DEVELOPING ENGINEERING DESIGN CRITERIA FOR ECOLOGICALLY SOUND ROAD CROSSINGS FOR ENDANGERED FISH IN GEORGIA

by

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(Under the Direction of DAVID GATTIE)

ABSTRACT

Research was carried out to determine the extent to which road crossings, especially culverts, act as barriers to the passage of the Cherokee darter (*Etheostoma scotti)* and other small weak-swimming fish in small streams of the Etowah River Basin, in north Georgia. Barriers to fish passage include excessive velocities, scouring and drops at culvert outlets, low depths and excessive turbulence. Physical parameters of 70 small stream road crossings (less than 50 $km^2$ drainage area) were measured and assessed for fish passage suitability against literature criteria. Statistical analysis indicated that most pipe and box culverts in the Etowah River Basin impact fish passage. For passage of weak-swimming fish, a natural streambed or similar should form in culverts. This requires bridges, bottomless culverts or adequately sized, embedded culverts, resulting in larger culvert spans, especially for the smallest streams studied. Costs of road crossing options were compiled and engineering design criteria were developed.

INDEX WORDS: stream crossings, road crossings, habitat fragmentation, fish passage, culverts, Etowah River Basin, Cherokee darter *(Etheostoma scotti)*, environmental engineering, ecology, small stream fish, Etowah Habitat Conservation Plan

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# CHAPTER 1

# INTRODUCTION

There is increasing awareness that road-stream crossings, in particular traditional box and pipe culverts, can block fish passage and thus cause fragmentation of fish habitat in small streams. The critical problems include scour at culvert outlets, effectively creating small dams that block fish passage; excessive velocities in the culverts (against which fish cannot swim); and insufficient depth of water. Habitat fragmentation due to small-stream crossings is proposed to have an impact on the federally threatened Cherokee darter *(Etheostoma scotti)*, which is endemic to small streams of the Etowah River Basin, located in the northern region of Georgia, USA. The Cherokee darter is an appropriate species for evaluating impacts of stream crossings because it is a small-bodied, benthic fish with limited swimming capabilities that resides predominantly in small streams that may frequently be crossed by culverts. These characteristics render the species vulnerable to fragmentation from crossings that create high water velocities or vertical barriers, which exacerbate threats to populations from other human impacts (Baggett et al. 2001).

## 1.1 The Etowah Habitat Conservation Plan (HCP)

The Etowah River Basin is biologically diverse, supporting an estimated 76 native fish species, 4 of which are endemic (the Cherokee darter, the Etowah darter and two Holiday darters), as well as 14 introduced species (Burkhead et al. 1997). Evidence exists that previously there were 91 native fish species, but 15 are considered extirpated (Burkhead et al. 1997). The presence of federally protected fish species in the basin potentially requires that developers obtain permits to allow them to 'incidentally take' endangered and threatened fish. "Take" is defined in the Endangered Species Act as harass, harm, pursue, hunt, wound, kill, trap, capture or collect any threatened or endangered species. Harm may include significant habitat modification if such alteration actually kills or injures a listed species through impairment of essential habitat (e.g. nesting or reproduction). The provisions of Section 10 of the Endangered Species Act provide a legal mechanism for requiring those involved in otherwise lawful activities (e.g. development) to take actions specified in a Habitat Conservation Plan (HCP) to protect endangered and threatened species and their habitat. To increase the efficiency and effectiveness of the HCP process in the Etowah River Basin, a group of counties and municipalities are in the process of developing a regional HCP that will stipulate ordinances and guidelines for development activities, designed to minimize loss of habitat and populations for imperiled aquatic species. Habitat conservation plans (HCPs) such as the Etowah HCP provide an opportunity to put in place mechanisms to protect endangered and threatened species and habitat while still allowing for development. HCPs need a strong scientific basis for their requirements. The Etowah HCP addresses many aspects of urbanization and the resulting impact on fish passage. Fish passage barriers caused by road crossings are just one aspect. It is hoped that the consultations with the counties affected by the HCP as well as the Georgia Department of Transport (GDOT) will lead to the recommendations from this research being applied to new developments in order to protect the endangered Cherokee darter and other organisms of the Etowah River Basin.

1.2 The Cherokee darter *(Etheostoma scotti)*

The Cherokee darter is found only in the Etowah River Basin and is listed as federally threatened. It is typically found in shallow water (0.1 to 0.5 m deep) in small to medium streams (1-15 m wide). It is a bottom dwelling darter and swims in the slow moving boundary layer at the stream bottom. It is a small fish, less than 5 cm in length.

The Cherokee darter is not a strong swimmer. While Cherokee darters are capable of swimming in the slower moving boundary layers at the bottom of streams, they are not thought to be capable of jumping large drops at the outlet of culverts, and there is no record of any Cherokee darter jumping in any studies or personal observations (Freeman 2004). It has been shown that most small-stream fish do not pass well through pipe culverts with velocities above 0.4 m/s (Warren and Pardew 1998). Some sources suggest 0.3 m/s is the maximum velocity small weak-swimming fish can withstand (Queensland

Department of Primary Industries and Fisheries 2004). Other obstacles to fish passage include insufficient depth as well as drops from the culvert outlet to the downstream water surface.

Habitat fragmentation of small-stream fish habitat due to stream crossings promotes loss of genomic heterogeneity and increases the probability of localized extirpation (Bauer et al. 1995; Warren and Pardew 1998). Blocked passage prevents fish from recolonizing areas where extirpation has occurred and may prevent access to habitat needed for spawning, foraging, escape from predators, access to prey and the use of thermal refugia.

### 1.3 Objectives and hypothesis

The objectives of the study are to:

1) Review the current literature to determine the parameters that make road crossings, particularly culverts, impassable or passable to small-bodied fish in small streams.

2) Conduct a survey of Etowah River Basin road crossings to determine the extent to which road crossings of different types serve as barriers to small-stream fish movement in the Etowah. The survey addresses:

a) Types of road crossings used on different size streams;

b) Differences in crossing types by county;

c) Enumeration of impassable crossings, with distribution by type, county and size;

d) Conditions which make crossings impassable;

3) Cost information for each crossing type for the range of stream sizes in the study;

4) Recommendations for new design criteria based on the findings of objectives 1, 2 and 3.

The hypothesis is that improper design and installation of road crossings, especially traditional box and pipe culverts, are impacting the passage of small-stream fish such as the Cherokee darter in the Etowah River Basin, and there are reasonable grounds to contend that this is detrimental to fish populations. By analyzing literature and survey results, the key causes of impassable culverts for small-stream fish in the Etowah can be determined. Subsequently, engineering design criteria for culverts can be formulated to provide adequate passage for the Cherokee darter, and other small-bodied fish, in new crossing installations.

# CHAPTER 2

# LITERATURE REVIEW

A survey of the current literature was conducted to determine if small resident fish in small streams need to move, how they move, what parameters best indicate the adequacy of a road crossing for fish passage, and how to design optimal road crossings. An increasing number of studies indicate that road crossings, especially culverts, can act as barriers to small fish passage in the USA (Toepfer et al. 1999; Schaefer et al. 2003; Warren and Pardew 1998) and to weak-swimming non-jumping fish in other countries such as Australia (Queensland Department of Primary Industries and Fisheries 2004). The need for passable road crossings for juvenile and adult anadromous salmon has been demonstrated and extensive culvert replacement programs are in place in Oregon and Washington to protect salmon (Washington Department of Fish and Wildlife 1999; 2003; Robison et al. 1999; Oregon Department of Forestry 2002). Small resident fish have different requirements to anadromous salmonids, and understanding these differences is important to determining suitable criteria for fish passage for small resident fish such as the Cherokee darter.

There is limited knowledge on the movement of small-stream nonanadromous fish, and the impact road crossings have on them is therefore more difficult to discern than for salmon. Small fish such as the Cherokee darter are too small for transmitter usage, and their movements must be traced by mark and recapture studies, which may not indicate the full extent of their movements. The impacts of habitat fragmentation on 'resident' fish populations are likely to become more apparent over the long term if they do not have specific migratory needs at specific stages of their lifecycle, but rather more general needs for habitat access.

## 2.1 Importance of fish passage for small-stream resident fish

The extent of natural movement of small-stream nonanadromous fish is an important, though difficult to determine, aspect of understanding the impact of road crossing barriers on their survival. Generally, studies of darter movement have indicated long-term residence in relatively small areas (Schaefer et al. 2003), with inter-habitat movements by a small proportion of individual darters (Freeman 1995). Other small-stream fish such as sunfish and minnows are capable of rapid dispersal and routine crossing of habitat boundaries (Warren and Pardew 1998; Freeman 1995). The traditional view of small-stream resident fish has been that they do not need to move great distances (Gerking 1959) in contrast with migratory fish. However small-stream fish have been found to be more mobile than this view proposed. Studies by Decker and Erman (1992) and Matheney and Rabeni (1995) indicate that small fish can be highly mobile. Moreover, small-stream fish can rapidly recolonize defaunated stream segments after causes of defaunation are removed (Peterson and Bayley 1993, Sheldon and Meffe 1994).

Road crossings may act as barriers to the movement of small-stream fish. Barriers to dispersal increase extinction risk by habitat fragmentation (Bestgen and Platania 1991; Winston et al. 1991; Warren and Pardew 1998). The ability to disperse promotes maintenance of populations in areas unsuitable for spawning (Schlosser 1995; Schlosser and Angermeier 1995) and allows access to critical habitat needed for spawning (Fausch and Young 1995), foraging, escape from predators or access to prey (Power 1987; Harvey et al. 1988; Harvey 1991) and the use of thermal refugia (Schaefer et al. 2003).

Most road crossing studies have focused on the need for habitat connectivity for anadromous salmon. They migrate from freshwater streams to the ocean at certain times (depending on species) in their lifecycle, and then migrate back to freshwater streams, even up into tiny headwater streams, to spawn. Juvenile salmon resident in the freshwater streams migrate to small headwater streams in the summer to find cooler water. Salmonids also migrate into side channels to escape winter floods (Robison et al. 1999; Oregon Department of Forestry 2002).

### *2.1.1 Importance of habitat connectivity for resident fish compared with anadromous fish*

#### *2.1.1.1 Fish passage requirements for small-stream nonanadromous fish*

Fish can be classified according to our understanding of their migratory patterns (Myers 1949; Harris 1984). Diadromous fish regularly migrate between saltwater and freshwater, usually to spawn. Anadromous fish are diadromous fish that spend most of their lives at sea and migrate to freshwater to spawn. Catadromous fish are diadromous fish that spend most of their lives in freshwater and migrate to the sea for spawning. Amphidromous fish are diadromous fish that migrate from freshwater to the sea or vice versa for purposes other than, or in addition to, reproduction. Potamodromous fish are truly migratory fish for which migrations occur wholly within fresh water. Nonanadromous fish reside wholly in freshwater.

In much of the literature, freshwater fish are classed as migratory or resident (non-migratory). However Gowan et al. (1994) argue that fish movement assessment methods are biased against detecting movement of 'resident' stream fish and Hall (1972) offers evidence supporting this, as well as arguing that many of the supposed reasons for migration of 'migratory' fish are also important to enhanced survival of 'resident' stream fish.

Whereas the life history requirements of anadromous fish indicate direct impacts of road crossing barriers, for nonanadromous fish the impact has not been directly linked to life history stages. Hall (1972) looked at the role of migration in a temperate stream ecosystem. Meek (1916) suggested that migration of fish might bring adult fish back to areas in which their ancestral eggs developed. Heape (1931) listed three principal types of migration: alimental (in response to food variation); climatic, in response to extremes in climate, especially temperature; and gametic, associated with reproduction. Competition for food is suggested as a factor favoring the development of migratory behavior such as seasonal occupation of fluctuating environments (Mayr and Meise 1930). For example, the very large primary production in estuary regions during spring is utilized by migrating animals, especially during their juvenile stages. Migration is considered a mechanism for removing an organism from unfavorable circumstances. The reason for return is not as clear (Hall 1972). Foster (1969) reviewed the possible causes for evolutionary development of migration in fish and considered possible factors to be changes in food availability, climate, salinity and topography over geological time. The need for exploitation of new resources combined with the need for adults or eggs to remain within certain physiological limits may have set the stage for the first fish migrations (Hall 1972).

Most studies of fish migration in freshwater have focused on species associated with oceans or lakes for part of their lifecycle. As pointed out by Hall (1972), very few studies of fish movement look at fish that spend their whole lives in a single freshwater stream. Some studies, especially of trout in freshwater streams, indicate that movement of stream fish is important (Stefanich 1952; Bjorn and Mallet 1964; Hunt 1964). Others, especially those focused on bass, indicate very little migratory behavior in stream fish. Funk (1955) presented results suggesting many streams have a 'mobile' and a 'sedentary' component of each fish species. This hypothesis is lent support from research on the leopard darter (Schaeffer et al. 2003) and the blackbanded darter (Freeman 1995). Whether the resident and mobile portions of a species change over time is not discernable from current data sets. Harcup et al. (1984) tracked individually tagged fish in each of 2 years, and they found frequent switching behavior in which formerly sedentary fish moved and formerly mobile fish became sedentary. Gowan et al. (1994) suggest this indicates that fish movement behavior in 'resident' fish is plastic, and thus individual fish can adapt to changing environmental conditions. Gowan et al. (1994) assert that the prevailing emphasis of fish studies in streams is on the sedentary portion of the population, and that moving fish are considered to be strays or transients (Gerking 1959; Jenkins 1969).

Gowan et al. (1994) reviewed research on Lawrence Creek in Wisconsin, showing that movement was important in the response of the trout population to habitat enhancement. They also suggested in current research methods there is a bias against detecting movement of fish, which was also noted by Gerking (1959). Fish movement studies most commonly involve mark and recapture of fish, relying on the recapture of marked fish from the same areas in which they are released. In a majority of cases, less than 50% are recaptured (Gowan et al. 1994). In studies in which a high proportion of resident fish (or fish during non-migratory periods) in a stream section are marked, it is common for the marked fish to be rapidly replaced with unmarked fish (Shetter and Hazard 1938; Decker and Erman 1992; Cunjak and Randall 1993; Gowan et al. 1994). Using radio telemetry and two-way weirs Gowen et al. detected substantial movement of 'resident' trout in streams in Colorado and Wyoming. Most studies using radio telemetry indicate that some fish move long distances (Clapp et al. 1990; Meyers at al. 1992; Gowan et al. 1994).

The studies of trout response to habitat enhancement in Lawrence Creek found that there was no increase in movement out of the (enhanced) study reaches and that capture efficiency was high (over 90%) (Riley and Fausch 1992; Riley et al. 1992). In 22 annual stream surveys from 1988 to 1990, 52% of adult trout found were unmarked, indicating a high rate of movement into the study reaches from regions outside the study sections. Gowan et al. (1994) believed that the rapid population increase after habitat enhancement was primarily due to trout migrating from regions outside the study section and not primarily due to increased fish productivity/fertility. Since the increase in fish population appeared to be primarily due to fish from outside the study reach, Gowan et al. (1994) also argued that the area is not likely to be attracting fish (detection at a distance) but is clearly attractive to them once they are in the regions of enhanced habitat. Gowan et al. (1994) highlight a study by Hunt (1971) on trout habitat enhancement as well as the studies on Lawrence Creek for another factor indicating trout movement, described as follows. Overwinter survival rates were believed to be the reason why fish population increased in areas of habitat enhancement. But stream sections adjacent to the enhanced sections also exhibited population increases. This indicated that fish movement between sections increased the overwinter survival rate of fish in sections adjacent to the enhanced stream sections.

Hall (1972) found it likely that upstream migrations were undertaken by a portion of all larger fish species in New Hope Creek, North Carolina. Fish in obviously ripe condition were almost invariably taken moving upstream while spent fish were always taken moving downstream. Hall (1972) found a tendency in nearly all fish species for larger individuals to move upstream and smaller individuals to move downstream, and that this tendency was related to reproduction. All larger fish showed this pattern (e.g. bluegill, chubsucker, redhorses and redbreast sunfish). Darters in this study, however, showed no particular pattern. Hall (1972) presented the idea that the movements observed in New Hope Creek were similar in function, if not magnitude, to the greater migrations of salmon. One explanation of this pattern, presented by Hall (1972), is the advantage of distributing the genetic stock throughout the stream. Very small fish with large surface-to-volume ratios affecting friction cannot swim upstream against the current, but the larger fish can, and do, while the small fish move downstream with the current. A large number of juvenile fish were found moving downstream after spending one year upstream. Suggested attribution of this was to prevent population pressure or because larger fish experience less stress in the deeper waters due to geometric adaptations to rocks, currents and microenvironments (Hall 1972).

Darters are small-bodied fish and therefore adults may be too small to benefit from deeper water in this way. But it does appear that, as with other small-stream resident fish populations, darters gain important and significant survival benefits from accessible, connected habitat.

### *2.1.2 Cherokee darter specifics*

#### *2.1.2.1 Life history, behavior and habitat requirements of the Cherokee darter*

As mentioned in Section 1.2, the Cherokee darter (Figure 2.1) is a nonanadromous, benthic (bottom dwelling) darter endemic to the Etowah River system. Cherokee darters occupy shallow water (0.1-0.5 m) in small to medium creeks (1-15 m wide). Cherokee darters are typically under 5 cm in length.

The Cherokee darter has been found in approximately 20 small tributary systems of the Etowah River Basin but healthy populations have been found at only a few sites (U.S. Fish and Wildlife Service Division of Endangered Species 1995). The Cherokee darter and its habitat are impacted by impoundments and deteriorating water and benthic habitat quality due to siltation, agricultural runoff and other pollutants, increased urbanization, and waste discharges. These factors have led to restriction and fragmentation of the Cherokee darter's current range. The Cherokee darter is intolerant of impoundment and exhibits a disjoint and discontinuous distribution pattern indicating fragmentation and isolation of populations, predominantly caused by Allatoona dam (U.S. Fish and Wildlife Service Division of Endangered Species 1995).


Figure 2.1. Etowah, Greenbreast, Cherokee and Coosa darters. Letter C is the Cherokee darter. Figure reproduced from Rodriguez (2001)

There are other darters found in the Etowah River Basin, including the federally endangered Etowah darter, *Etheostoma etowahae,* usually found in medium and large cool water creeks or small rivers (15-30 m wide) (US Fish and Wildlife Service Georgia Ecological Services 2000-2003). The Cherokee darter is more likely to be impacted by road crossings because it resides in smaller streams, on which culverts are typically used. The Cherokee darter is also threatened by habitat loss due to dam and reservoir construction, habitat degradation, and poor water quality.

Localized extirpation of eight populations of the Cherokee darter have been documented (Bauer et al. 1995), and extirpation of populations near Allatoona Dam can be inferred. Extirpation of other species from the Etowah River Basin in the recent past, such as the blue shiner *Cyprinella caerula* (Bauer et al. 1995), indicate that the Etowah River Basin ecosystem is under threat.

In a study of Cherokee darter spawning behavior (Storey 2003) it was found that spawning sites characteristically occurred in run and pool habitats, with moderate depth (0.1 to 0.6 m) and velocity (0 to

0.7 m/s). Spawning usually occurred on gravel substrates, although females oviposited on a range of bed sediments from medium gravel to bedrock. Males tended to maintain a 'roving territory' around the female they were courting. The female could travel several meters or more through a variety of habitat. Fine sediment appeared to negatively impact spawning (Storey 2003).

Because specific habitat may be required for spawning, road crossings may prevent access and impact species survival. If sediment covers areas of suitable habitat, the ability to move and access better habitat may enhance survival, emphasizing the importance to populations of unimpeded passage within stream systems. Movements are most likely to occur during low and moderate flows. During storm events, Cherokee darters most likely remain stationed in locations that provide refuge from high water velocities (Freeman 2004).

*2.1.3 Long range and short range movement of darters*

Freeman (1995) studied the movement of the blackbanded darter (*Percina nigrofasciata*) in natural reaches, using mark and recapture studies, in Ichawaynochaway Creek in the Coastal Plain of Georgia. The stream studied was larger (30 m to 40 m wide) than typical Cherokee darter streams. The blackbanded darter is benthic, as is the Cherokee darter. In the study, blackbanded darters were usually recaptured within 33 m of their original location, although some were recaptured between 43 and 420 m from their original location. One darter moved 95 m in one day. These results support arguments that many in a population of small fish such as darters tend to have small areas of habitat within which they remain, but some may travel greater distances (greater than 100 m) between different mesohabitats. Whether the portion of the population that travels greater distances changes over time was not addressed. It is not known whether these longer travel distances are routine travels or relatively rare events (Freeman 1995). Freeman (1995) suggested that the rates of recolonization of defaunated streams as well as other studies indicate routine travels are a strong possibility. 'Exploratory movements' are a possible reason for extended movements of small-stream fish (Schaefer et al. 2003; Freeman 1995).

In a study of the Leopard darter (*Percina pantherina*), Schaefer et al. (2003) found that only a few individuals within a population move long distances while most individuals tend to remain within a home pool, while making exploratory excursions into adjacent habitats. One leopard darter (Schaefer et al. 2003) was found 200 m from where it was marked and released. Periodic long-range movements may allow small fish to respond to variations in resources over a large area and a variety of stream habitats (Freeman 1995).

#### *2.1.4 When and in what flow rates do small-stream resident fish move?*

Blackbanded darters were observed to move infrequently during high flow events (Freeman 1995). At least 40% of long-range (>33 m) movements were not associated with high flow periods (flows greater than the 10% exceedance level). This shows that long distance movement is not necessarily associated with high flows for the blackbanded darter.

### 2.2 Road crossings (culverts) as barriers to small-stream fish passage

The major barriers to fish passage identified in the literature include excessive velocity, inadequate depth, and excessive drops at culvert outlets. Excessive turbulence in culverts and debris accumulation can also create barriers. (Washington Department of Fish and Wildlife 1999).

Warren and Pardew (1998) included the orange belly darter (*Etheostoma radiosum*) and the greenside darter (*Etheostoma blennioides*) in their mark and recapture study of fish in small streams through road crossings in Arkansas. They found that water velocity at road crossings was inversely proportional to fish movement. They also found that non-embedded pipe culverts (pipes with little or no riprap or riverbed material in them) consistently had the highest velocities and box culverts with concrete or gravel bottoms and fairly deep water (24-75 cm deep) had the lowest (Figure 2.2). Two of the pipe crossings also had small drops to the tailwater surface (5-8 cm) while two had submerged outlets.

Pipe culverts with velocities above 0.4 m/s showed practically no passage of fish through them. They detected no movement across a slab culvert suggesting that it acted as a complete barrier to fish movement for most of the year (it apparently remained exposed above the water surface throughout the study). Warren and Pardew (1998) also found studfish, sunfish, chub, bullhead, shiner, minnow, stoneroller, bass, hog suckers, bluegill, topminnow and perch in their study. No seasonal or directional bias was detected in fish movement, even in natural reaches, indicating that problematic road crossings acted as barriers in both directions. Depth was not correlated with fish movement, however box culverts with reasonable water depth provided good passage.

Warren and Pardew (1998) found that darter movement was independent of crossing type but was generally low compared to other fish families for all crossing types. In their study they included fords, pipe culverts, open box culverts and slab crossings. They found that pipe culverts and slab crossings (the slab crossing had a downstream vertical drop to the tailwater surface of 25 cm) reduced overall fish movement, diversity of movement, and movement of fish families relative to natural reaches. The assessments were carried out during summer low flows and spring base flows. Storm flows were not specifically assessed.

