

NON-PHYSICAL DETERRENTS TO PREVENT PASSAGE OF INVASIVE SPECIES

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Summary

Recognizing the time required to implement the full hydrologic separation of the Mississippi River and Great Lakes Basins, the Great Lakes Commission (GLC) and the Great Lakes & St. Lawrence Cities Initiative (Cities Initiative) sought to identify and evaluate interim solutions to reduce the risk of passage of Asian Carp from the Mississippi River into the Great Lakes. Ideally, the interim solution would also limit passage of all invasive species between the two watersheds but Asian Carp were given priority. Non-physical deterrents have been studied and implemented for decades with varying success. Noatch and Suski define non-physical deterrence as, “any stimulus or non-solid obstruction that discourages or prevents a selected species from passing through a target region” and notes that they typically do not constrain or restrict flow (Noatch, M. R. and Suski, C. D. 2012. Non-physical barriers to deter fish movements. Environmental Review, Vol. 20 2012). When applied to the Chicago Area Waterways System (CAWS), non-physical deterrents have the appeal of not affecting flood passage and/or transportation. However, all of the studies reviewed conclude that non-physical deterrents are not 100% effective in preventing passage of invasive species.

This white paper assembled the available research and summarizes technologies that are designed to deter fish, particularly Asian Carp, which have been or implemented in the field or are proposed for near-term implementation. The reviewed technologies include currently implemented barriers as well as research being conducted by private technology providers and/or at the university level. The white paper summarizes the most pertinent literature, scientific papers, research results, presentations, etc. and provides the list of references/bibliographies from the key researchers.

The USCOE GLMRIS provide a list of 90 controls in their “Inventory of Available Controls for Aquatic Nuisance Species of Concern.” The information provided by the Corps on each is presented in Appendix C of this report.

Need

To date, a breeding population of Asian Carp has not passed the electric fish barrier located near Romeoville, IL. It is noted, however, that the breeding population has yet to reach the barrier. Recognizing the concern, the US Army Corps Great Lakes and Mississippi River Interbasin Study (GLMRIS) has performed a study to evaluate the hydraulic forces caused by barge traffic that could entrain and pass carp through the electric field. Recent study results from the Corps of Engineers show that the electric barriers are not stopping the movement of all fish. The Corps conducted a series of underwater sonar recordings of the area within the electric barrier which showed fish passing through the electric field. A related study showed that barges can sweep fish through the electric barrier. These results underscore the need for a complete, long-term solution.

As addressed in all of the literature reviewed, non-physical barriers must be viewed as temporary. Carpenter and Terrell (USGS) found that “Nearly 39% of the 49 southwestern barrier and renovation projects that were amenable for assessment were compromised in less than 3 years.” (USGS. Carpenter J. and Terrell, J. W. September 2005. Effectiveness of Fish Barriers and Renovations for Maintaining and Enhancing Populations of Native Southwestern Fishes. Interagency Agreement Number 201814N756.) Similarly, Noatch and Suski stated, “The primary drawback to any non-solid fish barrier is the < 100% long term effectiveness associated with virtually every barrier system.” (Noatch, M. R. and Suski, C. D. 2012. Non-physical barriers to deter fish movements. Environmental Review, Vol. 20 2012)

On-going Research

All of the studies reviewed have listed the limitations of non-physical barriers particularly with regard to the wide variety of known invasive species in both watersheds. To alleviate some of these limitations, recent research has focused on coupling technologies to improve the effectiveness (notably electrical/acoustic stimuli and acoustic/bubble curtains). After reviewing and comparing the entire array of non-physical barriers, Noatch and Suski concluded, “To improve effectiveness of barriers, minimize the likelihood of acclimation, and provide additional safety/redundancy, future work should attempt to integrate multiple deterrent systems concurrently.” There are also new and exciting technologies being introduced that improve and/or augment existing deterrent strategies. GLMRIS continues to review new technologies but apparently will limit their recommendations to technologies with a proven track record (as reported by David Wethington, USCOE GLMRIS Project Manager to the CLC/Cities Initiative Advisory Committee).

Proven Effectiveness

Noatch and Suski evaluated the entire array of non-physical barriers to deter fish movements and aggregated the various technologies into nine types of barriers/deterrents: electric barriers, strobe lights, sound, bubble curtains, water velocity, hypoxia/hypercapnia, chlorine, and electromagnetism. The comparisons were presented, including, the advantages and disadvantages, in the following table:

Table 1. Summary of different non-physical barriers that could be implemented to deter the movements of fishes. Also listed are deployment conditions where barriers are likely to be successful, advantages and disadvantages of different barrier types, and representative citation showing the barrier in use.

Barrier/Deterrent	Deployment conditions	Advantages	Disadvantages	Relevant citations
Electricity	Site with adequate power source; appropriate water conductivity	Flexible deployment, very effective against recruited fish	May not affect smaller fish	Bullen and Carlson 2003; Savino et al. 2001; Clarkson 2004
Strobe lights	Consistent low water turbidity	Less infrastructure, potentially lower cost	Lower effectiveness, especially in daytime	Johnson et al. 2005a; Hamel et al. 2008
Sound (AFD)	Site with adequate acoustic characteristics	Effective across a wide range of environmental conditions	Variable effectiveness; frequencies must be chosen per species	Maes et al. 2004; Sonny et al. 2006
Bubble curtains	Low water turbidity, relatively shallow water	Few as a stand-alone deterrent; may enhance other deterrents	Low effectiveness, may not work under all conditions	Patrick et al. 1985; Stewart 1981
Water velocity	Target species that is a weak swimmer; narrow channel with adequate water flow	Selectively excludes nuisance species	Major modification to channel; few sites meet criteria	Hoover et al. 2003; Katopodis et al. 1994
Hypoxia and hypercapnia	Relatively shallow water, space needed for bulk gas storage	Potential to exclude virtually all fish	Large investment of research time and capital	
Pheromones	Confined spaces and (or) short term application	Potential to selectively exclude particular fish	Time and effort to procure pheromones in bulk quantity	Little and Calfee 2006; Johnson et al. 2005b
Chlorine	Highly constricted deployment space	Potential to exclude virtually all fish	Deleterious to almost all aquatic fauna; negative public perception	Giattina et al. 1981; Wilde et al. 1983
Electromagnetism	Constricted areas, choke points	Cost effective, low environmental impact	May not work on all teleost fishes	Northcutt et al. 1994; Gibbs and Northcutt 2004

After evaluating the available research, Noatch and Suski concluded:

“An Optimal barrier that relies on behavior modification will still be ineffective against organisms that are unable to “cooperate” such as larval or planktonic life stages transported by currents that cannot “choose” to leave the area.”

A very brief summary of the conclusions presented by Noatch and Suski is presented below.

- 1) Electrical Barriers** have been utilized for over 60 years but have never been considered 100% effective. The two largest challenges are: 1) effectiveness on small fish and 2) effectiveness when velocities exceed burst speeds of the fish.
- 2) Strobe Lights** introduce unnatural light levels in an effort to disorient fish assuming that the impacted fish will avoid the area. Unfortunately, several studies note a distinct ineffectiveness of strobe lights during daylight hours. There is also concern that long term habituation causes the tendency of the fish to flee the strobe light to become less effective.

“Studies to date do not suggest that strobe lights employed as a stand-alone method of deterrence could provide complete security in situations where total deterrence is the goal.” (Noatch and Suski)

- 3) Sound** and pressure wave, collectively referred to as acoustic fish deterrents (AFD), have displayed varied effectiveness and is influenced by bottom morphology, hydrology, and the angle of the sound waves. Ultrasound has generally not been effective. AFD with varying frequencies and decibel levels have been successfully implemented as fish deterrents in several different situations.

“In the case of Asian Carp, research has reported up to 95% reduction of passage of Asian carp when confronted with AFD devices” (Pegg and Chick 2004)

- 4) Bubble curtains** as a stand-alone fish barrier have limited potential for a number technical reasons (e.g. inability to maintain equal air pressure across varying depth over time). Studies have shown improved rates of deterrence when paired with a AFD or sound.

Pegg and Chick (2004) reported that an experimental barrier composed of a bubble curtain coupled with acoustic deterrents was 95% effective in confining the movements of Asian Carp. (Noatch and Suski)

- 5) Water velocity** can be used to as a barrier to selectively limit to movement of undesirable fish species while permitting passage of desirable species. This is NOT the challenge of the CAWS. Velocity barriers are impractical at very large scale; particularly on flat grades (like the CAWS). Velocity barriers have been researched and considered for control of Sea Lamprey and Round Gobies because of their maximum swimming speed. However, no one has proposed the use of velocity barriers to control Asian Carp.
- 6) Hypoxia and hypercapnia** (very low dissolved oxygen and high dissolved carbon dioxide) has shown to be effective in effecting the behavior of fish in general and Asian Carp in particular. Both approaches build upon the fact that the gills of a fish sense the change in dissolved oxygen (DO) and/or carbon dioxide and avoid the area as a survival mechanism. Thus both have the

potential of being an effective chemical barrier to deter fish movements and have the potential to be effective across all sizes of fish in a threshold value can be maintained. Very low dissolved oxygen has the challenge of producing odor issues associated with a reducing environment. High concentrations of CO₂ do not have this issue. Carbon dioxide (and/or nitrogen) is a naturally occurring gas that will not persist in the water column nor will does it pose a threat to birds or animals.

- 7) **Pheromones** which secrete chemical odors that elicit a specific behavioral response – are divided in to two groups; attractive pheromones and alarm pheromones. Attractive pheromones are typically excreted by a sexually receptive being. Alarm pheromones are believed to be released by fish when the skin of a fish is damaged. When collected and/or synthesized, pheromones can be used to excluded fish from a particularly location. It is believed that the alarm pheromones have a more immediate potential as a temporary barrier.

Pheromones have been researched and applied in the fight to control sea lamprey. Attractive pheromones have been used to capture female sea lampreys and chemicals emitted by decaying lampreys (a necromone) have been used to divert migrating lamprey away from targeted watersheds.

- 8) **Electromagnetism** targets the electrosensory pores in some fish species that provide an advantage to some fish in locating prey. The goal of the approach is to over-stimulate these receptors and thereby repel the targeted fish. No research on Asian Carp has been identified and there is little evidence that electromagnetism would be effective in repelling carp.
- 9) **Other Chemicals** include the wide variety of toxicants that are used to control and/or eradicate biological species. The largest drawback is the deleterious effects on non-target organism. Ideally the chemical barrier should be non-persistent and the application restricted to an area critical to passage of the target species. Common piscicides include rotenone, antimycin, and salicylanilide. These toxicants target to gills of fish and have limited effect on other species. Lampricide has been used extensively throughout the Great Lakes Species but the toxicity varies on other non-target fish.

Chlorine has been used for decades as a biocide and defoulant and is a strong oxidizer that attacks the gill tissue of fish. Sub-lethal chlorine gradients can be detected and avoided by numerous fish species. While chlorine degrades naturally in water, it is a hazardous chemical requiring special handling and safety procedures. There is also considerable regulatory/public concern over the persistence of chlorine and chlorinated compounds. Thus many water and wastewater treatment facilities are looking to technologies that maintain effective “kill” but results in little or no chemical by products.

Improvements in Existing Technologies

The USCOE have limited the technologies included in GLMRIS to “proven” technologies and thus have not included several technologies that have experienced improvements developed by the industry as they seek improvements that address the known shortcoming of the existing technologies. The following is a brief summary of three technologies that will continue to develop and should be monitored to see if these improvements make sufficient progress to be included in an interim solution to isolating Asian Carp from the Great Lakes.

Electrical Barriers

In 1999, Moy summarized the step required to build and demonstrate the effectiveness of an electrical barrier on the CAWS – initially targeting the Round Goby

*“The NISA Act of 1996 authorized the Corps of Engineers to carry out a demonstration study of an aquatic nuisance species dispersal barrier in the Chicago Sanitary and Ship Canal. This location is of great interest as the century old, man-made canal is the only aquatic link between the Mississippi River and Great Lakes drainages and forms a two-way avenue for invasive species dispersal. . . To identify likely dispersal barrier methodologies the Chicago District Corps assembled a Dispersal Barrier Advisory Panel comprised of 26 federal, state, academic, regional, municipal, commercial and environmental member entities. Recognizing that 100 percent control was unrealistic, the Panel members agreed that the objective of the barrier should be to reduce, to the extent possible, the dispersal of invasive species. No migratory species traverse this man-made canal however the barrier is expected to affect the passage of native as well as invasive species. . . . The project has three phases. Phase I will target bottom dwelling species, particularly the round goby (*Neogobius melanostomus*). Phase II will target actively swimming organisms in the entire water column. Finally, Phase III will address planktonic organisms.”* (Moy, P.B. 1999. **Development of an aquatic nuisance species barrier in a commercial waterway.** Pederson, J, editor. First National Conference on Marine Bioinvasions January 24-27 1999. Massachusetts Institute of Technology.)

