2009

Fish Passage and Abundance around Grade Control Structures on Incised Streams

J. T. Thomas
Hungry Canyons Alliance

A. N. Papanicolaou
University of Iowa

Clay L. Pierce
Iowa State University, cpierce@iastate.edu

D. C. Dermisis
University of Iowa

Mary E. Litvan
Missouri Department of Conservation

See next page for additional authors

Fish Passage and Abundance around Grade Control Structures on Incised Streams

Abstract

This paper summarizes research from separate studies of fish passage over weirs (Larson et al., 2004; Litvan, 2006; Litvan, et al., 2008a-c) and weir hydraulics (Papanicolaou and Dermisis, 2006; Papanicolaou and Dermisis, in press). Channel incision in the deep loess region of western Iowa has caused decreased biodiversity because streams have high sediment loads, altered flow regimes, lost habitat, and lost lateral connectivity with their former floodplains. In-stream grade control structures (GCS) are built to prevent further erosion, protect infrastructure, and reduce sediment loads. However, GCS can have a detrimental impact on fisheries abundance and migration, biodiversity, and longitudinal connectivity. Fish mark-recapture studies were performed on stretches of streams with and without GCS. GCS with vertical or 1:4 (rise/run) downstream slopes did not allow fish migration, but GCS with slopes ≤ 1:15 did. GCS sites were characterized by greater proportions of pool habitat, maximum depths, fish biomass, slightly higher index of biotic integrity (IBI) scores, and greater macroinvertebrate abundance and diversity than non-GCS sites. After modification of three GCS, IBI scores increased and fish species exhibiting truncated distributions before were found throughout the study area. Another study examined the hydraulic performance of GCS to facilitate unimpeded fish passage by determining the mean and turbulent flow characteristics in the vicinity of the GCS via detailed, non-intrusive field tests. Mean flow depth (Y) and velocity (V) atop the GCS were critical for evaluating GCS performance. Turbulent flow measurements illustrated that certain GCS designs cause sudden constrictions which form eddies large enough to disorient fish. GCS with slopes ≤ 1:15 best met the minimum requirements to allow catfish passage of a flow depth of ≥ 0.31 m and a mean flow velocity of ≤ 1.22 m/s.

Keywords

weir hydraulics, Iowa, grade control structures, index of biotic integrity

Disciplines

Aquaculture and Fisheries | Environmental Indicators and Impact Assessment | Environmental Monitoring | Natural Resources and Conservation | Natural Resources Management and Policy | Terrestrial and Aquatic Ecology

Comments

This proceeding is from *World Environmental and Water Resources Congress 2009: Great Rivers* (2009): 3082, doi:10.1061/9780784410363.

Authors

J. T. Thomas, A. N. Papanicolaou, Clay L. Pierce, D. C. Dermisis, Mary E. Litvan, and C. J. Larson

Fish Passage and Abundance around Grade Control Structures on Incised Streams

J. T. Thomas[1], A. N. Papanicolaou[2], C. L. Pierce[3], D. C. Dermisis[2], M. E. Litvan[4], and C. J. Larson[5]

[1]Hungry Canyons Alliance, Golden Hills RC&D Office, P.O. Box 189, Oakland, IA 51560-0189; PH (712) 482-3029; email: john.thomas@rcdnet.net
[2]IIHR - Hydroscience & Engineering, Dept. of Civil and Environmental Engineering, University of Iowa, Iowa City, IA 52242-1585; apapanic@engineering.uiowa.edu, dimitrios-dermisis@uiowa.edu
[3]U.S. Geological Survey, Iowa Cooperative Fish and Wildlife Research Unit, Iowa State University, Ames, IA 50011; cpierce@iastate.edu
[4]Missouri Department of Conservation, Southwest Regional Office, 2630 North Mayfair, Springfield, MO 65803; mary.litvan@mdc.mo.gov
[5]Iowa Department of Natural Resources, 5744 Lewis Road, Lewis, IA 51544; chris.larson@dnr.state.ia.us