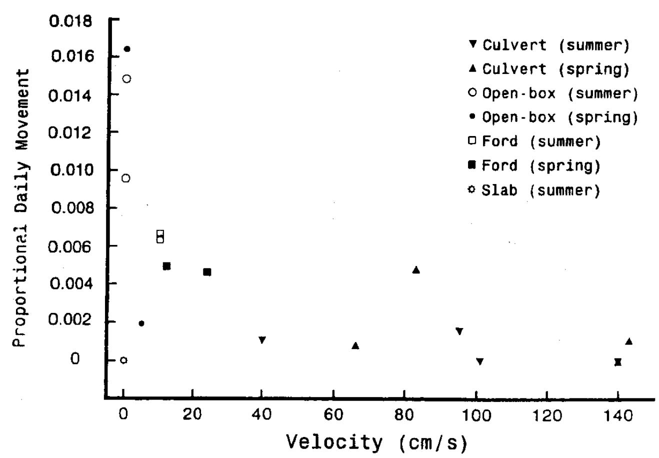


Figure 2.2. Velocity and crossing type. Figure reproduced from Warren and Pardew (1998)

Sunfish and minnow movement was lowest through pipe culverts and the exposed slab crossing and topminnows showed lowest movement through box culverts, pipe culverts and slab crossings, showing that not all small-stream fish are impacted by crossings in the same way.

Schaefer et al. (2003) identified one or two leopard darters moving downstream through a road crossing but no movement upstream. Across a natural riffle the only detected movement was also downstream. The road crossing site consisted of a combination of two round culverts approximately 60 cm in diameter and four box culverts approximately 3 m wide. Thus the downstream motions of the leopard darters may well have been through the box culvert openings. No further information on the culvert dimensions was given. Also, this 'combination' road crossing offers no insight into specific problems with culvert type.

### *2.2.1 Fish swimming ability in relation to passage through culverts*

Fish swimming ability directly impacts the maximum velocity, turbulence and outlet drop that fish can handle in order to pass through culverts. Studies of time to fatigue at different velocities and field measurements of velocity in culverts have been used to discern the velocities passable by fish. Weaker-swimming fish cannot withstand the same velocities as stronger swimming fish, and some fish can jump while others cannot. The velocity that is acceptable is also impacted by the length of the culvert because fish become fatigued if they swim too fast for too long.

Fish swimming speed can be categorized into burst speed, critical speed and sustained (or cruising) speed. The different categories reflect the muscles (classified as red or white muscles) used, and the different speeds possible are manageable for different lengths of time. Sustained speed is the slowest swimming speed and can be maintained indefinitely. Burst speed is the fastest speed a fish can swim (>10 body lengths/sec) but can be maintained for less than 20 seconds thus limiting the distance a fish can ascend through high velocity flows (Beamish 1978). For passage through relatively long culverts researchers study critical speed, which is a speed that can be prolonged for several minutes, enabling a fish to swim against increased velocity in a culvert and make it safely through to the other side. White muscles are typically not used for sustained speeds but are used for burst speeds. Red muscles are sunken deep in the interior of a fish and contract more slowly.

Jones et al. (1974) presented swimming ability data for migrating fish species to show that velocities between 0.3 and 0.4 m/s through 100 m long culverts should allow passage of mature salmon. Shorter culverts could provide passage at higher velocities. However in the study of Warren and Pardew (1998), culverts that did not allow passage were less than 10 m long and showed restricted passage at 0.4 m/s and above.

A study of the swimming performance of the leopard darter (Toepfer et al. 1999) found that no individual traveled further than 1.55 m in 10 minutes at any water velocity tested, 0.6 m/s being the maximum velocity tested and 0.25 m/s being the optimal velocity with respect to distance swum. Toepfer et al. (1999) argued that without refuges in culverts leopard darters would have trouble traversing even short culverts of less than 5.4 m. The leopard darters in the study were 5.8 cm long on average. After swimming at burst speed for a certain period of time they were swept to the mesh covering the water inlet in the laboratory study. In some cases they would recommence swimming and in other cases they would remain relatively stationary near the mesh (Toepfer et al. 1999).

For passage of the majority of native Australian stream fish, it is recommended that the velocity be kept below 0.3 m/s in culverts (Queensland Department of Primary Industries and Fisheries 2004). If the water depth in the culvert is too low (<0.2 m) and the water velocity over or through the culvert is too high (>0.3 m/s), fish may be swept back over the culvert edge.

Most Australian native fish do not jump when faced with barriers (Queensland Department of Primary Industries and Fisheries 2004). For stream crossings that are not at bed level the downstream side is usually impassable to most native Australian fish. It is likely that this would be the case for the Cherokee darter, which has never been seen to jump.

The Cherokee darter is a bottom dweller. As mentioned earlier, during storms, Cherokee darters most likely tend to remain in locations that provide refuge from high water velocities (Freeman 2004). Observations of leopard darters found that they remain close to the streambed to avoid high velocities during high flows (Toepfer et al. 1999). Therefore it can be argued that leopard darters are unlikely to move through crossings during storms. Because Cherokee and leopard darters swim along the bottom of streams, they may also be unlikely to navigate outlet drops from the culvert outlet to the streambed, even if they are submerged.

The maximum velocity, minimum water depth and maximum jump suitable for passage of several fish species through culverts is shown in Table 2.1.

Table 2.1 Fish swimming ability criteria for passage through culverts

| Fish Species | Length of Culvert (if Given) | Flow Type – Peak or Base Flow | Maximum Velocity | Minimum Depth | Maximum Jump | Source |
|---|---|---|---|---|---|---|
| Majority of Australian native steam fish | | Baseflow | 0.3 m/s (1.0 ft/s) | 0.2 m (0.65 ft) | 0 | Queensland Department of Primary Industries (2004) |
| Warm-water small-stream fish | 10 m (33 ft) | Baseflow or low flow | 0.4 m/s (1.3 ft/s) | | | Warren and Pardew (1998) |
| Adult Salmon | 91.5 m (300 ft) | Peak Flow – 10% exceedance flow | 0.6 m/s (2 ft/s) | 0.3 m (1 ft) | 0.3 m * (1 ft) | The National Marine Fisheries Service Southwester Region (2000) |
| Adult Salmon | 18.3 m (60 ft) | Peak Flow – 10% exceedance flow | 1.8 m/s (6 ft/s) | 0.3 m (1 ft) | | The National Marine Fisheries Service Southwester Region (2000) |
| Juvenile Salmon | Over 30.5 m (100 ft) | | 0.3 m/s (1 ft/s) Streambed simulation is required | | | The National Marine Fisheries Service Southwester Region (2000) |
| Juvenile Salmon | Short culverts | | 0.6m/s (2 ft/s) | | 0.15 m * (0.5 ft) | The National Marine Fisheries Service Southwester Region (2000) |
| Leopard Darter | 1.55 m (5.1 ft) | Baseflow | 0.25 m/s | | | Toepfer et al. (1999) |

* Oregon Department of Fish and Wildlife (2004)

In summary, traditional culverts do impact the passage of small-stream resident fish similar to the Cherokee darter. The importance is not fully understood, but it is likely to reduce genomic heterogeneity and increase the risk of local extirpation. Velocities below 0.3 or 0.4 m/s are required to provide passage to small non-jumping fish. Darters may have difficulty traversing velocities of 0.25 m/s over through traditional culverts of lengths over 5.4 m (Toepfer et al. 1999). The presence of even small drops to the downstream water surface may prevent passage of small non-jumping fish such as the Cherokee darter.

## 2.3 Designing better road crossings for fish passage

### *2.3.1 Problems with stream crossings and indicators of barrier crossings*

Culverts are typically smooth and designed for rapid water transport. Increased velocity (as compared with the natural stream velocity), excessive turbulence and downstream scour are common in many culverts. These features reduce their suitability for fish passage.

Streams are dynamic environments. Natural streams undergo changes over time in depth and bank locations. The rigid boundaries that culverts form do not change with the stream and this leads to the creation of barriers as the stream geomorphology changes (Washington Department of Fish and Wildlife 1999). Changes in hydrology due to land use change can exacerbate this process. Culverts that act as barriers to fish passage can also hamper the processes of sediment and debris transport.

### *2.3.2 Requirements for adequate fish passage – minimize scour and velocity and maximize depth*

Three keys to making culverts suitable for fish passage are 1) managing the water velocities in the culvert; 2) preventing drops (due to scour) in and around the culvert; and 3) providing adequate water depth (Robison et al. 1999). Minimizing turbulence in the culvert and avoiding upstream drops are also important measures, especially for weak-swimming, non-jumping fish. These factors interact and affect each other, which needs to be considered when developing design criteria to ensure adequate fish passage is provided over the long term.

Following is a summary of the key design recommendations and criteria for road crossings, based primarily on work carried out by the Oregon Department of Fish and Wildlife (Robison et al. 1999) and the Washington Department of Fish and Wildlife (1999, 2003). Other organizations have made slight changes and adopted similar criteria, such as the National Marine Fisheries Service - Southwest Region, in California (2000). These recommendations are directed at maintaining salmon populations but will also improve habitat connectivity for other fish. As will be seen in the following section, some criteria for salmon protection are suited to the protection of all species of fish including weak-swimming fish. These include designs that incorporate streambed material or riprap into the culvert bottom by sinking the culvert below the streambed, and ensuring adequate sizing of the culverts.

Guidelines have been given for Australian streams (Queensland Department of Primary Industries and Fisheries 2004) to protect migratory native fish, many of which, unlike salmon, do not jump. The same general design guidelines are used for native Australian fish as are used for salmon in North America although the maximum velocity criteria is lower (0.3m/s).

There are no current programs in place to provide passage specifically for the protection of small resident fish in small streams, although they benefit from programs for migratory fish when the design criteria are sufficient for their needs also. However, knowledge of their swimming capabilities gleaned from the literature (presented in the previous sections), such as velocity limitations and observed inability to jump, can be combined with recommendations for other fish to justify guidelines for suitable road crossing design criteria.

In this section the different parameters that impact fish passage are presented and the current best understanding of the requirements in relation to the Cherokee darter is presented.

### 2.3.3 *Velocity*

There are two velocities of importance to culvert design. One is the maximum velocity acceptable during fish passage. The other is the velocity during storm flow, which leads to scouring. Baseflow or average low flow velocities should be the target design velocities for Cherokee darter passage through road crossings because Cherokee darters hunker down during storms (Freeman 2004) and are more likely to move at low flows than high flows, except for being washed down stream. Traditional pipe culverts can have water velocities of up to 3 m/s, which exceeds the known sustained swimming speeds of any stream fish. The variation between the velocity in the culvert and the stream sections directly upstream and downstream is another important parameter because too great a change can result in hydraulic jumps at the culvert inlet or outlet, thus increasing the likelihood of scouring.

The slope, streambed roughness and wetted perimeter of the channel affect flow velocity. The formula governing the velocity in an open channel is Manning's equation (Eq. 1).

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad (1)$$

where:

R is the mean hydraulic radius in meters (the area of the cross section of water divided by the wetted perimeter)

S is the gradient expressed as the drop in the channel divided by its length

n is the roughness coefficient of the channel

Values of n are determined experimentally and increase for rougher surfaces.

Equation 1 states that velocity varies with slope to the power of ½ and is inversely proportional to the roughness coefficient, n.

Thus the simplest approach to reducing velocity through culverts is to increase roughness of the substrate, minimize slope of the culvert bottom (maintaining a slope approximately equal to the stream bed above and below the culvert is recommended to interfere as little as possible with the natural stream course), and to match the wetted perimeter as closely as possible to that of the natural stream bed (Clay 1995).

Culvert slopes greater than 0.5% to 1.0% in non-embedded culverts have been associated with excessive velocities that act as barriers to fish passage (Mirati 1999). More recent research indicates that at any slope, a non-embedded culvert may result in velocities too high for passage of juvenile salmon (Washington Department of Fish and Wildlife 2003) or weak-swimming fish (Washington Department of Fish and Wildlife 2003; Warren and Pardew 1998). No-slope, non-embedded culverts (where the culvert is installed at less than 0.5% slope) are considered as a possible design option for mature salmon; however they do not consistently provide velocities less than 0.4 m/s, which is required for passage of small fish. It is likely that even lower velocities are required for passage of Cherokee darters for reasons outlined in Section 2.2.1, mainly that leopard darters did not travel more than 1.55 m in 10 minutes at

0.25 m/s, which was the optimal velocity tested with respect to distance swum (Toepfer et al. 1999). Powers and Bates (1997) found that juvenile salmonid passage was lessened significantly through culverts with slopes greater than 0.2%.

Increasing culvert roughness reduces average water velocity. For juvenile salmon passage, culverts that are embedded in the stream (placed with their bottoms below the streambed, with streambed material in them), are recommended over non-embedded no-slope culverts, placed with bottoms at stream level. This is because the natural streambed material has increased roughness, which lowers the culvert velocity and correct culvert sizing and placement results in culvert cross-sections more similar to the natural stream profile. This reduces hydrological alteration and minimizes occurrence of hydraulic jumps at culvert inlets and outlets. The natural variation in velocity provided by the complex natural surface of the streambed material also tends to provide pockets of low velocity in the channel, for fish to rest in. Velocities of 0.2 m/s in natural cobble bed substrate are suitable for passage of most small-bodied fish in streams (Freeman 2004).

It has been argued (Buffington and Montgomery 1999; Barnard 2003) that average velocity as a criterion for fish passage is too simplified and abstract to capture the complexity of the hydraulics and morphology of natural streams, and as such it may not sufficiently capture the requirements of fish passage of all fish requiring it. Furthermore, allowable velocities for all species and age classes of fish requiring passage through a road crossing are difficult to determine.

Increasing streambed roughness can limit the flood flow (Clay 1995), which leads to requirements for larger culverts openings to pass flood flow, and thereby increases the project costs. To minimize hydrologic alteration at the culvert, culverts larger than those traditionally selected for stormwater management are required. Thus the maximum size necessary for storm flow or fish passage will need to be selected.

The inclusion of baffles or boulders has been recommended for reduction of velocity in some cases (Queensland Department of Primary Industries and Fisheries 2004, Oregon Department of Fish and Wildlife 1999). However increased turbulence associated with such obstacles can be problematic for juvenile salmon and weak-swimming small-stream fish.

Using the natural stream bed for roughness by placing the culvert bottom a minimum distance below the streambed, and/or installing a larger size of culvert, is recommended for reducing low and high flow velocities. Using multiple culverts can also increase the wetted perimeter as an alternative to increased culvert size. All these options will incur added cost to the design.

#### *2.3.4 Jumps or drops from culvert outlets*

Unless great care is taken in designing culverts, erosion can occur at or below the outlet of the culvert. Culverts are typically designed to take the maximum flow in the stream, and may therefore run full during large storms, possibly with considerable head at the inlet of the culvert (i.e. submerged culvert inlets). Drops from culvert outlets to the downstream streambed or water surface tend to develop over time. Given that most Australian native fish do not jump when faced with barriers where crossings are not at bed level (Queensland Department of Primary Industries 2004), the drop created on the downstream side is usually impassable to most native Australian fish. Fish that can jump (e.g. mullet and salmon) require deep pools with limited turbulence to jump from and resting pools or sufficient depth to jump into. Cherokee darters are unlikely to be capable of passing any jump.

Water at the entrance and exit of the culvert should be at the level of the stream bed. There should be no drop on the downstream side preventing fish from entering the culvert. Countersinking of culverts below stream bed is strongly recommended to prevent perching. All culverts should be designed with a specified minimum countersunk dimension. Twenty percent or more of the culvert diameter or rise is considered appropriate (Washington Department of Fish and Wildlife 2003).

In actively eroding areas, perching at the culvert outlet may occur. Special consideration should be given to culverts placed in channels that are degrading or are likely to degrade in the future (due to natural causes or changes in hydrology as a result of catchment land use changes). Bottomless culverts are preferred to minimize erosion in this instance.To protect a culvert from becoming perched, paving the outlet with riprap and river gravel has been recommended (Clay 1995), or construction of a concrete stilling basin, riprap, or both. However, some concrete box culverts with aprons have exhibited scouring at the edge of their apron. Even those non-embedded culverts installed in line with the streambed or at zero slope tend to scour over time creating drops to the downstream water surface.

Deliberately perched culverts should not be used in any case where passage is required. They act as barriers to fish passage from the first day of their installation. The use of concrete armoring must be carefully considered so that scouring is not merely moved further downstream. Concrete armoring is not recommended in this thesis. Long-term erosion processes at culvert outlets should receive more study or monitoring, as there is no clear solution for all scenarios.

*2.3.5 Crossing type*

The National Marine Fisheries Service, Southwest Region (2000) ranked the preferred crossing types, in order: 1) Bridge with no encroachment into 100 year flood plain; 2) streambed simulation strategies (bottomless arch, embedded culvert, ford, embedded round metal culvert) with less than 0.5% slope; and 3) baffled culvert or structure designed with a fishway for slopes greater than 0.5%. In salmon spawning areas they found that only full span bridges are acceptable. Baffled culverts are not recommended for weak-swimming, non-jumping fish. By extension, only stream simulation strategies or bridges would be acceptable for passage of the Cherokee darter.

The Oregon Department of Fish and Wildlife will allow the following types of crossings in the order shown: 1) bridge (with no approach embankment into the main channel); 2) streambed simulation strategies using a bottomless arch or embedded culvert design; 3) streambed simulation strategies using embedded round metal or concrete box culvert designs; 4) non-embedded culvert, placed at less than 0.5% slope; and 5) baffled culvert (various designs), placed at 0.5% to 12% slope or a structure with a fishway.

Non-embedded no-slope culverts have been shown to be problematic for weak-swimming fish and therefore once again, the only options are bridges or stream simulation strategies.

Streambed simulation refers to the situation where substrate and flow conditions in the crossing structure mimic the natural stream at a range of flows including the design fish passage flow. Different authors have used this term differently, and the requirements of stream simulation vary among authors. However, stream simulation always involves the natural streambed or similar filler material as a substrate at the bottom of the culvert or crossing, combined with adequate sizing of the culvert. The specific 'stream simulation design method' will be referred to as such to distinguish it from stream simulation techniques in general.

The Washington Department of Fish and Wildlife (2003) presents three culvert design methods that take fish passage into consideration all of which are intended to utilize the natural streambed material. They are the no-slope design option, the hydraulic design option and the stream simulation design option (Washington Department of Fish and Wildlife 2003). In all cases the bottom of the culvert should be placed below the streambed a minimum of 20% of the culvert diameter for round culverts or 20% of the vertical rise for elliptical culvert, and be filled with, or naturally allowed to fill with, natural streambed material or similar material. For bottomless culverts this depth criterion does not apply, although the footings should be buried sufficiently deep to ensure they do not become exposed from scour within the culvert. Since the Washington Department of Fish and Wildlife (2003) design guidelines are comprehensive, because they match or exceed the criteria for stream simulation of other design guidelines, and because they make specific reference to designs intended to protect all fish species, they have been selected as the model for culvert design for the Etowah River Basin and protection of the Cherokee darter. Reference to other criteria is made where necessary.

*2.3.5.1 Bridges*

Bridges, especially freespan bridges, are preferred where funding is available. The Washington Department of Fish and Wildlife (1999) suggests that for crossings 20 ft (6.1 m) or wider a bridge should be used. The Georgia Department of Transport uses bridges for drainage areas greater than 20 $mi^2$ (51.8 $km^2$). For economic reasons, bridges cannot be used on the majority of smaller crossings, because culverts are significantly cheaper.

*2.3.5.2 Bottomless culverts and embedded culverts*

Following bridges, bottomless culverts are preferred for fish passage (unless river substrate is too loose) or alternatively embedded pipe or box culverts. Prefabricated concrete arch culverts have been used successfully in fish passage enhancement projects in the states of Maryland, Tennessee, Washington and California, among others, especially in cases where the stream is not far below the road. Examples of these arches are shown in Figure 2.3.

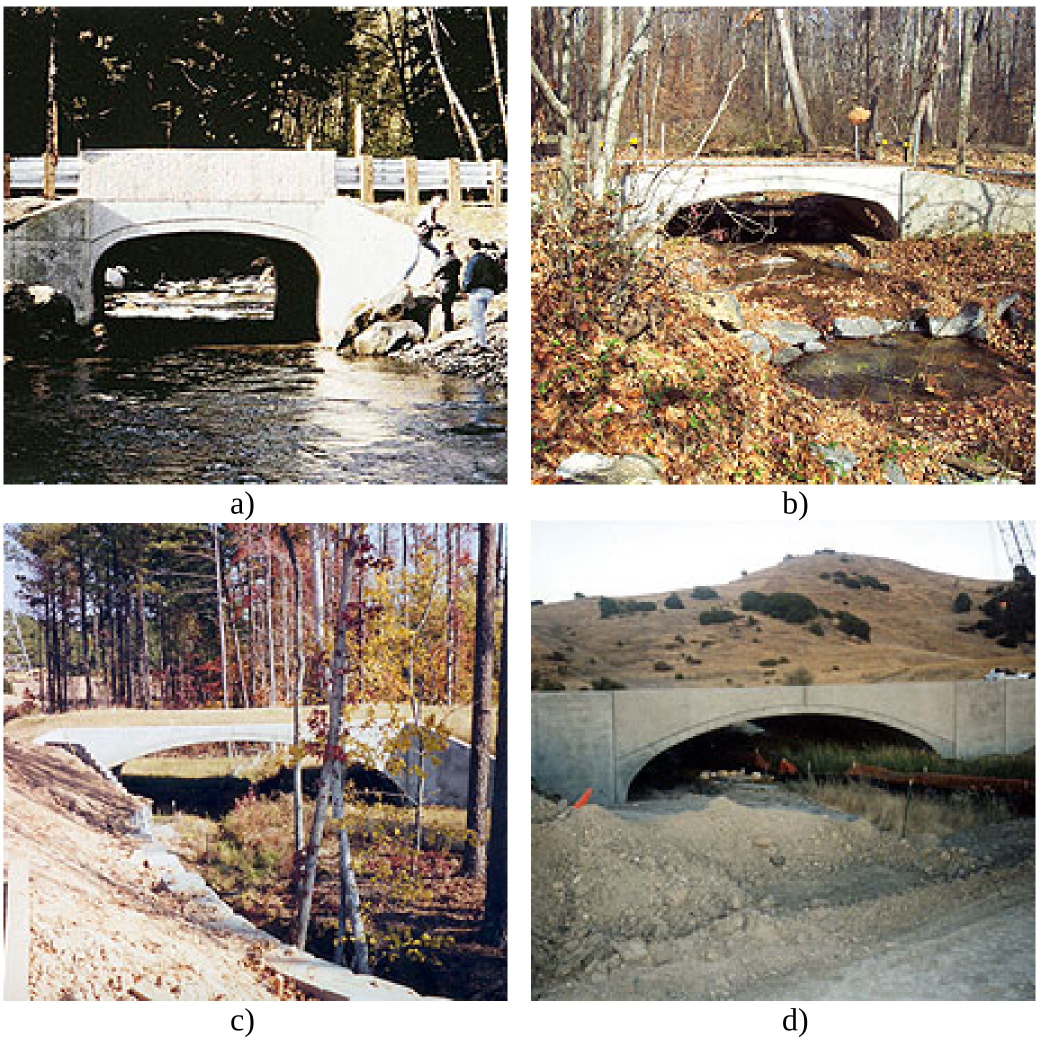


Figure 2.3 Arch culverts used for fish passage. a) Washington; b) Maryland (protecting the Fantail darter); c) Tennessee (installed in one day); d) California. Source a): U.S. Department of Transportation Federal Highway Administration. 2002; Source: b,c and d): CON/SPAN ® Bridge Systems

Because there can be structural issues with using bottomless culverts on alluvial river substrate, they are not preferred unless careful consideration is given to their installation by qualified engineers. The Georgia Department of Transportation has raised safety issues with their use in Georgia so they will not be required for fish passage enhancement in this thesis although they should be considered as an option. The following section (Section 2.3.6) outlines the recommended methods for designing embedded culverts, which do not have the same safety issues as bottomless culverts.