Now, nearly twenty years after the congressional authorization, the effectiveness of the electrical barrier remains in question. The studies to date detail the shortcomings of non-physical deterrents and recognize that they only serve as a temporary solution of keeping biological populations separated.

The electrical barrier installed on the CAWS was designed and built by the industry leader - Smith Root. By design, the system protects a wide cross section (160 feet), a substantial depth (25 feet), and requires a great deal of power (1850 kW max.)

<http://www.smith-root.com/barriers/sites/chicago-sanitary-and-ship-canal-2a/>

The Electrodes consist of bundled billets of steel 5 inches x 5 inches flash-butt welded on site, and lowered onto concrete sleepers. The system has a wide array 66 feet long targeted at large fish, and an adjacent narrow array 38 feet long with a higher field strength for smaller fish. Three pulsators provide redundancy. The placement of the electrodes (along the bottom of the canal) allows easy passage of barge traffic. However, because of the relatively deep depth and large width, a substantial current must be provided to assure that the voltage at the water surface is sufficient to deter small fish. This results in substantial electricity costs, safety concerns, and concern for its ability to deter small fish.

The concerns for efficacy are exacerbated by the rapid and turbulent flows experienced when a series of barges pass. On December 24, 2013, USCOE released a white paper that stated;

“Initial findings indicate that vessel-induced residual flows can trap fish and transport them beyond the electrical barriers, and that certain barge configurations may impact barrier electric field strength. Additionally, the preliminary DIDSON findings identified the potential for small fish (between 2-4 inches in length) to pass the barrier array in large groups, or schools.”

(<http://www.lrc.usace.army.mil/Portals/36/docs/projects/ans/docs/Fish-Barge%20Interaction%20and%20DIDSON%20at%20electric%20barriers%20-%2012202013.pdf>)

Another electrical barrier technology has entered the market that claims to have addressed the largest challenges experienced in traditional electrical fish barriers. The Neptun low-voltage DC fish-guidance system was developed in Poland and has the advantage of a non-linear distribution of the electric field. (<http://www.fishwaysglobal.com/>) In short, this eliminates the need for very high voltages above certain thresholds yet remains effective against small fish. The technology has demonstrated low energy consumption, no depth limitation and has been tested for effectiveness on Sea Lamprey by the Great Lakes Fishery Commission. At this time, there are no major installations of the Neptun technology in the United States.

Carbon Dioxide as a Chemical Barrier

Carbon dioxide has been targeted as a potential candidate to aid in the prevention of the upstream migration of Asian carp within the CAWS. A recent series of experiments have been conducted as part of a long term study to determine the effectiveness of CO₂ at not only preventing the passage of adult fishes, but also early life stages (e.g., eggs and larvae). To date, laboratory behavior trials have shown that at lower CO₂ levels (30 mg/L), fish showed a visible stress response (e.g., reduced ventilation, activation of stress genes); at moderate levels (70 mg/L) fish showed a loss of equilibrium, and at high levels (100 mg/L) fish completely avoided the area (unpublished data). It was also shown that fingerlings (juvenile fish 1-2") avoided areas of CO₂ as well, a response not typically observed in terms of an electric barrier. Additionally, a large scale study was recently implemented to demonstrate CO₂ effectiveness on a larger scale within experimental ponds. Using a large gas diffusion system and acoustic telemetry, fish movements were tracked in relation to the "wall" of CO₂ created by the diffuser. Analyses are still being conducted; however, initial results indicate evidence of fish avoidance to the CO₂.

Despite initial analyses of the large-scale pond study still being conducted on the efficacy of CO₂ as a potential barrier, the results to date are promising. A significant advantage CO₂ has over the electric barrier that this study has demonstrated is the avoidance of early life stage fishes to CO₂. However, many future considerations and challenges exist before CO₂ should be implemented in the field. In the presence of water, CO₂ converts to carbonic acid, effectively lowering the pH. The magnitude of this acidification depends on multiple factors, such as alkalinity of the water and the concentration and duration of CO₂ exposure. The higher acidity may pose a risk to man-made structures in the vicinity of the barrier, resulting in added damage or repair costs over the long term. Additionally, questions remain as to how a CO₂ barrier system can be implemented and the barrier maintained, which wholly depends on the implementation location. For example, in a riverine system water is constantly flowing. An implemented chemical barrier (e.g., CO₂) would need to remain effective while water is constantly being replaced. This challenge is compounded when a system is implemented in, for example, a lock-and-dam structure, where water is constantly turbulent and being replaced due to locking procedures and barge traffic. These issues would need to be addressed in order to understand how CO₂ behaves at large scales. Additional studies are needed to understand and effectively monitor CO₂ at large spatial scales, as well as under turbulent environments (e.g., heavy barge traffic).

Alternative Disinfectants

Disinfecting the large quantities of water passing through a lock poses a number of practical problems – notable transporting and storing large quantities of toxic chemicals. These chemicals are typically

chlorine based because they are inexpensive and readily available. However, once discharged to the environment, chlorine based disinfectants can also chemically interact with other constituents in the water column forming chlorinated compounds. To avoid these challenges, technology providers are developing new disinfectants such as H₂O₂ and/or peracetic acid that are effective yet eliminate chlorinated byproducts, generate no chemical residuals, and require only water, air and electricity to operate.

One of the technology providers is PeroxEgen which offers an On-site H₂O₂/PAA Generator. (http://www.eltronresearch.com/docs/PeroxEgen_tech_brief.pdf). One of the advantages of PAA is also one of its challenges. It has a very short half-life before degrading into its harmless byproducts. Thus the chemical must be generated onsite. This technology has been accepted in the food processing industry but has yet to be demonstrated in a municipal application. With ever growing concern about the use of chlorine and chlorinated disinfectants, it is expected that these new technologies will become commonplace - particularly given the timeframes being considered in the CAWS project.

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APPENDIX A

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Wofford, J.E.B., Gresswell, R.E., and Banks, M.A. 2005. Influence of barriers to movement on within-watershed genetic variation of coastal cutthroat trout. *Ecol. Appl.* 15(2): 628–637. doi:10.1890/04-0095.

APPENDIX B

SELECTED ANNOTATED BIBLIOGRAPHIC REFERENCES ON BARRIERS AND RENOVATIONS (From Carpenter and Terrell, USGS)

American Fisheries Society Fish Management Chemicals Subcommittee Task Force on Fishery Chemicals. 2000. Importance of rotenone as a management tool for fisheries. Fisheries 25: 22-23.

Notes: This editorial discusses how rotenone is one of few options that eradicates entire populations compared to mechanical methods that control populations. They list several rare species that would probably be extinct if it were not for rotenone. They note no public health effects have been reported from rotenone use as a piscicide. The editorial discussed registration status and the reasons why rotenone use is controversial. They recommend doing environmental impact analyses or assessments on proposed projects so as to communicate better with the public. They also suggest educating the public on benefits of the restoration, and discuss their future public information program.

Baxter, J.S., Birch, G.J., and Olmsted, W.R. 2003. Assessment of a constructed fish migration barrier using radio telemetry and floy tagging. North American Journal of Fisheries Management 23: 1030-1035.

Notes: The purpose of the barrier in this article was to reduce native non-sport fish within a stream. The barrier was installed, didn't work, and probably wasn't even necessary. "In hindsight this is a clear example of where a thorough review of the data prior to the initial construction....could have saved a lot of time, effort and cost". They also review marking vs. telemetry in this kind of study.

Abstract: We assessed the effectiveness of a constructed fish migration barrier in the Salmo River, British Columbia, Canada, 10 years after it was constructed. The barrier was initially installed to prevent an expected increase in upstream migration of suckers *Catostomus* spp., and northern pikeminnow *Ptychocheilus oregonensis* into the Salmo River following the creation of Seven Mile Reservoir on the Pend d'Oreille River. To determine the effectiveness of the barrier, we applied radio and Floy tags to these species in Seven Mile Reservoir to assess whether upstream migration over the barrier was occurring. After sampling below the barrier, 5 largescale suckers *C. macrocheilus* and 5 northern pikeminnow were radiotagged, whereas 124 suckers and 11 northern pikeminnow were Floy-tagged. Radio tracking surveys confirmed that most radio-tagged suckers and northern pikeminnow made migrations only within the reservoir, but one sucker was tracked above the barrier. This movement occurred after the peak of annual discharge. During snorkel surveys conducted above the barrier, we observed five Floy-tagged suckers. The results are discussed in relation to the use of tagging methods to monitor sucker and northern pikeminnow migrations and assess the effectiveness of constructed fish migration barriers.

Beamesderfer, R.C.P. 2000. Managing fish predators and competitors: deciding when intervention is effective and appropriate. Fisheries 25: 18-23.

Abstract: Fisheries management agencies increasingly are being asked to weigh tradeoffs between game, non-game, native, and nonnative species management. Oregon recently has been considering a variety of interspecific intervention activities aimed at protecting and rebuilding depleted native fishes or improving native game fish production by managing potential predators and competitors. Activities range from reduced harvest restrictions on fish predators and competitors to more aggressive removal programs. Chemical treatment and predator hazing also have been considered for potential benefits to more desirable fish populations. This paper describes a systematic decision-making process to determine for any given case if: (1) predation or competition is likely to be important, (2) potential predators or competitors can be affected by changes in harvest or other management actions, and (3) biological benefits outweigh costs and social/ political considerations. This process is applied to several of Oregon's problems to help identify examples where intervention might prove effective and appropriate.

Bills, T.D., and L.L. Marking. 1988. Control of nuisance populations of crayfish with traps and toxicants. Progressive Fish-Culturist 50: 103-106.

Notes: This article describes how trapping can suppress crayfish populations but not likely successful for control or elimination. Bathyroid was toxic to *Pimephales promelas* for 5 weeks after introduction; possibly due to the cold temperature (10°C). For instance, rotenone is detectable for 40 d at 5°C but is undetectable after 5 d in 24°C. Also, suspended solids absorb organic chemicals, thus requiring higher concentrations in A-3 field vs. laboratory conditions.

Abstract: Crayfish have long been a nuisance in fish-rearing ponds at fish hatcheries. The rusty crayfish (*Orconectes rusticus*) has displaced endemic species and caused serious declines of aquatic plants in some ponds and lakes in the midwestern USA. The authors attempted to evaluate the effect of intensive trapping on a crayfish population and to identify a selective chemical control agent and evaluate its effectiveness under field conditions. A crayfish population in a small pond was suppressed but not eliminated by trapping: adults were effectively harvested but efficiency diminished sharply as the population declined. Of 19 chemicals tested as possible control agents for crayfish, a synthetic pyrethroid (Baythroid) was by far the most toxic; 25 µg/L produced a complete kill of crayfish in the pond and was also the most selective for crayfish in laboratory tests

Bizios, L.J., and Tate, K.L. 1995. DRAFT Final report for the Arnett Creek native fish re-establishment project, Phase I. Heritage Grant #I93007. US Forest Service, Phoenix, Arizona.

Notes: Phase 1 includes: 1) designing a fish barrier; 2) installing a cattle guard (p. 15); 3) completing fish habitat inventory (p. 17). They also identified and mapped all waters in watershed to determine probability of chemical treatment to remove exotics. In the inventory, they evaluated suitability for reintroduction of multiple natives: *Agosia chrysogaster*, excellent; *Catostomus clarkii*, yes; *Gila intermedia*, doubtful; *C. insignis*, no; *Poeciliopsis occidentalis*, no.

Brooks, J.E., and Propst, D.L. 1999. Nonnative salmonid removal from the Black Canyon drainage, East Fork Gila River, June-October 1998, DRAFT.

Notes: Black Canyon has a Gila trout population above a barrier. The unauthorized stocking mentioned in this report is covered in detail in their 1999 Desert Fishes Council paper (see Appendix B). The authors successfully removed the recently-stocked non-natives by electrofishing (no chemical removal)

Brown, P.J., and Zale, A.V. 2005. Barriers to prevent nonnative fish movement: a review. Page 9 in: 38th Annual Meeting of the Montana Chapter of the American Fisheries Society.

