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Impacts of Barriers on Topeka Shiner Populations

Study SD2006-07-F

Final Report

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16. Abstract

This report presents a research study that investigated the effect of culverts on movement of Topeka shiner and other warm water fish species. The study was conducted in the James, Big Sioux and Vermillion Watersheds in Eastern South Dakota from 2007 to 2010. A combination of fish passage experiments, hydrologic and hydraulic data collection, hydraulic modeling and genetic investigations were used for the study. The study results show that culverts did impede fish movement for warm water fish species, including Topeka shiner. However, fish did pass through culverts in all studies designed to directly measure fish passage. Topeka shiners were documented passing through a range of conditions including water depths from 0.15 ft to 1.51 ft, average water velocities ranging between 0.03 ft/s and 2.6 ft/s, outlet drops up to 0.1 ft, culvert slopes between 0.55% and 2.12%, and lengths from 53 ft to 70.3 ft, with culvert materials consisting of concrete box, corrugated metal pipe (CMP) and structural steel plate (SSP) materials. Hydraulic data and modeling results indicate that the CMP and SSP created the most difficult passage conditions (due to high water velocities and large outlet drops), with the exception of one concrete structure that had an outlet drop of 2.7 ft at low water. It should be emphasized that CMP and SSP structures, if properly designed, constructed and maintained, can provide effective fish passage. They created difficult passage conditions in this study because of site specific conditions and channel degradation near them. Hydraulic data and modeling results indicate that the large culverts, such as the concrete box culverts in this study, that spanned the entire stream channel and were set deep in the stream created conditions that minimized fish passage impedance and thus provided the easiest movement for fish. The genetic study showed that there was moderate genetic differentiation between populations with a tendency for populations to be genetically similar to other populations in their drainage. At specific culvert sites, two cases showed statistically significant genetic differences above and below culverts and two did not. The authors recommend that new culvert installations in critical Topeka shiner habitat streams should be designed to span the entire stream channel and be set deep enough to maintain a natural substrate throughout the structure.

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LIST OF ACRONYMS

Acronym	Definition
ADT	Average Daily Traffic
ANOVA	Analysis of Variance
CA	Concrete Arch
CB	Concrete Box
CFS	Cubic Feet per Second
CMP	Corrugated Metal Pipe
DBH	Diameter Breast Height
DC	Downstream Control
DNA	Deoxyribonucleic Acid
DO	Dissolved Oxygen
DOT	Department of Transportation
DT	Downstream Treatment
GIS	Geographical Information System
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Center-River Analysis System
LSD	Least Significant Difference
mg	milligram
PCR	Polymerase Chain Reaction
PI	Passage Index
PIT	Passive Integrated Transponder
SDCL	South Dakota Codified Law
SDDOT	South Dakota Department of Transportation
SE	Standard Error
SSP	Structural Steel Plate
UC	Upstream Control
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UT	Upstream Treatment
VIE	Visible Implant Elastomer

1 EXECUTIVE SUMMARY

This research project was conducted on behalf of the South Dakota Department of Transportation (SDDOT). SDDOT oversees the highway transportation system throughout South Dakota and is interested in ensuring that road crossings are designed, constructed and maintained in a manner that minimizes detrimental effects to the environment, ensures safety for humans and is cost effective.

The Topeka shiner *(Notropis topeka)* is an endangered species that lives in the James, Vermillion, and Big Sioux watersheds in South Dakota (Shearer 2003). There is concern that culverts may reduce or restrict the movement of Topeka shiners in South Dakota. Because Topeka shiners are typically found in the uppermost reaches of watersheds that sustain permanent water (Kerns and Bonneau 2002; Bayless et al. 2003), a series of road crossings may fragment populations. Connectivity between distant habitats is required to allow refounding of metapopulation segments following local extinctions and to maintain the viability of the overall Topeka shiner metapopulation.

Culverts are an efficient and cost-effective means of conveying water underneath roadways; however, they can present barriers to the movement of fish and other aquatic species if improperly designed or constructed. In other cases, properly installed culverts may become fish barriers over time if the stream channel in the vicinity of the structure becomes degraded. Culvert barriers to fish are caused by excessive water velocity or outlet drops, insufficient water depth, and debris or sediment blockage (Baker and Votapka 1990; Bates et al. 1999; ODF 2000; and Votapka 1991). The purpose of this research was to better understand the factors that may influence the movement of Topeka shiner and other warm water fish species through culverts in eastern South Dakota, and to investigate the effect of culvert barriers on the distribution and genetic diversity of Topeka shiners.

There were three specific objectives that this research investigated.

1) Determination of whether various culvert types, designs, and in-place characteristics were acting as intermittent or permanent barriers to movement of the Topeka shiner.

2) Clarification of the effects of culvert types and designs and stream flow characteristics on Topeka shiner movement through and distribution upstream and downstream of culverts.

3) Development of strategies for mitigating existing culverts and improving new culvert designs to allow fish passage.

The research approach combined evaluations of stream hydrology, geomorphology, culvert hydraulics and fish ecology to address this problem. This project investigated the physical conditions (culvert type, length, slope, etc.) that limited the movement of Topeka shiners and other warm water fish species by performing passage experiments that directly assessed the movement of fish through culverts and compared that movement to natural stream reaches. Genetic testing was used to assess the effect of culverts on the genetic structure and diversity of Topeka shiners in eastern South Dakota. Hydraulic modeling combined with detailed measurements of stream hydrology was used to assess passage rates over a range of flow conditions.

The study area was the James, Vermillion, and Big Sioux watersheds in eastern South Dakota. The study performed detailed evaluation of passage at nine culvert crossings in four tributaries to the James River (Figure 1). In addition, fin clips were collected from Topeka shiners at locations in the

James, Vermillion and Big Sioux watersheds and analyzed to investigate genetic diversity of Topeka shiner.

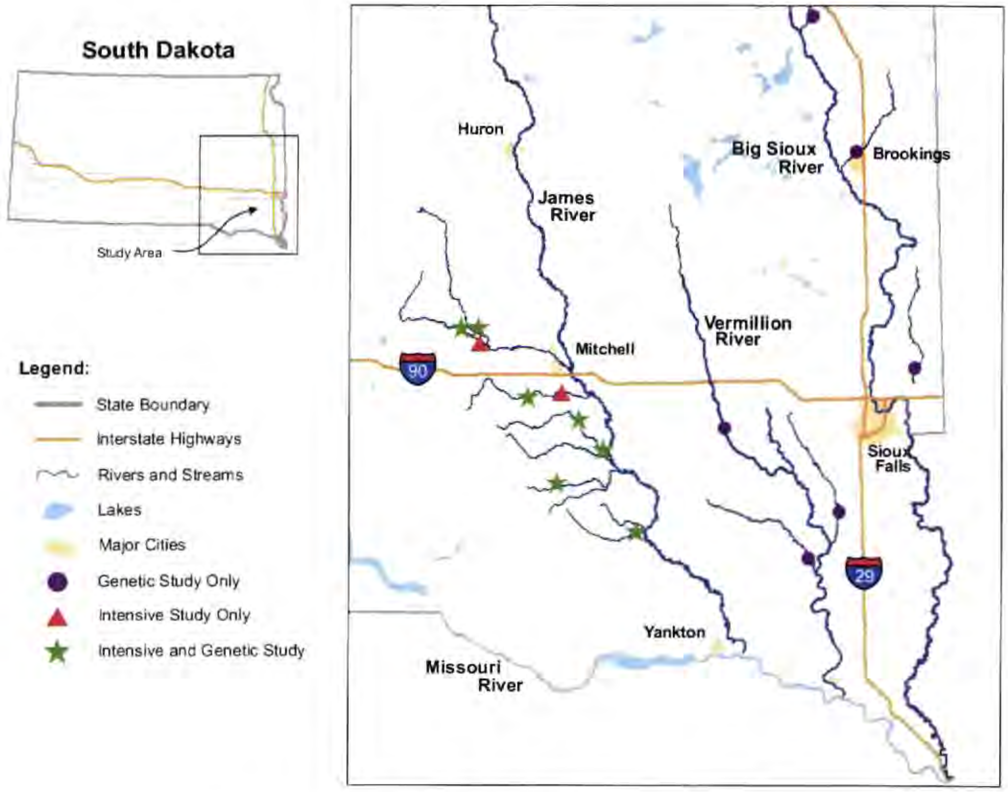

Figure 1: Map of All Study Locations

These watersheds are located in the Northern Glaciated Plains ecoregion (Bryce et al. 1996). Elevations range from 1300 ft to 2550 ft; surficial geology of this ecoregion is primarily glacial till. The region has a temperate continental climate with annual precipitation ranging from 16 to 22 inches, and mean annual frost free-days ranging from 90 to 140 days. Mean monthly minimum and maximum January air temperatures are -9.4° F and 23° F, whereas mean monthly minimum and maximum July air temperatures are 54° F and 86° F. Land use in this ecoregion is primarily agricultural, with tilled grain crops, hay, and pasture; some areas retain native woodland and wetlands (Bryce et al. 1996).

The James River basin is 14.1 million acres in area; its headwaters are in North Dakota (Berry et al. 1993). It is a turbid, warm water river with large fluctuations in seasonal discharges. Anthropogenic stressors on the James River include large numbers of low-head dams, eutrophication, and low dissolved oxygen levels, which causes fish kills. The river supports 57 fish species in 16 families, dominated by cyprinids, catostomids, ictalurids, centrarchids, and percids. Several species associated with the Missouri River occur in the lower reaches of the James River (Berry et al. 1993).

The Vermillion River basin is 1.43 million acres in area, and is located entirely within South Dakota. Like the James River, its flows are variable and it suffers from a number of anthropogenic stressors (Schmulbach and Braaten 1993). Fish species diversity is slightly lower than in the James River basin, with about 45-50 fish species present.

The Big Sioux River basin is 5.76 million acres in area, and includes portions of South Dakota, Iowa, and Minnesota. Sioux Falls is a natural barrier to fish movement, and three low head dams impede fish movements (Galat et al. 2005). The Big Sioux River is relatively natural and supports a healthy fish population of 66 native species (Galat et al. 2005).

Important findings and conclusions were developed from the results of this project.

- The study culverts impeded fish movement for many different fish species, including Topeka shiner. However, in all fish passage experiments, some fish moved through study culverts. In four cases with sufficient numbers of fish in a species (n>4), a species (green sunfish, johnny darter, orange spotted sunfish and black bullhead) moved through the control but did not move through the treatment.
- Topeka shiner were documented passing through three different culvert study sites with water depths ranging between 0.15 ft and 1.51 ft, average water velocities ranging between 0.03 ft/s and 2.6 ft/s, outlet drops up to 0.1 ft, culvert slopes between 0.55% and 2.12%, and lengths from 53 ft to 70.3 ft. These culverts consisted of concrete box (CB), corrugated metal pipe (CMP), and structural steel plate (SSP) materials.
- Based on hydraulic data and hydraulic modeling, the culverts that had the greatest potential (due to highest water velocity and outlet drops) to impede fish movements were two CMPs (Firesteel Creek No. 18 and 20) and one SSP (Twelvemile Creek No. 12). Firesteel Creek No. 18 and No. 20 had the smallest diameters in the study. Smaller diameter culverts constrict water flow and increase flow velocity. It should be emphasized that CMP and SSP structures, if properly designed, constructed and maintained, can provide effective fish passage. They created difficult passage conditions in this study because of their smaller diameter, their placement at relatively high slope, and local channel degradation.
- Based on hydraulic data and hydraulic modeling, the culverts that provided the best movement potential, from a physical conditions standpoint, were large concrete box culverts like those at Enemy Creek No. 4 and 5. These structures support the preferred design approach described in the SDDOT document titled: "Fish Passage Guidelines for Culvert Projects Impacting the Topeka shiner or Other Fishery Resources". The present SDDOT plan for new culvert installations that require passage of fish is to design the structure to be at least as wide as 1.2 times the stream channel bankfull width, and to place the culvert so that it will maintain a natural stream channel through the culvert.
- The genetics study showed that there was moderate genetic differentiation between major drainage basins (James, Big Sioux, and Vermillion) with a tendency for populations to be genetically similar to other populations within major drainage basins. At specific paired above- and below-culvert sites, two sites (Lone Tree Creek No. 27 and Twelvemile Creek No. 12) showed statistically significant genetic differences above and below culverts and two sites (Enemy Creek No. 4 and 14) did not.

Key implementation recommendations include the following:

1) SDDOT should design new culvert installations in streams within critical Topeka shiner habitat to span the entire stream channel (specifically stated the structure should be at least as

wide as 1.2 times the stream channel bankfull width) and provide a natural stream substrate through the structure. The preferred design approach is described in the SDDOT document titled: "Fish Passage Guidelines for Culvert Projects Impacting the Topeka shiner or Other Fishery Resources". This recommendation is based in part upon the hydraulic data and hydraulic modeling activities, which indicated that wider structures set at grade and deep within the stream provided the best movement potential (i.e. sufficient water depth, no outlet drop and low water velocities). Specific examples of this type of installation from this project include the large concrete box culverts at Enemy Creek No. 4 and 5. Other types of structures, such as CMP or SSP, can be used to provide fish passage in this manner as long as they are designed and constructed according to the guidelines specified in the aforementioned document. These design recommendations are similar to those used in other states or regions (Bates 2003; USDA-Forest Service 2008).

2) SDDOT should inventory all culverts on streams with Topeka shiner and prioritize barrier crossings for removal or replacement. The prioritization developed by Wall and Berry (2002) should be considered as a basis for developing a final prioritization method. Prioritization should be done on a watershed basis by considering all crossings collectively when making potential removal or replacement decisions. Additional methods for prioritizing barrier culverts have been developed by other states and should also be consulted during development of the final prioritization scheme (Washington Department of Fish and Wildlife 2000; O'Hanley and Tomberlin 2005).

3) If SDDOT or other agencies use FishXing to assess whether a road culvert is a potential barrier to fish passage, the user-defined tailwater rating curve method should be used in developing the model and assessing the structure. This method was found in this study to more accurately predict the hydraulic conditions at the outlet and within culverts. The tailwater channel cross section method, which uses uniform flow theory to calculate the rating curve as compared to the user-defined method which relies upon establishing it through field measurements, consistently overestimated the outlet drop, which in turn resulted in some crossings being identified as an outlet drop barrier when they actually had little to no outlet drop as measured in the field.

4) SDDOT and other interested agencies should consider future research that investigates Topeka shiner passage during high flow periods. The methods used in this study for the direct passage experiments are not implementable at high flow periods. Topeka shiners can spawn during months with large flows, therefore a high-flow study would shed more light on fish passage during some of the prolonged high water events such as those caused by the large rain storms that frequently occur in eastern South Dakota. To implement this study, SDDOT should research emerging tagging technologies for small-bodied fish. If the technology exists, a small passive integrated transponder (PIT) tag (or something similar) could be inserted into Topeka shiners and surrogate species. Antennae placed at the upstream and downstream ends of selected culverts and in control reaches could record the time that tagged fish moved through those areas. At the same time, continuous measurements of water flow, velocity and depths could be recorded to define the hydraulic environments during which fish successfully pass or are unable to pass through culverts. For an example of how this type of study could be

implemented see Cahoon et al. (2007). That study used PIT tags in rainbow and cutthroat trout to monitor their movements through five culverts during high flows.

5) SDDOT should implement a culvert monitoring program to determine how culverts installed following the guidance in "Fish Passage Guidelines for Culvert Projects Impacting the Topeka shiner or Other Fishery Resources" perform. This program should be developed in consultation with Wayne Stancill of the United States Fish and Wildlife Service (USFWS) and other fish passage practitioners.

2 PROBLEM DESCRIPTION

The Topeka shiner *(Notropis topeka)* is an endangered species that lives in the James, Vermillion, and Big Sioux watersheds in South Dakota (Shearer 2003). There is concern that barriers, such as culverts, may limit the movement of Topeka shiners in South Dakota. Because Topeka shiners are typically found in the uppermost reaches of watersheds that sustain permanent water (Kerns and Bonneau 2002; Bayless et al. 2003), a series of road crossings may fragment populations. Connectivity between distant habitats is required to allow refounding of metapopulation segments following local extinctions and to maintain the viability of the overall Topeka shiner metapopulation.

Culverts are an efficient and cost effective means of conveying water underneath roadways; however, they can present barriers to the movement of fish and other aquatic species if improperly designed or constructed. In other cases, properly installed culverts may become fish barriers over time as the stream channel in the vicinity of the structure becomes degraded. Culvert barriers to fish are caused by excessive water velocity, insufficient water depth, perched culverts and debris or sediment blockage (Baker and Votapka 1990; Bates et al. 1999; ODF 2000; and Votapka 1991). Although many studies have been conducted on the factors that limit fish movement, most of these studies are related to the passage of salmonids. There is a need to better understand the effects of barriers on aquatic species like Topeka shiner. The purpose of this research was to better understand the factors that may prevent, limit, or allow the movement of Topeka shiners through culverts in eastern South Dakota, and to investigate the effect of culvert barriers on their distribution and genetic diversity. During this project, researchers also investigated passage for several other warm water fish species. Some of these fish, in particular sand, bigmouth and red shiners, are similar in size and body shape to Topeka shiners and therefore provide additional insight for this study.

The research approach combined evaluations of stream hydrology, geomorphology, culvert hydraulics and fish ecology to address this problem. This project investigated the physical conditions (culvert type, length, slope, etc.) that limited the movement of Topeka shiners and other warm water fish species by performing passage experiments that directly assessed the movement of fish through culverts and compared that movement to natural stream reaches. Genetic testing was used to assess the *effect of culvert barriers on the genetic structure and diversity of Topeka shiners in eastern South Dakota. Hydraulic modeling combined with detailed measurements of stream hydrology was used to assess passage rates over a range of flow conditions.

2.1 Background Information

2.1.1 Topeka Shiner Description, Distribution and Life History

The Topeka shiner is a minnow found in portions of the Missouri, Mississippi, Kansas, and Arkansas River basins in the states of Kansas, Missouri, Nebraska, Iowa, Minnesota, and South Dakota (Lee et al. 1980). This species has a small, stout body; adults are typically 41-66 mm in total length to a maximum of about 76 mm (Pflieger 1997). Topeka shiners are olivaceous dorsally with prominently dark-edged scales. A dusky lateral stripe and a dark wedge-shaped spot at the base of the tail fin are present. Breeding males develop tubercles and orange-red pigmentation on fins and head (Pflieger 1997). Topeka shiners are most closely related to sand shiners *N. stramineus* (Schmidt and Gold 1995).

Topeka shiners reach sexual maturity in their second summer and spawning occurs in late May through August in Kansas and Missouri (Cross 1967; Cross and Collins 1995; Pflieger 1997; Kerns and Bonneau 2002). Spawning occurs in clean gravel over the nests of green sunfish *Lepomis cyanellus* and orange-spotted sunfish *L. humilis* (Pflieger 1997), although the species may use sand (Witte et al. 2009), or other silt-free substrates for spawning habitat (Tabor 1998). Young-of-the-year attain a total length of 20 to 39 mm by the end of their first summer, and 34 to 53 mm by the end of their second summer. Maximum life span is three years; however few individuals survive beyond two years old. Topeka shiners feed primarily on aquatic invertebrates; chironomids (midges) and ephemeropterans (mayflies) are important food items (Kerns and Bonneau 2002).

Topeka shiners are relatively tolerant of high temperatures, low concentrations of dissolved oxygen (Koehle and Adelman 2007), and high levels of ammonia and nitrate (Adelman et al. 2009). Topeka shiners are more sensitive to nitrite, however nitrite is generally transient (Koehle and Adelman 2007). Topeka shiners experience optimal growth at approximately 27° C and their critical thermal maximum was 39° C when acclimated to 31° C (Koehle and Adelman 2007). Topeka shiners can grow and survive at dissolved oxygen concentrations as low as 2 mg/L, but grow faster at 4 mg/L dissolved oxygen, and the dissolved oxygen concentration at which 50% of Topeka shiners died over 96 hours was 1.26 mg/L (Koehle and Adelman 2007).

Topeka shiners occur in small prairie streams with moderately clear, cool water and substrates comprising predominantly sand, gravel, cobble, and bedrock or clay hardpan (Minckley and Cross 1959; Cross 1967; Pflieger 1997). Many of these streams become intermittent in summer, but have permanent pools that are maintained by percolation through the streambed, groundwater seepage, or springs. These pools are important refuges during periods of intermittency. In drying pools, Topeka shiner juveniles were usually the last fish to succumb to deteriorating water quality (Kerns and Bonneau 2002). Pflieger (1997) reports that Topeka shiners form schools in midwater or near the surface of pools, however, Kerns and Bonneau (2002) observed Topeka shiners with snorkeling and in aquaria and reported that they had an affinity for the lower half of the water column and fed by taking food from the substrate. Most reports concur that Topeka shiners are rarely found in riffles (Tabor 1998; Kerns and Bonneau 2002). In Missouri, Topeka shiners occur in streams with relatively high gradients and low agricultural influence; these factors help maintain their preferred silt-free pool habitat (Pflieger 1997). In Kansas and Missouri, Topeka shiners were found only in the upper-most reaches of watersheds that sustain permanent water (Kerns and Bonneau 2002; Bayless et al. 2003). However in South Dakota and Minnesota, Topeka shiners have been collected in silty streams, and off-channel backwaters, sloughs, and borrow pits (Wall et al. 2001; Koehle and Adelman 2007). Topeka shiners found in larger streams are presumed to be strays (Tabor 1998).

2.1.2 Status of Topeka Shiner

The Topeka shiner was listed as an endangered species by the US Fish and Wildlife Service in December, 1998 (Tabor 1998). Many factors, including large-scale changes such as conversion of the prairie landscape to agricultural and urban uses and more localized factors, have led to the range-wide declines in Topeka shiner populations (Shearer 2003). Specific threats include habitat destruction, degradation, and fragmentation, siltation and reduced water quality, introduced species and stocking of predatory game fish, and stream channelization, impoundment, and dewatering (Cross 1967; Pflieger

1997; Tabor 1998; Winston 2000; Schrank et al. 2001; Mammaliti 2002; Shearer 2003; Knight and Gido 2005). By 1998, occurrences of Topeka shiner throughout its historical range had declined by 80%, mostly in the last 40-50 years. Topeka shiner are more persistent in the northern part of their range than in the southern part (Wall and Berry 2004). For example, in South Dakota the Topeka shiner has recently been documented in 80% of historical sites, as well as in many streams where they were not previously known to live (Shearer 2003). As a result of these recent surveys in South Dakota, the state rank of Topeka shiner has been downgraded from S2 (imperiled) to S3 (vulnerable).

2.1.3 Warm Water Fish Passage Studies

Fish passage studies have been completed on a variety of species inhabiting a range of different streams across North America. A review of these studies shows that historically they focused on anadromous species; however, as interest in the potential effects of barriers to fish has grown, the range of species studied has grown to include warm water fish that inhabit the mid-section of the United States. Anadromous fish have a life history that includes living a portion of their lives in saltwater and a portion in freshwater. The following review focuses on fish passage studies of warm water fish.

Warren and Pardew (1998) studied 21 culverts in west-central Arkansas using a mark-recapture technique. Their study examined the effect of four different types of crossings on warm water fish movement during base and summer low flows. Results showed that fish movement was an order of magnitude lower in culvert crossings than through open-box, fjord and natural reaches. No movement was detected through slab crossings. In addition, they found water velocity to be inversely proportional to fish passage.

Wall and Berry (2002) inventoried culverts and documented culvert conditions at 232 culverts at 81 sites in eastern South Dakota. This study used an approach that combined physical characteristics of crossings with reach habitat suitability for Topeka shiners to categorize sites for mitigation. Several physical factors (perch, embeddedness, blockage, gradient, and water velocity) were used to rank the difficulty of passage for each site. Habitat suitability information such as bank height, bank incision, head-cutting, substrate, riparian conditions, presence of pools, livestock use and macrophytes was collected and included in the final prioritization of study sites. This study identified seven sites (9%) as high priority for mitigation, 22 (27%) as medium priority for mitigation, and 52 (64%) as low priority for mitigation.

Rosenthal investigated passage of warm water fish species through five culverts in eastern Montana (Rosenthal 2007). This study found comparable passage rates between reference reaches (natural stream reaches without culverts) and culverts for four species and restricted passage through culverts compared to reference reaches for one. Conversely, in Arkansas, Rajput (2003) found fish were less than 50% likely to move across reaches with culverts compared to control reaches without culverts. Passage through culverts was measured only at locations without plunge pools (Rajput 2003). Findings from work done in Virginia and West Virginia showed cyprinid passage through culverts was negatively correlated with culvert slope, the product of slope x length, and velocity (Coffman 2005).

A recent study of warm water fish passage, including Topeka shiner, was performed on ten culverts, comprising five box structures, five low-water crossings, and ten natural riffles (control reaches) in northeastern Kansas (Bouska and Paukert 2009). They found that fish movement was greatest through control reaches (1.4 times more likely than any crossing). In addition, their study showed fish were twice as likely to move through box culverts when compared to low-water crossings. Their results also showed cyprinid movement increased with decreased slope and length, perching and increased crossing width (Bouska and Paukert 2009).

2.2 Study Areas

Our study area was the James, Vermillion, and Big Sioux watersheds in eastern South Dakota. The study performed detailed evaluation of passage at nine culvert crossings in four tributaries to the James River (see Figure 2). In addition, fin clips from Topeka shiners were collected at locations in the James, Vermillion and Big Sioux watersheds to investigate genetic diversity of Topeka shiner.

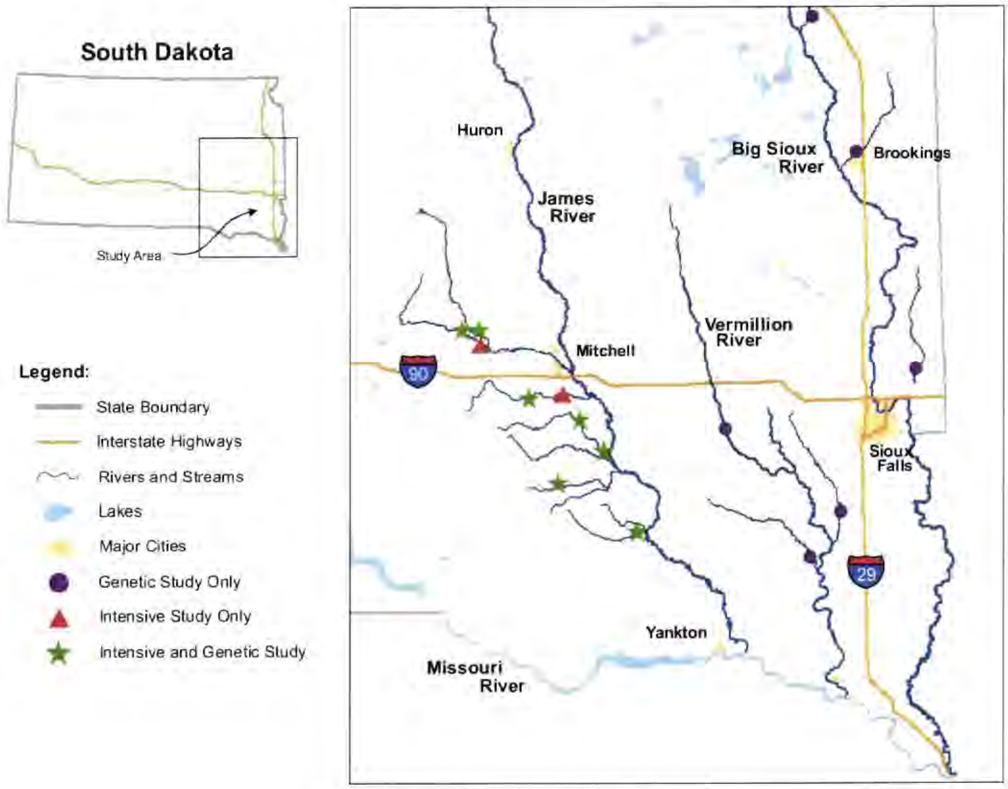

Figure 2: Map of All Study Locations

These watersheds are located in the Northern Glaciated Plains ecoregion (Bryce et al. 1996). Elevations range from 1300 ft to 2550 ft; surficial geology of this ecoregion is primarily glacial till. The region has a temperate continental climate with annual precipitation ranging from 16 to 22 inches, and mean annual frost free-days ranging from 90 to 140 days. Mean monthly minimum and maximum January air temperatures are -9.4° F and 23° F, whereas mean monthly minimum and maximum July air temperatures are 54° F and 86° F. Land use in this ecoregion is primarily agricultural, with tilled grain crops, hay, and pasture; some areas retain native woodland and wetlands (Bryce et al. 1996).

The James River basin is 14.1 million acres in area; its headwaters are in North Dakota (Berry et al. 1993). It is a turbid, warm water river with large fluctuations in seasonal discharges. Anthropogenic stressors on the James River include large numbers of low-head dams, eutrophication, and low dissolved oxygen levels, which causes fish kills. The river supports 57 fish species in 16 families, dominated by cyprinids, catostomids, ictalurids, centrarchids, and percids. Several species associated with the Missouri River occur in the lower reaches of the James River (Berry et al. 1993).

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The Big Sioux River basin is 5.76 million acres in area, and includes portions of South Dakota, Iowa, and Minnesota. The Sioux Falls in Minnehaha County are a natural barrier to fish movement, and three low head dams impede fish movements (Galat et al. 2005). The Big Sioux River is relatively natural and supports a healthy fish population of 66 native species (Galat et al. 2005).

Detailed study of fish passage was performed at three crossings on Firesteel Creek (Figure 3) located near Plankinton, South Dakota, three crossings on Enemy Creek (Figure 4) located just south of Mitchell, two crossings on Twelvemile Creek (see Figure 5) near Edgar and one crossing on Lone Tree Creek (see Figure 6). Only genetic studies were performed at Stray Horse Creek (Figure 7), Six Mile Creek (Figure 8), W. Pipestone Creek (Figure 9), W. Fork Vermillion Creek (Figure 10), Turkey Ridge Creek (Figure 11), and Long Creek (Figure 12). Study site selection followed a stratified sampling approach which is discussed in Section 4 of this report. Appendix A includes photographs of each culvert study site.

