Project Title: Kansas River Bowersock Dam Barrier Feasibility Study

Geographic Location: Kansas River at the Bowersock Dam

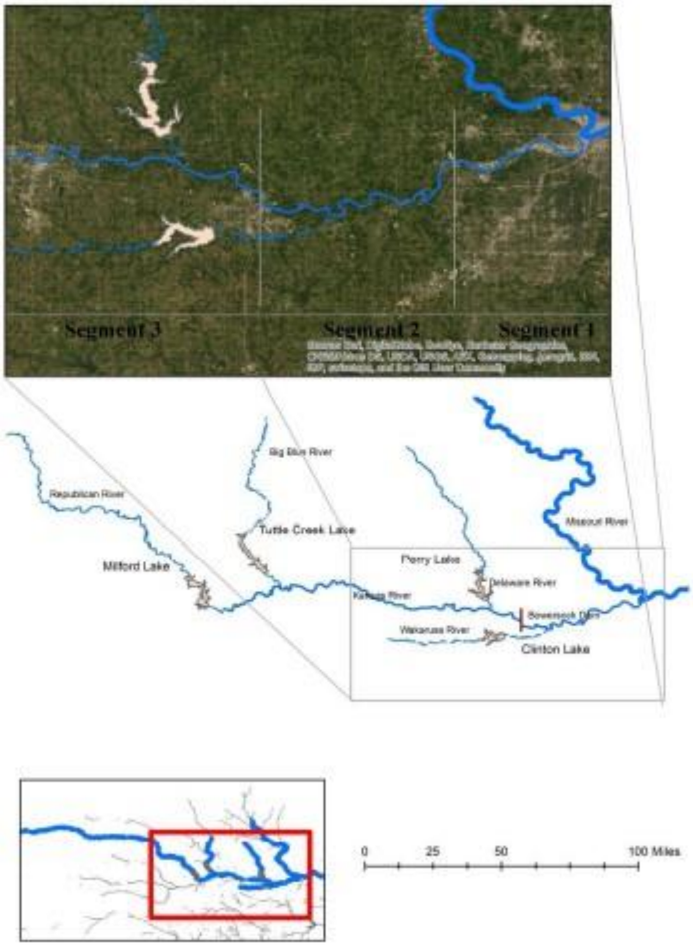

Figure 1: The lower Kansas River, showing the location Bowersock Dam (rkm 83) located in Lawrence, KS.

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Statement of Need:
Introduced invasive carps (bighead carp, black carp, grass carp, and silver carp) have become established in many portions of the Mississippi River basin since the 1970s. Bighead and silver carp were first noted in the Kansas River in 1987 and 1991, respectively (Kansas Fishes Committee 2014). Invasive carp were introduced into waters of the United States as the result of combinations of direct stockings by (or authorized by) various agencies, unauthorized stockings by private individuals, and unintentional escapes from university research facilities, federal and state agency facilities, and private aquaculture operations (Conover et al. 2007). The diets of

bighead and silver carp overlap with some native species (Sampson et al. 2009, Freedman et al. 2012). Bighead and silver carp can consume the majority of available plankton where populations become abundant and alter food webs (Freedman et al. 2012). These (and other) detrimental impacts of invasive carp have the potential to cause ecological, recreational, and economic harm.

The Kansas River drains approximately the north half of the state of Kansas and a portion of south-central Nebraska and flows east to its confluence with the Missouri River at Kansas City. The Bowersock Dam at Lawrence, Kansas serves as a barrier to the upstream movement of invasive carp and other fish except during periods of exceptionally high flows of approximately >120,000 cfs (Sarah Hill-Nelson, Bowersock Power and Mills Company, personal communication). Only six (6) bighead carp have been documented upstream of this barrier (KDWP, unpublished data). These fish likely passed over the Bowersock Dam during extreme flooding in 1993. At that time, the invasive carp population in the Kansas River was very low and the number of fish that migrated upstream over the dam was insufficient to establish a breeding population in the upper portion of the river basin. The Kansas River basin contains multiple flood control reservoirs upstream from the Bowersock Dam that largely mitigate high flow conditions on the mainstem river except for short-lived flooding that occurs immediately after extraordinary rainfall in the unimpounded portion of the basin.

A barrier to upstream movement of fish at Bowersock Dam that functions during high flow events could prevent invasive carp from establishing in the portion of the Kansas River Basin above Bowersock Dam. This section of river represents one of the few large, unimpounded reaches of Midwestern prairie rivers that remains unimpacted by invasive carp and harbors a relatively intact ecosystem of native fishes.

A feasibility study would be used to determine which current barrier technologies would be most practically integrated into this location to prevent upstream spread of invasive carp during high flow events. KDWP contracted with Juniper Environmental and Kansas Alliance of Wetlands and Streams to conduct the feasibility study and produce a report which includes information on potential barrier options as well as approximate costs.