URL: www.fisheries.org/AFSmontana/Misc/Abstracts%202005%20MCAFS%20Annual%20Meeting.pdf

Abstract: Barriers to non-native fish movement are important tools in the conservation of native fish species. Natural and manmade barriers provide protection to some of the last populations of native fish, and barriers are frequently used to help restore a species to a larger portion of its native range. We surveyed barriers being used to prevent non-native fish movement in an effort to make a wide variety of barrier designs available to managers and researchers. Barrier design, longevity, cost, and functionality vary, and there is some indication that those designing barriers lack the information necessary to build the best barrier to meet their management needs. A wide variety of materials are used to build barriers and each has associated advantages and disadvantages. We review the major types of barrier construction, as well as noteworthy innovative designs, and discuss the advantages and disadvantages of each. The falls barrier was found to be the most common type of barrier currently used to exclude non-native fish. Results of this survey have provided an array of barrier designs and have helped to highlight gaps in the knowledge base necessary to construct effective barriers. Other types of barriers included mesh, perched culverts and velocity barriers. Knowledge gaps in the design of barriers include, the jumping performance of wild fish, knowledge of proper barrier siting, and barrier designs that can accommodate both high and low discharge. A comprehensive manual on barrier design and an understanding of the jumping ability of wild fish are necessary before barrier designers can be expected to build effective barriers.

Bulow, F.J., Webb, M.A., Crumby, W.D., and Quisenberry, S.S. 1988. Effectiveness of a fish barrier dam in limiting movement of rough fishes from a reservoir into a tributary stream. *North American Journal of Fisheries Management* 8: 273-275.

Notes: Relevant quote on barrier effects: "possible negative effect...is that it impedes flow, creating pondlike habitat immediately upstream".

Abstract: We evaluated the effectiveness of a fish barrier that was constructed on the Roaring River, a tributary of Cordell Hull Reservoir, Cumberland River, Tennessee. The barrier was a steel-framed, stonefilled structure covered with concrete-capped gabions, and it spanned the width of the stream. We tagged 1,056 specimens of seven rough fish species over three occasions downstream from the barrier, but never recovered any tagged fish upstream from it. The barrier seems to be effective in limiting upstream migration of rough fishes.

Clarkson, R.W. 2004. Effectiveness of electrical fish barriers associated with the Central Arizona Project. *North American Journal of Fisheries Management* 24: 94-105.

Abstract: The Central Arizona Project (CAP) canal delivers Colorado River water into the Gila River basin. During its planning and construction, issues arose regarding the unwanted entrainment and transport of nonindigenous fishes and other aquatic biota into, through, and out of the canal. One control strategy was the emplacement of electrical fish barriers on two CAP tributary canals to prevent fishes from moving upstream into the Gila River drainage. The operation, maintenance, and effectiveness of these barriers are described for the period 1988–2000. Documented outages totaled more than 100 h, representing less than 0.001% downtime since installation. It is nearly certain that outages allowed immigration by undesired fish(es). Immigrations that occurred when the barriers were operating according to design criteria indicate that the barriers do not totally block the passage of upstream-migrating fish. The proximate sources of electrical barrier outage included component damage from lightning strikes, component breakdowns, failure to adhere to component maintenance and replacement schedules, failure to incorporate adequate protection and redundancies to certain system components, inadequate training of personnel, and unknown causes. Known outages of remote monitoring systems (which are necessary to document outages and understand the potential for undocumented barrier outages) totaled more than 400 d, representing about 3% of the period of barrier operations. The complexity of electrical barrier systems and the problems such intricacy creates for operation and monitoring may always preclude absolute effectiveness. Additional refinements to system components, personnel training, and operation procedures may reduce barrier failures but add further to that complexity. Management agencies will have to determine the cost effectiveness of such refinements.

Dawson, V.K., and Kolar, C.S. 2003. Integrated management techniques to control nonnative fishes. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin.

Notes: This report summarizes detailed life history information on Gila River basin natives and nonnatives in Appendix B tables. Most of the report is made up of very detailed information on piscicides. Chapter 9 covers barriers (physical control) and biological control. This report also contains a good A-8 summary of historical reviews of fish control projects.

Abstract: Many species of native fish from the southwestern United States, including those in the Gila River basin in Arizona and New Mexico, are critically imperiled in part because of the introduction and establishment of nonnative fishes. Effective methods for eradication and control of nonnative fishes are needed to rehabilitate the imperiled native fish fauna of the Gila River basin. The objective of this report is to assess the potential of applying techniques of integrated pest management to protect imperiled native fishes in the southwestern United States from invasive nonnative species. To accomplish this, reviews of pertinent literature were conducted in selected topic areas and the information presented in a series of chapters to document findings. Subject areas of the review included (1) life-history strategies for both native and nonnative species in those waters; (2) evaluation, identification, and characteristics of successful integrated pest management programs; (3) identification of potential and existing chemicals and appropriate chemical formulations for use as general and selective piscicides; and (4) procedures and costs associated with the discovery and development of new and perhaps taxon-specific piscicides. Characteristics of native fishes of concern were compared with those of nonnative fishes, and the

geographic ranges of native and nonnative fishes were mapped to identify potentially vulnerable conditions around which control strategies could be developed. The concept of chemical receptors and receptor responses are presented to help explain the basis of selective toxicity. A total of 45 chemicals were identified that have either been used as piscicides, or are currently in various stages of development. A rating system was developed that evaluates the usefulness of these chemicals in resolving problems caused by nonnative fishes. Only five of the chemicals (antimycin, rotenone, TFM, Bayluscide®, and Squoxin) achieved ratings of 75 or greater out of a possible score of 100. Chemical reclamations have not always been successful as indicated by reviews of hundreds of fish control projects with reported successes ranging from 43% to 82%. It is unlikely that the present arsenal of approved selective piscicides would be effective for controlling nonnative fishes in the southwestern United States because the fish communities are different from most areas where selective piscicides are being used, and the currently registered taxon selective piscicides target sea lampreys. A comprehensive list of formulations and associated delivery systems for applying registered piscicides are presented. The development of new chemical tools for selectively managing fish populations may be facilitated by the knowledge of the mode of action of candidate piscicides and their structure-toxicity relationships. An evaluation of the costs and benefits of chemical treatments, as well as the cost associated with the development and registration of new piscicides, are provided. Reclamation of habitats that are critically imperiled by invasive fishes may need to be implemented using general piscicides such as antimycin or rotenone. This would require that important extant native species be temporarily moved to refugia until after the treatments. In less critical situations, efforts could be directed toward development of integrated pest management techniques that include development and use of barriers, water-level manipulations, targeted overharvest, stocking of predators, sterilants, toxic baits, selective piscicides, attractants and repellants, immuno-contraceptive agents, viruses, chromosomal manipulations, gynogenesis, and transgenics.

Dowling, T.E., and Childs, M.R. 1992. Impact of hybridization on a threatened trout of the southwestern United States. Conservation Biology 6: 355-364.

Notes: This paper provides locations of native trout populations and good information on renovations.

Abstract: Trouts native to the American Southwest provide an excellent example of the plight of endangered fishes from this region. The native species, Apache trout and Gila trout (*Oncorhynchus apache* and *O. gilae*, respectively) have faced drastic reduction in habitat and detrimental interactions with introduced species, resulting in a dramatic decrease in numbers and sizes of populations. We used biochemical methods to identify diagnostic markers for the estimation of genetic relatedness and analysis of hybridization among native trouts and introduced cutthroat and rainbow trouts (*O. clarki* and *O. mykiss*, respectively). Restriction endonuclease analysis of mitochondrial DNA (mtDNA) indicated that Apache and Gila trout were very similar to each other, and more similar to rainbow trout than cutthroat. Diagnostic allozyme marker loci indicated that Apache trout hybridized extensively with rainbows in four populations and provided no evidence for reproductive isolation between the forms. Analysis of mtDNA, however, indicated that introduced haplotypes were rare in these same individuals, identifying a bias in the direction of gene exchange between species. The potential reproductive isolation and lack of information concerning population structure necessitate further study of Apache trout to determine the appropriate management strategy for this threatened species. This case demonstrates that extreme care must be exercised when considering elimination of any contaminated population lest the unique genetic identity of the native taxon be lost forever.

Hayes, D.B., Baylis, J.R., Carl, L.M., Dodd, H.R., Goldstein, J.D., McLaughlin, R.L., Noakes, D.L.G., and Porto, L.M. 2003. Biological effect of low-head sea lamprey barriers: designs for extensive surveys and the value of incorporating intensive process-oriented research. Journal of Great Lakes Research 29: 373-385.

Abstract: Four sampling designs for quantifying the effect of low-head sea lamprey (*Petromyzon marinus*) barriers on fish communities were evaluated, and the contribution of process-oriented research to the overall confidence of results obtained was discussed. The designs include: (1) sample barrier streams post-construction; (2) sample barrier and reference streams post-construction; (3) sample barrier streams pre- and post-construction; and (4) sample barrier and reference streams pre- and post-construction. In the statistical literature, the principal basis for comparison of sampling designs is generally the precision achieved by each

design. In addition to precision, designs should be compared based on the interpretability of results and on the scale to which the results apply. Using data collected in a broad survey of streams with and without sea lamprey barriers, some of the tradeoffs that occur among precision, scale, and interpretability are illustrated. Although circumstances such as funding and availability of pre-construction data may limit which design can be implemented, a pre/ post-construction design including barrier and reference streams provides the most meaningful information for use in barrier management decisions. Where it is not feasible to obtain pre-construction data, a design including reference streams is important to maintain the interpretability of results. Regardless of the design used, process-oriented research provides a framework for interpreting results obtained in broad surveys. As such, information from both extensive surveys and intensive process-oriented research provides the best basis for fishery management actions, and gives researchers and managers the most confidence in the conclusions reached regarding the effects of sea lamprey barriers.

Hepworth, D.K., Ottenbacher, M.J., and Chamberlain, C.B. 2001. A review of what did and did not work after 24 years of native trout restoration in southern Utah. Pages 42-45 in Shepard, B. Practical Approaches for Conserving Native Inland Fishes of the West. Sponsored by the Montana Chapter and the Western Division of the American Fisheries Society.

Notes: This paper reviews local ordinances and biologists' responses to attempted ban of antimycin; banning use impedes native fish recovery.

URL: <http://www.fisheries.org/AFSmontana/Misc/Symposium%20Abstracts/Abstracts.pdf>

Abstract: No.

Highlights from online paper: A review of what did and did not work after 24 years of native trout restoration in southern Utah. Conservation and recovery of native trout became a management issue in southern Utah in the 1970s after the Endangered Species Act (ESA) was passed and when several remnant populations of native Bonneville cutthroat trout *Oncorhynchus clarki utah* were identified (Behnke 1976). ... Our objective in this study was to review restoration projects conducted in southern Utah since 1977 and categorize success, failures, and problems in terms of what generally did and did not work. Methods Reviews were made of all data for known remnant populations of native trout in southern Utah, restoration projects that were completed, and restoration projects that are in progress (Tables 1 and 2)...Topics reviewed in the evaluation were: (1) genetic analyses, (2) criteria for selection of renovation projects, (3) success of renovating lakes and streams with rotenone, (4) sources of trout for re-introductions and wild brood stocks, (5) use of fish migration barriers, (6) practical consideration of metapopulations, and (7) socio-political issues. Results and Discussion ... We found six factors to be important in selecting sites for restoration of native trout populations. Restoration projects should be within historic distributions, have good trout habitat, be large enough to justify renovation efforts, avoid major land use conflicts, be feasible in terms of removing nonnative fishes and preventing their return, and have support from the general public, individuals and agencies responsible for land use management. Even for the smallest streams selected for renovation, it was evident that a one-time treatment with rotenone could fail to remove all nonnative fishes. Second treatments, timed approximately a year after the first treatment, were generally successful in completely eradicating target species. Springs and seeps posed the greatest problem in attaining complete eradication. ...We used fish migration barriers to expand the range of native trout and decrease fragmentation (Table 2). Barriers that worked best were adjacent to other obstacles which limited fish movement such as seasonally de-watered stream segments. The most vulnerable barriers were single-point structures where nonnative fishes had a continual presence immediately downstream (N Fork North Creek, Table 2). In cases where construction of barriers with secondary obstacles was not practical, we opted to construct multiple barriers (Table 2). ...Small projects conducted in isolated (fragmented) streams were less subject to negative interventions by man in comparison to larger systems. . . Obtaining regulatory clearances to conduct recovery projects has steadily become more complex and controversial. Concern has increased that native trout could potentially be listed under the ESA. On-the-ground projects were completed by promoting cooperation among state, federal, and county governments, as well working closely with the public. Summary and Conclusions: Despite some problems and delays, over 20 restoration projects were conducted within southern Utah during the past 24 years (Table 2). . .