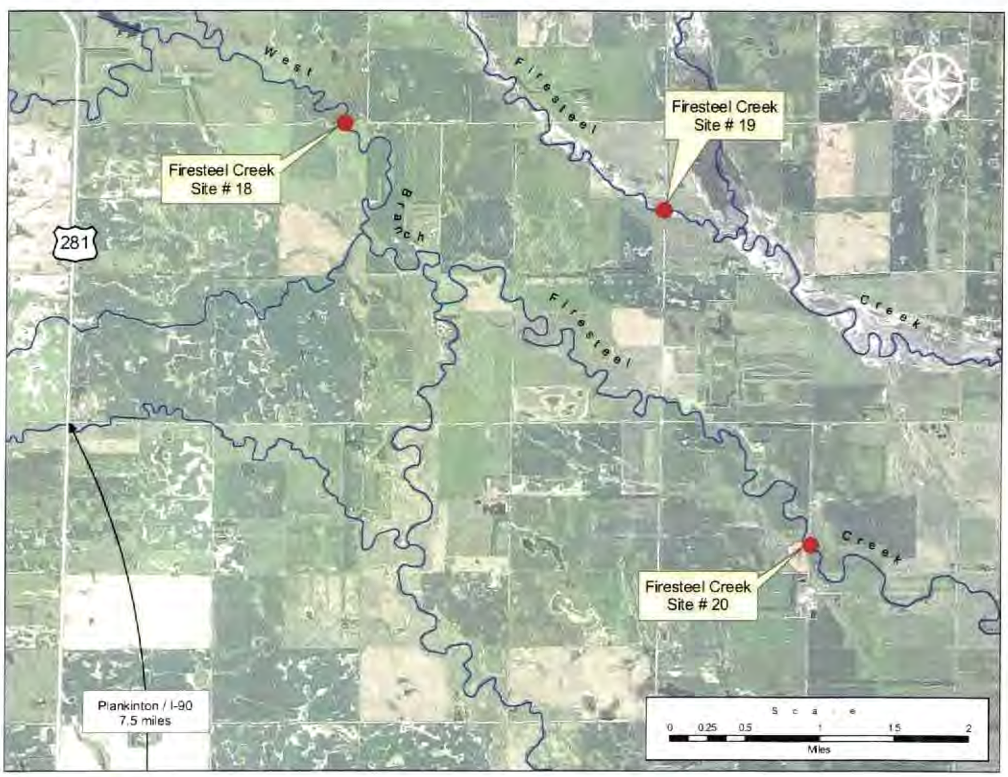

Figure 3: Aerial View of Culvert Study Sites in the Firesteel Creek Watershed

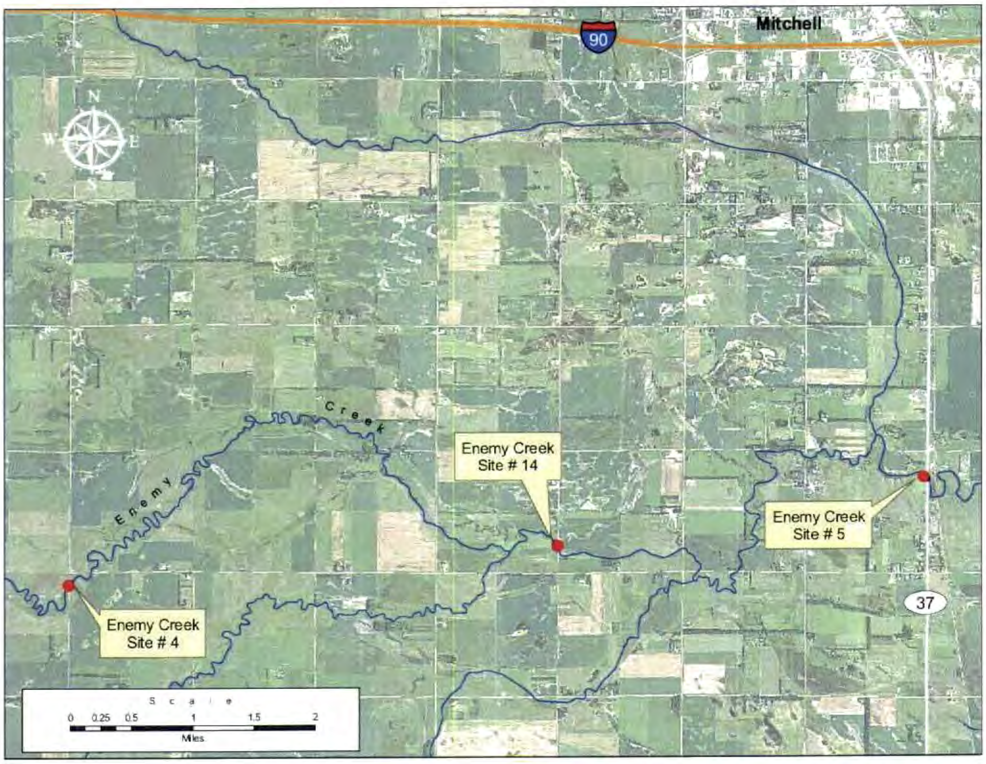

Figure 4: Aerial View of Culvert Study Site in the Enemy Creek Watershed

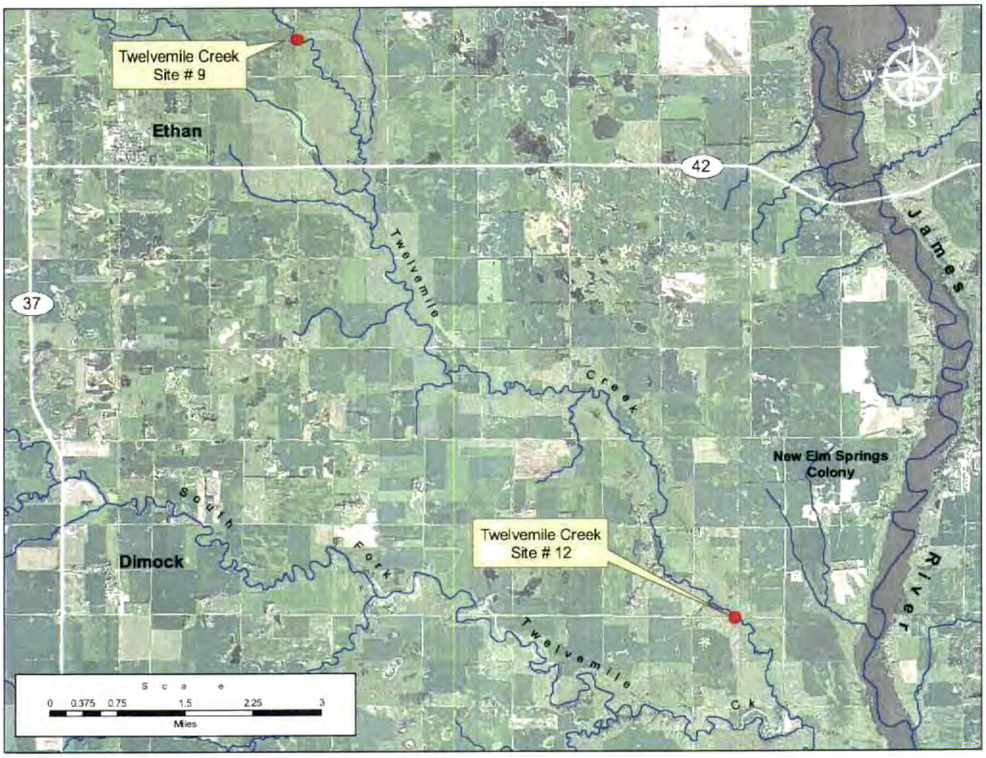

Figure 5: Aerial View of Culver Study Sites in the Twelvemile Creek Watershed

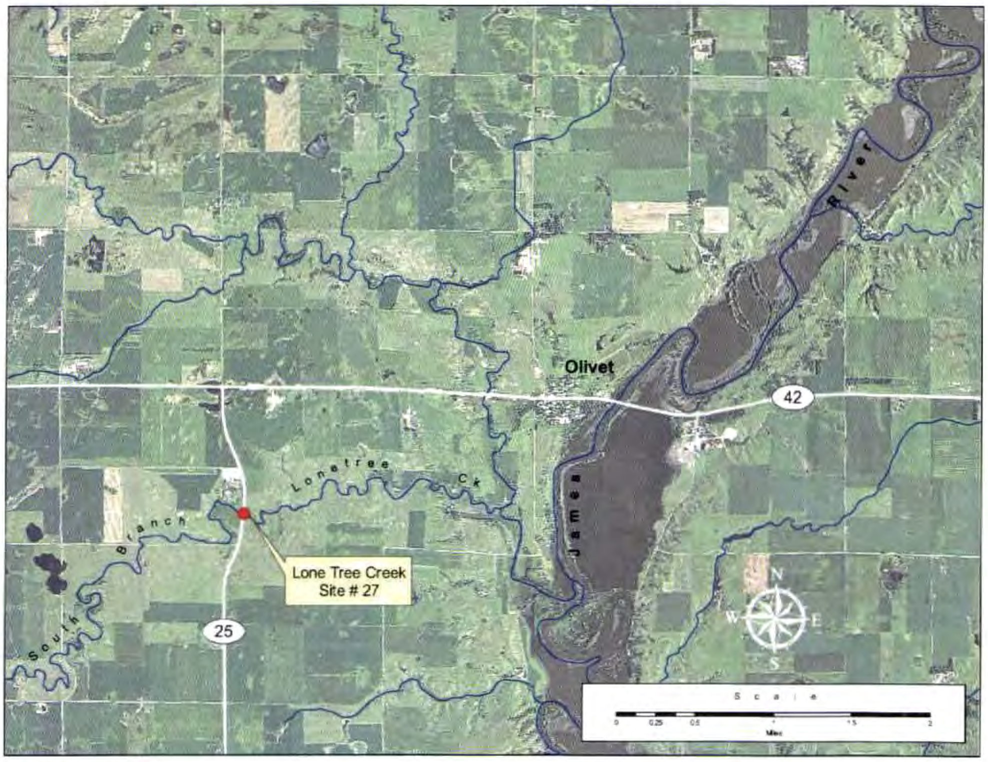

Figure 6: Aerial View of Culvert Study Site in the Lone Tree Creek Watershed

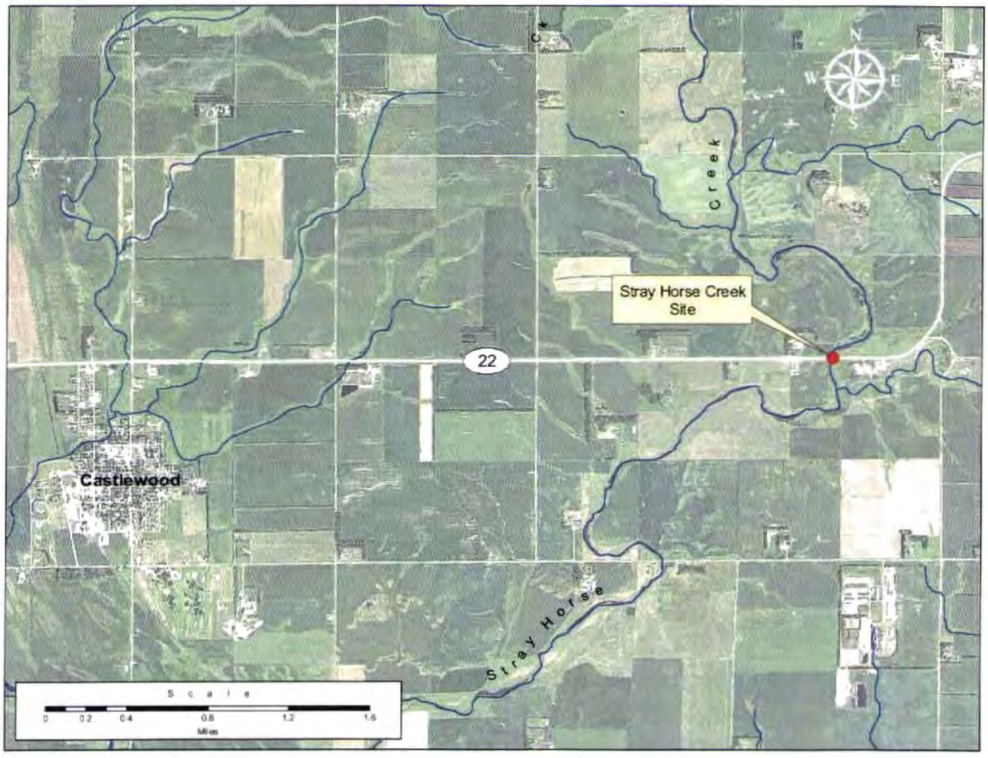

Figure 7: Aerial View of Culvert Study Site in the Stray Horse Creek Watershed

Figure 8: Aerial View of Culvert Study Site in Six Mile Creek Watershed

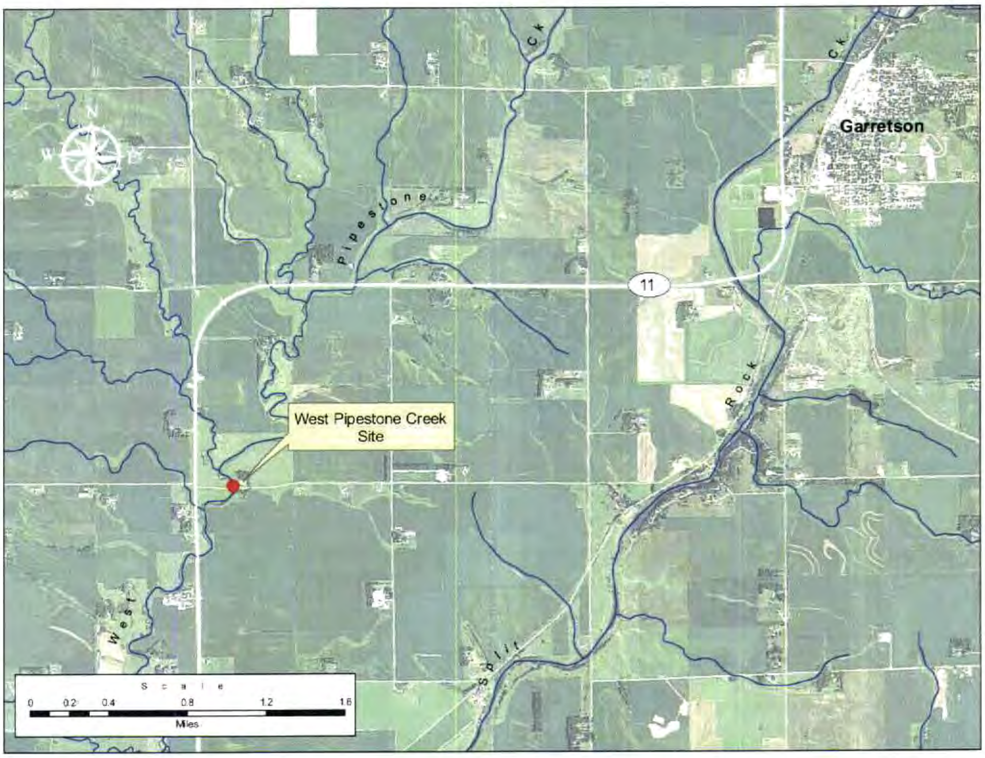

Figure 9: Aerial View of Culvert Study Site in the West Pipestone Creek Watershed

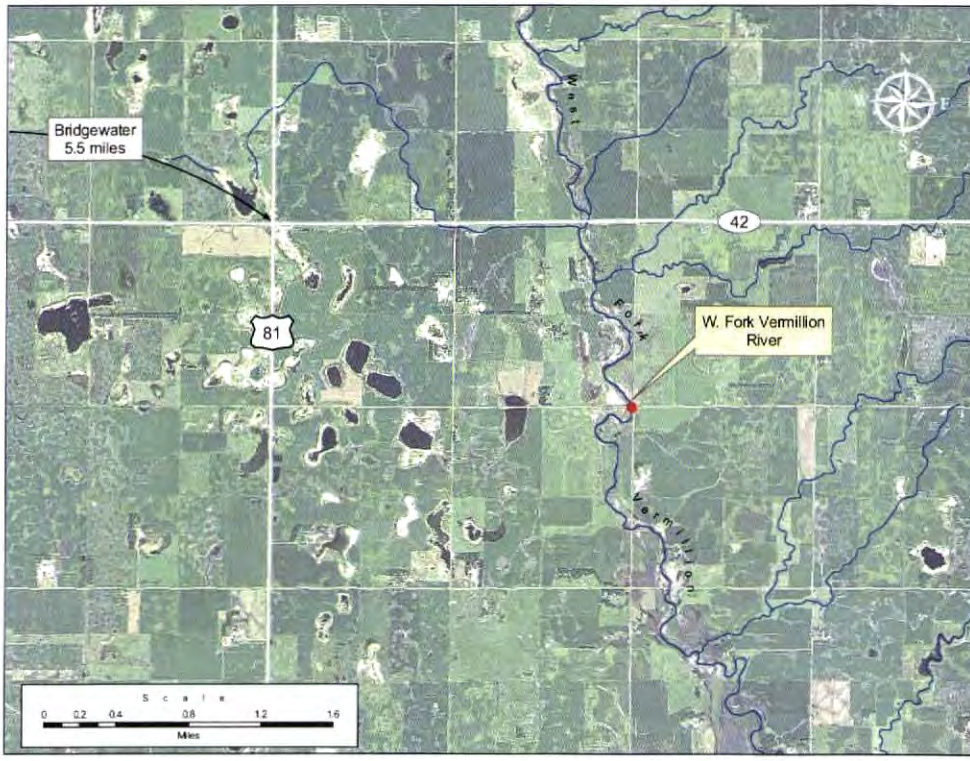

Figure 10: Aerial View of Culvert Study Site in the W. Fork Vermillion Creek Watershed

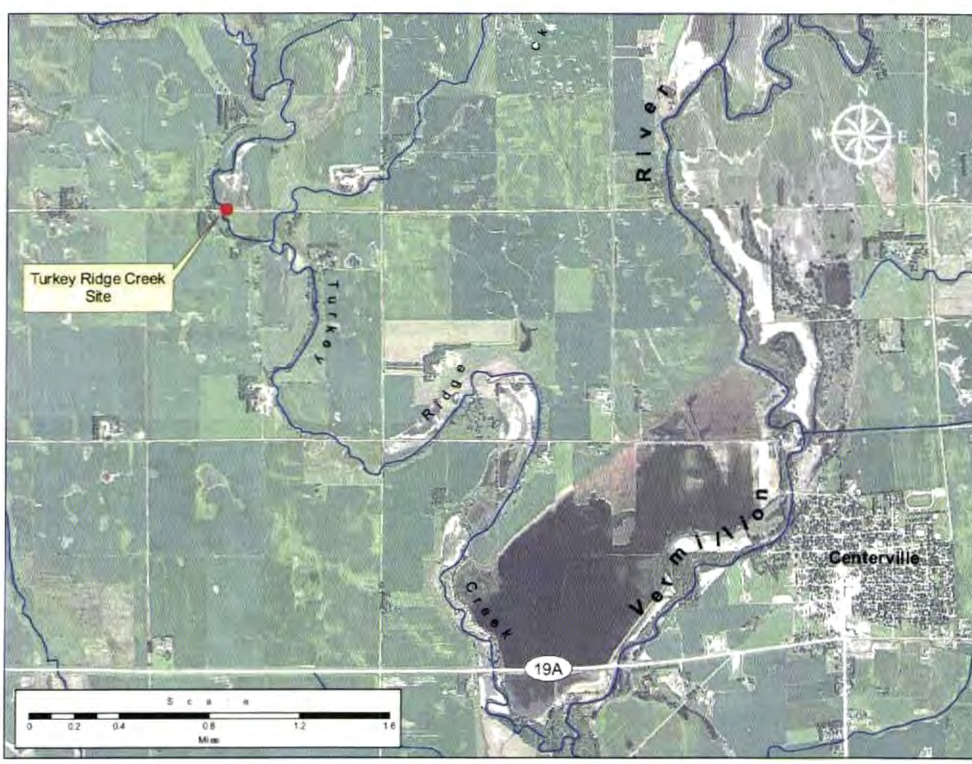

Figure 11: Aerial View of Culvert Study Site in the Turkey Ridge Creek Watershed

Figure 12: Aerial View of Culvert Study Site in the Long Creek Watershed

For the remainder of the document, all fish species are referred to by their common name. Table 1 summarizes the common and formal names as well as the abbreviations of all fish species captured during passage experiments.

Table 1: Common Names, Formal Names, & Abbreviations of Fish Species Captured During Study

Common Name	Formal Name	Abbreviation
Black Bullhead	*Ameiurus melas*	BLBU
Bigmouth Shiner	*Notropis dorsalis*	BMSH
Brassy Minnow	*Hybognathus hankinsoni*	BRMI
Central Stoneroller	*Campostoma anomalum*	CEST
Channel Catfish	*Ictalurus punctatus*	CHCA
Common Carp	*Cyprinus carpio*	COCA
Common Shiner	*Luxilus cornutus*	COSH
Creek Chub	*Semotilus atromaculatus*	CRCH
Fathead Minnow	*Pimephales promelas*	FAMI
Green Sunfish	*Lepomis cyanellus*	GRSU
Johnny Darter	*Etheostoma nigrum*	JODA
Largemouth Bass	*Micropterus salmoides*	LABA
Orangespotted Sunfish	*Lepomis megalotis*	OSSU
Red Shiner	*Cyprinella lutrensis*	RESH
Sand Shiner	*Notropis stramineus*	SASH
Shorthead Redhorse	*Maxostoma macrolepidotum*	SHRE
Stonecat	*Noturus flavus*	STCA
Tadpole Madtom	*Noturus gyrinus*	TAMA
Topeka Shiner	*Notropis Topeka*	TOSH
White Sucker	*Catastomas commersoni*	WHSU

3 OBJECTIVES

The purpose of this research was to better understand the factors that may influence the movement of Topeka shiner and other warm water fish species through culverts in eastern South Dakota, and to investigate the effect of culvert barriers on the distribution and genetic diversity of Topeka shiners. This research investigated three specific objectives:

1) *Determination of whether various culvert types, designs, and in-place characteristics were acting as intermittent or permanent barriers to movement of the Topeka shiner.* This objective was addressed by performing direct fish passage experiments, characterizing hydrologic and hydraulic conditions in the streams and culverts and performing hydraulic modeling.

2) *Clarification of the effects of culvert types, designs and flow characteristics on Topeka shiner movement through and distribution upstream and downstream of culverts.* This objective was addressed by performing direct fish passage experiments, characterizing hydrologic and hydraulic conditions in the streams and culverts and performing hydraulic modeling. We also investigated the effect of culvert barriers on genetic diversity by collecting fin clips from Topeka shiners in locations distributed throughout the James, Vermillion and Big Sioux watersheds and upstream and downstream of selected culverts.

3) *Development of strategies for mitigating existing culverts and improving new culvert designs to allow fish passage.* We achieved this objective by synthesizing the results of the field experiments and hydraulic modeling exercises with proposed culvert design methods (by SDDOT), other research and other fish passage design guidance.

The results of this research project are intended for use by SDDOT and others interested in improving passage conditions for warm water fish species, especially the endangered Topeka shiner.

4 TASK DESCRIPTION AND METHODS

This section of the report presents each task as outlined in the proposal. Methods associated with each task are detailed. Any deviations from the proposed methods are described. Some tasks overlapped with one another; therefore, descriptions for these tasks were combined to simplify the report and reduce redundancy.

4.1 Task 0: Project Management

Project management was performed throughout the project and included preparation of quarterly progress reports that described project activities to date, supervision of field technicians, oversight of all data collection activities, management of project budgets, and communication with SDDOT personnel and researchers.

4.2 Task 1: Literature Review

This task involved performing a literature review of available information on Topeka shiner, fish passage and related studies. Section 1.0 of this report includes a discussion of the more relevant studies. All of the reports, journal articles and documents gathered over the course of the study as part of the literature review are included on a compact disk. Many of these documents were gathered during previous studies of fish passage performed by the project's principal investigator or co-investigators. In addition, we have included the direct fish passage experimental data on this disk for future researchers.

4.3 Task 2: Recommendation for a Study Area

Initially, study areas were selected following a stratified sampling approach, with the strata representing removal priority and passage conditions. This approach began by reviewing the study sites investigated by Wall and Berry (2002). They assessed 81 road-stream crossings and categorized the culvert condition as poor, medium or high. In addition, they assessed reach habitat suitability and categorized it as low, moderate or high quality habitat for Topeka shiner. They combined the rankings in each category to reach a final prioritization for removal of low, moderate or high.

We proposed to randomly select three study culverts that were classified as high priority for removal (poor culvert condition and high reach habitat suitability), three study culverts classified as moderate priority for removal (medium culvert condition and high reach habitat suitability), and three study culverts classified as low priority for removal (good culvert condition and high reach habitat suitability).

We performed initial site visits during May and June 2007. Our May site visit was abandoned due to excessive rainfall and flooding conditions in the study areas. Several of the sites selected during the desktop review of the Wall and Berry report had conditions, such as excessively deep water, that would have prevented efficient collection of fish movement data using the techniques proposed. Therefore, we expanded our site inspections to identify additional crossings that would be more amenable to field data collection while still trying to maintain a range of culvert crossing conditions including high, moderate, and low priority for removal.

Table 2 summarizes study site information including the nine sites where detailed culvert studies were performed and locations where only fin clips were collected for the genetics study.

Table 2: Summary of Locations, Site Number, and Methods Used at Each Location

Basin	Creek or Stream Name	MSU Site Number or Name	Latitude	Longitude	Genetic Study?	Intensive Culvert Study?
James River Basin	Enemy	4	43.62769	-98.14606	Yes	Yes
	Enemy	5	43.64083	-98.00656	No	Yes
	Enemy	14	43.63198	-98.06660	Yes	Yes
	Twelvemile	9	43.56289	-97.94625	Yes	Yes
	Twelvemile and Dry	12	43.47083	-97.84939	Yes	Yes
	Firesteel	18	43.83296	-98.40876	Yes	Yes
	Firesteel	19	43.82495	-98.36584	Yes	Yes
	Firesteel	20	43.79273	-98.34551	No	Yes
	Lone Tree[1]	27	43.23014	-97.71455	Yes	Yes
Big Sioux River Basin	Stray Horse	Upper Big Sioux	44.73185	-96.95655	Yes	No
	Sixmile	Upper Big Sioux	44.33078	-96.78849	Yes	No
	W. Pipestone	Lower Big Sioux	43.68817	-96.56753	Yes	No
Vermillion River Basin	W Fork Vermillion	Upper Vermillion River	43.52883	-97.34833	Yes	No
	Turkey Ridge	Upper Vermillion River	43.14142	-97.01547	Yes	No
	Long	Upper Vermillion River	43.27239	-96.88788	Yes	No

[1]Only hydraulic modeling, a limited number of physical data sets, and water quality data were collected at the Lone Tree location.

4.4 Task 3: Stakeholder Interviews

Stakeholder interviews were performed over the course of the project and began during the initial scoping meeting in January 2007. The intention of these discussions was to gather information related to Topeka shiner, road-stream crossings, mitigation efforts, highway operations, road crossing design information, and other activities that either affect Topeka shiner and their habitats or that are affected by Topeka shiner (e.g, farm and ranch practices).

Many of the stakeholders were or are part of the technical review committee. Additional discussions were had with Ruth Howell of the SDDOT, Andy Burgess of the South Dakota Department of Game, Fish and Parks, and Nathan Morey, formerly with SDDOT and now with the US Army Corps of Engineers. Early in the project we discussed methods with Craig Paukert of Kansas State University. Dr. Paukert recently completed a project that investigated the effects of road crossings on Topeka shiner in Kansas (Bouska and Paukert 2009). We also discussed the project and related issues with landowners whenever possible.

4.5 Task 4: Scoping Meeting

Bob Bramblett and Matt Blank traveled to Pierre, South Dakota in early January of 2007 to attend two days of kickoff meetings for the project. Similar to stakeholder interviews, these meetings were primarily held to inform the researchers of the many issues and opinions related to Topeka shiner, and road crossing design, construction, and maintenance.

4.6 Task 5: Measure Movement of Topeka Shiners

4.6.1 Initial Fish Passage Experiment

The original fish passage experimental design followed mark-recapture protocols developed by the researchers over the course of three separate fish passage projects performed in Montana. We performed this study design at two of the crossing sites in the summer of 2007. The experiments entailed dividing the crossing into approximately 85-foot reaches upstream and downstream of an individual culvert (Figure 13). These reaches were identified as Upstream Treatment (UT) and Downstream Treatment (DT), respectively. Two additional 85-foot reaches were established downstream of the DT reach and separated by a "Theoretical Culvert". These reaches were identified as Upstream Control (UC) and Downstream Control (DC). The Theoretical Culvert was located a distance of natural stream equal to the length of the actual culvert in the experimental reach. Block nets were installed at the upper end of the UT reach, the downstream end of the DT reach, and at the downstream end of the DC reach to ensure a "closed" system for the duration of the study (Figure 13).

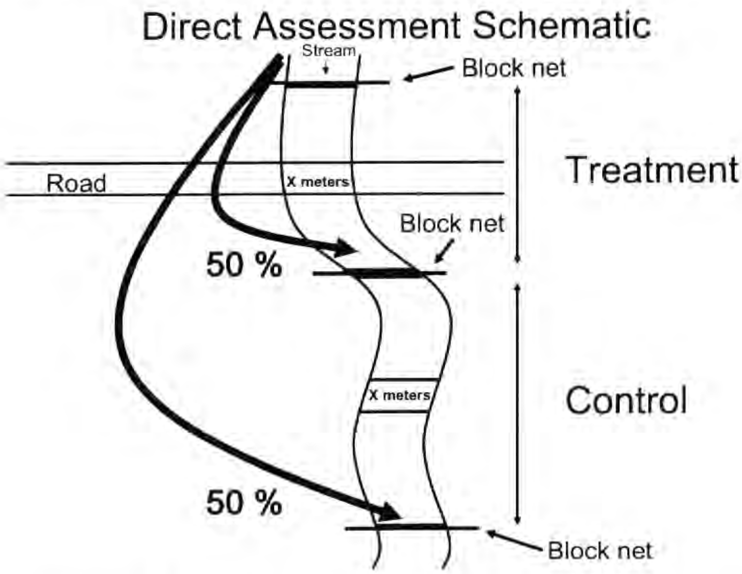

Figure 13: Schematic of original mark-recapture experiment (from Rosenthal 2007).

Fish were first collected upstream of the culvert of interest using 6 mm (0.24 inch) mesh seines. Seining was conducted in a downstream fashion with hauls being performed according to habitat features. All fish were placed in an aerated live well to ensure that incidental mortality was avoided. Fish were identified to species, measured to total length, split into treatment and control groups with equal numbers of fish, and marked using a Visible Implant Elastomer (VIE) tag, with tag color unique to each group.

Marked fish were allowed to recover in another aerated live well, and then released near the downstream block net in both the control and treatment reaches. The reasoning behind this active manipulation of fish has to do with the homing tendency of fish to return to their home range after displacement. Evidence exists in the literature that many species of warm-water fish use this homing tendency to return to natal streams for spawning (Linfield 1985), and to return to resting areas after migration to and from feeding areas (Clough & Ladle 1997). In previous tests of this approach (Burford 2005; Rosenthal 2007), we found that greater than 70% of tagged fishes (juvenile trout, creek chub), moved upstream in control reaches indicating the applicability of this approach for experimentally testing movement through culverts.

The control and experimental reaches remained blocked for a period of 48 hours. During this time, the fish were allowed to move within the upstream and downstream reaches, but could not leave at either end. After the fish had the allotted 48-hour period to move within this system, each of the four reaches (UT, DT, UC, DC) was sampled using multiple pass seining. Fish were placed in aerated live wells, and examined for VIE tags, identified to species, and measured to total length. Any fish with VIE tags collected upstream of the actual or Theoretical Culvert was considered to have passed through the reach of interest. Fish captured below either of these culverts were assumed to have remained stationary.

This experimental design yielded unsatisfactory results because of very low recapture efficiencies: <3% at Site No. 12 and < 5% at Site No. 18. The reason we had such low recapture was due to the difficulty we had in seining the large plunge pools downstream of the culverts. The pool depths were far greater than what could be waded, which in turn greatly hampered our ability to capture fish. Recapture rates this low would not provide the quantity or quality of data necessary to be able to understand the effect of culverts on the movement of Topeka shiners and other warm water fish. Because the mark-recapture technique relies upon the proportion of marked fish that are subsequently recaptured, this lack of sampling efficiency presented a problem.

4.6.2 Modified Direct Fish Passage Experiment

We modified the direct fish passage study design to accommodate a trapping system in place of seining. The overall approach in terms of studying the movement of fish by performing concurrent experiments at a culvert reach (treatment) and control reach (natural reach) remained the same. The new method used traps that allowed capture of fish moving upstream in place of seining. One set of traps was placed at the upstream end of the culverts and a fencing system was erected to direct all upward migrating fish into the traps. A second set of traps was placed at the upstream end of a control reach, with fences erected to direct fish into the traps. The control reach was a natural stream reach located between ½ to 1 mile downstream of the culvert reach to allow for sufficient habitat between the control and treatment studies. The fences were made of ⅛th inch poly mesh and were anchored to fence posts driven into the stream bed in a "V" shape, with the point of the "V" facing upstream. This set completely blocked off each reach with the only option for upstream movement being into the traps (Figure 14).

Figure 14: Treatment Trap (left) and Control Trap (right)

Each trap set consisted of a wooden trap (Figure 15) with ⅛- inch poly mesh to allow flow through the trap. The wooden trap was approximately 3 ft x 3 ft x 4 ft, with a ½- to 1-inch wide vertical slot that ran from the bottom of the trap to the top of the trap. The vertical slot was used so fish could enter the trap at any water level, and entry was not limited by changes in water depth or flow during the experiment. A baffle system was constructed inside the traps to provide a resting area for fish entering the trap system and to encourage them to remain in the trap away from the entrance. In addition to the wood trap, three conical shaped metal wire traps were placed in the "V" formed by the fencing weirs and anchored with lines to the fences. All four traps in a set were baited with dog food placed into mesh bags inside the trap. After setting each trap and fencing system, we would remove any fish from the culverts located downstream of the treatment trap using seines.

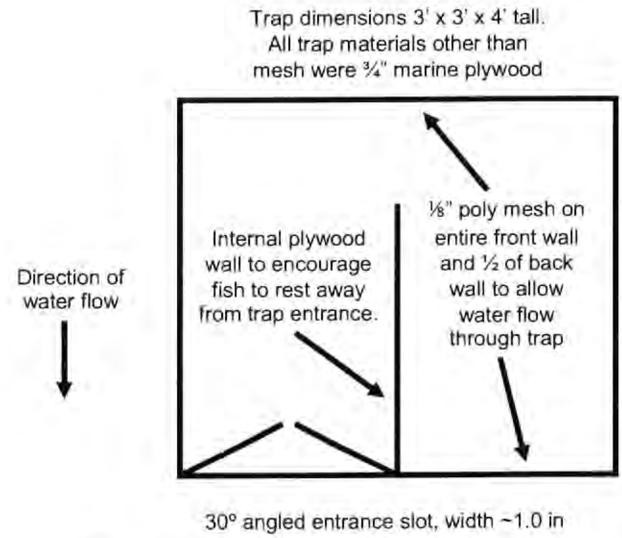

Figure 15 Wooden Trap Schematic

Hydraulic measurements including water depths, inlet and outlet drop height, and velocities were collected at the inlet and outlet of the culverts. A similar number of measurements of water depth and velocity were collected in natural stream reaches where discharge data was collected. In most instances, these measurements coincided with control reaches. Measurements were collected at the beginning of each experiment and daily during the experiments. Discharge measurements were collected using the USGS 0.6 depth method and were recorded daily during the experiments (USGS 1982). Velocity measurements and discharge were collected using a March McBirney flow mate meter. Velocity measurements at the culvert inlet and outlet were collected at the center of the culvert at a depth equal to 0.6 times the water depth. Water depth measurements at the inlet and outlet of the culvert were collected at the center. Inlet and outlet drop height was measured as the difference between the water surface in the culvert at the inlet or outlet and the water surface in the upstream pool or plunge pool adjacent to the culvert. We compared the hydraulic characteristics in the culvert to the natural/control reaches using Mann-Whitney U-tests ($\alpha = 0.05$).

We ran each experiment for three days. Once each day we would remove all of the fish captured in each trap and place them in an aerated live well. We anesthetized them with a mixture of water and MS-222, identified them to species and measured their total length. Fish were allowed to recover in aerated live wells. Once they had recovered, we placed them upstream of the weir fence system. At the very beginning of the project, we performed a set of trials with MS-222 to determine a proper dilution factor that would prevent unnecessary harm to Topeka shiner and other fish.

4.6.3 Morphological Surrogate Analysis

We used surrogates for Topeka shiner to investigate passage characteristics and conditions for studies where we did not capture sufficient numbers of Topeka shiner. The hydrodynamic forces experienced by fish and the swimming abilities of a fish are related to its body shape (i.e., morphology; reviewed by Matthews 1998). A fish moving through water experiences two types of hydrodynamic drag: friction and pressure drag. Friction drag is caused by friction between water molecules in the "boundary layer" (which moves with the fish) and water farther away from the fish. Pressure drag occurs when eddies create turbulence along and behind a fish; these eddies disrupt laminar flow and create pressure drag. Fish with similar body shapes and body roughness will experience similar hydrodynamic drag forces.

