AN ESTIMATION OF SURVIVAL AND INJURY OF FISH PASSED THROUGH THE HYDRO GREEN ENERGY HYDROKINETIC SYSTEM, AND A CHARACTERIZATION OF FISH ENTRAINMENT POTENTIAL AT THE MISSISSIPPI LOCK AND DAM NO. 2 HYDROELECTRIC PROJECT (P-4306) HASTINGS, MINNESOTA

FINAL REPORT

Normandeau Associates Project No. 21288.000

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December 2009

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EXECUTIVE SUMMARY

On April 24, 2008, and supplemented on April 30, September 26, November 7, and November 13, 2008, the City of Hastings, Minnesota (City), licensee for the 4.4-megawatt (MW) Mississippi Lock and Dam No. 2 Hydroelectric Project (FERC No. 4306), filed an application with the Federal Energy Regulatory Commission (Commission or FERC) to amend its license to install two 35-killowatt (kW) HGE hydrokinetic turbines (operating capacity) in the project's tailrace. The Commission granted an order amending the license on December 13, 2008 and authorized the installation of the first hydrokinetic turbine in U.S. history on December 23, 2008.

Article 65 of the FERC order (125 FERC ¶ 61,287) required the licensee to develop a Fish Entrainment and Survival Monitoring Plan (Plan). This Plan was filed with FERC and accepted by FERC on April 29, 2009. In accordance with the Plan, a Fish Survival and Injury Study was completed on June 13, 2009 to provide estimates of fish survival and injury (item #1 in Article 65) and to estimate predation (item #2 in Article 65).

The survival and injury of fish passed through the HGE hydrokinetic turbine was directly assessed using the HI-Z Turb'N tag (i.e., HI-Z tag) direct recapture technique. The turbine was tested while the conventional hydropower units were at maximum discharge. Procedures for handling, tagging, release, and recapture of the test fish were identical for treatment (passed through the turbine) and control groups (passed downstream of the turbine). All fish releases occurred between 5 and 11 June 2009. The following results were recorded:

- The recapture rate (physical retrieval of fish) was 98% each for the treatment groups of yellow perch and bluegill. The recapture rates for the control groups of yellow perch and bluegill were 96% and 100%, respectively. The recapture rate for the treatment group of adult channel catfish was 99% and 100% for the controls. The recapture rates for the smallmouth buffalo and bigmouth buffalo were 100% for both the treatment and controls.
- The 1 h direct relative survival estimates for the yellow perch and bluegill were 0.990 (SE=0.027) and 0.990 (SE=0.010), respectively. The 48 h calculated relative survival estimates for both of these species were 1.00 after adjusting for control mortalities. However, our protocols censor the 1 h relative survival value when control group survival is less than treatment group survival between 1 h and 48 h, therefore the more conservative rate of 0.990 was established for the yellow perch and bluegill.
- The 1 h survival estimate for channel catfish was 0.990 (SE=0.010) and the 48 h survival estimate, after adjusting for control group survival, was 1.00. The 1 h rate of 0.990 was again established as the 48 h survival rate for the channel catfish. The 1 h survival estimates for smallmouth buffalo and bigmouth buffalo were both 1.00. The 1 h survival estimate for both species combined was also 1.00. The 48 h survival estimates for smallmouth and bigmouth buffalo were 0.981 (SE=0.019) and 1.00, respectively. The combined 48 h survival estimate for both species was 0.990 (SE=0.010).

- The desired precision for the survival estimates of ≤±5%, 90% of the time was met for all species released through the HGE hydrokinetic turbine.
- Of the 196 small-sized treatment fish examined, none had turbine blade passage related maladies (visible injury, descaling > 20% per side, or loss of equilibrium). One yellow perch exhibited a visible injury, likely resulting from entanglement in the chain driven mechanism that transfers energy from the HGE hydrokinetic turbine. This fish may not have been injured if the inflated HI-Z tags were not on it. Two hundred one large-sized treatment fish were examined and none of the large-sized fish exhibited any passage related maladies.
- No predation was observed directly or indirectly (e.g., via interpretation of movements of radio tags on fish).
- Entrainment of fish previously entrained through the conventional Kaplan turbine units, or of fish residing in the Project tailrace is estimated to be low. Mortality to entrained fish, based on the empirical survival results are estimated to be between 193 and 636 fish per year from Pool 2 (i.e., from those previously entrained through the conventional Kaplan turbines). Utilizing the available data from Barnes and Williams (1991), it is estimated that with respect to game fishes entrained from Pool 2, 4 – 12 white bass, 1 – 5 channel catfish, and 0 – 2 largemouth bass per year would be killed by the HGE hydrokinetic units.

CONCLUSIONS

Based on the results of this evaluation, the HGE hydrokinetic unit has little if any considerable impact on the fish populations in the vicinity of the Mississippi Lock and Dam No. 2 Hydroelectric Project. The following are more detailed conclusions from this evaluation of fish entrainment, injury, and survival through the HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project.

Survival and Injury

1) The empirical study assumptions were valid and the precision of the survival estimates was within the pre-specified level of $\leq \pm$5% at $1 - \alpha = 0.90$, thus the results are reliable.
2) Survival estimates for small fish (115-235 mm TL) and large fish (388-710 mm TL) through the HGE hydrokinetic turbine (after 48 h) were 99%.
3) No turbine blade passage injuries were observed.
4) Fish that contact the HGE hydrokinetic turbine and barge apparatus (e.g., such as after entrainment through the conventional powerhouse), should not experience lethal injuries. Measured water velocities around the HGE hydrokinetic turbine (5.67 ft/sec to 9.68 ft/sec) are well below the laboratory study value of 20 ft/sec that is capable of causing injury/mortality to fish contacting hard objects.
5) The HGE hydrokinetic turbine design appears to eliminate the potential for fish to be injured in gaps at the turbine blade tip or hub. Additionally, the design and deployment of the tested HGE hydrokinetic turbine cannot inflict any pressure related

injuries on passed fish because there is no operational head and no opportunities for entrained fish to experience sudden lethal pressure changes.

6) The HGE hydrokinetic turbine has a low number of runner blades (three) and a relatively large runner diameter (144 in), both are characteristics of low impact turbines (Franke *et al*. 1997).

Predation

7) Predation was not a factor at the HGE hydrokinetic turbine site during this study even though ambient river temperature and size of test specimens were within the range where predation has been observed at other locations. Predation activity was not directly observed, or indirectly assumed to occur (based on behavior patterns of tagged fish), throughout the study. Many of the factors that reduce a fish's ability to avoid predators (e.g., stress, loss of equilibrium) are reduced or eliminated in the HGE hydrokinetic turbine. The hydrokinetic unit does not expose fish to pressure changes, severe turbulence, shear stress, or cavitation, and therefore should not affect a fish's ability to naturally avoid predators.

Entrainment

8) The HGE hydrokinetic turbine installation will be limited to two units, side by side in the tailrace at the Mississippi Lock and Dam No. 2 Hydroelectric Project. Given the results of this evaluation, there is no reason to believe that that second unit will pose any significant risk to the fish in the vicinity of Mississippi Lock & Dam No. 2.

9) The species composition and size of fish originating in the Project tailrace and passing through the HGE hydrokinetic turbine is not known; however, because survival was at or near 100% and there was no indication that fish were injured upon passing the turbine blades, the HGE hydrokinetic turbine should have little if any affect on entrained fish.

1.0 INTRODUCTION

1.1 LICENSING BACKGROUND

On April 24, 2008, and supplemented on April 30, September 26, November 7, and November 13, 2008, the City of Hastings, Minnesota (City), licensee for the 4.4-megawatt (MW) Mississippi Lock and Dam No. 2 Hydroelectric Project (Figure 1-1) (FERC No. 4306), filed an application with the Federal Energy Regulatory Commission (Commission or FERC) to amend its license to install two 35-killowatt (kW) HGE hydrokinetic turbines (operating capacity) in the project's tailrace (Figure 1-2). During the license amendment process, Hydro Green Energy consulted with the pertinent agencies to describe the technology and the proposal to install and use it, answer questions that the agencies had, as well as to gain an understanding of the concerns of each agency. As part of the process, the Commission Staff completed an Environmental Assessment (FERC 2008 [http://elibrary.ferc.gov/idmws/File_list.asp?document_id=13650653]). The Commission granted an order amending the license on December 13, 2008 and authorized the installation of the first hydrokinetic turbine in U.S. history on December 23, 2008.

Article 65 of the FERC order (125 FERC ¶ 61,287) required the licensee to develop a Fish Entrainment and Survival Monitoring Plan (Plan). The Plan, developed in accordance with Condition No. 3 of the State Water Quality Certificate, was accepted by FERC on April 29, 2009. In accordance with the Plan, a Fish Survival and Injury Study was completed on June 13, 2009 to:

1. provide estimates of fish survival and injury (item #1 in Article 65), and
2. to estimate predation (item #2 in Article 65).

A desk top evaluation of entrainment was also required by the FERC order (item #3 in Article 65). In fulfillment of the requirements of Article 65, this report provides results of the fish passage survival and injury aspect and provides a desktop characterization of the potential for fish entrainment based on estimated population variability in the tailrace of the Mississippi Lock and Dam No. 2 Hydroelectric Project and the impact of any such entrainment.

1.2 INTRODUCTION TO HYDROKINETICS

Hydrokinetic power refers to the generation of power from the flow, current, or velocity of water. Hydro Green Energy's hydrokinetic power system generates electricity exclusively from moving water (river currents, tidal currents, and ocean currents) without having to first construct dams, impoundments, or conduits. The HGE hydrokinetic turbine (Figure 1-3) is the industry's first surface-suspended, asymmetrically-ducted, horizontal axis turbine. Hydro Green Energy's technologies are covered by U.S. patent # 6955049, four international patents, and the company has dozens of U.S. and International Patents pending on the Company's core technologies. The turbine's three blades spin at 21 RPM, making the device the slowest spinning hydrokinetic turbine in the industry. The unit's rotor is 12 feet in diameter. The HGE hydrokinetic turbine holds a nameplate capacity of 100 kW at 3.5 m/s. The overall dimensions, including barge and support structure, for the unit is approximately 24 ft long x 15 ft wide x 15 ft deep. Hydro Green Energy's project in Hastings, Minnesota is the first FERC licensed and commercially operational hydrokinetic power station in U.S. history.

1.3 SITE DESCRIPTION

The United States Army Corps of Engineers' (USACE) Mississippi Lock & Dam No. 2 is located on the Mississippi River (rm 815.2) near the City of Hastings in Dakota County, Minnesota (Figure 1-1). Mississippi Lock and Dam No. 2 was built in 1930. The eastern dam portion is 722 feet (220 m) wide and has 19 tainter gates. There is also a wide earthen dam on the western side of the facility.

The conventional hydroelectric station at this site produces about 4.4 MW and is licensed by the City of Hastings, Minnesota, while the 110 × 600 ft (34 × 183 m) lock is operated by the USACE St. Paul District. The conventional hydropower project includes two Kaplan bulb turbines. The turbine intakes are guarded by trash racks with 3 ¾ inch clear rack spacing. The conventional project operates as run of river with a capacity factor of approximately 80%.

The City and Hydro Green Energy will operate the zero-head, in-stream hydrokinetic power equipment, which is located in the tailrace of the City's project (Figure 1-2), to generate additional electricity within the existing project footprint (incremental hydropower upgrade/cogeneration model for hydropower).

The tailrace of the conventional hydro project consists of rip rap to approximately 280 feet (85.3 m) downstream of the draft tubes (approximately the end of the skirt wall). Since project construction, the City and the USACE have maintained a scour protection area in the tailrace, consisting of 30-inch minimum rock fill layer topped with 42-inch rip rap. The City and the USACE periodically replace rip rap, as needed. The width of the tailrace is approximately 70 ft (21.3 m) and tailwater depth ranges from about 20 ft (6.1 m) at minimum tailwater elevation to almost 30 ft (9.1 m). Tailwater depth is generally lowest in summer and winter and higher in spring and fall.

The City's project is required to maintain a continuous minimum flow of 1,700 cfs, or the inflow of the reservoir, whichever is less. The hydraulic capacity of the conventional hydro turbines is 5,400 cfs (2,700 cfs from each of the two Kaplan bulb turbines). The remaining river flow over 5,400 cfs is passed primarily through spill gates, with some flow used to operate the locks. The percent of monthly average river flow passing through the conventional turbines ranges from 16 to 90 percent; however, the actual flow through the turbines depends on water year type (wet or dry), turbine maintenance schedule, flood control operations, and low head conditions at the dam.

The USACE records river flow at Lock and Dam No. 2. The average annual river flow at the site from 1987 to 2004 was 14, 818 cfs. Monthly average flows for the period of record at Lock and Dam No. 2 are shown in Table 1-1. It is only the flow velocity exiting from the City's project that is available to the HGE hydrokinetic turbine array for generation.

2.0 OBJECTIVES

The objectives of this study were to:

- estimate the survival/injury of fish passing through the hydrokinetic unit;
- estimate predation; and,
- characterize entrainment potential.

To meet the first two objectives, HI-Z Turb'N tagged (i.e., HI-Z tag, balloon tag) fish were inducted through the hydrokinetic unit (treatment group) and their survival and injury rates were estimated relative to a control group that was released into the tailrace immediately downstream of the hydrokinetic unit (Heisey *et al*. 1992). A desktop analysis of entrainment potential was conducted to address the third objective.

3.0 STUDY DESIGN

3.1 APPROACH

The HI-Z tag methodology was used to mark, recapture, and evaluate the direct effects of passage (including the potential for predation) of five species and two size classes of fish through the hydrokinetic unit. This methodology uses a controlled experimental approach. Control group fish experience all aspects of the methodology (e.g., handling, tagging, recapture, holding in tanks) that treatment group fish do, except that the treatment fish are passed through the hydrokinetic unit thus providing isolation of the experimental techniques. An additional utility of using control groups is that estimated survival (and injury) can be adjusted (within reason), based on any effects due to the experimental procedures, thus resulting in a relative estimate of survival.

Fish were tagged with two or more HI-Z tags (Figure 3-1). HI-Z tags were attached in the deflated condition. After passage through the hydrokinetic unit, the HI-Z tags inflated and buoyed the fish to the surface where they were recaptured by a boat crew. In addition to the balloon tags, a miniature radio tag also was attached to the fish to aid in the recapture. The radio tag allowed boat crews to locate the tagged fish and typically be nearby the location where the fish rise to the surface for recapture, minimizing their time at large. Finally, uniquely numbered Visual Implant tags (VI tags) (Northwest Marine Technology, Inc., Shaw Island, Washington) or Floy tags (Floy Tag, Inc., Seattle, Washington) were inserted into the fish during the tagging procedure. This allowed for the identification of individual fish or treatment/control groups.

Approximately 10 small fish were released individually and in succession directly upstream of the turbine and then recaptured just downstream. Approximately two large fish were released and recaptured in a similar manner. Upon recapture of the fish in the tailrace, the HI-Z and radio tags were quickly removed and the fish were transported to onshore holding tanks for latent mortality evaluation (48 hrs). Because each fish is uniquely identifiable by their VI or Floy tag, treatment and control groups were held in the same tank environment for the 48 hr holding period. After the holding period, or when a fish died, thorough examinations for injuries were conducted and a photographic record made of those fish with injuries.

The results of the empirical study were used in conjunction with existing information to characterize the entrainment potential and to estimate the overall impact of the HGE hydrokinetic system.

3.2 SAMPLE SIZE

One of the main considerations in the study design was to release an adequate number of fish such that the resulting survival estimates would be within a pre-specified precision (ε) level. The sample size to estimate survival and injury is a function of the recapture rate (PA), expected passage survival (τ) or injury, survival or injury of control fish (S), and the desired precision (ε) at a given probability of significance (α). Sample size requirements decrease with an increase in survival and recapture rates and decrease in injury rates (Heisey *et al*. 1992; Mathur *et al*. 1996). The reliability criteria for estimates of survival and injury included results within a level of precision $\leq \pm$ 5%, 90% of the time, or $1 - \alpha = 0.90$. The *a priori* sample size estimates were based on the following assumptions:

- Control group survival of 98%;
- Treatment (hydrokinetic unit) passage survival of 95% for small-sized fish and 90% for large-sized fish; and
- Treatment recapture rate of 99%.

Based on these assumptions, the *a priori* sample size was approximately 650 fish to meet the statistical precision desired by Hydro Green Energy. This included approximately 160 fish of each species/size class used in the analysis. The actual number of fish used in the field can vary if any of the three values in the above assumptions made to estimate the sample size vary.

3.3 SOURCE AND MAINTENANCE OF TEST FISH

The fish species and approximate sizes originally chosen for this study included:

- Smaller species
    - Bullhead *spp*. (*Ameiurus sp.*) (150 – 200 mm)
    - Yellow perch (*Perca flavescens*) (150 – 200 mm) or largemouth bass (*Micropterus salmoides*) (100 – 150 mm)
- Larger species
    - Freshwater buffalo sp. (*Ictiobus niger and I. bubalus*) (200 - 560 mm)
    - Flathead (*Pylodictis olivaris*) or channel catfish (*Ictalurus punctatus*) (380 – 610 mm)

Due to a requirement of the Minnesota Department of Natural Resources (DNR) collection permit that all cultured fish have Viral Hemorrhagic Septicemia (VHS) certification, certifiable bluegill (*Lepomis macrochirus*) were substituted for uncertified bullhead. Therefore, the species and actual sizes used in the study (Figures 3-2, 3-3, and 3-4) included (fish lengths measured as total length):

- Smaller species
  - Yellow perch (118-235 mm)
  - Bluegill (115-208 mm)
- Larger species
  - Channel catfish (451-627 mm)
  - Freshwater buffalo spp.
    - Bigmouth buffalo (388-482 mm)
    - Smallmouth buffalo (415-710 mm)

An aerated tank truck was used to transport the bluegill and yellow perch from a fish culture facility near Waconia, MN to a boat launch approximately 1 mile downstream of the Project. From there, fish were transferred into portable holding facilities and transported by boat to the site.

The larger species were provided by a commercial fisherman who used gillnets and seines to capture the buffalo and catfish within 40 miles of the Project. These species were held in an aerated tank and transported to site in a similar manner as described above.

At the site, fish were transferred into large circular holding pools, which were continuously supplied with ambient river water and covered to prevent escapement and to minimize exposure to external stimuli (Figure 3-5). Fish were held a minimum of 24 h prior to tagging to reduce the stress response due to handling and transport. Water temperature within these pools was recorded daily.

The treatment and control fish for a given day were randomly drawn from the same holding tank (i.e., same 'population') and thus unbiased.

3.4 TAGGING AND RELEASE OF FISH

3.4.1 Small Fish (yellow perch and bluegill)

Approximately 170 fish of each species (yellow perch one day, bluegill the following day) were removed from the holding tanks using a water sanctuary net, placed into a holding tank adjacent to the tagging site, and held for approximately 24 h prior to tagging. Fish were anesthetized (<5 min), measured to nearest mm, and HI-Z tags were attached via a stainless steel pin inserted through the musculature beneath the dorsal fin and another near the caudal peduncle. A radio tag was attached in combination with the dorsal HI-Z tag (Heisey *et al*. 1992, Figure 3-1). A uniquely numbered VI tag also was inserted in the opercle tissue for use in tracking 48 h survival of individual recaptured fish. Fish also received a fin clip to designate release group (specific treatment or control) in the event the VI tag became dislodged. HI-Z tagged fish were placed in a covered 5 gal container and continually supplied with ambient water until fully recovered from anesthesia (minimum 20 min). Once fully recovered, fish were individually placed into an induction system, the HI-Z tags were activated, and the fish were released. HI-Z tags began inflating approximately 2 - 3 minutes after the fish were released.

All treatment and control groups of the smaller fish were released through an induction apparatus (Figure 3-6) that consisted of a small holding basin attached to a 4 in diameter flexible hose. This induction apparatus was identical to that used in other investigations. The release hose was continuously supplied with water to ensure fish were transported quickly to the desired release point. The discharge end of the treatment release hose was secured in front of the turbine, centered, and approximately 4 ft beneath water's surface. The treatment hose was positioned to direct fish towards the outer area of the turbine blades where chances for injury would be highest (Figure 1-3 and 3-6). For control group releases, the hose was repositioned to release fish in the hydrokinetic unit's tailrace, approximately 4 ft beneath the surface. The flexible hose was held in place with rope attached to the barge.