It is worth noting that a unique opportunity currently exists in that the City of Lawrence, Kansas is in the early stages of a multi-million dollar, multi-stage renovation of the dam and surrounding area. If this project is initiated soon, this barrier technology could be more cost effectively implemented by integrating it into the larger renovation project.

This feasibility study is the first step in a project to prevent the further spread of invasive carp in the Kansas River basin, which supports Goals 1 and 3 of the Missouri River Basin Invasive Carp Control Strategy Framework (more specifically strategies 1.3 and 3.2). In addition, the project supports Goal 6 (strategy 6.3) by working with stakeholders to both educate and involve them in potential management activities.

Project Objective:

1. Conduct a feasibility study to determine the options and approximate costs for an invasive carp barrier at Bowersock Dam during high flow events.

Project Highlights:

- The physical characteristics of the Kansas River during times when upstream passage of bigheaded carp is most probable (i.e., high turbidity and fast, turbulent conditions) indicate that an acoustic deterrent deployed on the face of the dam will be the most likely of the current deterrent technologies to successfully prevent passage of these fishes.
- **Pending results of ambient background noise investigations, an acoustic deterrent system built to maintain a sound field in excess of 130 to 140 dB (ref. 1 µPa) in vulnerable areas would likely help deter passage of bigheaded carp into reaches upstream of Bowersock Dam.**

Methods: KDWP contracted with Juniper Environmental and Kansas Alliance of Wetlands and Stream, whom completed the feasibility study in January 2022. Here are the methods from the report:

We reviewed primary literature on current deterrent technologies and their efficacy for deterring a multitude of fish species via Web of Science (Clarivate) and Google Scholar (Google LLC) searches. We then narrowed our review to current literature specifically investigating the efficacy of deterrent systems for altering the behavior of bigheaded carp. This literature included information on physiological and behavioral effects of the deterrent systems on bigheaded carp when exposed to various stimuli. Additionally, this literature provided information on manufacturers that provide the various components for constructing different deterrent systems, and how to orient components of each system to achieve the greatest effect.

We also reviewed literature and informational materials (i.e., agency reports, fact sheets, videos, and presentations) published by various agencies (e.g., U.S. Fish and Wildlife Service, U.S. Geological Survey, U.S. Army Corps of Engineers) on existing and planned deterrent systems such as the Brandon Road Interbasin Project, the Lake Barkley Bio-Acoustic Fish Fence, and the acoustic barrier at Lock and Dam 19 on the Mississippi River. This information helped guide which deterrent technology would work best in the Kansas River at Bowersock Dam, and how to design the most effective system for this location.

In order to evaluate the frequency and duration that a potential deterrent system may need to be operational, we used discharge data from the Kansas River downloaded from the United States Geological Survey (USGS 2021) at a gaging station approximately 325 m downstream of Bowersock Dam (gage 06891080) to estimate discharges that correlate *to water level thresholds at the top of the dam, as well as one, two, and three meters below the top of the dam. We also estimated discharges at those same levels (e.g., -1 m, -2 m, -3 m) from the midbay floor of the powerhouse and from the Obermeyer gate. The elevation of the top of the structures was measured using National Geodetic Vertical Datum (NGVD19), whereas the elevation of the gage station is reported using North American Vertical Datum (NAVD88). Therefore, we used the NGS Coordinate Conversion and Transformation Tool (NCAT; National Geodetic Survey) to determine a correction factor to convert from NGVD19 to NAVD88 in order to relate the elevation at the top of the structures to the elevation of the downstream gage. We then calculated the difference in elevation between the top of the structures and the gage datum and used the rating curve for this gage to estimate discharges at the aforementioned water level thresholds. The Kansas River averages less than 2 feet per mile in gradient. The distance between the gage and Bowersock Dam is 0.2 miles; therefore, we assumed there was no significant difference in water surface elevations between the gage location and Bowersock Dam. We then used our discharge estimates to enumerate the number of days the Kansas River has exceeded those thresholds in the past ten years because gage data was only available at this location since 2012. Comparison of discharge data between the Lawrence gage and the upstream Lecompton gage (gage 6891000) was also used to predict past discharges at Lawrence and estimate the frequency and duration of threshold exceedance over the past 50 years (see Appendix A).*

Results and Discussion:

Overview of Fish Deterrent Systems

Various deterrent systems have been explored to prevent fishes from traversing barriers and passing critical locations similar to Bowersock Dam, including strobe light arrays, bubble curtains, electric barriers, and acoustic arrays (Ross et al. 1996; Taylor et al. 2005; Hamel et al. 2008; Noatch and Suski 2012; Zielinski and Sorensen 2016; Jesus et al. 2019; Dennis et al. 2019). Such non-physical barriers may be desirable where engineered physical structures are not practical due to hydrologic, economic, and ecological constraints (Noatch and Suski 2012; Kim and Mandrak 2017a). All non-physical barriers have advantages and disadvantages depending on conditions at the deployment location, cost and safety considerations, and the level of deterrence that is required. Non-physical barriers can never be expected to be 100 percent effective at preventing fish passage. However, a deterrent system may be able to reduce passage rates sufficiently to prevent establishment of a population of an invasive species above a selected location if the number of fish challenging the deterrent system is low enough and the system efficacy is high.