We determined which fish species had the most similar body shape to Topeka shiner in order to use the species as a surrogate in fish passage experiments where Topeka shiners were absent or only captured in small numbers. We selected red shiner *Cyprinella lutrensis*, sand shiner *Notropis stramineus*, and bigmouth shiner *N. dorsalis* as potential surrogates due to their similarity in body shape, size and phylogenic relatedness. We assumed that body roughness was similar among all species because they all have the same scale type (i.e., cycloid), similar fin ray and scale counts, similar fin placement and size, and the males of all species develop nuptial tubercles (Cross 1967). To compare body shape of the four species, we used a simple index of relative body depth which was the dorsoventral body depth/fork length. Because we did not have specimens of the fish species we used photographs and scientific illustrations. We used three separate photographs or illustrations for each species. We used photographs of red shiner, sand shiner, and bigmouth shiner from the Wisconsin Fish Identification Database (University of Wisconsin et al. 2010). For Topeka shiner, we used one photograph that we took in the field, a photograph by Garrold Sneegas, and a scientific illustration by Joseph R. Tomelleri. We tested if relative mean relative body depth was the same for the four species with a one-way analysis of variance (ANOVA) followed by a post hoc Fisher's Least Significant Difference (LSD) test to determine which pairs of species had significantly different relative body depths.

4.6.4 Analysis of Direct Passage Experiment Data

We used a chi-square goodness-of-fit test to compare the frequencies of fish observed passing upstream through the treatment to the frequencies of fish observed passing through the control. This analysis was done by pooling all fish captured in the treatment and comparing to all fish captured in the control at each site. Also, we compared the frequency of fish captured in each reach by species. We did not analyze species with less than four fish captured because of low densities.

We used t-tests to evaluate length differences by species between treatment and control reaches at each site. We only evaluated species with at least ten individuals captured in both the treatment and control reach.

We used simple linear regression to evaluate relationships between the passage index (PI) in relation to the physical factors that may impede passage including culvert outlet drop, slope, average water depth, length, average velocity and slope x length. The PI is simply the number of fish passing the treatment minus the number of fish passing the control, divided by the total number captured in both reaches. Therefore, if the PI is 0 or greater, more fish passed the treatment, and if it is less than 0, more fish passed through the control (Table 3).

We analyzed all fish combined, and by species if the species was captured in at least six paired experiments. The species specific analyses included Topeka shiner (n=6), red shiner (n = 6), sand shiner (n = 7), brassy minnow (n = 7), fathead minnow (n = 7) and green sunfish (n = 7).

For all statistical analyses, we used a significance level of 0.05.

Table 3: Interpretation of Passage Index (PI) Value

Value of PI	Interpretation
PI = 1	Some fish passed through the culvert (treatment) reach, but no fish passed through the natural (control) reach.
0 < PI < 1	Fish passed through both reaches, but more fish passed through the culvert than through the natural reach.
PI = 0	The same number of fish passed through the culvert and natural reach.
-1 < PI < 0	Fish passed through both reaches, but more fish passed through the natural reach than the culvert reach.
PI = -1	Some fish passed through the natural reach, but no fish passed through the culvert reach.

4.7 Task 6: Characterize the Hydraulic Environment

We used several methods to characterize the hydraulic environment through the study culverts and paired control reaches. This section describes the methods used to characterize the hydraulic environment.

4.7.1 Rating Curves, Hydrographs and Thermograms

We constructed a gaging station at each culvert study site, with the exception of the Lone Tree Crossing. We did not construct a gage station at Lone Tree Creek because it was located so far from the other study sites that we were not able to visit the site enough times to accurately monitor it. Each station consisted of a Schedule 40 PVC stilling well secured to the bank and streambed using metal t-posts. Two control points were established at the gage site to provide vertical control for the gaging station. We used a total station or a survey level to survey in the elevation of a datum on the stilling well to the survey cap on the control point. Measurements from the stilling well to the control were collected at the beginning and end of each field season. These measurements allowed us to identify if the gage had shifted due to freeze-thaw, ice or other hydraulic forces. We placed a TruTrack model WT-HR-1000 in each well to record water height, air temperature and water temperature. The recorder was set to record these data every hour.

We established a rating curve for each gage station. The rating curve establishes a relationship between stage and discharge which is unique to each gage site. We established a discharge measurement cross section near the gage site. Permanent bank pegs were driven into the banks on either side of the cross section. We measured discharge using the 0.6 x depth or the 0.2/0.8 x depth method following USGS protocols (USGS 1982). Velocity measurements were collected with a Marsh McBirney flow instrument. Each time we measured discharge we recorded the stage height as measured by the TruTrack. We collected as many discharge measurements as we could each summer at each gage site, with a minimum of ten discharge measurements over the course of the study. We attempted to collect discharge at as large of a range of flow rates as possible.

Using the rating curve, we created a hydrograph for each flow season for each gage site. The hydrographs show the estimated flow rate, updated every hour, for the period that the gage was installed at the site. We attempted to install the gages as early in the season as was practical and leave them in the streams as late as possible.

The TruTrack gage recorded water temperature on 1 hour intervals. Using this data we plotted a thermogram for each study site. The thermogram and hydrograph were plotted on the same graph.

4.7.2 Water Depth, Velocity and Outlet Drop

As previously described, hydraulic measurements including water depth, inlet and outlet drop height, and velocities were collected at the inlet and outlet of the culverts each time we measured discharge at a crossing. These measurements were done in addition to the hydraulic data measured as part of the passage experiments. If the crossing had more than one culvert, these measurements were collected at each culvert in the crossing. We created inlet depth, outlet depth, inlet average velocity, outlet average velocity and outlet drop rating curves. These curves describe the relationship between each hydraulic parameter and flow, similar to a stage-discharge relationship.

4.7.3 Site Survey and Hydraulic Modeling of Fish Passage

Stream geometry, including channel cross sections, thalweg alignment and floodplain characteristics were measured using a TOPCON total station instrument. We surveyed culvert characteristics including culvert length, inlet and outlet inverts, culvert diameter, road deck width and height, road embankments slopes, culvert diameter, and related geometric data to characterize the crossing and the stream channels both up- and downstream. We characterized stream channel and floodplain roughness using a combination of grab samples, visual inspection and professional judgment. We also took several photographs of each crossing location and the nearby stream channels. At most crossing locations, we collected several sets of photographs at different flow rates to document changes in culvert hydraulics.

We created hydraulic models of each crossing using the Hydrologic Engineering Center-River Analysis System (HEC-RAS) version 4.0 and FishXing Version 3.0. Both are available for download from the internet with no charge. HEC-RAS is a river modeling software that can be used to evaluate a large range of river and stream hydraulic conditions, including multiple stream networks, bridges and culverts, weirs and a variety of other features. It was developed by the US Army Corp of Engineers. FishXing is a hydraulic software that estimates water depth, outlet drop and water velocity through culverts and superimposes fish swimming abilities to determine if a structure may be acting as a barrier to fish passage. FishXing was developed by the USDA Forest Service.

One distinct advantage of FishXing compared to HEC-RAS is that it incorporates fish swimming abilities into the analysis. HEC-RAS only models hydraulic conditions. However, a person can export water depth and velocity data from HEC-RAS and evaluate passage using fish swimming abilities, but this requires additional effort. We did use this approach for some of the crossings and have developed our own Microsoft Excel spreadsheets to perform this task.

FishXing allows the user to estimate the barrier status of a crossing structure for a fish species of interest. Our analysis fish was the Topeka shiner. We used swim speed data for Topeka shiner collected by Adams et al. (2000). Fish swimming data used in the model were 1.15 ft/s for prolonged speed, five minutes for prolonged time, 1.88 ft/s for burst speed, and six seconds for time to exhaustion. These data are in the center of the ranges reported by Adams et al. (2000). We set the minimum flow depth, which is the threshold below which no passage is expected to occur, at 0.1 ft. Maximum leap height was set as 0.1 ft, based on passage experiment data from this project that documented Topeka shiner passing through an outlet drop of 0.1 ft. We modeled the entire range of recorded flows at each crossing structure and established passage windows for each crossing. A passage window is the range of flows that the crossing is estimated to be passable for the species of interest. Using the passage window and the hydrograph, we calculated the amount of time each crossing was estimated to be passable.

We created two separate hydraulic models of each crossing with FishXing. One model used the tailwater cross section method as the downstream boundary. To use this method, we measured the tailwater control cross section and entered the geometry of it in the model. The second model used a user-defined tailwater rating curve. We established the user-defined tailwater rating curve by collecting water depth at the tailwater cross section for a range of different discharges.

4.8 Task 7: Document Habitat, Rainfall, Climate, Water Quality, Natural Barriers, and Hydraulics in the Context of Other Potential Impactors

We collected water quality data at each crossing site during the study. The number of water quality measurements depended on how many times we visited the crossing site. Water quality parameters included temperature, pH, conductivity, and dissolved oxygen. As previously mentioned, we created thermograms for each crossing using the data from the gage station.

As part of this task, we reviewed the literature on the full range of stressors to Topeka shiner and their habitat.

4.9 Task 8: Conduct Microsatellite DNA Analyses

Genetic analysis of evolutionarily neutral molecular markers was used to quantify genetic similarities and differences among populations of Topeka shiners in the study area, and to provide some insight into how much gene flow there has been between populations. Sampling was designed to address two questions: how much gene flow is there between adjacent populations separated by culverts, and how is genetic diversity distributed in this species across the entire study area. The first question was addressed by sampling four pairs of locations in the James River. The second question was addressed by collecting seven other samples of shiners distributed throughout the James, Vermillion, and Big Sioux Rivers (Table 4). A total of 210 fish were sampled for genetic analysis at 15 locations. The number of fish sampled at each location ranged from 7 to 15, with an average of 14 fish per location. The Six Mile Creek study location was not included in Table 4 because only one fin clip was collected at this site. Because only one sample was collected, it was not used for any genetic analyses.

We used microsatellite loci to describe genetic relationships among populations of Topeka shiners. Microsatellite loci are sections of genome that do not code for proteins and, with few exceptions, have no known function. Genetic variations at microsatellite loci, therefore, are not expected to affect an individual's ability to survive and reproduce. Because of this, microsatellite markers are frequently used to infer the history of isolation and connectivity between populations.

Table 4: Location of genetic samples collected, including number of individuals sampled (N)

River	Location	N
James River	Lone Tree Creek, downstream	15
	Lone Tree Creek, upstream	15
	Twelvemile Creek, #9, downstream	15
	Twelvemile Creek, #9, upstream	15
	Enemy Creek, #14, downstream	15
	Enemy Creek, #14, upstream	15
	Enemy Creek, #4, downstream	15
	Enemy Creek, #4, upstream	15
	Firesteel Creek, #19, upstream	8
	Firesteel Creek, #18, downstream	15
Vermillion River	Long Creek	15
	Turkey Ridge Creek	7
	West Fork Vermillion	15
Big Sioux River	West Pipestone Creek	15
	Stray Horse Creek	15

Dorsal fin clips were collected from fish and stored in 90% ethanol. DNA was extracted from these tissue samples using a Qiagen DNeasy Tissue Kit (Qiagen, USA). Eleven microsatellite markers were genotyped. These included six originally described in the Topeka shiner (NTB42, NTC81, NTD10, NTF43, NTA22 and NTC15 [Anderson 2008]), one from the common shiner, *Luxilus cornutus* (LCO4 [Turner 2004]), two from the Cape Fear shiner, *Notropis mekistocholas* (NME208 and NME178 [Burridge 2003]), and two from the flathead minnow *Pimephales promelas* (PPRO118 and PPRO48 [Bessert 2003]). We used standard methods for PCR, visualization of PCR products, and scoring genotypes (e.g., Vu and Kalinowski 2009).

Genotype counts were tested for agreement with Hardy-Weinberg expectations using the Markov chain Monte-Carlo exact test of Guo and Thompson (1992) implemented by GENEPOP (version 4.0.10) to test for a deficiency of heterozygotes (Rousset and Raymond 1995; Rousset 2008). The amount of genetic diversity within populations was quantified using expected heterozygosity (Nei 1978) and allelic richness (Kalinowski 2004). GENEPOP 4.0.10 (Raymond and Rousset 1995; Rousset 2008) was used to calculate the average expected heterozygosity, H_{exp}, for each locus in populations. Results were averaged across loci and populations. *HP-Rare* (Kalinowski 2005) was used to estimate the allelic richness for each population.

The amount of genetic differentiation between sampling locations was quantified using Weir and Cockerham's estimator of F_{ST}, θ (Weir and Cockerham 1984). This statistic measures the amount of genetic differentiation between populations. θ ranges from 0 (indicating no genetic differences between populations) to 1 (indicating that populations have no alleles in common). The biological significance of values of θ is usually hard to assess. However, everything else being equal, θ is small when there is a lot of gene flow between populations and large when there is little or no gene flow between populations. For some analyses, upstream/downstream pairs of samples were combined for analysis. The statistical significance of genetic differences between populations was assessed using the pairwise test of genic differentiation implemented by GENEPOP 4.0.10 (Rousset 2008). Pairwise estimates of θ were summarized with a two-dimensional multidimensional scaling analysis performed by SYSTAT v. 12 using default parameters.

4.10 Task 9: Analyze Field and Laboratory Data to Develop a Comprehensive Model of Topeka Shiner Movement and Impacts

We have included the details of the work related to this task as part of Tasks 5, 6, 7 and 8. To avoid redundancy, see the discussion in those tasks.

4.11 Task 10: Evaluate Effects of Culvert Type and Design on Movement and Distribution of Fish

We synthesized the data collected as part of Task 5, 6, 7 and 8 to address this task. As a summary, we used the passage data to evaluate the effect of culverts on Topeka shiner and other warm water fish movement. Passage indices were analyzed relative to culvert and flow characteristics to attempt to identify design features that prevented, limited and allowed movement of fish. In addition, we documented passage of many different species of warm water fish relative to hydraulic conditions in culverts and culvert types.

We created hydrographs to evaluate flow conditions through the crossing structures over three years. Using hydraulic data and hydraulic modeling we estimated the amount of time that each crossing might be a barrier to Topeka shiner.

Last, but certainly not least, we evaluated the genetic diversity of Topeka shiner across four culverts and across the James, Big Sioux and Vermillion watersheds.

5 FINDINGS AND CONCLUSIONS

This section of the report presents research findings relative to each of the tasks. We combined some of the findings for some tasks because they were very similar. We felt that by combining similar tasks, the findings are more clearly presented and there is less redundancy.

5.1 Task 2: Recommendation for a Study Area

A total of nine culvert crossings were selected for study. Of the original nine culvert study locations, one was abandoned after the initial summer of field data collection. The reason the location was abandoned was that the gaging station was vandalized and the TruTrack stolen. During the initial phone conversation with the landowner of this property about securing permission to study the crossing and accessing the stream, there was some hesitation to allow access. Based on these circumstances, it was decided to find a new study location to replace this site. Suggestions for new crossing sites were solicited from the project manager and other SDDOT staff. Based on their suggestions, Lone Tree Creek was used as the new study location.

Table 5 summarizes the average culvert characteristics for the nine intensive culvert study locations. Culvert types included concrete box, concrete arch, corrugated metal pipes with annular corrugations, and structural steel plate structures. Seven of nine culvert study sites were multiple barrel sites with three sites having three barrels and the other four having two barrels. Mean culvert length was 72.8 ft ±10.9 SE (standard error). Overall culvert slopes had a mean of 0.86% ±0.22 SE. Mean outlet drop was 0.43 ft ±0.29 SE, with five study sites having no outlet drop. Total crossing width, calculated as the sum of all individual barrel widths at a crossing, had a mean of 22.5 ft ±3.1 SE.

Table 5: Average Characteristics of Study Locations with Intensive Culvert Data Collection

Stream	MSU Site Number	Culvert Type	# of Cells	Slope (%)	Outlet Drop (ft)	Length (ft)	Width/Diameter	Total Crossing Width (ft)
Enemy	4	Concrete Box	3	0.42%	0	34.5	10.0	30.0
Enemy	5	Concrete Box	3	0.20%	0	120.3	12.0	36.0
Enemy	14	Concrete Arch	3	0.19%	0	64.6	8.3	24.9
Twelvemile Creek	9	Concrete Box	2	0.55%	0	70.3	12.0	24.0
Twelvemile Creek	12	Structural Steel Plate	2	0.78%	0.73	134.0	12.0	24.0
Lone Tree	27	Concrete Box	2	0.78%	2.7	64.8	10.0	20.0
Firesteel	18	Corrugated Metal Pipes	1	0.97%	0.1	53.0	8.0	8.0
Firesteel	19	Structural Steel Plate	2	2.12%	0	54.5	14.0	28.0
Firesteel	20	Corrugated Metal Pipes[1]	2	1.73%	0.37	59.3	8.0	8.0

[1]The second culvert at this location is for high flow events only. It was dry during all site visits; therefore, only the main pipe was used for calculation of average characteristics

5.2 Task 3: Stakeholder Interviews

Over the course of the project, discussions with stakeholders were conducted. These began during the project kick-off meetings in January 2007 and continued throughout the project. Discussions were held with Dan Johnston, Nathan Morey, Daris Ormesher, Ginger Massie, Ted Eggebraaten, Dave Madden, Alice Whitebird, Dave Graves, Rich Phillips and Joan Bortnem of the South Dakota Department of Transportation, Craig Paukert of Kansas State University; Jim Oehlerking and Andy Mitzel of the US Army Corps of Engineers; Wayne Stancill, Natalie Gates and Vernon Tabor of the United States Fish and Wildlife Service, and Andy Burgess of the South Dakota Department of Game, Fish and Parks. In addition, discussions were had with landowners throughout the course of the study when possible.

Some of the key findings from these conversations, as they pertain to fish passage, are as follows:

1. There appears to be a concern that potential fish passage requirements may force replacements of many road crossings, and that, at the county level, there is little to no funding available to address this potential issue.

2. One problem that was identified with some existing road crossings is the potential for crossings to silt in over time.

3. Box culverts are preferred for most road crossings over small to medium sized streams because they are safer and can more economically meet site requirements than bridges. This is because they do not require guard rails which can increase the likelihood of vehicle collisions. In addition, guard rails can increase snow build up and drifting, which also increases the safety risk for vehicles.

4. A brief summary of the preferred new road crossing design was to embed the box culvert structure at least 12 inches below the natural streambed elevation to provide a natural substrate through the structure. This design method was assumed to reduce the likelihood of outlet drops from occurring and to provide conditions within the structure that will provide similar function as the natural stream channel. One part of this design was the assumption that the stream flow through the structure would create features that were similar to the natural channel. There also was discussion of a monitoring program that was either in place at the time this report was written or is being discussed and planned. The monitoring program would investigate embedded culverts to determine if they were indeed functioning as designed and planned—maintaining a natural sediment bottom that is not degrading or aggrading excessively over time.

5. Based on conversations with landowners, there appears to be a wide difference in opinions across the eastern part of the state where Topeka shiners live. Many landowners feel there is unnecessary regulation of their activities near streams inhabited by Topeka shiners. In one case, a landowner said he intentionally lied to state biologists about whether Topeka shiners were ever discovered in a stream running through his property. He felt that if that information were known, then he would be forced to spend a lot of money to improve and/or change his farming practices. On the other hand, there were some landowners who were very proud of the quality of their stream corridors, and were supportive of efforts to protect Topeka shiner. Several requested that we send them a list of the species that we sampled on their properties, and we did follow up and send them letters during the late winter of 2010.

6. There was some discussion of other factors that may affect Topeka shiner habitat and distribution. In particular, land use practices were discussed in some detail. During this discussion, it was apparent that, although synthesizing land use patterns with fish passage needs is important, this project should focus on fish passage through road crossings in terms of study design and methods. Placing each structure in the context of a watershed is then the next step in deciding whether a barrier culvert should be replaced, and how other factors may influence that decision. For instance, if there is a problem culvert in a watershed, yet the

habitat conditions upstream of the crossing are severely impaired by land-use activities, there may not be as much need to replace the problem structure.

7. Much of the other information from these discussions pertained to study site selection, other studies planned or in-progress, availability of data and reports, and suggestions on study design, analysis and implementation.

5.3 Task 4: Scoping Meeting

The initial project scoping meeting was held on January 4-5, 2007 at the SDDOT headquarters in Pierre, South Dakota. A summary of some of the information exchanged during those meetings is included in Section 5.2 of this report. Based on conversations in this meeting, we selected the James River Basin as the focus of the project, with only genetic sampling being performed in the Big Sioux and Vermillion watersheds. In addition, we selected sites that represented a range of different types of culvert installations, making sure to include some of the larger concrete box culverts.

5.4 Task 5: Measure Movement of Topeka Shiners

Sixteen weir trap studies were conducted between 2007 and 2009: eight at culvert sites and eight at control sites in natural stream reaches that were paired with each of the culvert sites. A total of 2,061 individual fish, comprised of 18 different species, were captured moving through control reaches as compared to a total of 438 fish, comprised of 18 different species, captured moving through culvert reaches. Figure 16 provides a summary chart showing the number of individuals by species captured in both culvert and control reaches. The most commonly captured species were brassy minnow, fathead minnow and sand shiner.

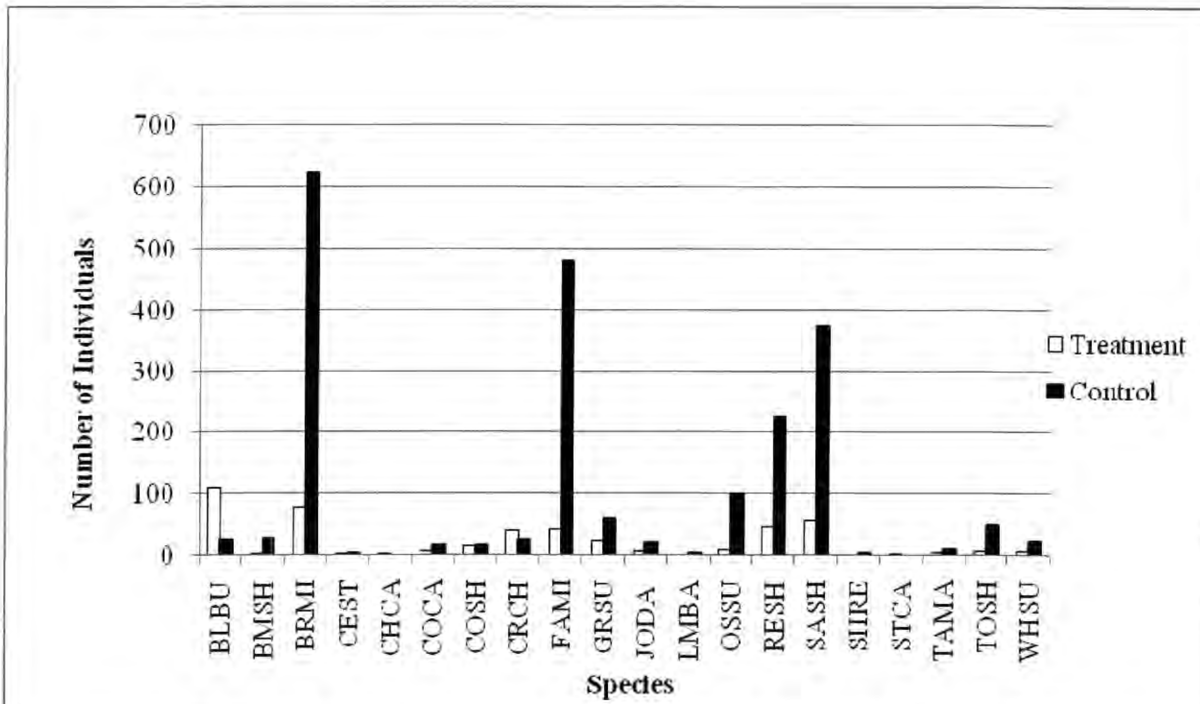

Figure 16: Species Composition for All Fish Captured During All Passage Experiments

Eight passage experiments, or four paired experiments, were performed in Firesteel Creek between August 2008 and October 2009. Figure 17 shows the species composition for the passage experiments performed at Firesteel Creek No. 18 on October 2008. Six passage experiments, or three paired experiments, were performed in Twelvemile Creek between 2007 and 2009. Two passage experiments, or one paired experiment, were performed in Enemy Creek in 2009. Graphs similar to Figure 16 for these other paired experiments are included in Appendix B.

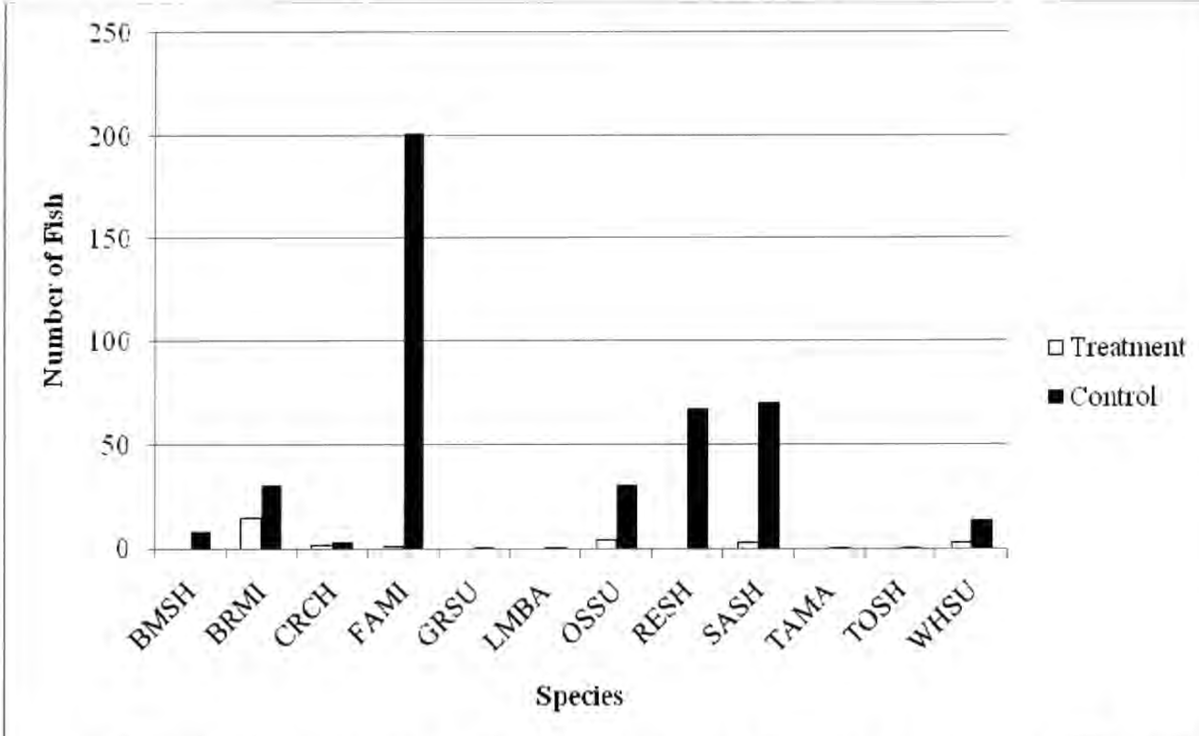

Figure 17: Species Composition in Control and Treatment Reaches of Firesteel Creek, No. 18

A total of 438 individual fish representing 18 species were documented passing through culverts in this study. Table 6 summarizes the physical information that each fish was able to traverse, organized by species. Topeka shiner were documented passing through three different culvert sites with water depths ranging between 0.15 and 1.51 ft, average water velocity ranging between 0.03 ft/s and 2.6 ft/s, outlet drops up to 0.1 ft, culvert slopes between 0.55% and 2.12%, lengths from 53 to 70.3 ft. These culverts consisted of concrete box, corrugated metal pipe and structural steel plate materials.

Table 6: Summary of Culvert Conditions Passed by Fish during Passage Experiments

Species	Number of Passage Experiments	Water Depth (ft)	Water Velocity (ft/s)	Outlet Drop (ft)	Slope (%)	Length (ft)	Culvert Type
SASH	6	0.15 - 1.51	0.03 - 3.65	0 - 0.7	0.55 - 2.12	53 - 134	CB, CMP, SSP
BRMI	7	0.15 - 1.51	0.03 - 3.65	0 - 0.7	0.55 - 2.12	53 - 134	CA, CB, CMP, SSP
BLBU	3	0.15 - 1.51	0.16 - 2.64	0 - 0.1	0.19 - 0.97	53 - 70.3	CA, CB, CMP
GRSU	2	0.15 - 1.51	0.16 - 2.64	0 - 0.1	0.55 - 0.97	53 - 70.3	CB, CMP
RESH	3	0.15 - 1.51	0.29 - 2.82	0 - 0.2	0.55 - 1.73	53 - 70.3	CB, CMP
BMSH	2	0.15 - 1.22	0.03 - 2.64	0 - 0.1	0.97 - 2.12	53 - 54.5	CMP, SSP
FAMI	6	0.15 - 1.51	0.03 - 2.64	0 - 0.1	0.19 - 2.12	53 - 70.3	CA, CB, CMP, SSP
TOSH	3	0.15 - 1.51	0.03 - 2.6	0 - 0.1	0.55 - 2.12	53 - 70.3	CB, CMP, SSP
OSSU	3	0.15 - 1.68	0.16 - 2.82	0 - 0.2	0.97 - 1.73	53 - 59.3	CMP
CRCH	5	0.15 - 1.68	0.27 - 2.82	0 - 0.2	0.19 - 1.73	53 - 70.3	CA, CB, CMP
WHSU	3	0.15 - 1.51	0.29 - 2.82	0 - 0.2	0.55 - 1.73	53 - 70.3	CB, CMP
COSH	2	0.45 - 1.51	0.27 – 1	0	0.55	70.3	CB
CHCA	2	0.48 - 1.51	0.29 - 2.82	0 - 0.2	0.55 - 1.73	59.3 - 70.3	CB, CMP
JODA	2	0.45 - 1.51	0.27 - 1.15	0	0.55	70.3	CB
TAMA	1	1.15- 1.51	0.34 - 0.53	0	0.55	70.3	CB
COCA	1	1.15- 1.51	0.34 - 0.53	0	0.55	70.3	CB
STCA	1	1.15- 1.51	0.34 - 0.53	0	0.55	70.3	CB
Note: CA - concrete arch, CB - concrete box, CMP - corrugated metal pipe, SSP - structural steel plate							

The species with the greatest relative body depth was red shiner, followed by Topeka shiner, sand shiner, and bigmouth shiner. Topeka shiner relative body depth was not significantly different from red shiner, but was significantly different from sand shiner and bigmouth shiner (Table 7). Even though this analysis showed a significant difference in relative body depth between Topeka shiner and sand and bigmouth shiner, we still feel that results for those potential surrogates are useful.

Table 7: Mean Relative Body Depth of Topeka Shiner, Red Shiner, Sand Shiner and Bigmouth Shiner

	Relative Body Depth (body depth/fork length)		P-values for pairwise comparisons			
Species	Mean	Std. Deviation	Topeka shiner	red shiner	sand shiner	bigmouth shiner
Topeka shiner	0.23	0.016	NA	0.052	0.031	0.017
red shiner	0.26	0.026	0.052	NA	0.001	0.001
sand shiner	0.20	0.011	0.031	0.001	NA	0.701
bigmouth shiner	0.19	0.006	0.017	0.001	0.701	NA

Table 8 summarizes passage experiment data for all studies and all species captured with the exception that species with only 1 individual captured (central stoneroller, largemouth bass, stonecat, and shorthead redhorse) were not included. In seven of eight paired experiments, there was a significant difference in the frequency of fish passing through treatment reaches when compared to control reaches for at least one species. In four cases, significantly more fish passed the treatment than the control; two instances were black bullhead, one was creek chub and the other was common carp. In 25 cases, significantly more fish passed through the control than the treatment reach; with notable cases including: Twelvemile Creek Number 9 where 41 Topeka shiner passed through the control and only three passed the treatment, three cases where significantly more red shiner passed through the control than the treatment, three cases where significantly more sand shiners passed through the control than the treatment, and two cases where significantly more bigmouth shiner passed through the control than the treatment.

Table 8: Results of Chi-Square Analysis and t-Tests for Passage Experiments

	Drainage	Enemy	Twelvemile	Twelvemile	Twelvemile	Firesteel	Firesteel	Firesteel	Firesteel
	Site	14	12	9	9	18	18	19	20
	Date	09-Oct	07-Oct	09-Aug	09-Oct	08-Aug	08-Oct	08-Oct	08-Oct
BLBU	T	8		3		98		0	0
	C	1		2		0		18	1
	p	.020		.655		<.001		<.001	-
BMSH	T					1	0		
	C					16	8		
	p					<.001	.005		
BRMI	T	1		15 (57)	25 (72)	8	14 (77)	7	6
	C	3		207 (47)	359 (80)	10	30 (77)	11	1
	p	.317		<.001 (.005)	<.001 (.009)	.637	.016 (.860)	.346	.059
CHCA	T	1							
	C	3							
	p	.317							
COCA	T		0	5					1
	C		14	0					0
	p		<.001	.025					-
COSH	T			1	12				
	C			3	12				
	p			.317	1				
CRCH	T			17 (91)	1		2		1
	C			16 (59)	4		3		0
	p			.862 (<.001)	.180		.655		-
FAMI	T	2		8	2	15	1	14 (46)	0
	C	2		181	2	8	201	85 (48)	1
	p	1		<.001	1	.114	<.001	<.001 (.148)	-
GRSU	T	0		5	0	17 (91)	0	0	0
	C	5		1	2	16 (59)	1	33	1
	p	.025		.102	-	.862 (<.001)	-	<.001	-
JODA	T	0		2	3	0			
	C	11		0	5	3			
	p	.001		-	.480	-			
OSSU	T			0		1	4	0	2
	C			1		48	30	17	3
	p			-		<.001	<.001	<.001	.655
RESH	T			2	0	22 (55)	0	1	4
	C			11	2	131 (55)	67	6	1
	p			.013	-	<.001 (.486)	<.001	.059	.18
SASH	T	0	3	9	3	22 (55)	3	16 (45)	0
	C	1	0	12	2	131 (55)	70	157 (43)	3
	p	-	-	.513	.655	<.001 (.486)	<.001	<.001 (.112)	-
TAMA	T	0		3	0	0	0	0	
	C	1		0	2	3	1	2	
	p	-		-	-	-	-	-	
TOSH	T	0		3	0	1	0	1	
	C	1		41	2	2	1	2	
	p	-		<.001	-	-	-	-	
WHSU	T			1	0		3		1
	C			4	4		13		0
	p			.180	.046		.012		-

1) Shading indicates significant differences in frequency or mean length of fish passing treatment compared to control. For cells with two numbers, the first number is the number of fish caught in a reach and the number in parentheses is the mean length. Mean lengths are only shown for species that have at least 10 individuals in both the control and treatment sample.