3.4.2 Large fish (buffalo spp. and catfish)

Approximately 170 fish of each species (catfish over two days, buffalo over two days) were removed from the holding tanks using a rubber meshed net, and placed into a holding tank adjacent to the tagging site and held for approximately 24 h prior to tagging. Fish were anesthetized (<5 min), measured to nearest mm, and HI-Z tags were attached via a cable tie threaded into a canula needle inserted through the musculature beneath the dorsal, pectoral, and pelvic fins and/or near the caudal peduncle. A radio tag was attached in combination with the dorsal HI-Z tag (Figures 3-7 and 3-8). A uniquely numbered Floy tag was inserted in the musculature below the dorsal fin for use in tracking 48 h survival of individual recaptured fish. HI-Z tagged fish were placed in a cooler that was continually supplied with ambient water until recovered from anesthesia (minimum 10 min). Once recovered, fish were individually placed into a larger induction system, tags were activated, and the fish released. Some of the larger more active fish were temporarily placed into a restraining tube to facilitate HI-Z tag activation (Figures 3-8 and 3-9; Heisey *et al*. 2008). HI-Z tags began inflating approximately two to three minutes after the fish were released.

Procedures for handling, tagging, release, and recapture of fish were identical for treatment and control groups. All fish releases occurred between 5 and 11 June 2009 (Table 3-1). Hydraulic conditions were stable during the study (Table 3-2). Pool 2 (forebay) elevations ranged between 687.0 and 687.2 ft mean sea level (msl) and tailwater elevation ranged between 675.4 and 675.5 ft msl. The two conventional hydropower turbines operated consistently and continuously (Table 3-2) during the study.

3.5 FISH RECAPTURE

After passing through the hydrokinetic unit, most fish were quickly located visually when they were buoyed by the balloon tags to the tailrace surface. Fish that were not located visually were monitored by the radio frequency. Boat crews were notified of the radio frequency of each fish upon its release. To minimize the potential for crew bias, no crew was specifically assigned to retrieve either control or treatment fish. The radio signal transmission enabled the boat crew(s) to follow the movement of each fish after passage and position the boats downstream for retrieval when the HI-Z tag(s) buoyed the fish to the surface. Fish that failed to surface and had active radio signals were tracked for a minimum of 30 min and then periodically thereafter to determine whether the fish appeared to be alive or preyed upon (moving signal) or whether the tag became detached (stationary signal).

Recaptured fish were placed into an on-board holding facility and HI-Z and radio tags were removed using a specially designed pin puller (for small fish) (Heisey *et al*. 1992), or with side cutters (for large fish) used to cut the cable ties. Each fish was immediately examined for maladies consisting of injuries, de-scaling (>20% per side), and loss of equilibrium, and assigned appropriate condition codes (see Classification of Recaptured Fish section and Table 3-3). Tagging and data recording personnel were notified via a two-way radio system of each fish's recapture time and condition. Appendix Tables A-1 and A-2 provide the daily tag recapture and 48 h survival/malady free data for each species. Appendix B provides the incidence of maladies, including injuries for each species. Appendices C-1 through C-6 provide the 1 h and 48 h survival statistical outputs for each species. Appendix D provides data on disposition of individual fish.

Each recaptured fish with a visible injury or scale loss was assigned a likely causal mechanism. Controlled laboratory experiments (Neitzel *et al*. 2000; PNNL *et al*. 2001) to replicate and correlate injury type and characteristic to a specific causative mechanism provides some indication of the cause of observed injuries in the field. However, some injury symptoms can be manifested by two different sources, which may lessen the probability of accurate delineation of a cause and effect relationship in the field (Eicher Associates 1987).

All fish recaptured alive were transferred from the recapture boats to an onshore circular holding pool for the 48h delayed assessment period (Figure 3-5). All fish released during a given testing day were held in the same holding pools for monitoring. Each pool was continuously supplied with ambient water and shielded to prevent potential fish escapement and/or avian predation.

3.6 CLASSIFICATION OF RECAPTURED FISH

As in previous investigations, the immediate post passage status of recaptured fish and recovery of inflated HI-Z tags dislodged from fish were classified as *alive, dead, subject to predation, inflated tag(s) only*, or *unknown*. The following criteria have been established to make these designations:

(1) *alive* – recaptured alive and remained alive for 1h;

(2) *alive* – when the fish does not surface but radio signals indicate movement patterns typical of swimming fish;

(3) *dead* - recaptured dead or dead within 1h of release;

(4) *dead* – when only inflated tag(s) without fish are recovered and telemetric tracking or manner in which inflated balloons surfaced are not indicative of predation (see number 6);

(5) *unknown* – when nothing is recaptured or radio signals are received only briefly and the subsequent status cannot be ascertained; and

(6) *predation* – when fish are either actually observed being preyed upon, predator is buoyed to the surface, or subsequent radio telemetric tracking and/or tag indicates

predation (i.e., rapid movements of tagged fish in and out of turbulent waters or sudden appearance of fully inflated tags).

Fish recaptured dead or those that die within 1 h following recapture were designated as 1 h post-passage mortality. Fish that die between 1 h and 48 h after passage were designated as 48 h post-passage mortality. All fish that died following release were necropsied to assess the probable cause of death. Additionally, all fish alive at 48 h were closely examined for injury. Injury and de-scaling was categorized by type, extent, and area of body. The re-examination of fish after 48 h minimizes additional handling stress that would occur with thorough examination immediately upon recapture and permit detection of injuries that may be overlooked when initially recaptured. Following examination and recovery from anesthesia, all live fish were returned to the river, as per the MNDNR permitting requirements.

3.7 DATA COLLECTION AND ANALYSES

Prior to tagging, the total length of each fish was measured to the nearest millimeter, and each fish was examined for any existing marks or injuries. The condition of each fish upon recapture and the amount of time between release and recapture was recorded.

Similar to previous HI-Z tag studies, a likelihood ratio test was used to estimate whether recapture probabilities were similar for live (P_A) and dead (P_D) fish (Mathur *et al*. 1996). This statistic tests the null hypothesis of the simplified/reduced model ($Ho{:}P_A=P_D$) versus the alternative of the generalized/full model ($Ho{:}P_A \neq P_D$). Depending upon the outcome of the analysis, the parameters and their associated standard errors were calculated using the appropriate model.

The 90% confidence interval on the estimated survival was calculated using the profile likelihood method (Hudson 1971) or by multiplying the standard error by 1.645. When applicable the profile method constructs confidence intervals without assuming normality for passage survival and is generally assumed superior to the normal approximations.

3.8 PREDATION

During the course of the study the field crew specifically monitored for predation activity. Predation can be either directly observed or indirectly assumed by the ‘behavior’ exhibited by the radio tagged test fish. Such behavior might include alternating locations between flow eddies and the tailrace main current, typical of predators such as a smallmouth bass that stage in slower velocity areas and dart into the current to capture prey. Behavior atypical of test fish and/or typical of a predator is classified as predation. This classification is used when fish are either visually observed being preyed upon, the predator is buoyed to the surface, or subsequent radio telemetric tracking and/or tag dislodgement indicate predation (i.e., rapid movements of tagged fish in and out of turbulent waters or sudden appearance of fully detached and inflated tags). Post-passage predation does not necessarily indicate mortality, as not all fish that are attacked by a predator die. Additionally, reported predation rates can be over-estimated, due to the HI-Z tags effect on the fish’s natural predatory avoidance response.

4.0 RESULTS

4.1 SURVIVAL AND INJURY

4.1.1 Recapture Rates

The recapture rate (physical retrieval of alive and dead fish) was 98% for the treatment groups of yellow perch and bluegill (Table 4-1). The recapture rates for the control groups of yellow perch and bluegill were 96% and 100%, respectively. Only two treatment group yellow perch were dead upon recapture. One was likely injured in the chain driven mechanism on the hydrokinetic unit and the other exhibited no obvious visible injuries. All of the treatment group bluegill were recaptured alive. All recaptured control group fish were alive.

The recapture rate for the adult channel catfish was 99% (Table 4-2). All control group channel catfish were recaptured. The recapture rates for the smallmouth buffalo and bigmouth buffalo were 100% (Table 4-3). All fish were alive upon recapture.

4.1.2 Retrieval Times

The average retrieval times for the treatment groups of the smaller fish species ranged between 1 and 221 minutes. The control groups of the smaller fish were retrieved within 1 and 47 minutes (Figure 4-1, Table 4-4). The large fish treatment groups were retrieved within 2 and 30 minutes, whereas the controls were retrieved within 2 and 9 minutes (Figure 4-2, Figure 4-3, Table 4-4).

4.1.3 Survival Estimates

The 1 h direct relative survival estimates for the small-sized fish, yellow perch and bluegill, were 0.990 (SE=0.027) and 0.990 (SE=0.010), respectively (Table 4-5). The 48 h calculated relative survival estimate for each of these species was 1.00 after adjusting for control mortalities. However, our protocols censor the 1 h relative survival value when control group survival is less than treatment group survival between 1 h and 48 h, therefore the more conservative rate of 0.990 was established for the yellow perch and bluegill.

For the large-sized fish, the 1 h survival estimate for channel catfish was 0.990 (SE=0.010) and the 48 h survival estimate, after adjusting for control survival, was 1.00 (Table 4-5). The 1 h rate of 0.990 was again established as the 48 h survival rate for the channel catfish. Survival estimates (1 h) for smallmouth buffalo and bigmouth buffalo were both 1.00 (Table 4-5). The 1 h survival estimate for both species combined was also 1.00. The 48 h survival estimate for smallmouth and bigmouth buffalo were 0.981 (SE=0.019) and 1.00, respectively. The combined 48 h survival estimate for both species was 0.990 (SE=0.010).

The desired precision for the survival estimates of ≤±5%, 90% of the time was met for all species released through the HGE hydrokinetic turbine (Table 4-5).

4.1.4 Injury/Malady Types and Causes

Since a very high percentage of the HGE hydrokinetic turbine passed fish were physically recaptured, all but four of the 196 (2.0%) small-sized and one of the 201 (0.5%) large-sized treatment fish were examined for visible injuries, loss of equilibrium, and scale loss. Of the total 196 small-sized treatment fish examined, none had turbine blade passage related maladies (Table 4-6). One yellow perch exhibited a visible injury, likely resulting from entanglement in the chain driven mechanism that transfers energy from the HGE hydrokinetic turbine. It is possible that the inflated HI-Z tags carried the fish into the chain drive, and therefore may not have been injured if not tagged. Two hundred one large-sized treatment fish were examined and none of the large-sized fish exhibited any passage related maladies (Tables 4-7 and 4-8).

4.1.5 Additional Data Collection

Flow velocities were recorded by a Swoffer model 2100 flow meter at 1 m and 2 m depth (from barge) in front of the HGE hydrokinetic turbine and also directly downstream of the turbine. Several readings were taken near the center and a few feet on either side due to the variable nature of the flow. The instantaneous velocities through the turbine ranged from 5.67 ft/sec to 9.68 ft/sec.

4.1.6 Predation

Predation was not evident or observed for the five species tested during this investigation. The ambient river temperatures observed during the study were approximately 62 to 69° F, temperatures that are normally conducive to predator activity.

4.2 ENTRAINMENT POTENTIAL

Fish that could be entrained through the HGE hydrokinetic turbines would be from two sources: fish passed through the conventional hydro turbines that then continue through an HGE hydrokinetic turbine, and fish residing in the powerhouse tailrace that move upstream of and then pass through an HGE hydrokinetic turbine.

Barnes and Williams (1991) conducted an entrainment monitoring program at the City of Hastings's conventional hydro project from June 1990 through April 1991. Fixed aspect hydroacoustics, supported by net sampling immediately upstream of the turbine intakes provided an indication of species composition by month and estimates of daily and monthly entrainment. Eleven species were identified at the City's project (Table 4-9). Mean daily entrainment numbers ranged from 57 fish in February to 1,266 in October. October far exceeded other months in the estimated number of fish entrained, the next highest was June with a mean estimate of 906 fish. The total estimated number of entrained fish for the sampling program was 112,443. The average daily entrainment rate was reported as 389 fish.

The other three primary factors that influence the impact the HGE hydrokinetic unit could have on the fish populations are the proportion of time the HGE hydrokinetic unit(s) operates, the amount of powerhouse flow that passes through the HGE hydrokinetic unit(s), and fish passage survival. The conventional hydro turbines have a capacity factor of approximately 80%. When the conventional turbines are not operating the HGE hydrokinetic unit(s) cannot operate, therefore the same 80% factor applies as a maximum for the hydrokinetic units. The HGE hydrokinetic units (with two installed) have minimum and maximum volumetric flows of 900 cfs and 3,000 cfs, respectively (City of Hastings 2008), or 17 – 56% of the conventional powerhouse discharge of 5,400 cfs. For this evaluation it is assumed that the ratio of the number of fish to a volume of water is 1:1 so that the number of fish entering the HGE hydrokinetic turbines is 17 - 56% of the number entrained through the City's conventional hydro turbines. The current HGE hydrokinetic turbine passage survival study found that 99% of fish of both test sizes (small = 115-235 mm TL, large = 388-710 mm TL) survived passage through the turbine after 48 h and showed no turbine related injuries.

Using these sources of information, a range in the annual entrainment impact to fish entrained from Pool 2 ascribed to the HGE hydrokinetic turbines (with two HGE hydrokinetic units installed) is:

- Low: (389 fish/day) x (365 days) x (0.8 capacity factor) x (0.17 proportion of flow) x (0.01 mortality) = 193 dead fish per year.

- High: (389 fish/day) x (0.8 capacity factor) x (0.56 proportion of flow) x (0.01 mortality) = 636 dead fish per year.

To date only one hydrokinetic turbine has been installed. If that remains the case, the estimated impact would be 50% of the numbers above, or 97 and 318 dead fish as the range extremes.

The Barnes and Williams (1991) list of species and number per species collected was used to calculate the relative abundance of fish entrained and the resulting mortality through the HGE hydrokinetic turbines was estimated for the scenarios of 17% and 56% of flow out of the conventional hydro units and passed through the HGE hydrokinetic unit(s) (Table 4-10). Based on these calculations, with respect to game fishes entrained from Pool 2, 4 – 12 white bass, 1 – 5 channel catfish, and 0 – 2 largemouth bass per year would be killed by the HGE hydrokinetic units.

Fish considered resident for this evaluation are those reported by Ickes *et al*. (2005) and collected as part of the Long Term Resource Monitoring Program (LTRMP) conducted by the USGS for the upper Mississippi River System. All sampling sites for the LTRMP are downstream of the City's project. The closest site, Pool 4, is 18.2 river miles downstream of the City's project which flows into Pool 3. In Pool 4, 86 species were collected from 1993 to 2002 and ranged from 58 in 2002 to 74 in 1994 and averaged 68 species per year (Ickes *et al*. 2005). Emerald shiner was numerically the most abundant fish collected and accounted for 74% of the total catch. Gizzard shad, bluegill, spotfin shiner, common carp, mimic shiner, white bass, black crappie, bullhead minnow, and freshwater drum were numerically the next most abundant fishes, accounting for 93% of the total catch. Emerald shiner, gizzard shad, and bluegill were also the most abundant fish collected in the combined study area that encompassed 768 river miles from Pool 4 to open water at river mile 29, and a 78 river mile stretch of the Illinois River. This assessment assumes species composition and numbers are similar between Pools 3 and 4.

Emerald shiner, spotfin shiner, mimic shiner, and bullhead minnow represent 80% of the numerical collection of fish from Pool 4. These are small highly fecund fish that are preyed upon by larger piscivorous fish collected in the Pool such as white bass, larger bluegill, and black crappie. These smaller species are more likely to be entrained in the HGE hydrokinetic turbines as a result of their prevalence in the fish community. Generally, these species have small home ranges so the individuals exposed to the turbines will be those in the immediate area and the tailrace.

Of the larger species that make up the remainder of the 93% of fish species caught most often in Pool 4 the common carp, the largest of these six species, is probably the least likely to encounter the turbines. Common carp prefer slow or standing water and soft, vegetative sediments, and feed primarily on vegetation and benthic organisms. The water at the HGE hydrokinetic turbine is fast moving and turbulent while the riverbed is covered with rip rap boulders. Gizzard shad and bluegill tend to avoid fast moving water. White bass and freshwater drum are probably more likely to encounter the HGE hydrokinetic turbines, particularly when chasing prey. The mortality rate for both small and large fish passing the HGE hydrokinetic turbines was found to be 1%. While the proportion of fish populations in Pools 2 and 3 that visit the small hydropower project forebay and tailrace (and thus may have some exposure to the HGE hydrokinetic units) is unknown, it is estimated to be less than 25%. This suggests a mortality rate of 0.25% for both prey species and larger species. Due largely to the very high survival of fish across the range of sizes tested, and in part to the small area occupied by the HGE hydrokinetic unit in the context of Mississippi River Pools 2 and 3, it is likely that the impact to populations in these pools is negligible.

5.0 PRINCIPAL FINDINGS AND DISCUSSION

The objectives of the study were met:

- The direct survival (including predation) and injury for small-sized (yellow perch and bluegill) and large-sized (channel catfish, smallmouth buffalo, and bigmouth buffalo) fish passed through the HGE hydrokinetic turbine were estimated within specific reliability criteria. The precision (ε) on survival estimates of the small and large-sized fish was within the desired criteria of ±0.05, 90% of the time. A combination of high recapture and control survival rates (both >95%) allowed the use of a relatively small number of fish without sacrificing precision.
- Predation was not observed on either control or treatment fish.
- Existing information along with results of the survival/injury empirical study provided for an estimate of impact to fish that may be entrained through the HGE hydrokinetic units.

There was no incidence of turbine blade inflicted injuries. The injury to one specimen was likely caused by the external chain drive mechanism and may have been due to the effect of the tags on the fish.

Laboratory studies suggest that water velocities above 58 ft/sec are capable of inflicting injury/mortality on fish when discharged into a water surface without hard objects (Neitzel *et al*. 2000). Fish may begin to suffer lethal injuries if discharged onto hard objects at velocities ≥20 ft/sec (Bell *et al*. 1972). The fish have the possibility of contacting the HGE hydrokinetic turbine (barge included), but based on the measured water velocities around the HGE hydrokinetic turbine (5.67 ft/sec to 9.68 ft/sec), the fish should not experience lethal injuries. These values are well below the laboratory studies value of 20 ft/sec, which is capable of causing injury/mortality to fish contacting hard objects.

Passage survival estimates can be considered valid with fulfillment of some underlying assumptions. The following assumptions, primarily related to the tag-recapture process, were fulfilled: handling, tagging, and release procedures did not differentially affect the survival rates of control and treatment groups; recapture crews did not differentially retrieve either group of fish; and both the treatment and control groups were exposed to the tailrace conditions for similar times. Although insertion of the tag, induction, and tag removal requires fish handling and may result in injury or mortality, these processes had minimal cumulative effects over the 48 h delayed assessment period. Only 10 of 198 (5.0%) control fish (all species combined) died while in the delayed assessment pools.

The tags (HI-Z and radio), especially upon inflation, may affect the mobility of fish, particularly smaller specimens, and may possibly increase the risk of injury and predation. One fish was injured and based on visual inspection, appeared to have been caught in the chain drive of the HGE hydrokinetic turbine. However, these factors did not appear to affect the study results. None of the control fish were preyed upon or injured during the study. The external tags should not lessen the chance of potential injury of HGE hydrokinetic turbine passed fish. In effect, the tag may actually increase the risk of injury since the fish (primarily smaller specimens) are less mobile. Because the tags are neutrally buoyant until inflated, the tagged fish should also have the same opportunity as untagged native fish to be exposed to mechanical, shear, and turbulent forces during turbine passage. The tags do not affect the entrainment of test fish because they are induced near the turbine at a point where they can not escape passage.