Strobe lights have been extensively studied for use as behavioral deterrents, particularly for salmonid fishes (Brown 2000). The reported effectiveness of strobe light systems for deterring fishes varies considerably across study systems and target species (Patrick et al. 1985; Johnson et al. 2005; Hamel et al. 2008; Sullivan et al. 2016). Several studies have found that strobe lights produced unsatisfactory results as deterrents of fish movement (McIninch and Horcutt 1987; Johnson et al. 2005; Flammang et al. 2014). Specifically, Ruebush et al. (2012) found the addition of strobe lights to a sound bubble barrier did not increase deterrence efficacy of this barrier for bigheaded carp and other riverine fishes. Strobe light intensity and ambient light levels may have strong influences on the effectiveness of light as a deterrent (Patrick et al. 1985; Johnson et al. 2005), and strobe light efficacy may be considerably reduced by turbidity (McIninch and Hocutt 1987). The Kansas River has high levels of suspended sediment (Thorp and Mantovani 2005), which is likely to limit the practicality of strobe light arrays in this system. Therefore, the use of strobe light systems for deterring passage of bigheaded carp at Bowersock Dam is not advisable.

Bubble curtains use air diffusers placed along the bottom of a channel to create a "fence" or "screen" of bubbles that produce visual, acoustic, and hydrodynamic stimuli. Bubble curtains have been found to be effective for reducing movements of some fishes, including bigheaded carp, both as stand-alone deterrents and as part of combined systems employing acoustic or strobe light deterrents in addition to the bubble curtain (Patrick et al. 1985; Taylor et al. 2005; Ruebush et al. 2012; Zielinski et al. 2014; Zielinski and Sorensen 2015; Zielinski and Sorensen 2016). The deterrent effect of bubble curtains on bigheaded carp is thought to be largely a result of the acoustic fields they generate (Zielinski and Sorensen 2016). Although generally inexpensive to install and maintain (Zielinski and Sorensen 2015), bubble curtains are difficult to install in locations with complex channel cross-sections because of the challenges of maintaining equal air pressure at different depths (Noatch and Suski 2012). Additionally, field applications of bubble curtains have largely been limited to small streams, lock chambers, and other confined areas with limited current. Fast currents and turbulent flows, particularly across a large crosssectional area, are likely to decrease the efficacy of a bubble curtain. Due to the high velocity currents and turbulent conditions in the Kansas River during high water events, particularly in the vicinity of Bowersock Dam, the efficacy of a bubble curtain for deterring passage of bigheaded carp at this location is questionable.

Electric barriers have been widely used to prevent populations of invasive fishes from accessing spawning areas and from further expanding their ranges to new waterbodies (Verill and Berry 1995, Swink 1999, Clarkson 2004). An electric barrier consists of an electric field generated by passing electrical current between two or more electrodes through the water medium. A portion of the electrical energy passing through the water will be transferred to fish encountering the field. Electrical current passing through the body of a fish will cause numerous physiological reactions, eliciting startle responses and avoidance behavior (Katopodis et al. 1994, Johnson et al. 2014, Kim and Mandrak 2017b). Currently, an electric barrier system operates on the Chicago Sanitary and Ship Canal (CSSC) to prevent interbasin passage of fishes between the Great Lakes and Mississippi River drainages (Moy et al. 2011). This barrier system has been subjected to several evaluations to determine its efficacy at preventing fish passage (e.g., Dettmers et al. 2005, Sparks et al. 2010, Parker et al. 2015, Parker et al. 2016, Davis et al. 2017) and has been expanded and undergone operational modifications to enhance its potential for inhibiting the upstream movement of fish (Holliman 2011, Parker et al. 2015). Although highly effective at deterring fish passage, electric barriers are extremely expensive to install, operate, and maintain, particularly across channels with large cross-sections and in waters with high conductivity. The scale of the area that would need to be electrified at Bowersock Dam to prevent passage of bigheaded carp would require an extremely large barrier system that would be cost prohibitive.

