, HWY8). The EGS was turned on continuously through May 1. The generator powering the EGS failed on the morning of May 2, allowing some carp to swim through the EGS, which was immediately reflected by high number of crossings at HWY8 antenna.

Activity 1 Status as of December 31, 2018:

We continued to test various fish ladder designs during the natural spawning migrations (see previous update). On June 7th, carp were present in large number on either side of the EGS, indicating that carp were returning to the lake after spawning. Natural spawning migrations were complete. We shut off the EGS and removed all but the first box in the fish ladder, in order to continue testing exit designs from the fish ladder. To do so, we built a fenced-in experimental arena (corral; 5 m long, 2.4 m wide) using PVC pipes downstream of the experimental fish ladder. This enabled controlled experiments of exit designs by placing PIT tagged carp into the corral. PIT antenna and datalogger placed at the exit of the fish ladder recorded the time each unique carp approached the exit and successfully exited through it. Videos were also recorded (5h videos recorded for 6 separate experiments) to verify carp exits and behavior. For each experiment we collected ~ 20 carp in Long Lake using boat electrofishing, and tagged them with PIT tags in the morning. The fish were then transported to the test area and placed inside the corral. Carp behavior in the corral, their attempts to exit through the weir and successful exits were monitored using PIT antennas until the next morning.

Overall, we conducted 20 experiments testing different exit designs. We tested rectangular vs. V-shaped openings that were located either at surface or bottom of the fish ladder that were 30 cm tall and varied in width between 20 cm and 25 cm. For the surface exits, we manipulated their positions in different experiments so that water depth inside the exit varied between 5 cm and 15 cm (Table 1). We also tested a metal weir (designed by Whooshh engineers for salmon passage) and a wooden replica of the Whooshh metal weir (manufactured by us). In each design, water flow (~ 30 cm/second, similar to velocity in stream riffles) was provided by using trash pumps located on shore.

Overall, the experiments suggested that carp were reluctant to pass through artificial exits. Underwater videos were especially useful in showing most carp approaching the exit multiple times, but not passing, even if the exit was relatively large and fully submersed (e.g. Experiments 5, 6, 7, 9; Fig. 1, Table 1). Many carp would even partially or fully pass through, only to return back into the fish ladder (video observation). Due to reluctant carp passage and exploratory nature of the experiments we tried many different designs, without extensive replication, in order to find promising, effective, and expedient exits. However, results were relatively consistent among the designs we tested (Table 1). It routinely took between 2 and 5 hours for 50% of the carp to leave the corral through the exit, and individual carp approached the exit, on average, 5 times until they actually exited (Table 1). Observations from videos indicate that passage may be a group process: 1) 1 or 2 individual carp approach the exit cautiously, 2) approach or partially breach exit multiple times 3) go through but quickly return, 4) eventually pass through, after which several fish leave all at once following the “leaders”.

It may be that over time, carp may learn to use artificial passage ways, but in order to meet short term goals of carp removal and Whooshh system optimization we will test other options where carp are directed into a large holding area (which we documented during spring 2018 tests as carp aggregated below the fish ladder) and then mechanically lifted into Whooshh. We have extensively researched and brainstormed new methods to “lift” carp into Whooshh system and we will focus on testing these methods this winter (see activity 2 update) so as to have new methods to test and apply during the 2019 spring migration.

Figure 1. Designs of various fish ladder exits tested, including location, shape, size, and material and whether or not water flow (via trash pump) was used to create a false weir. Each histogram depicts the time to exit, in decimal hours, for each carp. See Table 1 for more details and for water depths in exit (indicated as @)

Table 1. The amount of time it took for carp to swim through experimental exits after being placed in a fenced-in experimental corral. Min is time elapsed before the first carp from each experiment exited through the weir while Max is the time elapsed until the last carp exited through the weir. Quartiles, median and mean show averaged values across all individuals used in a particular experiment. Attempts show how many times (on average) carp tried to exit until it actually exited through the weir. Experiments 1,3, & 13 were removed due to technical issues with PIT antennas.

Design	Exp.	Date	@ Water depth in weir	# carp	# carp detected	Min. (dec. hrs)	1st Quartile	Median	Mean	Max.	Attempts/carp (Median)
Bottom 12" x 10"	5	6/13/18	n/a (fully submerged)	25	15	0.10	1.39	3.15	3.12	6.17	13
	6	6/14 - 6/15/2018	n/a (fully submerged)	19	16	3.88	5.92	12.11	10.56	14.53	6
	7	6/15/18	n/a (fully submerged)	20	20	0.73	0.91	2.01	2.70	5.40	5
	9	6/21/18	n/a (fully submerged)	20	19	0.02	1.85	4.05	3.52	8.40	5
Top 12" x 10"	8	6/18/18	4"	18	15	1.41	2.36	3.53	3.50	8.71	8
	10	6/22/18	4"	20	12	0.90	1.69	2.26	2.34	4.39	4
	11	6/25/18	5 3/4"	20	3	1.93	2.35	2.78	2.81	3.71	4
Top 12" x 8.5"	12	6/26/18	5 5/8"	20	6	0.57	1.29	3.06	3.92	7.97	7
Top 12" x 8.5" x 3.5"	17	7/5/18	5 1/4" (w/ slower pump speed)	20	20	1.09	1.66	2.98	3.15	5.51	5
	18	7/6/18	4 7/8" water depth	20	20	0.39	1.32	2.23	2.39	5.75	5
Top 12" x 8.5" x 8"	19	7/11/18	3"(w/ pump off)	20	18	0.88	3.67	5.33	5.21	8.07	3
	20	7/16/18	2" (w/ pump on)	20	15	3.09	4.21	5.23	5.28	9.44	2
	21	7/17 - 7/18/18	3" (w/ pump on)	20	19	2.89	4.15	4.49	6.35	17.28	4
	22	7/18/18	3" (w/ pump on)	20	13	3.03	3.54	3.85	4.47	6.63	5
	23	7/20/18	3" (w/ pump on)	20	11	3.76	3.99	4.08	5.02	7.84	2
Top 12" x 8.5" x 8"	2	6/8 - 6/9/2018	4"	110	97	0.31	2.48	3.87	5.69	24.86	4
	4	6/11/18	4"	20	11	5.66	6.82	6.85	7.05	7.82	3
	14	6/28 - 6/29/2018	5 3/8"	20	17	0.30	2.01	3.52	5.00	15.51	6
	15	6/29 - 6/30/2018	5 3/8"	20	14	0.81	2.94	8.91	10.39	19.85	4
	16	7/2/18	5 1/4" (w/ slower pump speed)	20	20	1.07	1.37	2.43	3.98	11.24	5
					AVERAGE	1.64	2.80	4.34	4.82	9.95	5

Activity 1 Status as of June 30, 2019:

Last year, Carp struggled to navigate through small fish ladder designs and subsequently would not volitionally enter the Whoosh transport stem. During carp migration (April 8 2019 – May 30, 2019) we tested a new method for using the Whooshh fish transport system. This system used a large fenced in area (15 x 80 feet) into which the migrating carp were funneled using the EGS (Figure 1 and 2). A large net (Figure 2 & 3) was deployed inside the fenced in area (the net had mesh bottom and mesh sides). The net had one small entrance, which could be shut once the carp aggregated inside the net. Then, the bottom of the net could be lifted using a large floating pipe inserted under the floor of the net, all carp were then pushed towards the upstream end of the net, and emptied into a boat. Whoosh transport system was positioned on the bow of the boat (Figure 4). The large fenced area was built in the same region as the fish ladder (Figure 1 & 2, see also Figure 1 from previous update). Numbers of carp that were directed into the trap/net were monitored using PIT tags and antennas.