### *2.3.6 Culvert design procedures*

There are three methodologies for designing culverts for fish passage. They are 1) the no-slope design option; 2) the hydraulic design option; and 3) the stream simulation design option (Washington Department of Fish and Wildlife 2003). The no-slope design option installs the culvert essentially at zero gradient and matches the width of the culvert at the level of the streambed to the bankfull stream width. The no-slope design leads to conservative (large culvert) designs. It is also limited to relatively short culverts in low gradient sites. The hydraulic design option requires hydrologic and open-channel flow calculations to meet design velocity, depth and turbulence criteria for a target fish species and age class, and usually results in smaller sized culverts than the no-slope design. The stream-simulation option uses sufficient pipe size and fill material to construct an artificial stream channel in the culvert, which should provide passage for all fish species migrating through the reach. When designing for juvenile salmon passage the no-slope or stream simulation design are usually required.

#### *2.3.6.1 No-slope design option*

A no-slope culvert has a flat gradient (Washington Department of Fish and Wildlife 2003), a width equal to or greater than the bankfull channel width at the elevation that the culvert meets the streambed, and has adequate flood capacity (this is checked once the culvert has been sized). The Washington Department of Fish and Wildlife no-slope option also requires that the downstream invert be placed below the streambed by a minimum of 20% times the culvert rise or diameter. The upstream invert should be sunk to a maximum of 40% of the culvert diameter or rise. This limits the product of stream slope times length of culvert to 2 times the pipe diameter. This design option is shown in Figure 2.4.

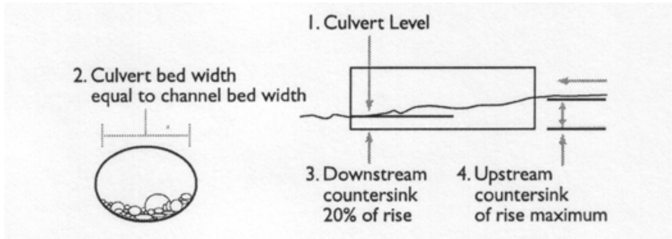


Figure 2.4 The no-slope design option. Figure reproduced from Washington Department of Fish and Wildlife (2003)

The Oregon Department of Fish and Wildlife (2004) requires that for a no-slope design culvert the slope of the culvert must be less than 0.5%. They do not require embedding of the culvert, although embedding for stream simulation is preferred over the non-embedded no-slope design.

As noted in Section 2.3.3, Powers and Bates (1997) found that juvenile salmonids passage was lessened significantly through non-embedded culverts with slopes greater than 0.2%. Also, it should be noted that design criteria have changed over time. For example, in earlier publications the Washington Department of Fish and Wildlife (1998) required 6 in (0.15 m) countersinking of no-slope culverts. This has now increased to 20% of the diameter or rise (Washington Department of Fish and Wildlife 2003).

*2.3.6.2 Hydraulic Design Option*

The hydraulic design option has been the main design option for fish passage through culverts, but no-slope and stream simulation design methods are now preferred (Washington Department of Fish and Wildlife 2003). Input parameters include the fish passage requirements of the target species, the culvert length and the hydrology. From these requirements the size, shape, roughness and slope of the culvert that provides the necessary velocity or depth, assuming open channel flow and no bed material, can be determined. The backwater elevation at the culvert outlet for the designed fish passage flow is determined and the culvert elevation selected so that the channel backwater at the fish passage flow is at least as high as the water surface in the culvert. Flood capacity must also be checked and if an adjustment to the channel profile upstream or downstream is required this should be done. This process may require several iterations.

The passage of species other than the target species is not specifically accounted for but designs adequate for trout should result in conditions conducive to deposition of natural bed material in the culvert resulting in a natural roughened channel through the culvert. If a pipe becomes deeply submerged and pressurized during a flood the flow may clear the culvert of any deposited material, but over time new material should accumulate. As with the other design methods, the Washington Department of Fish and Wildlife stipulates 20% of the diameter or rise for countersinking below the streambed level.

The Oregon Department of Fish and Wildlife (2004) still allows for small jumps from the downstream surface to the culvert outlet (15 cm (6 in) for juveniles and up to 30 cm (1 ft) for adult salmon). The Washington Department of Fish and Wildlife (2003) does not currently make allowances for such jumps in the design of culverts.

The Oregon Department of Fish and Wildlife (2004) hydrologic design calculations use a low flow depth of the 2-year, 7-day consecutive low flow discharge or the 95% exceedance flow for the fish species of concern. High design flow (for salmon) is Q10, the flow that is not exceeded more than 10% of the time during migration months.

The Oregon Department of Forestry (2002) uses hydraulic design on gradients up to 12%. Weirs or other flow obstructions may be located in the culverts in designs aimed at reducing velocity. This increases roughness and provides a series of pools and drops to increase depths and decrease velocity. Hydraulic engineering expertise is required. The pools and drops of such hydraulic designs may be problematic for darters so this option is not recommended.

*2.3.6.3 Stream simulation design option*

The stream stimulation design option assumes that if fish can migrate through a natural stream reach then they will be able to migrate through a man-made channel that simulates the natural stream channel. Stream simulation culvert design is recommended where passage of all species is required, or ecological connectivity is deemed important (Washington Department of Fish and Wildlife 2003).

Stream simulation culverts are sized wider than the natural channel width and the bed inside the culvert is sloped at a gradient equal to or greater than the gradient of the adjacent stream reach (Washington Department of Fish and Wildlife 2003). The culverts are filled with a sediment mix that emulates the natural channel. Bottomless culverts are also considered as stream simulation culverts. Stream simulation culverts are usually preferred when there is a steep slope or the culvert is long. Stream simulation culverts have not been designed in clear intentional ways very frequently to date and therefore there is still considered to be some risk of culvert bed failures (loss of culvert bed material from the culvert) in areas where the hydrology and geomorphology is not well understood or where stream simulation has not been used before.

The ratio of the culvert slope to the natural stream slope must be less than or equal to 1.25 (Washington Department of Fish and Wildlife 2003). Values less than 1.25 may be required if hydraulic analysis indicates that the flow regime changes in the culvert or at the culvert outlet. Flow regime changes are changes from subcritical to supercritical flow or vice versa and the energy associated with the change causes significant scouring. The location where the flow changes from subcritical to supercritical is called a hydraulic jump. If a hydraulic jump is anticipated, the culvert slope may need to be lessened. Minimizing culvert slope also reduces the shear stress between the culvert bottom (e.g. the pipe) and the bed material.

The width of the culvert bed in a stream simulation culvert should be equal to

$$W_{culvert\ bed} = 1.2\ W_{ch} + 2 \text{ (in feet)} \quad (2)$$

or $W_{culvert\ bed} = 1.2\ W_{ch} + 0.6$ (in meters)

where $W_{ch}$ = the bank full channel width

To date, Equation 2 has been applied successfully to primarily small, steep streams. In this design, 30-50% of the culvert rise or diameter is filled with natural bed material. In alluvial channels, slopes of up to 4% are acceptable. For more stable streams, slopes greater than 4% can be considered.

The Oregon Department of Forestry (2002) says that embedded culverts should be sized and placed so that after embedding, width is equal to or greater than the active channel width. This is likely to require 40% embedding of pipes. The Oregon Department of Forestry (2002) says that streambed simulation (embedded culverts) can be used easily on slopes up to 5% and in streams dominated by valley fill substrates several feet deep, up to slopes of 8%. The culvert bottom should be placed below the existing streambed. For slopes from 4% to 8% the culverts may need to have the inlet buried deeper than outlet so that culvert slope is 1.5% less than stream slope. Because these two sources recommend different acceptable slopes for this design method, it is recommended to follow the Washington Department of Fish and Wildlife (2003) guidelines as they are the most comprehensive, the most stringent, and they specifically address the passage of the majority of fish species and the requirement for a natural streambed or similar in the road crossing to meet the needs of weak swimming fish.

The Washington Department of Fish and Wildlife (2003) uses two options for constructing the bed material depending on slope. For slopes less than 4% the bed in the culvert is constructed of predominantly native material with bands of coarser rock (D100 for small streams to D100 multiplied by 2 in larger streams) to control the grade and channel cross-section shape. Figure 2.5 shows the stream simulation design option at low slopes.

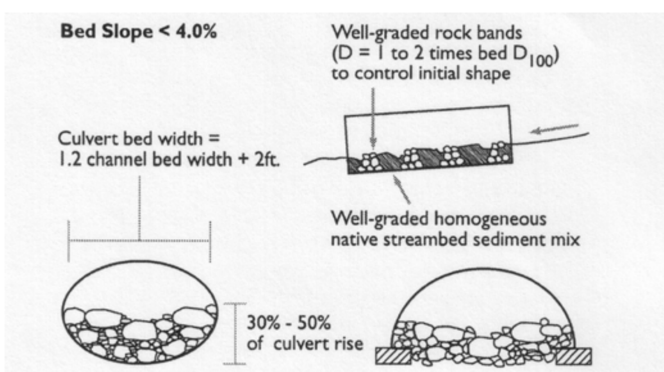


Figure 2.5 The stream simulation design at low slopes. Figure reproduced from Washington Department of Fish and Wildlife (2003)

For slopes greater than 4% the native bed material, or engineered bed material of similar make up is used throughout the fill. The beds in these gradients of streams are coarse and stable, so no bed-control structures are required. Figure 2.6 shows the stream simulation design option at high slopes.

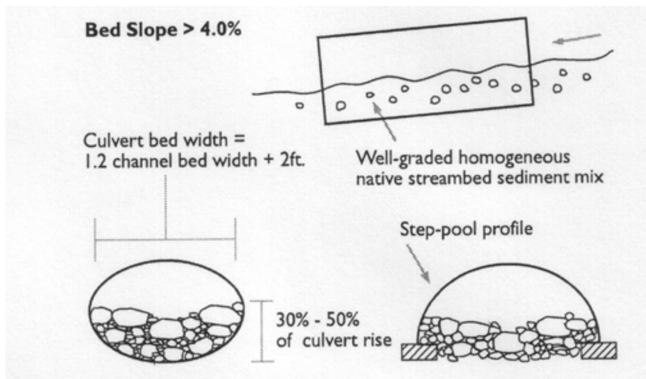


Figure 2.6 The stream simulation design at high slopes. Figure reproduced from Washington Department of Fish and Wildlife (2003)

*2.3.7 How much to embed a culvert*

As detailed above, the Washington Department of Fish and Wildlife (2003) stipulates for all culverts other than bottomless culverts, the bottom of the culvert should be placed below the streambed a minimum of 20% of the culvert diameter for round culverts or 20% of the vertical rise for elliptical culvert, and be filled with, or naturally allowed to fill with, natural streambed material or similar material. The Oregon Department of Fish and Wildlife (2004) says to place the culvert below the streambed a distance of at least 20% of height or 1 ft (30 cm), whichever is greater. The Oregon Department of Fish and Wildlife (2004) prefers but does not require this for no-slope culvert designs. The Washington Department of Fish and Wildlife (1998, 2003) says that typically 30-50% of the culvert rise is filled (embedded) in the stream simulation design method (embedding at other than zero slope). Again, the reasoning behind this is that the channel is thus raised to the widest part of a pipe culvert, and a deep, monolithic bed structure is created which allows for significant bed adjustments without exposing the bottom of the culvert. Clay (1995) surveyed many road crossing design recommendations and found generally agreement that the culvert bottom should be depressed below the normal stream gradient by a certain amount. For pipes less than 10 ft (0.3 m) in diameter, this was as little as 1 to 2 ft (0.3 to 0.6 m) below the stream gradient, and one fifth of the pipe diameter below the streambed for larger pipes.

For reasons stated in Section 2.3.5, namely because the Washington Department of Fish and Wildlife (2003) design guidelines are comprehensive, they match or exceed the criteria for stream simulation of other design guidelines, and because they make specific reference to designs intended to protect all fish species, they have been selected as the model for culvert design for the Etowah River Basin and protection of the Cherokee darter. It is the recommendation of this thesis that the Washington Department of Fish and Wildlife (2003) guidelines are followed and the culvert bottom be placed below the streambed by a minimum of 20% of the rise or diameter in the no-slope design option or 30-50% for the stream simulation design option.

### *2.3.8 Sediment Transport Equilibrium*

The stream simulation option typically requires that the culvert be in equilibrium with respect to the size and quantity of sediment transported into and out of the culvert. If the channel downstream has a tendency to degrade then the stream simulation culvert or any other culvert should be protected by countersinking a sufficient amount or installing bed controls downstream. If there is a significant lack of material entering the culvert from upstream the stream simulation or no-slope techniques may be problematic. Bottomless culverts could be looked at in this instance or experimental installations that have downstream controls to raise the water level in the culvert could be considered. However, downstream controls are likely to create barriers to passage of small-bodied fish.

Natural channels with 3-10% gradients are generally sediment limited, requiring a source of sediment to preclude scouring to all but the coarsest fraction, having no alluvial characteristics at all. Step-pool morphology is recommended for slopes over 3% (Washington Department of Fish and Wildlife 2003).

### *2.3.9 Material in culvert*

Culverts sunk below the streambed will often naturally acquire streambed material from upstream. When using the stream simulation design option, material may need to be placed in the culvert to avoid problems with scouring at either end while the culvert fills with material. The material in the culvert should be as similar as possible to that of the surrounding natural streambed. If there is riprap of a similar size to a portion of the streambed substrate then this could be used to fill the culvert with the expectation that smaller particles from upstream will collect over time.

### *2.3.10 Culvert slope*

In general, the culvert gradient should be no steeper than the streambed gradient above and below the culvert. It has been argued that slopes less than the stream gradient are suitable, even zero slope (Washington Department of Fish and Wildlife 1998, 2003). The Oregon Department of Forestry (2002) designs for culvert at zero grade for stream slopes less than or equal to 2.5%. The culvert slope should be less than or equal to 0.5% with the intention of 0%. Clay (1995) argues that any departure from the original stream gradient upsets the natural regime of the stream and should be avoided. This is in keeping with recommendations (Washington Department of Fish and Wildlife 2003) that the ratio between the culvert slope and the stream slope be no greater than 1.25 for stream simulation design. Long term assessment studies on new or improved culvert installations are scarce and ongoing studies will be needed for conclusive evidence.

### *2.3.11 High and low flow fish passage considerations*

In many cases, fish passage may be possible at low flow and not at high flow or vice versa. High fish passage design flow is based on the 2% exceedance discharge of daily occurring flow. Otherwise it is based on the cross-sectional area of active channel. Low flow design depth should be based on the 2-year, 7-consecutive day discharge or the 95% exceedance flow (The National Marine Fisheries Service, Southwest Region 2000). Salmon migrate during high flow periods whereas Cherokee darters are more likely to traverse culverts during low or base flows because they seek safe refuge in high flow events.

*2.3.11.1 Fish behavior during storm events and implications for culvert design flows*

During storm events, Cherokee darters tend to remain stationed in locations that provide refuge from high water velocities (Freeman 2004). This is comparable to behavior of the leopard darter; another federally threatened small benthic percid fish, which is found in Oklahoma and Arkansas. Leopard darters observed in the field in high current velocities (up to 0.50 m/s) were always observed to be flat against the substrate, whereas when swimming, they would typically remain 5-10 cm above the substrate. These observations indicate that fish similar to the Cherokee darter are unlikely to swim long distances during storm events and the design flowrate for adequate fish passage should be during low flow.

*2.3.12 Culvert size*

It has been stated that ensuring adequate sizing of the culvert usually minimizes scour, especially when combined with dissipation of the energy of the flowing water by rough culvert surfaces (such as the natural stream bottom), using flat culverts or using backwatering pools (Robison et al. 1999). Adequate sizing and countersinking has been shown to prevent scour plunge pools (Barnard 2003). Increasing culvert roughness by putting streambed material, boulders, riprap, baffles etc. in the culvert will reduce the flood flow capacity for the same culvert dimensions (Clay 1995). Therefore the substrate roughness needs to be considered in the design calculations.

*2.3.12.1 Sizing for passage of the 50-year flood*

Road crossing openings should be sized and designed to maintain structural integrity during the 100-year flood, and to pass the 50-year flood as required by state design guidelines (Atlanta Regional Commission 2001). If designing according to the methods outlined here, the fish passage requirements should result in a culvert sufficiently large to carry the 50-year storm and maintain structural integrity during the 100-year flood (no more than a 1 ft (0.3 m) deep backwater should occur at the culvert during a 100-year flood (McCafferty 2003, personal communication)). The reason being, fish passage designs typically have larger cross sectional areas than those sized for passage of design storm flows. However calculations should be made to ensure this. This is addressed in Section 4.3.

2.3.13 Pipe v box culverts

Clay (1995) argues that a metal pipe with corrugations is preferred over a concrete box culvert, because of the increased roughness provided by the pipe corrugations and the problems inherent in the box culvert's wide level cross section that is believed to be difficult for fish to ascend at low flows. However, smaller fish such as Cherokee darters may have less difficulty swimming upstream through a box culvert at low flows because they are small enough to swim in shallower depths than larger fish. Velocity is more likely to be a limiting factor than depth for such small, weak-swimming fish.

Compared with box culverts, pipe culverts are more prone to scouring at the outlet resulting in a perched outlet (Clay 1995). However, if culverts are embedded sufficiently far below the streambed, and filled with streambed material to match the natural streambed height, the type of culvert (box, pipe or arch) should not make a great difference to fish passage. Adequate sizing and embedding of culverts has been shown to prevent scour plunge pools (Barnard 2003).

*2.3.14 Skew, length and lighting*

Another consideration is skew of the culvert from the stream direction (extreme skew is greater than 30% and increases inlet contraction and turbulence at high flows). Long culverts affect stream sinuosity and can lead to problems for sediment transport. Culvert length, combined with excessive water velocity creates barriers to fish passage (Washington Department of Fish and Wildlife 1998). Fish cannot maintain *burst speeds* long enough to swim the entire length of most culverts. If the distance for which burst speed is required is too great, fish may tire before reaching the other end, and be swept back downstream. Long culverts are also dark, which may discourage some fish species from entering. For small native fish in Australia, culverts should be less than 6 m if no resting areas are available or water velocities exceed 0.3 m/s (Queensland Department of Primary Industries and Fisheries 2004). Toepfer et al. (1999) indicated that 5.4 m would likely be excessive for darters, such as the leopard darter. Stream simulation can be used for long culverts.

*2.3.15 Roughness, backwatering and resting refuges in culverts*

Another alternative is to use backwatering, drops and pools to dissipate the energy. This is an option that would be problematic for non-jumping fish. Creation of velocity shadows or hiding places inside culverts so that fish can rest or exist in places inside the culvert is also recommended for salmon (Robison et al. 1999). Stream simulation may provide such refuge for small fish.

Outlet backwatering to a minimum of 6 in (0.15 m) (where there is a downstream control structure such as a log or a weir backing the water up) or sinking the culvert into the streambed by 6 in (0.15 m) is recommended by Oregon Department of Fish and Wildlife (2004). Depressing the invert into the streambed, if it does not effectively fill with sediment, can cause upstream barriers to passage, blockage if the culvert is not oversized, and may require excavation of the upstream section to prevent a drop at the inlet. Backwatering may lead to a blockage of fish passage for small-bodied small stream fish if they cannot jump or swim over the obstacle. Therefore backwatering is not recommended in this thesis although it may be considered in experimental culvert designs if monitored.

Ensuring that slope criteria are met as well as sufficient sinking of culvert, sizing of culvert and the option to place fill material in the culvert if it does not naturally fill with streambed material, should prevent passage problems associated with embedding and sinking culverts.

*2.3.16 Multiple culverts*

The Queensland Department of Primary Industries (2004) also recommends multiple culverts. They claim that a multiple culvert structure built to stream width is arguably more beneficial to migrating fish than a single culvert that does not span the stream. Multiple culverts can allow water velocity to remain similar to the natural stream condition. Both box and pipe culverts can readily be incorporated into multiple culvert designs. When installing multiple culverts, the culverts can be staggered in height, with the lowest in the middle of the stream channel, concentrating the water during low flow. The ability to maintain streambed material in each culvert of the installation will vary. Multiple culverts are not the optimum design option because they will alter the stream hydrology however they may provide adequate stream width to minimise hydrological alteration and may be considered for fish passage as long as their performance is monitored before widespread use is considered.

*2.3.17 Fish presence*

Fish presence or potential is often considered when prioritizing road crossings for replacement. (Oregon Department of Fish and Wildlife 2004). There are increased costs associated with crossings designed for fish passage. The lower limit for presence of the Cherokee darter is typically about 0.5 $km^2$; but even smaller streams may have other fish such as creek chubs and salamanders. Therefore it is the recommendation of this thesis that all new crossings in the Etowah River Basin be designed so as to avoid downstream plunge pools and high base flow velocities through culverts, i.e. according to the design recommendations.

*2.3.18 Land use planning*

Well-chosen land use or road routing designs can minimize the number of stream-crossings required.

*2.3.19 Installation*

Installation issues include the need for fish screens if water is being temporarily pumped out for construction. Movement of stranded fish needs to be factored in. Impact on stream habitat, sediment creation and biota need to be minimized.

*2.3.20 Maintenance*

Fish passage barriers are often created due to a lack of culvert maintenance. Culverts are long-term features with 25-50 year lifetimes (Washington Department of Fish and Wildlife 1999). Culvert failure can cause extensive habitat damage. The use of fords or alternate road overflow locations may be desirable on forest roads susceptible to debris flows. Maintenance of culverts may require more attention to ensure they meet fish passage requirements over the long term.

After large storms, inspection and removal of debris should be carried out. Culverts should be inspected annually, possibly more frequently, to ensure correct operation. Annual reports should be required. Maintenance involving placement of new streambed material in culverts or addition of riprap to outlets to raise the streambed level may be ineffective if hydrologic conditions remain unchanged, and would lead to new scouring and loss of new material.

While the purpose of this research is to look at fish passage criteria for new culvert installations, maintenance and alteration of culverts already installed, may be important in the future in order to enhance fish passage. It may be required in the future if widespread fish passage enhancement is deemed necessary. Understanding issues with maintenance also provides understanding of the difficulties inherent in managing an inflexible man-made object in the confines of an everchanging stream system. Streams are governed by the processes of fluvial geomorphology. Stream beds are naturally maintained in a constant state of flux, with deposition and removal of streambed material altering the depth and, over time, the river channel position.

Instead of the expensive processes of completely removing impassable culverts (for which programs are in place in Oregon and Washington), other options exist but have not been proven. To improve culverts which exhibit perching, placing riprap or concrete sills or baffles, is recommended (Clay 1995). Paving of an eroded plunge-pool basin or placement of concrete sills or baffles has been recommended (Clay 1995) if the invert of the culvert pipe has been placed at or above the natural stream bed. However, placing more paved substrate in a fluvial system should be done only with careful consideration because it could lead to scouring downstream of the paved material. Clay (1995) argues that the level of scouring in the system would be known and therefore paving and placement of riprap would be suitable for old culverts. For weak-swimming fish this may be a problematic solution.

When velocity is excessive in old culverts, filling the bottom with streambed material may be beneficial but baffles may be required if this is insufficient (Clay 1995). For pipes placed at or above the natural stream bed, streambed material used to fill the pipe may scour out, or the added roughness provided by natural streambed material may be insufficient to reduce velocity sufficiently.  Baffles could include fastening boulders at intervals along the bottom of the culvert, or extend to formal concrete baffles. Boulders are usually sufficient for minor velocity barriers for anadromous salmonids. The boulders should be fastened (cementing them to culvert walls, holding them with steel reinforcing rods, bolts drilled into the pipe, or angle irons fastened to the pipe). Excessive turbulence associated with baffles makes them unsuitable for most designs intended to reduce velocity for passage of small-bodied stream fish such as the Cherokee darter. Baffles can become blocked with debris (Clay 1995) requiring frequent maintenance.