Acoustic deterrent systems have been used by fisheries managers to guide or disrupt fish movement behaviors (Nostch and Suski 2012). All fish are capable of detecting sound stimuli, although mechanisms of hearing and the range of detectable frequencies varies considerably across taxa (Popper et al. 2003; Popper and Fay 2011; Popper and Hawkins 2018). Many fish species are known to exhibit negative phonotaxis to certain frequencies, amplitudes, or patterns of sound in water (Putland and Mensinger 2019). This phenomenon has prompted considerable research on the potential use of acoustic deterrents to prevent native fishes from entering water intakes, pumping stations, and hydroelectric turbines (Ross et al. 1996; Maes et al. 2004; Jesus et al. 2019), as well as for blocking movements of invasive species (Taylor et al. 2005; Vetter et al. 2015; Murchy et al. 2017; Vetter et al. 2017). Bigheaded carps, as with all ostariophysan fishes, possess a Weberian ossicle apparatus that connects the swim bladder to the inner ear, allowing them to perceive a wider bandwidth of auditory stimuli at lower amplitudes than many other groups of fishes (Popper et al. 2003; Popper and Fay 2011). As such, recent investigations into the efficacy of acoustic deterrent systems for modifying behavior of bigheaded carp have shown considerable promise (e.g., Table 1). The lower cost of acoustic systems, relative to electrical barriers, combined with these systems' ability to be deployed in turbid, turbulent rivers make an acoustic deterrent system the best choice of the current available technologies to deter bigheaded carp from attempting to traverse Bowersock Dam.

Acoustic Deterrent Systems for Bigheaded Carp

The effectiveness of acoustic deterrent systems for bigheaded carp has largely been assessed in laboratory settings, with few field trials (Table 1). In general, laboratory and raceway trials have indicated that passage of bigheaded carp can be substantially reduced with the application of various acoustic stimuli, and that bigheaded carp can be repelled away from a sound source projected at sufficient amplitudes across frequency ranges that bigheaded carp are known to detect (Taylor et al. 2005; Murchy et al. 2017; Vetter et al. 2018; Dennis et al. 2019; Nissen et al. 2019). Bigheaded carps appear to be able to detect frequencies between 100Hz and 5 kHz, with a low-end threshold at approximately 500 Hz (Lovell et al. 2006; Vetter et al. 2018; Nissen et al. 2019).

Several types of acoustic stimuli have been assessed for their ability to alter behavior of bigheaded carp, including broadband sounds and pure tones. Complex sounds (e.g., random cyclic bursts, recording of an operating boat motor) have been reported to elicit more consecutive responses to the stimuli than pure tones (Table 1) as well as greater swimming speeds away from the sound source, although the specific attributes of these sounds that contribute to the negative phonotaxis response are uncertain.

Habituation, where the response of an organism to a stimulus diminishes over time or with repeated exposure, is a significant concern when employing any deterrent system. Consecutive responses to broadband sound stimuli indicate bigheaded carp do not habituate to this type of sound as easily as they do to pure tones (Vetter et al. 2015; Vetter et al. 2017). However, prolonged exposure to broadband sound can potentially cause auditory temporary threshold shifts in bigheaded carp at frequencies from 200 to 2,000 Hz with some recovery periods exceeding 96 hours (Nissen et al. 2019). Shifts in auditory temporary thresholds could influence the efficacy of deterrent systems, especially in applications where constant exposure is necessary to prevent movement. Thus, short durations or randomized intervals of broadband sound exposure may be necessary to prevent habituation to broadcasted sound stimuli and maintain the deterrent's effectiveness.

Available Acoustic Deterrent Technologies

An acoustic deterrent system will need to be comprised of several components including the speakers, amplifier, power cord and cables, an audio playback device, and a switch box, with the most critical component being the speakers. Speakers made by Lubell Labs, Inc. (Columbus, OH) were consistently used throughout the literature pertaining to acoustic deterrents for bigheaded carp (e.g., Vetter et al. 2015, Murchy et al. 2017; Vetter et al. 2017; Zielinski and Sorensen 2017; Nissen et al. 2019; Wamboldt et all. 2019). Additionally, Lubell Labs offers a wide variety of products with varying specifications (Table 2). Acoustic deterrent systems coupled with bubble curtains (e.g., SPA driven BAFF) designed by Fish Guidance Systems, Ltd. (United Kingdom), have also been used in laboratory and field applications (e.g., Pegg and Chick 2004; Taylor et al. 2005; Ruebush et al. 2012, Dennis et al. 2019), and the SPA system from this company may also be available independent of the BAFF.