2) Dash indicates insufficient sample size to perform analysis. T=treatment, C=control, p=probability

There were only four instances with significant differences between mean lengths of fish, when compared by species, between treatment and control reaches. At Twelvemile Creek Number 9, in the August 2009 study, there were significantly larger brassy minnows passing the treatment compared to the control (treatment = 57 mm, control = 47 mm, $p = 0.005$), and significantly larger creek chubs passing the treatment compared to the control (treatment = 66 mm, control = 50 mm, $p < 0.001$). At Firesteel Creek No 18, in the August 2008 study, there were significantly larger green sunfish passing the treatment compared to the control (treatment = 91 mm, control = 59 mm, $p < 0.001$). Conversely, at Twelvemile Creek Number 9 in the October 2009 study, there were significantly larger brassy minnows recorded passing the control as compared to the treatment (treatment = 72 mm, control = 80 mm, $p = 0.009$).

Passage indices were calculated for all fish species pooled and for individual species if they were captured in a minimum of six paired experiments (see Figure 18). For all species pooled, no significant relationships were found between the passage index and average water velocity, average water depth, outlet drop, length, slope or slope x length ($p = 0.41 - 0.75$). There was a slight positive trend between the passage index and average water depth, average water velocity, outlet drop, slope and slope x length; and a negative trend with length. One reason that may explain the lack of any statistically significant relationships is the sample size when the sixteen passage experiments are paired drops to eight. Another possible explanation is that the passage experiments may not have been performed under conditions that represent thresholds for physical conditions. A limitation of our passage experiment is that it cannot be performed during higher flow events, which typically create more difficult passage conditions.

Passage indices were calculated for Topeka shiner, sand shiner, red shiner, brassy minnow, green sunfish, and fathead minnow. There were no significant relationships between passage index and culvert characteristics for Topeka shiner. However, significant relationships between passage index values and culvert characteristics were observed for sand shiner, brassy minnow and red shiner (see Figure 19). Significant relationships were observed between passage index and length for sand shiner ($p = 0.003$), and passage index and outlet drop for both brassy minnow ($p = 0.007$) and red shiner ($p = 0.005$). In all of these cases, there was a positive relationship between the PI and the culvert characteristic. These results should be used with caution as the sample size is very small and the range of values for each of the "significant" characteristics is also very small.

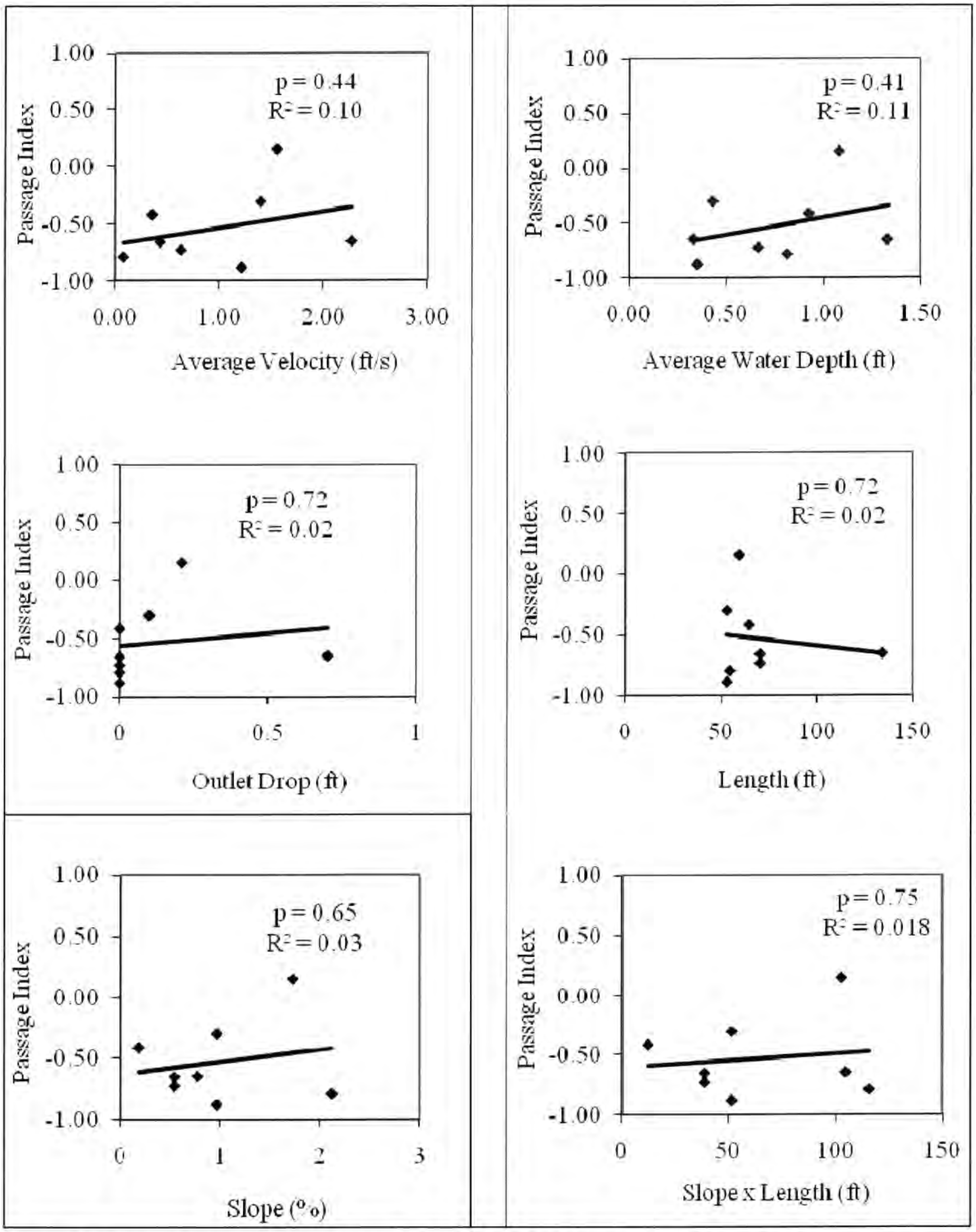

Figure 18: Regressions for All Species' Pooled Passage Indices and Physical Characteristics of the Crossings

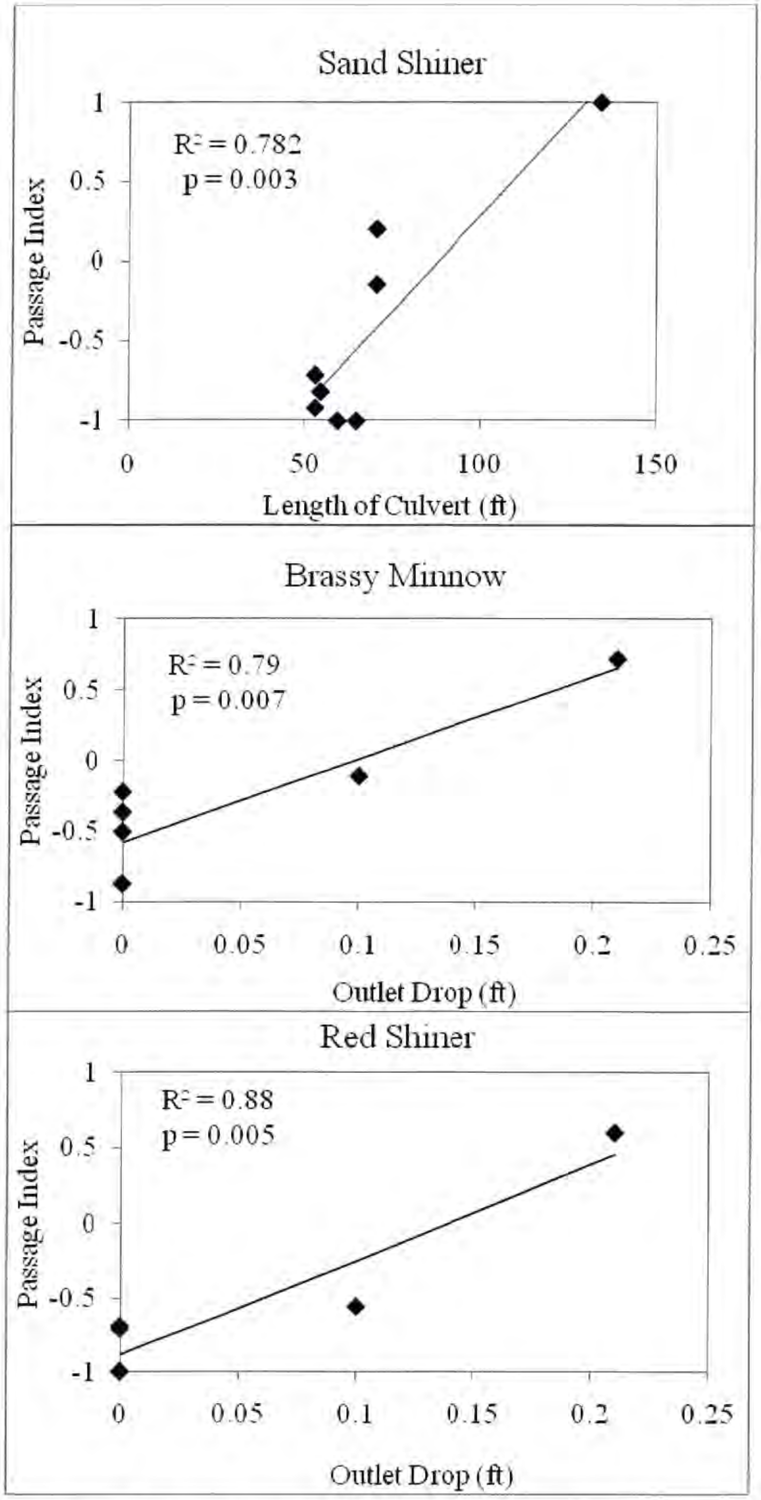

Figure 19: Significant Relationships between Passage Indices and Physical Characteristics of Individual Species

Task 6: Characterize the Hydraulic Environment

5.4.1 Rating Curves, Hydrographs and Thermograms

Rating curves and hydrographs at culvert crossing locations show some interesting patterns. As an example, the hydrograph and thermogram for Firesteel Creek No. 18 for the 2009 season is shown in Figure 20. Hydrographs for all other study locations and for all three field seasons are included in Appendix C. A wet cycle occurred during July of 2009 with several large rainstorms soaking the watershed. These storms produced a peak flow of 25 ft^3/s during the later part of the second week of July. The storm hydrograph shows a pattern that is representative of low gradient watersheds with soils that have low infiltration capacities (and common to all hydrographs in this study). Streams of this nature respond very quickly to rainfall creating a very steep rising limb with very little lag time between peak rainfall and peak flow. Conversely, the falling limb of the storm hydrograph is much longer than the rising limb because the low gradient systems drain slowly as the landscape retains moisture for several days to weeks.

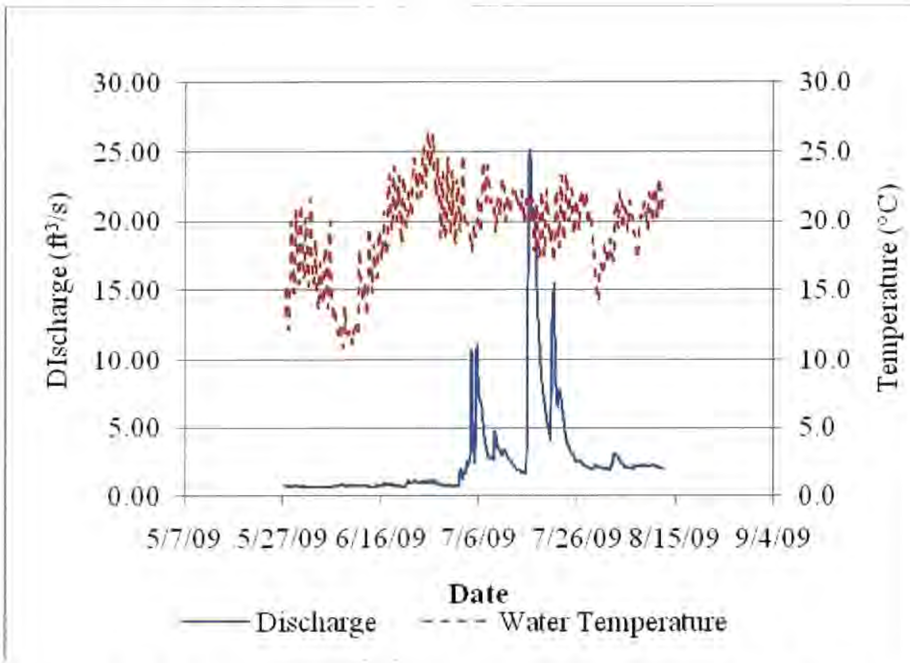

Figure 20: Hydrograph and Thermogram for Firesteel Creek No. 18 for 2009

Peak flow events measured at each gaging station are summarized in Table 9 for each of the three study years. Peak flows occurred during late summer and fall during 2007. Conversely during 2008, peak flows occurred during early June and in 2009 they occurred during a wet cycle in the early to middle of July. The largest flow events, overall, were observed during early June of 2008. The largest flow rate for the entire study was recorded at Firesteel Creek No. 18, during early June of 2008 at more than 300 cfs. This flow event overtopped the road near the culvert in two places.

Flow duration, which is the time period for elevated storm flows following a rainfall event, were overall highest in 2009, with the longest duration flow recorded at Firesteel Creek No. 19 – beginning on July 9 and lasting for 30 days.

Table 9: Summary of Recorded Flow Peaks and Durations

Drainage	Site Number	2007 Peak Flow Data Date	Flow (cfs)	Duration (days)	2008 Peak Flow Data Date	Flow (cfs)	Duration (days)	2009 Peak Flow Data Date	Flow (cfs)	Duration (days)
Enemy Creek	4	9-Aug	0.2	7	6-Jun	28.3	7	16-Jul	30.5	5
	5	8-Oct	0.4	4	7-Jun	150+	8.0	4-Jul	>150	11
	14	2-Aug	1.6	11	5-Jun	23.6	17.0	15-Jul	33	20
Twelvemile Creek	9	22-Jun	11.4	4	6-Jun	81.9	18	11-Jul	83.7	19
	12	4-Aug	55.6	6	8-Jun	123.7	22	11-Jul	95.9	21
Firesteel Creek	18	15-Oct	1.7	4	3-Jun	300+	?	16-Jul	24.6	5
	19	15-Oct	0.7	4	No Data For This Gage[1]			9-Jul	35.6	30
	20	15-Oct	3.2	4	No Data For This Gage[1]			5-Jul	8.5	5

1) Gages were lost in high water events at this location.
2) Flow estimates with a + sign indicate the flow is at least as big as the number.
3) Question mark in a cell indicates that the data was not available to estimate the parameter.

5.4.2 Water Depth, Velocity and Outlet Drop

Measurements of water depth and velocity were collected in both natural stream reaches and culvert reaches during site visits over the course of the project. Velocity measurements at the culvert inlet and outlet were collected at the center of the culvert at a depth equal to 0.6 times the water depth. Water depth measurements at the inlet and outlet of the culvert were collected at the center. Inlet and outlet drop height was measured as the difference between the water surface in the culvert at the inlet or outlet and the water surface in the upstream pool or plunge pool adjacent to the culvert. Water depth in the natural stream channel was taken at the thalweg, and water velocity was taken at 0.6 times the depth at the thalweg. Water depths ranged from dry conditions to up to four ft deep (see Figure 21) in the control reaches.

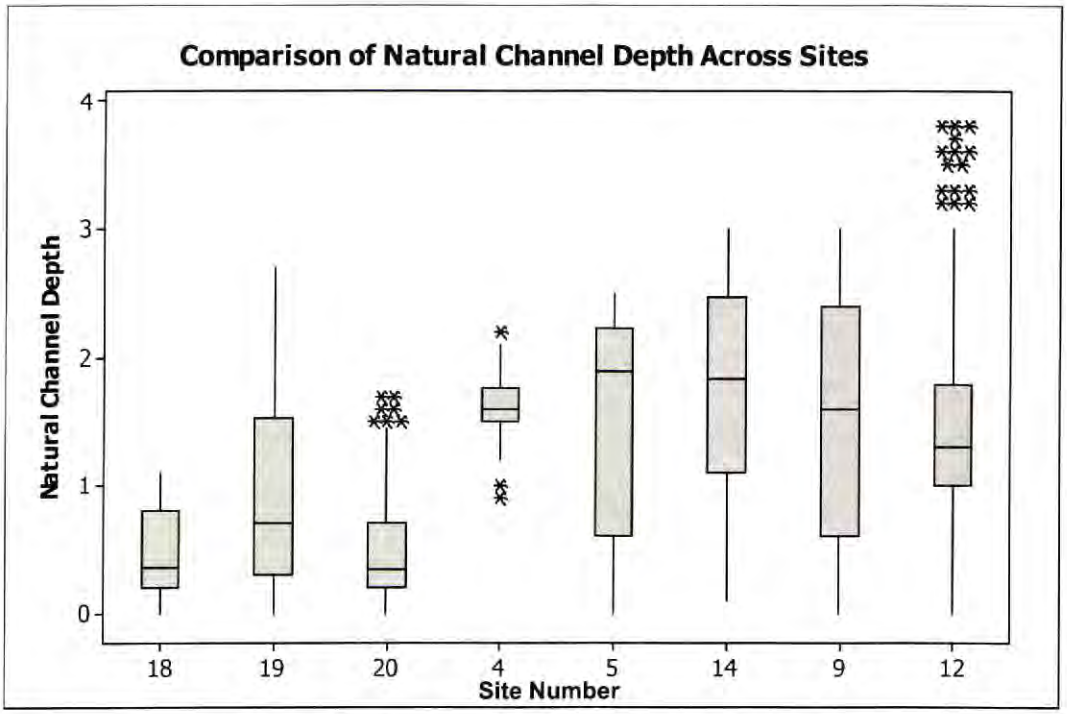

Figure 21: Box Plot of Natural Channel Depths

Averaged water velocities also showed a fairly large range across study locations, with a minimum of near 0.0 ft/s and a maximum of approximately 3 ft/s (see Figure 22).

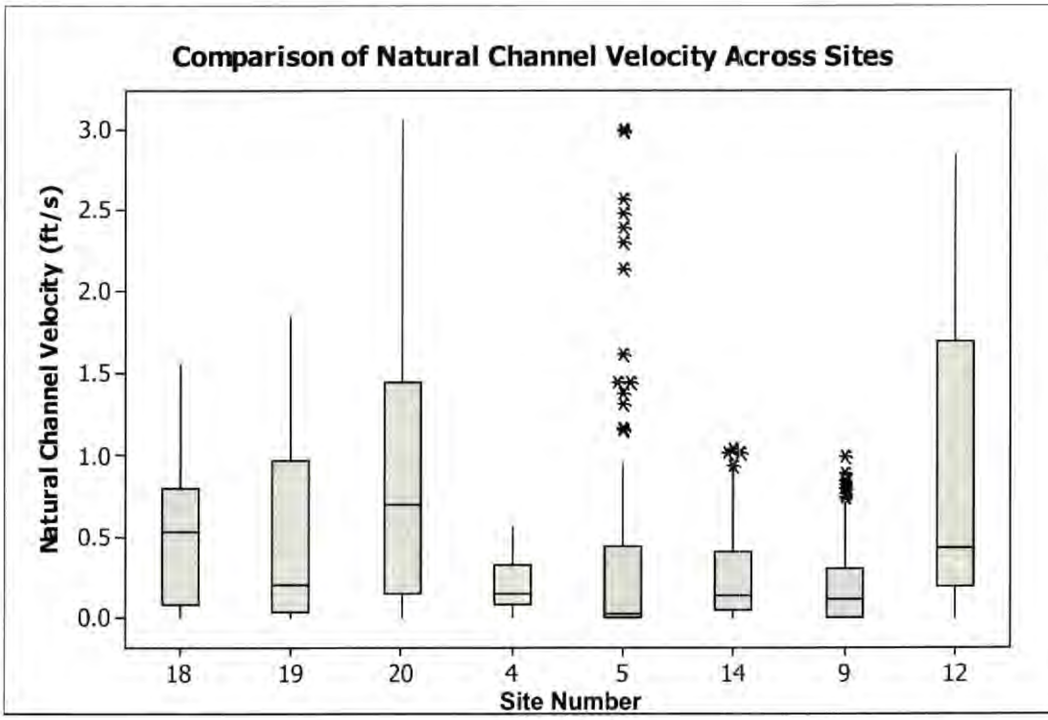

Figure 22: Box Plot of Natural Channel Average Velocities

Average water depth in culverts ranged from near zero to just over 4 ft (see Figure 23). The CMP at Firesteel Creek No. 18 and the SSP at Twelvemile Creek No. 12 had the shallowest water when compared to the other structures studied.

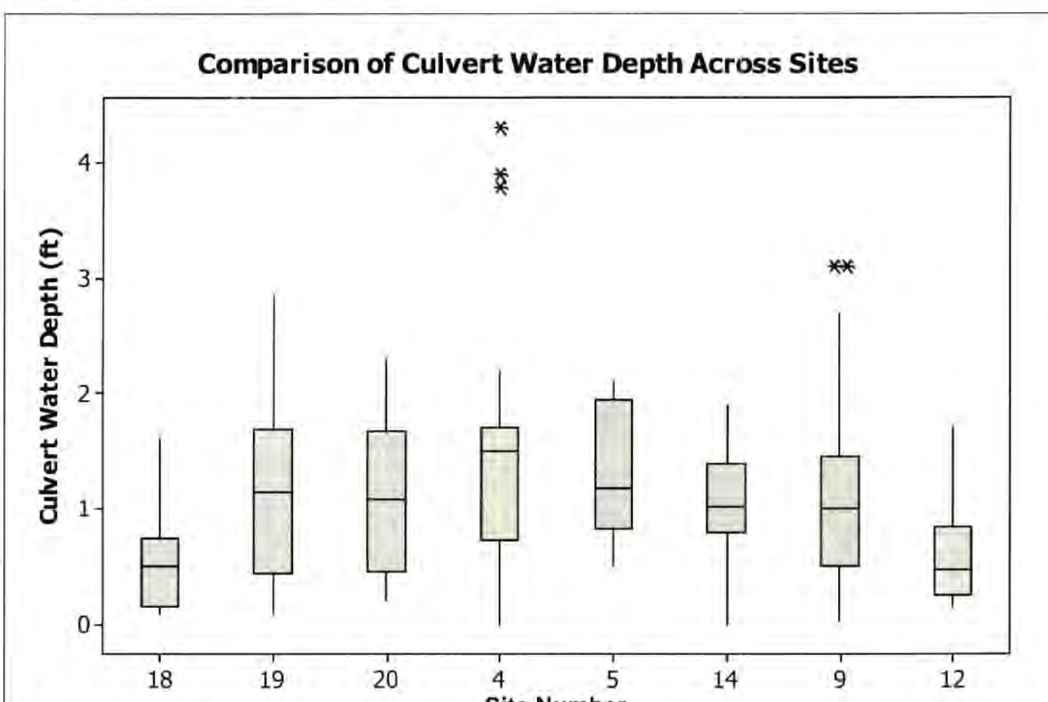

Figure 23: Box Plot of Average Culvert Water Depth

Average water velocity in culverts ranged from zero to over 8 ft/s (see Figure 24). Firesteel Creek No. 18 and No. 20, both CMPs, as well as Twelvemile Creek No. 12, a SSP, had the highest water velocities as compared to the other structures. Firesteel Creek No. 18 and 20 also have the smallest diameters as compared to the other structures. Smaller diameter pipes will constrict the flow and increase water velocities making them less desirable fish passage structures.

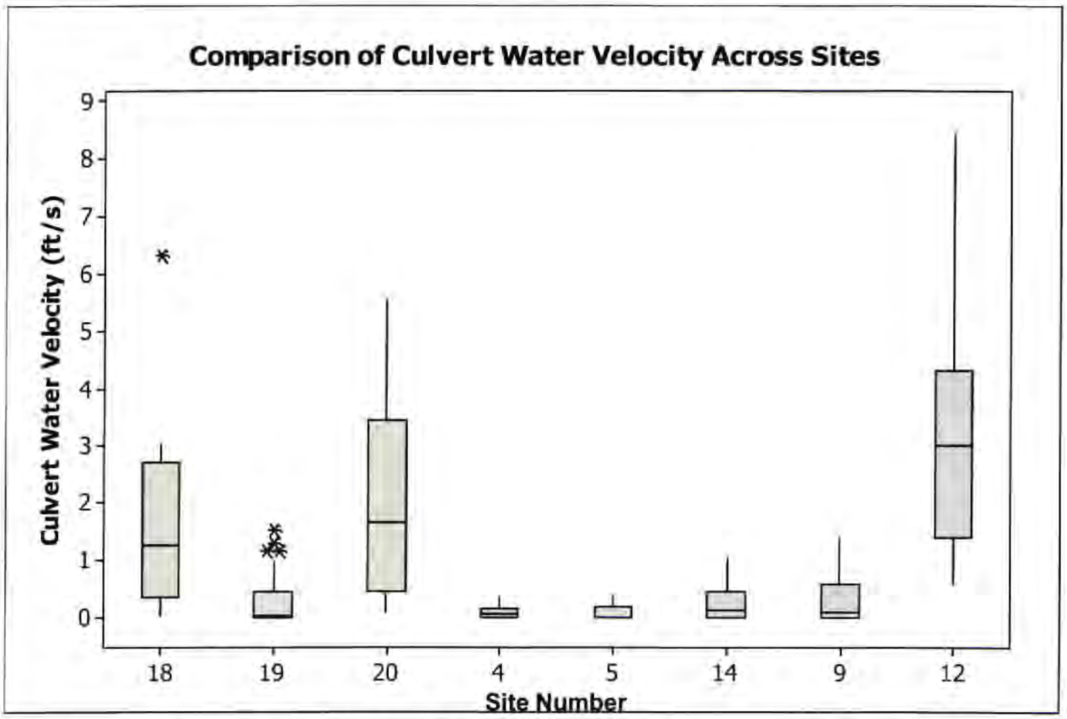

Figure 24: Box Plot of Culvert Water Velocity across Sites

Outlet drops ranged from 0 ft to over 1.0 ft (see Figure 25). Note: this figure does not show the outlet drop height for Site No. 27 on Lone Tree Creek (measured at 2.7 feet in July 2008) because only one measurement was collected and this figure shows sites with multiple measurements only.

Firesteel No. 18 and 20, Twelvemile No. 12, and Lone Tree Creek had the largest outlet drops during the study. As previously mentioned, Firesteel No. 18 and 20 as well as Twelvemile No. 12 also had the highest water velocities measured during the study. Higher water velocities increase the scouring at the culvert outlet, which creates the outlet drop.

Statistical comparisons between paired culvert hydraulic data and natural channel hydraulic data show some interesting trends. Hydraulic characteristics for culvert reaches and control reaches for Enemy Creek No. 4 and 5 were not significantly different. Both water depth and velocity were significantly different at four study locations, including both structures on Twelvemile Creek. Enemy Creek No. 4 and 5 are both wide spanning concrete box structures that have similar widths to the bankfull channel width of the streams they span.

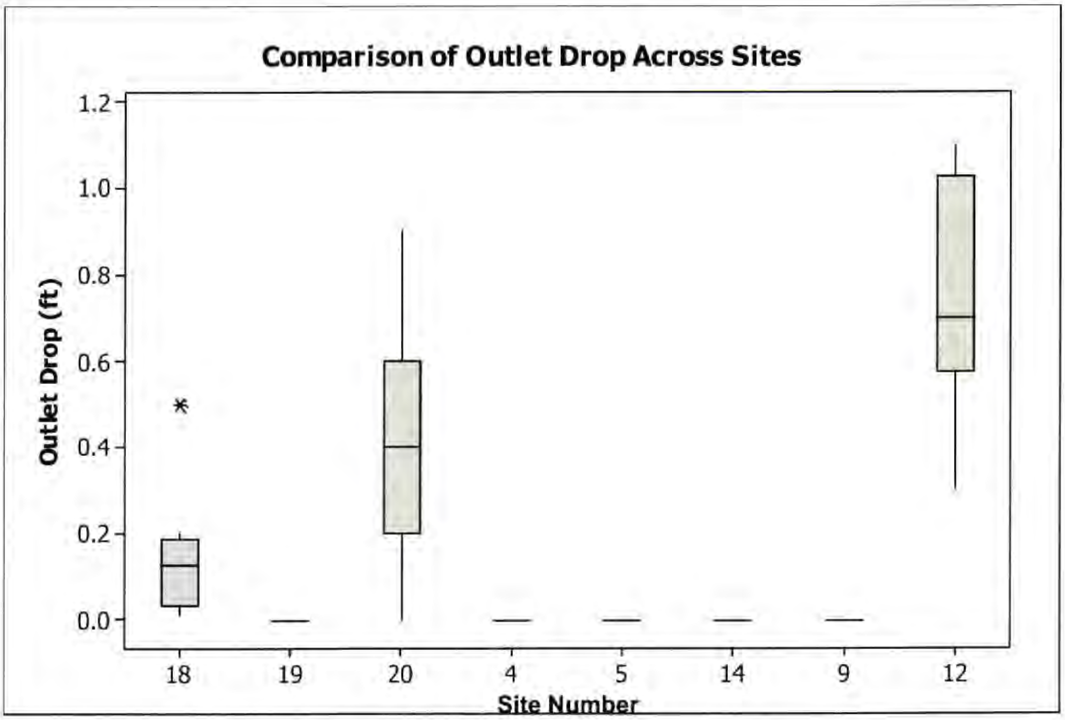

Figure 25: Box Plot of Outlet Drop across Sites

Table 10: Summary of statistical analyses of hydraulic variables between culvert and natural stream reaches.

Stream	Site Number	Significant Differences in Average Water Depth (y/n)	Significant Differences in Average Water Velocity (y/n)
Enemy	4	no	no
Enemy	5	no	no
Enemy	14	yes, $p < 0.001$	yes, $p < 0.001$
Twelvemile	9	yes, $p < 0.001$	yes, $p < 0.001$
Twelvemile	12	yes, $p < 0.001$	yes, $p < 0.001$
Firesteel	18	no	yes, $p = 0.002$
Firesteel	19	yes, $p = 0.018$	no
Firesteel	20	yes, $p < 0.001$	yes, $p = 0.002$

5.4.3 Hydraulic Modeling of Fish Passage

Barrier assessments using FishXing version 3.0 produced very different characterizations of passage for Topeka shiner depending on which type of tailwater condition was used for modeling. Table 11 summarizes the type of barrier, and estimated percent of the flow range that the software predicted the culvert to act as a barrier. As previously defined, two different models were constructed for each crossing: one using the tailwater channel cross section and a second using a user-defined (and field measured) tailwater rating curve. Using only the tailwater channel cross section, seven of nine structures were identified as passable for 0% of the measured flow ranges, with one structure characterized as having 38% of measured flows passable and a second as 5%. This contrasted dramatically with the estimated passage windows using a user-defined tailwater rating curve model. Only culvert sites at Twelvemile No. 12, Lone Tree Creek and Firesteel No. 18 were consistent between the two models. In five of six other sites, the user-defined tailwater rating curve method estimated more passage. The one exception to this occurred at Enemy Creek No. 5 were the amount of passable flows was estimated to be greater (38%) using the tailwater channel cross section method compared to only 15.9% estimated passage using the user-defined tailwater rating curve method.

Table 11: Comparison of Passage Windows Estimated by FishXing for Different Tailwater Conditions

Stream	MSU Site Number	Percent of Flow Range Predicted as Passable by FishXing with Tailwater Cross Section Method	Percent of Flow Range Predicted as Passable by FishXing with Tailwater Rating Curve Method
Enemy	4	0%, drop, depth, velocity	56.8%, depth and velocity
Enemy	5	38%, velocity	15.9%, depth and velocity
Enemy	14	5%, drop, depth, velocity	50.3% depth and velocity
Twelvemile	9	0%, drop, depth, velocity	42.9%, depth and velocity
Twelvemile	12	0%, drop and velocity	0%, drop and velocity
Lone Tree	27	0%, drop, depth, velocity	0%, drop, depth, velocity
Firesteel	18	0%, drop, depth, velocity	0%, drop and velocity
Firesteel	19	0%, depth, velocity	91.1%, depth
Firesteel	20	0%, drop, velocity	2.3%, depth and velocity

Passage windows are an effective way to visualize how a structure may be acting as a barrier relative to flow rates, seasons and critical movement periods for different fish species. It is important to use these models with caution as the thresholds are shown as abrupt even though they are actually probabilistic in nature (Cahoon et al. 2007). An example of a passage window is shown in Figure 26 for Twelvemile Creek No. 9.