A potential source of bias due to selective retrieval of treatment and control groups was minimized by not assigning a specific boat recovery crew to recapture either a treatment or control group of fish. Whichever crew was available for fish recapture was assigned the task of individual fish retrieval. Recapture crews were trained in fish handling and retrieved the buoyed fish without inflicting additional external damage. With some minor exceptions, the average recapture times for the treatment and control groups were similar and ranged from 3.4 to 7.2 minutes.

The primary risks associated with turbine passage are direct contact with rotating runner blades or other structural components, passage through hub or blade tip gaps, rapid change in water pressure relative to fish acclimation pressure history, and hydraulic shear forces or cavitation. These risks, however, are not universally applicable to all species and their life stages or at all turbines. Mechanically-related injuries are primarily a function of the number of runner blades and fish size relative to turbine runner diameter size (Franke *et al*. 1997). The studied HGE hydrokinetic turbine has a low number of runner blades (three) and a relatively large runner diameter (144 in); both are characteristics of low impact turbines (Franke *et al*. 1997).

The HGE hydrokinetic turbine design also appears to eliminate the potential for fish to be injured in gaps at the turbine blade tip or hub. Additionally, the design and deployment of the tested HGE hydrokinetic turbine cannot inflict any pressure related injuries on passed fish because there is no operational head and no opportunities for entrained fish to experience sudden lethal pressure changes.

A literature review (including EPRI 1992, 1996; Franke *et al*. 1997) indicates that scant information exists on survival rates of fish larger than 300 mm in passage through relatively large Kaplan type turbines. Since this is the first hydrokinetic turbine tested, comparable survival and injury data from other hydrokinetic turbines do not exist to provide a perspective on the results obtained during this investigation. However, a perspective on the effect of the tested turbine may be gleaned when compared with the few direct survival estimates reported on adult fish passing large propeller type turbines. Survival of adult American shad (*Alosa sapidissima*) (330-533 mm) passed through a five blade Kaplan and seven blade mixed flow turbine was 88.2 and 84.3%, respectively (Heisey *et al*. 2008). Survival estimates on adult walleye (*Sander vitreus*) (314-653 mm) passed through a six blade and and a five blade propeller turbine were 80.4 and 87.8%, respectively (North/South Consultants, Inc. and Normandeau Associates, Inc. 2007, 2009). Large northern pike (*Esox lucius*) (452-769 mm) passed through these same turbines had survival estimates of 65.8 and 75.5%. The turbine units in both of the above studies rotate at much higher speeds (77-109 rpm) than the HGE hydrokinetic turbine (21 rpm), they also have more blades, and thus survival would be expected to be lower than through the hydrokinetic unit.

Predation activity was not directly observed, or indirectly assumed to occur (based on behavior patterns), throughout the study. Passage through a conventional turbine can affect fish behavior, which can in turn increase the incidence of predation. Even fish that do not have obvious physical injuries can potentially be stressed, or have a temporary loss of equilibrium that would reduce the fish's ability to avoid predators. Many of the factors that reduce a fish's ability to avoid predators (e.g., stress, loss of equilibrium) are reduced or eliminated in the hydrokinetic unit. The hydrokinetic unit does not expose fish to pressure changes, severe turbulence, shear stress, or cavitation, and therefore should not affect a fish's ability to naturally avoid predators.

Predation was not a factor at the HGE hydrokinetic turbine site even though ambient river temperature and size of test specimens were within the range where predation has been observed at other locations. The yellow perch and bluegill used in this study were approximately the same size as juvenile salmon that have been tested in previous HI-Z tag studies where predation was observed (RMC and J. R. Skalski. 1994a). A HI-Z tag study was conducted at Stevens Creek Station on the Savannah River, Georgia where members of the striped bass family (*Morone* spp.) were the primary predators (RMC 1994). The predation rate was 6 and 11% (treatment and control fish, respectively) on HI-Z tagged blueback herring (*Alosa aestivalis*) (average length 165 mm) during the Savannah River study. Additionally, the ambient river temperature at Mississippi Lock and Dam No. 2 increased from approximately 62-69° F during the course of the study, a temperature range at which predators were likely present and active in the tailrace of the HGE hydrokinetic turbine.

As observed in past studies conducted by Normandeau, predation activity increases as ambient river temperatures approach 50.0° F. At ambient river temperatures above 50.0° F, predation has affected the recapture rates of HI-Z tagged fish at some projects. During an investigation at Rocky Reach Dam on the Columbia River, a principal cause of lower recapture probabilities appeared to be predation by the abundant northern pikeminnow (*Ptychocheilus oregonensis*) in the tailrace (RMC and Skalski. 1994a). Although quantification of predation by northern pikeminnow was not an objective of the study, a predation rate of approximately 8.8% was observed on HI-Z tagged fish. Northern pikeminnow predation rates increase with increased water temperature (Beyer *et al*. 1988; Reiman *et al*. 1991). No strong evidence of predation or high activity of northern pikeminnow was observed at Rocky Reach Dam in March of 1994 when ambient river temperatures were 7-9°C (44.6-48.2°F) (RMC and Skalski 1994b).

The HGE hydrokinetic turbine installation will be limited to at most two units, side by side in the tailrace at the Mississippi Lock and Dam No. 2 Project. Given the results of this evaluation, there is no reason to believe that that second unit will pose any significant risk to the fish in the vicinity of Mississippi Lock & Dam No. 2. The species composition and size of the fish originating in the Project tailrace and passing through the HGE hydrokinetic turbine is not known; however, because survival was at or near 100% and there was no indication that fish were injured upon passing the turbine blades, the HGE hydrokinetic turbine should have little if any affect on entrained fish.

6.0 **CONCLUSIONS**

Based on the results of this evaluation, the HGE hydrokinetic unit has little if any considerable impact on the fish populations in the vicinity of the Mississippi Lock and Dam No. 2 Hydroelectric Project. The following are more detailed conclusions from this evaluation of fish entrainment, injury, and survival through the HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project.

Survival and Injury

1) The empirical study assumptions were valid and the precision of the survival estimates was within the pre-specified level of $\leq \pm 5\%$ at $1 - \alpha = 0.90$, thus the results are reliable.

2) Survival estimates for small fish (115-235 mm TL) and large fish (388-710 mm TL) through the HGE hydrokinetic turbine (after 48 h) were 99%.

3) No turbine blade passage injuries were observed.

4) Fish that contact the HGE hydrokinetic turbine and barge apparatus (e.g., such as after entrainment through the conventional powerhouse), should not experience lethal injuries. Measured water velocities around the HGE hydrokinetic turbine (5.67 ft/sec to 9.68 ft/sec) are well below the laboratory study value of 20 ft/sec that is capable of causing injury/mortality to fish contacting hard objects.

5) The HGE hydrokinetic turbine design appears to eliminate the potential for fish to be injured in gaps at the turbine blade tip or hub. Additionally, the design and deployment of the tested HGE hydrokinetic turbine cannot inflict any pressure related injuries on passed fish because there is no operational head and no opportunities for entrained fish to experience sudden lethal pressure changes.

6) The HGE hydrokinetic turbine has a low number of runner blades (three) and a relatively large runner diameter (144 in), both are characteristics of low impact turbines (Franke *et al*. 1997).

Predation

7) Predation was not a factor at the HGE hydrokinetic turbine site during this study even though ambient river temperature and size of test specimens were within the range where predation has been observed at other locations. Predation activity was not directly observed, or indirectly assumed to occur (based on behavior patterns of tagged fish), throughout the study. Many of the factors that reduce a fish's ability to avoid predators (e.g., stress, loss of equilibrium) are reduced or eliminated in the HGE hydrokinetic turbine. The hydrokinetic unit does not expose fish to pressure changes, severe turbulence, shear stress, or cavitation, and therefore should not affect a fish's ability to naturally avoid predators.

Entrainment

8) The HGE hydrokinetic turbine installation will be limited to two units, side by side in the tailrace at the Mississippi Lock and Dam No. 2 Hydroelectric Project. Given the results of this evaluation, there is no reason to believe that that second unit will pose any significant risk to the fish in the vicinity of Mississippi Lock & Dam No. 2.

9) The species composition and size of fish naturally passing through the HGE hydrokinetic turbine is not known; however, because survival was at or near 100% and there was no indication that fish were injured upon passing the turbine blades, the HGE hydrokinetic turbine should have little if any affect on entrained fish.

7.0 ACKNOWLEDGMENTS

We would like to thank Hydro Green Energy, LLC for the opportunity to conduct this study. We wish to specifically thank Wayne F. Krouse; Chairman and CEO; Mark R. Stover; Vice President of Corporate Affairs, and Heidi Wahto; Hatch Energy and's Licensing Consultant, for their work and support of this project. A special thanks to Harvey Greenburg; HGE VP of Engineering; and Bob Hemphill; HGE Project Manager, who were on-site at the project and made sure the HGE hydrokinetic turbine ran smoothly.

We would like to thank John Zgoda and Gary Wytaske from the City of Hastings for the help they provided hauling equipment and allowing the study to start without any major problems.

Normandeau would like to thank Steven Lenhart and the rest of the US Army Corps of Engineers (USACE) at the Mississippi Lock and Dam No. 2 for their help with coordinating and accommodating the Normandeau crew.

A special thanks to the individuals and their crews who supplied the fish for this investigation. The yellow perch and bluegill were provided by Ron Radenmacher, an aquaculturist near Waconia, MN. The channel catfish and buffalo spp. were provided by Tim Adams, a commercial fisherman located near Wabasha, MN.

Normandeau would like to thank both the owners at Hub's Landing and Captain's Bay Marina. Normandeau utilized their boat ramps for launching boats and unloading fish from transport tanks. Mark and Monica Frazer operate Hub's Landing and Curt Saunders operates Captain's Bay Marina.

Tim Brush, Normandeau's Principal In Charge, played a major role in developing the study plan, information that lead to this HI-Z tag study, and production of the report. On-site Project Managers were Jennifer Stone and Steven Adams – together they kept all aspects of the field work running smoothly. Other team members were Paul Heisey, John Dulude, Joanne Fulmer, Sidney Graver, Dena Horton, John Pierce, Ken Cash, Steve Kauffman, Christian Gagne, and Tom Schäffer. Jennifer Griffin authored the entrainment portion of this report.

8.0 LITERATURE CITED

Barnes and Williams. 1991. Fish Entrainment Monitoring Program, City of Hastings Hydroelectric Project FERC Project No. 4306-008, Lock and Dam No. 2, Hastings Minnesota (June 1990-May 1991). Prepared by Barnes-Williams Environmental Consultants.

Bell, M. C., A. C. DeLacy, and H. D. Copp. 1972. A compendium on the survival of fish passing through spillways and conduits. Report prepared for U. S. Army Corps of Engineers, Portland, OR.

Beyer, J. M., G. Luccheti, and G. Gray. 1988. Digestive tract evacuation in northern squawfish (*Ptychocheilus oregonensis*). Can. J. Fish. Aquat. Sci. 45:548-553.

City of Hastings. 2008. Response to FERC additional information request, 19 June 2008.

Eicher Associates, Inc. 1987. Turbine-related fish mortality: review and evaluation of studies. Research Project 2694-4. Prepared for Electric Power Research Institute, Palo Alto, CA.

Electric Power Research Institute (EPRI). 1992. Fish entrainment and turbine mortality review and guidelines. EPRI. TR-1011231, Palo Alto, CA.

Electric Power Research Institute (EPRI). 1996. Guidelines for hydro turbine fish entrainment and survival studies. EPRI. W04083-01, Palo Alto, CA.

FERC. 2008. Environmental Assessment: Installation of hydrokinetic turbines. Mississippi Lock and Dam No. 2 hydroelectric project. Project No. 4306-017 Minnesota. Federal Energy Regulatory Commission Office of Energy Projects Division of Hydropower Administration and Compliance Washington, DC.

Franke, G. F., and nine co-authors. 1997. Development of environmentally advanced hydro turbine design concepts. Report prepared for the U. S. Department of Energy, DOE Idaho Operations Office, Idaho Falls, ID.

Heisey, P. G., D. Mathur, and T. Rineer. 1992. A reliable tag-recapture technique for estimating turbine passage survival: application to young-of-the-year American shad (*Alosa sapidissima*). Canadian Journal Fisheries and Aquatic Sciences 49:1826-1834.

Heisey, P. G., D. Mathur, J. L. Fulmer, and E. Kotkas. 2008. Turbine passage survival of late running adult American shad and its potential effect on population restoration. American Fisheries Society Symposium 61:141-152. Amer. Fish. Soc. Bethesda, MD.

Hudson, D.J. 1971. Interval estimation from the likelihood function. J. R. Stat. Soc. B. 33:256-262.

Ickes, B. S., M. C. Bowler, A. D. Bartels, D. J. Kirby, S. DeLain, J. H. Chick, V. A.

Barko, K. S. Irons, and M. A. Pegg. 2005. Multi-year synthesis of the fish component from 1993 to 2002 for the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP 2005 T005. 60 pp. + Appendixes A–E.

Mathur, D. P. G. Heisey, E. T. Euston, J. R. Skalski, and S. Hays. 1996. Turbine passage survival estimation for Chinook salmon smolts (*Oncorhynchus tshawytscha*) at a large dam on the Columbia River. Can. Journ. Fish. Aquatic. Sci. 53:542-549.

Neitzel, D. A., and nine co-authors, 2000. Laboratory studies of the effects of shear on fish final report FY 1999. Prepared for Advanced Hydropower Turbine System Team, U. S. Department of Energy, Idaho Falls, ID.

North/South Consultants, Inc. and Normandeau Associates, Inc. 2007. Fish movement and turbine passage at selected Manitoba Hydro Generating Stations, 2006-2007. Interim Report. Report prepared for Manitoba Hydro, Winnipeg, Manitoba, Canada.

North/South Consultants, Inc. and Normadeau Associates, Inc. 2009. Survival and movement of fish experimentally passed through a re-runnered turbine at the Kelsey Generating Station, 2008. Report prepared for Manitoba Hydro, Winnipeg, Manitoba, Canada.

Pacific Northwest National Laboratory (PNNL), BioAnalysts, ENSR International, Inc., and Normandeau Associates, Inc. 2001. Design guidelines for high flow smolt bypass outfalls: field, laboratory and modeling studies. Report prepared for the U.S. Army Corps of Engineers, Portland District, Portland, OR.

Reiman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:448-458.

RMC. 1994. Turbine passage survival of fishes at the Steven's Creek Hydroelectric Plant, Savannah River, Georgia. Report prepared for South Carolina Electric & Gas Company, Columbia, SC.

RMC and J. R. Skalski. 1994a. Survival of juvenile fall Chinook salmon (*Oncorhynchus tshawytscha*) in passage through a fixed blade Kaplan turbine at Rocky Reach Dam, Washington. Report prepared for Public Utility District No. 1 of Chelan County, Wenatchee, WA.

RMC and J. R. Skalski. 1994b. Survival of yearling fall Chinook salmon smolts (*Oncorhynchus tshawytscha*) in passage through a Kaplan turbine at Rocky Reach Hydroelectric Dam, Washington. Report prepared for Public Utility District No. 1 of Chelan County, Wenatchee, WA.

U.S. Army Corps of Engineers. Lock 2 Flow January 1959 – October 2007. October 24, 2007.

9.0 **TABLES**

Table 1-1. Monthly average flow (cfs) from 1987 through 2007 at the Mississippi Lock and Dam No. 2 Hydroelectric Project in Hastings, MN (USACE 2007).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	10,129	9,018	13,290	16,400	10,671	11,827	8,668	8,116	4,923	4,987	5,650	5,339
1988	3,881	3,514	9,990	13,640	8,526	2,893	1,477	2,706	3,183	4,035	4,051	3,497
1989	3,648	3,893	7,526	24,097	15,768	7,840	5,852	2,945	5,216	4,517	4,610	3,656
1990	3,297	3,443	10,070	7,727	13,368	24,510	15,003	11,452	5,377	5,422	5,680	3,703
1991	3,277	3,054	8,659	22,873	34,590	36,160	26,107	15,194	18,093	9,574	12,597	12,435
1992	9,190	7,872	33,439	23,810	16,848	13,153	22,110	10,129	10,323	9,984	13,353	7,477
1993	5,400	4,989	8,116	47,267	42,948	52,110	65,523	41,248	25,210	13,439	12,590	11,287
1994	8,535	7,589	25,403	35,513	38,584	20,690	21,713	14,574	11,637	17,410	13,127	8,797
1995	6,832	5,746	22,235	41,110	38,984	24,983	21,232	18,797	10,823	23,968	22,730	10,797
1996	8,571	8,524	18,455	42,547	36,245	28,150	13,855	7,787	4,803	6,365	12,990	11,000
1997	8,223	7,464	19,432	82,897	34,339	14,073	32,665	21,690	10,240	8,784	8,673	7,716
1998	5,090	9,236	17,271	38,783	16,755	18,947	20,871	6,765	4,083	7,884	13,350	10,374
1999	5,687	6,968	13,104	35,390	39,670	27,155	20,360	14,565	12,437	9,703	8,123	5,850
2000	5,448	5,752	12,994	8,997	12,823	16,283	14,403	5,455	3,893	3,981	10,627	5,526
2001	5,245	4,771	5,190	90,703	63,758	45,853	17,855	7,906	5,740	6,194	7,380	9,461
2002	6,877	6,050	7,245	24,770	22,087	21,750	27,923	21,829	15,737	17,271	12,067	7,206
2003	5,068	3,382	7,300	16,637	27,274	18,863	23,832	5,681	3,537	3,332	4,087	3,534
2004	2,574	2,698	8,226	11,623	11,129	34,717	13,984	6,584	13,920	14,058	14,980	7,981
2005	5,390	6,486	8,323	33,873	26,313	35,623	16,284	6,413	11,240	26,219	12,920	12,774
2006	11,748	13,011	14,858	42,383	38,558	16,317	5,235	4,274	3,837	4,148	4,303	4,226
2007	4,939	3,186	21,281	36,403	20,071	14,623	4,697	4,851	4,440	18,096		
Mean	6,145	6,031	13,924	33,212	27,110	23,168	19,031	11,379	8,985	10,446	10,194	7,632

Table 3-1. Daily schedule for releases of juvenile yellow perch, and bluegill, adult channel catfish, and smallmouth and bigmouth buffalo through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Date	Yellow Perch	Bluegill	Channel Catfish	Smallmouth Buffalo	Bigmouth Buffalo	Control	Analytical Sample	Actual Fish Released
5-Jun	101					50	**151**	151
6-Jun		99				50	**149**	150
7-Jun			50			25	**75**	75
8-Jun			25			15	**40**	40
9-Jun			25			10	**35**	35
9-Jun				2			**2**	2
10-Jun				39		21	**60**	61
11-Jun					50	25	**75**	75
11-Jun				11		4	**15**	15
Total	**101**	**99**	**100**	**52**	**50**	**200**	**602**	**604**

Table 3-2. Physical parameters (mean values for each scenario) measured during the releases of juvenile yellow perch, bluegill, adult channel catfish, and smallmouth and bigmouth buffalo through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

	Elevations			Conventional Turbines				Hydrokinetic Turbine
Date	Forebay (ft)	Tailwater (ft)	Head (ft)	1 MW	2 MW	No. Operating	Total cfs	Kilowatts[1]
5-Jun-09	687.12	675.37	11.75	1.06	1.08	2	2,700	21
6-Jun-09	687.01	675.41	11.60	1.03	1.06	2	2,700	21
7-Jun-09	687.22	675.40	11.82	1.03	1.06	2	2,700	21
8-Jun-09	686.99	675.47	11.52	1.03	1.06	2	2,700	21
9-Jun-09	687.10	675.46	11.64	1.03	1.03	2	2,700	21
10-Jun-09	687.03	675.44	11.59	1.03	1.06	2	2,700	21
11-Jun-09	687.00	675.49	11.51	1.03	1.03	2	2,700	21

[1]Although the conventional turbines discharge was at hydraulic capacity, the hydrokinetic turbine did not produce at the electrical generation capacity of 35 kW because its position in the tailrace along with the turbulence at the time were not optimal for maximum electrical generation output. This had no effect on the fish tests.