Lubell Labs model UW-30 is the smallest speaker reported in the literature and was primarily used in laboratory settings. This speaker also has the lowest maximum power output at 155 decibels (dB) at a frequency of 150 Hz. Recreonics (Louisville, KY) model 92-711 and Electro-Voice (Burnsville, MN) model UW30 were similar in size and had the same frequency response as the Lubell Labs UW-30, but additional output data were not available. Sound projected from the Lubell Labs UW-30 has been found to attenuate quickly, dropping to levels below 140 dB re 1 uPa at two meters away from the speaker (Vetter et al. 2015; Vetter et al. 2017). Lubell Labs model LL916(C & H) and LL964 (LL964 has higher impedance than the LL916) are larger than the UW-30 model, with a maximum power output of 180 dB at 1,000 Hz. During a field study, projected sound from these speaker models was reduced by a mean percent reduction of 53.5% at frequencies between 400 and 1,500 Hz, 7.5 meters downstream from the speaker. At frequencies above 1,500 Hz, mean percent reduction was 23% 7.5 meters downstream from the speaker (Wamboldt et al. 2019). Lubell Labs model LL-1424HP is the largest underwater speaker manufactured by this company and has a maximum output of 197 dB at a frequency of 600 Hz. We have not been able to find any studies using this speaker for data on sound attenuation. All speaker systems have a list of recommended accessories from the manufacturer that can be selected once the appropriate speaker is determined.

Site specific data on background acoustics, as well as the effective sound field, need to be determined to assess the effectiveness of an acoustic deterrent system. Researchers have used various hydrophones and associated data analysis software packages to analyze speaker output and map sound attenuation. Vetter et al. (2015; 2017) used a hydrophone made by High Tech Inc. (Long Beach, MS; model HTI-96- MIN) with the PowerLab recording hardware and LabChart 7 analysis software (AD Instruments, Colorado Springs, CO). Wamboldt et al. (2019) used the SoundTrap 300 STD by Ocean Instruments (Warkworth, NZ) and processed data with

MATLAB R2017B software (MathWorks Inc., Natick, MA). Sound detection equipment will need to be acquired in order to evaluate the ambient acoustic environment downstream of Bowersock Dam prior to establishing operational settings for an acoustic deterrent system.

Considerations for Appropriate Acoustic Deterrent System for Bowersock Dam

The scale of the acoustic deterrent system that will be necessary to prevent passage of invasive carps at Bowersock Dam depends on the ambient flow and acoustic environment present at and below the dam during high flow events. During flood stage when this barrier is most vulnerable to passage, water velocities may be too high for carp to swim upstream across the portion of the dam south of the powerhouse, creating a water velocity barrier in this area. Data on water velocities at varying discharges at Bowersock Dam are unavailable at this time, however, water velocities can be estimated using the equation:

$$V = 8\,H^{0.5}$$

Where V is the estimated water velocity and H is the gross head (i.e., the difference between the headwater and tailwater elevations) (Dr. Bruce McEnroe, University of Kansas, personal communication). The estimated water velocity at a discharge of 100,000 cubic feet per second (cfs) is approximately 7.6 m/s (Table 3), whereas the reported maximum estimated burst swimming speeds (i.e., 30 seconds sustained swimming) for bigheaded carp are approximately 2.57 m/s (Hoover et al. 2017). Parsons et al. (2016) estimated burst swimming speeds in excess of 8 m/s, however, these high speeds are accommodated in models built by Hoover et al. (2017) for time-to-fatigue (i.e., amount of time a fish can maintain a position in flowing water) of less than one second, suggesting bigheaded carp cannot maintain these speeds for long enough durations to circumnavigate the dam. These data indicate a water velocity barrier may be present over much of the dam, including the chute on the south side of the powerhouse, during high discharge events. Therefore, the acoustic deterrent system may only have to be configured to cover the portion of the river directly below the powerhouse.

The ambient background decibel levels produced by the torrent of water overtopping the dam during high flow conditions may challenge the ability of an acoustic deterrent system to produce a sound field sufficient to deter invasive carps across some portion of the river channel. Ambient background noise levels at varying discharges are unknown in this location. Estimates of ambient background sound levels are also unavailable because of the multitude of variables influencing sound levels at this location. Data to assess these conditions will be vital for determining an appropriate acoustic deterrent design, establishing appropriate speaker outputs, and fine-tuning the acoustic deterrent system for various flow conditions. The necessary acoustic data for making such determinations can be gathered using equipment outlined above, and we strongly recommend such assessments be conducted in order to maximize the effectiveness of a deterrent system at Bowersock Dam.

COST ESTIMATES

Given the uncertainties regarding ambient flow and acoustic conditions during high flow events, cost estimates for two scenarios for the deterrent system have been compiled that encompass the full range of potential system scales that may be required to ensure adequate deterrence: Scenario 1 is a system spanning the entire width of the dam and Scenario 2 concentrates deterrence on the area directly downstream of the north powerhouse and adjacent Obermeyer gate (Table 4; Table 5; Figure 2). Scenario 1 provides deterrence in the event that current velocities are found to be insufficient to prevent carp passage across multiple sections or a majority of the dam and background acoustics will allow for an effective sound deterrent across the majority of the channel.

Scenario 1 will cover a span of 246m with 123 speakers installed along the dam front every two meters. In order to supply power to the speakers, a custom-built amplifier and transformer will be needed. These components will deliver power through two, 8 2- or 3- gauge bus cables running the entire length of the dam. Individual speakers will be tied into the bus cable with standard speaker wiring. Although the custom-built amplifier and transformer will create additional costs, this negates the need for large diameter conduits being installed to run approximately 64 individual speaker wires from the amplifiers to the speakers (Table 4).