ABSTRACT

This paper summarizes research from separate studies of fish passage over weirs (Larson *et al*., 2004; Litvan, 2006; Litvan, *et al*., 2008a-c) and weir hydraulics (Papanicolaou and Dermisis, 2006; Papanicolaou and Dermisis, in press). Channel incision in the deep loess region of western Iowa has caused decreased biodiversity because streams have high sediment loads, altered flow regimes, lost habitat, and lost lateral connectivity with their former floodplains. In-stream grade control structures (GCS) are built to prevent further erosion, protect infrastructure, and reduce sediment loads. However, GCS can have a detrimental impact on fisheries abundance and migration, biodiversity, and longitudinal connectivity. Fish mark-recapture studies were performed on stretches of streams with and without GCS. GCS with vertical or 1:4 (rise/run) downstream slopes did not allow fish migration, but GCS with slopes ≤ 1:15 did. GCS sites were characterized by greater proportions of pool habitat, maximum depths, fish biomass, slightly higher index of biotic integrity (IBI) scores, and greater macroinvertebrate abundance and diversity than non-GCS sites. After modification of three GCS, IBI scores increased and fish species exhibiting truncated distributions before were found throughout the study area. Another study examined the hydraulic performance of GCS to facilitate unimpeded fish passage by determining the mean and turbulent flow characteristics in the vicinity of the GCS via detailed, non-intrusive field tests. Mean flow depth (Y) and velocity (V) atop the GCS were critical for evaluating GCS performance. Turbulent flow measurements illustrated that certain GCS designs cause sudden constrictions which form eddies large enough to disorient fish. GCS with slopes ≤ 1:15 best met the minimum requirements to allow catfish passage of a flow depth of ≥ 0.31 m and a mean flow velocity of ≤ 1.22 m/s.

INTRODUCTION

Channelization of streams and land use changes during the first half of the 20th century caused western Iowa stream channels to become unstable. Coupled with the highly erosive loess soils found in the deep loess region of western Iowa, the channels began to downcut and widen, causing an estimated $1.1 billion in damages to public and private infrastructure (by exposing buried bridge pilings, culvert outlets, utility lines, etc., and increasing their likelihood of failure), loss of farmland, and increased sediment loads (Baumel 1994). Streams that were once merely wetlands or shallow meandering streams are now deep, non-meandering, ditches nearly 9.1 m deep. Obviously, these streams have highly altered flow regimes (Hansen, 1971; Shields *et al*. 1994); channel roughness is lower and flow velocities and discharges are much higher than they once were. These scoured channels have lost much, if not all, of their original habitat; for example, many of these streams are devoid of riffle-pool sequences, except at very low baseflow. Prime fish habitat has been shown to be adversely affected by bed degradation in other studies (Shields *et al*. 1994; Raborn and Schramm 2003). Due to extreme downcutting, many channels have lost lateral connectivity with their former floodplains, except in the most extreme flow discharge events. Many streams are starting to establish a new, much thinner floodplain in the ditch bottom by widening of the channel due to bank failure. Extensive channel erosion has also caused dramatically increased sediment loads. The altered flow regimes, loss of habitat, loss of connectivity, and high sediment loads caused by channel incision has led to decreased biodiversity (Hansen, 1971; Shields *et al*., 1994; Bravard *et al*., 1997; Cooper *et al*., 1997; Shields *et al*., 1998; Raborn and Schramm 2003). Bunn & Arthington (2002) noted that in highly altered environments, invasive species may find it easier to out-compete native species in the new, altered environment. This may explain the abundance of invasive species such as carp in western Iowa streams. At a larger scale, what happens in western Iowa in terms of biodiversity and sediment loading will affect the Missouri and Mississippi Rivers (i.e., decreased dam storage due to siltation) and the Gulf of Mexico (i.e., hypoxia) due to longitudinal connectivity.