Table 3-3. Condition codes assigned to fish and dislodged HI-Z tags for fish passage survival studies.

Status Codes	Description		
*	Turbine/passage-related malady		
4	Damaged gill(s): hemorrhaged, torn or inverted		
5	Major scale loss, >20%		
6	Severed body or nearly severed		
7	Decapitated or nearly decapitated		
8	Damaged eye: hemorrhaged, bulged, ruptured or missing, blown pupil		
9	Damaged operculum: torn, bent, inverted, bruised, abraided		
A	No visible marks on fish		
B	Flesh tear at tag site(s)		
C	Minor scale loss, <20%		
E	Laceration(s): tear(s) on body or head (not severed)		
F	Torn isthmus		
G	Hemorrhaged, bruised head or body		
H	LOE		
J	Major		
K	Failed to enter system		
L	Fish likely preyed on (telemetry, circumstances relative to recapture)		
M	Minor		
P	Predator marks		
Q	Other information		
R	Replaced due to unrecoverable conditions		
T	Trapped inside tunnel/gate well		
V	Fins displaced, or hemorrhaged (ripped, torn, or pulled) from origin		
W	Abrasion / Scrape		
Survival Codes			
1	Recovered alive		
2	Recovered dead		
3	Unrecovered – tag & pin only		
4	Unrecovered – no information or brief radio telemetry signal		
5	Unrecovered – trackable radio telemetry signal or other information		
Dissection Codes			
1	Shear	M	Minor
2	Mechanical	N	Heart damage, rupture, hemorrhaged
3	Pressure	O	Liver damage, rupture, hemorrhaged
4	Undetermined	R	Necropsied, no obvious injuries
5	Mechanical/Shear	S	Necropsied, internal injuries
6	Mechanical/Pressure	T	Tagging/Release
7	Shear/Pressure	W	Head removed; i.e., otolith
B	Swim bladder ruptured or expanded		
D	Kidneys damaged (hemorrhaged)		
E	Broken bones obvious		
F	Hemorrhaged internally		
J	Major		
L	Organ displacement		

Table 4-1. Summary tag-recapture data for juvenile yellow perch and bluegill released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace. Proportions are given in parentheses.

	Yellow perch				Bluegill			
	Treatment		Control		Treatment		Control	
Number released	101		50		99		50	
Number recaptured alive	97	(0.960)	48	(0.960)	97	(0.980)	50	(1.000)
Number recaptured dead	2	(0.020)	0	(0.000)	0	(0.000)	0	(0.000)
Number assigned dead*	1	(0.010)	1	(0.020)	1	(0.010)	0	(0.000)
Dislodged tags	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Stationary radio signals	1	(0.010)	1	(0.020)	1	(0.010)	0	(0.000)
Number undetermined	1	(0.010)	1	(0.020)	1	(0.010)	0	(0.000)
Number held	97	(0.960)	48	(1.000)	97	(0.980)	50	(1.000)
Number alive 48 h	97		47		94		46	
Number Died in holding	0		1		3		4	

* includes dislodged HI-Z tags and stationary radio signals

Table 4-2. Summary tag-recapture data for adult channel catfish released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace. Proportions are given in parentheses.

	Channel catfish			
	Treatment		Control	
Number released	100		50	
Number recaptured alive	99	(0.990)	50	(1.000)
Number recaptured dead	0	(0.000)	0	(0.000)
Number assigned dead*	1	(0.010)	0	(0.000)
Dislodged tags	1	(0.010)	0	(0.000)
Stationary radio signals	0	(0.000)	0	(0.000)
Number undetermined	0	(0.000)	0	(0.000)
Number held	99	(0.990)	50	(1.000)
Number alive 48 h	99		45	
Number died in holding	0		5	

* includes dislodged HI-Z tags and stationary radio signals

Table 4-3. Summary tag-recapture data for adult smallmouth and bigmouth buffalo released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace. Proportions are given in parentheses.

	Smallmouth Buffalo				Bigmouth buffalo				Combined buffalo			
	Treatment		Control		Treatment		Control		Treatment		Control	
Number released	52		25		50		25		102		50	
Number recaptured alive	52	(1.000)	25	(1.000)	50	(1.000)	25	(1.000)	102	(1.000)	50	(1.000)
Number recaptured dead	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Number assigned dead*	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Dislodged tags	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Stationary radio signals	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Number undetermined	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Number held	52	(1.000)	25	(1.000)	50	(1.000)	25	(1.000)	102	(1.000)	50	(1.000)
Number alive 48 h	51		25		50		25		101		50	
Number died in holding	1		0		0		0		1		0	

* includes dislodged HI-Z tags and stationary radio signals

Table 4-4. Summary of fish retrieval data for fish released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

	Retrieval Times	Average (min)	Minimum (min)	Maximum (min)
Yellow perch	Treatment	5.8	1	221
	Control	3.6	1	47
Bluegill	Treatment	3.4	1	16
	Control	3.6	1	26
Channel catfish	Treatment	6.7	3	16
	Control	7.2	3	26
Smallmouth buffalo	Treatment	6.1	2	30
	Control	6	2	13
Bigmouth buffalo	Treatment	5.6	2	18
	Control	5.3	2	7

Table 4-5. Survival estimates of fish passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

	Yellow Perch	Bluegill	Channel catfish	Buffalo spp.		
				Smallmouth	Bigmouth	Combined
1 h	0.990	0.990	0.990	1.00	1.00	1.00
SE	0.027	0.010	0.010	N/A	N/A	N/A
CI	0.946-1.00	0.963-0.999	0.974-1.01*	N/A	N/A	N/A
48 h	1.00**	1.00**	1.00**	0.981	1.000	0.990
SE	N/A	N/A	N/A	0.019	N/A	0.010
CI	0.959-1.00	0.963-1.00	0.983-1.00	0.950-1.00	N/A	0.974-1.00

* Calculated by multiplying SE by 1.645

** 1 h rate established for 48 h as conservative value.

Table 4-6. Summary of malady data and malady-free estimates for juvenile yellow perch and bluegill released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace. Proportions are given in parentheses.

	Yellow perch				Bluegill			
	Treatment		Control		Treatment		Control	
Number released	101		50		99		50	
Number examined for maladies	99	(0.980)	48	(0.960)	97	(0.980)	50	(1.000)
Number with passage related maladies	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Visible injuries		(0.000)		(0.000)		(0.000)		(0.000)
Loss of equilibrium only		(0.000)		(0.000)		(0.000)		(0.000)
Scale loss only		(0.000)		(0.000)		(0.000)		(0.000)
Number without passage related maladies	99	(0.980)	48	(0.960)	97	(0.980)	50	(1.000)
Without passage related maladies that died	2	(0.020)	1	(0.021)	3	(0.031)	4	(0.080)
Malady free rate	1.000		1.000		1.000		1.000	

Table 4-7. Summary of malady data and malady-free estimates for adult channel catfish released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace. Proportion are given in parentheses.

	Channel catfish			
	Treatment		Control	
Number released	100		50	
Number examined for maladies	99	(0.990)	50	(1.000)
Number with passage related maladies	0	(0.000)	0	(0.000)
Visible injuries		(0.000)		(0.000)
Loss of equilibrium only		(0.000)		(0.000)
Scale loss only		(0.000)		(0.000)
Number without passage related maladies	99	(0.990)	50	(1.000)
Without passage related maladies that died	0	(0.000)	5	(0.100)
Malady free rate	1.000		1.000	

Table 4-8. Summary of malady data and malady-free estimates for adult smallmouth buffalo and bigmouth buffalo released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace. Proportions are given in parentheses.

	Smallmouth Buffalo				Bigmouth buffalo				Combined buffalo			
	Treatment		Control		Treatment		Control		Treatment		Control	
Number released	52		25		50		25		102		50	
Number examined for maladies	52	(1.000)	25	(1.000)	50	(1.000)	25	(1.000)	102	(1.000)	50	(1.000)
Number with passage related maladies	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)	0	(0.000)
Visible injuries		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)
Loss of equilibrium only		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)
Scale loss only		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)
Number without passage related maladies	52	(1.000)	25	(1.000)	50	(1.000)	25	(1.000)	102	(1.000)	50	(1.000)
Without passage related maladies that died	1	(0.019)	0	(0.000)	0	(0.000)	0	(0.000)	1	(0.010)	0	(0.000)
Malady free rate	1.000		1.000		1.000		1.000		1.000		1.000	

Table 4-9. Species, number, and length range of fish collected by Barnes and Williams (1991) for fish entrainment monitoring at the Mississippi Lock and Dam No. 2 Hydroelectric Project. Fish were collected in nets placed immediately upstream of the intake structure of the turbines.

Month	Species	Number	Min TL (mm)	Max TL (mm)
June	Rosyface shiner	4	38	64
	Channel catfish	1	254	
	Quillback	1	241	
	Sucker	1	216	
	Freshwater drum	1	114	
July	Rosyface shiner	8	51	70
	Gizzard shad	3	32	38
	White bass	1	305	
	Freshwater drum	1	267	
	Channel catfish	1	32	
August	White sucker	14	19	64
	Rosyface shiner	120	22	97
	Quillback	4	38	111
	Gizzard shad	25	38	134
	White bass	2	48	168
	Spotted gar	3	165	229
	Freshwater drum	13	210	364
	Channel catfish	1	241	241
September	Gizzard shad	23	90	202
	Rosyface shiner	5	36	74
	Common carp	1	57	
	White bass	1	331	
October	Gizzard shad	3	58	80
	Rosyface shiner	1	190	
	White bass	2	223	225
	Freshwater drum	3	140	255
	Flathead catfish	166	37	337
	Largemouth bass	1	358	
November	Gizzard shad	2	44	141
	White bass	1	309	
December	Freshwater drum	1	234	
January	Gizzard shad	2	140	152
	Freshwater drum	1	333	
February	Units down, no fish collected	0		
March	Freshwater drum	1	317	
	Gizzard shad	1	179	
	Flathead catfish	1	76	
April	Freshwater drum	2	284	394

Table 4-10. Numerical estimate of annual entrainment and mortality of fish, by species, through two[1] HGE hydrokinetic turbines after passing the Mississippi Lock and Dam No. 2 Hydroelectric Project. Species and number collected are from Barnes and Williams (1991). Entrainment and mortality estimates are based on a daily mean of 389 fish entrained through the conventional turbines (Barnes and Williams 1991), 80% capacity factor for the HGE hydrokinetic turbines and volumetric flow of 17-56% from the conventional turbines to the HGE hydrokinetic turbines.

			Entrainment		Mortality	
Species	**No. Collected**	**Relative Abundance**	**17% of Flow**	**56% of Flow**	**17% of Flow**	**56% of Flow**
Gizzard shad	222	0.526	10,158	33,463	102	335
Rosyface shiner	140	0.332	6,406	21,103	64	211
Freshwater drum	22	0.052	1,007	3,316	10	33
Sucker	15	0.036	686	2,261	7	23
White bass	8	0.019	366	1,206	4	12
Quillback carpsucker	5	0.012	229	754	2	8
Channel catfish	3	0.007	137	452	1	5
Spotted gar	3	0.007	137	452	1	5
Flathead catfish	2	0.005	92	301	1	3
Common carp	1	0.002	46	151	0	2
Largemouth bass	1	0.002	46	151	0	2
Sums	422	1.000	19,310	63,609	193	636

[1] To date only one HE hydrokinetic unit has been installed. If that remains the case, the annual impact to fish range extremes would be 50% of those values above, or 97 and 318 fish as the range extremes.

10.0 FIGURES

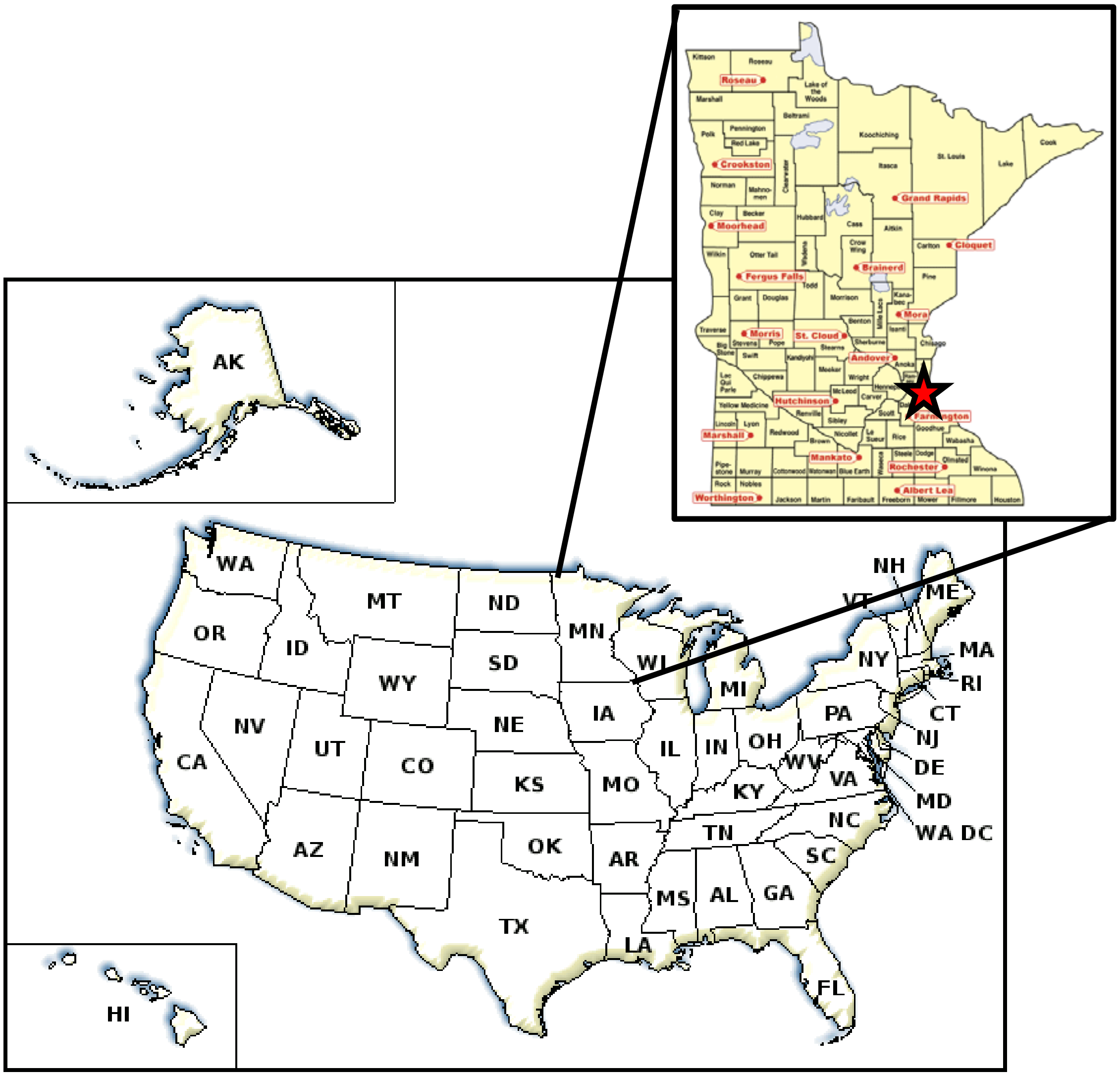


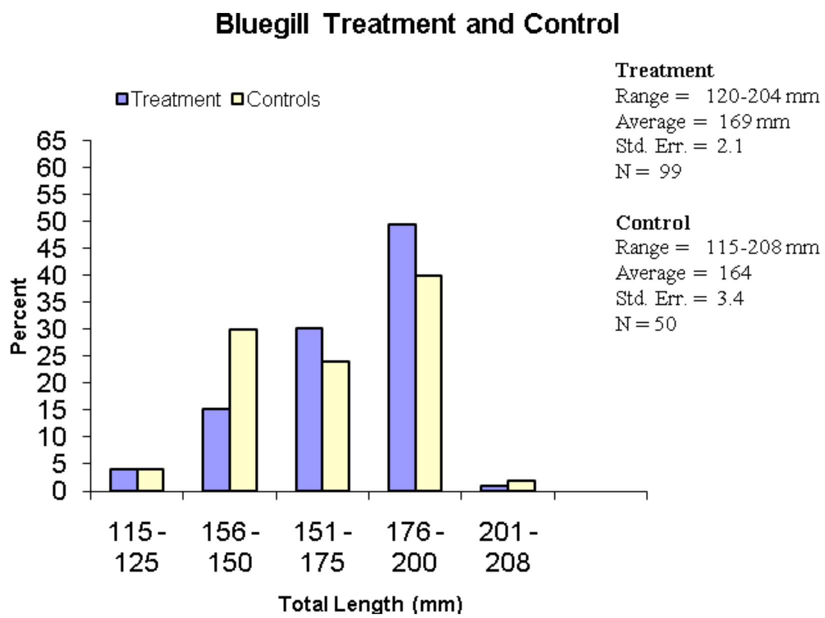
Figure 1-1. Map of the United States with Minnesota as inset. Star denotes location of the Mississippi Lock and Dam No. 2.

Figure 1-2. Aerial view of Mississippi River at the U.S. Army Corps of Engineers Lock & Dam No. 2, Hastings, Minnesota (P-4306), showing location of HGE's hydrokinetic unit (not visible in this photo).

Figure 1-3. HGE hydrokinetic turbine prior to submergence in the tailrace of the Mississippi Lock and Dam No. 2 Hydroelectric Project near Hastings, MN.

Figure 3-1. Bluegill with HI-Z Turb N' Tags (HI-Z tags) and radio tag attached before (top photo) and after passage (bottom photo) through the HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project.

A.