Holden, P.B. 1991. Ghosts of the Green River: impacts of Green River poisoning on management of native fishes. Pages 43-54 in Minckley, W.L., and Deacon, J.E. Battle against extinction: native fish management in the American west. University of Arizona Press, Tucson.

Notes: This chapter covers in detail the rotenone renovation of upper Green River basin in 1962 prior to the impoundment of Flaming Gorge Reservoir: it discusses the politics, rationale, opposition, operation, and aftermath (stocking of the reservoir). Species of concern were bonytail, roundtail chub, humpback chub, Colorado pikeminnow, and razorback sucker. Relevant quotes: "...poisoning without consideration for ecological consequences caused concerns for both native fishes and non-native salmonids..." (p 53); "none of the native Colorado River fishes were known to be problems in reservoirs elsewhere, and in fact might have acted as a buffer against population explosions of other non-game species in the early years following impoundment." (p 53).

Hubbs, C.L. 1963b. Secretary Udall reviews the Green River fish eradication program. Copeia 1963: 465-466.

Notes: Secretary Udall of the Department of the Interior reviewed the 1962 Green River eradication program and issued the following directives on any future reclamations where Federal funds are involved: 1) adequate research should be undertaken on the effects of rotenone, potassium permanganate, or other fish controlling agents, under varying environmental conditions, before additional reclamations are undertaken; 2) whenever a reclamation may pose a danger to a unique species, a dominant consideration in evaluating the advisability of the project is the potential loss to the pool of genes of living material; 3) possible deleterious effects of future projects are to be evaluated by competent and disinterested parties; 4) as follow up to the 1962 event, Secretary Udall ordered the Park Service and Bureau of Sport Fisheries and Wildlife to study the impairment of fish populations in Dinosaur National Park.

Hyatt, M.W. 2004. Investigation of crayfish control technology. Final Report. Arizona Game and Fish Department, Phoenix.

Abstract: No.

Excerpt from Executive Summary: North America is home to 390 native species of crayfishes, 75% of the world's total. No native crayfish occur in Arizona or the Colorado River basin of western North America; however, they have been widely introduced to this landscape and have become widespread and abundant throughout the Colorado River basin. Nonindigenous crayfishes have greatly altered North American lake and stream ecosystems, harmed fisheries, extirpated many populations of native crayfishes, and contributed to the global extinction of at least one native crayfish species. The economic cost alone of a small subset of freshwater Nonindigenous species in the United States has recently been estimated at 4.1 billion dollars annually. In Arizona, crayfish pose a serious threat to the long-term survival of many species of native fishes and amphibians. Due to the potential harmful effects to native flora and fauna, there is a need for the development of methods to control or eradicate Nonindigenous species. This report provides a complete literature review of methods that have been tested for the purpose of controlling or eradicating nonindigenous crayfishes and methods that have not been tested, but have potential. Five broad categories of control were considered: legislative, mechanical, biological, physical, and chemical. Legislative control, while in effect at both the state and national level, has been unsuccessful. Mechanical control methods include manual removal, trapping, and electrofishing. Trapping, despite being the most common method used, has failed in every case to eliminate or even control crayfish. Biological control includes the use of fish predators, diseases, and microbial insecticides. Although some cases demonstrated an inverse relationship between the presence of fish predators and crayfish numbers, in no case did fish predators eradicate a population of crayfish. Crayfish plague is lethal to non-North American crayfish, but not to North American crayfish. If a strain of this disease lethal to North American crayfish could be developed, it might prove to be an effective method of control. Physical methods include de-watering, habitat destruction, and barriers. The ability of crayfish to travel over-ground for long distances and to survive for long periods of time in their burrows during dry periods, renders physical methods useless in most cases. Chemical methods include biocides, rotenone, and pheromones. Although rotenone will kill crayfish, any dosage sufficient to cause crayfish mortality results in the death of almost all other living organisms first. Research on the potential of using pheromones as a means of control has just recently begun. Early results of these studies do not look promising, but pheromones may prove effective in helping detect low density crayfish populations. Biocides proved to be the only method with any potential for eradicating or controlling crayfish.

Laurent, P.J. 1995. Eradication of unwanted crayfish species for astacological management purposes. Freshwater Crayfish 8: 121-133.

Abstract: Crayfish eradication can be achieved in ponds with low concentrations (0.06 to 0.13 mg/ L) of the insecticide fenthion (commercial formulation, BAYTEX). Fenthion is highly toxic to *Orconectes limosus* at concentrations as low as 0.006 mg/ L. The 24-h LC50 was determined at a water temperature of 20 degree C plus or minus 0.1 degree C. Three ponds were treated with fenthion without apparent injuries to vertebrates; however, among invertebrates, arthropods were affected. Even at fenthion concentrations high enough to be harmful to fish, death of crayfish occurred only after several hours of contact with the toxicant. Fenthion remains toxic to crayfish for several weeks, even at low concentrations, so restocking of treated ponds cannot be undertaken immediately.

Lennon, E., Hunn, J.B., Schnick, R.A., and Burress, R.M. 1971. Reclamation of ponds, lakes and streams with fish toxicants: a review. FAO Fisheries Technical Papers 100.

Notes: Comprehensive review of chemical renovations worldwide, up to 1970. Includes short but informative historical accounts of many early renovations, including 1961 renovation of San Juan River for sportfish, at the expense of bonytail and flannelmouth sucker, and 1962 Green River renovation. From Section 4.5: "There are few unqualified successes in stream reclamation, but this is not surprising when one considers the great diversity of streams, the difficulties of attaining uniform dispersal of a toxicant throughout the confines of a stream, the problems of maintaining sufficient concentration of a toxicant and duration of exposure over long distances, and the lack of toxicants that are formulated specifically for use in streams. The art of stream reclamation is evolving more slowly than that of lake reclamation because of the greater complexities."

Abstract: The Food and Agriculture Organization of the United Nations commissioned the U.S. Bureau of Sport Fisheries and Wildlife to prepare a review of literature on the reclamation of ponds, lakes, and streams with fish toxicants. Total or partial reclamation of small ponds, especially fish production ponds, with general or selective toxicants is a very common practice. The eradication of undesirable fishes from public lakes and streams began over 60 years ago, but accelerated within the past two decades as wild waters increasingly required fish management and as improved toxicants became available. Toxicants such as the organochlorines and organophosphates, borrowed from agriculture, are being replaced with controls that are more specific to fish or more appropriately formulated for aquatic application. Formulations of rotenone and antimycin are the most used, general fish toxicants in the United States; TFM is a successful, selective toxicant for larval sea lampreys in tributaries to the Great Lakes; and Squoxin is in advanced stages of development as a selective toxicant for squawfishes in salmonid streams on the west coast of North America. The review of literature and a widely circulated questionnaire indicate that 27 countries, in addition to the United States, and Canada, have used or are using fish toxicants for the control of undesirable fishes. Indicated, too, is the need for much research on all aspects of reclamation -- on the biology of target fishes; on alternatives to chemical control; on safe, effective, and non-persistent toxicants; on formulations and dispensing apparatus to reach and kill target fishes with the least possible contamination of the environment; on controls that may be integrated with toxicants to enhance reclamations; and on methods and equipment for pre- and Post-treatment surveys and evaluations.

Ling, N. 2003. A review of the use and toxicity of rotenone for fisheries management purposes. Science for Conservation 211: 40 pp.

Notes: Includes tables of lethal concentrations of rotenone on various fish species, invertebrates, molluscs, crayfish (*Cambarus*), aquatic insects, amphibians, birds, mammals. Paper also includes discussion of bait technology (selective fish baits laced with rotenone), section on manipulating food webs and water quality (by decreasing cladoceran-eating fish) with rotenone. Also discusses advantages, disadvantages, alternatives, public health concerns, ecological safety, recommended protocol.

URL: www.doc.govt.nz/Publications/004~Science-and-Research/Science-for-Conservation/PDF/SFC211.pdf

Abstract: No.

Excerpt from Introduction: Rotenone has been used extensively in North America since the 1930s for managing freshwater fisheries and for fisheries research. The literature on rotenone is vast. Roark (1932) published a bibliography on the use of *Derris* species as insecticides and listed 475 papers. More than 1000 papers have been

published on rotenone since 1990 and the literature is currently expanding at more than 100 papers per year. Recent research interest in rotenone stems mainly from biochemical interest in its highly specific action in selectively inhibiting mitochondrial activity and its possible anticancer properties. Rotenone is now recognized as the most environmentally benign of the commonly used fish poisons (piscicides or ichthyocides) and remains extremely useful for the chemical rehabilitation of fish habitats to remove noxious species and for research sampling. In response to recent public concerns about large-scale rotenone use in fisheries management, the American Fisheries Society has established a rotenone stewardship program to provide advice on the safe use of rotenone, and to encourage good planning and public involvement in future rotenone program (AFS 2000). This brief review summarizes the toxicity of rotenone to aquatic and terrestrial animals and the use of rotenone in fisheries management and research. An ecological risk assessment for rotenone use in New Zealand is also provided.

Lopinot, A.C. 1975. Summary on the use of toxicants to rehabilitate fish populations in the Midwest. Pages 1- 4 in Eschmeyer, P.H. Rehabilitation of fish populations with toxicants: a symposium. American Fisheries Society, North Central Division, St. Louis, Missouri.

Notes: Data are given by state and province: importance as management tool; if use restricted; types and amounts used in 1972; number of water bodies and acreage treated; number and miles of streams treated. Yearly data include total and mean acres treated.

Abstract: A survey on the use of fish toxicants in the Midwest showed that more than 22,000 gallons of 2- 1/2% rotenone were used in 1972 to rehabilitate fish populations. During 1963-72 more than 121,000 acres of water and about 4,200 miles of streams were treated with toxicants. Data are given for each state and province in the Midwest.

Maceina, M.J., Slipke, J.W., and Grizzle, J.M. 1999. Effectiveness of three barrier types for confining grass carp in embayments of Lake Seminole, Georgia. North American Journal of Fisheries Management 19: 968-976.

Abstract: Three types of barriers were evaluated in Lake Seminole (13,158 ha) to determine the success of confining triploid grass carp *Ctenopharyngodon idella* in two embayments (250 and 350 ha) that were almost entirely covered with submersed macrophytes. In 1995, two different physical barriers that permitted boat passage were constructed. One had tandem V-shaped weirs placed at the entrance of a cove, and the other had two gated barriers that confined an embayment connecting two arms of the reservoir. Grass carp were radio-tagged, stocked into the confined areas ($N = 119$ for the V-shaped barrier and $N = 69$ for the gated barrier), and tracked from December 1995 through September 1997 to estimate escape rates. In addition, 18,000 triploid grass carp fitted with coded wire tags were stocked in December 1995 into the two confined areas. A low-voltage (3–4 V) electric barrier (Smith-Root, Inc.) was installed in December 1997 at one of the V-shaped funnel barriers, and an additional 84 grass carp were radio-tagged and tracked for 13 months. Based on verified locations outside the confined areas, an average of 9% of the grass carp escaped through the V-shaped, and 23% escaped through the gated barriers each year. However, based on missing fish, tag functioning rates determined from dead fish or expelled tags, and locations of fish before becoming missing, potentially up to 42% of the grass carp escaped from the V-shaped barriers and 35% escaped from the gated barriers each year. In addition, electrofishing surveys conducted in summer 1998 downstream of the tailrace in the Apalachicola River, Florida, indicated that 68% of the grass carp were escaped fish (coded wire tag present) that were stocked nearly 3 years earlier into the confined areas. After the V-shaped barrier was fitted with an electric barrier, no verified escapes occurred and with the exception of one fish, every radio-tagged grass carp was found within the confined area. Therefore, the maximum escape rate was only 1.3% per year, if this fish did indeed escape. Thus, the electric barrier and confinement structure have the potential to provide managers with a tool to confine grass carp in specific areas of large water bodies. Over many years, control of excessive aquatic macrophytes with this system is about 10% of the cost of herbicide treatments or mechanical harvesting.

Marking, L.L. 1992. Evaluation of toxicants for the control of carp and other nuisance fishes. Fisheries 17: 6- 13.