The most efficient and affordable way to prevent further channel incision and erosion, protect infrastructure, and reduce sediment loads is to build grade control structures. There are many types of grade control structures (GCS), but important fisheries are found in drainage areas > 7.8 km^2 which are most often controlled with weirs (Fig. 1A-D). Weirs are constructed with steel sheet pile, typically driven into the streambed 6.1 m, with a riprap and concrete grout slope immediately downstream, a riprap stilling basin downstream of the weir slope, and riprap covered banks. Only limestone bedrock is available in western Iowa, and it is found in relatively thin ledges (< 2.4-3.1 m), but due to bedding planes and stratification boulders greater than a 0.77 m^3 are very rare. Riprap also tends to fracture due to freeze/thaw processes and then move under higher flow conditions, so concrete grout is used to lock the riprap in place. Weirs are placed at regular intervals to locally decrease the stream slope and change the stream profile from an erosive steep incline to a stable stair-step pattern. Weirs allow a drop in stream elevation in a controlled setting, prevent further degradation, decrease sediment loads and turbidity, and increase water quality. GCS have shown to be very economical, with every dollar invested in building a GCS, protecting more than $4.24 in property value and 889 kg of soil.

Figure 1. A) Sheet pile weir with loose riprap slope, originally built at 1:20 (rise/run), but note how rock has moved away from the sheet pile weir (black arrows). B) Sheet pile weir with 1:20 grouted riprap slope. C) Sheet pile weir with 1:4 grouted riprap slope. D) Sheet pile weir with 1:20 fish ladder and steel baffles.

Numerous government agencies affiliated with western Iowa have attempted to halt the process of channel degradation by constructing GCS over the last forty years; more than 750 GCS have been built already in western Iowa. A group of concerned government officials and private landowners formed the Hungry Canyons Alliance (HCA) to provide funding for some of these GCS. Despite these attempts at controlling streambed degradation, the problem is still widespread necessitating the construction of more GCS.

The subjects of streambed degradation, GCS, and the HCA is discussed in much greater detail in an accompanying paper in these proceedings entitled "Fish Passage and Abundance around Grade Control Structures on Incised Streams" by J. Thomas.

In-stream GCS may also increase habitat and flow diversity. The rock rip-rap used to construct GCS adds a unique substrate to the streams of western Iowa that are mostly dominated by silt and sand bottoms. GCS have been shown to affect flow characteristics within a stream, creating slower water above the structure and a scour pool below the structure (Shields *et al*. 1995). These changes in flow and habitat conditions may result in different fish and macroinvertebrate communities near and far away from these structures and increased biological diversity within the stream (Tiemann *et al*. 2004). The modification of local hydraulic conditions may actually increase habitat for benthic macroinvertebrates during low flow conditions (Gore and Hamilton 1996). Artificial riffles have been shown to support macroinvertebrates at levels similar to natural riffles within the same stream (Ebrahimnezhad and Harper 1997). An increase of macroinvertebrates in stream segments altered by GCS would provide enhanced food resources for nearby fish communities, possibly resulting in improved growth and body condition of fish (Shields *et al*. 1995). Increased depth and substrate types found near GCS may increase diversity, growth, and reproduction potential of fish communities near GCS (Shields and Hoover 1991). Scour holes below GCS may be better fisheries resources than natural scour holes because of habitat stability (Cooper and Knight, 1987). However, some studies have shown that fish communities do not differ between un-altered stream reaches and reaches with GCS (Raborn and Schramm 2003).