Scenario 2 would provide deterrence only in the vicinity of the north powerhouse in the event that current velocities are found to be sufficient to prevent carp passage across the majority of the dam width. This scenario would concentrate deterrence at the known low-velocity area near the north bank where bigheaded carp are known to congregate (Figure 3), as well as for the Obermeyer gate if water velocity measurements at the gate deem this spot vulnerable. Scenario 2 will cover a span of approximately 49m with 24 speakers installed on the powerhouse providing coverage for the powerhouse, with two speakers placed on the south side to cover the adjacent chute. This system will be made up of three smaller systems: eight speakers wired in tandem with two resistors and a single amplifier. This system will not require any custom-built equipment and can use standard sound equipment available from most retailers (Table 5).

Table 1: List of studies, species, setting, and sound parameters (frequencies, decibels, complex or single tone, and fish response) detailed in the primary literature investigating acoustic deterrent systems and their effects on bigheaded carp.

Study	Study Setting	Species	Sound Parameters			Fish Response
			Frequency (Hz)	Decibels (dB ref. 1uPa)	Tone	
Murchy et al. 2017	Laboratory	Silver Carp, Bighead Carp	60 – 10,000	~ 146 – 155	Broadband	90.5% decrease in successful crossings.
Dennis et al. 2019*	Laboratory	Silver Carp, Bighead Carp	20 – 10,000	~ 90 – 160	Broadband	76 ± 29% blockage efficiency.
Dennis et al. 2019*	Laboratory	Silver Carp, Bighead Carp	20 – 2,000	~ 100 – 160	Proprietary	78 ± 27% blockage efficiency.
Taylor et al. 2005†	Laboratory	Bighead Carp	20 – 2,000	N/A	Cyclic	95% of crossing attempts repelled.
Ruebush 2011†	Field	Silver Carp, Bighead Carp	500 – 2,000	N/A	N/A	> 99% of bigheaded carp were blocked.
Wamboldt et al. 2019	Field	Silver Carp, Bighead Carp	20 – 5,000	150 – 155	Broadband	No significant reduction in crossing.
Vetter et al. 2015*	Pond	Silver Carp	0 – 10,000	~ 150	Broadband	Elicited response on average of 11 consecutive exposures.
Vetter et al. 2015*	Pond	Silver Carp	500 – 2,000	~150	Pure	Failed reaction at > 88% of exposures.
Vetter et al. 2017*	Pond	Bighead Carp	600 – 10,000	~155	Broadband	Elicited a median of 20 consecutive exposures.
Vetter et al. 2017*	Pond	Bighead Cap	500 – 2,000	~155	Pure	Failed reaction at 47% of exposures.

* Results from the same study assessing efficacy of multiple tones.

† Results from a study using a SPA driven BAFF or similar acoustic and air bubble system.

Table 2: List of speaker systems and specifications used in various studies or identified from web searches or conversations with biologists, engineers, and/or manufacturers. Lubell Labs prices are discounted for dealers.

Company	Model	Dimension	Operating Depth (ft.)	Frequency Response (Hz)	Price per Unit
Lubell Labs	UW-30	7.2" Diameter	4 – 10	10 – 10,000	$ 309
Lubell Labs	LL916(C & H)	11" x 11" x 7.8"	4 – 60	200 – 23,000	$ 1,245
Lubell Labs	9484	N/A	4 – 6	100 – 23,000	$ 1,464
Lubell Labs	LL964	11" x 11" x 7.8"	6 – 50	200 – 20,000	$ 1,404
Lubell Labs	LL-1424HP	16.5" x 16.5" x 16.5"	6 – 40	200 – 9,000	$ 6,242
Recreonics	92-711	7.16" Diameter	N/A	10 – 10,000	$ 871
Electro-Voice	UW30	7.2" Diameter	4 – 10	10 – 10,000	$ 323

Table 3: Estimated water velocities at Bowersock Dam for differing discharges using the equation $V = 8 H^{0.5}$. Head height data gathered from USGS gauge 06891080.

River discharge (m^3/s)	Velocity (m/s)
28.3	12.5
56.6	12.2
113.3	11.9
169.9	11.6
566.3	10.1
2831.7	7.6

Table 4: Rough cost estimates for an acoustic deterrent system at Bowersock Dam for scenario 1 that would provide coverage across the entire east face of the dam.