Abstract: The eradication of undesirable organisms from lakes and streams began more than 80 years ago and has accelerated during the last 40 years as toxicants and technology have improved. The control of nuisance or undesired fish populations is a continuing need, and common carp, *Cyprinus carpio*, are often the target of

reclamation projects. Rotenone is a registered toxicant that can be effective for control of carp, but is thought to be too expensive by some fish managers. Antimycin is also highly toxic to carp and selectively kills some other undesirable species, but is ineffective at high pH, in limited supply, and in jeopardy for reregistration. Several other toxicants have been identified, but not developed. Salicylanilide I is highly toxic to all fish species, contains no molecules or functional groups that seem to cause oncogenicity, and is detectable by analytical methods. The selectivity of GD-174 to carp was demonstrated in the laboratory and in small ponds, but not in the field. Baythroid was selectively toxic to the rusty crayfish, *Orconectes rusticus*. Development of these promising new chemicals is unlikely because private industry will not pay the high cost to register a minor-use piscicide with low market potential. New funding sources must be found to pay for the reregistration of existing fishery chemicals and the registration of new compounds.

Martinez, P.J. 2002. Westslope warmwater fisheries. Job Progress Report, Federal Aid Project F-325-R7. Colorado Division of Wildlife, Fort Collins.

Notes: This report discusses the barrier net set up at Highline Lake. Discusses two projects: Job No. 1: Warmwater fishery enhancement and nonnative fish control strategies. Objectives include: 1) evaluate nonnative fish control strategies; 2) Mark largemouth bass stocked into Highline Lake and monitor for fish escapement; 3) Net selection/ installation/ evaluation; 4) Develop new protocol to track non-natives in response to control efforts. Job No. 2: Trophic and bioenergetics investigations for warmwater fish management. Objectives include: 1) do stable isotope analysis to determine source of exotics in Colorado River and floodplain; 2) Start data collection for bioenergetics evaluation of smallmouth bass in Yampa; 3) estimate food web impacts of northern pike removal. Includes 7 substantial appendices, including: copies of powerpoint presentations on B) talk on GIS approach to evaluating nonnative stocking and D) studies on Highline Barrier Net; G) Grass carp in relationship to screen.

McClay, W. 2000. Rotenone use in North America (1988-1997). Fisheries 25: 15-21.

Notes: This article compares number of treatments by objective; in this time period, a very small number of treatments were done for restoration of natives or removal of non-natives: only 4% of all reported treatments. However, in terms of the amount of waters treated, 37% of the total volume of standing water and 24% of the total length of flowing water was for restoration or non-native removal.

Abstract: Rotenone has been used as a management tool by fisheries managers for more than 50 years. In recent years, a few projects have resulted in public controversy and in some states, rotenone use has been limited or temporarily prohibited. The American Fisheries Society's Task Force on Fishery Chemicals developed and implemented a Rotenone Stewardship Program for fisheries management using Federal Aid Administrative Funds. An initial survey of fish and wildlife agencies in North America was conducted to determine current trends, restrictions, and issues. The survey accounted for an estimated 87% of the rotenone used. The number of states and provinces using rotenone has changed little since 1949, but the quantity of rotenone used declined during the ten-year survey period of 1988–1997. Manipulation of fish communities to maintain sport fisheries and quantification of fish populations (sampling) were the most common uses of rotenone by North American fish and wildlife agencies. Other important uses included treatment of rearing facilities and eradication of exotic fish. The most important issues facing fish and wildlife agencies using rotenone were public acceptance and understanding of projects and environmental concerns. Responses from the survey were used to develop a manual of administrative and technical guidelines for the safe and effective use of rotenone.

McClay, W. 2002. Rotenone use in North America: an update. Fisheries 27: 19-20.

Notes: This article summarizes survey questions to government agencies; 75 of 86 surveys were filled out. The article includes information such as scope of use (principal reasons were quantifying populations, manipulation, and treating rearing ponds); quantities used and water treated; issues in order of importance (public notification and education; public health; collection and disposal; and water quality).

Abstract: The American Fisheries Society (AFS) Fish Management Chemicals Subcommittee (FMCS) conducted a survey of governmental agencies in North America to determine patterns and issues relating to the use of rotenone during the period of 1988-1997 (McClay 2000). This report is a follow-up survey that covers the three-year period from 1998 to 2000.

Meronek, T., Bouchard, P., Buckner, E., Burri, T., Demmerly, K., Hatleli, D., Klumb, R., Schmidt, S., and Coble, D. 1996. A review of fish control projects. *North American Journal of Fisheries Management* 16: 63-74.

Abstract: We searched the fisheries literature to assess the success of fish control projects. We reviewed 250 control projects from 131 papers. Usually each treated body of water was considered a project. Fish control treatments were divided into four categories: chemical applications (145), physical removal and reservoir drawdowns (70), stocking of fish (29), and any combination of chemical and physical methods(6). Success was judged by changes in standing stock, growth, proportional stock density, relative weight values, catch or harvest rates, and other benefits, such as angler satisfaction. Reduction in standing stock was the most common determinant of success. Of the 250 projects, we considered 107 (43%) to be successful, 74 (29%) to be unsuccessful, and 69 (28%) to have insufficient data to determine success. The most successful projects targeted rough fish. Total elimination was more successful (63%) than partial reduction (40%) in 221 waters. Success was not strongly related to size of water body. Success of chemical application was similar for treatment with rotenone (48%) and with antimycin (45%). Success rates for physical removal methods (nets, traps, seines, electrofishing, drawdowns, and combinations of physical treatments) ranged from 33 to 57%. Stocking certain species of fish to control others was the least successful, 7 of 29 water bodies (24%). Combined chemical and physical methods were successful in 4 of 6 projects (66%). Stocking after chemical or physical treatment may have increased success of fish control projects; 10 of 17 such projects (59%) were successful, a higher percentage than for chemical treatments, physical treatments, or stocking alone. An overall success rate of less than 50% for such a large number and wide variety of projects indicates that there is considerable room for improvement of fish control projects. The large percentage of unsuccessful projects and the complexity of factors influencing fish communities suggest that control projects should include critical evaluation of assumptions and of suspected causes of problems, explicit rationale and objectives, and pretreatment and long-term post treatment study.

Minckley, W.L., and Mihalick, P. 1981. Effects of chemical treatment for fish eradication on stream-dwelling invertebrates. *Journal of the Arizona-Nevada Academy of Science* 16: 79-82.

Notes: This study found dramatic short-term effects on invertebrates but longterm changes were minimal.

Abstract: Stream-dwelling invertebrates were decimated by application of 10 µg per liter of antimycin A A-24 for fish eradication in Ord Creek, Apache County, Arizona. Three years later, numbers, biomass, and diversity of invertebrates were similar to pre-treatment conditions, but possible taxonomic changes were indicated.

Moy, P.B. 1999. Development of an aquatic nuisance species barrier in a commercial waterway. Pederson, J, editor. *First National Conference on Marine Bioinvasions January 24-27 1999. Massachusetts Institute of Technology.*

URL: <http://massbay.mit.edu/exoticspecies/conferences/1999/abstract8.html>

Abstract: No.

Excerpts from Report: The NISA Act of 1996 authorized the Corps of Engineers to carry out a demonstration study of an aquatic nuisance species dispersal barrier in the Chicago Sanitary and Ship Canal. This location is of great interest as the century old, man-made canal is the only aquatic link between the Mississippi River and Great Lakes drainages and forms a two-way avenue for invasive species dispersal. . .To identify likely dispersal barrier methodologies the Chicago District Corps assembled a Dispersal Barrier Advisory Panel comprised of 26 federal, state, academic, regional, municipal, commercial and environmental member entities. Recognizing that 100 percent control was unrealistic, the Panel members agreed that the objective of the barrier should be to reduce, to the extent possible, the dispersal of invasive species. No migratory species traverse this man-made canal however the barrier is expected to affect the passage of native as well as invasive species. . . .The project has three phases. Phase I will target bottom dwelling species, particularly the round goby (*Neogobius melanostomus*). Phase II will target actively swimming organisms in the entire water column. Finally, Phase III will address planktonic organisms. Construction of Phase I, which will consist of an electric barrier array, is expected to begin in Spring 1999. Laboratory and small-scale field trials currently in progress will help identify ideal field intensities and potential effect on native species. Monitoring of the project will help determine its success and effectiveness. Development of Phase II is already underway; implementation of the full water column electric barrier depends in part, upon safety and liability concerns. Other methodologies under consideration or development include

infrasound, bubble screens and water jets. Though considered effective, at this time, chemical control was recommended for use only as a stopgap or emergency measure.

Rinne, J.N., Minckley, W.L., and Hanson, J.N. 1981. Chemical treatment on Ord Creek, Apache County, Arizona to reestablish the Arizona trout. Journal of the Arizona-Nevada Academy of Sciences 16: 74- 78.

Notes: Threatened Apache trout were being replaced in Ord Creek by nonnative brown and brook trout. Chemical renovation of the stream was proposed and conducted. First treatment was in August 1977, and in September 1978 intensive sampling revealed only brook trout fry; there were no adult Apache trout. The upper reach was re-treated in September 1978 and appeared effective. A survey in 1981 (which may have been angling only) found only adult Apache trout. The authors' conclusions: multiple treatments may be necessary: timing and habitat complexity may have contributed to initial failure.

Abstract: Arizona trout (*Salmo apache*), a threatened species, was being displaced in Ord Creek, Apache County, Arizona, by introduced brown trout (*S. trutta*) and brook trout (*Salvelinus fontinalis*). The stream was treated with Antimycin A after removal of a stock of the native species. Procedures, and the effects of the ichthyotoxin, are reviewed. *Salmo apache* was reintroduced, but a year after treatment only young-of-the-year brook trout were present. Another treatment in 1978 succeeded in eradicating the nonnative species, and the Arizona trout introduced in October 1980 are surviving in the stream.

Robinson, A.T., Avenetti, L.D., and Cantrell, C. 2004. Evaluation of Apache trout habitat protection actions. Technical Guidance Bulletin No. 7. Project F-14-R. Arizona Game and Fish Department, Research Branch, Phoenix.

URL: Available from http://www.azgfd.gov/w_c/research.shtml

Notes: This report evaluates barrier effectiveness, and provides information on chemical renovations. Definition of failure: non-native salmonids found above barrier. They determined failure by 1) historical evaluation and 2) marking salmonids below barriers and looking for marked salmonids above barriers. Results: 64% barrier failure rate, mostly due to barrier needing repair or reconstruction. Conclusions: They question effectiveness of gabion barriers due to failure rate. Passage through interstitial spaces considered a problem; they suggest a possible solution would be to cover gabion barriers with concrete or create a solid concrete backfilled barrier (longer life, less maintenance). Problems: equipment to remote areas; higher cost. Methods to reduce angler transport: restricting vehicle access, regulation changes, education, law enforcement, remote cameras.

Sloat, M.R. 1999. The use of artificial migration barriers in the conservation of resident stream salmonids. Unpublished report.

Abstract: Fishery managers attempting to rehabilitate populations of rare salmonids often barricade streams to prevent upstream movement of non-native competitors. Migration barriers play an important role in the preservation of native fish species by preventing colonization of remaining habitats by nonnative fishes. However, barriers may also create problems for native fish populations by fragmenting fish populations, reducing gene flow, and increasing the chance of extinction through stochastic events. The extent of published literature addressing on-the-ground implementation, as well as the ecological consequences of management by isolation does not reflect this management action's widespread occurrence. I provide a review of basic barrier design criteria, as well as a critical evaluation of the use of artificial migration barriers in the conservation of resident stream salmonids.

Swink, W.D. 1999. Effectiveness of an electrical barrier in blocking a sea lamprey spawning migration on the Jordan River, Michigan. North American Journal of Fisheries Management 19: 397-405.

Abstract: Mark-recapture studies indicated that a pulsed-DC electrical barrier set to a 2-ms pulse width and 10 pulses/ s completely blocked the spawning migration of sea lampreys *Petromyzon marinus* in the Jordan River, Michigan. Capture efficiency of fyke nets averaged 24% for four groups, about 300 tagged sea lampreys each, released upstream of the barrier; no unmarked sea lampreys and none of the 1,194 sea lampreys tagged and released downstream of the barrier were captured in the fyke nets while the barrier was energized. At a lower pulsator setting (1-ms pulse width; 10 pulses/ s), 1 of 900 sea lampreys released below the barrier was recaptured in the nets. Sea lampreys from downstream were captured in the fyke nets after the barrier was de-energized, indicating that the barrier should remain in operation later than mid-July. Both sea lampreys and

teleosts exposed to the electrical field were stunned but exhibited no apparent damage at either barrier setting. The pulsed-DC electrical barrier should help reduce the use of chemical lampricides for controlling sea lampreys in some Great Lakes streams and would be particularly suited for streams where even the smallest low-head barrier would create an unacceptably large impoundment.