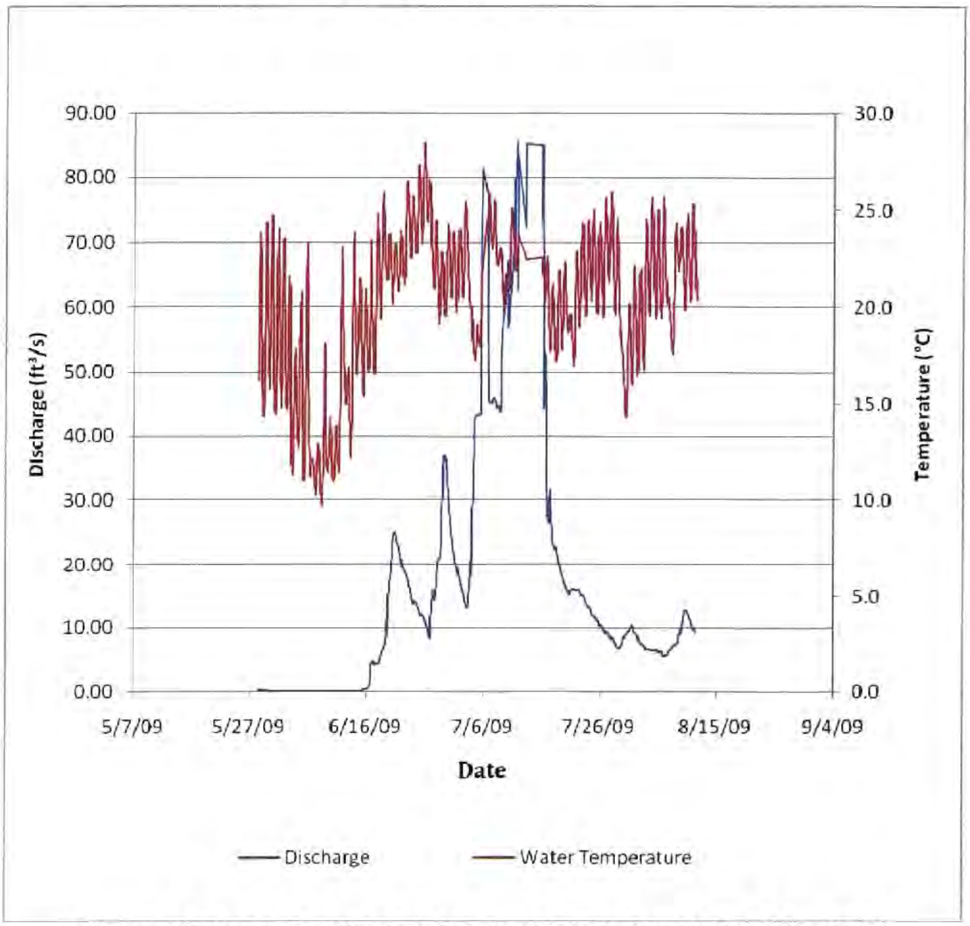

Figure 26: Passage Window for Twelvemile Creek No. 9 for 2009

The even dashed line on the figure depicts an estimate for the upper threshold, above the line velocities are estimated to be too great to allow for passage of Topeka shiner. The dashed-dot line depicts an estimate for the lower threshold for passage, below which there is insufficient flow in the structure and the water depth is such that the structure may act as a barrier. Using the thresholds, the crossing may have been preventing Topeka shiner movement during the last part of May and early June during low flows as well as during the middle of July during the wet cycle previously discussed. The passage experiment performed during August of 2009 at this location measured three Topeka shiner passing this culvert compared to 41 passing through the treatment. Passage windows for other years and for all gaged culvert crossings are included in Appendix C.

A summary of the estimated percent of time that each crossing may be a barrier to passage, estimated using the user defined tailwater rating curve method, is shown in Table 12. Percent of time that flows may be a barrier to passage for Topeka shiner ranged from a low of 26% at Enemy Creek No. 5 to a high of 100% for Twelvemile Creek No. 12 and Firesteel Creek No. 18, with Firesteel Creek No. 20 estimated at 99%. All three of the structures that are estimated as barriers 100% of the time are either corrugated metal pipes or structural steel plate culverts. The lowest amount of time estimated as barriers were at Enemy Creek No. 4 and 5. Both of those crossings use triple barrel box structures and both are at relatively low gradients with widths similar to bankfull flow.

Table 12: Percent of Time That Each Crossing May Be a Barrier Estimated Using FishXing with User-Defined Tailwater Rating Curve

Stream	MSU Site Number	Number of Days Recorded	Hydraulic modeling estimate of % of time of measured hydrograph that structure may be acting as a barrier
Enemy	4	273	35%
Enemy	5	342	26%
Enemy	14	345	92%
Twelvemile	9	369	60%
Twelvemile	12	312	100%
Firesteel	18	211	100%
Firesteel	19	161	73%
Firesteel	20	167	99%

5.5 Task 7: Document Habitat, Rainfall, Climate, Water Quality, Natural Barriers, and Hydraulics in the Context of Other Potential Impactors

These watersheds are located in the Northern Glaciated Plains ecoregion (Bryce et al. 1996). Elevations range from 396 m to 777 m; surficial geology of this ecoregion is primarily glacial till. The region has a temperate continental climate with annual precipitation ranging from 40 to 56 cm, and mean annual frost free-days ranging from 90 to 140 days. Mean monthly minimum and maximum January air temperatures are -23° C and -5° C, whereas mean monthly minimum and maximum July air temperatures are 12° C and 30° C. Land use in this ecoregion is primarily agricultural, with tilled grain crops, hay, and pasture; some areas retain native woodland and wetlands (Bryce et al. 1996).

Basic water quality parameters were measured periodically over the course of the study at each culvert site. Grab samples using a YSI meter were collected for pH, conductivity, dissolved oxygen and temperature. Table 13 provides a summary of water quality sampling results for grab samples with mean values for each parameter at each site, and the maximum and minimum values in parentheses. Continuous measurements of air and water temperature were collected by the TruTrack. Continuous water temperature measurements are included as thermograms on the hydrographs created for each gaging station (see Appendix C).

Based on a comparison of water quality thresholds and values cited in Bayless et al. (2003) and Kohle and Adelman (2007), it appears that the temperatures are within normal ranges at all sites for Topeka shiners. Some of the dissolved oxygen (DO) values are quite high, which may be due to the air entrainment caused by plunging flows into the culvert outlet pools where measurements were typically collected. Enemy Creek No. 4, No. 5 and No. 14 had the lowest DO levels; yet they still were above the 2.0 mg/L threshold listed as a lower limit for survival in Kohle and Adelman (2007).

Table 13: Summary of Water Quality Parameters

Stream	MSU Site Identification Number	Temperature (°C)	Conductivity (µs/cm)	Dissolved Oxygen (mg/L)	pH
Enemy	4	25.5 (20.3 to 29)	2654 (2630 to 2702)	4.78 (2.13 to 8.96)	7.98 (7.74 to 8.12)
Enemy	5	22.8 (18.5 to 26.6)	2553 (2096 to 3010)	2.61 (2.43 to 5.26)	8.14 (7.99 to 8.25)
Enemy	14	26.5 (20 to 30.8)	2654 (2503 to 2758)	2.92 (2.67 to 3.79)	8.1 (7.87 to 8.25)
Twelvemile	9	25.2 (19.2 to 29.8)	2501 (1300 to 1738)	12.6 (7.87 to 16.69)	8.2 (7.7 to 8.52)
Twelvemile	12	24.2 (14.7 to 28.6)	2225 (1962 to 2403)	8.4 (3.08 to 15.58)	8.2 (8.00 to 8.55)
Lone Tree	27	24.5 (23.4 to 25.6)	1658 (1608 to 1708)	7.8 (5.8 to 9.8)	7.9 (8 to 7.82)
Firesteel	18	24 (17.6 to 27.5)	1300 (1095 to 1601)	12.6 (2.77 to 13.7)	8.0 (7.41 to 8.42)
Firesteel	19	24.4 (18.7 to 29.1)	1712 (1342 to 2116)	10.3 (4.64 to 15.88)	8.5 (8.15 to 9.13)
Firesteel	20	23.3 (20.2 to 26.1)	1729 (1476 to 1982)	8.9 (4.48 to 13.23)	8.76 (8.5 to 8.78)

There are natural barriers that may be influencing the movement of fish. Beaver dams are very prevalent in the study drainages and likely impede some fish movement at some flows. Over the course of the study, we observed beaver dams constructed within the inlet and/or outlet of three different culvert study sites: Firesteel Creek No. 18, Firesteel Creek No. 20 and Twelvemile Creek No. 12. We attempted to remove the dams before any field data was collected at a location. In the case of Firesteel Creek No. 18, beavers quickly (within days) rebuilt the dam once we had removed it from the culvert barrel. We speculate that beaver dams constructed within the barrels of culverts likely function as more of a barrier than those constructed within the natural stream channels. This thought stems from the connection between the beaver dam and the culvert materials. Without detailed study, however, it is very difficult to say exactly how much impedance natural barriers create for Topeka shiner and other warm water fish species.

5.6 Task 8: Conduct Microsatellite DNA Analyses

Hardy-Weinberg[1] tests revealed a statistically significant tendency towards lower heterozygosities[2] than expected (5 out of 15 populations ×11 loci = 165 tests were statistically significant at the 0.05 level using a Bonferoni correction). A plausible explanation for this trend is the presence of null alleles (i.e., alleles that do not amplify during polymerase chain reaction). However, as there were only five statistical significant deviations from Hardy-Weinberg expectations, this is unlikely to substantially affect the rest of the analysis.

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[1] The Hardy-Weinberg principle states that both allele and genotype frequencies in a population remain constant—that is, in equilibrium—from generation to generation unless specific disturbing influences are introduced.

[2] Zygosity refers to the similarity of genes for a trait (inherited characteristic) in an organism. If both genes are the same, the organism is homozygous for the trait. If both genes are different, the organism is heterozygous for that trait.

Table 14: Amount of Genetic Diversity at the Loci Genotyped

Locus Name	Number of Alleles	Average Expected Heterozygosity, *H*
NTB42	6	0.47
NTC81	10	0.56
NTD10	5	0.05
NTF43	8	0.13
NTA22	4	0.09
NTC15	4	0.14
LCO4	13	0.23
NME208	30	0.82
NME178	13	0.53
PPRO118	29	0.87
PPRO48	13	0.67
Average	*12.2*	*0.41*

The populations of Topeka shiners sampled had modest amounts of genetic variation. The simplest measure of how much genetic variation is present in a population is the number of alleles (genetic variants) present at each locus (location in the genome). For the eleven loci genotyped, there were, on average, over 12 alleles per locus (Table 14). This is not notably high or low, but in many of the sampled populations, the allele frequencies were quite skewed. At five of the loci, the most common allele had a frequency of over 0.85. This affects the average amount of genetic variation present within individuals. This latter quantity is measured by the average expected heterozygosity within individuals. This quantity is the average fraction of individuals that are heterozygous at a locus, that is, have two different alleles. Averaged over all populations and loci, the expected heterozygosity was quite low—only 0.41. This indicates that populations of Topeka shiners are relatively small, or have been small in the recent evolutionarily past.

The amount of genetic differentiation between populations as measured by Weir and Cockerham's (1984) θ was moderate (Table 15).The global value of Weir and Cockerham's θ was 0.12, and pairwise values of θ were frequently less than 0.05. θ has a range of [0,1] with 0 indicating that populations have the same alleles present in the same frequencies. This usually occurs when populations are connected by high rates of gene flow. The maximum value of θ occurs when populations share no alleles, which occurs when populations have been isolated for a long time. It is difficult to infer the evolutionary history of populations from the amount of genetic differentiation between populations, but the observed value of 0.12 clearly indicates that all the sampled populations are not part of a single randomly mating population.

Populations from each of the three rivers sampled (James, Vermillion, and Big Sioux) tended to be genetically more similar to each other than to populations in other rivers. This is evident in the multidimensional scaling plot (Figure 27). As the figure shows, the two locations sampled from the Big Sioux River were genetically similar to each other, as were the five locations sampled from the James River. There was, however, one important exception. Fish from Turkey Creek in the Vermillion River basin clustered with fish from the James River. This may be because fish from the James River recently moved to Turkey Creek, or could be an artifact of sampling. Another notable feature of the data is that the three samples from the Vermillion River were quite different from each other. This indicates that there is not a lot of gene flow within the Vermillion River.

Table 15: Summary of Genetic Differentiation Ranging from 0 to 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Lone Tree DS	-														
2. Lone Tree US	0.02	-													
3. Twelvemile #9 DS	0.03	0.05	-												
4. Twelvemile #9_US	0.03	0.05	0.02	-											
5. Enemy #14 DS	0.05	0.04	0.03	0.02	-										
6. Enemy #14 US	0.07	0.05	0.05	0.04	0.00	-									
7. Enemy #4 DS	0.10	0.06	0.08	0.05	0.04	0.04	-								
8. Enemy #4 US	0.07	0.05	0.03	0.05	0.00	0.02	0.04	-							
9. Firesteel #18 DS	0.10	0.12	0.08	0.02	0.07	0.08	0.09	0.12	-						
10. Firesteel #19 US 1	0.06	0.08	0.09	0.02	0.08	0.08	0.10	0.11	0.08	-					
11. Long Creek	0.18	0.14	0.19	0.11	0.17	0.14	0.12	0.21	0.18	0.09	-				
12. Turkey Ridge	0.06	0.07	0.08	0.06	0.03	0.03	0.12	0.05	0.12	0.07	0.19	-			
13. W Fork Vermillion	0.09	0.13	0.15	0.09	0.15	0.15	0.16	0.16	0.17	0.02	0.20	0.13	-		
14. W Pipestone	0.07	0.11	0.12	0.10	0.13	0.12	0.11	0.15	0.14	0.11	0.15	0.11	0.16	-	
15. Stray Horse	0.18	0.17	0.21	0.16	0.19	0.15	0.17	0.20	0.25	0.17	0.18	0.13	0.21	0.05	-

A value of pairwise θ for the study locations. This measure of genetic differentiation ranges from 0 (no genetic differentiation) to 1 (populations do not share alleles).

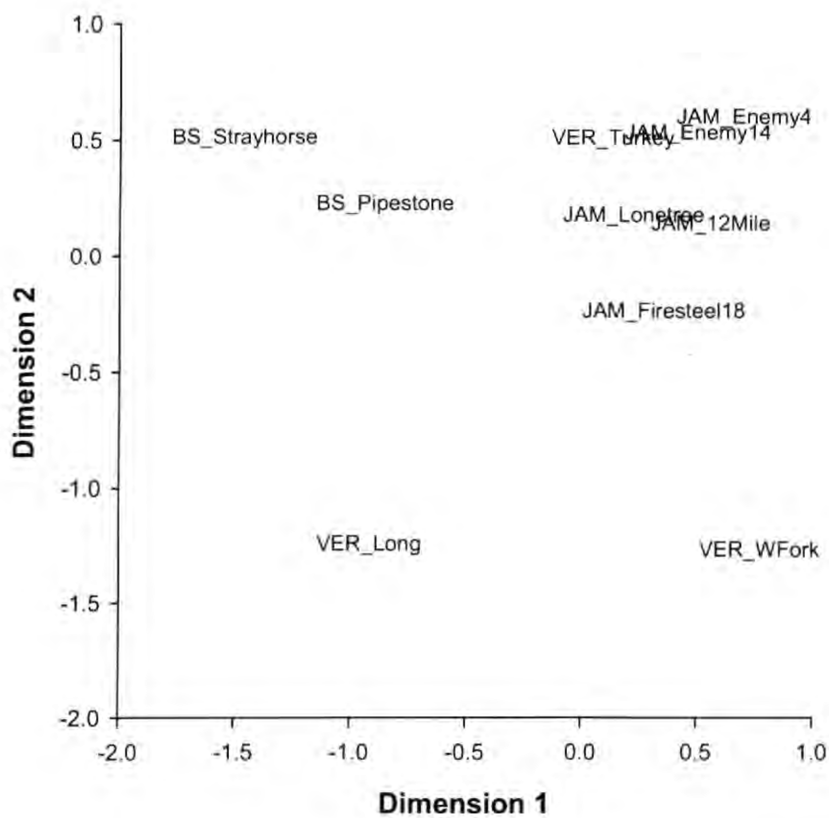

Figure 27: Multidimensional Scaling Plot of Genetic Similarities among Populations Sampled

The axes of a Multidimensional Scaling Plot are statistical abstractions and do not represent any biological or physical variable. Populations that are next to each other on this plot are genetically similar; populations that are more distant are more different genetically. Labels with the prefix "BS" are populations from the Big Sioux River. Labels with the prefix "VER" are from the Vermillion River. Labels with the prefix "JAM" are from the James River.

Analysis of genetic diversity across culverts showed mixed results (Table 16). At two locations, Lone Tree Creek and Twelvemile Creek, there were small, but statistically significant ($P < 0.05$) genetic differences above and below a culvert. At the other two pairs of study sites, there were no statistically significant genetic differences. The genetic differences observed across the Twelvemile Creek culvert contrasts with the study of fish movement (Table 8) which showed movement through this culvert. Reconciling the results is difficult, because if fish were moving between the two collection sites, we would not expect statistically significant allele frequencies at the two locations.

Table 16: Genetic Differentiation across Culverts

Location	Θ	*P* value
Lone Tree Creek	0.0245	0.005
Twelvemile Creek, #9	0.0173	0.02
Enemy Creek, #14	0.0000	0.67
Enemy Creek, #4	0.0373	0.49

Note: θ is a measure of genetic difference that ranges from 0 (no genetic differences) to 1.0 (populations share no alleles in common). The *P*-value for the null hypotheses, $\theta = 0$ is also shown.

An analysis of the distribution of genetic diversity up and down each of the three rivers did not show any evidence of population fragmentation (Table 17). If road crossings have been evolutionarily significant impediments to gene flow, population genetics theory predicts that upstream populations isolated from downstream populations should have fewer alleles than downstream populations. There was no evidence of this (Figure 28). The population with the most alleles, Long Creek in the Vermillion River, had the most alleles, and was relatively close to the Missouri River, but there was no statistically significant trend ($P = 0.39$ for a linear regression).

Table 17: Expected Heterozygosity and Average Number of Alleles

River	Location	H	N_a	Distance Upstream from Missouri River (miles)
James River	Lone tree Creek, downstream	0.44	2.66	39
	Lone tree Creek, upstream	0.40	2.68	39.1
	12 Mile Creek, #9, downstream	0.35	2.50	73
	12 Mile Creek, #9, upstream	0.46	3.28	73.1
	Enemy Creek, #14, downstream	0.35	2.56	91
	Enemy Creek, #14, upstream	0.38	2.64	91.1
	Enemy Creek, #4, downstream	0.36	4.74	97
	Enemy Creek, #4, upstream	0.32	2.38	97.1
	Firesteel Creek, #19, upstream	0.63	4.13	118
	Firesteel Creek, #18, downstream	0.35	2.49	123
Vermillion River	Long Creek	0.39	7.90	52
	Turkey Ridge Creek	0.34	2.69	48
	West Fork Vermillion	0.65	5.83	103
Big Sioux River	West Pipestone Creek	0.41	2.82	104
	Stray Horse Creek	0.31	2.09	195

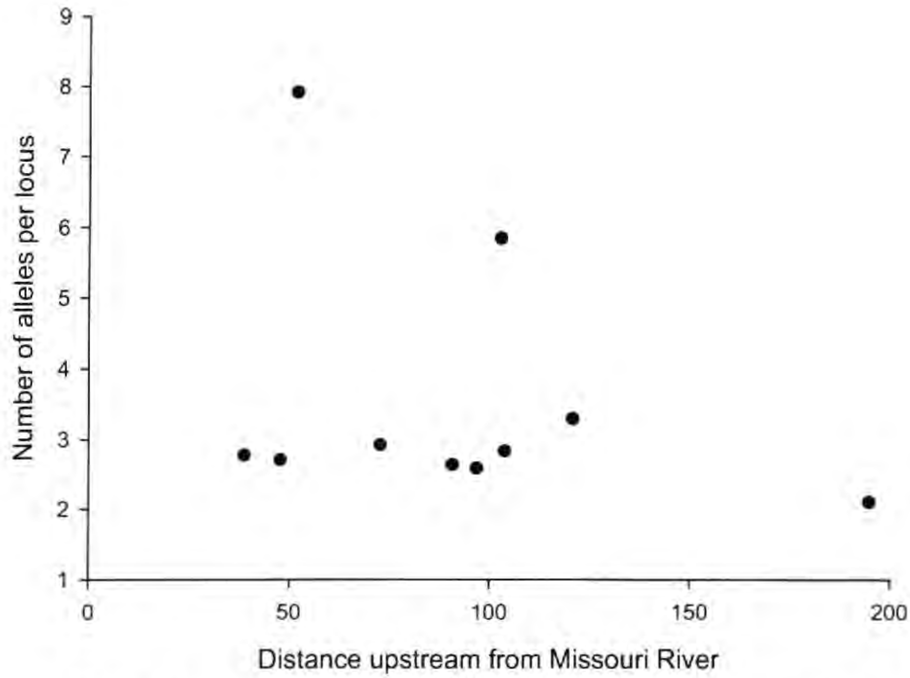

Figure 28: Average Number of Alleles per Locus Plotted Against Miles Upstream from the Missouri River

5.7 Task 9: Analyze Field and Laboratory Data to Develop a Comprehensive Model of Topeka Shiner Movement and Impacts

The discussion for this task has been grouped with others to reduce redundancy with previous data and discussions.

5.8 Task 10: Evaluate Effects of Culvert Type and Design on Movement and Distribution of Fish

Due to the limited number of Topeka shiner captured during passage experiments, this discussion will be extended to all fish species captured, and will attempt to synthesize the passage experiments with the hydrology and hydraulic measurements, and the hydraulic modeling efforts. As previously stated, overall fish movement was greater through control reaches than treatment reaches, a similar finding to other studies of warm water fish passage (Bouska and Paukert, 2009; Coffman 2005; Rajput 2003; and Warren and Pardew 1998). This finding shows that study culverts did, in general, impede movement of fish during the passage experiments.

The passage experiment conducted on Twelvemile Creek No. 9 during August 2009 showed a significant difference in the frequency of Topeka shiner passing the treatment ($n = 3$) as compared to the control ($n = 41$) indicating this structure is impeding passage at the flow rate when the experiment was performed. It is important to note; however, that some Topeka shiners were passing this culvert. The culvert is a double barrel concrete box structure. We speculate that the relatively clear water and shallow depths in this structure during the experiment may have created conditions that the Topeka shiner did not prefer to travel, a behavioral barrier so to speak, because the water depth and velocities alone should not have prevented passage.

From a hydraulics perspective, the "best" culverts for fish movement, of those studied here, appear to be large box structures set at low gradients as in the case of Enemy Creek No. 4 and 5. These structures had large water depths and very low velocities, both conditions that promote easy movement and passage of fish. In addition, the hydraulic modeling showed that these two structures were passable for the greatest amount of the measured hydrographs.

Hydraulically, the two CMPs and one SSP (Firesteel Creek No. 18 and 20, and Twelvemile Creek No. 12) were the "worst" culverts for fish movement because they were much narrower than the other structures, they had outlet drops, and they created velocities that were higher than the other types of structures. As shown in Figure 24, the two CMPs and one SSP created the highest water velocities as compared to the other structures in this study. It should be emphasized that CMP and SSP structures, if properly designed, constructed and maintained, can provide effective fish passage – they created difficult passage conditions in this study because of site specific conditions and channel degradation near them.

In extreme cases, like Lone Tree Creek No. 27, culverts are complete barriers to upstream movement of small bodied prairie fish like Topeka shiner due to excessive outlet drops (in this case greater than 2 ft). It is interesting to note that the genetics study did show small, yet statistically significant genetic differences above and below this culvert also.

Combining all of the data in this study with the findings from other fish passage studies in warm water environments indicates that, in general, culverts that are wide or wider than the stream width, and set at low gradients will provide better fish passage conditions than narrower, steep structures. Examples of the types of structures that appear to allow the most movement in this study are Enemy Creek No. 4 and 5. These structures were found to provide the most passable flows using the FishXing model with the user defined rating curve. In addition, the genetics study at Enemy Creek No. 4 did not show any statistically significant genetic differences above and below this culvert.

5.9 Summary of Findings and Conclusions

There are several important findings and conclusions that are re-stated here. The study culverts did impede fish movement for many different fish species, including Topeka shiner. However, in all fish passage experiments, some fish did move through study culverts indicating that none of them were total barriers to upstream fish movement. In four cases with sufficient numbers of fish in a species ($n>4$), a species (green sunfish, johnny darter, orange spotted sunfish and black bullhead) moved through the control but did not move through the treatment.

Topeka shiner were documented passing through three different culvert study sites with water depths ranging between 0.15 ft and 1.51 ft, average water velocities ranging between 0.03 ft/s and 2.6 ft/s, outlet drops up to 0.1 ft, culvert slopes between 0.55% and 2.12%, and lengths from 53 ft to 70.3 ft. These culverts consisted of concrete box, corrugated metal pipe and structural steel plate materials.

From a hydraulics perspective, the "best" culverts for fish movement, of those studied here, appear to be large structures set at low gradients as in the case of Enemy Creek No. 4 and 5. These structures had large water depths and very low velocities, both conditions that promote easy movement and passage of fish. In addition, the hydraulic modeling showed that these two structures were passable for the greatest amount of the measured hydrographs.

Hydraulically, the two CMPs and one SSP (Firesteel Creek No. 18 and 20, and Twelvemile Creek No. 12) were the "worst" culverts for fish movement because they were much narrower than the other structures, they had outlet drops, and they created velocities that were higher than the other types of structures. As shown in Figure 24, the two CMPs and one SSP created the highest water velocities as compared to the other structures in this study. It should be emphasized that CMP and SSP structures, if properly designed, constructed and maintained, can provide effective fish passage – they created difficult passage conditions in this study because of site specific conditions and channel degradation near them.

The genetic study showed that there was moderate genetic differentiation between populations with a tendency for populations to be genetically similar to other populations in their drainage. At specific culvert sites, two cases showed statistically significant genetic differences above and below culverts and two did not.

6 IMPLEMENTATION RECOMMENDATIONS

Although the original intent of this study was to investigate potential issues related to Topeka shiner passage, we have included recommendations based on information from other species studied during this project. Key implementation recommendations include the following:

1) SDDOT should design new culvert installations in streams within critical Topeka shiner habitat to span the entire stream channel (specifically stated the structure should be at least as wide as 1.2 times the stream channel bankfull width) and provide a natural stream substrate through the structure. The preferred design approach is described in the SDDOT document titled: "Fish Passage Guidelines for Culvert Projects Impacting the Topeka shiner or Other Fishery Resources". This recommendation is based in part upon the hydraulic data and hydraulic modeling activities, which indicated that wider structures set at grade and deep within the stream provided the best movement potential (i.e. sufficient water depth, no outlet drop and low water velocities). Specific examples of this type of installation from this project include the large concrete box culverts at Enemy Creek No. 4 and 5. Other types of structures, such as CMP or SSP, can be used to provide fish passage in this manner as long as they are designed and constructed according to the guidelines specified in the aforementioned document. These design recommendations are similar to those used in other states or regions (Bates 2003; USDA-Forest Service 2008).

2) SDDOT should inventory all culverts on streams with Topeka shiner and prioritize barrier crossings for removal or replacement. The prioritization developed by Wall and Berry (2002) should be considered as a basis for developing a final prioritization method. Prioritization should be done on a watershed basis by considering all crossings collectively when making potential removal or replacement decisions. Additional methods for prioritizing barrier culverts have been developed by other states and should also be consulted during development of the final prioritization scheme (Washington Department of Fish and Wildlife 2000; O'Hanley and Tomberlin 2005).

3) If SDDOT or other agencies use FishXing to assess whether a road culvert is a potential barrier to fish passage, the user-defined tailwater rating curve method should be used in developing the model and assessing the structure. This method was found in this study to more accurately predict the hydraulic conditions at the outlet and within culverts. The tailwater channel cross section method, which uses uniform flow theory to calculate the rating curve as compared to the user-defined method which relies upon establishing it through field measurements, consistently overestimated the outlet drop, which in turn resulted in some crossings being identified as an outlet drop barrier when they actually had little to no outlet drop as measured in the field.

4) SDDOT and other interested agencies should consider future research that investigates Topeka shiner passage during high flow periods. The methods used in this study for the direct passage experiments are not implementable at high flow periods. Topeka shiners can spawn during months with large flows, therefore a high-flow study would shed more light on fish passage during some of the prolonged high water events such as those caused by the large rain storms that frequently occur in eastern South Dakota. To implement this study, SDDOT should research emerging tagging technologies for small-bodied fish. If the technology exists, a small passive integrated transponder (PIT) tag (or something similar) could be inserted into Topeka shiners and surrogate

species. Antennae placed at the upstream and downstream ends of selected culverts and in control reaches could record the time that tagged fish moved through those areas. At the same time, continuous measurements of water flow, velocity and depths could be recorded to define the hydraulic environments during which fish successfully pass or are unable to pass through culverts. For an example of how this type of study could be implemented see Cahoon et al. (2007). That study used PIT tags in rainbow and cutthroat trout to monitor their movements through five culverts during high flows.

5) SDDOT should implement a culvert monitoring program to determine how culverts installed following the guidance in "Fish Passage Guidelines for Culvert Projects Impacting the Topeka shiner or Other Fishery Resources" perform. This program should be developed in consultation with Wayne Stancill of the USFWS and other fish passage practitioners.

7 ANALYSIS OF RESEARCH BENEFITS

There are a couple key benefits of this research and its findings.

Based on the research, there is evidence that older crossing structures, in general, have not entirely interfered with Topeka shiner or other warm water fish species movements in the study streams. It should be pointed out that this is a general statement that should not be taken to mean that all culvert crossings, from a fish passage standpoint, are performing well, but rather that many seem to be providing sufficient fish passage during the time that this study was performed. This benefit may mean that some of the immediate pressure to replace many of the older crossings can be relaxed and efforts could be focused on identifying the crossings that are likely total barriers and focusing replacement efforts on them.

The research also indicates that SDDOT's new culvert design plans should create conditions that will allow safe passage of Topeka shiner and other warm water fish species.

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APPENDIX A: SITE PHOTOGRAPHS