Although large dams obviously present obstacles to fish movement, GCS in streams are more serious blockages to fish movement than originally believed (Ovidio & Philippart, 2002) and may limit the longitudinal connectivity of a stream. Streams in western Iowa with GCS tend to have a drainage area of less than 150 km^2. These are warm-water streams where the predominant fish species are channel catfish, flathead chub, creek chub, black bullhead, and yellow bullhead, all of which are not powerful swimmers. Preliminary sampling efforts and angler reports in western Iowa indicated a decline in channel catfish numbers, size and distribution, and species diversity. It is hypothesized that the downstream slope of GCS can be made gentle enough to allow for fish passage. However, the gentler the slope, the more money the GCS cost because of the additional rip-rap needed to create the longer downstream riffle. For example, the cost of a GCS with a 1:20 (rise/run) downstream slope is approximately $40,000 more than the same GCS with a 1:4 downstream slope. The Hungry Canyons Alliance (HCA) and Iowa Department of Natural Resources (DNR) commissioned research to determine the right balance between making GCS ecologically sound while making them inexpensive to build. The purpose of this paper is to review and disseminate the results of this research: two fish sampling studies (Larson *et al*., 2004; Litvan, 2006; Litvan, *et al*., 2008a-c) and one hydraulic (Papanicolaou and Dermisis, 2006; Papanicolaou and Dermisis, in press) study of the effects GCS have on fish passage and abundance. Nowhere in literature has the issue of fish passage been approached from both biologic (mark-recapture) and engineering (hydraulic analysis) viewpoints, making the combination of these studies unique.

METHODS

Fish Sampling Studies

The following methods and results sections dealing with fish sampling studies and GCS are discussed in more detail in Larson *et al*. (2004), Litvan (2006), and Litvan *et al*. (2008a-c). The Iowa Department of Natural Resources (DNR) and Iowa State University sampled fish on streams controlled by GCS through two different sampling studies, but because the methods were the same, they are not differentiated in this methods section. Fish sampling occurred at sites near GCS with different downstream slopes of 1:4, 1:10, 1:15, and 1:20 (rise/run) and at reference sites not near a GCS. Sites near GCS are defined as reaches that extend from the scour pool below the GCS downstream to a point that is within 40 times the average summer wet width of the stream. Sites not near a GCS are defined as points more than 40 times the average summer wet width of the stream away from a GCS.

Passive gear (hoop nets baited with soy cakes and minnow traps) was used to collect fish for mark/recapture and community analyses during the summer at seven sites, five of which were near GCS. The fourteen hoop nets and fourteen minnow traps (two of each type at each of seven stations) were set for periods of twenty-four hours, four to five days a week. Captured channel catfish, flathead chub, creek chub, black bullhead, and yellow bullhead were measured for length and weight and given a site-specific tag or fin clip and released at the station of capture. All captured fish were inspected for previous fin clips or tags. Marked fish that were recaptured were measured for length and weight, the site of their recapture was noted, and they were given a site-specific fin clip indicating their site of recapture.

Electrofishing equipment was used to collect fish for community analyses and to increase the number of recaptures of marked fish during the fall and spring. A total of 10 sites (five GCS sites and five non-GCS sites which included the seven summer sampling sites) were sampled with a single pass of two backpack electrofishing units for a distance of 280 m (approximately 40 times the average summer wet width of the stream. A block net was placed at the upstream boundary of the electrofishing reach. Target fish species collected were identified, measured for length and weight and inspected for fin clips or tags. A combination of hook and line angling, casting nets, and bank electrofishing techniques were used to sample deep scour pools below GCS that were not accessible with hoop nets or backpack electrofishing methods. Fall and spring sampling periods were scheduled at times corresponding with seasonal migration movements of catfish in order to increase the chance of recapturing marked fish that had moved over GCS. Fish movement over a GCS was evident if a fish marked below a GCS is recaptured at an upstream sampling site or if a fish marked above a GCS is recaptured at a downstream sampling site. Physiochemical measurements including turbidity, dissolved oxygen, pH, canopy coverage, substrate, channel wet width, depth, flow, and water temperature were measured before each sampling event.