Thompson, P.D., and Rahel, F.J. 1998. Evaluation of artificial barriers in small Rocky Mountain streams for preventing the upstream movement of brook trout. North American Journal of Fisheries Management 18: 206-210.

Notes: This paper represents one of the few studies that evaluated barriers by marking and recapturing fish.

Abstract: Artificial barriers are important management tools for protecting populations of native fishes from encroaching nonnative species. We evaluated the effectiveness of gabion and culvert barriers in preventing upstream movement of brook trout *Salvelinus fontinalis* in four small Rocky Mountain streams that contained native populations of Colorado River cutthroat trout *Oncorhynchus clarki pleuriticus*. A rock-filled gabion in one stream and a road culvert in a second stream appeared to block upstream movement of brook trout; no fish marked and released downstream of the barriers were subsequently found upstream of the barriers. However, in a third stream, 18 of 86 brook trout marked and placed downstream of a rock-filled gabion barrier were later found upstream of the barrier during 3 years of evaluation. These fish ranged in length from 81 to 224 mm total length, so all size-classes were able to navigate past the structure. One brook trout moved upstream past the gabion twice, the second time during low flows when all water was percolating through the structure. We concluded that brook trout were able to move upstream through the rocks in this gabion barrier because fine sediments had not filled in all the interstitial spaces. Attention should be given to preventing movement of fish through gabion-type barriers, not just over or around them. In the fourth stream, 1 of 48 marked brook trout was found upstream from a road culvert barrier. Because this barrier appeared to be functioning properly during our study, we suspect this fish was moved upstream by an angler.

U.S. Fish and Wildlife Service (USFWS). 1998b. Little Colorado River spinedace, *Lepidomeda vittata* Recovery Plan. Albuquerque, New Mexico. 51 pp.

Abstract: No.

Excerpt from Introduction: The Little Colorado River spinedace (spinedace), *Lepidomeda vittata*, is currently restricted to north flowing tributaries of the Little Colorado River in Apache, Coconino and Navajo counties of eastern Arizona . . . The other species of spinedace occur in extreme northwest Arizona (*L. mollispinis*) and in Nevada and Utah (*L. albivallis* and *L. altivelis*, Miller and Hubbs 1960; Minckley 1973; LaRivers 1962). The spinedace was included in the U.S. Fish and Wildlife Service's (USFWS) "Review of Vertebrate Wildlife for Listing as Endangered or Threatened Species" (USFWS 1982). At that time, the species was considered a category one species, indicating that the USFWS had substantial information on hand to support a proposal to list the species as endangered or threatened. On 12 April 1983, the USFWS was petitioned by the Desert Fishes Council to list the spinedace. This petition was found to contain substantial scientific or commercial information and a notice of the finding was published on 14 June 1983 (USFWS 1983). After review and evaluation of the petition's merits, the USFWS found the petitioned action warranted. A notice of finding was published on 13 July 1984 and the species was proposed for listing on 22 May 1985 (USFWS 1984, 1985). The spinedace was listed as threatened in 1987 (USFWS 1987). Areas designated as Critical Habitat includes 31 miles of East Clear Creek, Coconino County, from its confluence with Leonard Canyon upstream to Blue Ridge Reservoir and from the upper end of Blue Ridge Reservoir to Potato Lake; eight miles of Chevelon Creek, Navajo County, from the confluence with the Little Colorado River upstream to the confluence of Bell Cow Canyon; and five miles of Nutrioso Creek, Apache County, from the Apache- Sitgreaves National Forests boundary upstream to Nelson Reservoir Dam (USFWS 1987).

Verrill, D.D., and Berry, Jr. C.R. 1995. Effectiveness of an electrical barrier and lake drawdown for reducing common carp and bigmouth buffalo abundances. North American Journal of Fisheries Management 15: 137-141.

Notes: Carp is an introduced species but bigmouth is native to Minnesota.

Abstract: An overabundance of common carp *Cyprinus carpio* and bigmouth buffalo *Ictiobus cyprinellus* in North and South Heron lakes, Minnesota, has hindered production of food plants for waterfowl. These shallow (maximum depth, 1.5 m), turbid lakes are partially drawn down each winter. Common carp were radio-tracked in both lakes during the winters of 1991 and 1992 to monitor their movements and survival. Four of six radio-tagged fish died during the first winter because of low water, but all of an additional 12 radio-tagged common carp survived the second winter. The fish overwintered in water 28–50 cm deep under about 40 cm of ice cover. To assess the ability of an electrical barrier across the outlet stream to prevent migration into the Heron lakes basin, 1,600 common carp and bigmouth buffalo were marked with dart tags and released downstream from the barrier. No tagged fish were among the 3,376 fish caught upstream from the barrier. Catches of the two species per unit gillnetting effort in South Heron Lake were lower in August 1992 than in August 1991, suggesting that lake-level drawdown and the electrical barrier reduced both populations.

Young, M.K. 2001. Pheromonal attraction: the potential for selective removal of nonnative species.

Shepard, B. Practical Approaches for Conserving Native Inland Fishes of the West. Sponsored by the Montana Chapter and the Western Division of the American Fisheries Society.

URL: <http://www.fisheries.org/AFSmontana/Misc/Symposium%20Abstracts/Abstracts.pdf>

Abstract: Introductions of non-native species are believed to be the greatest threat to the persistence and recovery of many subspecies of cutthroat trout (Young 1995). For example, brook trout *Salvelinus fontinalis* have invaded and replaced populations of cutthroat trout *Oncorhynchus clarki* regardless of habitat conditions. To maintain or restore populations of cutthroat trout to such streams, biologists often attempt to remove brook trout by using toxicants (Gresswell 1991) such as rotenone or antimycin, or by using repeated electrofishing passes (Thompson and Rahel 1996). Both techniques rarely completely eradicate the target species, even after repeated treatments, and for toxicants, concerns have been raised about its effects on water quality and nontarget species. Electrofishing has the added disincentive of being extremely labor intensive. Consequently, an alternative technique that is less arduous, less controversial, and more species-specific than either poisoning or electrofishing is needed. A common approach to pest control in the agricultural industry is the use of pheromones to attract reproductively active individuals to traps. Pheromones are a hormonal chemical signal, often released to attract mates or synchronize mating. Salmonids also appear to release and detect pheromones that influence

APPENDIX C
USCOE Summary of Barriers for GLMRIS

Appendix B - Available Controls for the ANS of Concern – Chicago Area Waterway System (CAWS) - This table contains a comprehensive list of available options and technologies to prevent the transfer of ANS via aquatic pathways. No analysis of constraints, impacts, regulatory requirements, or technological feasibility has been conducted at this time, and a particular Control may not be suitable for a specific location or situation.

Fact Sheet	ANS Control	Selective for ANS of Concern – CAWS	Status ²	Targeted Organisms of Concern – CAWS							Comments Refer to fact sheets for additional information on each Control	
				algae	annelid	bryozoan	crustacean	fish	mollusk	plant		protozoan
Accelerated Water Velocity	Accelerated Water Velocity	N	Available	X	X	X	X	X	X	X	X	<ul style="list-style-type: none"> Not effective in preventing downstream ANS movement Must have a length and speed of flow greater than the organism's leaping ability and swimming endurance
	Acoustic Fish Deterrents	N	Experimental				X					<ul style="list-style-type: none"> Under development for control of fish May not be effective on all fish species
Algaecides [§]	Pulsed Pressure Wave	N	Experimental				X					<ul style="list-style-type: none"> Not lethal unless an organism is very close to sound source
	Copper Sulfate and Chelated Copper Formulations (ethanolamines, ethylene diamines, triethanolamines, triethanolamine+ethylene diamine, and copper citrate/gluconate)	N	Available, Registered	X								<ul style="list-style-type: none"> May be effective on diatoms (<i>Cyclotella cryptica</i>, <i>C. pseudostelligera</i> and <i>Stephanodiscus binderanus</i>) and grass kelp (<i>Enteromorpha flexuosa</i>) Chelated copper formulations may be effective on red macro-algae (<i>Bangia atropupurea</i>) Reduced efficacy in waters with high pH and water temperatures < 15 °C
	Endothall (as the mono(N,N-dimethylalkylamine) salt) CAS #: 66330-88-9	N	Available, Registered	X								
	Algaecides containing Sodium Carbonate Peroxyhydrate CAS #: 15630-89-4	N	Available, Registered	X								<ul style="list-style-type: none"> May be effective on diatoms (<i>C. cryptica</i>, <i>C. pseudostelligera</i> and <i>S. binderanus</i>), and grass kelp (<i>E. flexuosa</i>)

[§] Pesticides must be applied in accordance with the USEPA-approved product label guidelines. Users must confirm pesticide registration status prior to application. The registration status, trade name, and availability of pesticides are subject to change.
² **Status**

Available - An option or technology that has been implemented in the field.
Experimental - A novel option or technology, or a chemical that is not a U.S. Environmental Protection Agency (USEPA)-registered pesticide under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).
Registered - A chemical that is a USEPA-registered pesticide under FIFRA for the fact sheet use in compliance with the USEPA-approved product label.
When Not Registered for a Use - A product can only be used for the control of ANS, if the product is labeled for ANS Control. Under FIFRA section 2(ee), where an ANS is not listed on the pesticide label, the product may still be used to control those species so long as the site, where the pesticide is to be used, is on the label. If the use site is not listed on the pesticide label, the proposed new use must be submitted to the USEPA for a "new use assessment", which may require the USEPA to conduct human health and ecological risk assessments.



Fact Sheet	ANS Control ¹	Selective for ANS of Concern - CAWS	Status ²	Targeted Organisms of Concern – CAWS							Comments Refer to fact sheets for additional information on each Control
				algae	annelid	bryozoan	crustacean	fish	mollusk	plant	

Alteration of Water Quality § The status of these chemicals is in part based on results of a Pesticide Product Information System (PPIS) index query at http://ppis.ceris.purdue.edu/ run on 11/10/2011. The Chemical Abstracts Service (CAS) numbers were used to enter the query and for convenience have been provided.	Gases	Carbon Dioxide (CO ₂)	N	Available, When Not Registered for a Use	X	X	X	X	X	X	X	<ul style="list-style-type: none"> • May repel fish at sub-lethal levels • Lowers pH • Creates irreversible cell damage and death
		Ozone	N	Available	X	X	X	X	X	X	X	<ul style="list-style-type: none"> • Rendered ineffective in the presence of organic matter • Used commercially to decontaminate water • Ozone oxidation is toxic to most small waterborne organisms • Destroys the epithelium covering the gill lamella in fish • Adult fish are more tolerant than young fish • Nitrogen supersaturation is a cause of gas bubble disease in fish
		Nitrogen	N	Available	X	X	X	X	X	X	X	<ul style="list-style-type: none"> • Creates a solid precipitate from suspended solids within the water column which settles • Alum is not classified as a pesticide, therefore does not require FIFRA registration • Deoxygenated compound
	Solids	Alum	N	Available	X							
		Sodium Thiosulfate CAS #: 7772-98-7	N	Experimental	X	X	X	X	X	X	X	

¹ This table contains a comprehensive list of available options and technologies to prevent the transfer of ANS via aquatic pathways. No analysis of constraints, impacts, regulatory requirements, or technological feasibility has been conducted at this time, and a particular Control may not be suitable for a specific location or situation.