Each day during the migration the fence was closed early in the morning so as to trap the carp and load them onto a boat. Once in the boat carp were scanned for PIT tags and sent via the Whooshh to water tanks with anesthetic and eventually to pickup truck beds for disposal. This approach was tested on ten different days during April and May. Overall, although carp had to be manually handled this method has great potential, as we were able to remove 4500 carp during the spawning migration. We have also determined how this process could be automated by using additional sets of electrodes that can be used to push the carp that aggregate inside the fence as needed and cause them to aggregate tightly in one area (for removal) or stun them with electricity and remove with a conveyor belt system that could load them into Whoosh (see activity 2).

The EGS, which is the keystone element of our design, functioned very well despite extremely high waters throughout the spawning migration. Additional fencing was built to keep fish from passing around EGS on the flooded banks. The PIT tag antenna downstream of the EGS detected many fish, including 339 of 458 carp that were PIT tagged last year in Long Lake (downstream of Rice Creek study site). This high percentage supports previous reports of high participation in carp spawning migrations within Rice Creek Watershed. This data is currently being analyzed.

Figure 1. Fenced in area upstream of EGS. Note: exceptionally high water, flooded well beyond banks of creek

Figure 2. Downstream view of fenced in area with aluminum poles used to raise net.

Figure 3. Net in raised position.

Figure 4. Boat with Whooshh transport system. Netted carp would be dumped into boat placed manually into transport system to be moved to water tanks with anesthetic.

Figure 5. Euthanized carp in truck bed after being transported via Whooshh.

Activity 1 Status as of December 31, 2019:

Data from the 2019 spring migration has been largely analyzed. Even during the extremely high water levels that occurred in spring 2019, our system, which included an Electric Guidance System (EGS) to block the carp and direct them into an enclosure/trap, large enclosure towards which the carp were funneled, and a net deployed inside the enclosure to catch and remove the carp, performed relatively well. The EGS blocked over 95% of migrating carp and on many days, between 30% and 60% of the carp were directed into the enclosure. Over 4,000 carp were removed using the net. However, removal with the net proved to be too laborious and time consuming. A better and faster system was needed. We believe we solved this problem by using a combination of low voltage electrodes positioned inside the enclosure and a partially-submersed conveyer to remove the carp out of the water and transport them into a receptacle (see activity 2 for detailed description of the conveyer system).

Carp migration began on 4/7/19. Overall, there were 1,000 unique PIT tagged carp detected at EGS during April 6 – May 31, 2019 (Fig. 1). Migration was most intense during April 8 – May 7.

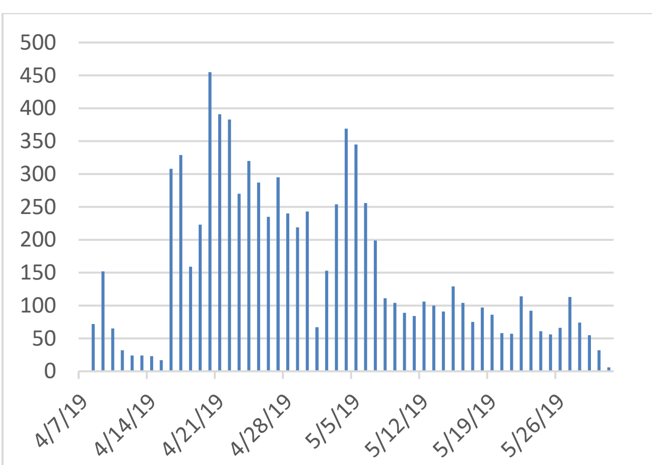


Figure 1. Numbers of PIT tagged carp attempting to cross the EGS during spring spawning migration of 2019.

During early migration period April 8 – April 19, 2109 there were 559 unique PIT carp that were migrating upstream and trying to cross the EGS. Many for multiple days. Of those, only 11 were detected at HWY8 PIT antenna located upstream. This suggests that 98% carp were successfully blocked by EGS. Vandalism occurred in short succession on 4/20 when a hole was cut in a snow fence we built on shore to prevent carp migration over flooded banks and 4/24 when the EGS was turned off. This resulted in 484 PIT tagged carp crossing EGS and being detected at the upstream HWY8 antenna during 4/20 – 4/30. The EGS was turned back on 4/24. Between 4/24 and 5/7/19, there were 558 carp attempting to cross the EGS. Of those 24 were able to cross EGS (96% barrier efficiency) until the EGS was turned off again on 5/7/19. Numbers of migrating carp declined after 5/7 to less than 100 PIT tagged individuals per day. Overall, despite the very high water levels, and very motivated fish that challenged the barrier continuously, the barrier showed over 95% efficiency. The efficacy might have been higher if not for the challenging field conditions – on many days the water was out of the banks and flowing around the EGS; there were deep undercut banks and the water was flowing over land. We attempted to managed these conditions by building physical barriers for carp trying to cross over flooded land, but these barriers were probably not as effective as the EGS, and we suspect that the carp that managed to cross our site, did so by exploring flooded banks and undercuts.

We closely monitored how many of the migrating carp were directed into our enclosure/trap and how many of those fish were captured in the net deployed inside the enclosure between 4/15 and 5/9/19 (Table 1). During that time, 3152 PIT tagged carp (unique fish * days combination) were attempting to cross the EGS and migrate upstream. Of those, 684 entered the enclosure at least once (Table 1). Of those, 209 were captured in the net (Table 1). Percentage of migrating carp that were directed into the enclosure varied daily from zero to 65% (Table 1). We expect that more fish would be directed into the enclosure if we were able to empty the enclosure more effectively (emptying the enclosure took several hours). We hypothesize that there is a maximal density of carp that fit in the enclosure and many fish swim in and out of it frequently. This was corroborated by the finding that although 684 PIT carp visited the enclosure, we captured only 209 PIT carp. Overall, we believe that more carp would have been directed into the enclosure and captured if our removal method was faster and caused less disturbance (emptying the enclosure more frequently to allow new carp to swim in). We believe that we have developed such a method in Activity 2 by designing a system where carp inside the enclosure are aggregated using electrodes and removed from the water using a conveyer belt.