Figure 29: Upstream Side of Enemy Creek No. 4 Study Site

Figure 30: Upstream Side of Enemy Creek No. 5 Study Site

Figure 31: Upstream Side of Enemy Creek No. 14 Study Site

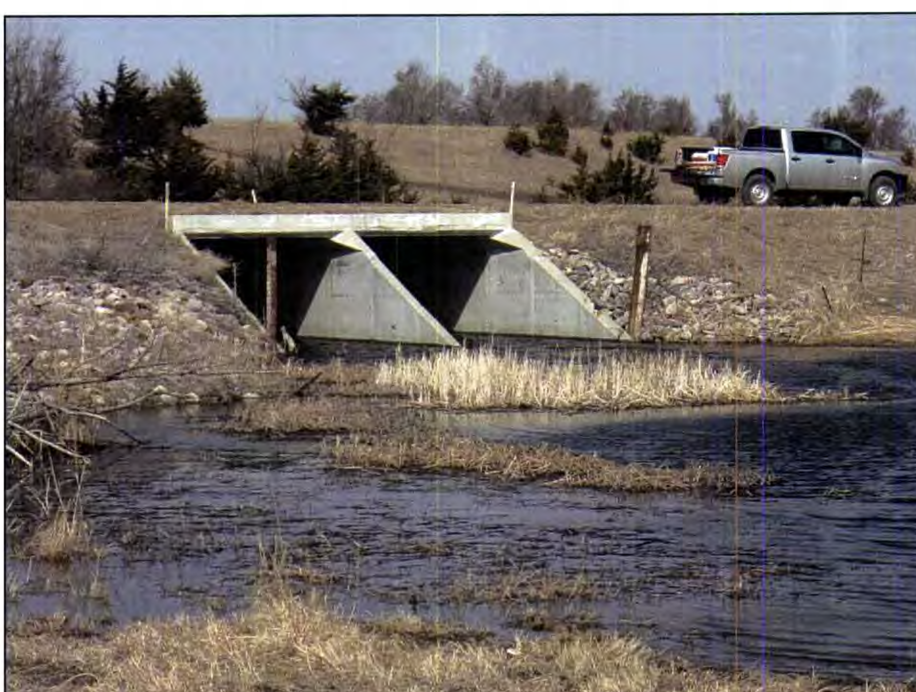

Figure 32: Downstream End of Twelvemile Creek No. 9 Study Site

Figure 33: Downstream End of Twelvemile Creek No. 12 Study Site

Figure 34: Downstream End of Lone Treek Creek No. 27 Study Site

Figure 35: Downstream End of Firesteel Creek No. 18 Study Site

Figure 36: Downstream End of Firesteel Creek No. 19 Study Site

Figure 37: Downstream End of Firesteel Creek No. 20 Study Site

APPENDIX B: SPECIES COMPOSITION IN PASSAGE EXPERIMENTS

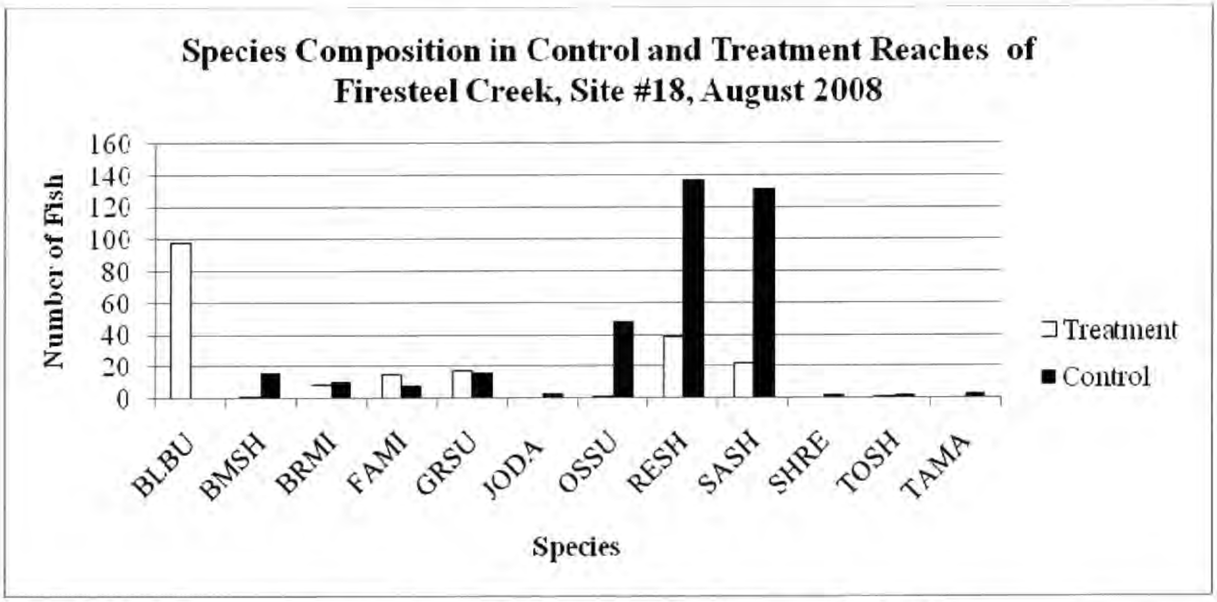

Figure 38: Species Composition in Firesteel Creek #18

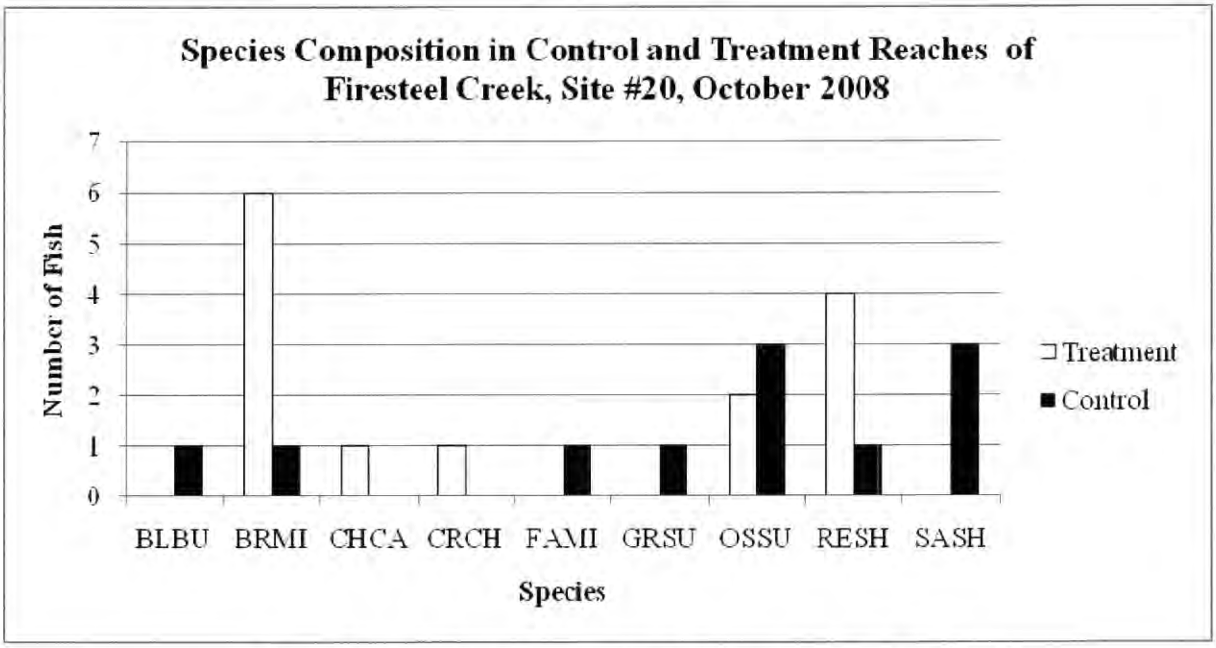

Figure 39: Species Composition in Firesteel Creek #20

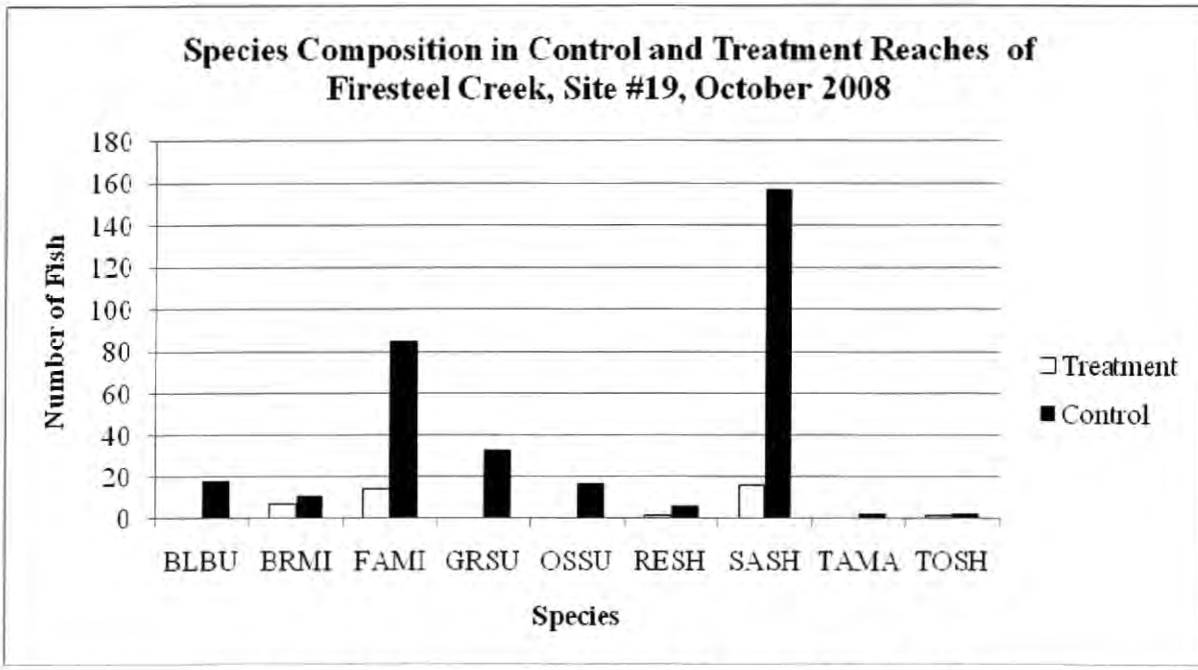

Figure 40: Species Composition in Firesteel Creek #19

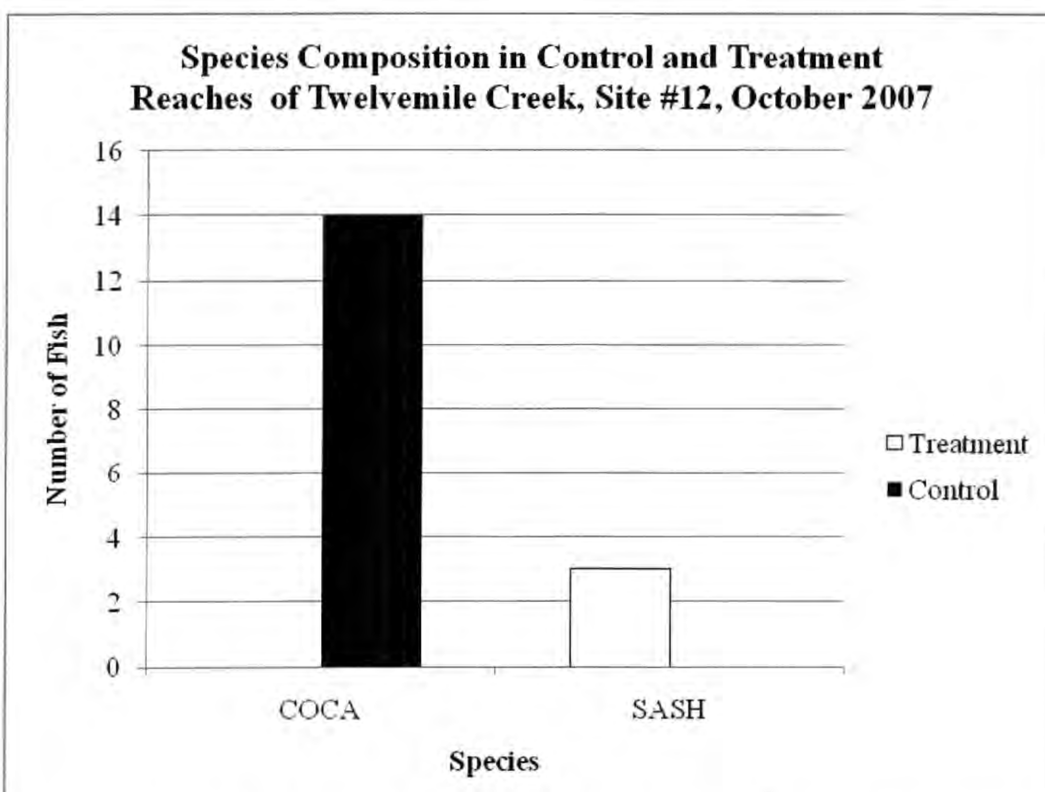

Figure 41: Species Composition in Twelvemile Creek #12

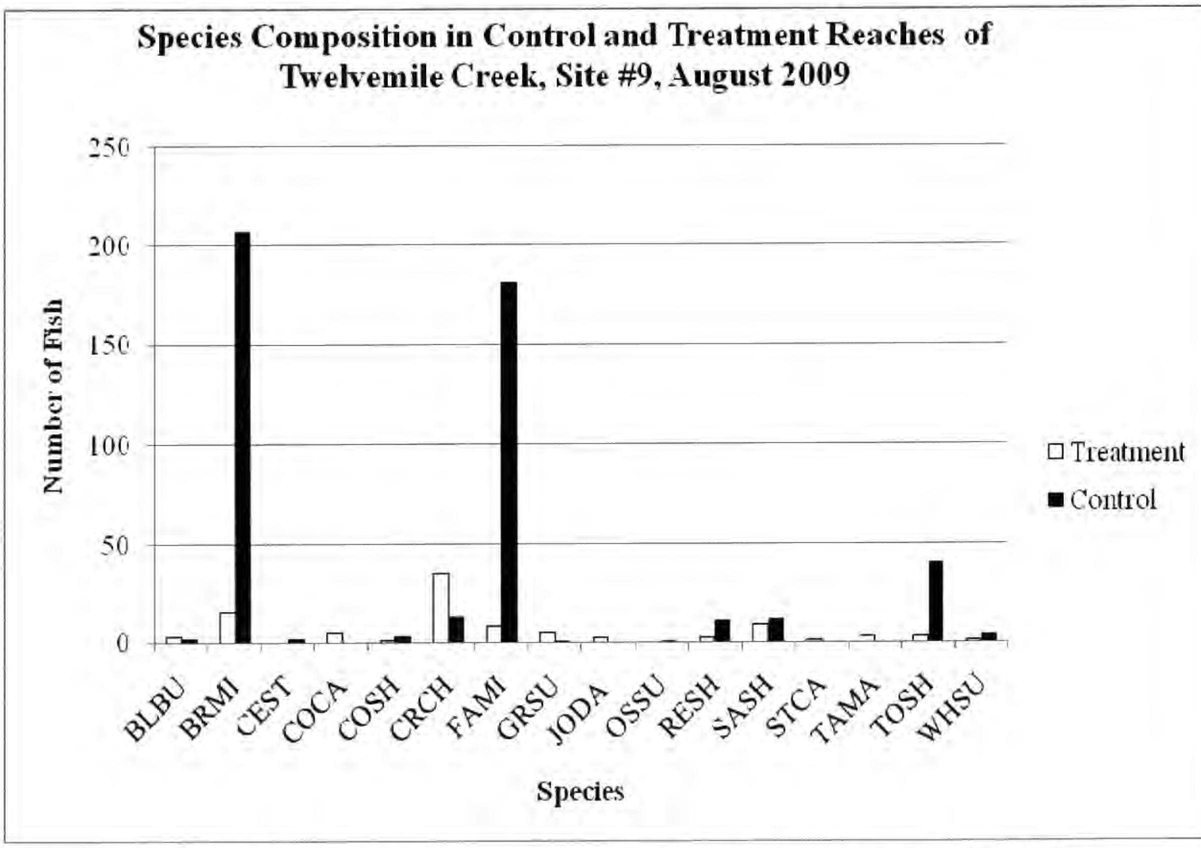

Figure 42: Species Composition in Twelvemile Creek #9, August 2009

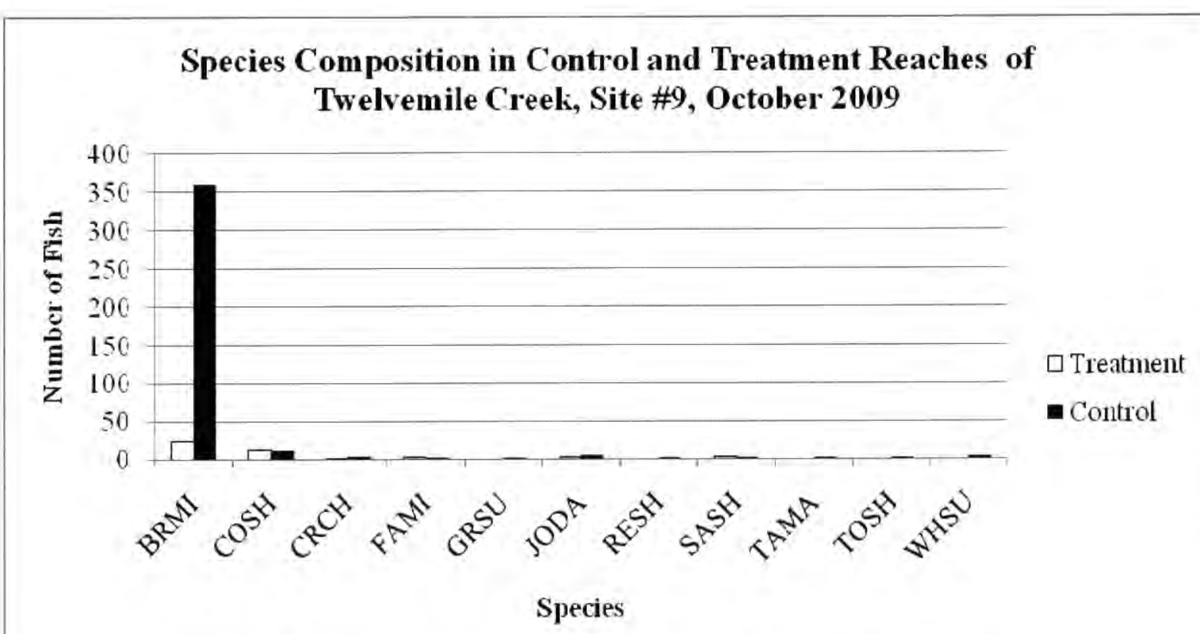

Figure 43: Species Composition in Twelvemile Creek #9, October 2009

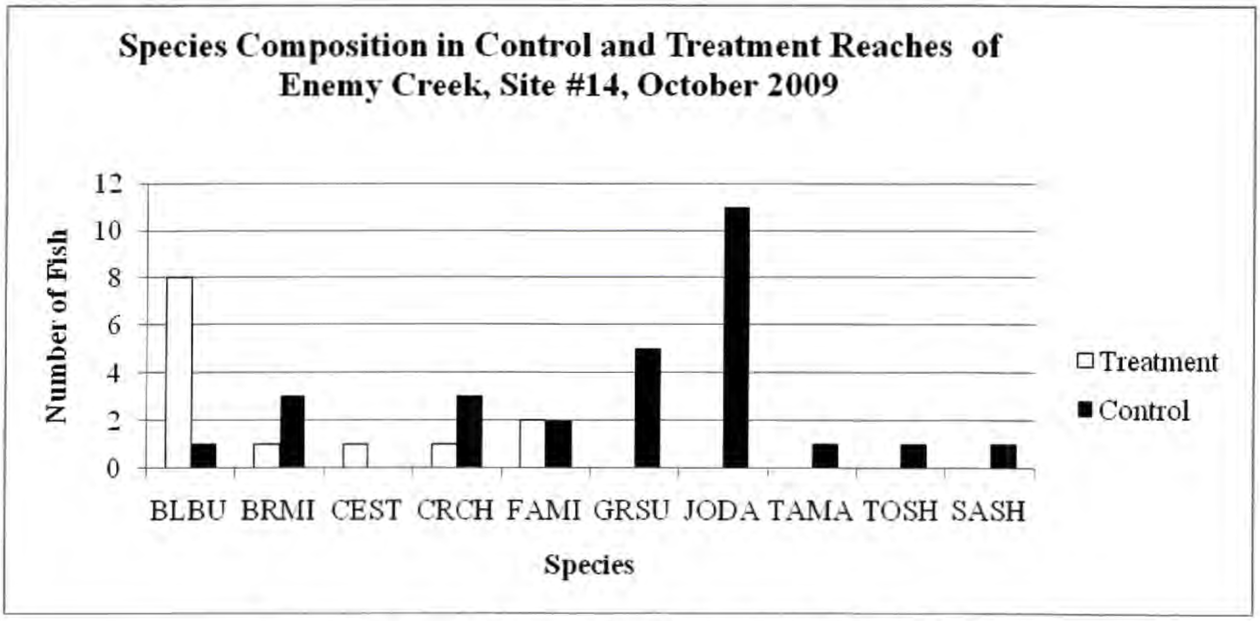

Figure 44: Species Composition in Twelvemile Creek #14

APPENDIX C: HYDROGRAPHS AND THERMOGRAMS FOR STUDY CULVERTS

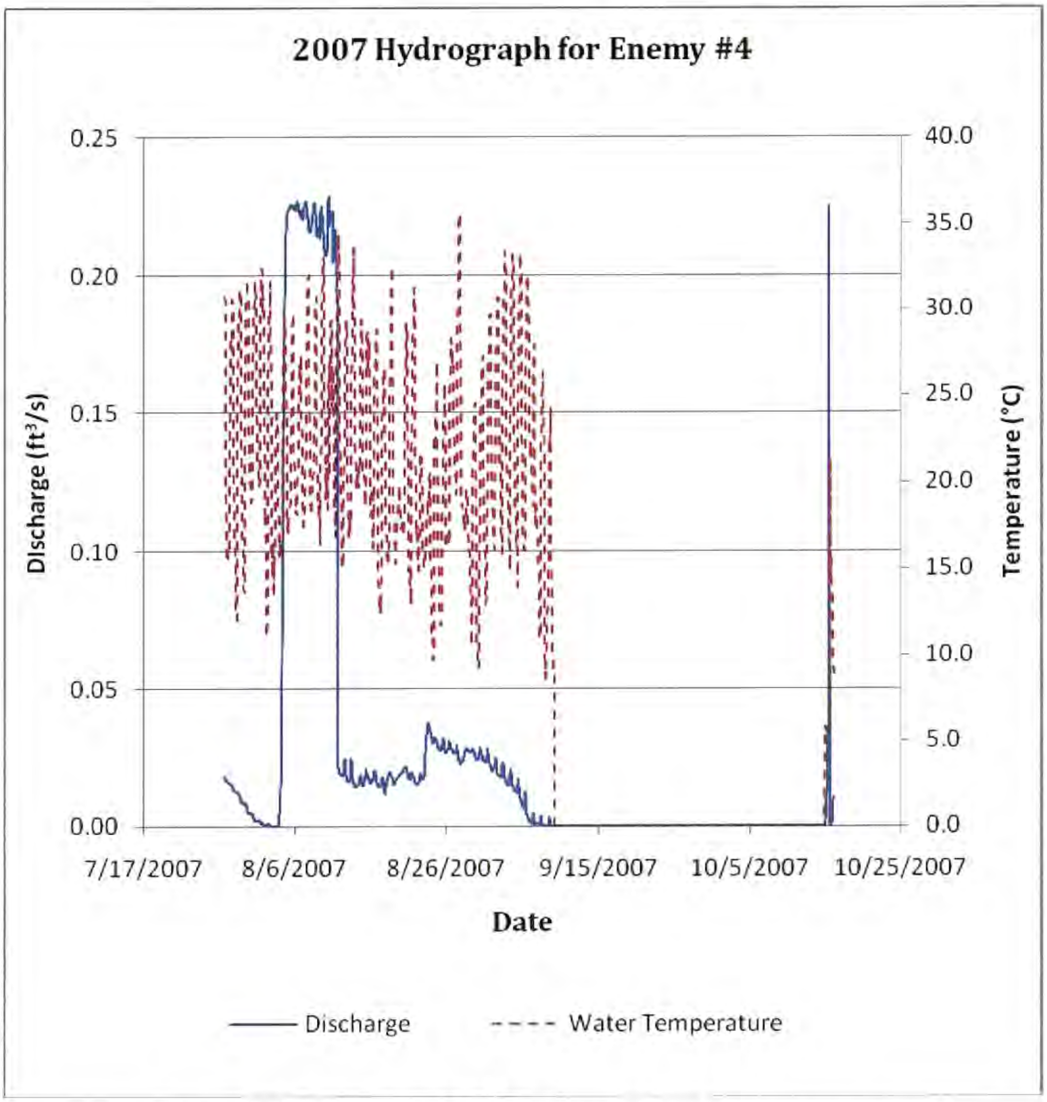

Figure 45: Enemy #4 2007 Hydrograph and Thermogram

Modeling estimated structure as a depth barrier at less than 0.17 cfs. Modeling estimated it as passable at all other flows.

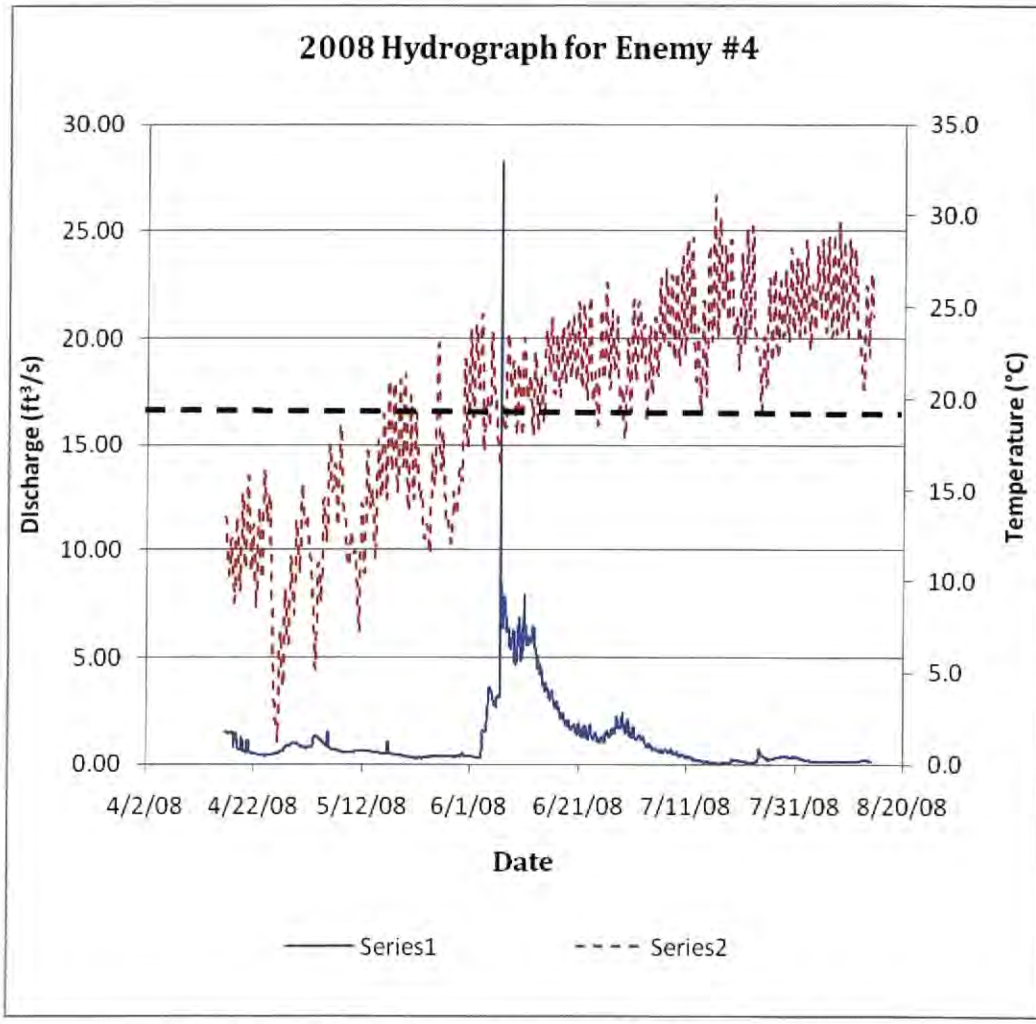

Figure 46: Enemy #4 2008 Hydrograph and Thermogram

Modeling estimated structure to be a depth barrier at less than 0.17 cfs and a velocity barrier at flows greater than dashed line. Modeling estimated it to be passable at all flows in between.

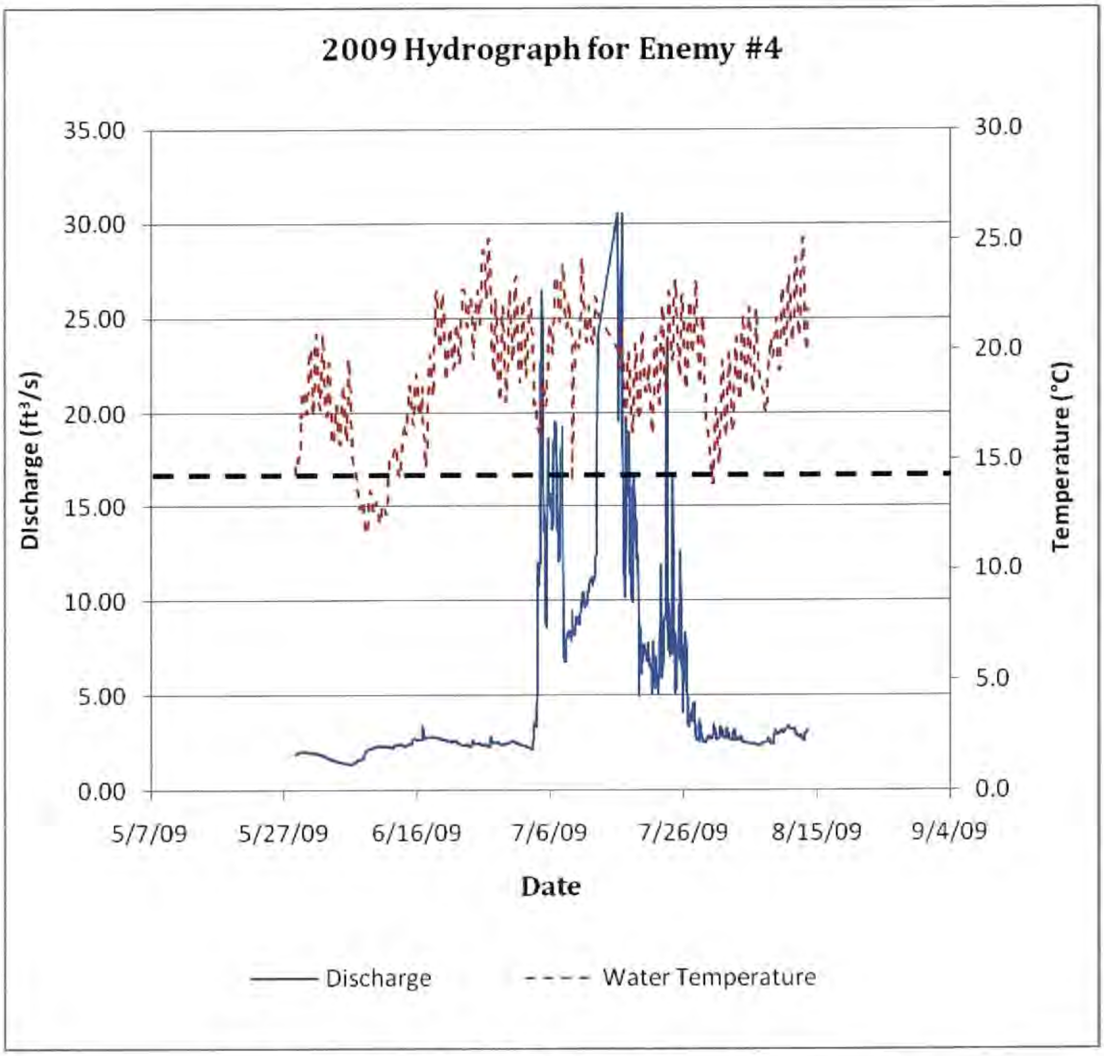

Figure 47: Enemy #4 2009 Hydrograph and Thermogram

Modeling estimated structure to be a depth barrier at less than 0.17 cfs and a velocity barrier at flows greater than the dashed line. Modeling estimated it as passable in between.

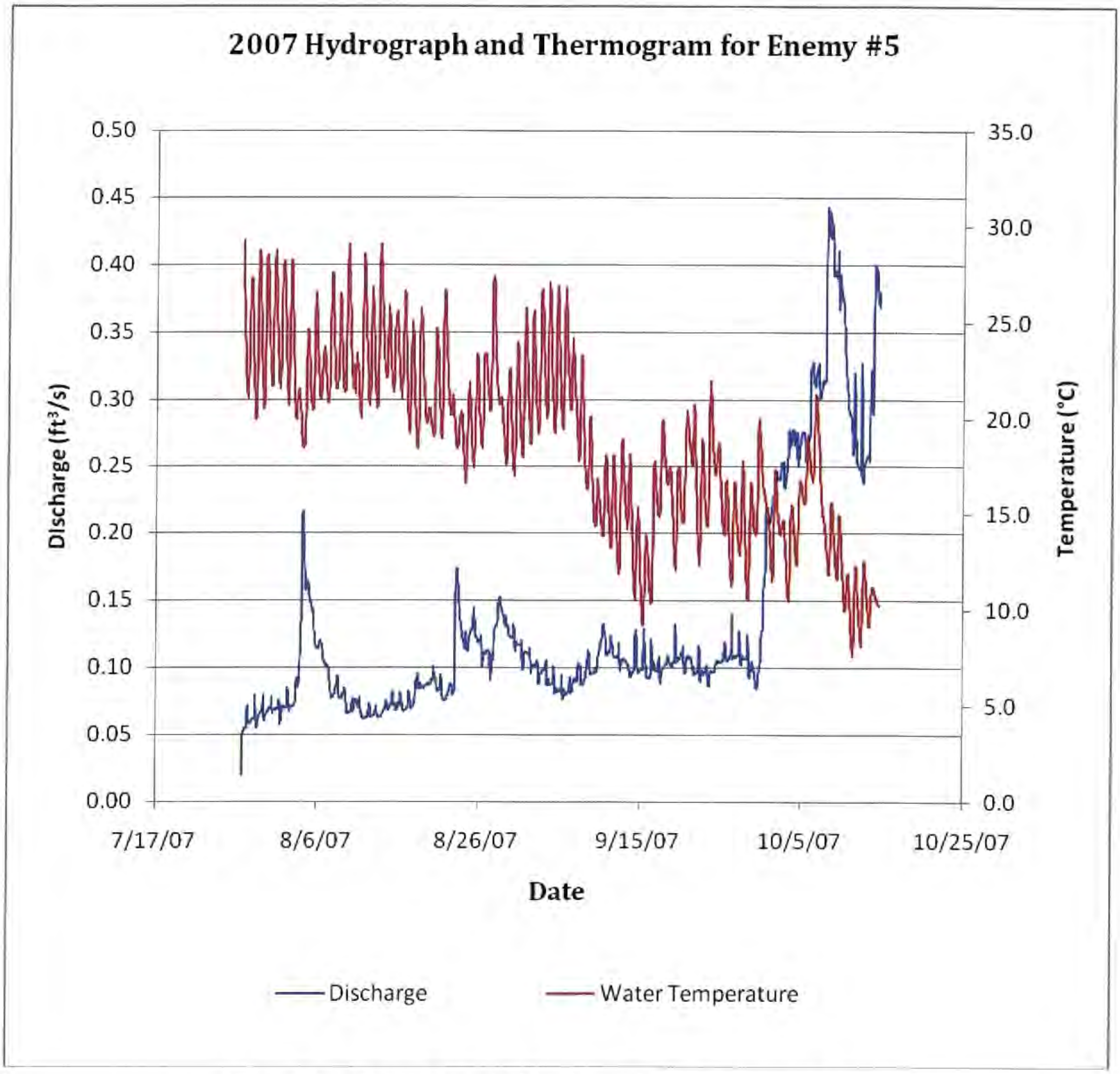

Figure 48: Enemy #5 2007 Hydrograph and Thermogram

Modeling estimated structure to be passable at all flows.

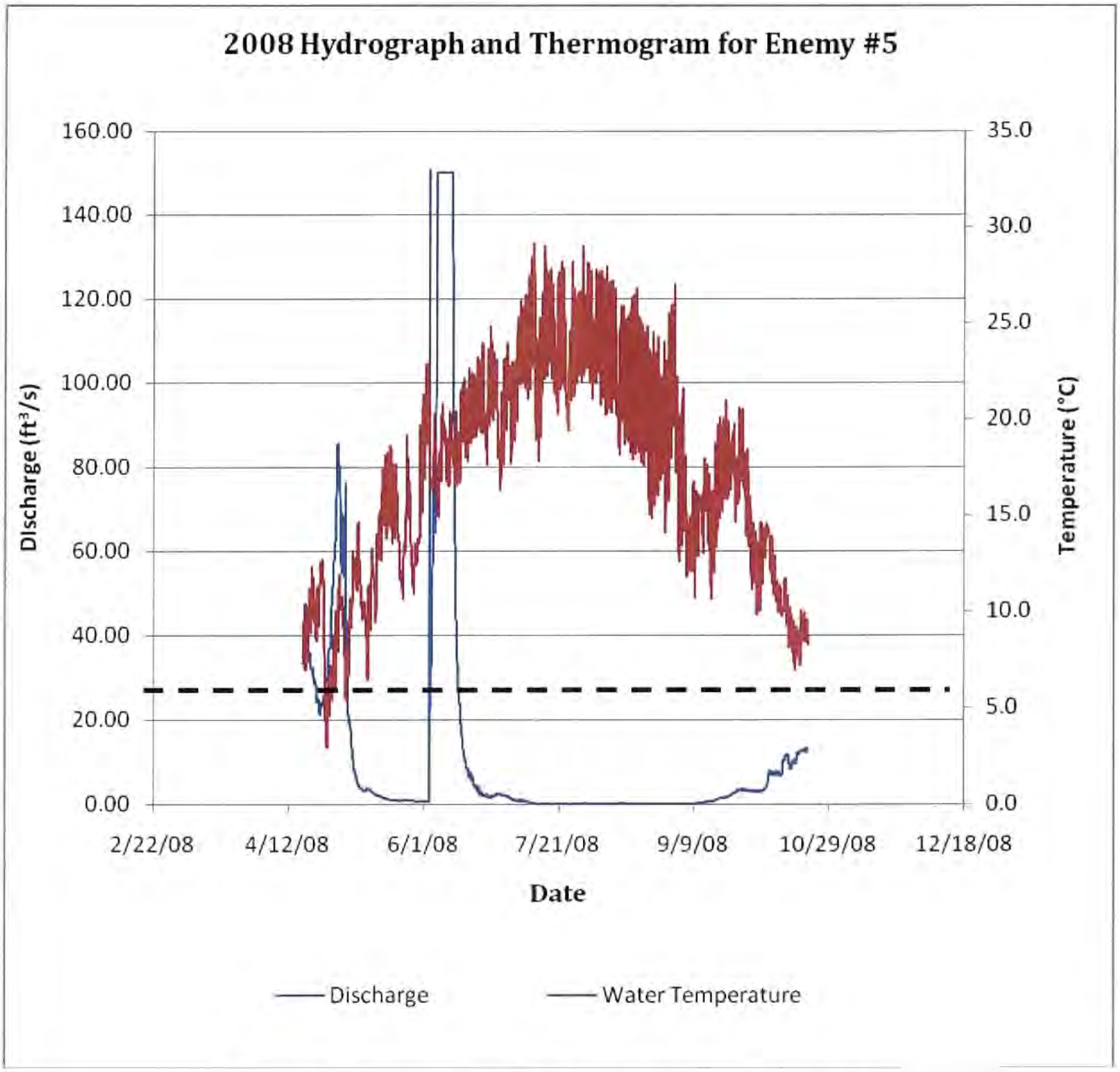

Figure 49: Enemy #5 2008 Hydrograph and Thermogram

Modeling estimated structure to be passable at all flows.