² **Status**
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Fact Sheet	ANS Control ¹	Selective for ANS of Concern - CAWS	Status ²	Targeted Organisms of Concern - CAWS						Comments Refer to fact sheets for additional information on each Control
				algae	annelid	bryozoan	crustacean	fish	mollusk	
Aquatic Herbicides The status of these chemicals is in part based on results of a Pesticide Product Information System (PPIS) index query at http://ppis.ceris.purdue.edu/ run on 11/13/2011. The Chemical Abstracts Service (CAS) numbers were used to enter the query and for convenience have been provided.	2,4-D (both the amine and butoxy-ethyl ester formulations) CAS #: 94-75-7	N	Available, Registered					X		<ul style="list-style-type: none"> May be effective on Cuban bulrush (<i>Oxycaium cubense</i>) and water chestnut (<i>Trapa natans</i>) Tank mixing with other herbicides improves plant control
	Diquat CAS #: 85-00-7	N	Available, Registered					X		<ul style="list-style-type: none"> Effective on Cuban bulrush (<i>O. cubense</i>) when tank mixed with 2,4-D or glyphosate May be effective on dotted duckweed (<i>Landoltia (Spirodela) punctata</i>)
	Fluridone CAS #: 59756-60-4	N	Available, Registered					X		<ul style="list-style-type: none"> May be effective on dotted duckweed (<i>L. (S.) punctata</i>) Plants must be exposed to a lethal dose for a minimum of 45 days for optimal results
	Glyphosate CAS #: 1071-83-6	N	Available, Registered					X		<ul style="list-style-type: none"> Effective on Cuban bulrush (<i>O. cubense</i>) when tank mixed with 2,4-D May be effective on swamp sedge (<i>Carex acutiformis</i>), reed sweetgrass (<i>Glyceria maxima</i>), and marsh dewflower (<i>Murdannia keisak</i>)
	Imazapyr CAS #: 81334-34-1	N	Available, Registered					X		<ul style="list-style-type: none"> May be effective on swamp sedge (<i>C. acutiformis</i>), reed sweetgrass (<i>G. maxima</i>), and Cuban bulrush (<i>O. cubense</i>)
	Triclopyr CAS #: 55335-06-3	N	Available, Registered					X		<ul style="list-style-type: none"> May be effective on water chestnut (<i>T. natans</i>)
Benthic Barriers	Textile or Plastic	N	Available					X		<ul style="list-style-type: none"> Not effective for floating plants such as dotted duckweed (<i>L. (S.) punctata</i>) Ongoing research investigating effectiveness on mollusks
	Silt	N	Available						X	<ul style="list-style-type: none"> Created by applying excessive silt/sand to smother bottom-dwelling organism Application to control aquatic nuisance species has not been widely studied

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				algae	annelid	bryozoan	crustacean	fish	mollusk	

Biocides for Industrial Use [§] Unless noted by BGS, information was obtained from (U.S. Coast Guard Research and Development Center. <i>Evaluation of Biocides for Potential Treatment of Ballast Water: Final Report.</i> (Report No. CG-D-01-05) Washington, DC, 2004) The status of these chemicals is based on results of a Pesticide Product Information System (PPIS) index query at http://ppis.ceris.purdue.edu/ run on 9/28/2011. The Chemical Abstracts Service (CAS) numbers were used to enter the query and for convenience have been provided. Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.	Isothiazolone (Sea-Nine®) CAS #: 64359-81-5	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Antifouling agent used in hull coatings
	2-(thiocyanomethylthio) benzothiazole (TCMTB) CAS #: 21564-17-0	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Antifouling agent Disinfection of industrial water systems
	Benzalkonium Chloride CAS #: 8001-54-5	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Corrosive Disinfection of industrial water systems
	Bromine CAS #: 7726-95-6	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Purification of drinking water, cooling systems, and surfaces Corrosive Requires a controlled application; reacts quickly Presence of organic matter limits effectiveness Residuals remain in water after treatment Requires frequent applications
	Chlorine (free chlorine, hypochlorous acid, hypochlorite salts) CAS #: 7782-50-5	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Registered under FIFRA as a fungicide
	Chlorine Dioxide CAS #: 10049-04-4	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Pulp and paper water treatment systems Disinfection of industrial water systems
	Chlorothalonil CAS #: 1897-45-6	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Antifouling agent
	Dibromonitropropionamide (DBNPA) CAS #: 10222-01-2	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Not persistent and degrades rapidly under acidic conditions
	Dichlofluanid CAS #: 1085-98-9	N	Experimental	X	X	X	X	X	X	<ul style="list-style-type: none"> Slight to moderate efficiency in presence of organic matter Some residuals remain in water after treatment
	N-(3-Chloroallyl) Hexamethylenetetramine chloroallyl chloride (Dowicil® 75) CAS #: 4080-31-3	N	When Not Registered for a Use	X	X	X	X	X	X	
Glutaraldehyde CAS #: 111-30-8	N	When Not Registered for a Use	X	X	X	X	X	X		

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				algae	annelid	bryozoan	crustacean	fish	mollusk	

Biocides for Industrial Use [§] (continued) Unless noted by ^{B,GS} , information was obtained from (U.S. Coast Guard Research and Development Center. <i>Evaluation of Biocides for Potential Treatment of Ballast Water: Final Report</i> , (Report No. CG-D-01-05) Washington, DC, 2004) The status of these chemicals is based on results of a Pesticide Product Information System (PPIS) index query at http://ppis.ceris.purdue.edu/ run on 9/28/2011. The Chemical Abstracts Service (CAS) numbers were used to enter the query and for convenience have been provided. Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.	Hydrogen Peroxide CAS #: 7722-84-1 CAS #: 79-21-0	N	When Not Registered for a Use	X	X	X	X	X	X	<ul style="list-style-type: none"> Disinfection of drinking water, cooling systems and surfaces Presence of organic matter limits effectiveness Moderately corrosive Some residuals remain in water after treatment
	Iodine CAS #: 7553-56-2	N	When Not Registered for a Use		X	X				<ul style="list-style-type: none"> Disinfection of drinking water, cooling systems and surfaces Requires a controlled application and reacts quickly Corrosive Presence of organic matter limits effectiveness Residuals remain in water after treatment Requires frequent applications
	2-methylthio-4-terbutylamino-6-cyclopropylamino-striazine (Irgarol®) CAS #: 28159-98-0	N	When Not Registered for a Use				X			<ul style="list-style-type: none"> Antifouling agent
	Fatty Amines (Mexel® 432)	N	Experimental					X		<ul style="list-style-type: none"> Rapid degradation in the environment Scale dispersant & corrosion inhibitor
	Peracetic Acid (Peraclean®) CAS #: 79-21-0 CAS #: 7722-84-1	N	When Not Registered for a Use					X		<ul style="list-style-type: none"> No known toxic residual; more potent than hydrogen peroxide Rapidly active at low concentrations against a wide range of microorganisms Corrosive Highly efficient in presence of organic matter Wastewater treatment
Phenol CAS #: 108-95-2	N	When Not Registered for a Use						X	<ul style="list-style-type: none"> Disinfectant & low corrosivity Little or no residuals remain in water after treatment 	

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Fact Sheet	ANS Control ¹	Selective for ANS of Concern - CAWS	Status ²	Targeted Organisms of Concern - CAWS						Comments Refer to fact sheets for additional information on each Control			
				algae	annelid	bryozoan	crustacean	fish	mollusk		plant	protozoan	
Biocides for Industrial Use ^S (continued) Unless noted by ^{B,GS} , information was obtained from (U.S. Coast Guard Research and Development Center. <i>Evaluation of Biocides for Potential Treatment of Ballast Water: Final Report</i> , (Report No. CG-D-01-05) Washington, DC, 2004) The status of these chemicals is based on results of a Pesticide Product Information System (PPIS) index query at http://ppis.ceris.purdue.edu/ run on 9/28/2011. The Chemical Abstracts Service (CAS) numbers were used to enter the query and for convenience have been provided. Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.	Polyhexamethylene Biguanide (PHMB) CAS #: 32289-58-0	N	When Not Registered for a Use	X				X				<ul style="list-style-type: none"> Disinfection of industrial water systems 	
	Potassium Permanganate CAS #: 7722-64-7	N	Experimental	X			X		X				<ul style="list-style-type: none"> Organic matter limits effectiveness & moderately corrosive Some residuals remain in water after treatment
	Vitamin K (SeaKleen®) CAS #: 11032-49-8	N	Experimental	X			X		X				<ul style="list-style-type: none"> Ballast water treatment Toxic to a broad spectrum of marine and freshwater organisms (fish larvae and eggs, planktonic crustaceans, bivalve larvae, <i>Vibrio</i> bacteria, and dinoflagellates)
	Silver (Ionic or Salts) Ions CAS #: 15046-91-0	N	Experimental	X									<ul style="list-style-type: none"> Disinfection of industrial water systems Limited applications of metal ions or salts Not generally used due to human side effect risk
	Sodium Chlorite CAS #: 7758-19-2	N	When Not Registered for a Use	X			X		X				<ul style="list-style-type: none"> Disinfection of drinking water, cooling systems and surfaces Presence of organic matter limits effectiveness Residuals remain in water after treatment Requires frequent applications and corrosive
	Sodium Hydroxide ^{B, GS} CAS #: 1310-73-2	N	When Not Registered for a Use	X			X		X				<ul style="list-style-type: none"> Under consideration for use in ballast water treatment Mollusk mortality following 17 to 31 day exposure to NaOH-adjusted pH of 9.3 to 9.6.^B ^BBowman, M.F. and R.C. Bailey. 1998. Upper pH tolerance limit of the zebra mussel (<i>Dreissena polymorpha</i>). <i>Canadian Journal of Zoology</i>, vol. 76, pp. 2119-2123. <1% survival of test organisms including algae, annelids, crustaceans and fish with 48-hr exposure to pH adjustments of 11.5 to 12.5 using NaOH ^{GS} ^{GS}TenEyek, M. 2009. Great Ships Initiative Bench-Scale Test Findings, Technical Report – Public, Sodium Hydroxide (NaOH). GSI/BS/5.
Triclosan CAS #: 3380-34-5	N	When Not Registered for a Use						X				<ul style="list-style-type: none"> Stable and incompatible with strong oxidizing agents Wastewater treatment 	
Zineb (Thiocarbamate) CAS #: 12122-67-7	N	Experimental						X				<ul style="list-style-type: none"> Antifouling agent & disinfection of industrial water systems 	

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<p>Biological Controls §</p> <p>Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.</p>	Introduced Predatory Fish Species	N	Available				X	X			<ul style="list-style-type: none"> Includes both carnivorous, herbivorous and molluscivorous fish species Best used in waters with no outflows Predatory fish are non-selective feeders
	Introduced Predatory Insect Species	N	Experimental						X		<ul style="list-style-type: none"> United States Department of Agriculture (USDA) has not approved of any insects for use as biological controls of plants identified as ANS of Concern – CAWS Although a leaf beetle (<i>Galerucella birmanica</i>) was found to cause complete defoliation of water chestnut (<i>T. natans</i>), research was suspended in 2002
	<i>Pseudomonas fluorescens</i> CL 145A	N	Registered					X			<ul style="list-style-type: none"> May be effective on European fingernail clam (<i>Sphaerium corneum</i>), the European pea clam (<i>Pisidium amnicum</i>), and the European stream valvata (<i>Valvata piscinalis</i>) Active ingredient (<i>Pseudomonas fluorescens</i> CL 145A) approved by the United States Environmental Protection Agency (USEPA) in July 2011 (Reg. No. 84059-4) Formulation of commercial product as Zequanox™ is pending review by USEPA as of October 2010; Section 3 registration expected in March 2012 Ongoing research to assess impacts to non-target mollusks
	Targeted Disease Agents	N	Experimental				X				<ul style="list-style-type: none"> Under consideration for carp species

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Controlled Harvest and Overfishing	Controlled Harvest and Overfishing	N	Available				X					<ul style="list-style-type: none"> Requires sorting and returning of native fish species Requires continual capture over a long period of time, or intensive harvest during critical periods of concentration and reproduction (e.g., migration and spawning season) Once harvesters, processors, and communities become economically dependent on harvesting nuisance fish, pressure to manage a sustainable population of these fish may conflict with the original purpose of removing them from the environment
	Deleterious Gene Spread	Daughterless Gene	Y	Experimental			X					<ul style="list-style-type: none"> Researched as a Control for silver carp (<i>H. molitrix</i>), bighead carp (<i>H. nobilis</i>), black carp (<i>Mylopharyngodon piceus</i>), and sea lamprey (<i>Petromyzon marinus</i>) Researched as a Control for common carp Manipulation of genes can manifest unforeseen and significant undesirable side effects and would require extensive research before being accepted as a Control The Food and Drug Administration regulates genetically engineered animals
Dredging and Diver Dredging	Trojan Y Chromosome	Y	Experimental				X					<ul style="list-style-type: none"> Not effective on dotted duckweed (<i>L. (S.) punctata</i>) Requires careful disposal or reuse of dredged material to prevent the transfer of ANS to a new location May remove other ANS of Concern - CAWS and non-target organisms that reside in sediment
	Dredging and Diver Dredging	N	Available						X			