Table 1. Numbers of PIT tagged carp migrating upstream (at EGS), directed into out fence/trap, caught inside the trap. Also shown are total numbers of captured carp (including those that were not PIT tagged).

Period	PIT At EGS	PIT in Fence	PIT Caught	All Caught
4/15 5:00 pm – 4/17 5:50 am	357	233	42	986
4/17 5:00 pm – 4/18 7:00 am	125	1	1	8
4/18 5:00 pm – 4/19 5:50 am	143	0	0	2
4/19 10:00 am – 4/19 3:30 pm	110	1	5	106
4/21 9:00 am – 4/22 9:00 am	395	149	3	86
4/22 5:00 pm – 4/23 9:00 am	241	4	0	24
4/24 12:00 – 4/24 7:15 pm	165	10	13	247 EGS OFF
4/25 10:30 am – 4/25 2:00 pm	115	0	24	386
4/25/6:00 pm – 4/26 9:00 am	186	22	40	754
4/26 2:00 pm – 4/30 9:30 am	355	103	40	972
5/2 4:30 pm – 5/3 11:00 am	164	2	6	103
5/3 1:00 om – 5/5 6:00 pm	408	142	23	188
5/6 5:00 pm – 5/7 9:00 am	209	0	0	15 EGS OFF
5/7 11:00 am – 5/9 9:00 am	179	17	12	138

Activity 1 Status as of June 30, 2020:

Planned work for this activity ended in December 2019. Nevertheless, using the remaining funds in the project we conducted a proof of concept test of the technology we developed during natural carp spawning migration. In April 2020, we added a system of two conveyers to our field site in Rice Creek, which already included the electric guidance system that guided carp into a fenced in area and a system of portable electrodes inside the fenced in area for aggregating carp on top of conveyers (described above). The entire system was tested on five separate days during the carp spawning run in April and May 2020. The goal of those tests was to determine if carp can be removed without manual labor other than two operators needed to control the switches for the electrodes and conveyers. The tests were successful. During the 5 trails, 808 carp that aggregated inside the fenced in enclosure were removed: 19 carp on 4/22, 15 carp on 4/23, 150 carp on 4/24, 535 carp on 4/26 and 89 carp on 5/20. While we identified that several improvements could be made to increase the efficiency of the system, including larger fenced in area, steeper angle of the electric guidance system in relation to stream axis, more densely-spaced electrodes inside the fenced in area, and larger drives on the conveyers, overall the system is ready for commercial applications. Should more funding be available, these improvements could be conducted and tested during future spawning migrations of common carp. The system could also be tested on other invasive fish, such as the bighead or silver carp during their seasonal migrations.

Final Report Summary:

As a result of work conducted under Activity 1, we developed a technology that is currently being commercialized by the University of Minnesota. This project started by testing whether the Whooshh system developed for migrating salmon might be adopted for common carp removal during spring migrations. Over the course of two field seasons we determined that the Whoosh technology is not easily adaptable for carp management because it requires that carp voluntarily swim into the Whooshh through a system of fish ladders. Despite testing several designs of fish ladders, we were unable to identify any that would work. However, we developed an alternative solution that appears to be effective and easier to deploy. We developed a technology comprised of a low-voltage fish guidance system that guides the migrating carp into a large fenced in area constructed from vertical PVC pipes that slide into the stream bottom via horizontal support beams, a system of low-voltage electrodes placed inside the fenced in area that can be activated as needed to crowd the carp that aggregate inside the fenced in area and then briefly immobilize them, and a system of partially-submersed conveyers that collect the immobilized carp from the stream and carry them on land. This entire system was successfully tested in the spring of 2020 during natural carp spawning migration. This project was possible by leveraging additional funding and collaborations with the Rice Creek Watershed District, Procom Systems and Carp Solutions. The technology we developed might be also tested and applied for other invasive fish, including the bighead and the silver carp.

ACTIVITY 2: Laboratory tests of the Whooshh System or its components to optimize entry ways for carp migrating up- or downstream.

Description: We will conduct laboratory tests to optimize the design of entry ways into the Whooshh System for carp migrating up- or downstream. We will focus on designing shallow riffles and flow attractants that the carp might cue on while migrating upstream. This work will be conducted during the off-season (September-March) under controlled laboratory conditions, or a field site where conditions could be easily manipulated, where different flow velocities and water temperatures will be tested. Separate tests will be conducted during the day and at night to mimic realistic field conditions (carp often migrate at night). One to two species of native fish (such as the northern pike (*Esox lucius*) or bigmouth buffalo (*Ictiobus cyprinellus*)) that often migrate together with the carp will also be tested to maximize species-specificity of the Whooshh System so that the carp might be removed while the migration of native fish is unobstructed.

Summary Budget Information for Activity 2:

ENRTF Budget:	**$ 111,065**
Amount Spent:	**$ 111,065**
Balance:	**$ 0**

Outcome	**Completion Date**
1. Preliminary tests of prototype entry ways in progress	December 31, 2017
2. Prototype entry way designed for use during the first field season	June 30, 2018
3. Laboratory tests to perfect entry ways in progress	December 31, 2018
4. Improved entry way designed for use during the second field season	June 30, 2019
5. Final tests of entry ways completed; final report written	December 31, 2019

Activity 2 Status as of December 31, 2017:

A first test of an entry way into a mock version of Whooshh ("Gate") was conducted and showed that 74% of carp could be directed into it within 24h. This result is deemed very satisfactory, given the realistic field conditions of our site.

More specifically, for the summer and fall of 2017, we opted to conduct field tests instead of laboratory tests because field tests offered more realistic conditions. To conduct first tests of possible entry ways into the Whooshh system, we tested the performance of the low-voltage fish guidance system that was installed at our study sites (Activity 1). The guidance system was installed at approximately 45-degree angle in relation to stream channel to guide the carp towards one side of the stream (Figure 2). At that site we then installed a small gateway (4 feet wide) and placed a wire antenna around its circumference. The antenna was used to determine the passage of carp, which were implanted with PIT tags, through the passage way. Then we built a narrow channel going upstream of the entry way to simulate a shoot that would direct the carp into Whooshh.