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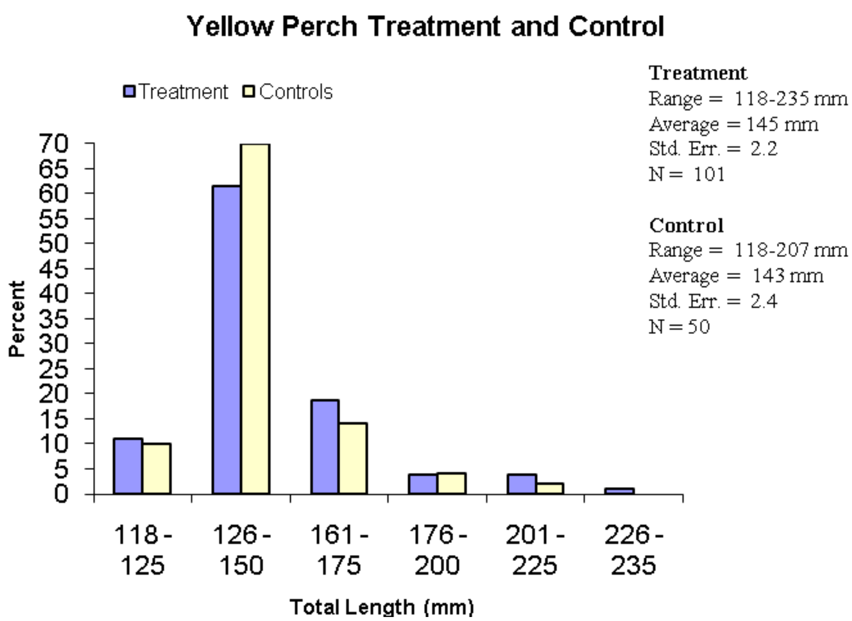


Figure 3-2. Total length (mm) frequency distribution of all treatment and control: A. yellow perch and B. bluegill through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

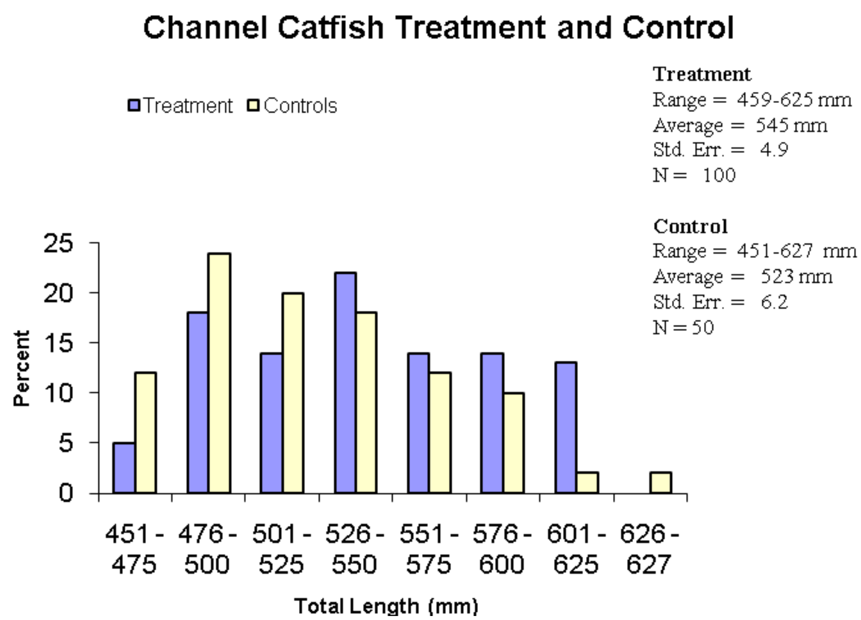
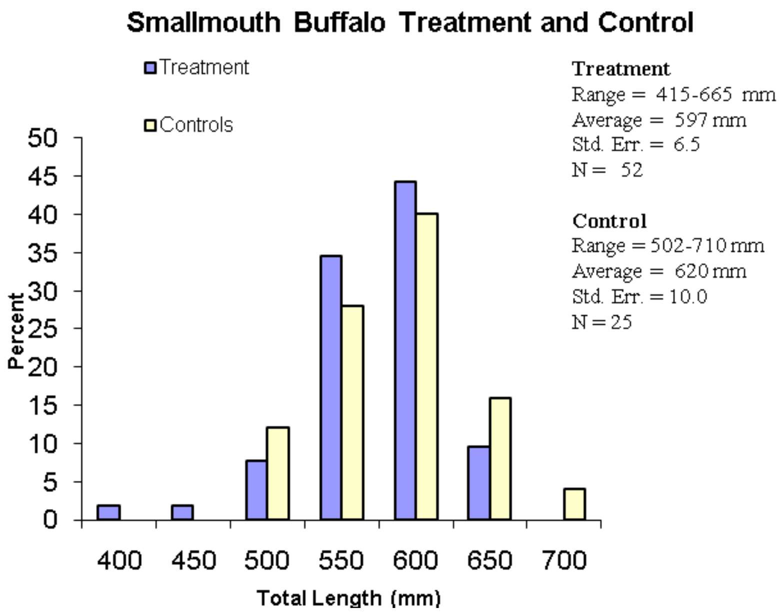


Figure 3-3. Total length (mm) frequency distribution of all treatment and control channel catfish through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

A.



B.

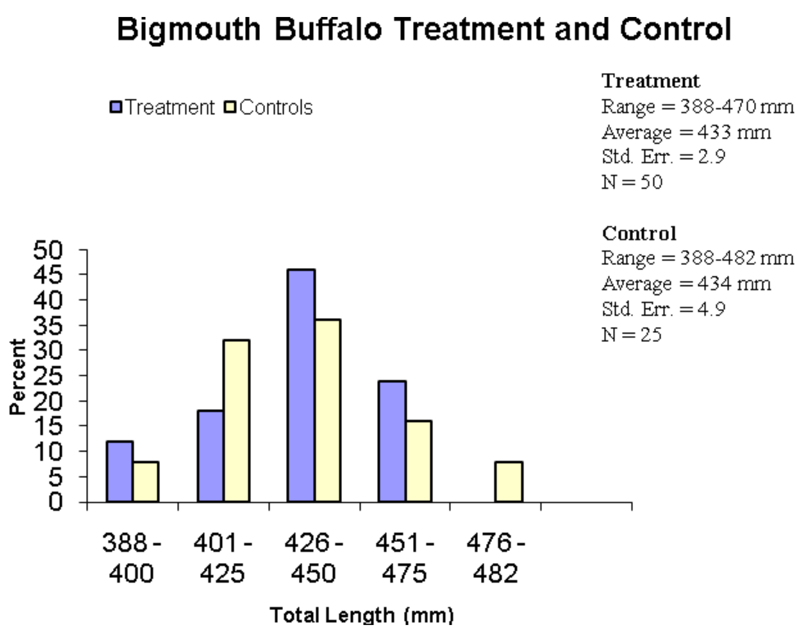


Figure 3-4. Total length (mm) frequency distribution of all treatment and control: A. smallmouth buffalo and B. bigmouth buffalo through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

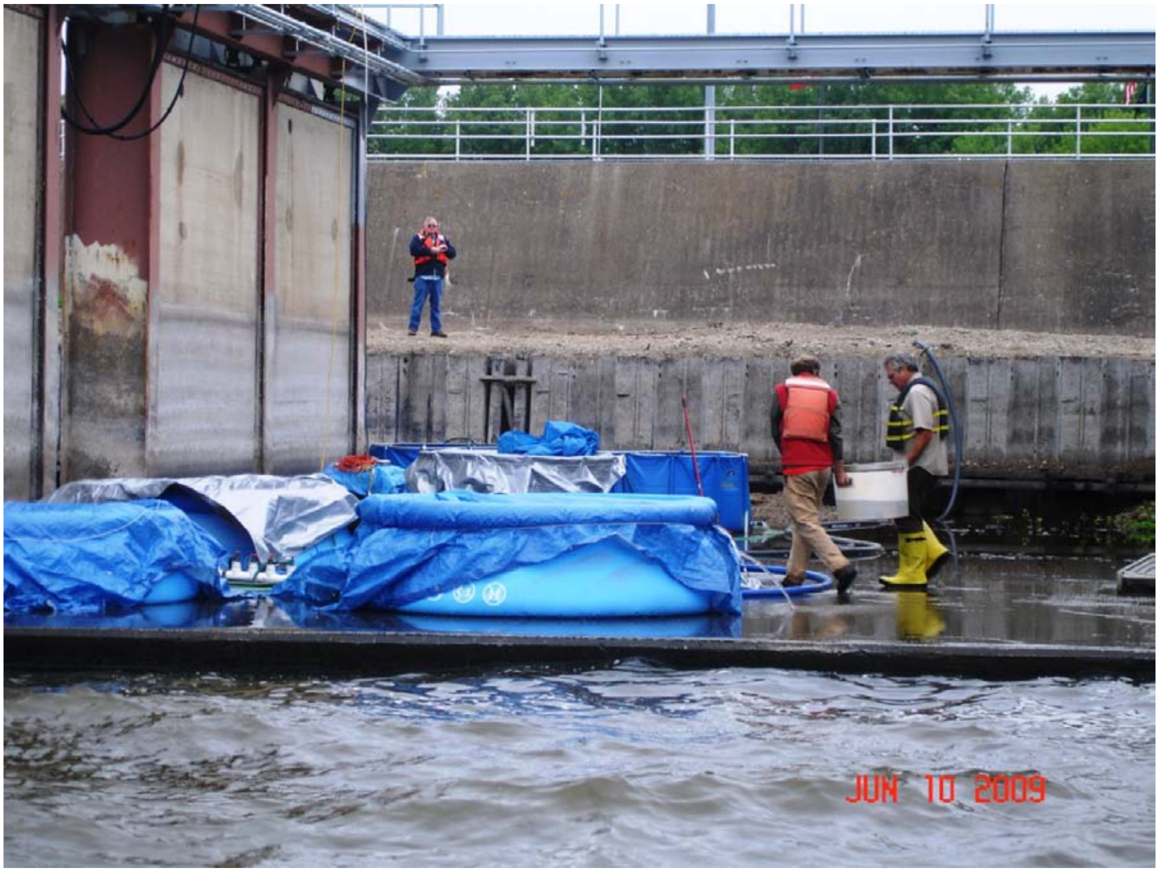


Figure 3-5. Crew moving recaptured large-sized fish into holding ponds for delayed assessment.

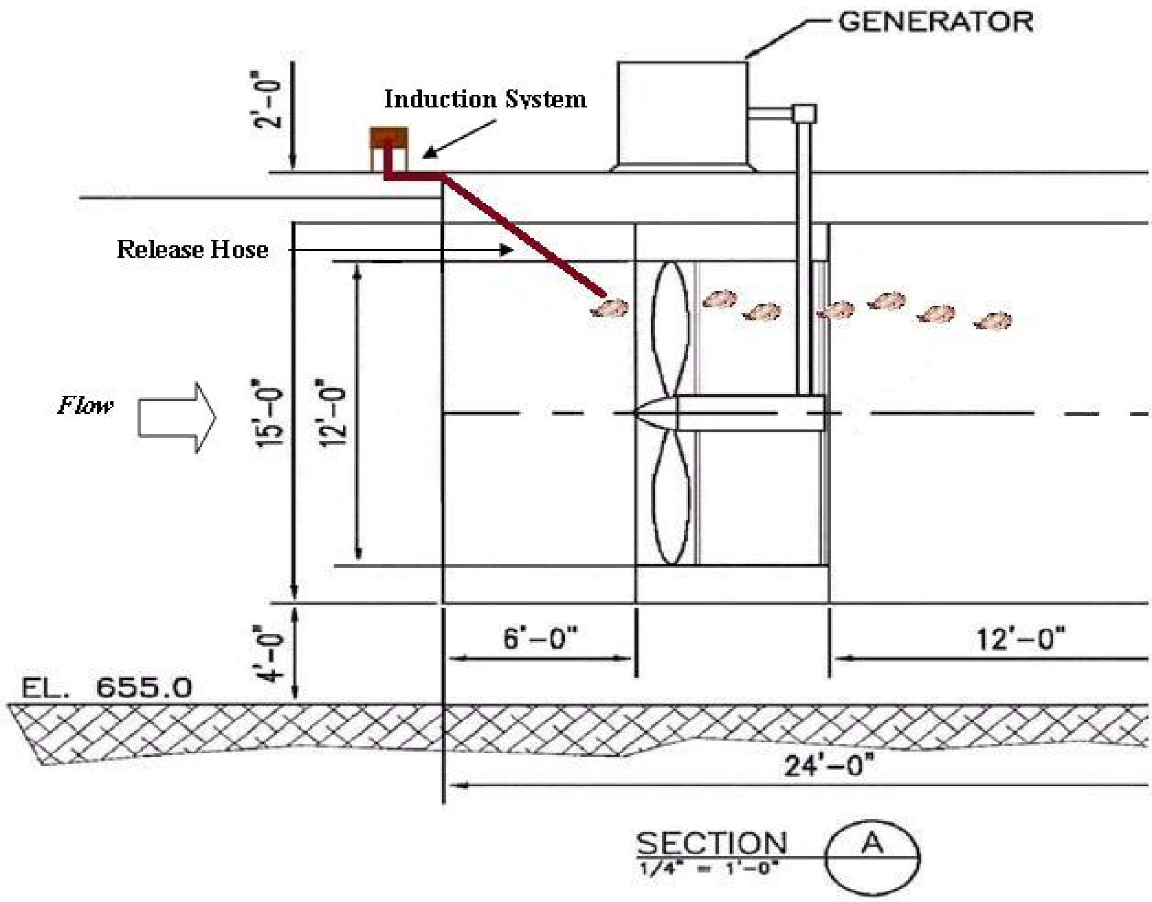


Figure 3-6. Conceptual cross section schematic of an HGE hydrokinetic turbine showing placement of a fish induction system. Induction system is used to introduce tagged fish into the unit at a point of commitment to entrainment.

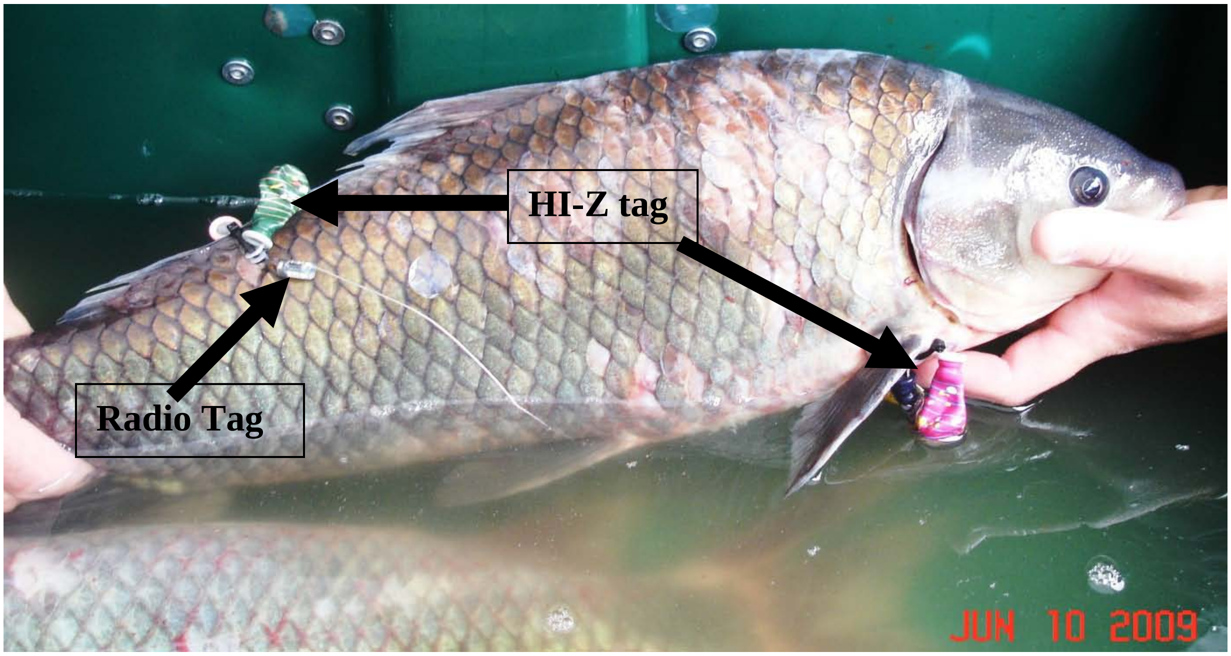
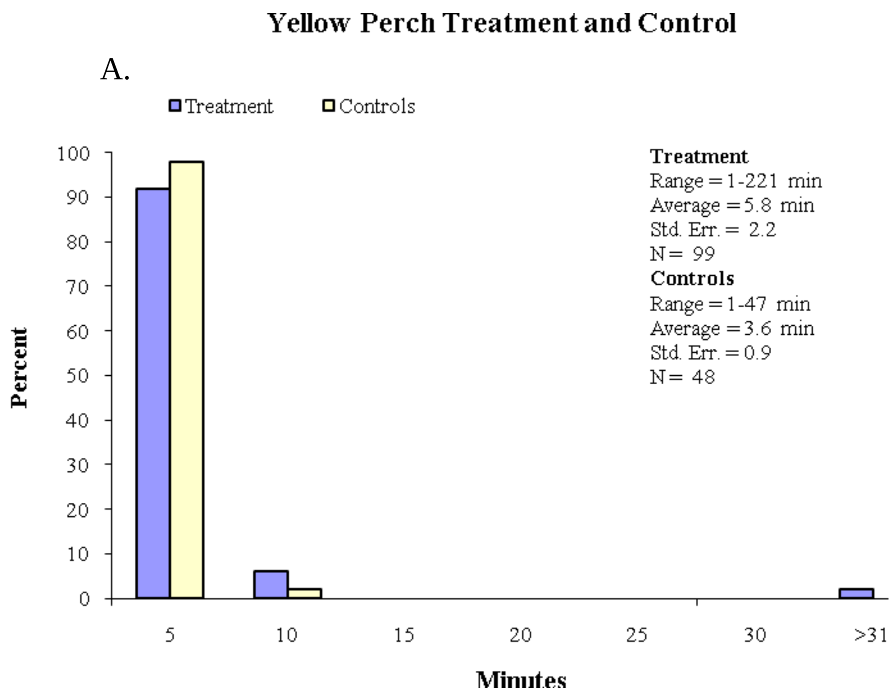


Figure 3-7. Smallmouth buffalo with HI-Z tags and radio tag attached, fish is ready for release.

Figure 3-8. Fish in restraining tube for tagging.

Figure 3-9. Large fish induction system, configured for control releases, located on the HGE hydrokinetic barge.



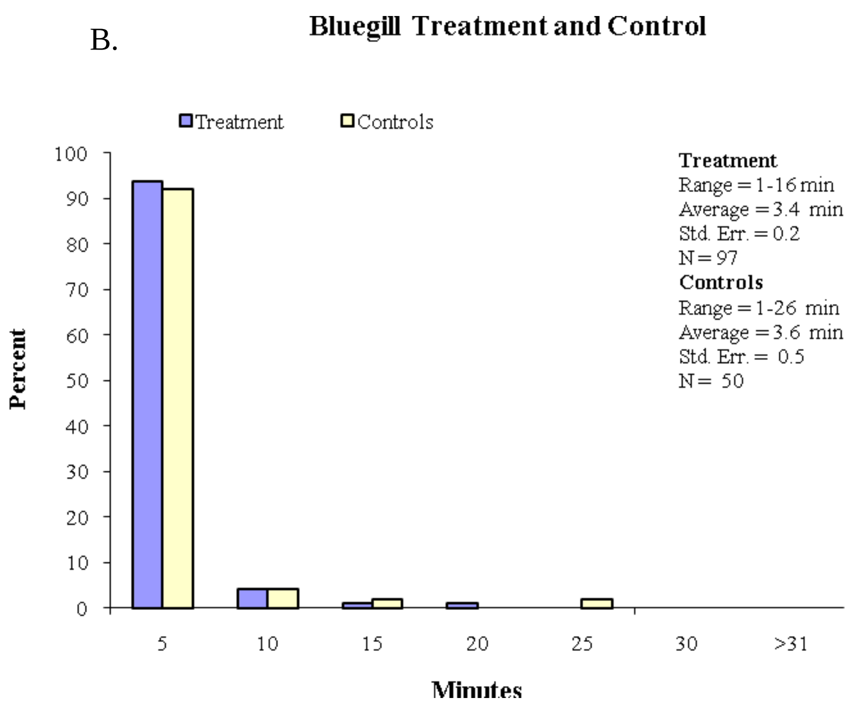
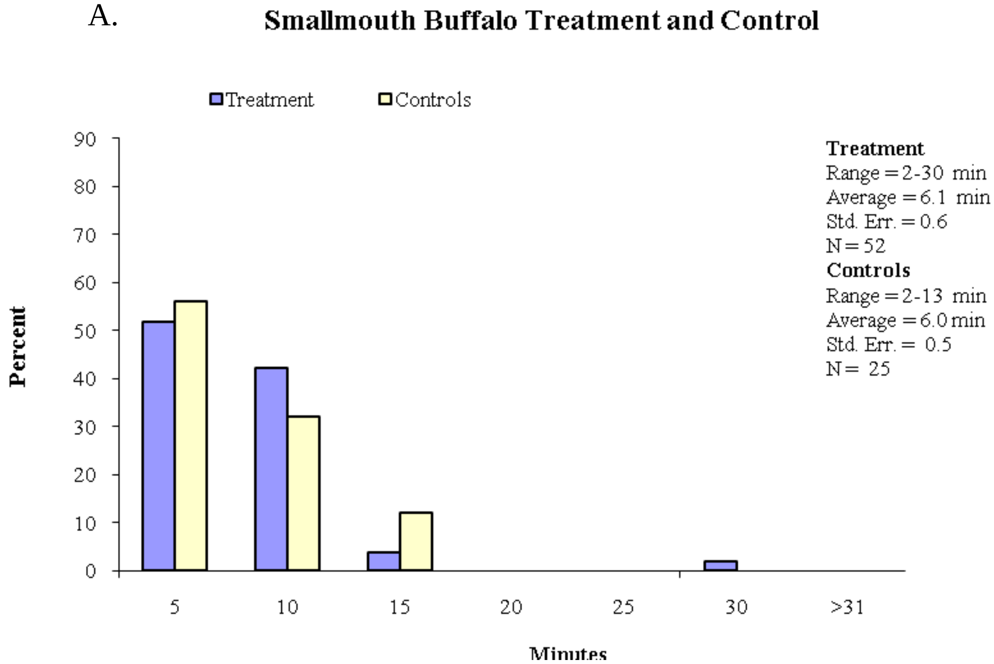


Figure 4-1. Frequency distribution of the retrieval time (minutes) for treatment and control juvenile A. yellow perch and B. bluegill passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

A.