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Electron Beam Irradiation	Electron Beam Irradiation	N	Available			X				X	<ul style="list-style-type: none"> Used in irradiation of food, environmental waste, medical sterilization, and water treatment Requires a closed system and not appropriate for open water application May require pretreatment to remove suspended solids Used in irradiation of food, environmental waste, medical sterilization, and water treatment
Hydrologic Separation	Physical Barriers	N	Available	X	X	X	X	X	X	X	<ul style="list-style-type: none"> Modifies flow within waterway, including stormwater and combined sewer overflow discharge, and conveyance and commercial water dischargers and withdrawal of water
Irrigation Water Chemicals [§]	Acrolein CAS #: 107-02-8	N	Available, Registered, Restricted Use Product*	X					X		<ul style="list-style-type: none"> For control of submersed and floating weeds and algae only in irrigation canal systems in western states, provided the appropriate state registrations are also in place Toxic to fish and other aquatic organisms at labeled use rates
	Xylene CAS #: 1330-20-7	N	Registered	X					X		<ul style="list-style-type: none"> For use only in irrigation and drainage canals designated by the Bureau of Reclamation and cooperating water user organizations For use in Programs of the Bureau of Reclamation and Cooperating Water User Organizations within the following states, provided that the appropriate state registrations are also in place: AZ, CA, CO, ID, KS, MT, NE, NM, NV, ND, OK, OR, SD, TX, UT, WA, and WY For control of submersed weeds in irrigation and drainage canals Toxic to fish and other aquatic organisms at labeled use rates

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Lethal Temperature	Pressurized Hot Water/Steam Treatment	N	Available	X	X	X	X	X	X	X	X	X	<ul style="list-style-type: none"> Hot water has been used to kill zebra and quagga mussels at municipal and industrial facilities, and high pressure hot water is used to clean ANS off of recreational boats
	Hot Water Thermal Barrier	N	Available	X	X	X	X	X	X	X	X	X	<ul style="list-style-type: none"> Difficult to manage in open water system, must be completely mixed throughout the water column During cold weather conditions, warm water temperatures may attract fish
	Freezing	N	Available	X	X	X	X	X	X	X	X	X	<ul style="list-style-type: none"> Freezing is often combined with winter water level drawdowns to expose the ANS to freezing air temperatures Cluster mussels are more tolerant of reduced air temperatures than individual organisms
	Carbon Dioxide (CO ₂) Pellet (dry ice) Blasting	N	Available	X	X	X	X	X	X	X	X	X	<ul style="list-style-type: none"> Method used extensively to remove organics from aircrafts producing no deterioration of surfaces CO₂ pellets convert to a gas at ambient temperatures, leaving no residue.
Light Attenuating Dyes [§]	Desiccation	N	Available	X	X	X	X	X	X	X	X	X	<ul style="list-style-type: none"> Desiccation can only be achieved in areas where water levels can be controlled Exposure to air quickly leads to death for active water-breathing organism—mollusks and plants are more tolerant and require longer drying period
	Light Attenuating Dyes	N	Registered	X							X		<ul style="list-style-type: none"> May suppress growth of water chestnut (<i>T. natans</i>) if applied prior to plant germination (pre-emergence) Not effective for suppressing growth of floating aquatic plants or emergent shoreline vegetation identified as ANS of Concern – CAWS Not effective on floating algal mats May suppress the growth of non-target plants and algae Only for use in contained waterbodies with little or no outflow Do not apply to waters used for human consumption

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Manual Harvest Mechanical Control Methods	Manual Harvest	Y	Available							X		<ul style="list-style-type: none"> • Labor-intensive • Selectively dependent upon training and skill of staff
	Mechanical Harvesting	N	Available							X		
	Shredding	N	Available							X		
	Mowing	N	Available							X		<ul style="list-style-type: none"> • Not effective on dotted duckweed (<i>L. (S.) punctata</i>) • May disturb non-target organisms in equipment path
	Chaining	N	Available							X		
	Roto-tilling	N	Available							X		
	Rotovating										X	

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<p>Molluscicides [§]</p> <p>The status of these chemicals is based on results of a Pesticide Product Information System (PPIS) index query at http://ppis.ceris.purdue.edu/ run on 9/28/2011. The Chemical Abstracts Service (CAS) numbers were used to enter the query and for convenience have been provided.</p> <p>*A product, or its uses, classified as "Restricted Use" may only be applied by a certified pesticide applicator or under the direct supervision of a certified applicator. Information on restriction of use of a pesticide is found in the Code of Federal Regulations (Chapter 40, Part 152.160-175)</p>	<p>Quaternary and Polyquaternary Ammonium Compounds; Aromatic Hydrocarbons; Endothall as the Mono (N,N-dimethylalkylamine) Salt (TD2335 Industrial Biocide-Molluscicide) CAS #: 145-73-3</p>	N	Registered				X			<ul style="list-style-type: none"> Used for recirculating and once-through cooling water systems For control of established populations of freshwater and saltwater mollusks in closed systems Is non-selective at use rates to control mollusks 	
		<p>Metals and their salts (Copper Sulfate and Chelated Copper Formulations)</p> <p>Niclosamide CAS #: 1420-04-8</p>	N	Registered				X			<ul style="list-style-type: none"> Can be used to control mollusks in open water systems Is non-selective at use rates to control mollusks
		N	Available, Registered, Restricted Use Product*				X			<ul style="list-style-type: none"> First developed as a lampricide Used for control of snails in aquaculture ponds Toxic to fish and aquatic invertebrates at recommended use rates for control of snails in aquaculture ponds 	
Pheromones	Repellent and Attractant Pheromones	Y	Experimental				X			<ul style="list-style-type: none"> Under investigation as an attractant and/or deterrent for silver carp (<i>H. molitrix</i>), bighead carp (<i>H. nobilis</i>), black carp (<i>M. piceus</i>), and sea lamprey (<i>P. marinus</i>) 	

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<p>Piscicides §</p> <p>The status of these chemicals is based on results of a Pesticide Product Information System (PPIS) index query at http://ppis.ceris.purdue.edu/ run on 9/28/2011. The Chemical Abstracts Service (CAS) numbers were used to enter the query and for convenience have been provided.</p> <p>*A product, or its uses, classified as "Restricted Use" may only be applied by a certified pesticide applicator or under the direct supervision of a certified applicator. Information on restriction of use of a pesticide is found in the Code of Federal Regulations (Chapter 40, Part 152.160-175)</p>	Antimycin A CAS #: 1397-94-0	N	Available, Registered, Restricted Use Product*				X				<ul style="list-style-type: none"> Effectiveness can vary with the surfactant used. Requires approximately 8 to 32 hours to kill cyprinid species such as bighead carp (<i>H. nobilis</i>) and silver carp (<i>H. molitrix</i>) Restricted use pesticide due to aquatic toxicity and need for highly specialized applicator training
	Niclosamide CAS #: 1420-04-8	N	Available, Registered, Restricted Use Product*				X				<ul style="list-style-type: none"> First developed as a lampricide Used for control of snails in aquaculture ponds Toxic to aquatic invertebrates; non-target organisms may be killed at rates recommended for sea lamprey control Limited geographically to the Great Lakes Basin, the Lake Champlain system and the Finger Lakes For use only by United States Department of Interior, United States Fish & Wildlife Service (USFWS), state fish and game, Fisheries and Oceans Canada, and Provincial Certified Applicators trained in sea lamprey control
	Rotenone (Both Standard Application and Via Oral Delivery Platforms) CAS #: 83-79-4	N	Available, Registered, Restricted Use Product*				X				<ul style="list-style-type: none"> Kills bighead (<i>H. nobilis</i>) carp and silver carp (<i>H. molitrix</i>) within approximately 4 hours May be toxic to other aquatic organisms
TFM (3-Trifluoromethyl-4-nitrophenol) CAS #: 88-30-2	N	Available, Registered, Restricted Use Product*					X			<ul style="list-style-type: none"> Designed only to control sea lamprey (<i>P. marinus</i>) Limited geographically to the Great Lakes Basin, the Lake Champlain system and the Finger Lakes For use only by certified applicators of USFWS, Fisheries and Oceans Canada, and provincial and state fish and game employees Non-target organisms may be killed at labeled use rates 	

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Sensory Deterrent Systems	Underwater Strobe lights	N	Experimental					X					<ul style="list-style-type: none"> Used to prevent upstream movement of fish May not prevent downstream movement of aquatic organisms
	Underwater Sound	N	Experimental					X					
	Acoustic Air Bubble Curtain	N	Experimental					X					
	Electric Barrier	N	Available					X					<ul style="list-style-type: none"> Must be configured to stop upstream and downstream movement of fish May impact non-target aquatic organisms
Ultrasound	Ultrasound	N	Available	X									<ul style="list-style-type: none"> Used in small water bodies and water treatment plants Ultrasound may be effective on diatoms (<i>C. cryptica</i>, <i>C. pseudostelligera</i> and <i>S. binderanus</i>) Most effective on enclosed bodies of water Additional research may be needed to investigate potential impacts on non-target organisms Under investigation for use against aquatic vascular plants (non-algae)
Ultraviolet Light	Ultraviolet (UV) Light	N	Available	X				X					<ul style="list-style-type: none"> Used in fish hatcheries and water treatment facilities Used to treat contained flowing systems Best used after suspended solids, iron and manganese have been filtered from water May impact non-target aquatic organisms
Vertical Drop Barrier	Vertical Drop Barrier	N	Available		X	X	X	X	X	X			<ul style="list-style-type: none"> Does not prevent aquatic organism movement downstream May impact upstream movement of non-target organisms
Williams' Cage Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.	Williams' Cage	Y	Experimental							X			<ul style="list-style-type: none"> May be effective on silver carp (<i>H. molitrix</i>) and sea lamprey (<i>P. marinus</i>) Does not prevent aquatic organism movement downstream

¹ This table contains a comprehensive list of available options and technologies to prevent the transfer of ANS via aquatic pathways. No analysis of constraints, impacts, regulatory requirements, or technological feasibility has been conducted at this time, and a particular Control may not be suitable for a specific location or situation.

² **Status** - A novel option or technology that has been implemented in the field.

Experimental - A novel option or technology, or a chemical that is not a U.S. Environmental Protection Agency (USEPA)-registered pesticide under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

Registered - A chemical that is a USEPA-registered pesticide under FIFRA for the fact sheet use in compliance with the USEPA-approved product label.

When Not Registered for a Use - A product can only be used for the control of ANS, if the product is labeled for ANS Control. Under FIFRA section 2(ee), where an ANS is not listed on the pesticide label, the product may still be used to control those species so long as the site, where the pesticide is to be used, is on the label. If the use site is not listed on the pesticide label, the proposed new use must be submitted to the USEPA for a "new use assessment", which may require the USEPA to conduct human health and ecological risk assessments.

³ Pesticides must be applied in accordance with the USEPA-approved product label guidelines. Users must confirm pesticide registration status prior to application. The registration status, trade name, and availability of pesticides are subject to change.



APPENDIX D
ECT Presentation to GLC/Cities Initiative Advisory Committee

The potential for CO₂ as a chemical barrier for Asian carp



Background

- Electric barrier
 - Costly
 - Effective?
 - Hazardous to humans?
- Why CO₂?
 - Non-discriminatory
 - Low biological impact
 - Cost-effective?

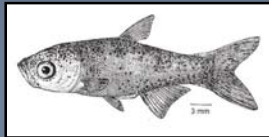


Previous work

- Laboratory Studies
 - Physiological
 - Behavioral



Progress to date



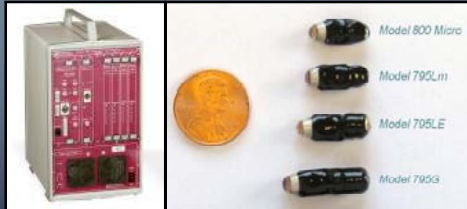
- Early life stage impacts
 - Eggs, larvae, fingerlings
 - Fingerlings do avoid

- Large-scale
 - Experimental ponds
 - CO₂ diffusion system
 - Telemetry



Large-scale study

- Experimental ponds
- Multiple fish per trial
- Telemetry



Results

- Trials completed end of Sept.
- Oct. 1 government shutdown
 - Initial raw data: evidence of fish avoidance



Lessons to be learned?



- How CO₂ behaves at large scales
- Efficient ways to deliver CO₂
- How to monitor CO₂ at large spatial scales



Challenges ahead

- *In-situ* implementation
- Environmental impacts



Challenges ahead

- EPA permitting
- Registrant
- Continue investigating alternative approaches and technologies



Next steps

- *In situ* application
- Potential test sites
 - Brandon Road Lock and Dam
- 2014 implementation?