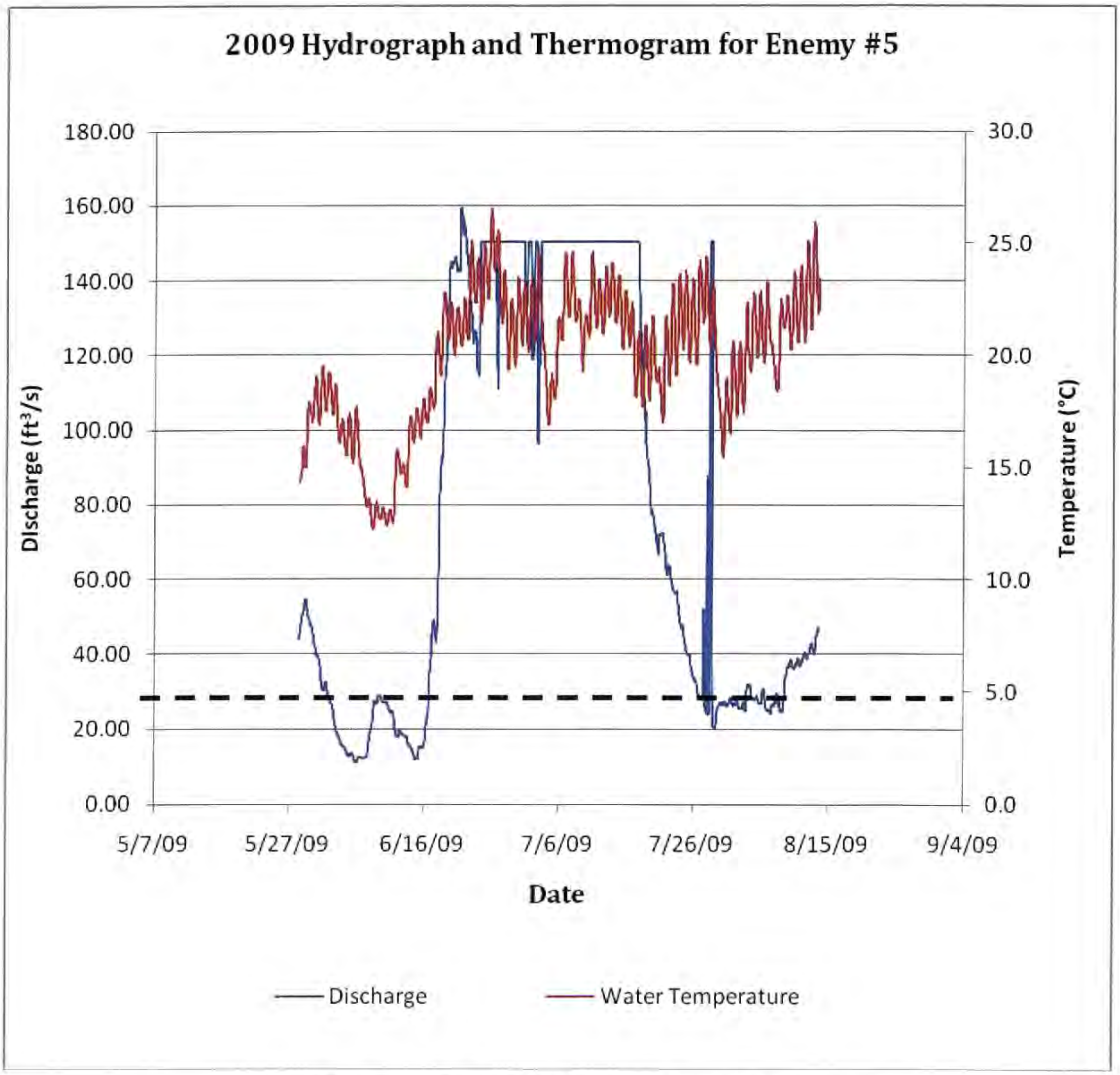

Figure 50: Enemy #5 2009 Hydrograph and Thermogram

Modeling estimated structure to be passable at all flows.

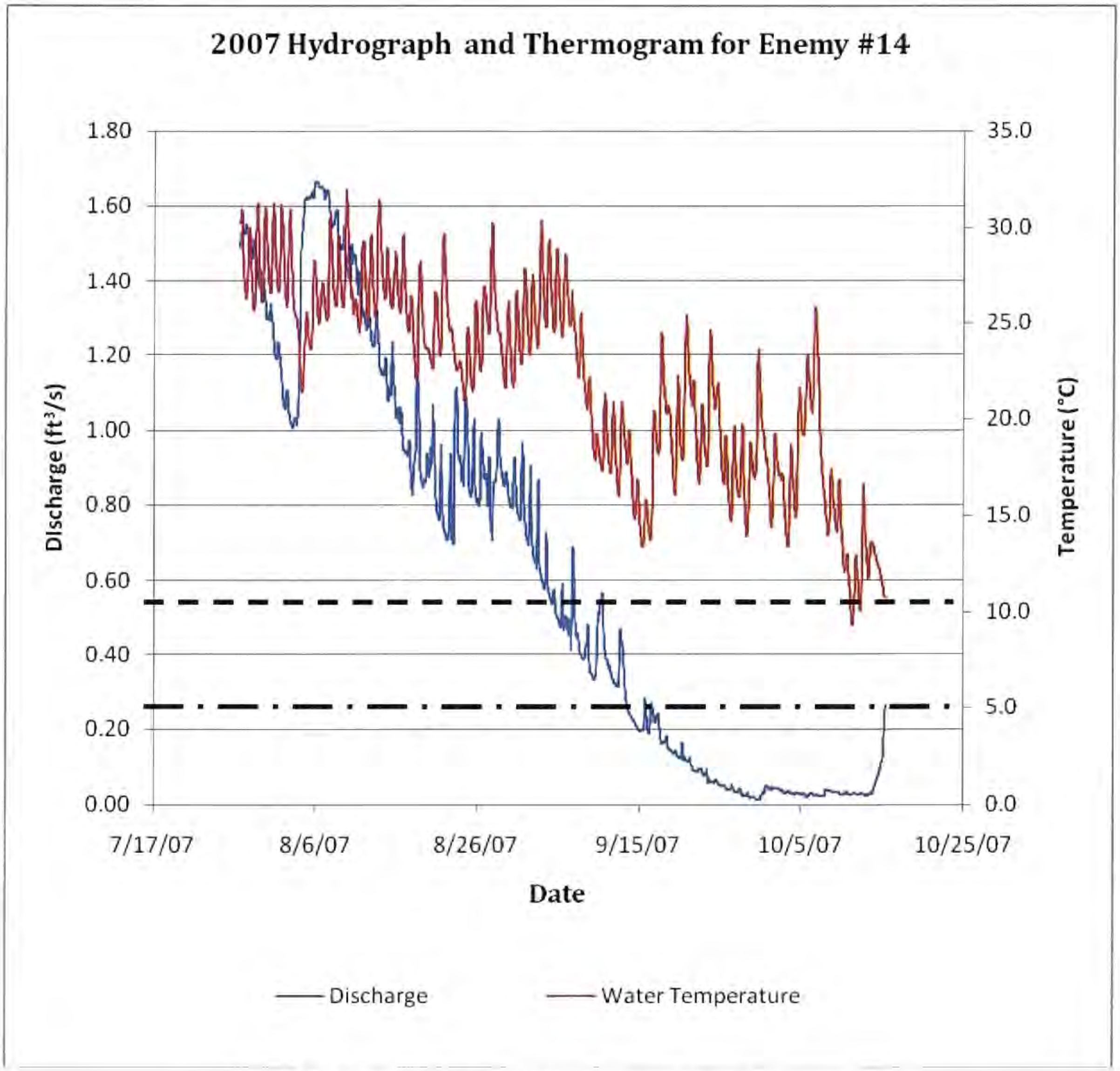

Figure 51: Enemy #14 2007 Hydrograph and Thermogram

Modeling estimated structure to be a depth barrier at flows less than dash-dot line and velocity barrier at flows greater than the dashed line. Modeling estimated it to be passable at flows between the two lines.

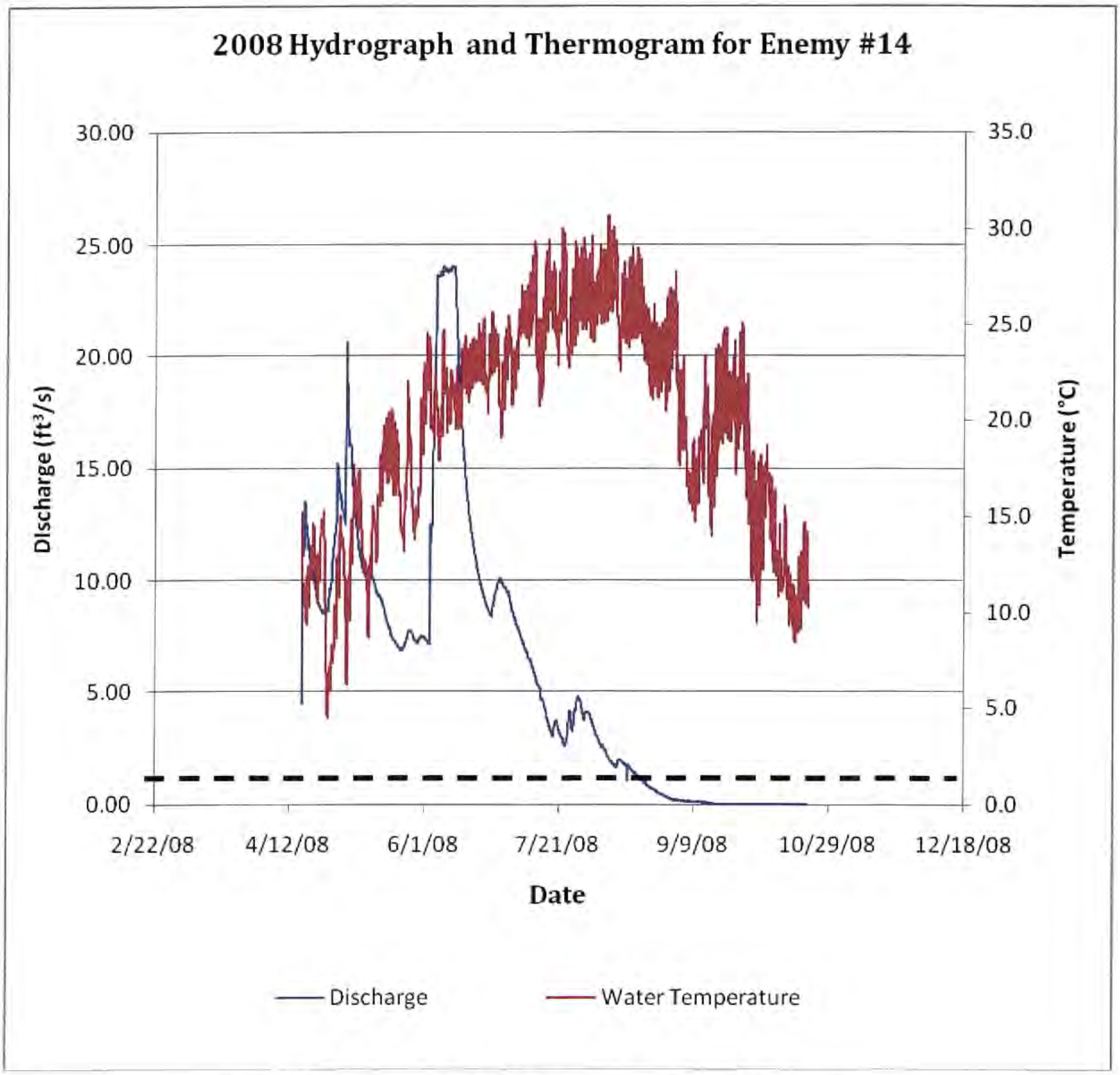

Figure 52: Enemy #14 2008 Hydrograph and Thermogram

Modeling estimated structure to be a velocity barrier at flows greater than the dashed line and passable at flows less than the dashed line.

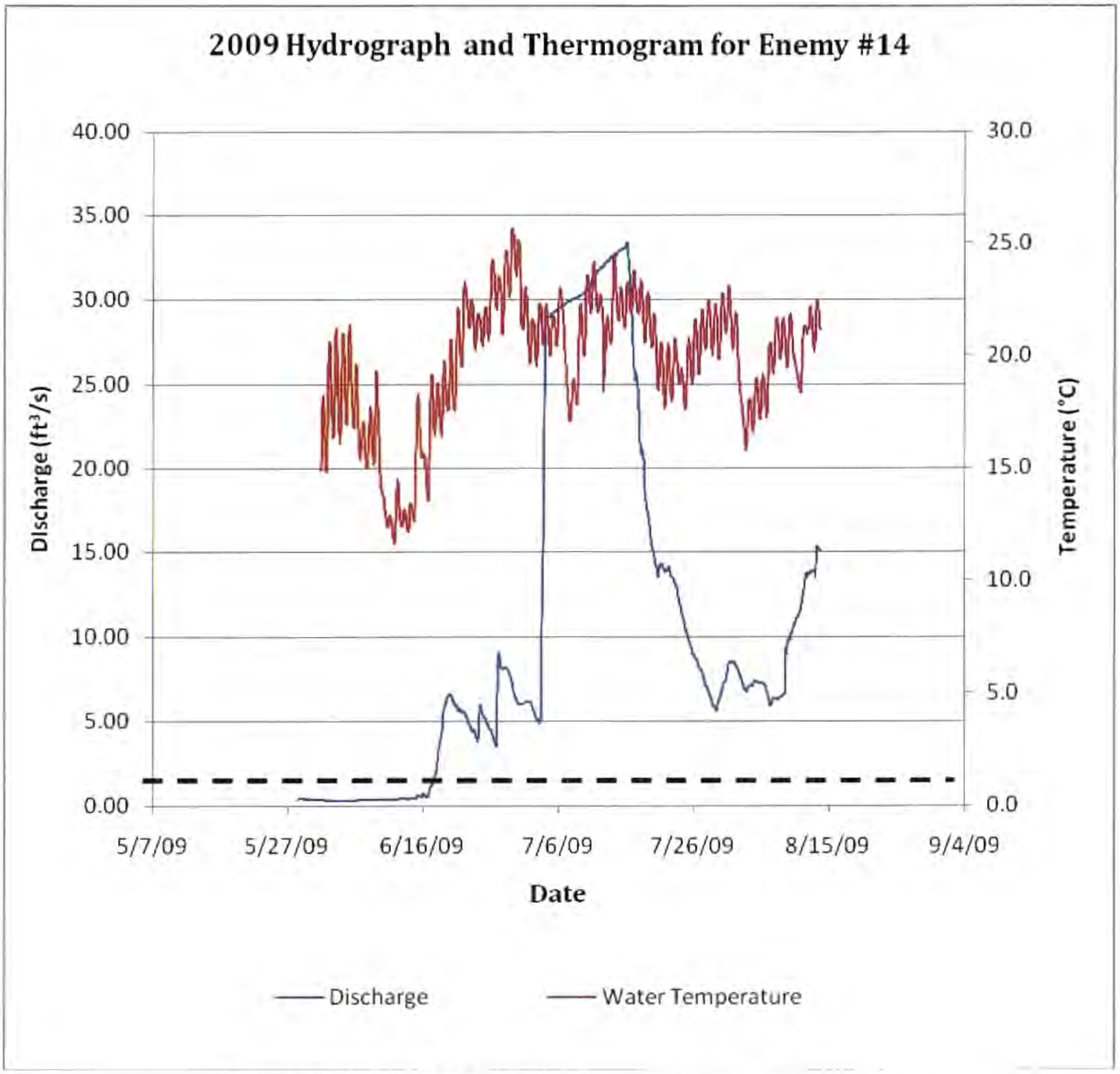

Figure 53: Enemy #14 2009 Hydrograph and Thermogram

Modeling estimated structure to be a velocity barrier at flows greater than the dashed line and passable at flows less than the dashed line.

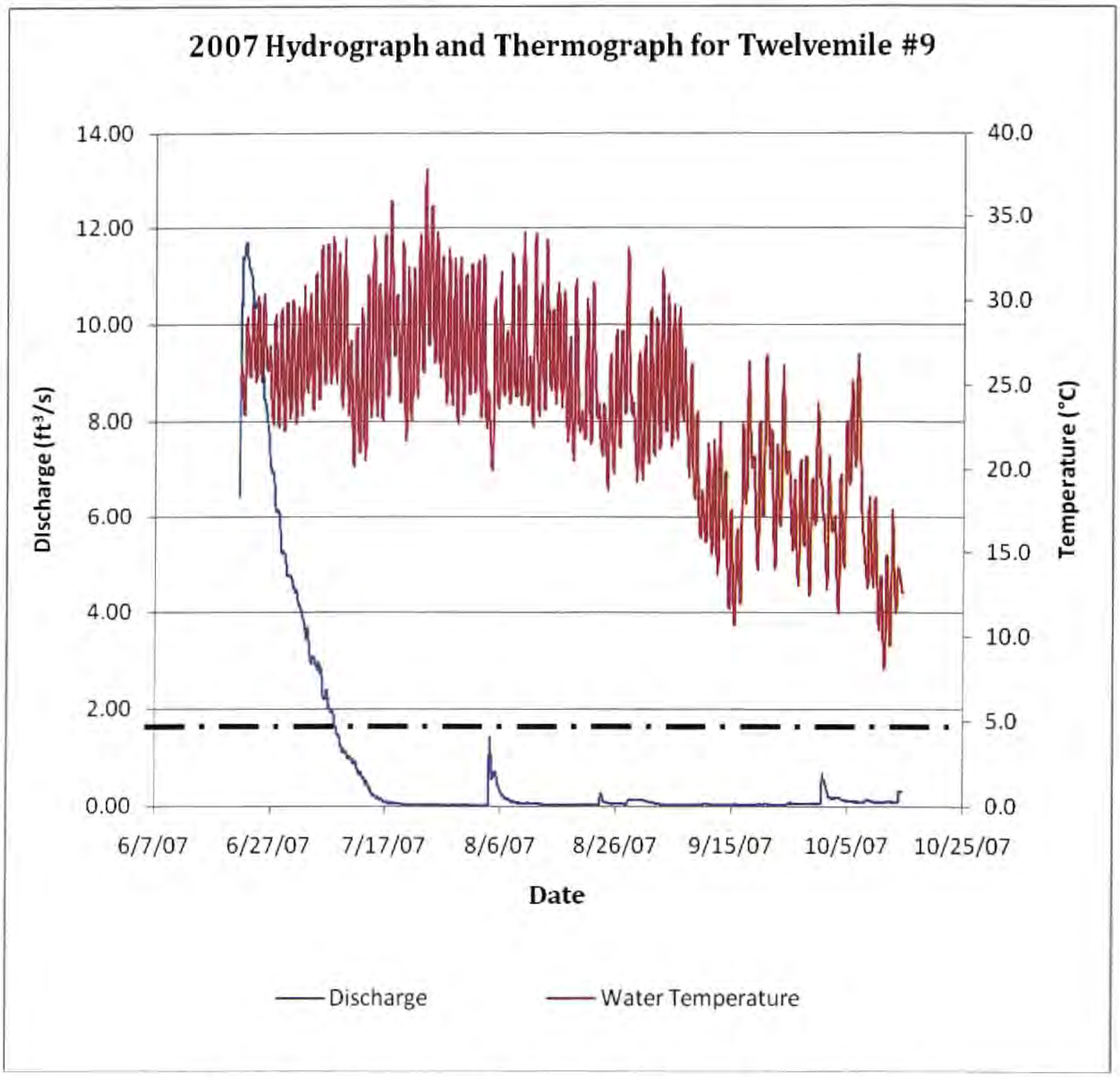

Figure 54: Twelvemile #9 2007 Hydrograph and Thermogram

Modeling estimated structure to be a depth barrier at flows less than the dash-dot line and passable at all other flows.

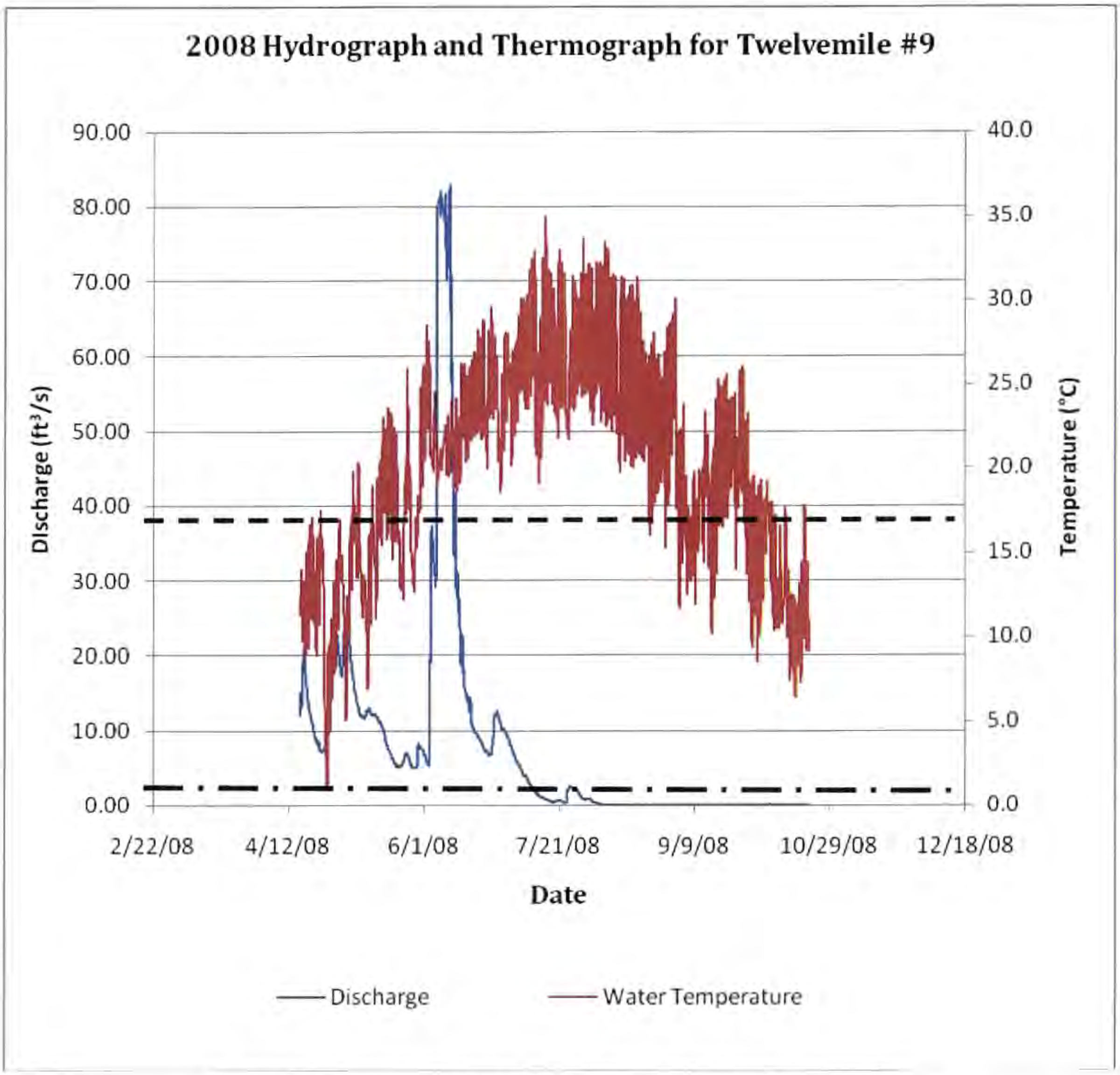

Figure 55: Twelvemile #9 2008 Hydrograph and Thermogram

Modeling estimated structure to be a depth barrier at flows less than the dash-dot line and a velocity barrier at flows greater than the dashed line. Modeling estimated it to be passable in between.

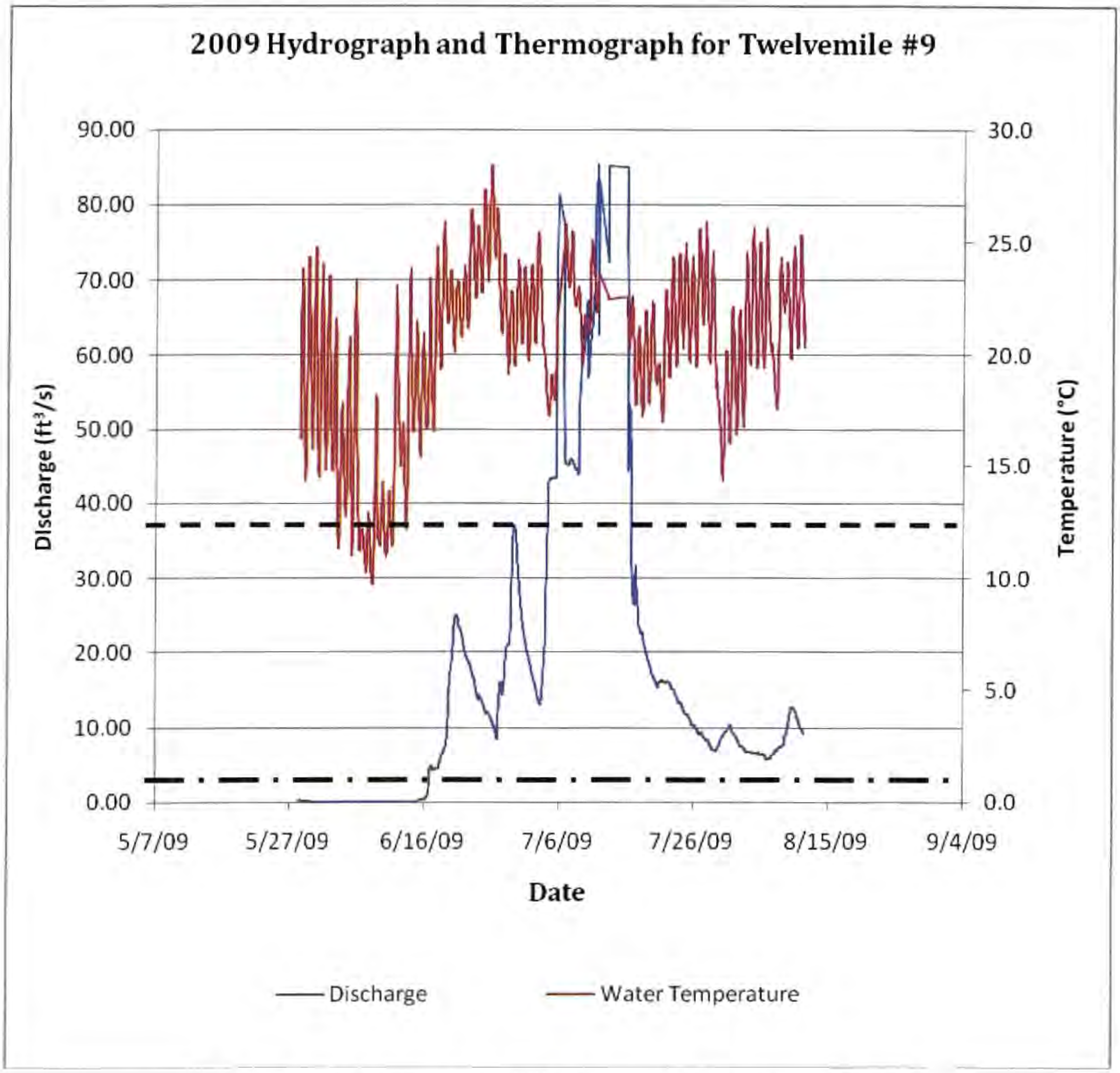

Figure 56: Twelvemile #9 2009 Hydrograph and Thermogram

Modeling estimated structure as a depth barrier at flows less than the dash-dot line and a velocity barrier at flows greater than the dashed line. Modeling estimated it to be passable in between.

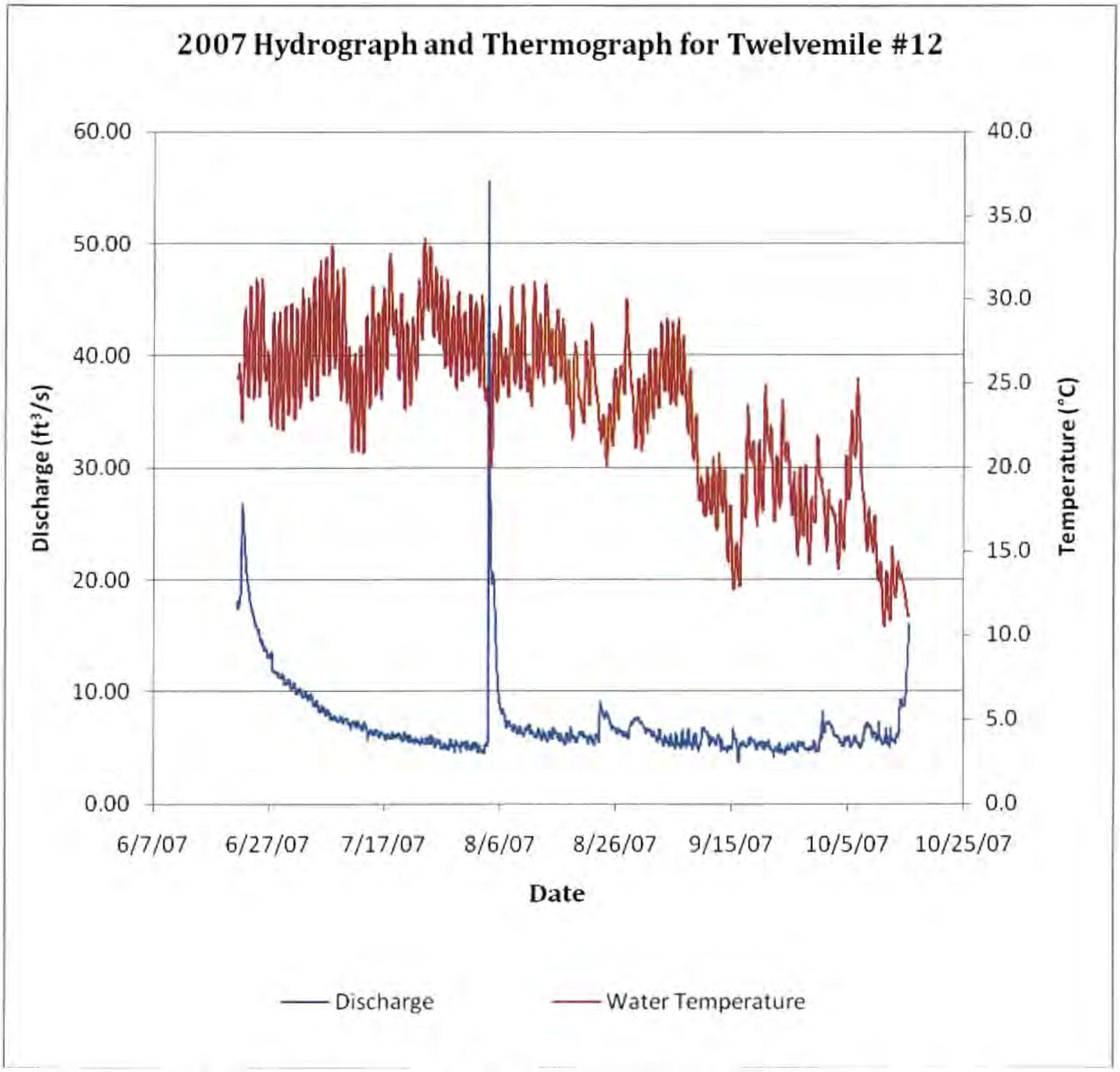

Figure 57: Twelvemile #12 2007 Hydrograph and Thermogram

Modeling estimated no passage through this structure.