The slopes of all GCS were measured to verify that the intended design slope had not decayed due to high-flow events or age. Vertical distance was measured at the sheet pile across the width of the channel. Longitudinal slope was measured using a clinometer from the top of the sheet pile to the end of the GCS and at three shorter intervals within the GCS slope. These measurements were repeated during the spring, summer, and fall throughout the study.

During the summer, macroinvertebrate samples were collected from 20 sites: five sites were at a GCS, five were upstream of a GCS, five were downstream of a GCS, and five sites served as reference sites and more than 1 km away from any GCS. Macroinvertebrates were collected at two randomly chosen gird areas along a 10 m transect. Rocks lying within the predetermined grid spacing were scrubbed by hand, allowing dislodged organisms to flow downstream into a kick net. Washed rocks were placed outside of the sampling quadrant and the remaining substrate was disturbed with a 30 second kick. The two samples taken along the transect were combined and preserved. In the laboratory, macroinvertebrates were counted and identified to the family level. Macroinvertebrate community structure from each site was evaluated by quantifying the number of taxa present, the number of individuals in each taxon, total macroinvertebrate biomass, and total macroinvertebrate abundance.

An index of biotic integrity (IBI) was used to help determine the status of fish community surveys. Twelve metrics were used to determine each communities IBI score: 1) number of native species; 2) number of sucker species; 3) number of sensitive species; 4) number of benthic invertivores; 5) percentage of total abundance of the top three species; 6) percentage of fish as benthic invertivores; 7) percentage of fish as omnivores; 8) percentage of fish as top carnivores; 9) percentage of fish as lithophilous spawners; 10) percentage of fish assemblage tolerance index; 11) adjusted catch per unit effort; and 12) adjustment for high percentages of deformities, erosions, lesions, and tumors..

Hydraulic Study

The following methods and results sections dealing with a hydraulic study of GCS are discussed in more detail in Papanicolaou and Dermisis (2006) and Papanicolaou and Dermisis (in press). The study was performed by IIHR-Hydroscience & Engineering, The University of Iowa. Twenty-two GCS were selected for determination of hydraulic characteristics: eight riprap weirs (Fig. 1A), ten grouted riprap weirs (Fig. 1B, C), and four fish ladder weirs (baffled and unbaffled) (Fig. 1D). A ground survey was performed for all of these weirs, from which weir slope was determined. The surveys were also used as background information for Acoustic Doppler Velocimeter (ADV) or Large-Scale Particle Image Velocimetry (LSPIV) measurements.

Time-averaged point measurements of mean flow characteristics (water depth and streamwise velocity) were performed during a low flow season for all 22 GCS and repeated during a high flow season for 8 representative GCS. Mean flow measurements of velocity at low flow were made upstream, atop, and downstream of each GCS using an Acoustic Doppler Velocimeter (ADV). An ADV uses a transducer that generates a narrow beam of sound at a known frequency (10MHz). This sound is reflected in all directions in the water. While receivers sample the reflected sound, the ADV measures the change in frequency between the transmitted and received signals which is proportional to the velocity along the bistatic axis of that receiver. Mean flow measurements of velocity at high flow were made upstream, atop, and downstream of each GCS using the Large Scale Particle Image Velocimetry (LSPIV) technique. LSPIV measurements use video equipment to capture the movements of small particles (mulch) as they float on the water surface over a GCS. Froude numbers were calculated to classify different reaches (pool, run, and riffle-glide).

Survey data were combined with the video in an LSPIV software package to calculate the two-dimensional (2-D) velocity field around GCS. Stream discharge was calculated from the combination of the 2D velocity LSPIV data with the 1D vertical velocity ADV data. The discharge was then used for developing stage-discharge equations.

For two GCS (a riprap weir and a baffled fish ladder weir), turbulent flow characteristics were measured at low flow with a high-frequency ADV to determine instantaneous velocities, turbulent intensities, and Reynolds stresses in three dimensions.