Given the lack of effective designs which could be effected without cementing or firm placement of riprap, maintenance of existing culverts is not recommended at this point for improving fish passage in the Etowah River Basin. If this option is desired in the future, test culverts with riprap placed at the outlet to raise the plung-pool bottom level could be installed. Without lowering the culvert bottom so that streambed material can be retained it will be difficult to enhance fish passage without creating downstream obstacles to fish passage.

2.4 Current road crossing design procedures used in Georgia

When the upstream drainage area is less than 20 $mi^2$ (51.8 $km^2$), the Georgia Department of Transportation (GDOT) will consider using a culvert. Above this size, they typically install only bridges. ‘The decision to use a culvert is based on cost (vs. a bridge) and the ability to match the culvert width to the size of the stream’ (McCafferty 2003, personal communication).

The Georgia Stormwater Management Manual section on culvert design (Atlanta Regional Commission 2001) requires that culverts be designed to manage (remain structurally sound during) the 100-year flood. The GDOT culverts are designed so that they are able to match the natural width of the stream and carry a 50-year flood on state routes (McCafferty 2003, personal communication). Also, the culverts must be capable of carrying sufficient volume so that no more than a 1 ft (0.3 m) deep backwater occurs at the culvert during a 100-year flood. The design procedure requires determination of hydrologic parameters from field data. Parameters that need to be determined for the site include the design discharge rate, maximum culvert rise (or culvert diameter), headwall, headwater elevation, bevel, tailwater, tailwater rating curve, overbank, roadway overtopping, culvert performance curve, endwall, discharge range or flow profiles, USGS regression equations, inlet elevation, outlet elevation, culvert length, Manning’s n values of the main channel and left and right overbanks, and channel slope. An illustration of some of these parameters is shown in Figure 2.7. Headwalls and endwalls are structures placed at the ends of culverts to retain the road formation soil around and above the culvert ends, direct the entry/exit of water to/from the culvert and prevent erosion at the entrance and exit to the culvert. They may be constructed from rock, concrete, etc. Roadway overtopping is determined for storm flows greater than the design storm flow, when water will flow over the roadway because the flow is too great to flow through the culvert. Tailwater and headwater depths are determined from channel dimensions, channel roughness and stream discharge. The overbank dimensions and roughness coefficients are required because they determine the stream flow regimes and profiles in floods that exceed the main channel, which will affect the headwater and tailwater rating curves and thus the culvert performance curve. Bevel-edged inlets are designed to improve hydraulic performance of the inlet.

Many design options are not strictly defined and are a matter of designer preference. Parameters considered in the selection process include barrel shape (pipe, box, etc.), number of barrels, culvert span, culvert rise, culvert slope, inlet type (e.g. conventional, bevel edged), material, Manning's n for culvert material, inlet depression (or fall, the distance between the natural streambed surface elevation and the culvert inlet elevation), inlet and outlet inverts. Thus the type of culvert to be used in an installation (box, pipe, embedded or bottomless) is not mandated; nor is the material of construction.

The type of culvert chosen is also based on the velocities that would occur during a flood (McCafferty 2003, personal communication). The culvert must be such that the velocity will not cause a blowout at the downstream end of the culvert. There is no requirement for the "natural" velocities to be met, only that there is no structural instability. In other words, in north Georgia where the substrate may be bedrock, there is little concern about the resulting velocities, where as in south Georgia where the soils are sandy and less stable, the velocities will be minimized. Georgia Best Management Practices (BMPs) for Forestry require that culvert bottoms be placed level with the streambed.

Private road crossings are not always designed according to the GDOT guidelines. Culverts sized to pass the 25- or 10- year storms may be used on smaller roads that are used infrequently.

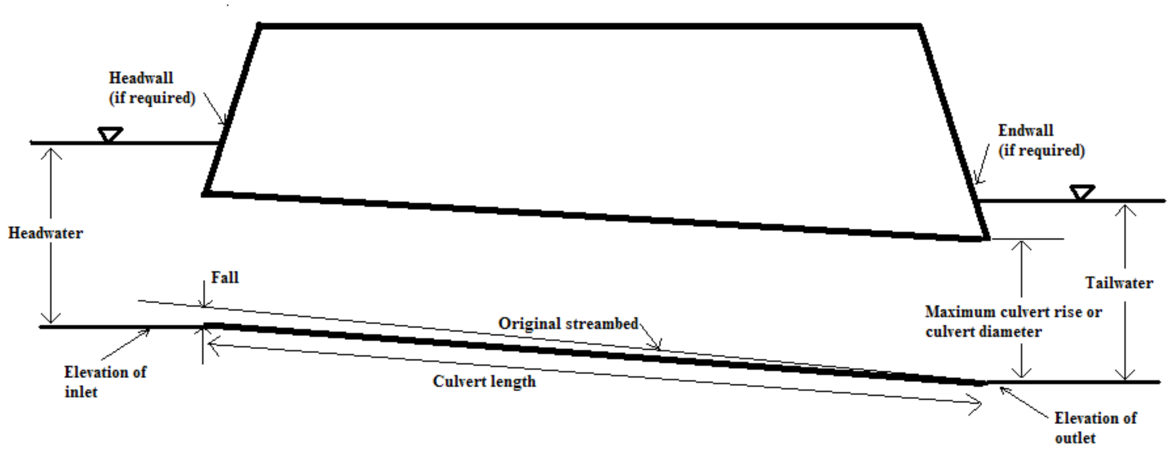


Figure 2.7 Some culvert dimensions and parameters required for GDOT culvert design. For descriptions of these and other parameters see Section 2.4. Although headwater and tailwater elevations are shown here above the culvert rise or diameter, during most flows they will be below the maximum culvert rise or diameter.

## 2.5 Summary of literature review findings – criteria for fish passage

### *2.5.1 Velocity*

Warren and Pardew (1998) found that velocities above 0.4 m/s impede fish passage in small streams. The Queensland Department of Primary Industries (2004) recommends maintenance of base flow velocities below 0.3 m/s for passage of the majority of native Australian fish. For many darters 0.25 m/s is likely to be excessive over typical culvert lengths. The strict criteria for impassable culverts is therefore set at 0.25 m/s to make conservative estimates of the number of impassable culverts in the Etowah River Basin survey. 0.4 m/s is also assessed as the more lenient criteria. Velocity alone is not sufficient criteria for an impassable culvert, but it is a factor.

### *2.5.2 Culvert type*

Bridges, especially freespan bridges are the preferred option from a fish passage perspective, but are prohibitively expensive to use frequently on small streams. Non-embedded pipe culverts are prone to scouring and creation of perched culverts. Non-embedded pipe culverts also reduce the channel cross-section. Non-embedded box culverts are prone to prohibitively high velocities combined with very shallow depth at base flow. Countersinking and embedding culverts helps avoid these problems because roughness causes velocity to decrease and protecting the culvert outlet with streambed material and riprap protects it from scour. Bottomless culverts (arches or boxes) are recommended for fish passage but the stream substrate needs to be considered since loose soft substrates will pose problems with scouring around the foundations, creating safety and stability issues.

### *2.5.3 Percent embedding*

Embedding of box and pipe culverts is recommended for meeting the passage requirements for juvenile salmon and most likely is necessary to meet the requirements of small weak-swimming benthic fish such as the Cherokee darter. The recommended depth to countersink and embed a culvert varies among authors. The minimum is 10 to 20% (Clay 1995) and the maximum is 30-50% in stream simulation design (Washington Department of Fish and Wildlife 2003). Embedding a culvert to 40% of its diameter is recommended because it results in a wider cross section that is more likely to match the natural width of the stream. However, increasing the depth at which the culverts are embedded increases material costs because larger culverts are required to accommodate the fill material as well as the storm flows. Until evidence is provided to the contrary it seems reasonable to require 20% of the diameter or rise of the culvert be embedded (countersunk below the streambed and filled, or allowed to fill, with streambed material) for the no-slope designs. At higher slopes stream simulation (30-50% countersinking and filling with streambed material) may be required to allow for natural processes of sediment erosion and supply. At slopes over 3%, step pool morphologies may need to be considered to prevent loss of culvert bed material since in some states slopes of 3-10% are associated with lack of upstream sediment.

### *2.5.4 Culvert size*

When fish passage is considered, larger culverts are required for two reasons. First, embedding a culvert to simulate the natural streambed requires larger pipes to include the fill material as well as the design flow. The increased roughness of the substrate may also decrease the flood flow capacity. The other reason given in the literature is that larger pipes should produce less scouring at the outlet because flow is less constricted during maximum storm flow events. If culverts are being embedded and sized for fish passage, sizing must also be adequate for passage of the 50-year flood, although this needs to be checked for each design. The protection at the outlet offered by streambed material should minimize scouring problems. The design size and the depth to embed a culvert have not been given definitive limits in the literature and require further study. At this time, culverts designed for the 50-year flood, at 20% embedding and to match the culvert bed width to the bankfull stream width are recommended, but once installed they should be inspected as part of long term studies in the Etowah. In streams with high slopes (over 2.5%) stream simulation options may be more suitable, requiring sizing of the culvert bed width to be 1.2 times the bankfull stream width plus an extra 2 ft (0.6 m).

#### *2.5.5 Scour depth as indicator of impassability*

For adult salmon, drops at culvert outlets of less than 1 ft (0.3 m) are recommended. For juvenile salmon, drops of less than 6 in (0.15 m) are recommended. Many native Australian fish are unlikely to pass upstream through culverts with jumps of even a couple of inches. Similarly, the Cherokee darter has not been observed to jump at all.

The drop to the water surface will vary depending on stream discharge. The drop to the stream bottom will not vary with water level. The drop to the water surface at baseflow was selected as one of the criteria indicating fish passability. Criteria of 0.15 m (6 in) (recommended for juvenile salmon) at base flow is selected to conservatively estimate the number of impassable culverts 0.02 m was selected as the more stringent criteria to estimate the number of impassable culverts due to any detectable drop because any drop may be impassable to small fish and the occurrence of any drop is also likely to be associated with a lack of any streambed material in the culvert, providing a smooth surface.

In making recommendations for fish passage criteria, it is probable that embedded culverts will be required to reduce the occurrence of perched culverts. Without protecting the culvert outlet, scouring will occur over time and small drops will form on most culverts, especially pipe culverts. Adequate sizing and countersinking has been shown to prevent scour plunge pools (Barnard 2003).

*2.5.6 Impact of new design requirements*

Since the Georgia Department of Transportation already requires that culverts match the natural stream width and pass the 50 year flood it is possible that new designs for road crossings will not be significantly larger than those currently required. For counties and private owners not currently matching the stream width or sizing for the 50-year flood (especially on small streams and little used roadways) the new recommendations may be more arduous.

## 2.6 Initial guidelines for fish passage design criteria

Synthesizing the findings of the literature review, the recommended design criteria to be followed are as follows:

- Bridges (especially freespan bridges) are the preferred option for all streams and are required for large streams and rivers. It is recommended that bridges be used to cross any stream with a drainage area equal to or greater than 20 $mi^2$ (51.8 $km^2$), following GDOT guidelines (i.e., only bridges are typically considered for streams draining over 20 $mi^2$ (51.8 $km^2$));
- If bridges are infeasible due to cost or other factors, bottomless culverts or embedded culverts shall be employed. Embedded culverts can be used for stream slopes up to 8%. Embedded culverts shall be placed so that the inlet is deeper than the outlet for slopes between 4% and 8%;
- Two embedded culvert design procedures are acceptable. The no-slope design option (on stream slopes less than 2.5%) and the stream simulation design option, as defined by the Washington Department of Wildlife (2003) on stream slopes up to 8%;
- The no-slope design option (Section 2.3.6.1) requires sizing the culvert so that the culvert bed width is equal to the bankfull width of the stream. The culvert must be embedded to a to a minimum of 20% of its diameter or rise. The cross sectional area must be sufficient to pass the 50-year flood. No-slope embedded culverts should only be used on stream slopes less than 2.5% with culvert gradients less than or equal to 0.5%;

- The stream simulation design option (Section 2.3.6.3) requires sizing the culvert so that the culvert bed width is equal to 1.2 times the bankfull width of the stream plus an extra 0.6 m (2 ft). It requires sinking the culvert below the streambed by 30-50%. If the culvert does not naturally fill with streambed substrate, similar material should be placed in the culvert to match the natural streambed elevation. The slope in the culvert should not be more than 1.25 times the upstream stream slope;
- For embedded culverts, fill shall consist of natural stream material or material of a similar size and composition as in the adjacent streambed. The use of larger material (e.g. rip rap), for structure in the stream simulation design option for slopes up to 4%, may be required, interspersed with material similar to natural streambed material;
- Road crossing openings shall be sized to pass the 50-year flood and maintain structural integrity in the 100-year flood;
- Under no circumstances shall perched culverts be acceptable;
- Culverts shall be designed to minimize downstream scour, so that they will not become perched over time. Size, slope relative to the stream, and embedding should ensure this.
- At base flow, water velocity through culverts should not exceed 0.3 m/s;
- During construction, duration and extent of stream channel disturbance shall be minimized to the greatest extent practicable. All attempts shall be made to minimize erosion of banks and sedimentation of streams during construction;
- Variances to these requirements shall be considered for streams draining less than 0.3 $km^2$.

## CHAPTER 3

## METHODS

### 3.1 Road crossings in the Etowah River Basin

Seventy road-stream crossing sites were selected from across the Etowah River Basin. They were selected using a random stratified design so that twenty sites had drainage areas between 1 and 3 $km^2$, twenty sites 3 and 9 $km^2$, twenty sites 9 and 25 $km^2$ and ten sites had drainage areas between 25 and 50 $km^2$. These categories were selected because each subsequent minimum value represents a doubling of the two-year flood. The Cherokee darter is typically found in small streams with drainage areas up to 50 $km^2$, although the full extent of Cherokee darter habitat is not certain. Drainage area of 1 $km^2$ was selected as a minimum size for site locations for the study.

The road-stream crossings were located using ArcView 3.2, a GIS based mapping software. Random points were generated across the Piedmont region of the Etowah watershed. At each point on a stream, the drainage area above that location could be discerned using the software and the closest road-stream crossing to each point that met the necessary drainage area criteria could be determined. The sites selected were then located on detailed local maps. In some cases the local maps had more up to date street names, or slightly different road locations than ArcView 3.2.

Stratified random site selection was determined to be the appropriate method because initial attempts at completely random site selection within the 1-50 $km^2$ range resulted in significant skew towards very small streams. The GDOT installs culverts on streams with drainage areas less than 20 $mi^2$ (51.8 $km^2$) (McCafferty 2003, personal communication). Any size culvert can cause fish passage problems and different designs and crossing types are used for different stream sizes. For these reasons stratified random site selection was chosen.

The doubling of the two-year flood was selected to separate the stratification categories because the two-year flood is considered relevant to the size and geomorphology of a stream (Leigh 2003, personal communication). There are no specific stream size criteria for selecting different culvert types. Culvert type is selected on a case-by-case basis.

Flood discharge relationships based on drainage area for the Etowah River Basin (Stamey and Hess 1993) were obtained and used to determine the drainage areas at which a doubling of the two-year flood flow occurred. Appendix A shows these calculations, which determined category stratification cutoffs at 1, 3, 9 and 25 $km^2$ drainage areas.

The method of point selection was intended to ensure that all counties in the Etowah were represented without bias toward counties with high numbers of culverts, such as Cobb and Cherokee counties. Randomly selecting site locations by aerial location rather than by road crossing, high-density counties are not over represented. Figure 3.1 shows the random site locations generated across a map of the Etowah region.

## 3.2 Field data collection

The parameters measured in the field were those selected as important in determining whether a crossing was impassable or not, and why. These physical and hydrological measurements were taken at each site. The parameters determined to be important from the literature review and analysis of open channel and culvert flow equations are:

i. Crossing type
ii. Crossing size (diameter or width and height, length)
iii. Slope
iv. Velocity
v. Flowrate
vi. Stream width
vii. Water depth in culvert
viii. Drop at the outlet to downstream water surface or the bottom of the plunge pool
ix. Scour plunge pool dimensions
x. Presence of streambed material or similar material in culverts

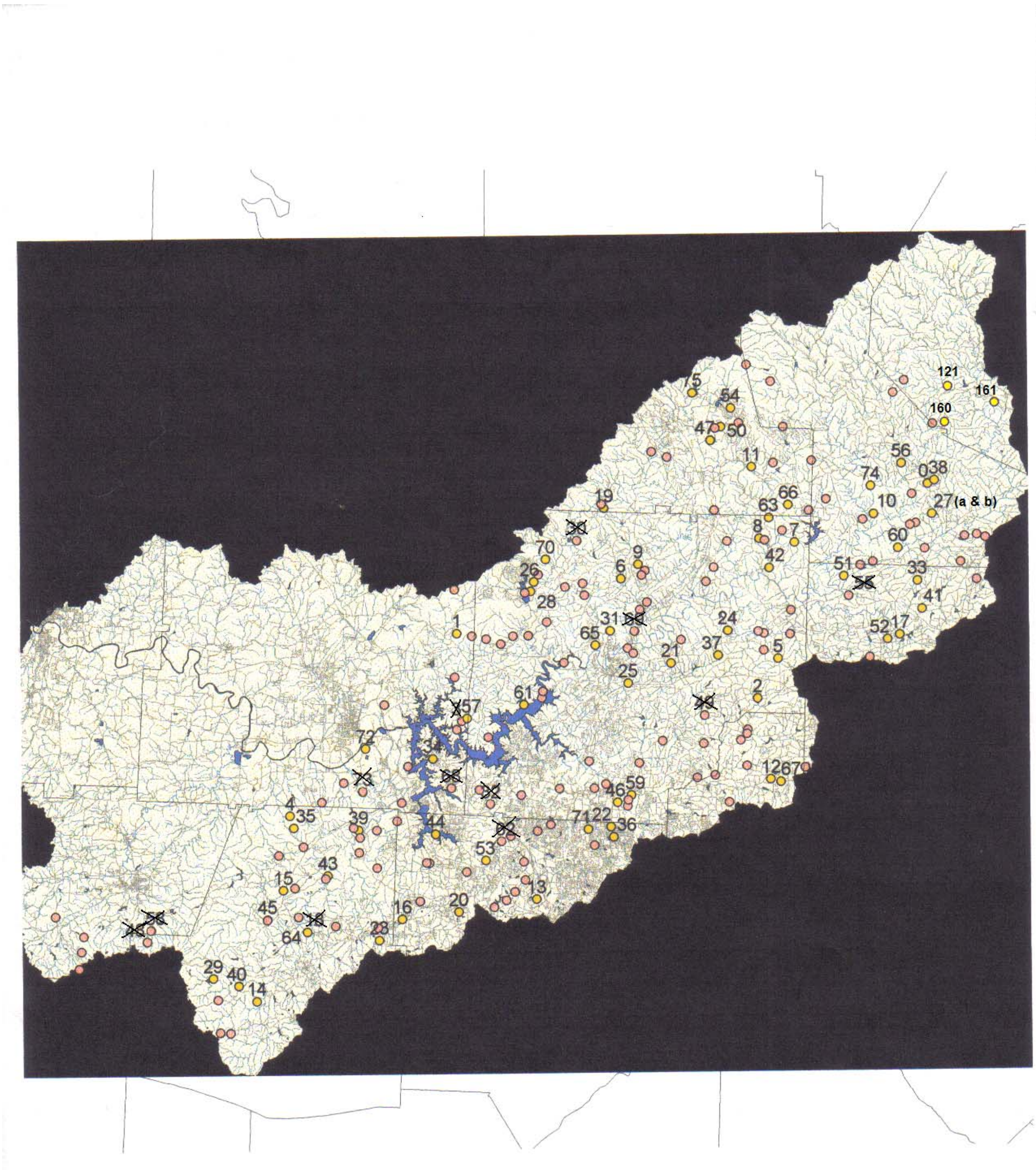


Figure 3.1. Random site locations across the Etowah River Basin . Generated in ArcView 3.2. The site locations can be found in Appendix B as 'Culvert #'. The sites used are numbered and have yellow dots. Pink dots are other random points that were not used. Site stratification into drainage size areas is not shown here. Numbers crossed out indicate crossings that were not found, involved difficult access or were discarded from the data set because they were excess sites. The yellow dots indicate the random point locations used to find the closest sites. Actual site locations are the closest road crossing meeting the drainage area criteria. For actual site locations, please see Appendix B for road and stream names.

The data sheet used to take measurements at each site is shown in Figure 3.2. Culvert drainage area was obtained from ArcView 3.2. Culvert dimensions were measured using measuring tapes and yard sticks (most culverts are large enough to be entered by field crew). Culvert velocity and cross-sectional flowrates were obtained using a Doppler flowmeter attached to a depth rod and a measuring tape to take cross-sectional readings in the streams of the velocity 40% of the depth below the surface (which represents the location for measuring the approximate average velocity). Each cross-section was divided into a minimum of 10 sections for readings. Sometimes the velocity in the culverts was difficult to obtain because of high turbulence or shallow depth affecting readings, so velocity was later calculated for all sites using the culvert dimensions and the flowrate obtained for the stream.

In multiple opening road crossings the flow was apportioned using the term, $AR^{2/3}$ , from Manning's equation (where A is the cross-sectional area of the flow and R is the hydraulic radius as defined for Equation 1), which can be calculated from the water depth and culvert dimensions. Inaccuracy in this technique arises because it applies to normal, developed uniform flow. The water in some of the culverts appeared to be at supercritical flow, which would have higher velocities in these openings than in the others. Other sources of error include the inherent assumption that slope in each opening at a crossing was equal and that the roughness was the same. In most cases this assumption appeared to be acceptable because most times culvert openings were installed at the same slope using the same building materials. The presence of riprap or stream sediment in the culverts would affect the flow apportioning; however it would be very time consuming to effectively take this into consideration. In most cases where the main flow opening was with or without sediment in opposition to other openings, by far the majority of flow was in the main opening.

For the water depth in each culvert opening a maximum value was typically sufficient because the depth distribution of a cross section could be approximated using the maximum depth and the culvert dimensions.

| | | | |
|---|---|---|---|
| **Names/Initials of Officers:** | | | |
| **Culvert #:** | **Stream:** | **Road:** | **County:** |
| **Culvert Size (Watershed Drainage Area or Other):** | | | |
| **Date (Month, Day, Year):** / / | | | |
| **Time Started:** | | **Time Ended:** | |

| | | |
|---|---|---|
| **Culvert Type:** Box / Pipe – Concrete / Corrugated Metal / PVC Bridge Other: | | |
| **Number of Openings:** | **Road Surface:** Paved / Gravel | **Number of Lanes:** |
| **Culvert Diameter:**<br>Corrugation Wavelength:<br>Corrugation Height: | **Culvert Width:**<br>**Culvert Height:** | |
| **Culvert Length:** | **Sketch:** | |
| **Culvert Slope/Change in Height:** | | |
| **Overhang:** | | |
| **Drop to Bottom:** | | |
| **Drop to Water Surface:** | | |
| **Upstream 'Jump':** | | |
| **Max water depth in culvert today:** | | |
| **Velocity in Culvert at Inlet:** | | |
| **Velocity in Culvert at Outlet:** | | |
| **D50:** | | |
| **Scour pool:** Length: | Max Depth: | Width: |
| **High water mark in floods (above water surface):** | | |
| **Sediment in Culvert: Yes / No** | **Stream Gradient: Low / Med / High =** | |
| **Riparian Buffer Condition:** | | |
| **Stream Condition:** | | |
| **Substrate:** | | |

| | |
|---|---|
| **Typical Cross Section** **Upstream / Downstream** | **Width:** |

***Cross Section Flowrate Data:***

| Width (Units: ) | Depth (Units: ) | Velocity (Units: ) | Width (Units: ) | Depth (Units: ) | Velocity (Units: ) |
|---|---|---|---|---|---|
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| | | | | | |
| **Average Depth:** | | **Average Velocity:** | | **Average Flowrate:** | |
| **Notes:** | | | | | |

Figure 3.2 Data Sheet 1: Culvert hydrology / geomorphology data sheet**.** Data sheet last updated June 4, 2004

A digital camera was used for taking a picture of most of the road crossings for later reference. In some cases a suitable photograph was difficult to obtain, and several photographs were lost. The photographs of the sites are shown in Appendix E.