Scenario 1 Estimate (810 foot span across the entire structure)				
	Unit	Quantity	Cost per Unit	Total
Speakers	Speaker	123	$1,404.00	**$172,692.00**
Amplifiers	Amplifier	1	$5,000.00	**$5,000.00**
Transformer	Transformer	1	$1,500.00	**$1,500.00**
Anchor Bolts	Box of 25	20	$225.27	**$4,505.40**
Housing	Single Unit	123	$100.00	**$12,300.00**
Wiring Harness	Harness w/ Pigtails	123	$200.00	**$24,600.00**
Wiring	Bus Cable	1,000 ft.	$3/ft.	**$3,000.00**
	Speaker (Spool)	2	$400.00	**$800.00**
Access Improvement	Gravel and Grading	1	$3,000.00	**$3,000.00**
Connection to Local Power	System Power	1	$3,200.00	**$3,200.00**
Install Labor	Hour for Crew of Two	441	$560.00	**$246,960.00**
			Sub Total	$477,557.40
	Project Management and Administration			$27,600.00
			EXTENDED TOTAL	**$505,157.40**

Table 5: Rough cost estimates for an acoustic deterrent system at Bowersock Dam for scenario 2 that would provide coverage to the east face of the powerhouse and the chute to the south of the powerhouse.

Scenario 2 Estimate (160 foot span below north powerhouse)				
	Unit	Quantity	Cost per Unit	Total
Speakers	Speaker	25	$1,404.00	$35,100.00
Amplifiers	Amplifier	4	$500.00	$2,000.00
Transformer	Transformer	7	$300.00	$2,100.00
Anchor Bolts	Box of 25	4	$225.27	$1,802.16
Housing	Single Unit	25	$100.00	$2,500.00
Wiring Harness	Harness w/ Pigtails	25	$200.00	$5,000.00
Wiring	Bus Cable	NA	NA	NA
	Speaker (Spool)	2	$400.00	$800.00
Access Improvement	Gravel and Grading	1	$3,000.00	$3,000.00
Connection to Local Power	System Power	1	$3,200.00	$3,200.00
Install Labor	Hour for Crew of Two	115	$560.00	$64,400.00
			Sub Total	$119,902.16
	Project Management and Administration			$12,660.00
			EXTENDED TOTAL	$132,562.16

Figure 2: Satellite imagery of Bowersock Dam. Orange lines represent (A) the width of the entire dam and the extent for the acoustic deterrent system described in scenario 1, and (B) the width of the powerhouse (solid line) and Obermeyer gate (dotted line) and the extent of the acoustic deterrent system described in scenario 2. Images were captured using Google Earth®.

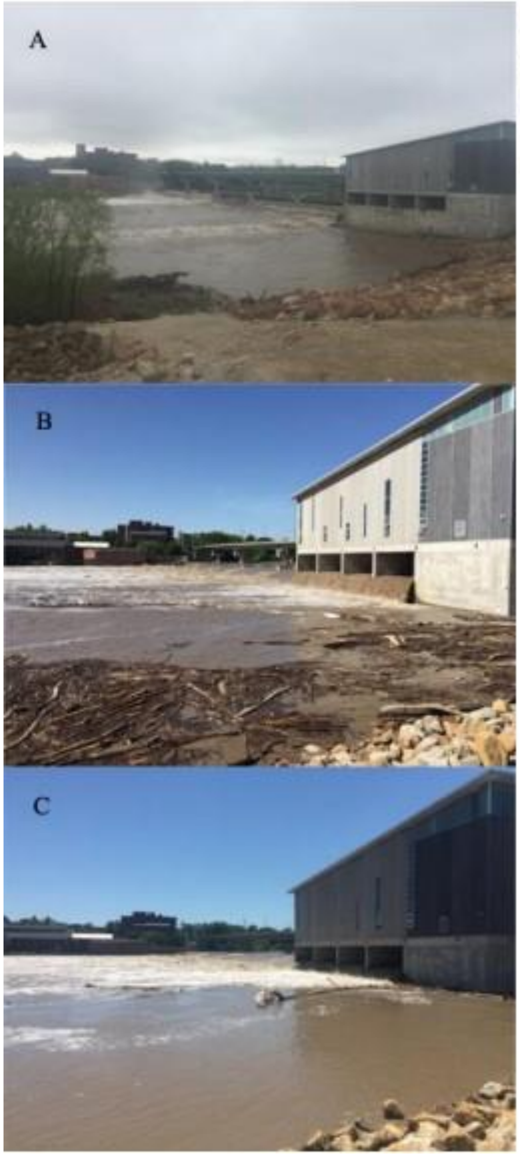

Figure 3: Water levels at Bowersock Dam during discharge events in the summer of 2019. Pictures show discharges of (A) ~15,000 cubic feet per second (cfs), (B) ~ 70,000 cfs and (C) ~ 98,000 cfs.