RESULTS

Fish Sampling Studies

The first sampling study showed that the slope of a GCS can impact fish movement. Within a 3 year sampling period, between 10 and 28 percent of recaptured channel catfish and between 15 and 30 percent of recaptured flathead and creek chubs were able to move over GCS with a 1:20 downstream slope. However, within the same 3 year sampling period, no channel catfish and flathead and creek chubs were able to move over GCS with a 1:4 downstream slope. However, extremely low water conditions may have restricted migration behavior regardless of weir design. Species diversity was 1.57 times greater downstream of a 1:4 GCS than upstream.

The second sampling study reinforced the results of the first study. GCS with vertical or 1:4 (rise/run) downstream slopes did not allow fish migration, but GCS with slopes ≤ 1:15 did. GCS sites were characterized by greater proportions of pool habitat, maximum depths, fish biomass, and greater macroinvertebrate abundance and diversity than non-GCS sites. Fish community scores (IBI) were also slightly higher (5%) in stream reaches with GCS versus stream reaches without GCS. 98% of all fish movements over a GCS were in the upstream direction and occurred when streamflow was relatively high. Macroinvertebrate biomass, numerical densities, and diversity were greater in stream reaches with GCS versus stream reaches without GCS. Before modification, only 1% displayed movement over a GCS, but after modification 14.5% of all recaptured catfish, bullheads, and chub showed movement over GCS with 1:15 downstream slopes. After modification of three GCS, IBI scores increased at seven of nine sites and fish species, including channel catfish, which exhibited truncated distributions before modification were found throughout the study area afterwards.

Hydraulic Study

Performance of each GCS was described in terms of meeting the minimum requirements for catfish passage as determined by the Iowa DNR: a minimum flow depth of 0.31 m and a maximum velocity of 1.22 m/s. The best performing GCS had minimum flow depths greater than 0.31 m and maximum velocity requirement of less than 1.22 m/s. The worst performing GCS did not meet either requirement. Without considering drainage area, the best performance was exhibited by low gradient (≤ 1:16 slopes) grouted or riprap weirs and fish ladders with baffles. The worst performing GCS were the high gradient (≥ 1:6) grouted or riprap weirs and fish ladders without baffles.

The limiting factor for fish passage was different depending on GCS drainage area. When the drainage area is less than 51.8 km^2, the best GCS is the low gradient (≤ 1:16 slopes) weirs because flow depth is the limiting factor for fish passage, and low gradient weirs will provide deeper flows than high gradient weirs. When the drainage area is larger than 259 km^2, the best GCS is the low to medium gradient (1:10-1:16 slopes) weirs because maximum velocity is the limiting factor for fish passage, and low-medium gradient weirs will have slower velocities than high gradient weirs. When the drainage area is between 51.8 and 259 km^2, the best GCS is either a low or medium gradient (≤ 1:10 slopes) weirs because flow depth or maximum velocity are the limiting factors for fish passage.

Measurements where ideal for evaluating the performance of structures at low flow due to the fact low flow conditions persisted throughout the study period; thus, recommendations concerning minimum flow depth requirements may be more accurate than recommendations of maximum velocity requirements because of the low flow conditions. Relations for stage-discharge measurements may not be good predictors for conditions exceeding a recurrence period of 1 year due to the low flow conditions.

Velocities atop GCS were about 10 times greater in magnitude than the upstream approach flow; thus, critical conditions occur over a GCS. Turbulence measurements showed that weirs had lower levels of turbulence compared to fish ladders with baffles; however, stresses on all GCS were ≤ 5.3 N/m^2, which is much less than 1,600 N/m^2 needed to cause fish mortality. Average catfish fork lengths are 0.3 m; turbulent flow measurements illustrated that fish ladders with baffles form eddies 30% larger than the average fork length, which is enough to disorient fish. Fish ladders were observed to often catch debris, probably due to the large quantity of vertical steel sheet pile exposed. Grouted riprap slopes were observed to degrade less quickly and were more resistant to large flow events than riprap slopes.