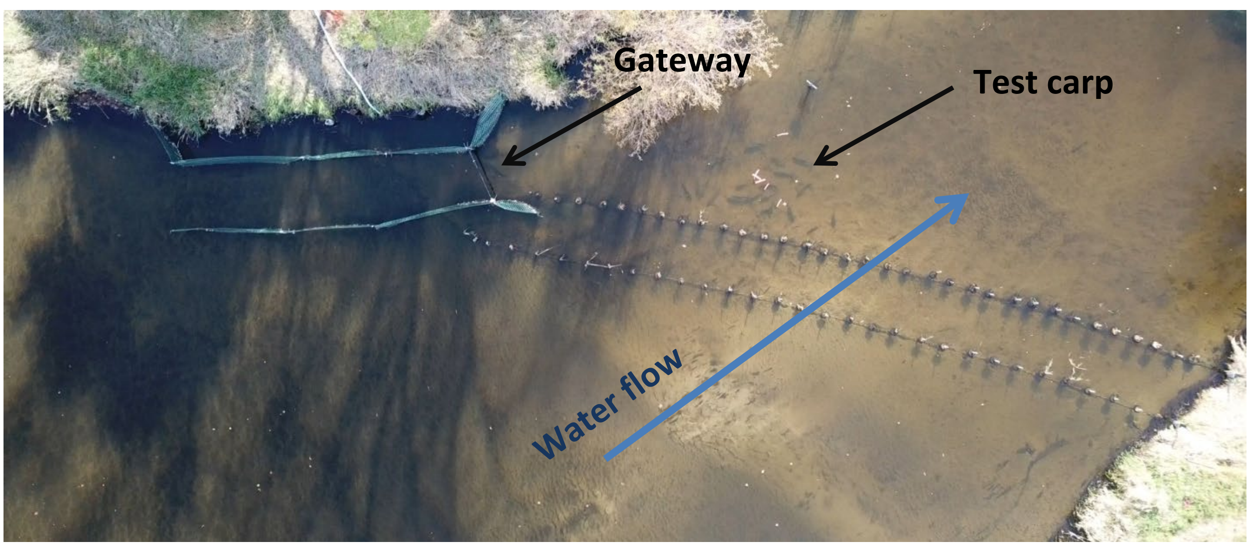


Figure 2. The electric guidance system (EGS; two rows of electrodes) and a mock version of a gateway into Whooshh (green snow fencing) in Rice Creek. Blue arrow shows direction of water flow. The carp are visible on the downstream side of the EGS navigating their way upstream towards the mock entrance into Whooshh.

The performance of the EGS and gateway was tested on six occasions. Three times when the EGS was on, and three times when it was off. Each time, approximately 50 carp were captured in Long Lake, implanted with PIT tags and released at the test site. A temporary physical barrier was placed downstream of the carp to prevent them from leaving the test site. Passage of the carp through the gateway was monitored over 24h using a PIT reader. In addition, small floats were attached to the dorsal fins of 10 carp and these fish were observed for one hour to count the number of times they attempted to pass through the EGS, how many times they were able to pass through the EGS (undesirable) and how many times they passed through the gateway (desired).

The results showed that when the EGS was on, 74.2% were successfully directed through the gate within 24h. When it was off, only 18.7% carp were successfully directed through the gate. In addition, when the EGS was on, no carp were ever able to successfully swim through the electric barrier. When the EGS was off, 46.2% carp swam through the electric barrier. Overall, these results very satisfactory.

Table 1. Results of testing the EGS system to guide carp into a mock version of Whooshh "Gate".

		Carp with floats			Carp with PIT tag PIT tags
Date	Treatment	Approach EGS	Cross EGS	% Crossed through EGS	% Crossed through Gate
10/24	EGS Off	32	7	21.8%	21.3%
10/25	EGS Off	19	7	36.8%	16.7%
10/27	EGS Off	10	8	80%	18.2%
Mean				46.2%	18.7%
10/12	EGS On	63	0	0%	90.2%
10/23	EGS On	104	0	0%	72.3%
10/26	EGS On	70	0	0%	60.0%
Mean				0%	74.2%

Activity 2 Status as of June 30, 2018:

We consulted with Whooshh engineers during their on-site visit in winter 2018 to develop prototype entry ways into Whooshh. We focused on designing a floating carp ladder. A floating carp ladder was needed because the Whooshh is designed in such a way that is sits ~ 25 cm above the surface of the stream (Fig. 1). Thus, a fish ladder was needed whose entrance was at the stream level (so that the migrating carp can easily swim into it) but the exit was 25 cm above the stream level leading the carp directly into Whooshh (Fig. 1, 2). The ladder consisted of several chambers (60 cm wide, 120 cm long) connected via fish passages or artificial weirs (Fig. 2, 3). The weirs were designed to hold back enough water so that water level would increase by ~ 10 cm between each chamber. Water pump was attached to the top weir (exit of the fish ladder) to pump water through the ladder and artificially raise water level above the natural height of the stream. The ladder was placed on floats to accommodate increases and decreases in water level (Fig. 3).

The prototype carp ladder was installed in our field site before the onset of carp migration to allow daily tests (see Activity 1). These tests are ongoing.

Figure 1. Carp ladder (plywood boxes) attached to the entrance to Whooshh. Note that the entrance to whoosh is ~ 25 cm above the surface of the stream, thus, the exit from the ladder had to be at the same level.

Figure 2. Downstream view of the carp ladder. The entrance to the ladder is at stream level and the water level increases by ~ 5-10 cm at each step of the ladder. Water pump was attached to the ladder exit to pump water through it.

Figure 3. A PVC fence was used to guide carp into the ladder. An electric guidance system (EGS) is stretched across the stream to the left of the fence. Carp that migrate upstream are deflected by EGS and directed into the fence, floating carp ladder, and then Whooshh. For more details of the field design see Activity 1.

Activity 2 Status as of December 31, 2018:

Efficacy tests of prototype carp ladder, with various exit designs were conducted during natural carp migration and continued after migration (see Activity 1). Results from early spring suggested that carp are more careful and less willing to pass through fish ladders exit/weir than previously expected (see Activity 1 updates). For the immediate purpose of having ready-to-use designs we will test a verified successful method to "lift" carp into Whooshh entrance: holding net + lifting device. Using observations from 2018 we will use the EGS to direct carp into a large holding area via a one-way funnel. The holding area will be comprised of a large net (10 m wide, 40 m long) with mesh sides and bottom. The net will be placed upstream of the EGS and in place of fish ladder (see Fig. 1 & 3 in Activity 2 Status as of June 30, 2018). Carp that aggregate within it (as shown by PIT antennas) would then be pushed forward and aggregated at the base of the whoosh. This will be done by inserting a floating PVC pipe under the bottom of the net and pushing it forward. Once carp are aggregated, a mechanical scoop and a winch can be used to lift the carp into Whooshh. This method is currently used to move carp from box nets into boats for removal and can easily to adapted into the Whooshh system. If successful, it could be mechanized with minimal on-site supervision. A key assumption here is that carp that aggregate within the holding net cannot easily leave it. This will depend on the efficacy of the one-way funnel system. We are in the process of establishing laboratory arenas to conduct such tests.

For more long-term applications of the Whooshh technology that might utilize fully autonomous entry ways where carp enter Whooshh on their own, we will conduct laboratory tests of technologies that showed promise for other fish, such as the Archimedes screw (Fig. 2). The Archimedes screw is comprised of a slowly-rotating spiral ("screw") inside a tube (Fig. 2). Once the fish enters the bottom compartment, it is then carried upwards and exits through the top. The Archimedes screw has two major advantages. One, the entrance to the screw is on the bottom of the stream, a preferred position in the water column for benthic fishes such as carp. This technology is already in use to help move migrating eels, another benthic species, around dams. Second, this is a passive system and would not require further man hours, although it would require some power to turn the turbine, allowing rotation of the screw and ultimately "lifting" fish above water and into the Whoosh entrance.