(*Photo Credit:* Jake Werner)

Recommendations:
Data on water velocities and ambient background sound at river levels that may be conducive for bigheaded carp to traverse Bowersock Dam will be vital when finalizing designs for a deterrent system at this barrier. Water velocity data should be gathered along the top of the concrete structure as well as inside the midbay to the powerhouse and at the Obermeyer gate to assess if water velocities at these locations will prove to be too strong for bigheaded carp to navigate. Results of water velocity assessments will also provide insight as to which section or sections of the dam are vulnerable to passage by bigheaded carp and guide locations where ambient background noise data should be collected. Once vulnerable areas are identified, ambient background noise should be mapped within six meters of the face of the dam because leaping capabilities of bigheaded carp have been estimated to have a maximum height of 1.87m to 2.24m and cover a horizontal distance of 2.81m to 5.82m (Parsons et al. 2016).

The report recommends spacing the speakers approximately two meters apart along the face of the dam in both scenarios 1 and 2 to maintain a cohesive sound field with maximum sound levels as sound has been found to attenuate quickly from maximum output levels in laboratory and field trials (e.g., Vetter et al. 2015; Vetter et al. 2017; Wamboldt et al. 2019). Zielinski and Sorensen (2017) documented that bigheaded carp avoided areas with sound levels in excess of 130 – 140 dB (ref. 1 μPa), therefore, maintaining the largest possible sound field in excess of these levels will be critical in deterring carp, and speaker distance may need fine adjustments to achieve these levels.

In order to deter passage over the top of the concrete dam or the bottom of the powerhouse midbay, the speakers should be placed approximately 3.5m below either of these structures to ensure the speakers will be submersed when river levels reach heights that are vulnerable to passage of bigheaded carp (e.g., maximum estimated leaping capabilities 2.24m [Parsons et al. 2016]). The speakers should be turned on once water levels reach 0.5m above the speakers, or 3 meters below the top of each structure. At the top of the dam, this correlates to a discharge of approximately 24,762 cfs (Figure 4), which has been exceeded for a total of 207 out of 3,365 days of record (average of 20.7 days/year; Figure 5; Table 7). However, the speakers could also be placed higher on the dam to introduce sound higher in the water column to provide deterrence for more extreme discharge events. For example, the speakers could be placed 2.5m below the top of the dam and turned-on once water levels reach 2m below the top the dam, which correlates to a discharge of approximately 37,329 cfs (Figure 4) that has been exceeded for a total of 77 out of 3,365 days of record (average of 7.7 days/year; Figure 5; Table 7). Water levels that reach 3 m below the midbay floor correlate with a discharge of 57,466 cfs (Table 8; Figure 6), which has been exceeded for a total of 12 days out of 3,365 days of record (average of 1.2 days/year). Speakers placed at 2.5m below the midbay floor would be turned on once water levels reach 2m below this level, which correlates to discharges of 79,052 cfs and has been exceeded for a total of 2 days out of 3,365 days of record (average of 0.2 days/year). Additionally, sound should be initiated for short durations or randomized intervals to prevent habituation to the broadcasted sound stimuli and maintain the deterrent’s effectiveness and should use complex broadband sound (Table 1).

The Obermeyer gate is submerged at flows of approximately 54,841 cfs (0.7 m below the top of the dam; Table 7), which has been exceeded for a total of 15 days out of 3,365 days of record. Our models indicate that water velocities will exceed the swimming speed capabilities of bigheaded carp during these flows, but the design does include 2 speakers on the south face of the powerhouse to provide additional deterrent for the Obermeyer chute. However, these speakers projected sound will likely not provide sufficient coverage over the entirety of the chute (approximately 7.3 m), and the geometry and construction of the chute will likely prove difficult to effectively attach speakers to in order to maintain a cohesive sound barrier. If river velocity measurements taken in this area prove to be less then bigheaded carps swimming speed capabilities during flood stages, an electric barrier at the top of the chute may be a viable deterrent option, but would require additional assessment and design evaluation in order to implement.

The report recommends using speakers manufactured by Lubell Labs, Inc. Specifically, model LL964 because this particular model can produce sound levels up to 177 dB/μPa/m at 1,000 Hz, which is within bigheaded carps' hearing range (Lovell et al. 2006; Vetter et al. 2018; Nissen et al. 2019). Although the speaker model LL-1424HP can achieve higher output levels (e.g., 197 177 dB/μPa/m at 600 Hz) than the LL964, it is much larger than the LL964 making it more vulnerable to damage from debris in the river. Additionally, the LL-1424HP is over four times more expensive than the LL964 (Table 2) and may be cost prohibitive. The LL964 also has a higher impedance than the LL916, meaning this model can operate with longer cable lengths with minimal insertion loss using standard OS cable. These speakers can be tested out of the water periodically to ensure the systems is still working, but at a reduced drive (10 Vrms), and have an operating temperature of 0°C - 41°C. Lubell Labs Inc. also offers a five-year warranty on their products, although they tend to hold up well in applications by researchers in the artic (Brian Lubell, Lubell Labs Inc., personal communication), suggesting they are highly durable under exposure to freeze/thaw cycles.

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