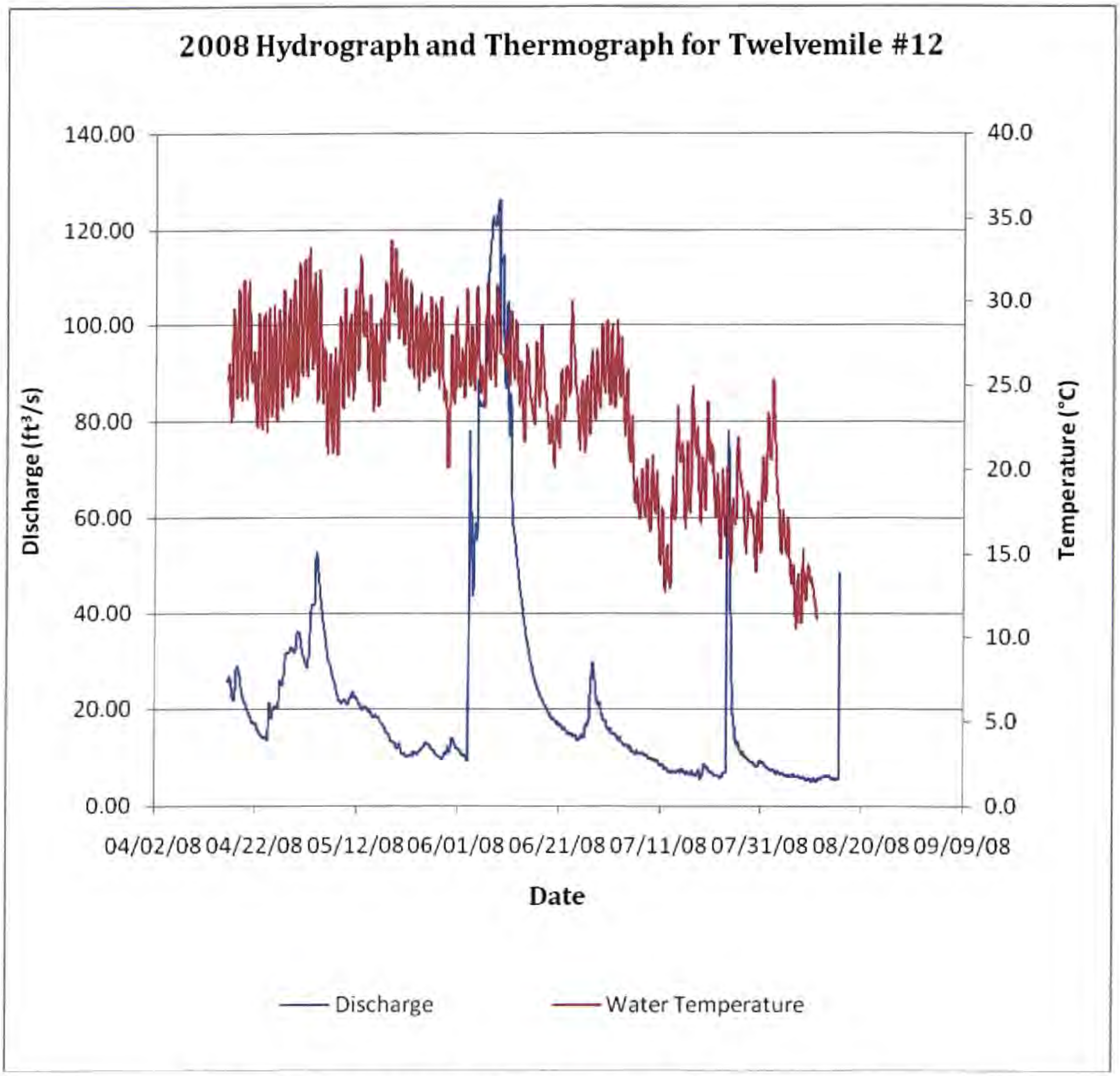

Figure 58: Twelvemile #12 2008 Hydrograph and Thermogram

Modeling estimated no passage through this structure.

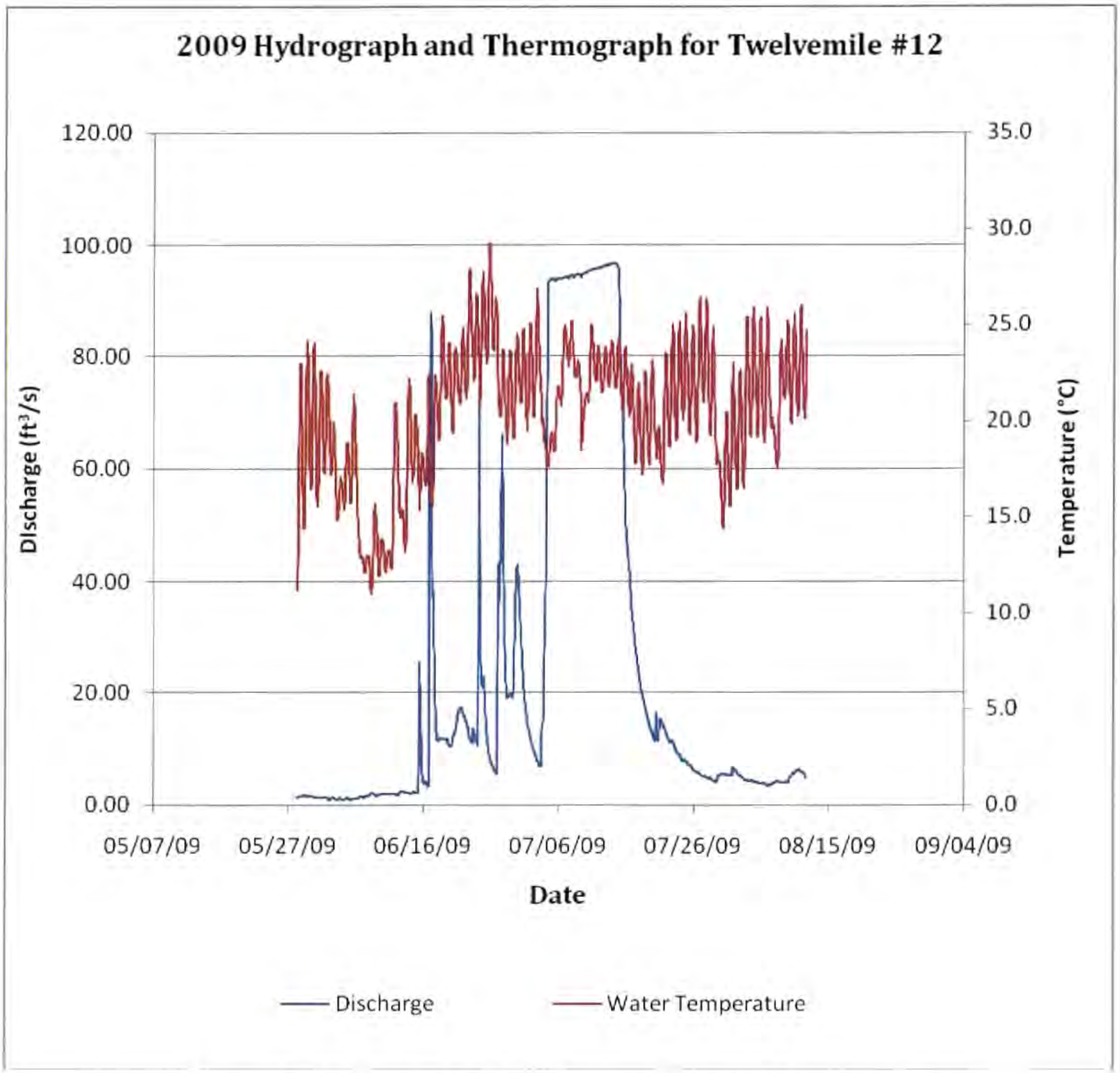

Figure 59: Twelvemile #12 2009 Hydrograph and Thermogram

Modeling estimated no passage through this structure.

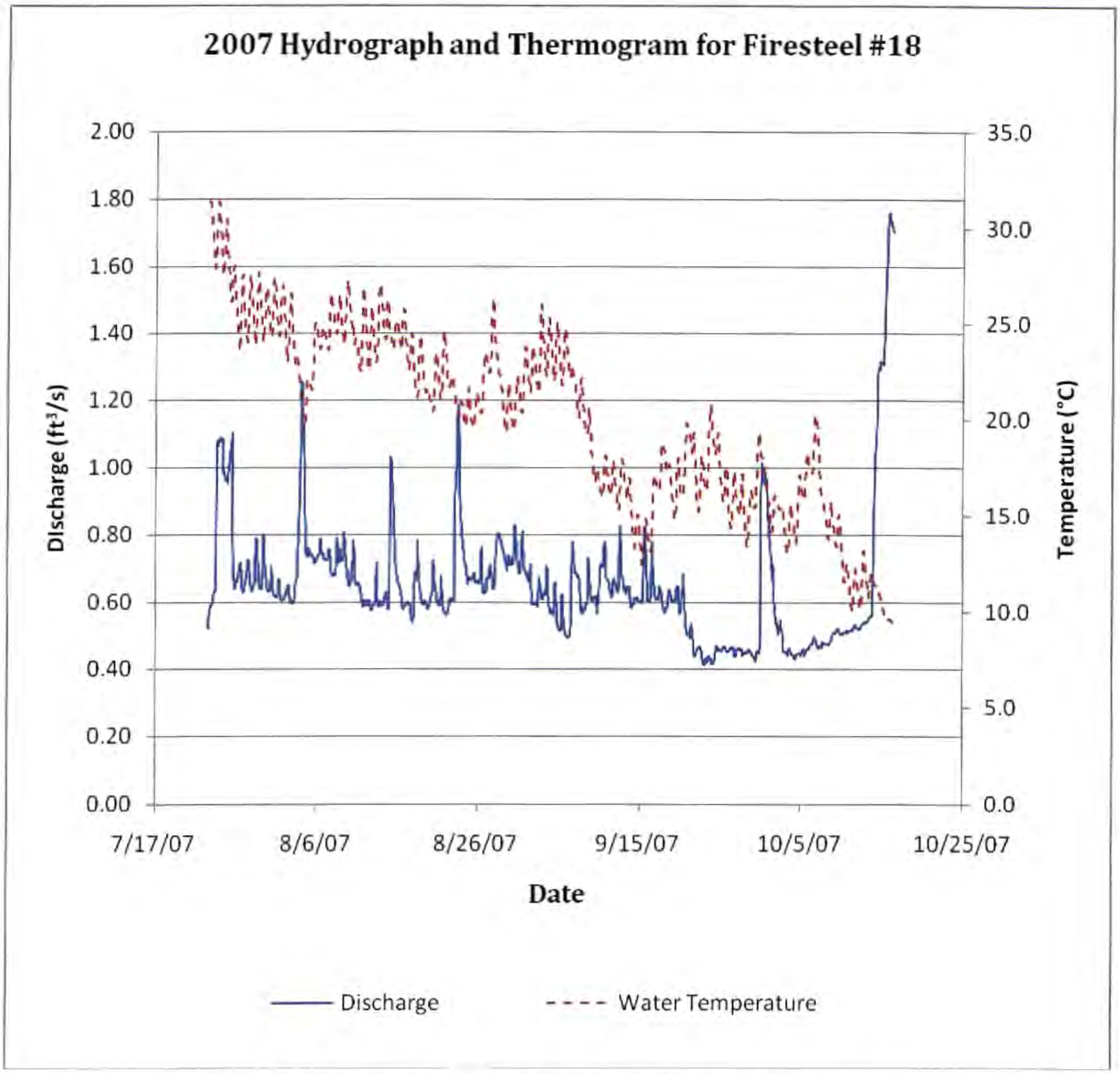

Figure 60: Firesteel #18 2007 Hydrograph and Thermogram

Modeling estimated no passage through this structure.

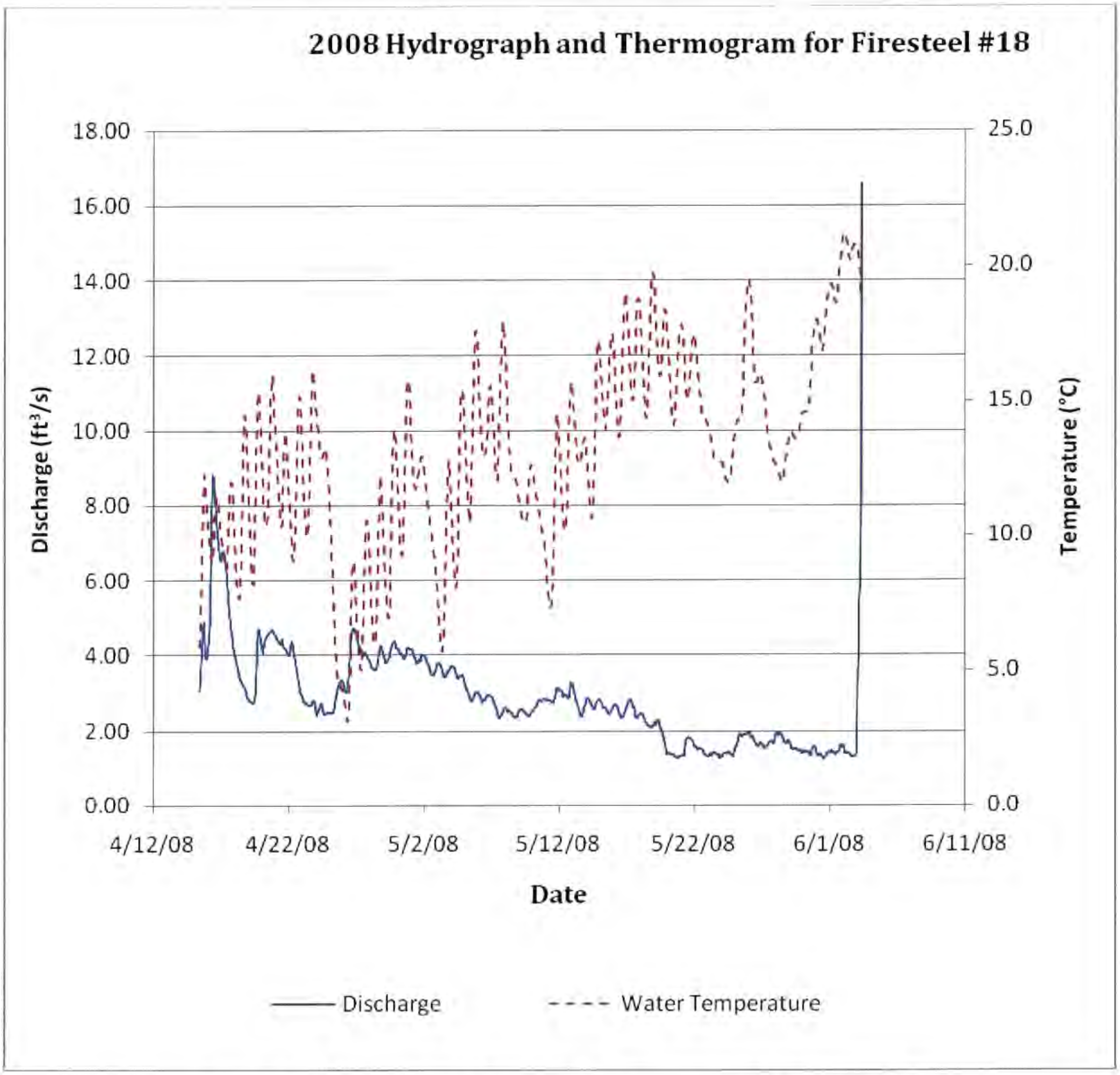

Figure 61: Firesteel #18 2008 Hydrograph and Thermogram

Modeling estimated no passage through this structure.

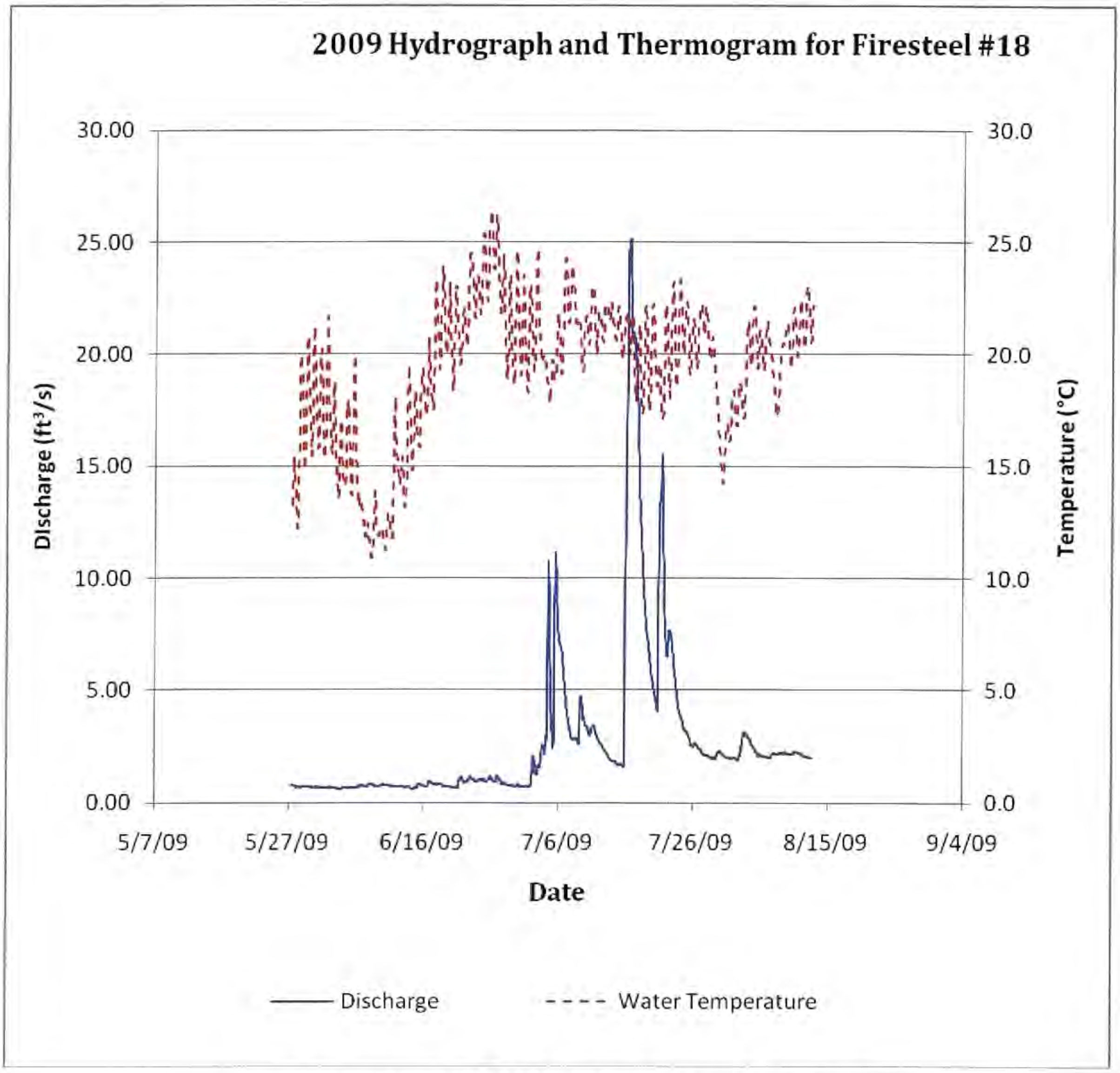

Figure 62: Firesteel #18 2009 Hydrograph and Thermogram

Modeling estimated no passage through this structure.

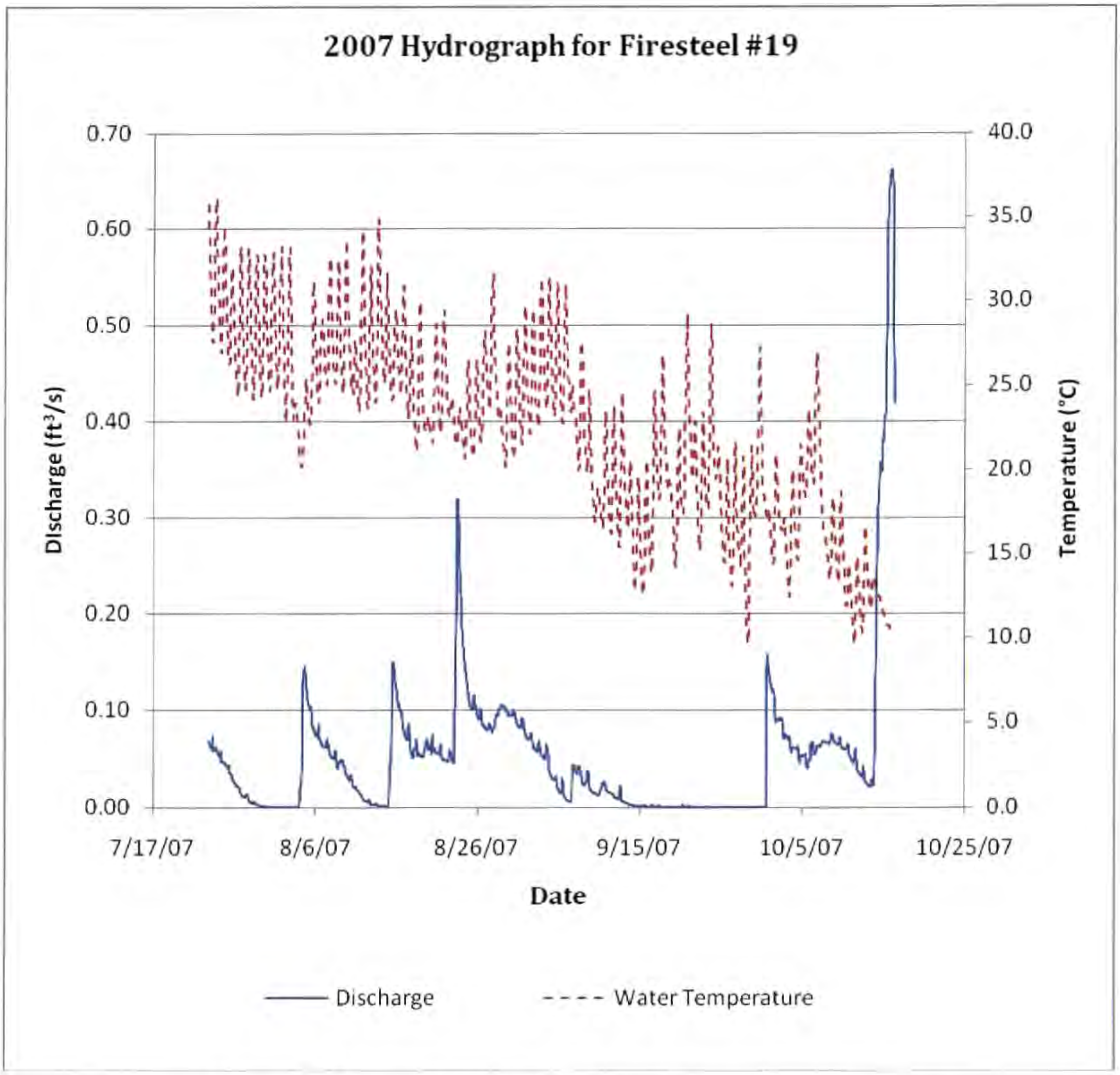

Figure 63: Firesteel #19 2007 Hydrograph and Thermogram

Modeling estimated this structure to be a depth barrier at all flows on this Hydrograph and Thermogram.

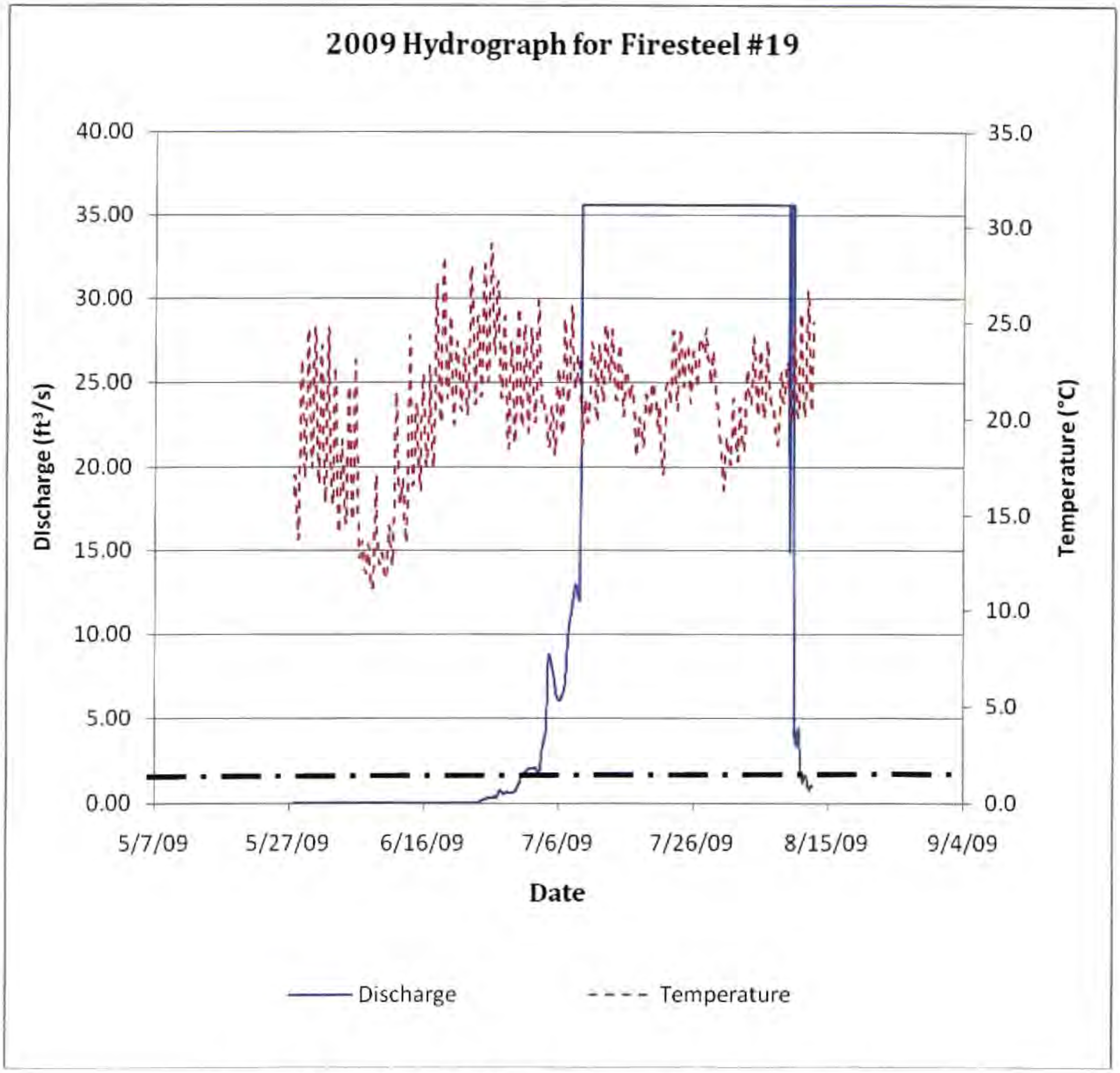

Figure 64: Firesteel #19 2009 Hydrograph and Thermogram

Modeling estimated this structure to be a depth barrier at flows less than the dash-dot line and passable at flows greater than the line.

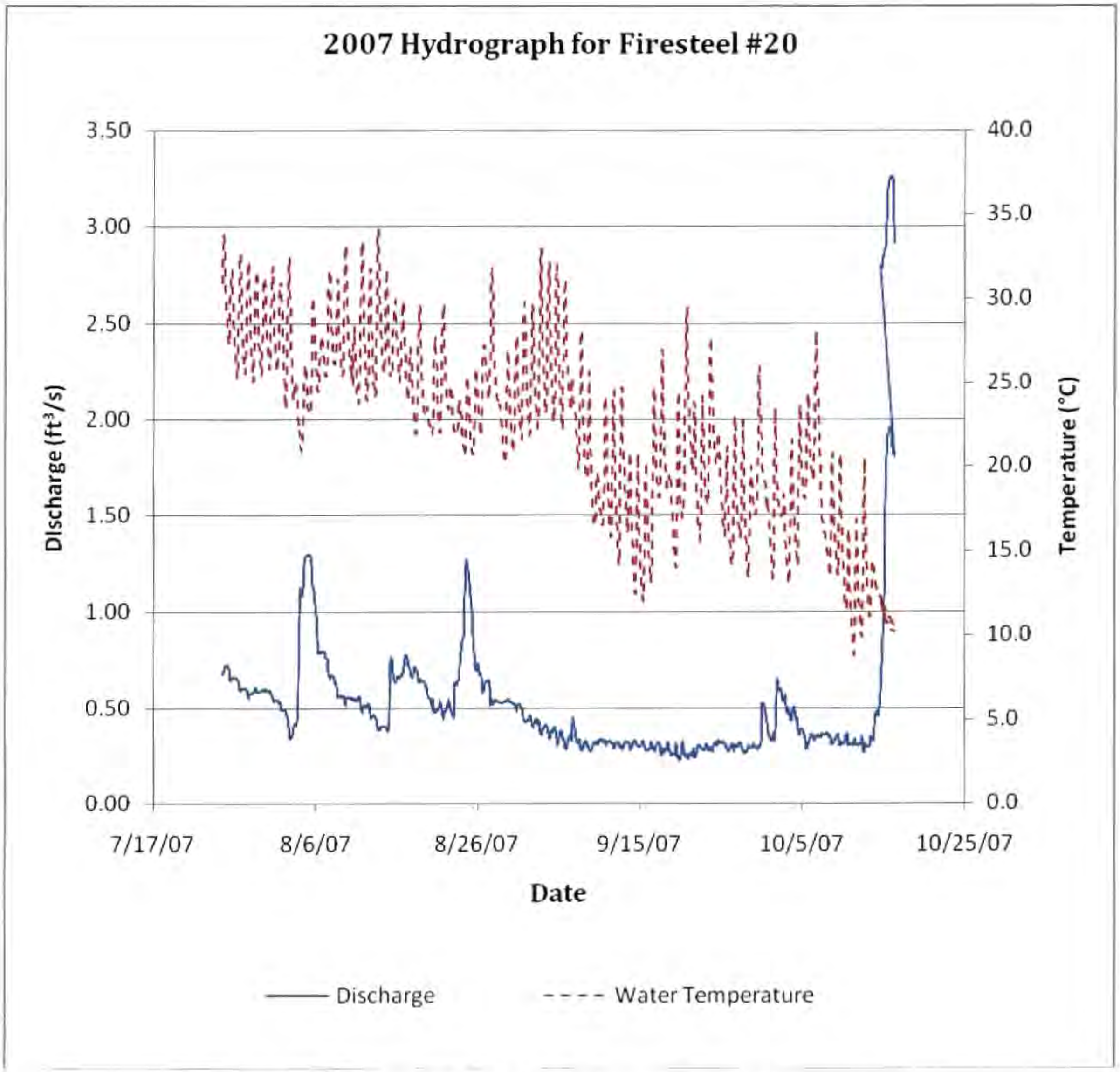

Figure 65: Firesteel #20 2007 Hydrograph and Thermogram

Modeling estimated this structure to be a barrier at all flows on this Hydrograph and Thermogram.

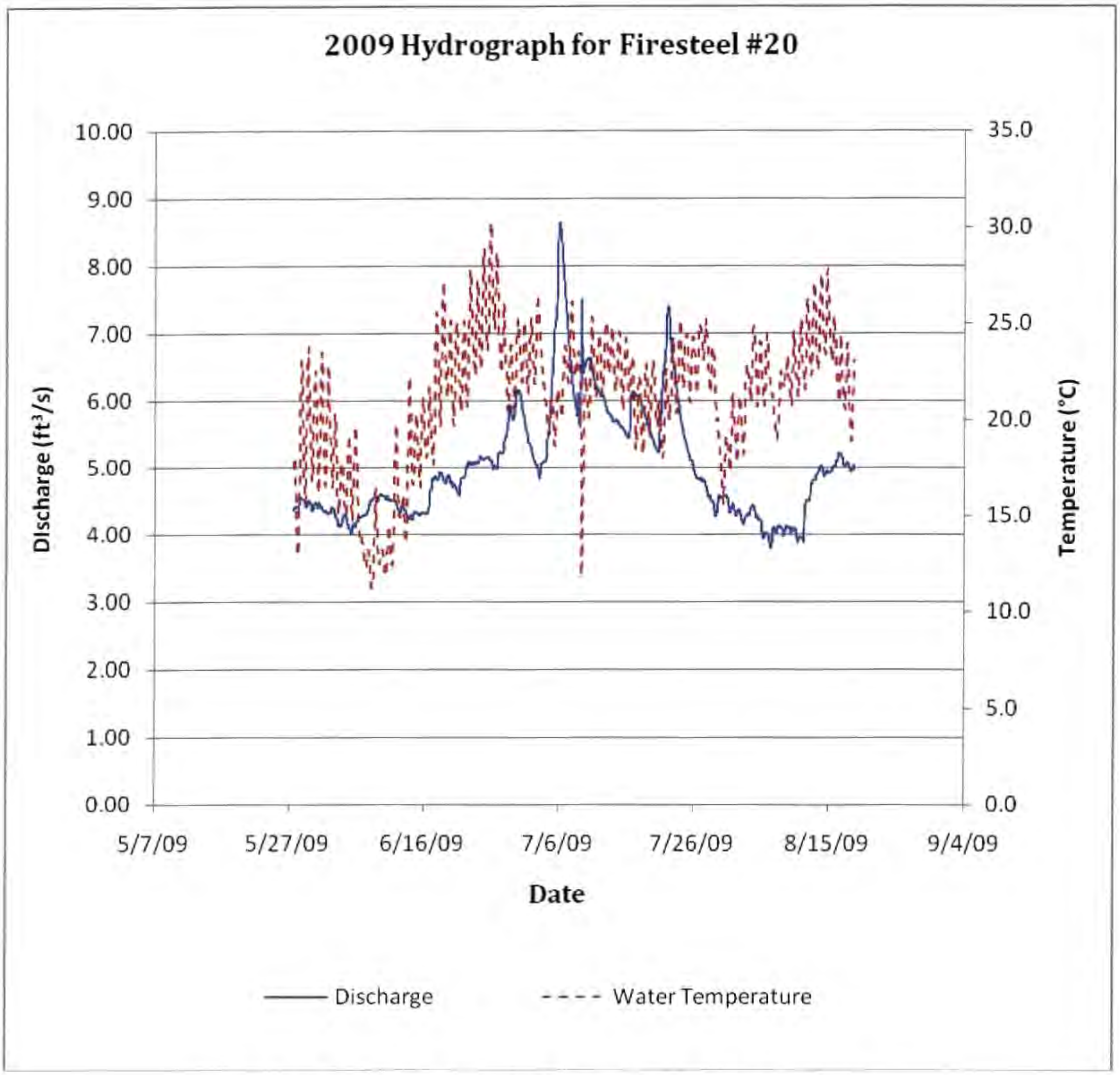

Figure 66: Firesteel #20 2009 Hydrograph and Thermogram

Modeling estimated this structure to be a barrier at all flows on this Hydrograph and Thermogram.