We are in the process of building a laboratory version of Archimedes screw that we will test this winter using juvenile carp.

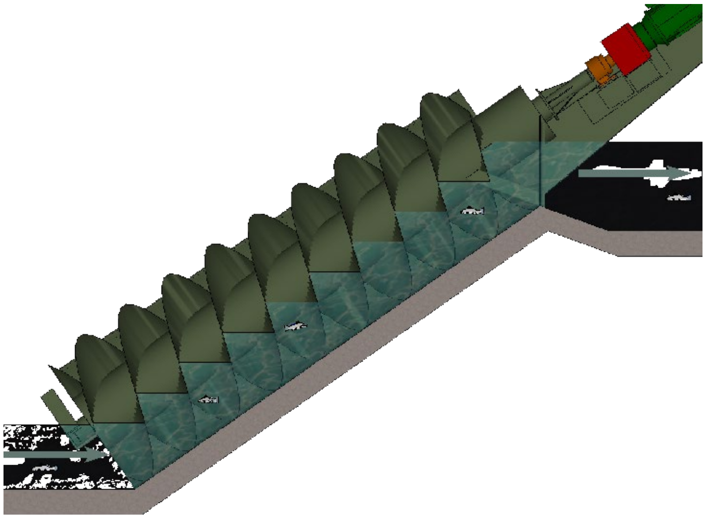


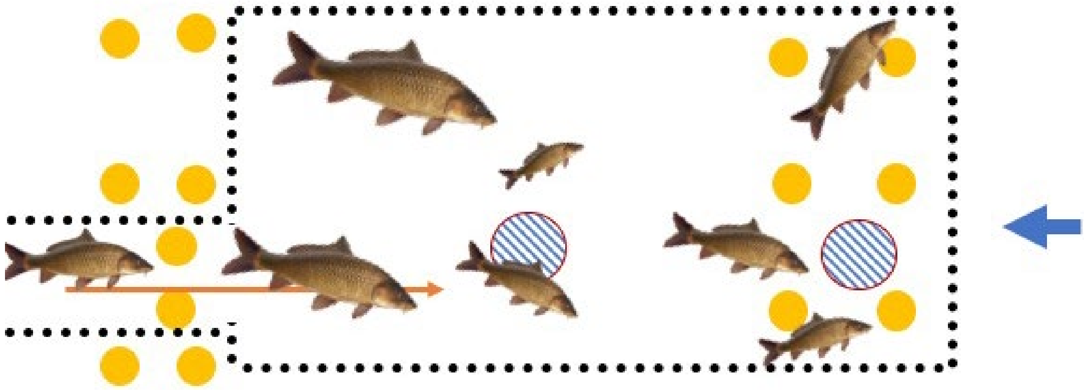
Figure 2. Archimedes screw, adapted from 3Helixpower.com ©

Activity 2 Status as of June 30, 2019:

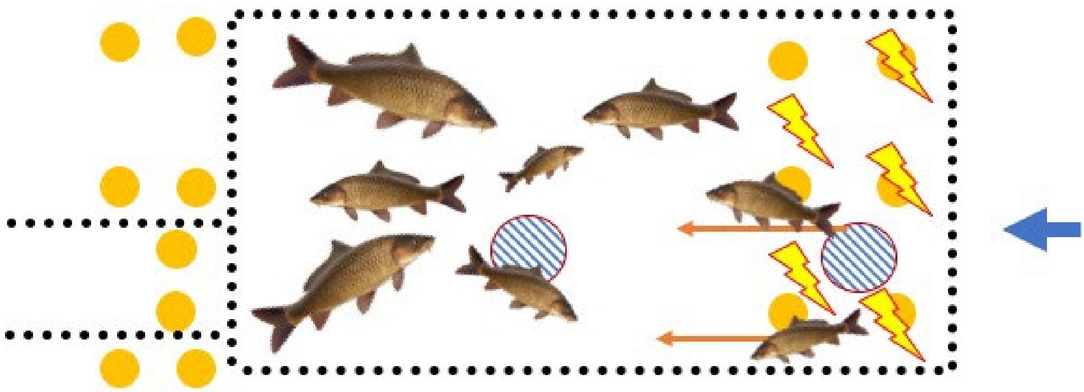
Experimental designs were tested to potentially allow for volitional or even forced entry into the Whooshh fish transport system. The main hurdle is that the entrance to whoosh is ~ 25 cm above the surface of the stream, thus, carp must be raised above this high to allow for entrance. Based on observations of carp aggregations we decided that a combination of forced mass aggregation and various lifting methods might be possible.

Mass aggregations were forced using systems of portable electrodes (portable EGS) that can be turned on in sequence to direct the carp inside the trap. Five tests (starting on 14 May 2019) were conducted inside the large fenced area (Activity 1) to begin to understand the appropriate voltage settings. Visual observations confirmed carp behavior at all voltage settings and were used as the basis for the controlled experiments. To further facilitate these tests, a smaller fenced in area (35' x 15') was built to further test out ability to aggregate carp (starting 22 May 2019). Steps for this method are outlined below in the "Method for using portable EGS to induce dense aggregations" section. During five experiments in the smaller fenced area carp were allowed into the fenced area at night and trapped in the morning by closing the entrance gate. The carp were allowed to swim freely inside the fenced in area for 2 hours. Then, electricity would be systematically turned on starting upstream, moving the carp downstream. Then the downstream electrodes would be turned on confining the carp between the upstream and downstream electrodes for two hours. Whether we were able to force that carp to remain tightly aggregated over this small area was determined by placing PIT antennas that monitored how carp used the fenced in area. In all experiments once electricity was on, all carp detections were in the non-electrified area and NO carp were detected in the electrified area. All tests had ~ 30 carp. All tests confirmed that the portable EGS is able to confine carp to a small area using electricity. Once confined in a small area carp are more susceptible to transport either using and Archimedes screw (see below) or a conveyor belt (in development).