Culvert slope was obtained by various methods, including a clinometer, a yardstick used at the outlet to site the inlet height in some cases, and where access was suitable, a viewfinder and tripod with a stage reading rod. Culvert slope was difficult to measure with any accuracy. A more sophisticated clinometer (with finer delineation of slope than 1 degree intervals) should be used in future similar studies, because very low slopes (0.2%) are associated with impassable culverts (Powers and Bates 1997).

Presence of riprap or streambed material in each culvert was noted although due to the difficulty of digging into the substrate and the variation in sediment depth throughout culverts that were not completely filled with sediment, it was difficult to accurately assess depth of sediment.

High water marks were noted in culverts (lines of rust where water had risen to in corrugated metal pipes, changed concrete color in concrete culverts due to water level) and as scouring of the stream banks near culvert outlets. However, additional time and expertise would be required to accurately estimate bankfull width, which was determined late in the research timeline as important to new culvert design.

The drop to the water surface or plunge pool from the culvert outlet was measured directly down from the culvert opening, or from the edge of the culvert apron in culverts that had concrete aprons that were not covered in streambed material. Pipe culvert outlets were assessed for overhang, defined as the distance from the culvert opening to the edge of the plunge pool wall in cases where the pipe opening had suffered scouring below the pipe or where the culvert was perched.

As with many of the culvert studies done in the past, it was only as new information was obtained that new measurements were identified as important to the analysis. While riverbed substrate was qualified (noting the presence of pebbles, cobbles, sand, clay, boulders, bedrock) D50 was not explicitly measured. A 100-step pebble count would be recommended at all or at a statistically relevant number of sample sites in the Etowah River Basin to better quantify the substrate makeup. This is because scour plunge pool dimensions are impacted by substrate size and similarity between the substrate in embedded culverts and the substrate in the streams may indicate the long-term susceptibility of the culvert bed to failures (significant loss of culvert bed material or alteration of slope in the culvert).

Stream widths of representative sections of stream upstream and downstream were determined using a tape measure. This required a certain level of judgment because stream widths vary along the length of a stream reach.

Riparian and stream conditions were noted but not used in the analysis of the sites.

Scour plunge pool dimensions were measured using yardsticks and tape measures. By walking around the plunge pool in waders the deepest point was found and the widest point perpendicular to the culvert opening was measured for plunge pool. The distance from the culvert outlet to the point where the stream began to narrow again was taken as the length of the plunge pool.

3.3 Statistical analysis

Regression analysis (linear and power regression lines), graphs and analysis of variance (ANOVA) were used to study the relationships between the parameters that were considered likely to affect passage for small-bodied fish. Drainage area, flow rate, culvert type, vertical drop at the outlet, culvert slope, water depth in the culvert, scour pool dimensions, presence and depth of sediment, and the typical stream width on the day that each site was assessed (used as an approximation to the bankfull or active stream width) were considered as parameters. Velocity, depth in the culvert and drop to the downstream surface were considered as dependent variables.

Initially, using the conservative criteria of 0.4 m/s maximum average velocity through a culvert and maximum 0.15 m (6 in) drop to the water surface, culverts were identified as passable or impassable. Using more stringent criteria of 0.25 m/s maximum velocity and the presence of any drop to the water surface at base flow (0.02 m), culverts were again identified as passable or impassable. Even these criteria are likely to give a conservative estimate of the number of impassable culverts in the Etowah River Basin study, given that velocities over 0.25 m/s for distances greater than 1.55 m were found to be problematic for leopard darters (Toepfer et al. 1999) as detailed in Section 2.2.1. But using the fish passage criteria of

0.25 m/s maximum velocity over distances of 1.55 m, or culvert lengths without refuges of 5.4 m, none of the road crossings in the study could be considered passable except bridges and culverts with streambed material, or those in sluggishly moving streams with exceptionally low velocities. The presence of any drop to the bottom at the outlet of a culvert, even if there is no drop to the water surface, could also be problematic because it indicates that the culvert has no sediment in it at the outlet and that scouring is occurring. Drop to the bottom alone is not a criteria affecting fish passage so the occurrence of a drop to the bottom alone does not indicate an impassable culvert in this analysis (Section 4.1.2, Table 4.3).

Excessive velocity is recognized as having critical impact on fish passage. However, as stated in Section 2.3.3 and by (Buffington and Montgomery (1999) and Barnard (2003), average velocity may not be a sufficient or suitable criterion for fish passage. Culvert length and the presence of streambed material have also been shown in the literature to impact passage. Identifying culverts that exceed average velocity criteria will provide a lower limit on the number of impassable culverts and will help explain problems with fish passage. As mentioned in Section 3.2 the velocity estimation procedure at many road crossings was imperfect for several reasons. Some culverts did not allow effective direct measurements because the culverts were too small, the water level was too shallow, or the turbulence in the water was very high and interfered with the readings. Using the stream flowrates, the road crossing dimensions, and the depth in each opening, the average velocity in the opening could be estimated. The flowrate measurement had some error in it, estimated at 30% from taking repeat readings in some streams, but in some cases the error was likely higher due to difficulty locating cross sections with low turbulence. This error might be avoided in the future by taking more readings in a cross-section, but some error will be unavoidable in natural channel flowrate measurement. However, it can be assumed that across the entire data set the flowrate estimation error will become a random error and should not greatly affect the number of road crossings determined to be impassable on the basis of velocity criteria.

### 3.4 New culvert design analysis

In order to make recommendations on new culvert designs the new fish passage culvert design techniques from the literature (no-slope and stream simulation) were used to size pipes based on estimated bankfull width and the resulting sizes and costs were compared to traditional pipes sized for passage of the 50-year flood. Computer modeling using SEDCAD 4 was carried out to determine design pipe diameters for the 50-year flood (and the 100-year flood with 1 ft (0.3 m) excess headwater). The SEDCAD 4 modeling results and the no-slope and stream simulations were also compared to the single pipe sizes used in the Etowah River Basin for passage of the same size 50-year flood, to determine if pipe culverts in the Etowah River Basin may be undersized for passage of the required storm flow (which may contribute to scouring).

The no-slope and stream simulation designs were compared with the larger road crossings in the Etowah River Basin study, by comparing total available width to pass the stream discharge and total available cross-sectional area.

Because Cherokee darters are more likely to move at low flows than high flows the hydraulic method for designing culverts for fish passage is not applicable. With sufficient roughness and shallow enough slope the velocities can be controlled at below 0.3 m/s at low flows in the single pipe culvert sizes used in the Etowah River Basin. However, the creation of scour pools due to excessive flow during high flows and the maintenance of a culvert bed resembling the streambed are not addressed by sizing a pipe to maintain low velocity at low flow, but require analysis at high flows to avoid scouring. Further research on minimum pipe sizes that do not create scour pools when countersunk and filled with streambed material could lead to smaller pipe sizes being accepted in the future, but the hydraulic design does not address this issue in the absence of data on scour pool creation and pipe size.

SEDCAD 4 was also used to explore which factors influenced scour plunge pool geometry, with limited success. Zero tailwater was assumed for pipe sizing because values ranging from zero up to the pipe diameter resulted in the same pipe design sizes. When assessing scour pool dimensions the tailwater was set at 0.1 ft (0.03 m) less than the outlet invert and 0.1 ft (0.03 m) more than the channel crest. The SEDCAD 4 pipe diameters are given in commercial increments of 54, 66, 72, 84, 96, 108 and 120 in. No larger sizes are available for the analysis although larger culverts can be constructed in new culvert installations. If the plunge pool was less than the pipe diameter plus 4 ft (1.2 m) SEDCAD 4 would not proceed with the calculation.

Low or base flow analysis was carried out to determine if new designs were likely to provide acceptable velocities for fish passage, and what impact slope, culvert width, substrate (roughness), flowrate have on depth and velocity. Base flow depths and velocities were approximated using Manning's equation. Culvert sizes resulting from the SEDCAD 4 analysis, the no-slope and stream simulation designs, and the average crossing characteristics for each size category or crossings were thus assessed, as well as the average of all crossings with a single pipe installed, which provided the easiest basis of comparison across all techniques for determining culvert adequacy for small streams.

For corrugated metal pipes, a Manning's n value of 0.024 was used and for concrete pipes, 0.011 was used. Natural streambed material roughness values in the literature range from values similar to those for corrugated metal pipes up to 0.04 or 0.05 for cobble beds. Higher values are associated with vegetation or larger flow obstacles. A value of 0.04 was selected as an average value for fairly uniform natural streambed material that would be suitable for culvert bed substrate.

CHAPTER 4

RESULTS

4.1 Etowah River Basin road crossing study results

*4.1.1 Road crossing types in the Etowah River Basin*

The distribution of road crossing types is shown based on drainage area (Figures 4.1 and 4.2 and Table 4.1) and by county (Figure 4.3).

As can be seen in Figure 4.2, pipes are used mainly on small streams, whereas boxes and bridges are used on a wide range of stream sizes. There is no real lower limit in terms of drainage area for the use of any road crossing type.

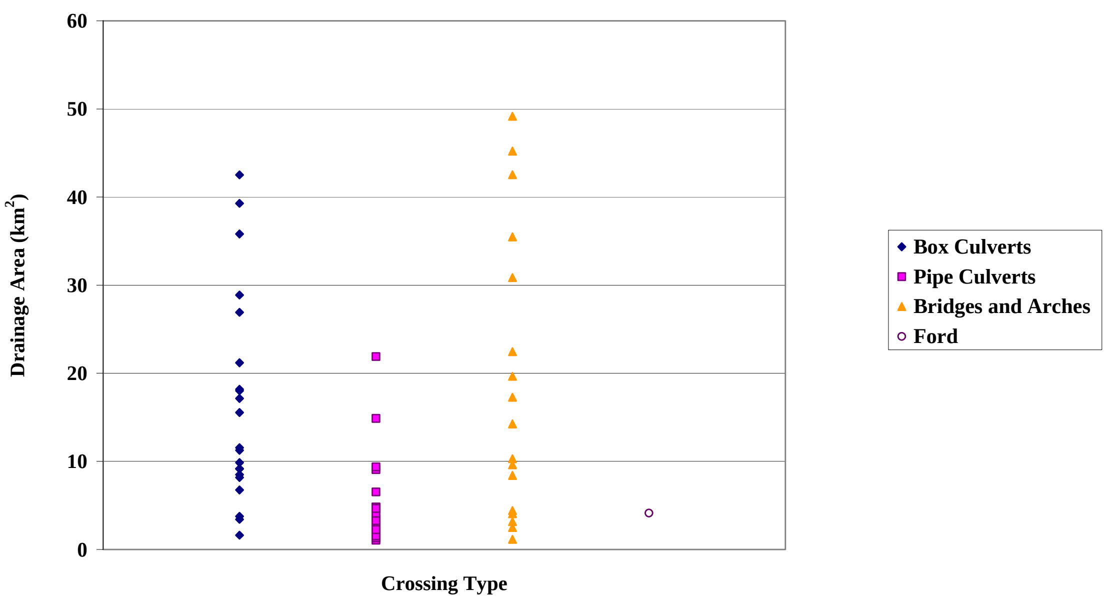


Figure 4.1 Road crossing type usage by stream size (indicated by drainage area)

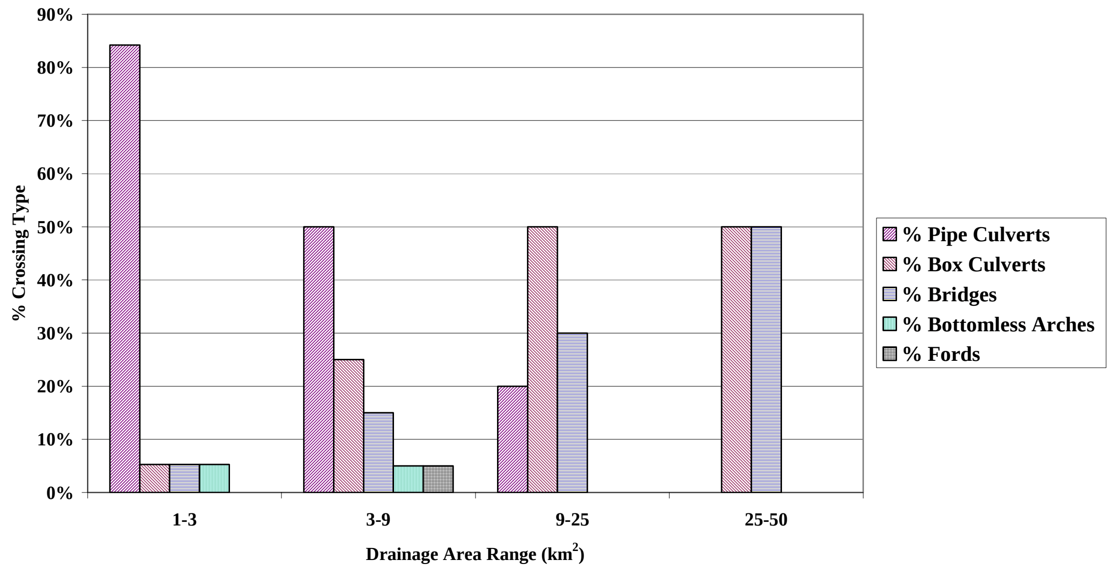


Figure 4.2 Road crossing type usage by drainage area range

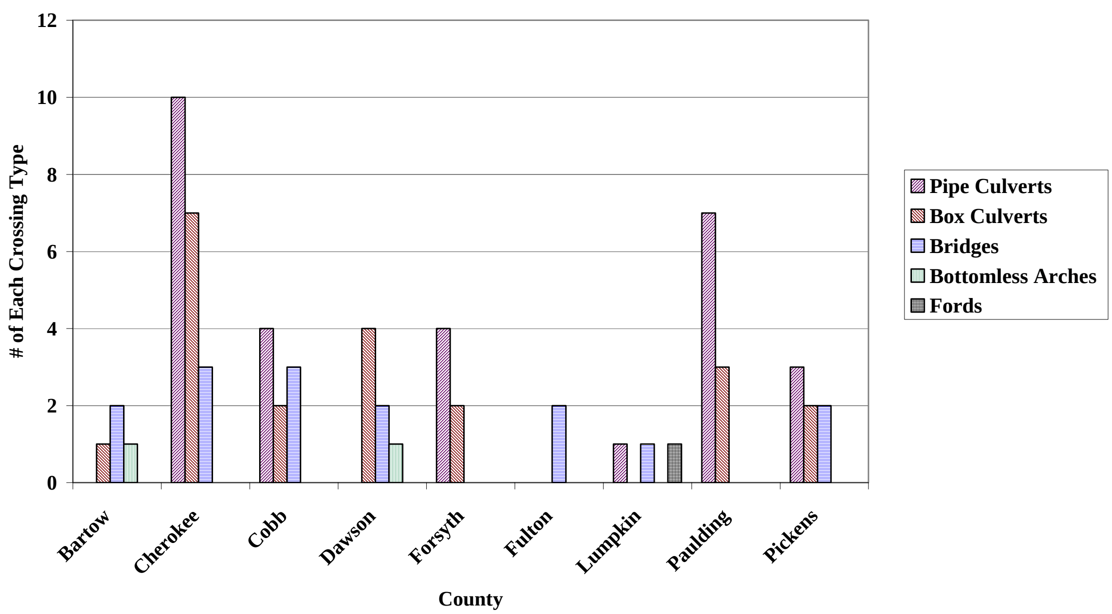


Figure 4.3 Road crossing type usage by county

Table 4.1 Road crossing types by drainage category

| | 1-3 | 3-9 | 9-25 | 25-50 | Total |
|---|---|---|---|---|---|
| Total Crossings | 20 | 20 | 20 | 10 | 70 |
| # of Pipe Culverts: | 17 | 10 | 4 | 0 | 31 |
| # of Box Culverts: | 1 | 5 | 10 | 5 | 21 |
| # of Bridges: | 1 | 3 | 6 | 5 | 15 |
| # of Bottomless Arches: | 1 | 1 | 0 | 0 | 2 |
| # of Fords: | 0 | 1 | 0 | 0 | 1 |

### *4.1.2 Impassable road crossings*

The criteria selected to indicate impassable culverts are based on literature results. Conservative estimates were made using the criteria that velocity greater than 0.4 m/s or a drop greater than 0.15 m (6 in) to the water surface from the culvert outlet indicates an impassable culvert. Applying more stringent conditions, velocities greater than 0.25 m/s are considered impassable and any drop to the water surface or to the bottom at low flow was considered a barrier. This second set of criteria can be looked at in two ways. First, any drop to the surface is likely to be impassable for Cherokee darters, and the presence of any drop at the outlet indicates the culvert has no or little sediment. According to Toepfer et al's (1999) results, culverts over 5.4 m long and without refuges are likely to be impassable for leopard darters, which have similar body size and stream habitat to Cherokee darters. The average culvert length in the Etowah River Basin was 18.3 m long. Only two culverts were less than 5.4 m in length. Some were over 50 m long. These very stringent conditions for fish passage should offer insight into the upper limit on the number of impassable culverts. Literature information on the need to embed culverts to provide a natural streambed for small weak-swimming fish (and also the results shown in Section 4.2) indicate that the presence of embedded material or sinking of the culvert below the bed may also be necessary criteria for fish passage. This is addressed in Section 4.2.

According to conservative criteria (Table 4.2) the study found 16 impassable pipe culverts out of 29, and 13 impassable box culverts out of 22. The 18 bridges and arches were all considered passable. One bridge exhibited excessive velocity and fairly shallow water over bedrock, however the high depth and natural streambed material of most bridges would likely provide low velocities near the boundary layer. The shallow depth in most high velocity culverts combined with smooth culvert walls would not provide as much variation in velocity in a cross-section. While this may seem like a loose interpretation of the stated criteria for passage, it should be noted that velocity alone is not considered adequate criterion for assessing fish passage. The knowledge of fish swimming ability is limited and the presence of natural streambed may be a better criterion. Thus the level of deviation from the natural streambed may be a better criterion. In three cases the drop upstream of the culvert created by a blockage is the cause of the impassability. In one case the blockage compounds the already high velocity. These are included as impassable culverts. According to the criteria they could possibly be made passable by removing the upstream blockage. However without a sediment bed in the culvert, removing the blockage might not necessarily enhance passage.

The results according to more stringent criteria are shown in Table 4.3. Out of 29, 24 pipe culverts were considered impassable, while 14 of 22 box culverts were considered impassable. In ten cases that are considered impassable according to the strict criteria (Table 4.3), but not according to the more lenient criteria (Table 4.2), it is due to the lower velocity required. In one case it is due to the presence of a drop to the surface of 0.08 m. A drop to the water surface occurred at the outlet of a small arch (0.13 m). However the drop was not sharp and could possibly be passed at slightly higher flows, so this is not included in the impassable culverts although it could be considered impassable. Because of the presence of natural streambed material in bridges, excessive velocities in bridges are not included in the impassable road crossings, although the excessive velocities are noted. Due to high depth indicating potential for low velocity near the stream bottom, and the roughness of the natural stream channels (large boulders and cobbles were the stream substrate in many large crossings) likely to provide added friction near the stream bottom and reduce velocity, high velocities in road crossings with stream cross-sections very similar to the natural channels are unlikely to detrimentally impact fish passage. No pipe crossings were notably embedded. Two appeared to have been deliberately placed so that their bottoms are sunk below the streambed (Section 4.2). One filled with sand in a flood.

Table 4.2 Impassable culverts in the Etowah River Basin according to conservative, more lenient criteria

| Impassable More Lenient Conditions | 1-3 | 3-9 | 9-25 | 25-50 | Total |
|---|---|---|---|---|---|
| Impassable | 8 | 10 | 8 | 4 | 30 |
| Velocity > 0.4 m/s | 4 | 8 | 7 | 5 | 24 |
| Drop > 0.15 m | 6 | 3 | 4 | 0 | 13 |
| Pipes Impassable | 7 | 7 | 3 | 0 | 17 |
| Pipes Velocity > 0.4 m/s | 5 | 6 | 3 | 0 | 14 |
| Pipes Drop > 0.15 m | 3 | 1 | 2 | 0 | 6 |
| Boxes Impassable | 1 | 3 | 5 | 4 | 13 |
| Boxes Velocity > 0.4 m/s | 0 | 3 | 3 | 4 | 10 |
| Boxes Drop > 0.15 m | 1 | 1 | 2 | 0 | 4 |
| Other | 1 Arch (Drop) | | Bridge over bedrock (velocity) | Bridge (velocity, fairly deep) | |
| Upstream Jumps Included | 1 pipe: drop upstream | 1 pipe: drop upstream | 1 pipe: drop upstream + velocity. 1 box: drop upstream | | |

Table 4.3 Impassable culverts in the Etowah River Basin according to more stringent criteria (higher number of impassable culverts). Drop to the bottom is shown but does not contribute to the total number of impassable culverts.

| Impassable More Stringent Conditions | 1-3 | 3-9 | 9-25 | 25-50 | Total |
|---|---|---|---|---|---|
| Impassable | 15 | 10 | 10 | 5 | 40 |
| Velocity > 0.25 m/s | 10 | 9 | 9 | 5 | 33 |
| Drop (any drop > 2 cm to bottom) | 14 | 6 | 9 | 3 | 32 |
| Drop (any drop > 2 cm to water surface) | 7 | 3 | 5 | 2 | 17 |
| Pipes Impassable | 13 | 7 | 4 | 0 | 24 |
| Pipes Velocity > 0.25 m/s | 9 | 6 | 4 | 0 | 19 |
| Pipes Drop (any drop > 2 cm to bottom) | 12 | 4 | 4 | 0 | 20 |
| Pipes Drop (any drop > 2 cm to water surface) | 5 | 2 | 2 | 0 | 9 |
| Boxes Impassable | 1 | 3 | 5 | 5 | 14 |
| Boxes Velocity > 0.25 m/s | 1 | 3 | 3 | 5 | 12 |
| Boxes Drop (any drop > 2 cm to bottom) | 1 | 2 | 4 | 3 | 10 |
| Boxes Drop (any drop > 2 cm to water surface) | 1 | 1 | 3 | 2 | 7 |
| Other | 1 Arch (Drop) | | 2 Bridges (velocity), 1 over bedrock | 3 Bridges (velocity), fairly deep | |
| Upstream Jumps | 1 pipe: drop upstream + small drop downstream to bottom | 1 pipe: drop upstream. | 1 pipe: drop upstream + velocity 1 box: drop upstream + downstream | | |

Virtually all crossings other than bridges or bottomless arches would be more suitable for fish passage if culverts were embedded, as evidenced by velocities excessive for fish passage and scouring at the outlets. Shallow water depths (less than 5 cm) occurred in many culverts.