B.

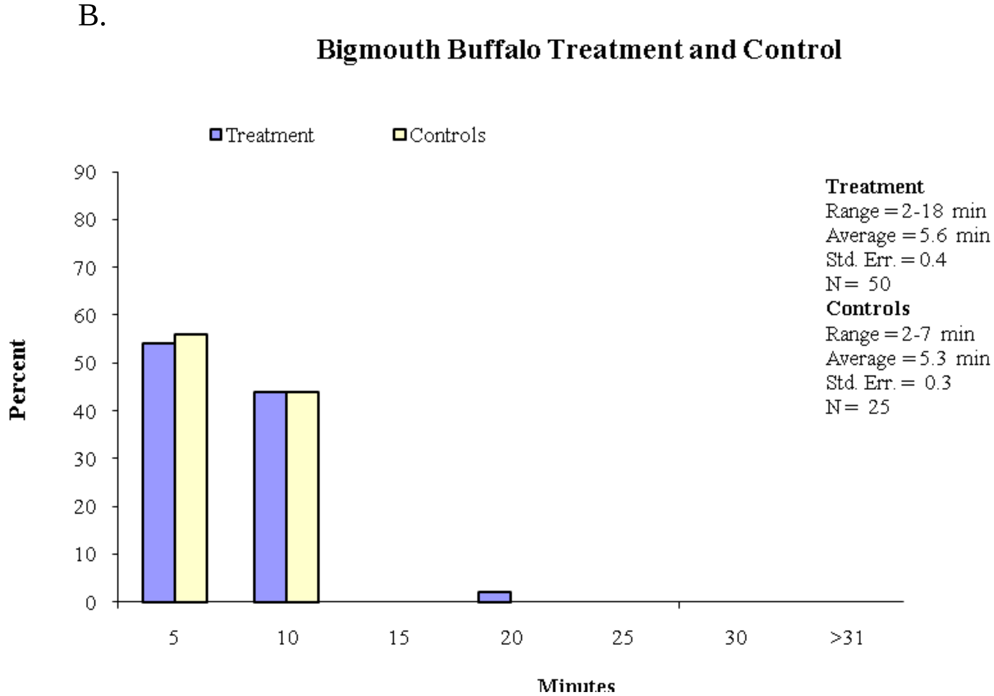


Figure 4-2. Frequency distribution of the retrieval time (minutes) for treatment and control A. smallmouth buffalo and B. bigmouth buffalo passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

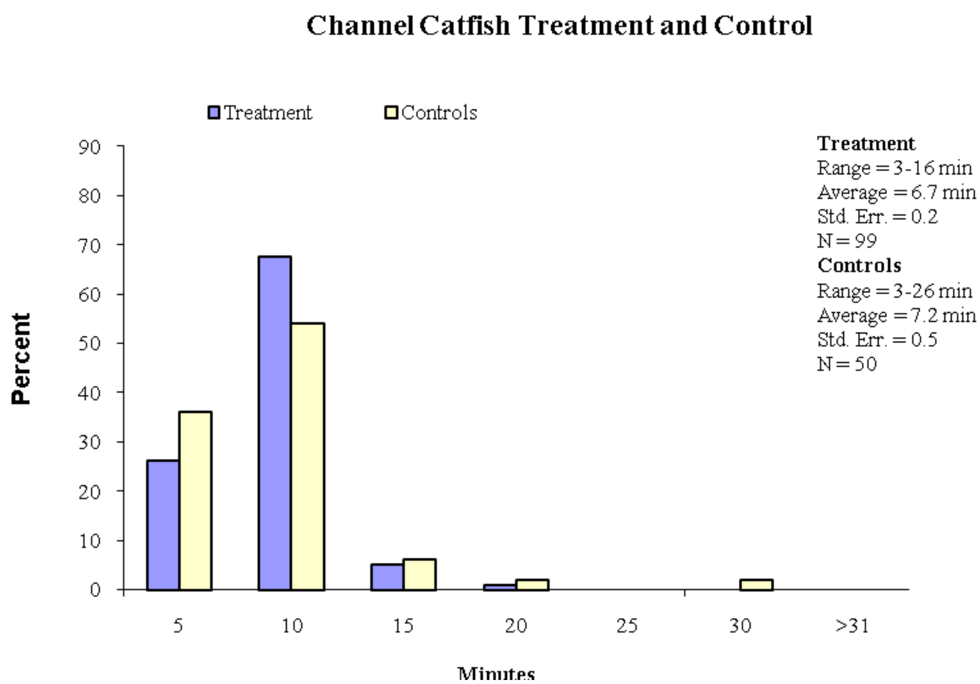


Figure 4-3. Frequency distribution of the retrieval time (minutes) for treatment and control channel catfish passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009.

11.0 APPENDIX

Appendix Table A-1. Daily tag-recapture data for releases of juvenile yellow perch and bluegill, and adult channel catfish, smallmouth buffalo and bigmouth buffalo through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2, Hydroelectric Project June 2009. Control fish were released into the tailrace.

	6/5	6/6	6/7	6/8	6/9	6/10	6/11	Totals
Yellow perch								
Number released	101	--	--	--	--	--	--	**101**
Number alive	97	--	--	--	--	--	--	**97**
Number recovered dead	2	--	--	--	--	--	--	**2**
Assigned dead**	1	--	--	--	--	--	--	**1**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	1	--	--	--	--	--	--	**1**
Undetermined	1	--	--	--	--	--	--	**1**
Held and Alive 1 h	97	--	--	--	--	--	--	**97**
Alive 24 h	97	--	--	--	--	--	--	**97**
Alive 48 h	97	--	--	--	--	--	--	**97**
Bluegill								
Number released	--	99	--	--	--	--	--	**99**
Number alive	--	97	--	--	--	--	--	**97**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	1	--	--	--	--	--	**1**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	--	1	--	--	--	--	--	**1**
Undetermined	--	1	--	--	--	--	--	**1**
Held and Alive 1 h	--	97	--	--	--	--	--	**97**
Alive 24 h	--	97	--	--	--	--	--	**97**
Alive 48 h	--	94	--	--	--	--	--	**94**

Appendix Table A-1. Continued

	6/5	6/6	6/7	6/8	6/9	6/10	6/11	Totals
Channel catfish								
Number released	--	--	50	25	25	--	--	**100**
Number alive	--	--	49	25	25	--	--	**99**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	--	1	--	--	--	--	**1**
Dislodged tags	--	--	1	--	--	--	--	**1**
Stationary radio signals	--	--	--	--	--	--	--	**0**
Undetermined	--	--	--	--	--	--	--	**0**
Held and Alive 1 h	--	--	49	25	25	--	--	**99**
Alive 24 h	--	--	49	25	25	--	--	**99**
Alive 48 h	--	--	49	25	25	--	--	**99**
Smallmouth buffalo								
Number released	--	--	--	--	2	39	11	**52**
Number alive	--	--	--	--	2	39	11	**52**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	--	--	--	--	--	--	**0**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	--	--	--	--	--	--	--	**0**
Undetermined	--	--	--	--	--	--	--	**0**
Held and Alive 1 h	--	--	--	--	2	39	11	**52**
Alive 24 h	--	--	--	--	2	39	11	**52**
Alive 48 h	--	--	--	--	2	39	10	**51**

Appendix Table A-1. Continued

	6/5	6/6	6/7	6/8	6/9	6/10	6/11	Totals
				Bigmouth buffalo				
Number released	--	--	--	--	--	--	50	**50**
Number alive	--	--	--	--	--	--	50	**50**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	--	--	--	--	--	--	**0**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	--	--	--	--	--	--	--	**0**
Undetermined	--	--	--	--	--	--	--	**0**
Held and Alive 1 h	--	--	--	--	--	--	50	**50**
Alive 24 h	--	--	--	--	--	--	50	**50**
Alive 48 h	--	--	--	--	--	--	50	**50**
				Yellow perch Control				
Number released	50	--	--	--	--	--	--	**50**
Number alive	48	--	--	--	--	--	--	**48**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	1	--	--	--	--	--	--	**1**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	1	--	--	--	--	--	--	**1**
Undetermined	1	--	--	--	--	--	--	**1**
Held and Alive 1 h	48	--	--	--	--	--	--	**48**
Alive 24 h	47	--	--	--	--	--	--	**47**
Alive 48 h	47	--	--	--	--	--	--	**47**

Appendix Table A-1. Continued

	6/5	6/6	6/7	6/8	6/9	6/10	6/11	Totals
Bluegill Control								
Number released	--	50	--	--	--	--	--	**50**
Number alive	--	50	--	--	--	--	--	**50**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	--	--	--	--	--	--	**0**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	--	--	--	--	--	--	--	**0**
Undetermined	--	--	--	--	--	--	--	**0**
Held and Alive 1 h	--	50	--	--	--	--	--	**50**
Alive 24 h	--	50	--	--	--	--	--	**50**
Alive 48 h	--	46	--	--	--	--	--	**46**
Channel catfish Control								
Number released	--	--	25	15	10	--	--	**50**
Number alive	--	--	25	15	10	--	--	**50**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	--	--	--	--	--	--	**0**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	--	--	--	--	--	--	--	**0**
Undetermined	--	--	--	--	--	--	--	**0**
Held and Alive 1 h	--	--	25	15	10	--	--	**50**
Alive 24 h	--	--	25	14	9	--	--	**48**
Alive 48 h	--	--	23	13	9	--	--	**45**

Appendix Table A-1. Continued

	6/5	6/6	6/7	6/8	6/9	6/10	6/11	Totals
Smallmouth buffalo Control								
Number released	--	--	--	--	--	21	4	**25**
Number alive	--	--	--	--	--	21	4	**25**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	--	--	--	--	--	--	**0**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	--	--	--	--	--	--	--	**0**
Undetermined	--	--	--	--	--	--	--	**0**
Held and Alive 1 h	--	--	--	--	--	21	4	**25**
Alive 24 h	--	--	--	--	--	21	4	**25**
Alive 48 h	--	--	--	--	--	21	4	**25**
Bigmouth buffalo Control								
Number released	--	--	--	--	--	--	25	**25**
Number alive	--	--	--	--	--	--	25	**25**
Number recovered dead	--	--	--	--	--	--	--	**0**
Assigned dead**	--	--	--	--	--	--	--	**0**
Dislodged tags	--	--	--	--	--	--	--	**0**
Stationary radio signals	--	--	--	--	--	--	--	**0**
Undetermined	--	--	--	--	--	--	--	**0**
Held and Alive 1 h	--	--	--	--	--	--	25	**25**
Alive 24 h	--	--	--	--	--	--	25	**25**
Alive 48 h	--	--	--	--	--	--	25	**25**

**Primarily fish where only balloon tag(s) were recaptured.

Appendix Table A-2. Daily 48 h survival/malady free data for recaptured juvenile yellow perch and bluegill, and adult channel catfish, smallmouth buffalo and bigmouth buffalo passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

	6/5	6/6	6/7	6/8	6/9	6/10	6/11	Totals
Yellow perch								
Number released	101	--	--	--	--	--	--	**101**
Number alive and malady free	97	--	--	--	--	--	--	**97**
Maladies / died*	2	--	--	--	--	--	--	**2**
Number assigned dead	1	--	--	--	--	--	--	**1**
Undetermined	1	--	--	--	--	--	--	**1**
Bluegill								
Number released	--	99	--	--	--	--	--	**99**
Number alive and malady free	--	94	--	--	--	--	--	**94**
Maladies / died*	--	3	--	--	--	--	--	**3**
Number assigned dead	--	1	--	--	--	--	--	**1**
Undetermined	--	1	--	--	--	--	--	**1**
Channel catfish								
Number released	--	--	50	25	25	--	--	**100**
Number alive and malady free	--	--	49	25	25	--	--	**99**
Maladies / died*	--	--	0	0	0	--	--	**0**
Number assigned dead	--	--	1	0	0	--	--	**1**
Undetermined	--	--	0	0	0	--	--	**0**
Smallmouth buffalo								
Number released	--	--	--	--	2	39	11	**52**
Number alive and malady free	--	--	--	--	2	39	10	**51**
Maladies / died*	--	--	--	--	0	0	1	**1**
Number assigned dead	--	--	--	--	0	0	0	**0**
Undetermined	--	--	--	--	0	0	0	**0**
Bigmouth buffalo								
Number released	--	--	--	--	--	--	50	**50**
Number alive and malady free	--	--	--	--	--	--	50	**50**
Maladies / died*	--	--	--	--	--	--	0	**0**
Number assigned dead	--	--	--	--	--	--	0	**0**
Undetermined	--	--	--	--	--	--	0	**0**

Appendix Table A-2. Continued

Yellow perch Controls								
Number released	50	--	--	--	--	--	--	**50**
Number alive and malady free	47	--	--	--	--	--	--	**47**
Maladies / died*	1	--	--	--	--	--	--	**1**
Number assigned dead	1	--	--	--	--	--	--	**1**
Undetermined	1	--	--	--	--	--	--	**1**
Bluegill Controls								
Number released	--	50	--	--	--	--	--	**50**
Number alive and malady free	--	46	--	--	--	--	--	**46**
Maladies / died*	--	4	--	--	--	--	--	**4**
Number assigned dead	--	0	--	--	--	--	--	**0**
Undetermined	--	0	--	--	--	--	--	**0**
Channel catfish Controls								
Number released	--	--	25	15	10	--	--	**50**
Number alive and malady free	--	--	23	13	9	--	--	**45**
Maladies / died*	--	--	2	2	1	--	--	**5**
Number assigned dead	--	--	0	0	0	--	--	**0**
Undetermined	--	--	0	0	0	--	--	**0**
Smallmouth buffalo Controls								
Number released	--	--	--	--	--	21	4	**25**
Number alive and malady free	--	--	--	--	--	21	7	**28**
Maladies / died*	--	--	--	--	--	0	0	**0**
Number assigned dead	--	--	--	--	--	0	0	**0**
Undetermined	--	--	--	--	--	0	0	**0**
Bigmouth buffalo Controls								
Number released	--	--	--	--	--	--	25	**25**
Number alive and malady free	--	--	--	--	--	--	25	**25**
Maladies / died*	--	--	--	--	--	--	0	**0**
Number assigned dead	--	--	--	--	--	--	0	**0**
Undetermined	--	--	--	--	--	--	0	**0**

*Maladies / died category fish were not turbine related

Appendix B. Incidence of maladies, including injury, scale loss, and temporary loss of equilibrium (LOE) observed on recaptured juvenile yellow perch and bluegill, and adult channel catfish, smallmouth buffalo and bigmouth buffalo through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2, June 2009. Control fish were released into the tailrace.

Date	TestLot	FishID	LD	Per	Comments	Malady	Photo
					Yellow perch control		
6/5/09	1	V02	dead	24h	Necropsied, no obvious injuries	No	Yes
					Bluegill control		
6/6/09	2	V39	dead	48h	No visible marks on fish	No	Yes
6/6/09	2	V43	dead	48h	No visible marks on fish	No	Yes
6/6/09	2	V45	dead	48h	No visible marks on fish	No	No
6/6/09	2	V77	dead	48h	No visible marks on fish	No	No
					Channel catfish control		
6/7/09	3	157	dead	48h	Necropsied, no obvious injuries	No	Yes
6/7/09	3	171	dead	48h	Necropsied, no obvious injuries	No	No
6/8/09	4	181	dead	24h	Necropsied, no obvious injuries	No	Yes
6/8/09	4	180	dead	48h	Necropsied, no obvious injuries	No	No
6/9/09	5	380	dead	24h	Necropsied, no obvious injuries	No	No
					Yellow perch		
6/5/09	1	S34	dead	1h	No visible marks on fish	No	Yes
6/5/09	1	S52	dead	1h	Damaged eye: missing; Flesh tear at tag site; Fish got tangled up in the chain drive mechanisum, injury not due to turbine blades, probabily would not have been injured if inflated HI-Z tag was not on fish.	No	Yes
					Bluegill		
6/6/09	2	T50	dead	48h	No visible marks on fish	No	No
6/6/09	2	T69	dead	48h	No visible marks on fish	No	No
6/6/09	2	V96	dead	48h	Necropsied, no obvious injuries	No	Yes
					Smallmouth buffalo		
6/11/09	7	348	dead	48h	No visible marks on fish	No	No

Appendix C-1. Forty-eight hour survival estimates for juvenile bluegill passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Control fish released: 50, 46 recaptured alive and 4 assigned dead; treatment fish released: 99, 94 recaptured alive and 4 assigned dead.

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S =	0.9459	(0.0186)	Control group survival
Pa = Pd	0.9933	(0.0067)	Recovery probability
Tau =	**1.0**	**N/A**	**Turbine survival***
1-Tau =	1.0	N/A	Turbine mortality*

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood: -37.122528
Variance-Covariance matrix for estimated probabilities:
0.00035 -0.00000
-0.00000 0.00004

Profile likelihood intervals:

	Turbine survival	Turbine mortality
	*__90 percent: (0.9628, 1.0000)__	**(0.0000, 0.0372)**
	95 percent: (0.9517, 1.0000)	(0.0000, 0.0483)
	99 percent: (0.9282, 1.0000)	(0.0000, 0.0718)

==

Likelihood ratio statistic for equality of recovery probabilities: 12.001166
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

Appendix C-2. Forty-eight hour survival estimates for adult channel catfish passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Control fish released: 50, 45 recaptured alive and 5 assigned dead; treatment fish released: 100, 99 recaptured alive and 1 assigned dead.

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S =	0.9600	(0.0160)	Control group survival
Pa = Pd	1.0	N/A	Recovery probability*
Tau =	**1.0**	**N/A**	**Turbine survival***
1-Tau =	1.0	N/A	Turbine mortality*

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -25.191622
Variance-Covariance matrix for estimated probabilities: 0.00026

Profile likelihood intervals:

	Turbine survival	Turbine mortality
90 percent:	**(0.9829, 1.0000)**	**(0.0000, 0.0171)**
95 percent:	(0.9762, 1.0000)	(0.0000, 0.0238)
99 percent:	(0.9603, 1.0000)	(0.0000, 0.0397)

===

Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

Appendix C-3. Forty-eight hour survival estimates for adult smallmouth and bigmouth buffalo, combined, passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Combine Control fish released: 50, 50 alive and 0 assigned dead; Combine treatment fish released: 102, 101 alive and 1 assigned dead.

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

estim. std.err.
S = 1.0 N/A Control group survival*
Pa = Pd 1.0 N/A Recovery probability*
Tau = 0.9902 (0.0098) Turbine survival
1-Tau = 0.0098 (0.0098) Turbine mortality

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -5.620055
Variance-Covariance matrix for estimated probabilities: 0.00010

Confidence Interval**
Turbine survival
90 percent: (0.974, 1.000)

==

Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

**Confidence Interval is ±1.64 X Standard Error

Appendix C-4. Forty-eight hour survival estimates for adult smallmouth buffalo passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Control fish released: 25, 25 alive and 0 assigned dead; treatment fish released: 52, 51 alive and 1 assigned dead.

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

estim. std.err.
S = 1.0 N/A Control group survival*
Pa = Pd 1.0 N/A Recovery probability*
Tau = 0.9808 (0.0190) Turbine survival
1-Tau = 0.0192 (0.0190) Turbine mortality

* **--** Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -4.941566
Variance-Covariance matrix for estimated probabilities: 0.00036

Confidence Interval**
Turbine survival
90 percent: (0.950, 1.000)

===

Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

**Confidence Interval is ±1.64 X Standard Error

Appendix C-5. Forty-eight hour survival estimates for juvenile yellow perch passed through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Control fish released: 50, 47 alive and 2 assigned dead; treatment fish released: 101, 97 alive and 3 assigned dead.