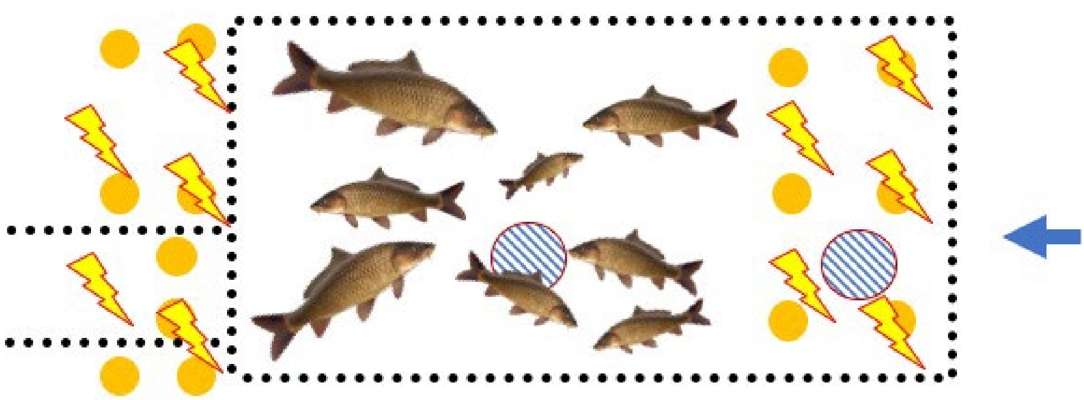
Method for using portable EGS to induce dense aggregations



Step 1 Allow carp to enter the fenced in area. Dashed circle lines are PVC fencing. Blue arrows indicate direction of water flow. Orange arrow indicates fish entering small fenced in area. Yellow circles are paired electrodes from portable EGS. Red circles with blue cross hatch are PIT tag antennas.



Step 2. Close small fenced in area and turn on upstream electrodes to move carp downstream. This is a gradual process that starts at low voltage to ensure all carp move from upstream area, rather than becoming temporarily paralyzed.



Step 3. Turn on downstream electrodes to confine carp to smaller area within fenced area. Tightly aggregating carp enables more removal options (e.g. Archimedes Screw and conveyor belt).

Figure 1. Carp trapped in small fenced in area, built within large fenced area.

Once carp are in a tight aggregation, they are forced into action and are actively seeking a way out. This might make them more likely to enter the Archimedes screw (AS) that raises them above the water level to the height of the whoosh entrance. Rather than build a full scale AS we wanted to start by experimenting with designs in a laboratory setting with smaller fish. After several different models we have now successfully built and tested a mini-AS prototype (Figure 2 & 3). This prototype can be manually or electrically powered to move goldfish and small carp through the AS. Experiments indicate that the ideal speed is > 1 rotation per second which creates enough suction to force fish into screw, without allowing them to swim back out. Multiple tests were successful for goldfish and juvenile carp, with several individuals of both species successfully traversing the screw without any rotation. A large prototype was made from a 55-gallon plastic drum and successfully moved water and carp. However, the materials used to build the large prototype were not identical to those of the mini-AS and could not handle the large amount of water and carp. While it was not an ideal AS, the larger version did show promise. In the future we hope to find help from industry to help us manufacture a larger sturdier AS appropriate for field tests. Overall the AS is promising system and these results suggests carp can be elevated above the water and into the Whooshh transport system.

Alternatively, plans are being made for testing the efficacy of using a partially-submersed conveyer belt to remove the tightly aggerated carp after they are briefly stunned with electricity and collect on the belt surface using water flow. Based on our observations, this approach might show the most promise and might be most scalable for practical and largely automated management applications. Tests of the conveyor system are scheduled for late summer 2019.

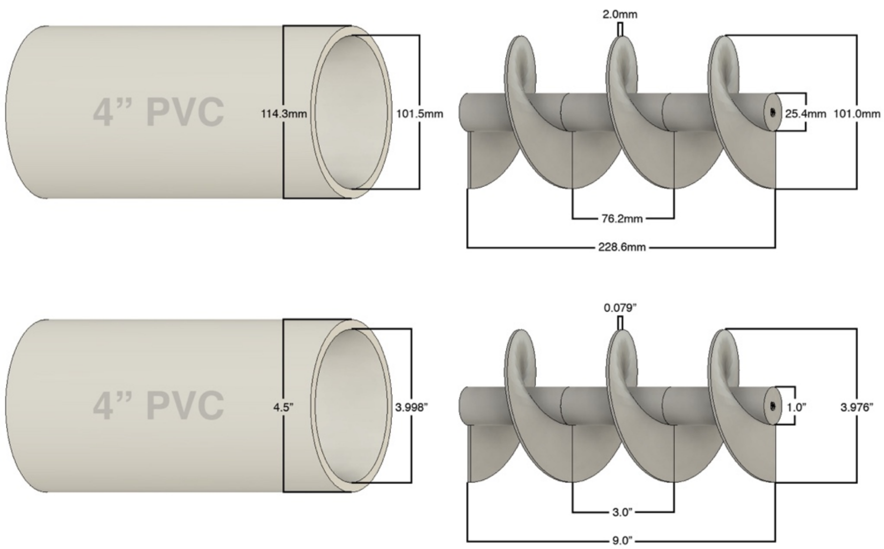


Figure 2. Design layout for mini-Archimedes screw prototype.

Figure 3. 3D printed auger mounted in PVC pipe, with hand crank. Motor powered spinning was achieved by removing hand crank and directly attaching drill to bolt.

Activity 2 Status as of December 31, 2019:

We successfully designed and tested a system for removing migrating carp with minimal human assistance. To develop this system, we used an enclosure built using PVC pipes (described in more detail in out June update). The enclosure was 15' wide and 35' long. At the downstream end of the enclosure, we added a narrow channel (15' long and 30" wide) also made using PVC pipes (Figure 3). Inside the enclosure we placed 22 electrodes arranged in pairs. These electrodes were designed to be turned on in sequence going from upstream to downstream to cause the carp to aggregate in the downstream end of the enclosure and eventually force the carp to aggregate in the narrow channel at the downstream end of the enclosure. At the downstream end of the narrow channel we placed a conveyer (10' long, 30" wide) (Figure 3). The upstream end of the conveyer rested on the bottom of the stream white the downstream part extended above the water surface (Figure 3). In the narrow channel directly upstream of the conveyer we placed 2 additional electrodes. The function of those electrodes was to temporarily paralyze the carp that aggregated right in front of the conveyer. Once paralyzed, the carp drifted with the water current, collected on the surface of conveyer belt and were removed from the water (Figure 3).

Figure 3. Conveyer used to remove carp from the stream.

To test the system, we placed 48 adult carp in the PVC enclosure in late October 2019. Then, we conducted several tests while adjusting the arrangement of electrodes. In the first test, 5 carp were captured and conveyed out of the stream. Two more electrodes were added to better direct the carp towards the conveyer system and in the second run we conveyer 12 carp. Two additional electrodes were added and in the third test we conveyed 34 carp (70% of carp stocked din the enclosure). The test was repeated the following day, when again, 70% of the carp were successfully conveyed. During our tests, conveyed carp were collected in a plastic container. However, the carp could be placed into Whooshh, or secondary conveyer to move them on land. Overall, we believe we developed a system that is ready for a full-scale application in the spring of 2020 to remove large numbers of carp during their spawning migration with minimal human assistance. As funding for this project ends, the full test of the system will be pursued by Rice Creek Watershed District. If successful, the system developed in this project could be used across Minnesota and elsewhere to remove migrating common carp. The system could also be adapted to remove other migrating invasive fish.

Activity 2 Status as of June 30, 2020:

No updates. This activity ended in December 2019.