*4.1.3 Sources of error in the analysis*

It is difficult to estimate the error in calculations of stream flowrates and calculated culvert velocities. There was as much as 30% error in calculations of stream flowrates as approximately 10 points were used at each cross section. Downstream stream width showed a linear relationship with drainage area with an $R^2$ value of 0.55. Road crossing total width showed a linear relationship with drainage area with an $R^2$ value of 0.31. There was no linear relationship between slope and velocity. Although velocity is a function of slope, the range of slope values compared to the accuracy in obtaining them was low, and there are other factors likely to impact the relationship. Velocity did not correlate well with road crossing type except when the presence of sediment in the culvert was considered (Section 4.2). Bridges on average had lower velocities than pipes or box culverts for similar flowrates.

The collected results from the culvert study are given in Appendix B, whereas Appendix C and D show the calculations used to determine stream flowrate and calculated culvert velocities, respectively.

4.2 Embedded culverts – presence of sediment in main channels

Table 4.4 shows the results of analyzing the impact that the presence of streambed material in the road crossings has on velocity and water depth. Of the 70 data points, three bridges were removed for lack of any velocity data. One box culvert and one pipe culvert were ignored because the box culvert was downstream from a dam and the pipe culvert inflow appeared to be pumped with the outflow feeding into a dam.

As can be seen in Table 4.4, the presence of natural streambed material is associated with lower velocities and increased depth, although there is still variability throughout a single culvert opening not captured here. In cases where there is sediment in the main channel, the depth of water is the depth above the sediment. There is some inaccuracy in this depth because of variation in sediment depth. Many culverts may have sediment in areas other than the main channel but this was not considered, only looking at the impact of stream sediment on velocity (or vice versa).

Table 4.4 Presence of sediment in main channel vs velocity and depth by crossing type

| Type of Crossing | Sediment Occurs in Main Channel | # of Crossings | Average Velocity of Group (m/s) | StDev of Velocity of Group (m/s) | Max Vel in Group (m/s) | Average Depth of Group (m) | StDev of Depth of Group (m) | Average Flowrate of Group ($m^3/s$) | StDev of Depth of Group ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|---|
| Boxes and Pipes | Yes | 12 | 0.18 | 0.11 | 0.47 | 0.31 | 0.17 | | |
| Box | Yes | 6 | 0.21 | 0.14 | 0.47 | 0.26 | 0.10 | 0.41 | 0.47 |
| Pipe | Yes | 6 | 0.14 | 0.08 | 0.23 | 0.35 | 0.23 | 0.10 | 0.44 |
| Boxes and Pipes | No | 37 | 0.48 | 0.34 | 1.38 | 0.18 | 0.20 | | |
| Box | No | 13 | 0.45 | 0.26 | 1.11 | 0.10 | 0.12 | 0.25 | 0.18 |
| Pipe | No | 24 | 0.50 | 0.24 | 1.38 | 0.23 | 0.11 | 0.06 | 0.06 |
| Bridges, Arch, Ford, Stream Sim Box | Yes | 16 = 2 Arches, 1 Bottomless Box, 12 Bridges, 1 Ford | 0.21 | 0.23 | 0.98 | 0.23 | 0.21 | 0.25 | 0.23 |

Note: Average depth is given for each bridge and arch road crossing, because there was significant variation in depth across a cross-section. Pipe culvert depths given are maximum depths (measured at the lowest point in each pipe cross-section). Maximum depth in bridges and arches were typically 25 % or more greater than the average depth. This can be seen in Appendix C by determining the maximum depth measured for bridges and arches and comparing to the average depth. In most cases the flowrate measurements for bridges and arches were measured in the crossings or as close as possible to the upstream or downstream openings.

It is difficult in some cases to determine whether the sediment in the culvert lowers the velocity or vice versa. Natural streambed material typically has a higher Manning's roughness coefficient (0.04 on average) compared with concrete or corrugated metal pipes (0.011 and 0.025 on average respectively), which will reduce velocity. It is likely that high velocities during high flow periods, in part due to the design of the road crossing, may reduce the amount of sediment in a culvert, while at low flows the presence of the sediment will reduce velocities. On average, the depths of water in culverts with sediment are higher than those without. This again could be a result of the sediment impeding the velocity or due to the design of the road crossing (for example, culverts placed with their bottoms below the streambed may have greater depths).

Three pipe culvert installations deserve special mention. Containing minimal sediment, these culverts nevertheless exhibit relatively high depth and low velocity. Two are located in Cherokee county and one in Paulding county. They appear to be placed with their bottoms below the streambed because the depth in the culverts is greater than the typical stream depth. In the two road crossings in Cherokee (Figure 4.4, no photo of the Paulding site is available), riprap is placed directly downstream of the culverts, which may act as a downstream control device, maintaining water level in the culverts. This does not appear to block fish passage. Although the inlet to one culvert appears problematic (shallow water indicating increased velocity) these culverts appear to provide relatively tranquil flow. It should be noted that they also appear to be fairly recent installations, so over time they may create a scour pool. Therefore, they should be monitored to assess whether the tendency to scour is lessened with this design. It would appear from these results that natural channels in culverts are likely to reduce the velocities at base flow or low flow, and thus enhance fish passage.

Figure 4.4 Culverts with bottoms placed below the streambed in Cherokee county.

Box culverts with sediment in them also were found in the Etowah River Basin. Two were either bottomless or embedded. Two box culverts with outlet drops to the water surface maintained some sediment in the culvert. One had a middle culvert opening placed with the culvert bottom below the streambed, although the water was mostly diverted through a side culvert opening, which was placed in line with the natural streambed.

#### *4.2.1 SEDCAD 4 analysis of plunge pool (scour pool) creation*

The SEDCAD 4 analysis of plunge pool creation offered little insight into options to minimize plunge pools. The SEDCAD 4 designs do not incorporate any streambed material into the culverts. Full pipe flow is assumed for determining plunge pool dimensions. Froude numbers close to 2, which were the lowest numbers that could be achieved resulted in dimensions similar to the plunge pools observed in the Etowah River Basin. Single pipe installations with obvious scour pool dimensions had scour pools with average dimensions of length 8.7 m +/- 95% C.I. 3.2 m, depth 0.69 m +/- 95% CI: 0.59 m, width 4.9 +/- 95% CI: 3.80.Calculating plunge pools (also called scour pools) required a combination of D50 particle size, pipe diameter and flowrate. D50 values of 0.75 ft (for a 5.5 ft pipe) or greater were required to obtain these low Froude numbers and reasonable culvert scour pool dimensions. Using the 50-year storm flow, even at the lowest Froude numbers calculated plunge pool depths around 4 m. With D50 values of approximately 2 in (5 cm) the plunge pool dimensions were over 100 ft (30 m) in width and length, and 30 ft (9.0 m) in depth whether the 50-year or the 2-year storm flow was used. Using the 2-year flood instead of the 50-year flood, with D50 over 0.75 ft resulted in more reasonable plunge pool depths (around 1 m). While the 50-year storm flow is important to sizing a culvert, it is not the flowrate associated with most channel formation processes. Further research into D50 values in the Etowah River Basin is required. The objective is to avoid plunge pool formation, however, therefore the inability to include sediment in the culvert itself implies that SEDCAD 4 is not useful for such analyses.

### 4.3 Results of culvert sizing design analysis

#### *4.3.1 Are cross-sectional areas of culverts installed in the Etowah River Basin adequate for the 50-Year flood?*

In order to determine the suitability of any new designs for road crossings, they must first be capable of passing the 50-year storm flow as required by the Georgia Department of Transportation. It has been noted that culverts can be designed for the 25- or 10-year flood for small roads. Figure 4.5 shows the cross sectional areas of each crossing type and the design openings required to pass the 50-year storm flow. On average, box culverts and bridges are adequate to pass the 50-year storm flows. As can be seen in Figure 4.6, there is no particular county that appears to be significantly under-sizing culverts for flood management, although the counties with more urban development (Cherokee and Cobb) have no examples of undersized crossings on the larger drainage areas.

Figure 4.7 shows the cross-sectional areas on normal axes. It is clear from this perspective also that many road crossings are undersized. Cross sectional areas are calculated using a program developed by Tollner (2004).

Figure 4.8 shows the cross-sectional areas required for passage of the 25- and 10-year storm flows as well, and compares these to the pipe crossing cross sectional areas. These sizes are sometimes installed on smaller roads and streams. However, it can be seen that some of the crossings are likely to be too small to pass even these design floods. This may be acceptable from a flood management perspective if there is sufficient distance between the road surface and the pipe to prevent overflowing (or in some cases water flowing over the road may be acceptable during large storms, such as on small roads that receive little usage). From the perspective of fish passage these small openings are inadequate and may require the greatest increase in design size to meet fish passage requirements. On average they appear to be sized for the 10-year flood. Cross-sectional areas for the 10- and 25-year storm flows are obtained by extrapolating the relationships obtained using the program from Tollner (2004). Using SEDCAD 4 (not shown) and allocating greater numbers of pipes for higher flows, cross-section areas for the 10- and 25-year storm flows were slightly higher than the values shown here.

Two bridges are excluded from Figures 4.5, 4.6 and 4.7 because the cross-sectional areas available for flow were extremely large (approximately 130 $m^2$ for a drainage area of 49.2 $km^2$ in Fulton county and approximately 400 $m^2$ for a drainage area of 17.3 $km^2$ in Bartow county.

*4.3.1.1 SEDCAD 4 single pipe sizing analysis*

Ten road crossings assessed at base flow in the Etowah River Basin road crossing study consisted of a single pipe opening. The average pipe diameter of these crossings (with an average drainage area of 1.96 $km^2$) was only 5.4 ft. (Two single pipe road crossings were assessed at storm flow and not included in this analysis, because one of the objectives was to assess base flow properties, as will be mentioned later). One pipe for a drainage area of 1.04 $km^2$ was only 3 ft in diameter.

This result indicates that the single pipe culvert installations are undersized to pass the 50-year storm. This is also shown in Figure 4.5, which indicates that many pipe culverts may be sized for the 10-year storm (or not sized with any particular storm-flow requirement). This is highly probable because the GDOT has stated that, on small roads, culverts may be designed to pass the 10- or 25-year storms. In some cases of private land-owners installing culverts, little or no design effort is used.

SEDCAD 4 was used to size non-embedded pipes to pass the 50-year flood for the Etowah River Basin for various drainage area sizes, with no headwater above the top of the pipes, and to pass the 100-year flood with no more than 1 ft (0.3 m) headwater above the pipe diameter. For a drainage area of 1.5 $km^2$ the acceptable pipe diameter is 10 ft based on the flood frequency relationships for the Etowah River Basin (Stamey and Hess 1993). The SEDCAD 4 analysis is designed for single pipes analyses. For larger flows, multiple pipes can be used to approximate required cross-sectional areas. The results require slightly larger cross-sectional area totals than determined using the program from Tollner (2004). This is likely to be because the pipe sizes used in SEDCAD 4 are based on commercial piping sizes and therefore will be slightly larger than the minimum required if any pipe size was possible. Added pipe surface area may also be a factor in increasing resistance to flow.

*4.3.2 How crossings currently installed alter the stream width at low flow*

Figures 4.9 and 4.10 show how road crossings can alter stream width, which is one aspect of altering the hydrology through the road crossings. As can be seen in Figure 4.9, some road crossings, especially smaller ones, do not equal the wetted width at low flows even if their entire width (all openings and full pipe diameters) are utilized. The width of water in the crossing openings on the day

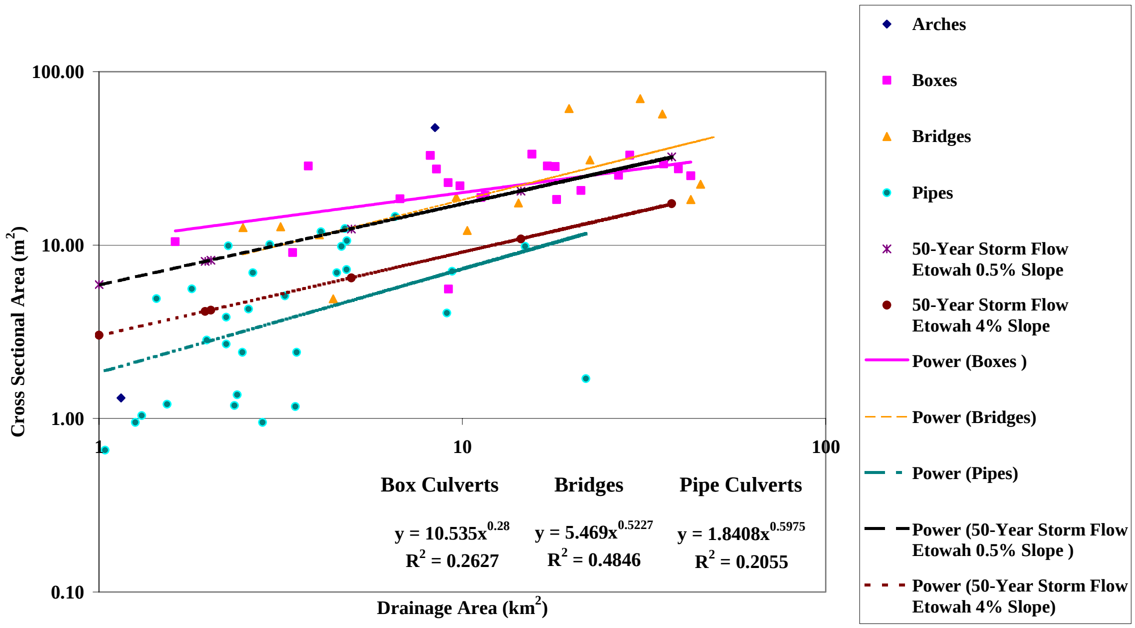


Figure 4.5 Cross-sectional area vs drainage area by crossing type, compared with cross-sectional area required to pass the 50-year flood

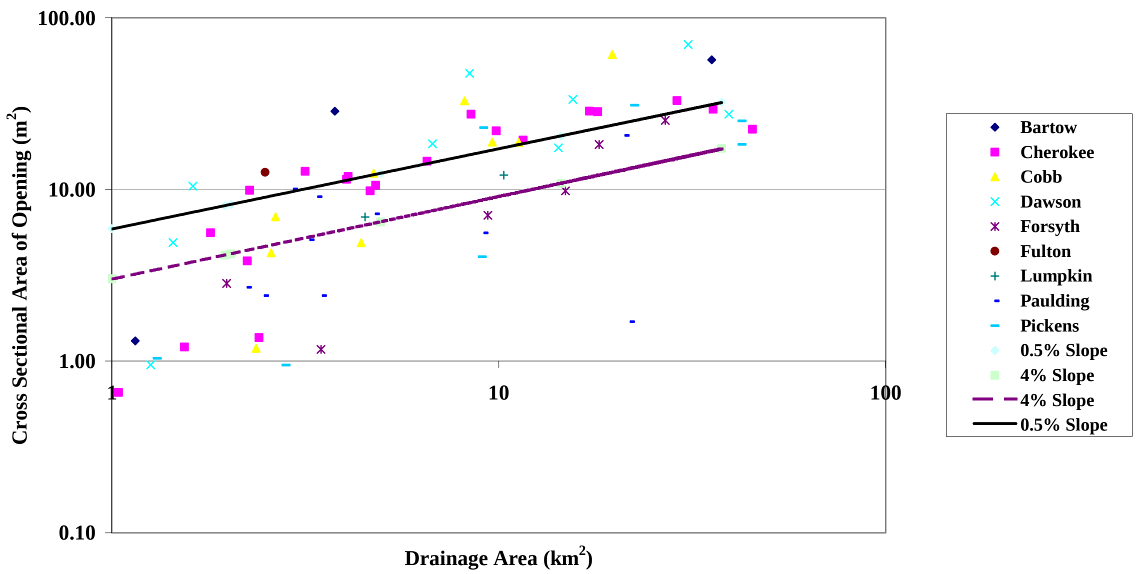


Figure 4.6 Cross-sectional area of opening vs drainage area for all counties

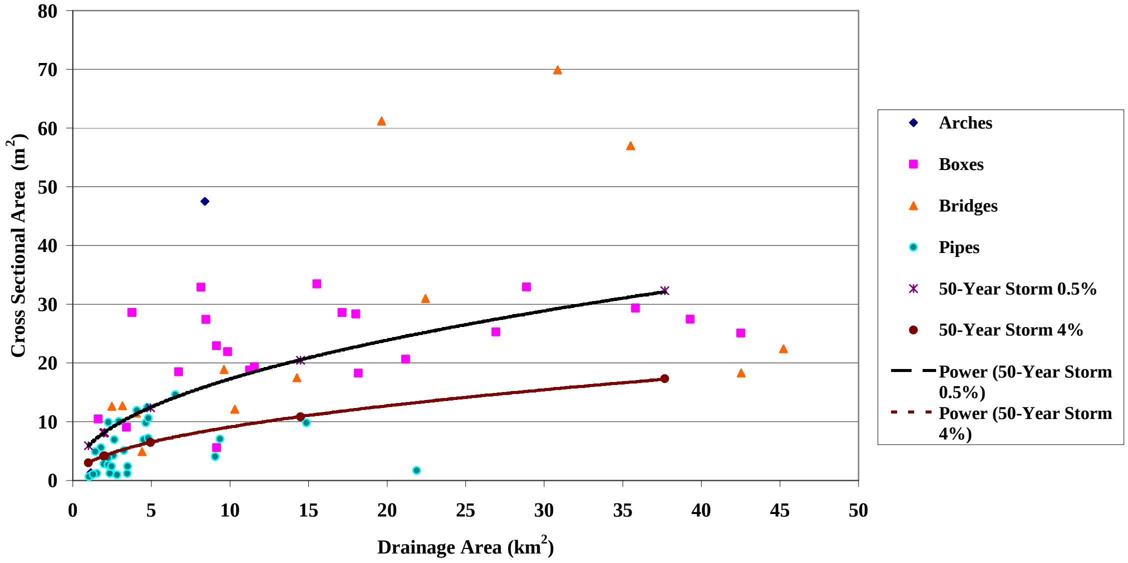


Figure 4.7 Cross-sectional area vs drainage area by crossing type

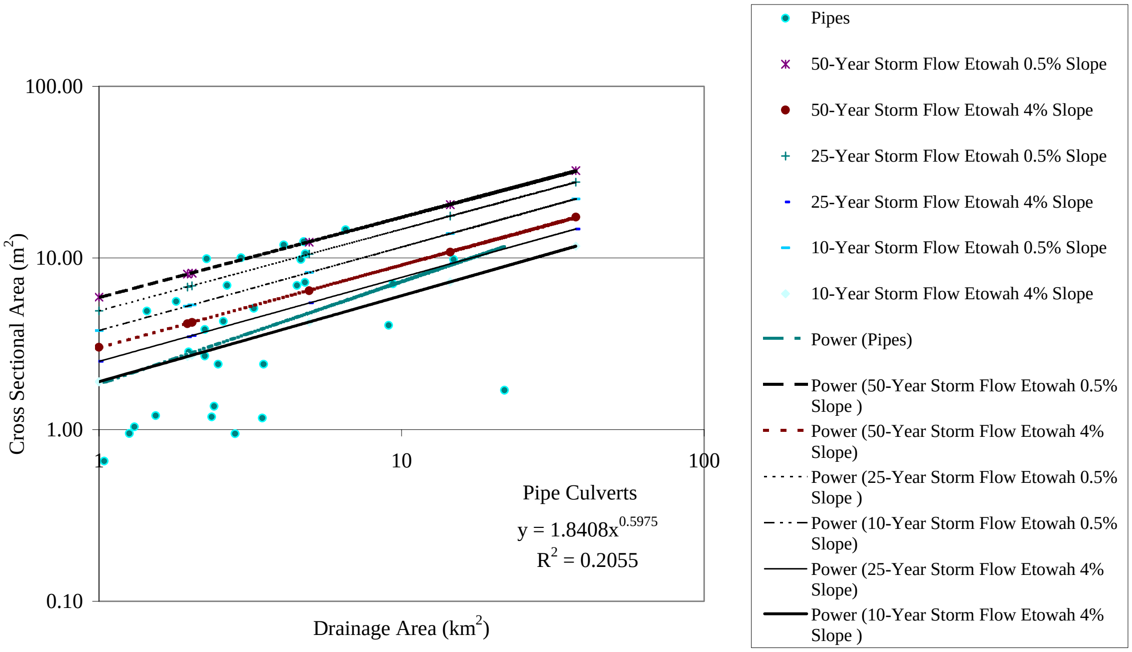


Figure 4.8 Pipe cross-sectional area vs drainage area, compared with 50-, 25- and 10-year floods

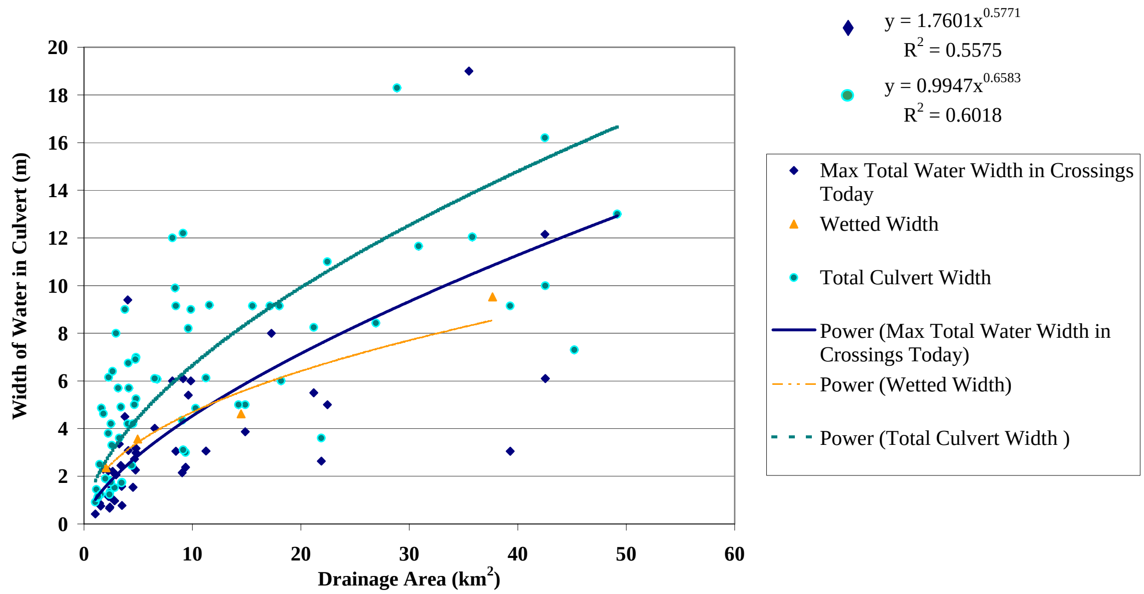


Figure 4.9 Wetted width, total culvert opening width available, and maximum total water width in crossings on the days measured

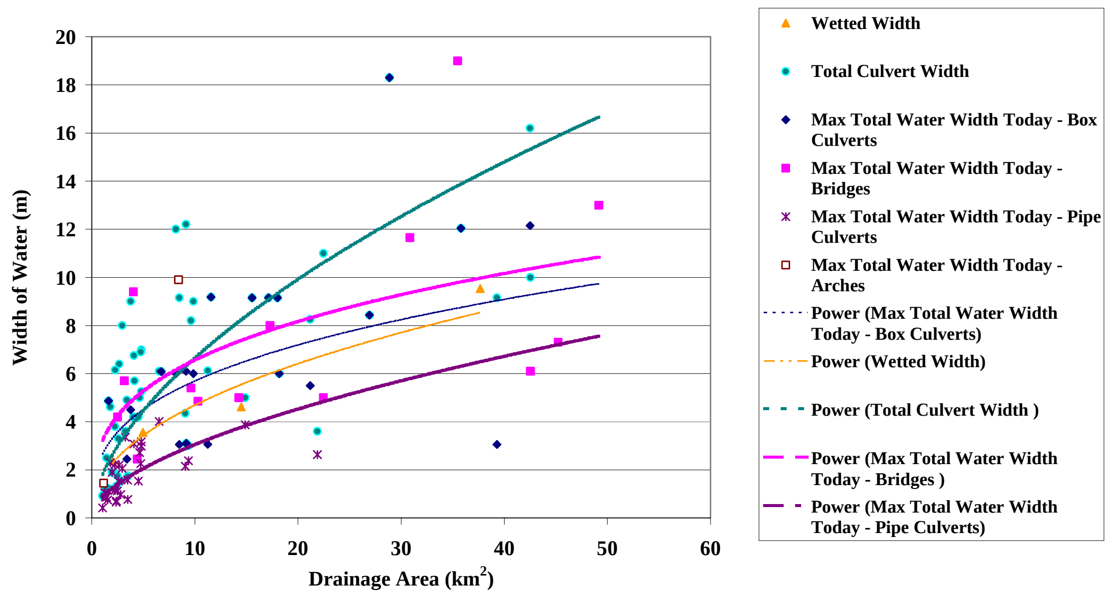


Figure 4.10 Maximum total water width on the days measured by culvert type (wetted width and overall total culvert width also shown)

measurements were taken was determined (from the water depth and the road crossing dimensions) for the openings that had flow. Total width was then determined by adding the widths in each opening with flow. As can be seen in Figure 4.10, pipe culverts on average reduced the stream width by a quarter to a third. Box culverts and bridges tended to widen the stream.