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

estim. std.err.
S = 0.9664 (0.0148) Control group survival
Pa = Pd 0.9868 (0.0093) Recovery probability
Tau = 1.0 N/A Turbine survival*
1-Tau = 1.0 N/A Turbine mortality*

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -32.522656
Variance-Covariance matrix for estimated probabilities:
0.00022 -0.00000
- 0.00000 0.00009

Profile likelihood intervals:

	Turbine survival	Turbine mortality
90 percent:	**(0.9587, 1.0000)**	**(0.0000, 0.0413)**
95 percent:	(0.9486, 1.0000)	(0.0000, 0.0514)
99 percent:	(0.9274, 1.0000)	(0.0000, 0.0726)

Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

Appendix C-6. One hour survival estimates for juvenile bluegill released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Control fish released: 50, 50 alive, 0 assigned dead. Treatment fish released: 99, 97 alive, 0 assigned dead**.**

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S =	1.0	N/A	Control group survival*
Pa = Pd	0.9933	(0.0067)	Recovery probability
Tau =	0.9898	(0.0102)	Turbine survival
1-Tau =	0.0102	(0.0102)	Turbine mortality

* **--** Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -11.580431

Variance-Covariance matrix for estimated probabilities:

0.00004 0.00000
0.00000 0.00010

Profile likelihood intervals:

	Turbine survival	Turbine mortality
90 percent:	(0.9633, 0.9989)	(0.0011, 0.0367)
95 percent:	(0.9558, 0.9994)	(0.0006, 0.0442)
99 percent:	(0.9391, 0.9999)	(0.0001, 0.0609)

===

Likelihood ratio statistic for equality of recovery probabilities: 0.821062
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

Appendix C-7. One hour survival estimates for adult channel catfish released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Control fish released: 50, 50 alive, 0 assigned dead. Treatment fish released: 100, 99 alive, 1 assigned dead.

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S =	1.0	N/A	Control group survival*
Pa = Pd	1.0	N/A	Recovery probability*
Tau =	0.9900	(0.0099)	Turbine survival
1-Tau =	0.0100	(0.0099)	Turbine mortality

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -5.600153

Variance-Covariance matrix for estimated probabilities:0.00010

Profile likelihood intervals:

	Turbine survival	Turbine mortality
90 percent:	(0.0000, 1.0000)	(0.0000, 1.0000)
95 percent:	(0.0000, 1.0000)	(0.0000, 1.0000)
99 percent:	(0.0000, 1.0000)	(0.0000, 1.0000)

==

Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

Appendix C-8. One hour survival estimates for juvenile yellow perch released through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace.

Controls: 50 released, 48 alive, 1 dead. Treatment: 101 released, 97 alive, 3 dead.

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

estim. std.err.
S1 = 0.9796 (0.0202) {Control group survival
Pa = Pd 0.9881 (0.0068) Recovery probability
Tau = 0.9902 (0.0268) Turbine/Control ratio

* -- Because of contraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -48.1045

Variance-Covariance matrix for estimated probabilities:

0.00040799 0.00000000 0.00000000 0.00000000
0.00000000 0.00004668 0.00000000 0.00000000

Confidence intervals:
Turbine 1 Tau
90 percent: (0.9461, 1.0344)
95 percent: (0.9376, 1.0428)
99 percent: (0.9211, 1.0593)
==
Likelihood ratio statistic for equality of recovery probabilities: 0.0080
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

Appendix D. Short term passage survival data on recaptured juvenile yellow perch and bluegill, and adult channel catfish, smallmouth buffalo and bigmouth buffalo through an HGE hydrokinetic turbine at the Mississippi Lock and Dam No. 2 Hydroelectric Project, June 2009. Control fish were released into the tailrace. Description of codes and details on injured fish are presented in Table 2-2 and Appendix Table B-1.

Fish ID	Total Length (mm)	Time			No. HI-Z tags recovered	Survival Code	Status Codes			
		Re-leased	Re-covered	Minutes at large			1	2	3	4
5-Jun-09		**Testlot 1**			**Water temp = 69°F**					
	Yellow perch Treatment									
XK9	145	10:53	10:57	*4*	2	1	A			
XL0	121	10:46	10:51	*5*	2	1	A			
XL1	128	10:48	10:50	*2*	2	1	A			
XL2	136	10:52	10:56	*4*	2	1	A			
XL3	136	10:54	10:57	*3*	2	1	A			
XL4	143	11:27	11:30	*3*	2	1	A			
XL5	137	11:24	11:27	*3*	2	1	A			
XL6	136	11:26	11:28	*2*	2	1	A			
XL7	125	11:25	11:27	*2*	2	1	A			
XL8	195	11:23	11:27	*4*	2	1	A			
XL9	235	11:23	11:25	*2*	2	1	A			
O56	135	11:51	12:34	*43*	2	1	A			
O59	131	11:53	11:55	*2*	2	1	A			
O58	125	11:52	11:55	*3*	2	1	A			
O57	143	11:49	11:54	*5*	2	1	A			
N96	168	11:49	11:52	*3*	2	1	A			
N95	151	12:24	12:28	*4*	2	1	A			
P53	137	11:51	11:53	*2*	2	1	A			
S00	132	11:48	11:52	*4*	2	1	A			
S01	170	12:27	12:31	*4*	2	1	A			
S02	128	12:25	12:30	*5*	2	1	A			
S03	123	12:26	12:29	*3*	2	1	A			
S04	145	12:25	12:31	*6*	2	1	A			
S05	132	12:26	12:32	*6*	2	1	A			
S06	130	12:28	12:30	*2*	2	1	A			
S07	152	12:33	12:37	*4*	2	1	A			
S08	161	12:34	12:37	*3*	2	1	A			
S09	135	12:35	12:39	*4*	2	1	A			
S10	132	12:36	12:41	*5*	2	1	A			
S11	157	12:35	12:37	*2*	2	1	A			
S12	146	13:00	13:06	*6*	2	1	A			
S13	122	13:01	13:04	*3*	2	1	A			
S14	130	13:02	13:08	*6*	2	1	A			
S15	122	13:02	13:06	*4*	2	1	A			
S16	118	13:03	13:06	*3*	2	1	A			
S17	219	13:06	13:10	*4*	2	1	A			
S18	133	13:08	13:10	*2*	2	1	A			
S19	139	13:04	13:08	*4*	2	1	A			
S20	168	13:06	13:10	*4*	2	1	A			
S21	202	13:05	13:08	*3*	2	1	A			
S22	128	13:38	13:40	*2*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time			No. HI-Z tags recovered	Survival Code	Status Codes			
		Re-leased	Re-covered	Minutes at large			1	2	3	4
5-Jun-09		**Testlot 1**			**Water temp = 69°F**					
	Yellow perch Treatment									
S23	126	13:37	13:41	*4*	2	1	A			
S24	123	13:36	13:39	*3*	2	1	A			
S25	137	13:37	13:40	*3*	2	1	A			
S26	126	13:38	13:40	*2*	2	1	A			
S27	186	13:39	13:45	*6*	2	1	A			
S28	202	13:40	13:45	*5*	2	1	A			
S29	126	13:41	13:45	*4*	2	1	A			
S30	128	13:42	13:43	*1*	2	1	A			
S31	140	13:41	13:44	*3*	2	1	A			
S32	129	14:03	14:06	*3*	2	1	A			
S33	131	14:02	14:06	*4*	2	1	A			
S34	127	14:04	17:45	*221*	2	2	A			
S35	131	14:04	14:09	*5*	2	1	A			
S36	137	14:04	14:06	*2*	2	1	A			
S37	143	14:06	14:09	*3*	2	1	A			
S38	132	14:07	14:11	*4*	2	1	A			
S39	138	14:07	14:09	*2*	2	1	A			
S40	169	14:09	14:13	*4*	2	1	A			
S41	137	14:08	14:12	*4*	2	1	A			
S42	133	14:34	14:36	*2*	2	1	A			
S43	124	14:35	14:39	*4*	2	1	A			
S44	128	14:32			0	4				
S45	120	14:36	14:39	*3*	2	1	A			
S46	143	14:33	14:35	*2*	2	1	A			
S47	132	14:38	14:40	*2*	2	1	A			
S48	167	14:44	14:45	*1*	2	1	A			
S49	153	14:42	14:43	*1*	2	1	A			
S50	138	14:41	14:42	*1*	2	1	A			
S51	193	14:39	14:42	*3*	2	1	A			
S52	163	15:10	15:13	*3*	1	2	8	B	T	
S53	140	15:07	15:09	*2*	2	1	A			
S54	153	15:08	15:10	*2*	2	1	A			
S55	156	15:04	15:08	*4*	2	1	A			
S56	188	15:06	15:09	*3*	2	1	A			
S57	143	15:11	15:17	*6*	2	1	A			
S58	131	15:17	15:20	*3*	2	1	A			
S59	146	15:15	15:17	*2*	2	1	A			
S60	151	15:12	15:15	*3*	2	1	A			
S61	123	15:16	15:19	*3*	2	1	A			
S62	137	15:43	15:44	*1*	2	1	A			
S63	149	15:41	15:43	*2*	2	1	A			
S64	159	15:40	15:43	*3*	2	1	A			
S65	136	15:42	15:45	*3*	2	1	A			
S66	151	15:41	15:45	*4*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	5-Jun-09	**Testlot 1**			**Water temp = 69°F**					
	Yellow perch Treatment									
S67	140	15:45	15:47	*2*	2	1	A			
S68	134	15:48	15:50	*2*	2	1	A			
S69	156	15:44	15:47	*3*	2	1	A			
S70	147	15:46	15:48	*2*	2	1	A			
S71	150	15:47	15:49	*2*	2	1	A			
S72	141	15:55	15:58	*3*	2	1	A			
S73	137	15:57	16:00	*3*	2	1	A			
S74	152	15:56	15:59	*3*	2	1	A			
S75	142	15:58	16:00	*2*	2	1	A			
S76	148	15:54	15:59	*5*	2	1	A			
S77	150	16:01	16:05	*4*	2	1	A			
S78	137	15:59	16:03	*4*	2	1	A			
S79	143	16:00	16:03	*3*	2	1	A			
S80	137	16:03	16:05	*2*	2	1	A			
S81	165	16:02	16:06	*4*	2	1	A			
T00	210	16:10			0	5	T			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	5-Jun-09	Testlot 1			Water temp = 69°F					
	Yellow perch Control									
S82	148	16:55	16:57	*2*	2	1	A			
S83	132	16:59		*2*	0	5	L			
S84	128	16:57	17:01	*4*	2	1	A			
S85	148	16:58	17:01	*3*	2	1	A			
S86	125	16:56	16:59	*3*	2	1	A			
S87	133	17:04	17:06	*2*	2	1	A			
S88	137	17:02	17:04	*2*	2	1	A			
S89	137	17:03			0	4				
S90	136	17:04	17:05	*1*	2	1	A			
S91	172	17:01	17:05	*4*	2	1	A			
S92	150	17:26	17:29	*3*	2	1	A			
S93	146	17:27	17:30	*3*	2	1	A			
S94	137	17:24	17:28	*4*	2	1	A			
S95	170	17:28	18:15	*47*	2	1	A			
S96	140	17:25	17:28	*3*	2	1	A			
S97	138	17:30	17:32	*2*	2	1	A			
S98	148	17:29	17:32	*3*	2	1	A			
S99	140	17:33	17:35	*2*	2	1	A			
V00	136	17:34	17:36	*2*	2	1	A			
V01	148	17:31	17:35	*4*	2	1	A			
V02	122	17:55	17:57	*2*	2	1	A			
V03	132	17:54	17:59	*5*	2	1	A			
V04	124	17:57	18:00	*3*	2	1	A			
V05	133	17:58	18:00	*2*	2	1	A			
V06	120	17:57	18:01	*4*	2	1	A			
V07	133	18:03	18:05	*2*	2	1	A			
V08	136	18:02	18:04	*2*	2	1	A			
V09	142	18:01	18:03	*2*	2	1	A			
V10	131	18:02	18:05	*3*	2	1	A			
V11	142	18:00	18:02	*2*	2	1	A			
V12	128	18:16	18:19	*3*	2	1	A			
V13	133	18:16	18:18	*2*	2	1	A			
V14	143	18:17	18:19	*2*	2	1	A			
V15	176	18:16	18:17	*1*	2	1	A			
V16	146	18:15	18:18	*3*	2	1	A			
V17	207	18:19	18:21	*2*	2	1	A			
V18	118	18:20	18:22	*2*	2	1	A			
V19	157	18:20	18:25	*5*	2	1	A			
V20	150	18:20	18:22	*2*	2	1	A			
V21	130	18:19	18:21	*2*	2	1	A			
V22	153	18:35	18:38	*3*	2	1	A			
V23	143	18:37	18:40	*3*	2	1	A			
V24	155	18:38	18:40	*2*	2	1	A			
V25	156	18:34	18:37	*3*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
5-Jun-09		**Testlot 1**			**Water temp = 69°F**					
	Yellow perch Control									
V26	190	18:36	18:40	*4*	2	1	A			
V27	140	18:41	18:43	*2*	2	1	A			
V28	156	18:38	18:40	*2*	2	1	A			
V29	143	18:38	18:40	*2*	2	1	A			
V30	137	18:41	18:44	*3*	2	1	A			
V31	147	18:40	18:42	*2*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	6-Jun-09	**Testlot 2**			**Water temp = 65°F**					
	Bluegill Treatment									
V87	168	10:24	10:27	*3*	2	1	A			
V88	180	10:25	10:29	*4*	2	1	A			
V89	122	10:26	10:28	*2*	2	1	A			
V90	163	10:24	10:29	*5*	1	1	B			
V91	190	10:25	10:29	*4*	2	1	A			
V82	169	10:23	10:24	*1*	2	1	A			
V83	144	10:22	10:26	*4*	2	1	A			
V84	185	10:21	10:32	*11*	2	1	A			
V85	180	10:21	10:23	*2*	2	1	A			
V86	190	10:22	10:25	*3*	2	1	A			
V92	173	10:49	10:51	*2*	2	1	A			
V93	190	10:48	10:52	*4*	2	1	A			
V94	158	10:48	10:50	*2*	2	1	A			
V95	132	10:50	10:53	*3*	2	1	A			
V96	132	10:50	10:52	*2*	2	1	A			
V97	133	10:52	10:56	*4*	2	1	A			
V98	142	10:53	10:56	*3*	2	1	A			
T00	184	10:51	10:54	*3*	2	1	A			
T01	178	10:51	10:56	*5*	2	1	A			
T02	132	10:52	10:55	*3*	2	1	A			
T03	187	11:51	11:54	*3*	2	1	A			
T04	182	11:50	11:52	*2*	2	1	A			
T05	127	11:50	11:52	*2*	2	1	A			
T06	120	11:52	11:54	*2*	2	1	A			
T07	190	11:51	12:07	*16*	2	1	H			
V63	170	11:52	11:57	*5*	2	1	A			
T08	158	11:53	11:58	*5*	2	1	A			
T09	180	11:53	11:58	*5*	2	1	A			
T10	188	11:54	11:59	*5*	2	1	A			
T11	159	11:54	12:00	*6*	2	1	A			
T12	185	12:17	12:18	*1*	2	1	A			
T13	163	12:15	12:18	*3*	2	1	A			
T14	190	12:15	12:17	*2*	2	1	A			
T15	188	12:16	12:19	*3*	2	1	A			
T16	139	12:16	12:20	*4*	2	1	A			
T17	170	12:19	12:21	*2*	2	1	A			
T18	179	12:17	12:19	*2*	2	1	A			
T19	190	12:18	12:21	*3*	2	1	A			
T20	204	12:19	12:23	*4*	2	1	A			
T21	173	12:18	12:22	*4*	2	1	A			
T22	175	12:34	12:35	*1*	2	1	A			
T23	147	12:33	12:35	*2*	2	1	A			
T24	185	12:33	12:41	*8*	2	1	A			
T25	180	12:34	12:36	*2*	2	1	A			
T26	176	12:35	12:38	*3*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time			No. HI-Z tags recovered	Survival Code	Status Codes			
		Re-leased	Re-covered	Minutes at large			1	2	3	4
	6-Jun-09	Testlot 2			Water temp = 65°F					
	Bluegill Treatment									
T27	183	12:35	12:39	*4*	2	1	A			
T28	177	12:36	12:39	*3*	2	1	A			
T29	178	12:37	12:39	*2*	2	1	A			
T30	183	12:35	12:40	*5*	2	1	A			
T31	152	12:36	12:38	*2*	2	1	A			
T32	172	12:54	12:59	*5*	2	1	A			
T33	188	12:52	12:57	*5*	2	1	A			
T34	187	12:53	12:56	*3*	2	1	A			
T35	155	12:52	12:57	*5*	2	1	A			
T36	182	12:53	12:56	*3*	2	1	A			
T37	181	12:56	12:58	*2*	2	1	A			
T38	183	12:55	13:00	*5*	2	1	A			
T39	194	12:55	12:59	*4*	2	1	A			
T40	198	12:56	13:00	*4*	2	1	A			
T41	120	12:57	12:59	*2*	2	1	A			
T42	189	13:21	13:24	*3*	2	1	A			
T43	171	13:21	13:27	*6*	2	1	A			
T44	153	13:20			0	5	T			R
T45	185	13:20	13:23	*3*	2	1	A			
T46	132	13:20	13:23	*3*	2	1	A			
T47	128	13:22	13:26	*4*	2	1	A			
T48	153	13:23	13:26	*3*	2	1	A			
T49	173	13:21	13:25	*4*	2	1	A			
T50	128	13:23	13:26	*3*	2	1	A			
T51	185	13:22	13:28	*6*	2	1	A			
T52	184	13:44	13:48	*4*	2	1	A			
T53	174	13:45	13:48	*3*	2	1	A			
T54	188	13:46	13:49	*3*	2	1	A			
T55	186	13:45	13:47	*2*	2	1	A			
T56	175	13:44	13:46	*2*	2	1	A			
T57	187	13:48	13:51	*3*	2	1	A			
T58	176	13:48	13:51	*3*	2	1	A			
T59	175	13:49	13:50	*1*	2	1	A			
T60	158	13:47	13:50	*3*	2	1	A			
T61	163	13:47	13:49	*2*	2	1	A			
T62	160	14:10	14:12	*2*	2	1	A			
T63	192	14:06	14:09	*3*	2	1	A			
T64	161	14:08	14:12	*4*	2	1	A			
T65	161	14:07	14:08	*1*	2	1	A			
T66	190	14:09	14:10	*1*	2	1	A			
T67	173	14:11	14:14	*3*	2	1	A			
T68	183	14:10	14:12	*2*	2	1	A			
T69	129	14:12	14:15	*3*	2	1	A			
T70	169	14:14	14:18	*4*	2	1	A			
T71	187	14:13	14:17	*4*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
6-Jun-09		**Testlot 2**			**Water temp = 65°F**					
	<u>Bluegill Treatment</u>									
T72	184	14:23	14:28	*5*	2	1	A			
T73	154	14:26			0	5				
T74	182	14:24	14:28	*4*	2	1	A			
T75	151	14:26	14:27	*1*	2	1	A			
T76	185	14:25	14:29	*4*	2	1	A			
T77	124	14:31	14:33	*2*	2	1	A			
T78	142	14:29	14:31	*2*	2	1	A			
T79	145	14:30	14:32	*2*	2	1	A			
T80	180	14:28			0	4				
T81	192	14:29	14:31	*2*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	6-Jun-09	**Testlot 2**			**Water temp = 65°F**					
	Bluegill Control									
V32	192	9:29	9:32	*3*	2	1	A			
V33	191	8:26	8:30	*4*	2	1	A			
V34	180	8:28	8:30	*2*	2	1	A			
V35	174	8:29	8:31	*2*	2	1	A			
V36	160	8:44	8:45	*1*	2	1	A			
V37	153	8:31	8:33	*2*	2	1	A			
V38	177	8:30	8:32	*2*	2	1	A			
V39	143	8:31	8:36	*5*	2	1	A			
V40	150	8:32	8:36	*4*	2	1	A			
V41	137	8:31	8:34	*3*	2	1	A			
V42	190	8:42	8:44	*2*	2	1	A			
V43	135	8:45	8:51	*6*	2	1	A			
V44	170	8:44	8:48	*4*	2	1	A			
V45	134	8:43	8:45	*2*	2	1	A			
V46	120	8:44	8:46	*2*	2	1	A			
V47	181	8:46	8:49	*3*	2	1	A			
V48	187	8:47	8:50	*3*	2	1	A			
V49	155	8:45	8:59	*14*	2	1	A			
V50	208	8:45	8:48	*3*	2	1	A			
V51	136	8:46	9:12	*26*	2	1	A			
V52	156	9:20	9:24	*4*	2	1	A			
V53	139	9:21	9:22	*1*	2	1	A			
V54	148	9:20	9:22	*2*	2	1	A			
V55	188	9:19	9:21	*2*	2	1	A			
V56	180	9:19	9:20	*1*	2	1	A			
V57	137	9:22	9:24	*2*	2	1	A			
V58	187	9:23	9:24	*1*	2	1	A			
V59	172	9:22	9:23	*1*	2	1	A			
V60	192	9:21	9:23	*2*	2	1	A			
V61	131	9:23	9:25	*2*	2	1	A			
V62	159	9:36	9:38	*2*	2	1	A			
V99	178	9:34	9:38	*4*	2	1	A			
V64	190	9:36	9:40	*4*	2	1	A			
V65	184	9:34	9:40	*6*	2	1	A			
V66	130	9:35	9:37	*2*	2	1	A			
V67	190	9:39	9:41	*2*	2	1	A			
V68	175	9:37	9:42	*5*	2	1	A			
V69	161	9:37	9:40	*3*	2	1	A			
V70	126	9:38	9:40	*2*	2	1	A			
V71	128	9:38	9:42	*4*	2	1	A			
V72	182	9:52	9:54	*2*	2	1	A			
V73	160	9:52	9:54	*2*	2	1	A			
V74	178	9:51	9:54	*3*	2	1	A			
V75	197	9:51	9:56	*5*	2	1	A			
V76	192	9:50	9:55	*5*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
6-Jun-09		**Testlot 2**			**Water temp = 65°F**					
	Bluegill Control									
V77	115	9:56	10:00	*4*	2	1	A			
V78	150	9:56	9:58	*2*	2	1	A			
V79	170	9:55	10:00	*5*	2	1	A			
V80	181	9:54	9:57	*3*	2	1	A			
V81	135	9:54	9:58	*4*	2	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	7-Jun-09	**Testlot 3**			**Water temp = 63°F**					
	Channel catfish Treatment									
451	590	9:20	9:26	*6*	4	1	A			
452	475	9:31	9:37	*6*	4	1	A			
454	560	9:50	9:56	*6*	4	1	A			
455	464	9:53	9:59	*6*	4	1	A			
456	515	10:00	10:04	*4*	4	1	A			
458	570	10:09	10:15	*6*	4	1	A			
459	535	10:16	10:21	*5*	4	1	A			
460	595	10:24	10:34	*10*	4	1	A			
461	475	10:28	10:32	*4*	4	1	A			
462	600	10:35	10:45	*10*	4	1	A			
463	505	10:42	10:49	*7*	4	1	A			
464	555	10:55	11:01	*6*	4	1	A			
465	620	10:54	11:01	*7*	4	1	A			
466	517	11:07	11:20	*13*	4	1	A			
467	517	11:10	11:20	*10*	4	1	A			
468	540	11:26	11:40	*14*	4	1	A			
469	535	11:27	11:32	*5*	4	1	A			
470	515	11:44	11:50	*6*	4	1	A			
471	485	11:46	11:50	*4*	4	1	A			
472	480	11:59	12:06	*7*	4	1	A			
473	610	11:58	12:09	*11*	4	1	A			
474	590	12:13	12:21	*8*	4	1	A			
475	500	12:14	12:19	*5*	4	1	A			
476	615	12:29	12:40	*11*	4	1	A			
477	605	12:31	12:37	*6*	4	1	A			
478	487	12:48	12:53	*5*	4	1	A			
479	500	12:46	12:53	*7*	4	1	A			
480	518	13:00	13:05	*5*	4	1	A			
481	552	13:02	13:08	*6*	4	1	A			
482	497	13:13	13:17	*4*	4	1	A			
483	459	13:14	13:17	*3*	4	1	A			
484	570	13:23	13:31	*8*	4	1	A			
485	580	13:22	13:28	*6*	4	1	A			
486	511	13:39	13:44	*5*	4	1	A			
487	542	13:38	13:43	*5*	4	1	A			
488	582	13:50	13:59	*9*	4	1	A			
489	570	13:48	13:54	*6*	4	1	A			
490	545	14:02	14:07	*5*	4	1	A			
491	505	14:01	14:08	*7*	4	1	A			
492	607	14:12	14:18	*6*	4	1	A			
493	548	14:13	14:19	*6*	4	1	A			
494	538	14:23	14:29	*6*	4	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time			No. HI-Z tags recovered	Survival Code	Status Codes			
		Re-leased	Re-covered	Minutes at large			1	2	3	4
	7-Jun-09	**Testlot 3**			**Water temp = 63°F**					
	Channel catfish Treatment									
495	578	14:24	14:28	*4*	4	1	A			
496	546	14:32	14:37	*5*	4	1	A			
497	522	14:33	14:39	*6*	4	1	A			
498	610	14:40	14:46	*6*	4	1	A			
499	575	14:42			2	3				
500	592	14:50	14:56	*6*	2	1	A			
151	508	15:02	15:16	*14*	2	1	A			
152	522	15:05	15:14	*9*	4	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	7-Jun-09	**Testlot 3**			**Water temp = 63°F**					
	Channel catfish Control									
153	528	15:32	15:58	*26*	4	1	A			
154	552	15:31	15:46	*15*	4	1	A			
155	530	15:49	15:59	*10*	4	1	A			
156	545	15:48	15:54	*6*	4	1	A			
157	627	16:03	16:20	*17*	4	1	A			
158	567	16:03	16:10	*7*	4	1	A			
159	470	16:09	16:13	*4*	4	1	A			
160	500	16:08	16:13	*5*	4	1	A			
161	566	16:19	16:27	*8*	4	1	A			
162	600	16:21	16:28	*7*	4	1	A			
163	544	16:30	16:36	*6*	3	1	A			
164	511	16:31	16:36	*5*	4	1	A			
165	530	16:39	16:44	*5*	4	1	A			
166	504	16:41	16:44	*3*	4	1	A			
167	596	16:56	17:01	*5*	4	1	A			
168	528	16:55	17:02	*7*	4	1	A			
169	505	16:58	17:03	*5*	4	1	A			
170	480	17:04	17:10	*6*	4	1	A			
171	473	17:03	17:10	*7*	4	1	A			
172	461	17:09	17:14	*5*	2	1	A			
173	461	17:10	17:16	*6*	4	1	A			
174	451	17:29	17:36	*7*	4	1	A			
175	530	17:28	17:36	*8*	4	1	A			
453	484	9:39	9:43	*4*	4	1	A			
177	577	17:26	17:32	*6*	4	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	8-Jun-09	**Testlot 4**			**Water temp = 63°F**					
	Channel catfish Treatment									
193	499	13:02	13:08	*6*	4	1	A			
194	516	13:01	13:07	*6*	4	1	A			
195	553	13:14	13:20	*6*	4	1	A			
196	583	13:17	13:23	*6*	4	1	A			
197	560	13:28	13:35	*7*	4	1	A			
198	581	13:30	13:35	*5*	4	1	A			
199	538	13:43	13:48	*5*	4	1	A			
200	546	13:44	13:52	*8*	4	1	A			
1	618	13:57	14:04	*7*	4	1	A			
2	476	13:58	14:03	*5*	4	1	A			
3	615	14:08	14:14	*6*	4	1	A			
4	542	14:09	14:14	*5*	4	1	A			
5	540	14:20	14:26	*6*	4	1	A			
6	545	14:22	14:27	*5*	4	1	A			
7	538	14:36	14:40	*4*	4	1	A			
8	585	14:37	14:42	*5*	4	1	A			
9	573	14:49	14:55	*6*	4	1	A			
10	592	14:51	14:58	*7*	4	1	A			
11	610	14:59	15:08	*9*	4	1	A			
12	584	15:00	15:08	*8*	4	1	A			
13	540	15:11	15:18	*7*	4	1	A			
14	543	15:12	15:19	*7*	4	1	A			
15	568	15:18	15:27	*9*	4	1	A			
16	490	15:21	15:28	*7*	4	1	A			
17	528	15:27	15:33	*6*	4	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	9-Jun-09	**Testlot 5**			**Water temp = 62°F**					
	Channel catfish Treatment									
18	556	10:19	10:26	*7*	4	1	A			
19	615	10:21	10:27	*6*	4	1	A			
20	504	10:37	10:44	*7*	4	1	A			
21	480	10:39	10:46	*7*	4	1	A			
22	535	10:59	11:05	*6*	4	1	A			
23	544	11:00	11:06	*6*	4	1	A			
24	604	11:12	11:19	*7*	4	1	A			
26	568	11:11	11:20	*9*	4	1	A			
27	550	11:23	11:27	*4*	4	1	A			
28	478	11:24	11:27	*3*	4	1	A			
29	625	11:34	11:42	*8*	4	1	A			
30	519	11:37	11:46	*9*	4	1	A			
31	499	12:32	12:39	*7*	4	1	A			
32	501	12:30	12:34	*4*	4	1	A			
33	501	12:42	12:49	*7*	4	1	A			
34	543	12:43	12:53	*10*	4	1	A			
35	545	12:53	13:01	*8*	4	1	A			
36	522	12:55	13:01	*6*	4	1	A			
37	520	13:14	13:22	*8*	4	1	A			
38	520	13:15	13:21	*6*	4	1	A			
39	470	13:34	13:40	*6*	4	1	A			
40	525	13:36	13:43	*7*	4	1	A			
41	613	13:48	14:04	*16*	4	1	A			
42	600	13:46	13:53	*7*	4	1	A			
43	572	13:55	14:00	*5*	4	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
9-Jun-09		**Testlot 5**			**Water temp = 62°F**					
Channel catfish Control										
44	499	14:44	14:52	*8*	4	1	A			
45	558	14:42	14:49	*7*	4	1	A			
47	493	14:51	14:59	*8*	4	1	A			
48	481	14:50	14:56	*6*	4	1	A			
49	592	15:03	15:17	*14*	4	1	A			
50	505	15:01	15:07	*6*	4	1	A			
376	503	15:17	15:22	*5*	4	1	A			
378	515	15:18	15:27	*9*	4	1	A			
379	520	15:34	15:38	*4*	4	1	A			
380	476	15:31	15:35	*4*	4	1	A			