Final Report Summary:

Our goal from the onset was to develop devices and technologies with commercial applications. Thus, this work focused on developing and testing many prototypes of devices needed to guide and remove the carp, discarding ones that showed little promise or were impractical, and testing further those that showed promise. While our initial intent was to conduct laboratory tests, we were able to switch to field tests, which provided much more realistic results. First, a technology was needed to block migrating carp and direct them into a trap. The portable low-voltage electric systems available commercially was tested for that purpose and shown to be very effective (over 90% carp blocked), easy to deploy and maintain. Then an enclosure had to be designed that was inexpensive, easy to install and durable under high flow conditions. For that purpose, we used PVC pipes inserted into stream bottom through openings in horizontal support beams. While seemingly trivial, this design was quite ingenious as each pipe could be easily adjusted individually to accommodate uneven bottom and scouring. Once these tasks were accomplished, our main challenge was to develop a technology for the carp to swim into the Whooshh system. We tested several designs of floating fish ladders, but none were effective. We also built and tested Archimedes screw in the laboratory, but it also proved ineffective after initial tests. A breakthrough occurred when we decided to use a partially submersed conveyer to remove the carp along with portable electrodes that could be used periodically to crowd the carp over the conveyer and then immobilize them so that they collected on the surface of the conveyer and were then transported out of the stream. This system was successfully tested in the summer 2019 using stocked carp and in spring 2020 using naturally migrating carp. The conveyer can be used to load carp into the Whooshh system, but it can also be used independently to collect the carp from the stream and carry them on land. This technology appears to be ready for commercial applications. Should more funds be available, further tests should focus on perfecting ways to increase the rates with which migrating carp enter the trap (PVC enclosure) and perfecting the system of electrodes inside the trap for aggregating carp over the conveyers.

V. DISSEMINATION:

Description: We anticipate publishing at least 1 peer-reviewed publication on the overall effectiveness of the Whooshh system to remove invasive common carp during their seasonal migrations. We will also present our findings at the national meeting of the American Fisheries Society, at the regional Midwest Fish and Wildlife Meeting, and at the regional AIS meetings. In addition, we will post our findings at the MAISRC website/Facebook account via monthly updates, and at the MAISRC annual showcase. Finally, we will communicate our findings with MAISRC extension to develop educational material for the public.

Status as of December 31, 2017:

- ABC (KSTP – 5) http://kstp.com/news/salmon-cannon-used-minnesota-rid-invasive-carp-species/4602530/

Status as of June 30, 2018:

- Minnesota Board of Soil and Water Resources: https://medium.com/@MnBWSR/the-potential-application-is-huge-3789a37fa190.

- MAISRC: https://www.maisrc.umn.edu/news/carp-guidance

- Bajer et al. 2018. Accepted. Field test of a low-voltage, portable electric barrier to guide invasive common carp into a mock trap during seasonal migrations. Management of Biological Invasions

- Bajer et al. 2018. Field test of a low-voltage, portable electric barrier to guide invasive common carp into a mock trap during seasonal migrations. Minnesota chapter of the American Fisheries Society. St. Cloud MN, February 2018.

Status as of December 31, 2018:

- U of M. “Training Common Carp to Aggregate So They Can Be Removed” by MAISRC & Eve Daniels. November 2018. https://www.youtube.com/watch?v=MSbfa6-y4RE

- MINNPOST. “This Sucks: U of M Researchers Hope to Turn The ‘Salmon Cannon’ Into A Carp Vacuum” October 2018. https://www.minnpost.com/environment/2018/10/this-sucks-u-of-m-researchers-hope-to-turn-the-salmon-cannon-into-a-carp-vacuum/

- Hundt PJ and Bajer PG. Toward a new common carp management tool: Testing species-specific corn-based toxic bait. UMISC - NAISMA Joint Conference, October 2018, Rochester, Minnesota

- Hundt PJ and Bajer PG. New common carp management techniques: Selective toxins and Whooshh. 2018 MAISRC showcase. St. Paul, MN
  PowerPoint available: https://www.maisrc.umn.edu/files/maisrcshowcasesept2018publicpptx

Status as of June 30, 2019:

- KTSP 5 – Twin Cities ABC affiliate. “U of M researchers experiment with 'Carp Cannon' to stop spread of invasive fish” by Kevin Doran. 29 May 2019 https://kstp.com/news/u-of-m-researchers-experiment-with-carp-cannon-to-stop-spread-of-invasive-fish/5370984/

- The New York Times. “Fish Cannons, Koi Herpes and Other Tools to Combat Invasive Carp” by JoAnna Klein. 4 June 2019. https://www.nytimes.com/2019/06/04/science/carp-whooshh-cannon.html

Status as of December 31, 2019:

- Hundt PJ and Bajer PG. New common carp management techniques: Selective toxins and Whooshh. 2019 MAISRC showcase. St. Paul, MN.

Status as of June 30, 2020:

- Bajer PG, Hundt PJ, Kukulski E, Kocian M. 2020. Developing automated systems for removing common carp during spawning migrations. North American Lake Management Society, November 2020, Minneapolis, MN. Abstract submitted.
- Bajer PG, Hundt PJ, Kukulski E, Kocian M. 2020. Developing automated systems for removing common carp during spawning migrations. Management of Biological Invasions. In preparation. To be submitted by September 2020.

Final Report Summary:

To date, one manuscript has been published and another is nearing a submission in peer-reviewed literature; two TV interviews for local stations; three press articles including one in the New York Times; four regional or national conferences; four MAISRC presentations or publications.

VI. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview:

***This section represents an overview of the preliminary budget at the start of the project. It will be reconciled with actual expenditures at the time of the final report.**

Budget Category	$ Amount	Overview Explanation
Personnel:	$ 228,065	34% PI reduced to 25% in the final year, 50% postdoc for 2.5 years, 3 summer techs for 2 years 4 months each year
Professional/Technical/Service Contracts:	$27,000	Equipment rental and installation, MCL lab use, statistical consulting
Equipment/Tools/Supplies:	$34,000	PIT tags, PIT antennas, PIT readers, elements to build entry ways to whoosh system, pumps to simulate current, waders, nets.
Capital Expenditures over $5,000:	$	
Fee Title Acquisition:	$	
Easement Acquisition:	$	
Professional Services for Acquisition:	$	
Printing:	$	
Travel Expenses in MN:	$8,000	Mileage (~4000 miles) to experimental sites x $0.37 mile + truck rental U of M $900/month x 3 months x 2 years
Travel outside MN	$2,000	Attending scientific conferences in USA to present results of this work
Other:	$1,935	Costs of publishing 2 peer reviewed papers
TOTAL ENRTF BUDGET:	**$301,000**	

Explanation of Use of Classified Staff:

Explanation of Capital Expenditures Greater Than $5,000:

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 2.1

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.04

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
	$	$	
State			
Rice Creek Watershed District	$80,000	$0	To pay for rental of Whooshh System
TOTAL OTHER FUNDS:	**$80,000**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:

Partners receiving ENRTF funding

- University of Minnesota: Przemyslaw Bajer – PI, 34% salary and benefits for 2.5 yrs ($95,000) to oversee and conduct experiments, post-doctoral researcher 50% salary and benefits for 2.5 yrs ($ 87,000) to conduct the experiments; 3 undergraduate field technicians ($15/h 4 months x 2 years) to assist in the field during 2 field seasons.
- Whooshh Innovations, LLC – provide Whooshh System or its specific components for field and laboratory trials, $ 105,000 (of which $80,000 will be paid by Rice Creek Watershed District). The statement below was prepared by the Office for Technology Commercializtion at the University of Minnesota and Whooshh Innovations to describe the nature of the relationships between the two:
  "We (University of Minnesota; UMN) see the relationship strictly as a straightforward transaction, where UMN is paying a fee to rent equipment from Whooshh Innovations (WI) during the study period (two years) for the sole purpose of a biological study with carp as described in an agreed study plan. As part of the standard Whooshh lease agreement, Whooshh personnel will do the initial set-up of the Whooshh system on-site, and provide training on the proper operation and maintenance of the Whooshh equipment. The lease agreement will prohibit reverse engineering or modification of the Whooshh equipment. UMN will identify the location for the initial set-up of the Whooshh equipment and UMN will be responsible for take-down and set-up after initial set-up or if the location changes. The lease agreement will clearly describe the major components to be delivered as part of the lease. If Whooshh develops any modification, derivative work or new technology (hereafter "new work") for use with the Whooshh equipment during the study period, Whooshh is under no obligation to provide UMN such new work under the lease agreement. If UMN independently and separately files and obtains a patent on an idea arising out of and within the scope of the study project, (and not by reverse engineering or modifying the Whooshh equipment), UMN could, but is not required, to offer Whooshh an opportunity to become a commercial partner. Whooshh has no automatic rights to such technology developed by UMN."

Partners NOT receiving ENRTF funding

- Rice Creek Watershed District – help with selecting study sites, on-site logistic support, pays for renting the Whooshh System ($80,000)
- Ramsey-Washington Metro Watershed District - help with selecting study sites, on-site logistic support
- Minnehaha Creek Watershed District - help with selecting study sites, on-site logistic support

B. Project Impact and Long-term Strategy:

Innovative ways to remove invasive fish during their spawning migration would enable effective and practical management strategies for common carp and possibly also other invasive fish in Minnesota. Many watershed districts would be trained on how to use and adopt this technology in their specific locales. This project is also of interest to MN DNR and groups involved in efforts to restore native fishes by increasing passage over dams and improving connectivity between bodies of water.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
ENRTF 2015: Common carp management using biocontrol and toxins	7/1/15 – 7/31/17	$413,000
ENRTF 2015: Common carp management using biocontrol and toxins: Phase II	7/1/17 – 7/31/19	$406,000

		$

VIII. REPORTING REQUIREMENTS:

- **The project is for 2.5 years, will begin on 07/01/17, and end on 12/31/19.**
- **Periodic project status update reports will be submitted June 30 and December 31 of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2020**.

IX. VISUAL COMPONENT or MAP(S):

Adapting stream barriers to remove invasive fish during their seasonal migrations

Each spring, up to 90% of common carp migrate from lakes to marshes using small streams

Thousands of common carp below a barrier in Purgatory Creek, MN. These fish migrate each year from the lake in which they overwinter into a shallow marsh 1 mile upstream.

Capturing these fish would accelerate carp management in many locales. Carp's tendency to challenge barriers could be used against them by creating openings in barriers that lead into devices that remove carp.

An existing technology developed to transport salmon over dams could be modified to remove migratory common carp from many barrier sites in MN
Photo: Whooshh Innovations
Videos:
http://www.whooshh.com/fish-passage1.html

We propose two activities:

1. Field: Adapt the existing technology for carp removal in MN
2. Lab: Optimize entry ways into Whoshh System for carp migrating upstream or downstream.

Environment and Natural Resources Trust Fund
Final M.L. 2017 Project Budget
Project Title: Adapting Stream Barriers to Remove Common Carp
Legal Citation: M.L. 2017, Chp. 96, Sec. 2, Subd. 06d, as extended M.L. 2018, Chp. 214, Art. 4, S
Project Manager: Bajer, Przemyslaw
Organization: University of Minnesota/MAISRC
M.L. 2017 ENRTF Appropriation: $ 301,000
Project Length and Completion Date: 3 Years, June 30, 2020
Date of Report: June 30, 2020

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Budget 06/30/2019	Amount Spent
BUDGET ITEM		
Personnel (Wages and Benefits)	$123,000	$123,000
Przemyslaw Bajer, Project Manager: $98,000 (66.5% salary, 33.5% benefits), 34% FTE for 2.5 years		
Postdoctoral researcher to run experiments: $67,000 (66.5% salary, 33.5% benefits), 50% FTE for 2.5 years		
Three undergrad summer technicians to help with experiments for 2 years, 3 months		
Professional/Technical/Service Contracts	$27,000	$26,130
Renting equipment from Whooshh, equipment installation and calibration for 2 field seasons	$25,000	$25,000
Return shipping of Whooshh System	$2,000	$1,130
Statistical consulting U of M	$0	$0
MLCL space; lab tabks rental		
Equipment/Tools/Supplies	$29,000	$29,000
2000 PIT tags, antenna wires, supplies to build entry ways, waders, nets, PIT readers, pumps to simulate current.	$18,000	$18,000
Conveyor system	$11,000	$11,000
Capital Expenditures Over $5,000		
Fee Title Acquisition		
Easement Acquisition		
Professional Services for Acquisition		
Printing		
Travel expenses	$9,000	$8,683
Mileage (~5000 miles) to experimental sites x $0.37 mile + truck rental U of M $900/month x 4 months x 2 years.	$8,000	$7,683
Travel outside MN: attending conferences in USA to present results of this work.	$1,000	$1,000
Other	$1,935	$1,935
Costs of publishing 2 scientific publications	$1,935	$1,935
COLUMN TOTAL	**$189,935**	**$188,748**

Activity 1 Balance	Revised Budget 06/30/2019	Amount Spent	Activity 2 Balance	TOTAL BUDGET
$0	$105,065	$105,065	$0	$228,065
$870	$0	$0	$0	$27,000
$0				$25,000
$0				$2,000
	$0	$0	$0	$0
	$0	$0	$0	$0
$0	$5,000	$5,000	$0	$34,000
$0	$5,000	$5,000	$0	$23,000
$0				$11,000
$317	$1,000	$1,000	$0	$10,000
$317				$8,000
$0	$1,000	$1,000	$0	$2,000
$0				$1,935
$0				$1,935
$1,187	**$111,065**	**$111,065**	**$0**	**$301,000**

TOTAL BALANCE
$0
$870
$0
$0
$0
$0
$0
$0
$0
$317
$317
$0
$0
$0
$1,187