DISCUSSION AND CONCLUSIONS

These studies describe the effects of GCS have on fish migration and fish and macroinvertebrate abundance and biodiversity. This paper details the results of three studies commissioned to describe the effects of GCS on biota through field sampling (Larson *et al*., 2004; Litvan, 2006; Litvan, *et al*., 2008a-c) and through hydraulic characterization of GCS (Papanicolaou and Dermisis, 2006; Papanicolaou and Dermisis, in press). These studies showed that vertical to steeply sloping (>1:15) GCS will restrict fish migration, whereas gently sloping (<1:15) GCS will allow fish migration; however, extremely low water conditions can restrict migration behavior regardless of weir design. Following modification of weirs to <1:15 slopes, fish community scores (IBI) did not decrease longitudinally along the channel from downstream to upstream, indicating increased longitudinal connectivity. GCS can also have a positive effect on fish and macroinvertebrate communities with respect to increased biota abundance, habitat, and biodiversity compared to stream reaches without GCS. Fish migrating over a GCS will not die due to turbulent stresses because all GCS tested had low enough levels of turbulence. Because fish ladders often catch debris and riprap is not as strong or as resistant to high flows, future GCS should incorporate a grouted riprap slope. Weirs with 15:1 are now recommended for all GCS because they allow fish passage, but are less expensive than 1:20 GCS.

These studies were instrumental in creating design criteria for future GCS to be built in western Iowa that will control channel incision while allowing fish passage and increased longitudinal connectivity. They also showed that engineers and ecologists can cooperatively work together to design GCS that can not only protect streams from the affects of channel incision but can also allow for fish migration, greater biodiversity, and better longitudinal connectivity of the stream systems in western Iowa.

ACKNOWLEDGEMENTS

Any GCS mentioned in this report were built using Hungry Canyons Alliance (HCA) or USDA Natural Resource Conservation Service (NRCS) Emergency Watershed Protection (EWP) funds. Funding for the Larson *et al*. (2004) study was provided by Iowa DNR Fisheries Bureau. The Litvan (2006) study was funded by the HCA (17%), Iowa DNR Fisheries Bureau (11%), US Geological Survey (22%), US Fish and Wildlife Service (15%), and Iowa State University (35%). The study by Papanicolaou and Dermisis (2006) was funded by the HCA (25%), Iowa DNR Fisheries Bureau (25%), and Iowa DOT Highway Research Board (50%).

REFERENCES

Baumel, C. (1994). “Impact of degrading western Iowa streams on private and public infrastructure costs.” *Stream Stabilization in Western Iowa*, Iowa DOT HR-352, Golden Hills Resource Conservation and Development, Oakland, Iowa, 4.1-4.39.

Bravard, J. P., Amoros, C., Pautou, G., Bornette, G., Bournaud, M., Creuzé Des Châtelliers, M., Gibert, J., Peiry, J. L., Perrin, J. F., and Tachet H. (1997). “River incision in south-east France: Morphological phenomena and ecological effects.” *Regulated Rivers: Research and Management*, 13, 75–90.

Bunn, S. E., and Arthington A. H. (2002). “Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity.” *Environmental Management*, 30(4), 492–507.

Cooper, C. M., and Knight, S. S. (1987). “Fisheries in man-made pools below grade-control structures and in naturally occurring scour holes of unstable streams.” *Journal of Soil and Water Conservation,* 42, 370–373.

Cooper, C. M., Testa, S., and Shields, F. D. (1997). “Invertebrate response to physical habitat changes resulting from rehabilitation efforts in an incised unstable stream.” *Management of Landscapes Disturbed by Channel Incision*, University of Mississippi, Oxford, MS, pp. 887– 892.

Ebrahimnezhad, M., and Harper, D. M. (1997). “The biological effectiveness of artificial riffles in river rehabilitation.” *Aquatic Conservation: Marine and Freshwater Ecosystems*, 7, 187-197.