### *4.3.3 New culvert designs using no-slope (20% embedded) stream simulation design techniques*

#### *4.3.3.1 Estimating bankfull width for new culvert designs*

In order to determine the size of new road crossing designs using the no-slope (20% embedded) or the stream simulation design techniques, bankfull width needs to be estimated.

In the Etowah River Basin study, bankfull width was not determined in the field. Although wetted width on the day was measured, it was difficult to determine bankfull width with any accuracy. High water marks in culverts, changes in vegetation, and heights of bank scouring were noted, however bank slope was not measured.

Therefore when it was determined that bankfull width was essential, only estimates could be made. From photos, smaller streams appeared to increase in size by 100% of the wetted width at low flow. Tables 4.5 and 4.6 list some of the average parameters for each drainage area category. The upstream width (or downstream if upstream was not easily obtained) is used as the wetted width.

Bankfull width can be estimated from visible high water marks in culverts and stream-bank slope. Larger streams are not expected to increase by as much as small streams, because they are already wider than small streams, and typically have steeper banks. An example of a small stream and a large stream in the Etowah River Basin are shown in Figure 4.11. This difference in bank slope can be seen.

The initial culvert sizing analysis looked at three cases: bankfull = 50%, 100% and 150% greater than the average wetted width for five cases. The single pipe culvert installations (1.96 $km^2$ drainage area, 1.72 m wetted width), then each of the stream size categories in the study: 1-3 $km^2$, 3-9 $km^2$, 9-25 $km^2$ and 25-50 $km^2$ drainage areas. These values were then compared with bankfull width determined using the relationship from Rosgen (1996) after Dunne and Leopold (1978).

For determining the average wetted width for each category, the sites measured during a storm, one day after a storm, and the two sites that appeared to be pump or dam fed were not included in the average values.

a)

b)

Figure 4.11. Photos for comparing likely bankfull widths of small and large streams in the Etowah River Basin. a) Small stream in the Etowah River Basin – estimate bankfull width 100% greater than wetted width b) Larger stream – estimate bankfull width 50% greater than wetted width.

Table 4.5. Average values for road crossings sites in each size category at base flow or low flow only

| Stratification Class | 1-3 $km^2$ | | 3-9 $km^2$ | | 9-25 $km^2$ | | 25-50 $km^2$ | |
|---|---|---|---|---|---|---|---|---|
| | Mean | St Dev | Mean | St Dev | Mean | St Dev | Mean | St Dev |
| Drainage Area ($km^2$) | 1.99 | 0.59 | 4.95 | 1.80 | 14.55 | 4.91 | 37.63 | 6.80 |
| Typical Width Upstream (m) | 2.00 | 0.80 | 3.67 | 1.69 | 4.73 | 2.16 | 9.12 | 4.24 |
| Typical Width Downstream (m) | 2.28 | 0.86 | 3.83 | 2.49 | 4.06 | 1.72 | 9.49 | 2.84 |
| Flowrate ($m^3/s$) | 0.03 | 0.03 | 0.08 | 0.06 | 0.21 | 0.17 | 0.75 | 0.46 |
| Flowrate ($ft^3/s$) | 1.14 | 0.97 | 3.00 | 2.10 | 7.59 | 6.13 | 26.7 | 16.29 |

Table 4.6. Average values for road crossings sites in each size category for all sites

| Stratification Class | 1-3 | | 3-9 | | 9-25 | | 25-50 | |
|---|---|---|---|---|---|---|---|---|
| | Mean | St Dev | Mean | St Dev | Mean | St Dev | Mean | St Dev |
| Drainage Area ($km^2$) | 2.03 | 0.59 | 4.95 | 1.74 | 14.49 | 4.74 | 37.67 | 7.35 |
| Typical Width Upstream (m) | 2.35 | 1.36 | 3.56 | 1.55 | 4.62 | 2.09 | 9.53 | 3.66 |
| Typical Width Downstream (m) | 2.50 | 1.23 | 3.87 | 2.41 | 4.13 | 1.67 | 9.07 | 2.89 |
| Flowrate ($m^3/s$) | 0.04 | 0.04 | 0.10 | 0.07 | 0.25 | 0.18 | 0.63 | 0.48 |
| Flowrate ($ft^3/s$) | 1.46 | 1.39 | 3.39 | 2.30 | 8.77 | 6.53 | 22.2 | 17.0 |

These average drainage areas and average upstream widths were used to plot wetted width and bankfull flow as a % of wetted width as shown in Figure 4.12. The bankfull estimates are made for the average drainage area of the sites in each drainage area size category. As shown in Figure 4.13, the regression line (power relationship) of the average of each size category is very similar to the regression line resulting from all data points measured at naturally low flows.

As can be seen in Figure 4.12, the approximation that bankfull width is 100% greater than wetted width for small streams is close to the prediction using the relationship for Eastern USA of Rosgen (1996) after Dunne and Leopold (1978). The approximation that bankfull width is 50% greater than wetted width is close to the prediction for larger streams. This makes sense. The larger streams in the Etowah River Basin tend to have steeper banks than small streams and be located in deeper, more developed channels, as can be seen in photos of the sites (Figure 4.11). It would appear reasonable for the sake of approximating new culvert design sizes to say that bankfull widths are 50% to 100% greater than wetted width at low flows in the Etowah River Basin. The Rosgen (1996) after Dunne and Leopold (1978) relationship is for the entire Eastern USA, however, so these sizing estimations are only to be used as an indication of likely sizes required. Careful estimation of bankfull width in the Etowah River Basin would be required for actual installations of no-slope or stream simulation culverts. A more in depth study of bankfull widths in the Etowah River Basin would be desirable because estimation of bankfull width requires significant experience for accurate measurements.

Until more extensive studies are done to determine bankfull stream widths in the Etowah River Basin, the relationship between bankfull stream width and drainage area as presented by Rosgen (1996) after Dunne and Leopold (1978) appears to be the most suitable for estimating bankfull stream width.

*4.3.3.2 New Culvert Design Spans and Diameters*

Using the no-slope design (culvert bottom placed 20% below the streambed and embedded), the culvert is sized so that the culvert bed width is equal to the bankfull size. Embedding the culvert 20% of the diameter below the streambed results in a pipe diameter 25% larger than the required culvert bed width. For larger structures with straight sides, spans need be only equal to the bankfull width.

For the stream simulation techniques assuming 30%, 40% and 50% fill, the culvert is sized so that the culvert bed width is equal to the bankfull size multiplied by 1.2 plus and extra 2 ft. For pipe culverts, the required diameters are 8.4%, 2.5% and 0% greater than the culvert bed width for 30%, 40% and 50% sinking and embedding, respectively.

The average drainage area of single pipe installations surveyed at low or base flow was 1.96 $km^2$. The average pipe diameter for these installations was 1.65 m (5.4 ft). Using the estimation of bankfull stream width given by the Rosgen (1996) after Dunne Leopold (1978) relationship, the no-slope design for this drainage area requires a 4.9 m (16.2 ft) pipe diameter or a 3.9 m (12.9 ft) culvert bed (or minimum arch or bridge span).

Using the stream simulation design technique with 40% sinking of the culvert bottom, the required pipe diameter is 5.5 m (17.9 ft) with a culvert bed width of 5.3 m (17.5 ft). This value is compared with those at bankfull widths 50% to 150% greater than wetted width in Table 4.7.

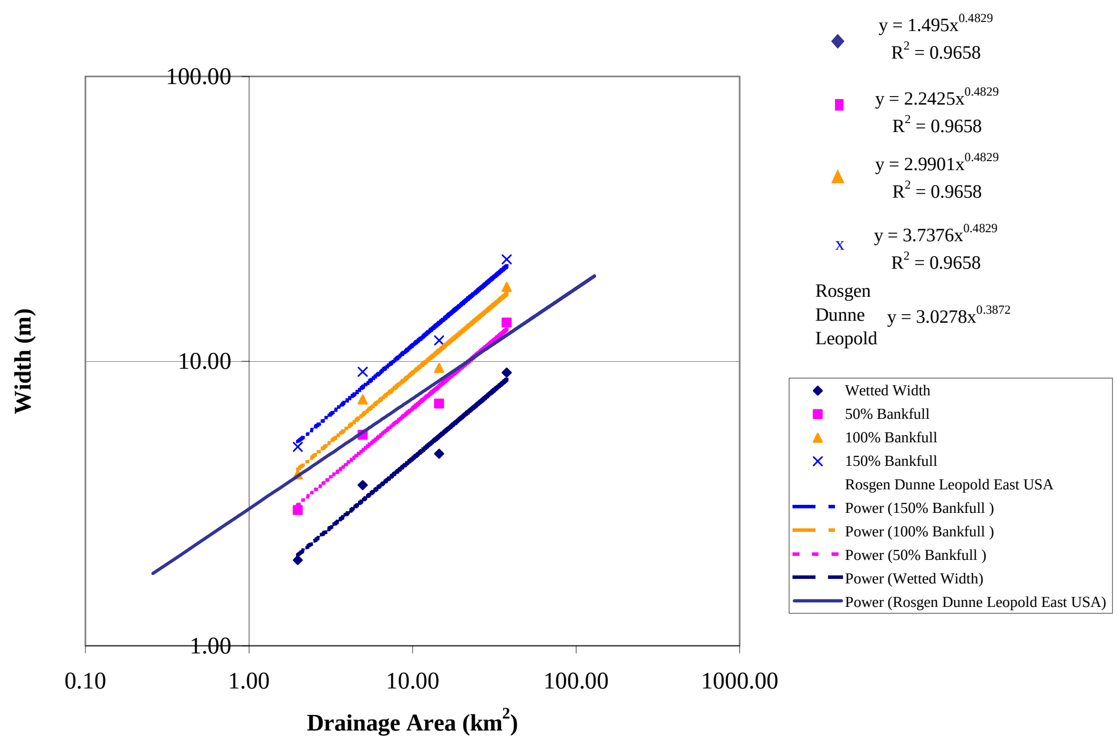


Figure 4.12 Bankfull estimation (power equations for best fit) from stream wetted width compared with Rosgen (1996) after Dunne and Leopold (1978) (power equation for best fit) for Eastern USA

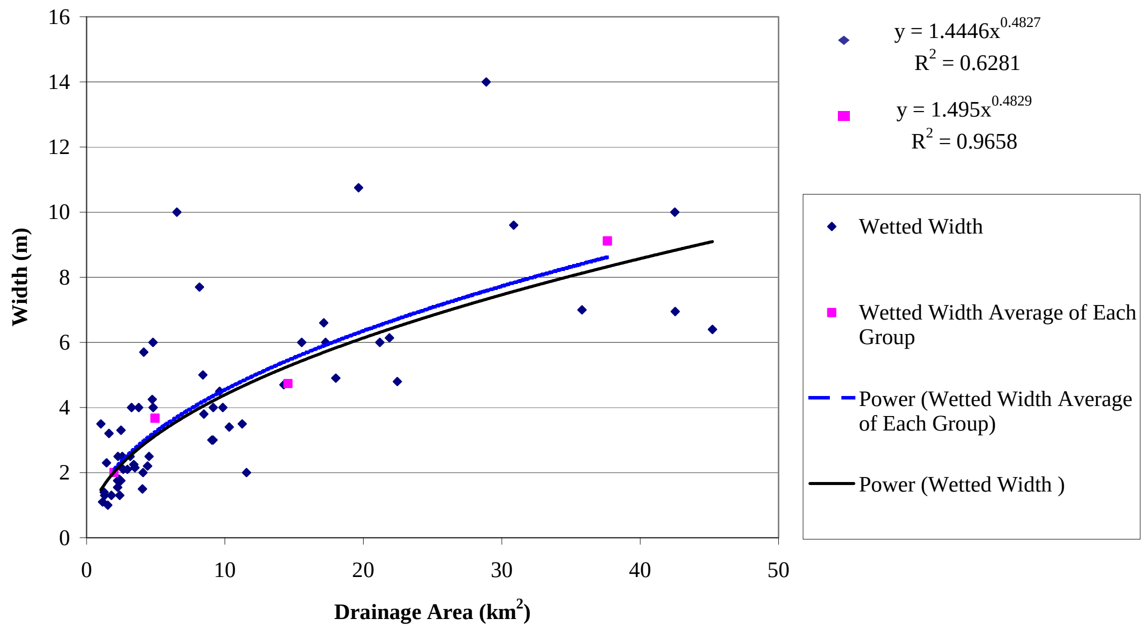


Figure 4.13 Wetted width vs drainage area for all sites other than those measured at storm flow or pumped or dammed upstream. Average of each category (1-3 km$^2$, 3-9 km$^2$, 9-25 km$^2$ and 25-50 km$^2$ ) is shown against this. Regression lines (power relationship) are shown.

Using SEDCAD 4, it was determined that a 10 ft diameter pipe is required to pass the 50-year flood for a drainage area of 1.5 $km^2$. Larger pipes could not be assessed using SEDCAD 4. The SEDCAD 4 analysis could not reduce the allowable culvert size to account for the culvert bed material, 14.24% by volume (for no-slope design with 20% of the pipe diameter filled with streambed material). So a SEDCAD 4 analysis for 20% of the pipe diameter filled with streambed material would require at a minimum, 14% increase in pipe cross-sectional area to pass the 50-year flood.

Table 4.7. Culvert diameters required for small average 'single pipe' stream (1.96 $km^2$). Different bankfull stream widths considered.

| | | Culvert Diameter (m/ft) | | | |
|---|---|---|---|---|---|
| Average Drainage Area of Single Pipe Culverts 1.96 $km^2$ | Stream Width (m/ft) | 20% No-Slope | 30% Stream Sim | 40% Stream Sim | 50% Stream Sim |
| Wetted width | 1.72 / 5.6 | 7.1 / 2.2 | 9.9 / 3.0 | 9.2 / 2.8 | 9.0 / 2.7 |
| Bankfull 50% > wetted width | 2.6 / 8.5 | 10.6 / 3.2 | 13.7 / 4.2 | 12.8 / 3.9 | 12.6 / 3.8 |
| Bankfull 100%> wetted width | 3.4 / 11.3 | 14.0 / 4.3 | 17.6 / 5.4 | 16.4 / 5.0 | 16.0 / 4.9 |
| Bankfull 150%> wetted width | 4.3 / 14.1 | 17.7 / 5.4 | 21.4 / 6.5 | 20.0 / 6.1 | 19.6 / 6.0 |
| Bankfull from Rosgen Dunne Leopold relationship * | 3.9 / 12.9 | 16.2 / 4.9 | 19.1 / 5.8 | 17.9 / 5.5 | 17.5 / 5.3 |

* Source: Rosgen (1996) and Dunne and Leopold (1978)

Figure 4.14 shows culvert opening widths that are likely to be required for new designs for fish passage based on either the no-slope design (with 20% embedding) or the stream simulation design. The relationship from Rosgen (1996) as originally determined by Dunne and Leopold (1978) for eastern USA was used to determine bankfull flow. For no-slope design in culverts with straight walls, such as arches or box shapes, bankfull width is the design width. However, for pipes, 80% of the diameter is the width at the location where the culvert bed meets the streambed. Thus the design diameter is 125% of bankfull width. Stream simulation designs assume 40% of the culvert is embedded which results in diameters only 2% greater than the width at the location where the streambed and culvert bed meet. These new design widths are compared with the current total width of the road crossings found in the Etowah River Basin road crossing study, as an indication of where larger crossing sizes will be required. Many of the larger streams are low slope streams so the no-slope design is likely to be acceptable and therefore the bankfull width is sufficient. On average, the larger crossings are wider than bankfull whereas the smaller culverts are narrower than bankfull. The smaller culverts may also require stream simulation in some cases since they will be located in the higher slope areas more often than larger streams. Stream simulation is required for slopes greater than 2.5%. Figure 4.15 focuses on the smaller drainage area streams, where the following increases in the size of the opening span will be required. A 50% increase in opening size is required if bankfull width is sufficient to provide fish passage, an increase of 63% is required is pipes are used with 20% embedding and the no-slope design. Around 75% increase in size of the diameter or span is required if the stream simulation design is used. The required increase span is new designs compared to current designs is less for larger size streams. Where bankfull width is sufficient, on average, the span required for larger crossings may be less than the size of many current installations, although further assessment of bankfull at each site where a new installation in planned would be needed to confirm this.

Results presented in Figures 4.16-4.18 are calculated using the program from Tollner (2004). Figures 4.16 and 4.17 show the design diameters using the no-slope design method and the stream simulation design method. As mentioned, the span required would be 25% less than shown for the no-slope design if a straight-sided culvert, rather than a pipe, is used. 2% less span would be required based on the stream simulation method. Depth of water in the 50-year flood as well as depth of sediment is shown. The velocities shown in Figure 4.18 help explain why the extra sediment depth is required in the stream simulation culvert design method due to stream slope. Velocities during storm flow are so high at 4% slope that it is likely that some sediment removal during storm flow will occur. Over time after the storm, the sediment will build up, but there has to be sufficient sediment depth that it will not scour to a bare culvert. The 50-year storm flow is easily passed using these designs. The larger stream sizes would not be using a pipe but an arch or bridge and the height required is only that height sufficient to provide adequate water depth during the 50-year flood. Also, sediment requirements would be less in larger crossings than those shown in Figures 4.16 and 4.17, because they only need to be 20% (no-slope design) or 30%-50% (stream simulation) of the total height of the structure, not a proportion of the span. If the structure is bottomless, design requirements specified by the manufacturer should be followed. Most

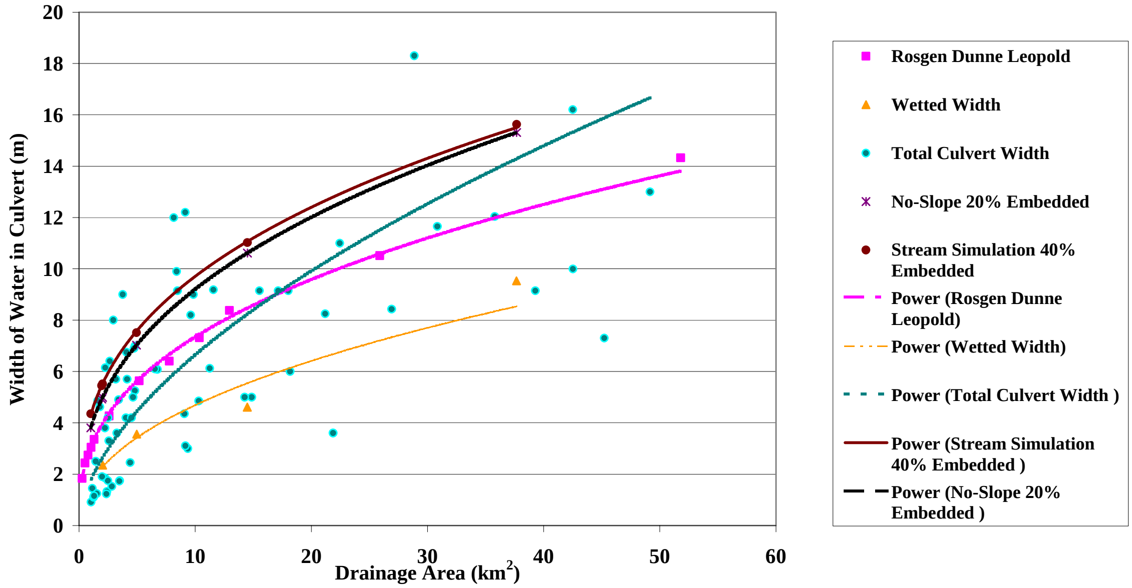


Figure 4.14 New culvert design sizes – water width comparisons for new designs, current installations and bankfull (Rosgen (1996) after Dunne and Leopold (1978)) and wetted width

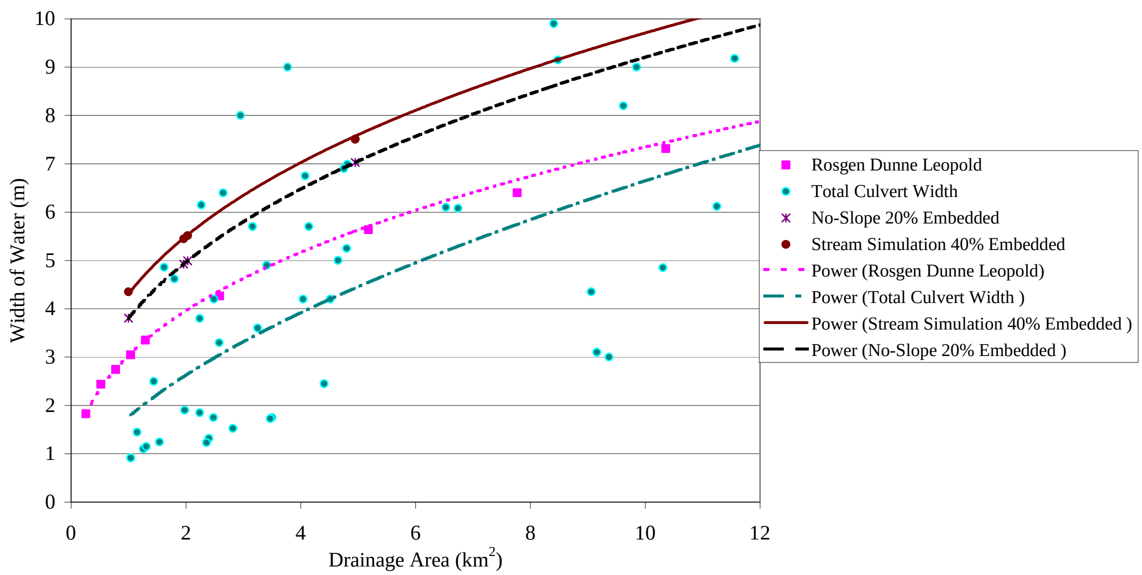


Figure 4.15 Zoom in on small size drainage areas – where most significant size increases are likely to be required.