Fish ID	Total Length (mm)	Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
9-Jun-09		**Testlot 5A**			**Water temp = 62°F**					
Smallmouth buffalo Treatment										
385	625	16:18	16:48	*30*	4	1	A			
386	633	16:28	16:38	*10*	3	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
10-Jun-09		**Testlot 6**			**Water temp = 62°F**					
Smallmouth buffalo Treatment										
357	565	13:14	13:20	*6*	6	1	A			
358	600	13:15	13:21	*6*	6	1	A			
359	645	13:30	13:33	*3*	6	1	A			
360	585	13:32	13:38	*6*	6	1	A			
361	625	13:49	13:53	*4*	6	1	A			
362	535	13:51			0	5	T	R		
363	640	14:01	14:08	*7*	6	1	A			
364	611	14:06	14:14	*8*	6	1	A			
365	415	14:13	14:20	*7*	6	1	A			
366	630	14:14	14:19	*5*	5	1	A			
367	640	14:29	14:32	*3*	6	1	A			
368	535	14:30	14:36	*6*	5	1	A			
369	625	14:42	14:48	*6*	6	1	A			
370	560	14:44	14:49	*5*	6	1	A			
371	587	14:57	15:02	*5*	6	1	A			
372	595	14:58	15:05	*7*	6	1	A			
373	594	15:11	15:16	*5*	6	1	A			
374	598	15:14	15:19	*5*	6	1	A			
375	573	15:26	15:29	*3*	5	1	A			
326	506	15:28	15:33	*5*	6	1	A			
327	528	15:40	15:43	*3*	6	1	A			
328	634	15:42	15:46	*4*	6	1	A			
329	600	15:55	16:05	*10*	2	1	A			
330	642	15:57	16:03	*6*	5	1	A			
331	655	16:11	16:15	*4*	6	1	A			
332	545	16:12	16:18	*6*	6	1	A			
333	665	16:23	16:30	*7*	6	1	A			
334	624	16:24	16:30	*6*	6	1	A			
335	624	16:38	16:42	*4*	6	1	A			
336	625	16:39	16:43	*4*	6	1	A			
337	580	16:53	16:57	*4*	6	1	A			
338	615	16:55	17:02	*7*	5	1	A			
339	665	17:12	17:17	*5*	6	1	A			
340	650	17:15	17:22	*7*	4	1	A			
341	470	17:26	17:29	*3*	6	1	A			
342	655	17:28	17:33	*5*	6	1	A			
343	610	17:36	17:42	*6*	5	1	A			
344	560	17:38	17:40	*2*	6	1	A			
345	615	17:53	17:58	*5*	5	1	A			
346	564	17:52	17:56	*4*	6	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
10-Jun-09		**Testlot 6**			**Water temp = 62°F**					
Smallmouth buffalo Control										
387	619	9:34	9:37	*3*	6	1	A			
388	573	9:35	9:37	*2*	6	1	A			
389	533	9:46	9:59	*13*	6	1	A			
390	590	9:48	9:52	*4*	5	1	A			
391	580	10:03	10:12	*9*	6	1	A			
392	645	10:04	10:09	*5*	6	1	A			
393	646	10:23	10:28	*5*	6	1	A			
394	610	10:24	10:32	*8*	6	1	A			
395	650	10:41	10:52	*11*	6	1	A			
396	548	10:42	10:49	*7*	4	1	A			
397	602	10:54	11:00	*6*	6	1	A			
398	680	10:57	11:02	*5*	6	1	A			
399	585	11:07	11:13	*6*	5	1	A			
400	620	11:08	11:15	*7*	6	1	A			
351	670	11:33	11:39	*6*	6	1	A			
352	625	11:34	11:40	*6*	6	1	A			
353	634	11:47	11:51	*4*	6	1	A			
354	564	11:48	11:52	*4*	6	1	A			
355	645	12:04	12:09	*5*	6	1	A			
356	570	12:03	12:08	*5*	6	1	A			
347	710	18:06	18:17	*11*	3	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes: 1	2	3	4
	11-Jun-09	**Testlot 7**			**Water temp = 62°F**					
	Smallmouth buffalo Treatment									
348	570	8:46	8:57	*11*	6	1	A			
349	595	8:47	8:54	*7*	6	1	A			
350	570	8:56	9:02	*6*	6	1	A			
301	590	8:58	9:13	*15*	6	1	A			
302	610	9:13	9:19	*6*	6	1	A			
303	607	9:12	9:16	*4*	6	1	A			
304	596	9:21	9:25	*4*	6	1	A			
305	602	9:23	9:27	*4*	6	1	A			
306	602	9:35	9:39	*4*	6	1	A			
307	590	9:37	9:41	*4*	6	1	A			
308	580	9:48	9:54	*6*	6	1	A			

Fish ID	Total Length (mm)	Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes: 1	2	3	4
	11-Jun-09	**Testlot 7**			**Water temp = 62°F**					
	Smallmouth buffalo Control									
309	502	10:00	10:04	*4*	5	1	A			
310	570	10:02	10:07	*5*	6	1	A			
311	678	10:12	10:17	*5*	6	1	A			
312	630	10:11	10:15	*4*	6	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	11-Jun-09	**Testlot 8**			**Water temp = 62°F**					
	Bigmouth buffalo Treatment									
313	442	10:31	10:38	*7*	4	1	A			
314	440	10:33	10:38	*5*	4	1	A			
315	418	10:44	10:50	*6*	4	1	A			
316	441	10:42	10:48	*6*	4	1	A			
317	438	10:52	10:57	*5*	4	1	A			
318	451	10:50	10:57	*7*	4	1	A			
319	430	10:59	11:03	*4*	4	1	A			
320	410	11:00	11:05	*5*	4	1	A			
321	430	11:08	11:13	*5*	4	1	A			
322	445	11:09	11:14	*5*	4	1	A			
323	462	11:17	11:22	*5*	4	1	A			
324	436	11:19	11:24	*5*	4	1	A			
325	423	11:28	11:34	*6*	4	1	A			
401	388	11:26	11:29	*3*	4	1	A			
402	441	11:36	11:42	*6*	4	1	A			
403	433	11:34	11:38	*4*	4	1	A			
404	465	11:45	11:49	*4*	4	1	A			
405	452	11:47	11:50	*3*	4	1	A			
406	426	11:56	12:00	*4*	4	1	A			
407	399	11:55	11:59	*4*	4	1	A			
408	412	12:08	12:14	*6*	4	1	A			
409	436	12:07	12:12	*5*	4	1	A			
410	453	12:18	12:26	*8*	4	1	A			
411	392	12:17	12:21	*4*	4	1	A			
412	425	12:26	12:32	*6*	4	1	A			
413	467	12:28	12:35	*7*	4	1	A			
414	442	12:40	12:43	*3*	4	1	A			
415	461	12:39	12:46	*7*	4	1	A			
416	432	12:53	13:03	*10*	4	1	A			
417	395	12:54	12:58	*4*	4	1	A			
418	428	13:05	13:10	*5*	4	1	A			
419	415	13:07	13:15	*8*	4	1	A			
420	391	13:15	13:18	*3*	4	1	A			
421	445	13:17	13:27	*10*	4	1	A			
422	430	13:24	13:30	*6*	4	1	A			
423	425	13:26	13:31	*5*	4	1	A			
424	429	13:38	13:44	*6*	4	1	A			
425	438	13:36	13:43	*7*	4	1	A			
426	453	13:46	13:54	*8*	4	1	A			
427	410	13:44	13:48	*4*	4	1	A			
428	428	13:54	13:57	*3*	4	1	A			
429	396	13:52	13:56	*4*	4	1	A			
430	470	14:03	14:06	*3*	4	1	A			
431	458	14:01	14:05	*4*	4	1	A			

Appendix D. Continued

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	11-Jun-09	**Testlot 8**			**Water temp = 62°F**					
	Bigmouth buffalo Treatment									
432	460	14:08	14:15	*7*	4	1	A			
433	451	14:10	14:28	*18*	4	1	A			
434	431	14:16	14:19	*3*	4	1	A			
435	440	14:14	14:20	*6*	4	1	A			
436	446	14:23	14:29	*6*	4	1	A			
437	423	14:24	14:30	*6*	4	1	A			

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
	11-Jun-09	**Testlot 8**			**Water temp = 62°F**					
	Bigmouth buffalo Control									
438	437	14:45	14:52	*7*	4	1	A			
439	415	14:44	14:49	*5*	4	1	A			
440	445	14:53	15:00	*7*	4	1	A			
441	427	14:51	14:57	*6*	4	1	A			
442	420	15:01	15:05	*4*	4	1	A			
443	446	15:00	15:04	*4*	4	1	A			
444	418	15:05	15:09	*4*	4	1	A			
445	482	15:07	15:13	*6*	4	1	A			
446	471	15:13	15:19	*6*	4	1	A			
447	416	15:11	15:18	*7*	4	1	A			
448	405	15:21	15:26	*5*	4	1	A			
449	420	15:20	15:26	*6*	4	1	A			
450	388	15:19	15:24	*5*	4	1	A			
101	430	15:27	15:32	*5*	4	1	A			
102	480	15:26	15:33	*7*	4	1	A			
103	436	15:35	15:39	*4*	4	1	A			
104	460	15:38	15:40	*2*	4	1	A			
105	461	15:48	15:52	*4*	4	1	A			
106	435	15:49	15:55	*6*	4	1	A			
107	431	15:59	16:04	*5*	4	1	A			
108	440	16:00	16:07	*7*	4	1	A			
109	465	16:07	16:12	*5*	4	1	A			
110	398	16:08	16:13	*5*	4	1	A			
111	415	16:16	16:23	*7*	4	1	A			
112	420	16:18	16:21	*3*	4	1	A			