Gore, J. A., and Hamilton, S. W. (1996). “Comparison of flow-related habitat evaluations downstream of low-head weirs on small and large fluvial ecosystems.” *Regulated Rivers: Research and Management*, 12, 459-469.

Hansen, D. R. (1971). “Effects of stream channelization on fishes and bottom fauna in the Little Sioux River, Iowa.” *ISWRRI No. 38*, Iowa State Water Resources Research Institute, Ames, Iowa.

Larson, C. J., Atchison, G. J., and Menzel, B. W. (2004). *Annual Progress Report to the Iowa Department of Natural Resources Fisheries Bureau for an Evaluation of Effects of Weirs in Walnut Creek on Fish Abundance and*

Movement, Cold Springs Southwest Regional Office, Iowa Department of Natural Resources.

Litvan, M. E. (2006). *An Evaluation of Effects of Grade Control Structures on Fish Movement and Fish Communities in Turkey Creek, Cass County, IA and Macroinvertebrate Communities in Walnut Creek, Montgomery County, IA*. M.S. Thesis, Iowa State University, Ames, Iowa.

Litvan, M. E., Pierce, C. L., Stewart, T. W., and Larson, C. J. (2008a). "Fish Passage in a Western Iowa Stream Modified by Grade Control Structures." *North American Journal of Fisheries Management*, 28:1384–1397.

Litvan, M. E., Pierce, C. L., Stewart, T. W., and Larson, C. J. (2008b). "Fish Assemblages in a Western Iowa Stream Modified by Grade Control Structures." *North American Journal of Fisheries Management*, 28:1398–1413.

Litvan, M. E., Stewart, T. W., Pierce, C. L., and Larson, C. J. (2008c). "Effects of Grade Control Structures on the Macroinvertebrate Assemblage of an Agriculturally Impacted Stream." *River Research and Applications*, 24: 218–233.

Ovidio, M., and Philippart, J. C. (2002). "The impact of small physical obstacles on upstream movements of six species of fish." *Hydrobiologia*, 483, 55-69.

Papanicolaou, A. N., and Dermisis, D. C. (2006). *Field Investigation of Hydraulic Structures Facilitating Fish Abundance and Passage through Bridges in Western Iowa Streams*, Iowa DOT TR-521, IIHR-Hydroscience & Engineering, University of Iowa, Iowa City, Iowa.

Papanicolaou, A. N., and Dermisis, D. C. (In press). "Fish passage over hydraulic structures in Midwestern Rivers of the USA." *J. River Basin Management*.

Raborn, S. W., and Schramm, H. L. (2003). "Fish assemblage response to recent mitigation of a channelized warmwater stream." *River Research and Applications*, 19, 289-301.

Shields Jr., F. D., and Hoover, J. J. (1991). "Effects of channel restabilization on habitat diversity, Twenty Mile Creek, Mississippi." *Regulated Rivers: Research and Management*, 6, 163-181.

Shields, F. D., Knight, S. S., and Cooper, C. M. (1994). "Effects of channel incision on base flow stream habitats and fishes." *Environmental Management*, 18(1), 43-57.

Shields Jr., F. D., Knight, S. S., and Cooper, C. M. (1995). "Incised stream physical habitat restoration with stone weirs." *Regulated Rivers: Research and Management*, 10, 181-198.

Shields, F. D., Knight, S. S., and Cooper CM. (1998). "Rehabilitation of aquatic habitats in warmwater streams damaged by channel incision in Mississippi." *Hydrobiologia*, 382, 63– 86.

Thomas, J. T. (this volume). "Hungry Canyons Alliance: Streambed Stabilization in Western Iowa."

Tiemann, J. S., Gillette, D. P., Wildhaber, M. L., and Edds, D. R. (2004). "Effects of lowhead dams on riffle-dwelling fishes and macroinvertebrates in a midwestern river." *Transactions of the American Fisheries Society*, 133, 705-717.