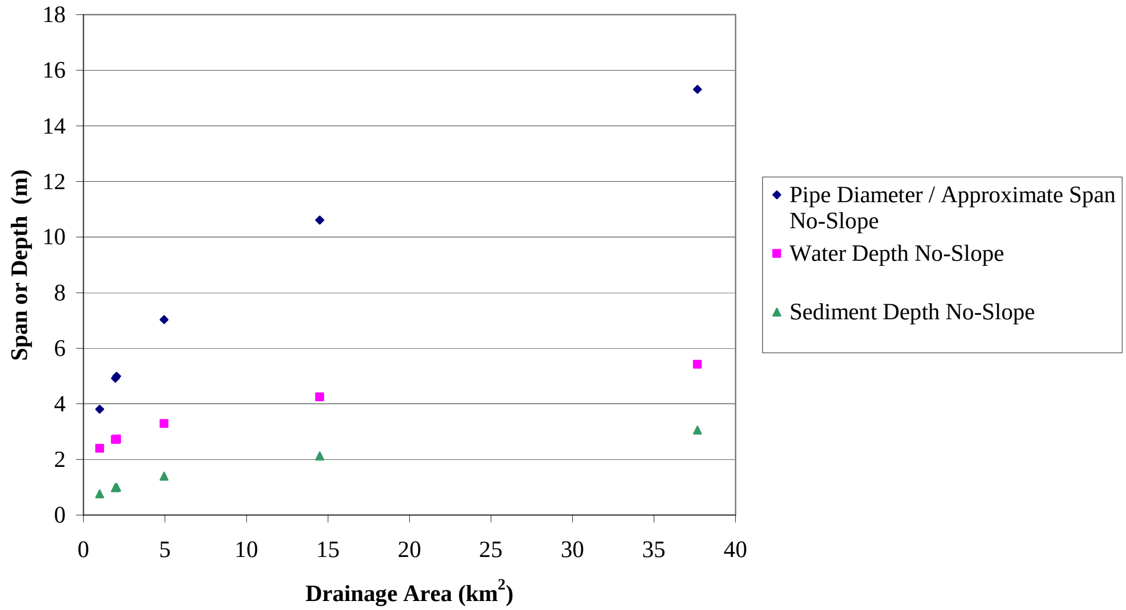


Figure 4.16 Water depth, sediment depth and pipe diameter or arch span for no-slope design (0.5% slope), with 20% of diameter or rise embedded

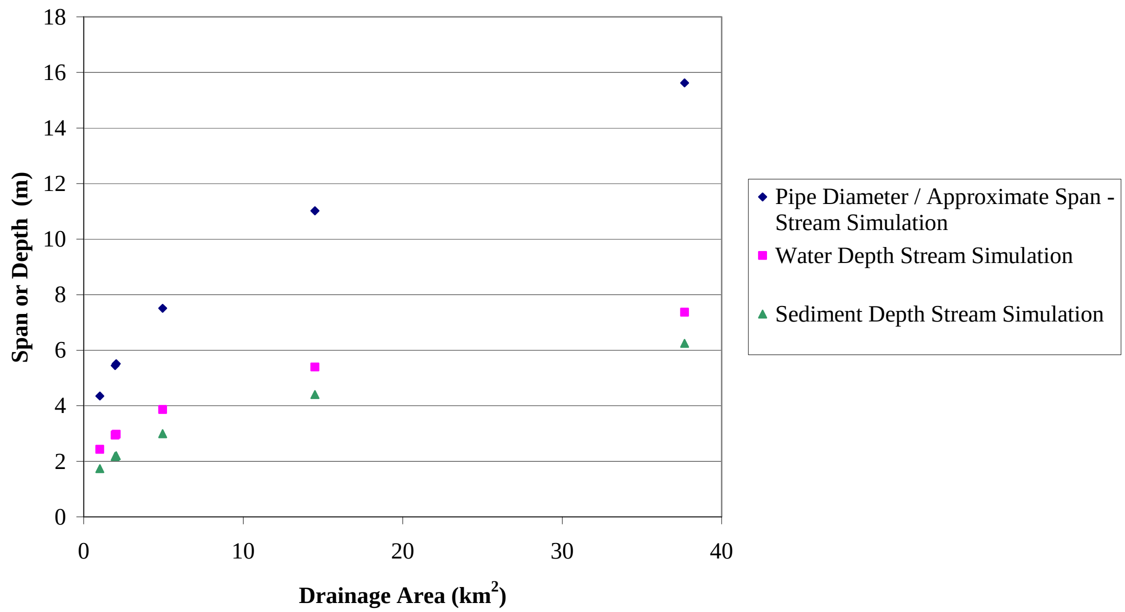


Figure 4.17 Water depth, sediment depth and pipe diameter or arch span for stream simulation design at 4% slope, 40% of diameter or rise embedded.

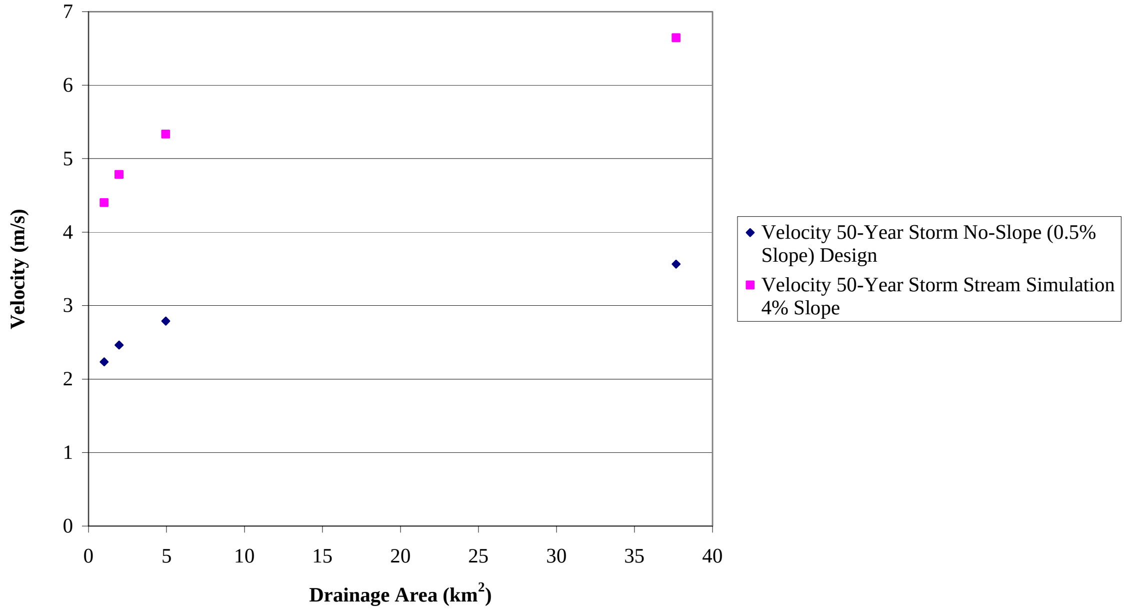


Figure 4.18 50-year storm flow velocities in no-slope designs and stream simulation designs

stream simulation culvert design studies are for smaller streams thus the sediment depth of culverts with closed bottoms should be assessed over time larger streams that use the no-slope or the stream simulation design options.

*4.3.4 Calculations of velocity and depth at base or low flow*

Using Manning's equation (Equation 1), the depth and velocity at base flow or low flow were calculated for several sizes and designs of culverts. Corrugated metal pipes of 10 ft and 5.5 ft in diameter, with a Manning's roughness coefficient of 0.025. A no-slope design with a flat culvert bed (streambed material filling 20% of the diameter of the bottom of the culvert) was also assessed, treating the flow cross-sectional area as a trapezoid with side slopes that would result if the same culvert bed width and maximum culvert width was used. A typical roughness coefficient attributable to natural channels was used (0.04) for the 20% embedded culvert. A 10 ft pipe diameter was selected, as it is one of the largest commercially available pipe sizes. Once the natural streambed material fills the culvert, the flow cross section is likely to be variable, not approximated as a trapezoid, and not completely fill the pipe cross-section.

The average flowrate at low flow of the single pipe installations was determined and used in the analysis of low flow velocities. It was determined to be 0.022 $m^3/s$ +/- 95% CI: 0.030 $m^3/s$ (0.76 $ft^3/s$ +/- 95% CI: 1.07 $ft^3/s$). For the purpose of these calculations, it was assumed that the flow in the 20% embedded channel could be approximated by normal flow (i.e. not impacted by constriction at the culvert) the depths were quite shallow at low flows. Even at negligible slope (0.05%), the depths were around 8 cm. With slopes of 0.5% the depths were 4-6 cm at low flow. The velocities were around 0.1 m/s for slopes of 0.05% and 0.26 m/s for slopes of 0.5%. Slope is an important factor influencing velocity at these low flows. Slopes of 2 and 3 % have velocities of 0.3 and 0.36 m/s.

As flow increases, average velocity increases. At 0.5% slope in the 20% embedded channel, average velocities of 0.35 m/s occur for 0.085 $m^3/s$ (3 $ft^3/s$). At 0.142 $m^3/s$ (10 $ft^3/s$) this would be 0.55 m/s. Roughness also impacts velocity. At 0.142 $m^3/s$ (10 $ft^3/s$), with a slope of 0.5% and a roughness of 0.025 (assuming the trapezoidal cross-section of the 20% embedded, 10 ft diameter pipe) the average velocity calculated is 0.75 m/s.

At the same low flow of 0.022 $m^3/s$ (0.76 $ft^3/s$), the corrugated pipes gave low velocities at 0.05% slope, of 0.2 m/s. While this velocity is lower than the velocity used to determine impassability of culverts in the Etowah River Basin study, this velocity could still be too high for movement through a long pipe with no refuges.

These calculations did not take into consideration the constricting effect at culvert inlets that can cause supercritical flow through smooth culverts. Calculating critical depth for a rectangle of width 8 ft (80% of diameter of 10 ft pipe) the critical depth is 0.020 m (0.066 ft). The critical velocity is 0.44 m/s (1.45 ft/s).

The results of the low and medium flow velocity analysis is shown in Table 4.8. By varying pipe diameter and geometry, roughness, slope and flowrate the impact of depth and velocity can be seen.

Another advantage of natural bed materials is the creation of sinuosity, due to a meandering of the channel, which can effectively increase the apparent roughness, and create areas of low velocity for resting places as a fish migrates through the culvert.

Table 4.8 Low and medium flow analysis of velocity and depth

| Pipe Diameter (m/ft) | % Embedded Material | Drainage Area (km2) | Flowrate m3/s / ft3/s | Slope | Roughness | Depth (ft) | Depth (m) | Velocity (ft/s) | Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 1.68/5.5 | 0 | 1.96 | 0.022/0.76 | 0.05% | 0.025 | 0.65 | 0.20 | 0.76 | 0.23 |
| 3.1/10 | 0 | 1.96 | 0.022/0.76 | 0.05% | 0.025 | 0.63 | 0.19 | 0.76 | 0.23 |
| 1.68/5.5 | 20% | 1.96 | 0.022/0.76 | 0.05% | 0.04 | 0.41 | 0.12 | 0.41 | 0.13 |
| 3.1/10 | 20% | 1.96 | 0.022/0.76 | 0.05% | 0.04 | 0.28 | 0.08 | 0.34 | 0.10 |
| 3.1/10 | 20% | 1.96 | 0.022/0.76 | 1.00% | 0.04 | 0.11 | 0.03 | 0.85 | 0.26 |
| 3.1/10 | 20% | 1.96 | 0.022/0.76 | 2.00% | 0.04 | 0.09 | 0.03 | 1.04 | 0.32 |
| 3.1/10 | 20% | 1.96 | 0.022/0.76 | 3.00% | 0.04 | 0.08 | 0.02 | 1.18 | 0.36 |
| 1.68/5.5 | (20%) | 1.96 | 0.022/0.76 | 1.00% | 0.025 | 0.12 | 0.04 | 1.42 | 0.43 |
| 1.68/5.5 | (20%) | 1.96 | 0.022/0.76 | 2.00% | 0.025 | 0.10 | 0.03 | 1.75 | 0.53 |
| 1.68/5.5 | (20%) | 1.96 | 0.022/0.76 | 3.00% | 0.025 | 0.09 | 0.03 | 1.98 | 0.60 |
| 3.1/10 | 20% | 1.96 | 0.022/0.76 | 0.50% | 0.04 | 0.14 | 0.04 | 0.69 | 0.21 |
| 3.1/10 | (20%) | 1.96 | 0.022/0.76 | 0.50% | 0.025 | 0.10 | 0.03 | 0.92 | 0.28 |
| 1.68/5.5 | (20%) | 1.96 | 0.022/0.76 | 0.50% | 0.025 | 0.20 | 0.06 | 0.85 | 0.26 |
| 3.1/10 | 20% | 1.96 | 0.022/0.76 | 0.20% | 0.04 | 0.18 | 0.06 | 0.52 | 0.16 |
| 3.1/10 | (20%) | 1.96 | 0.022/0.76 | 0.20% | 0.025 | 0.14 | 0.04 | 0.69 | 0.21 |
| 1.68/5.5 | (20%) | 1.96 | 0.022/0.76 | 0.20% | 0.025 | 0.20 | 0.06 | 0.86 | 0.26 |
| 3.1/10 | 20% | 1.96 | 0.085/3.06 | 0.50% | 0.04 | 0.32 | 0.10 | 1.18 | 0.36 |
| 3.1/10 | 20% | 1.96 | 0.142/10.00 | 0.50% | 0.04 | 0.68 | 0.21 | 1.84 | 0.56 |
| 3.1/10 | 20% | 1.96 | 0.142/10.00 | 0.50% | 0.04 | 0.50 | 0.15 | 2.47 | 0.75 |

Note: (20%) indicates that a flat bottomed trapezoid is used to model the flow although roughness is equivalent to a corrugated metal pipe in these instances. 20% (not bracketed) indicates a flat bottomed trapezoid with roughness equivalent to a natural stream substrate.

The main findings of the velocity and depth analysis at low flow are that in either size of pipe, even at very slight slopes, the velocities are not maintained below velocities suitable for fish passage even with natural streambed roughness. Pockets of low velocity due to channel variation and sinuosity are likely the reasons why natural channel bottoms are better for fish passage. Lower velocity near the boundary layer is also not accounted for by average velocity assessment.

The hydraulic design option could be applied by considering fish passage criteria for velocity limits at low flows and ensuring large enough culverts with low enough slopes. However, once slope exceeds 2.5% (upper limit of no-slope designs), the velocities calculated for natural streambed roughness or corrugated pipe roughness are excessive for fish passage (>0.25 m/s) even at low flows, as shown in Table 4.8.

At low flows, to minimize velocity, the slope must be as low as possible and roughness should be high. At higher flowrates, even very low slopes (0.5%) and natural streambed roughness will exhibit average velocities above recommended fish passage velocities. Fish may be able to swim in the boundary layer near the surface although at very high flows they are not likely to move far in either natural channels or culverts.

*4.3.5 Etowah River Basin designs compared with stream simulation road crossings in Washington State*

Figure 4.19 shows the difference between the two-year flood flow in the Etowah River Basin and the two-year flood flow at sites with different drainage areas in Washington (Barnard 2003). Etowah River Basin floods are approximately 300% greater than the average two-year floods at the Washington sites. Although average annual rainfall in Washington is more variable than that in the Etowah River Basin, this does not account for the much lower 2-year floods in Washington. The average annual rainfall across all the Washington sites was similar to the average rainfall in the Etowah River Basin. The reason for this large difference in two-year floods is not known, although permeability differences may be a cause. Figure 4.20 compares the spans of stream simulation style crossings currently in use in Washington with the likely design spans of no-slope and stream simulation culverts to be used in the Etowah River Basin. Bankfull widths in the Etowah River Basin are similar to the spans at 2 $km^2$ drainage area and 1.4 times greater in the Etowah River Basin at 5 $km^2$. However for widths adequate for stream simulation the spans required are 40% and 75% greater at 2 $km^2$ and 5 $km^2$.

The nine pipe culverts looked at in West Washington (Barnard 2003) range from 3.0 to 4.3 m (10 to 14 ft) in diameter. The 2-year flood for the Washington pipe culverts was on average only 0.55 m3/s (19.5 ft3/s). This compares with a 2-year flood discharge of 1.98 m3/s (70 ft3/s) for a drainage area of only 0.5 $km^2$ in the Etowah River Basin (calculated using U.S. Geological Survey flood discharge regression equations (Stamey and Hess 1993)). For a drainage area of 1.96 $km^2$, the 2-year flood

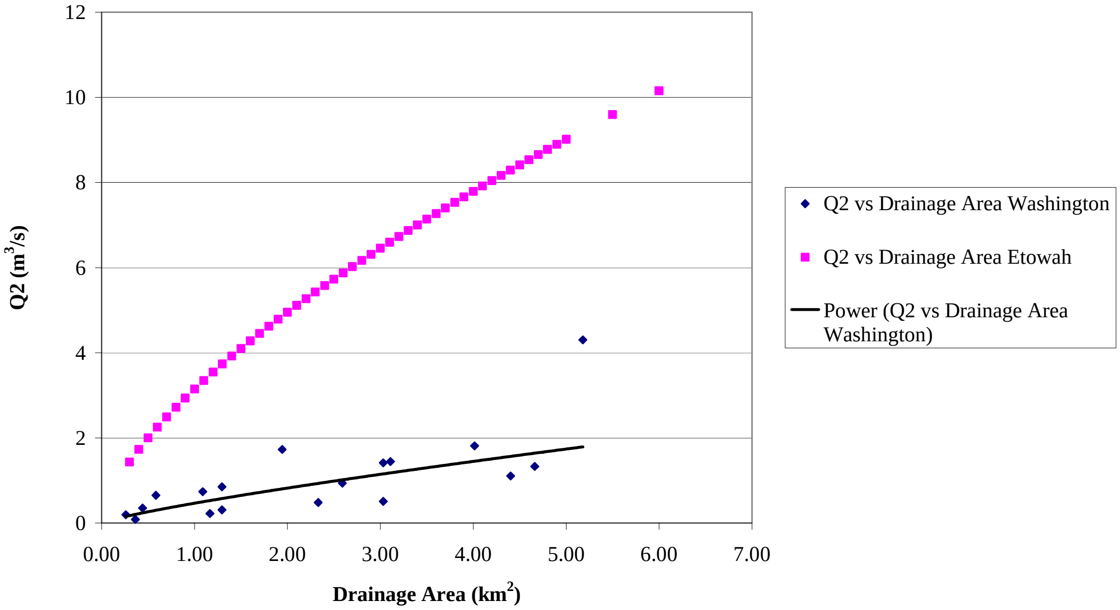


Figure 4.19 Two-year flood discharge vs drainage area comparison of the Etowah River Basin to Washington State sites with stream simulation road crossings (Washington data source: Barnard (2003)).

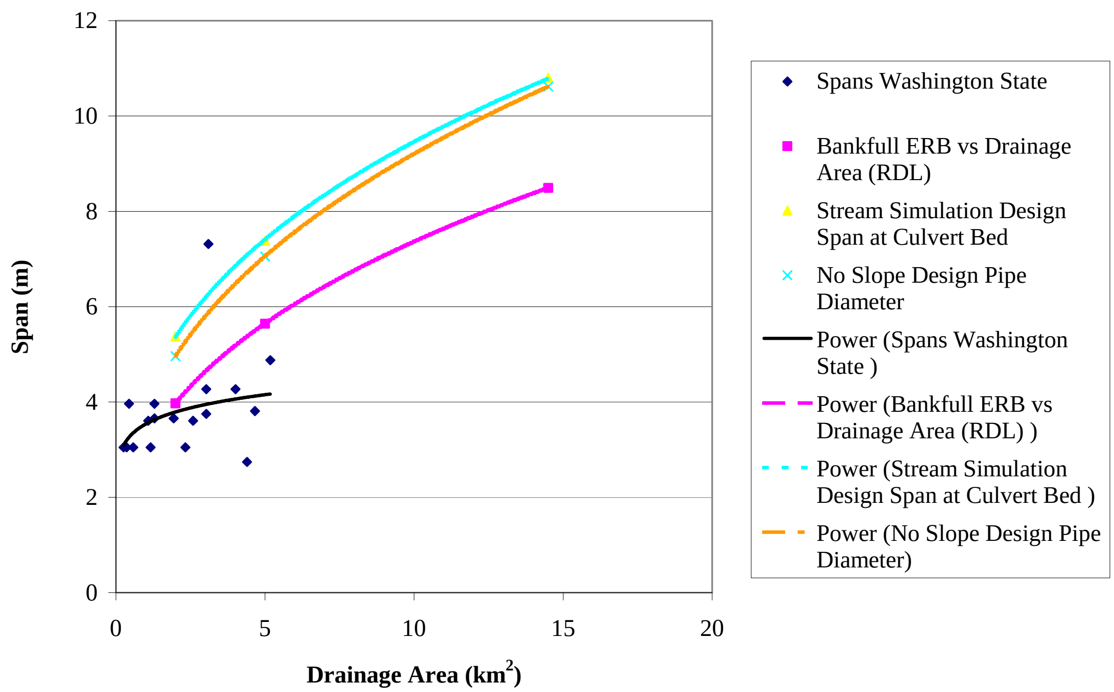


Figure 4.20 Culvert spans in Washington State and likely culvert spans for the Etowah River Basin (Washington State data source: Barnard (2003)).

discharge is closer to 4.8 $m^3/s$ (170 $ft^3/s$). The U.S. Geological Survey regression equations (Stamey and Hess 1993) for the region inclusive of the Etowah River Basin (Region 1) are applicable to drainage areas as small as 0.45 $km^2$.

The West Washington stream simulation culverts (Barnard 2003) also include three arches (bottomless culverts) with 3.7-4.9 m (12-16 ft) spans, average 2-year flood of 1.67 $m^3/s$ (59 $ft^3/s$); 2 box culverts with 4.3 and 7.3 m (14 and 24 ft) spans, average 2-year flood 1.93 $m^3/s$ (68 $ft^3/s$) and 5 pipe-arch culverts (shaped like flattened pipes) with 2.7-4.0 m (9-13 ft) spans, average 2-year flood 1.84 $m^3/s$ (65 $ft^3/s$).

The range of 2-year flood discharges for all installations in the Washington survey (Barnard 2003) was from 0.085 to 4.3 $m^3/s$ (3 to 152 $ft^3/s$) and the 100-year flood discharges ranged from 0.23 to 9.7 $m^3/s$ (8 to 343 $ft^3/s$). West Washington has high variation in annual rainfall, with respect to distribution across the area of the study, whereas the Etowah River Basin has little variation in annual rainfall across the region. The area of West Washington being studied has highly varying annual rainfall, from 10 to 180 inches in annual rainfall depending on the area. The mean of the average annual precipitation of the West Washington sites was 57.5 inches. The highest average annual precipitation of the West Washington sites was 80 inches and the lowest 30 inches. In the Etowah River Basin, annual rainfall is more constant with respect to location, with average annual rainfall of 70-80 inches near the Blue Ridge to a low of 50-52 inches in southern reaches. However, the mean average annual rainfall for the two regions is similar, thus rainfall alone is not the reason for the much larger flood flows typical of the Etowah River Basin.

To allow passage of all fish species, a natural channel bed needs to form within the culvert (Washington Department of Fish and Wildlife 2003). Thus new installations in the Etowah River Basin will need to be assessed over time to ensure that natural channel beds are forming in no-slope culvert designs and that the beds are maintained in stream simulation culverts. If there are instances where 20% sinking is insufficient, stream simulation design (deeper culvert embedding, larger culvert bed widths, and manual or mechanical placement of bed structure) may be required for some future designs in the area. Deliberate placement of streambed material or streambed simulation material may be found necessary in no-slope designs, which may become apparent soon after the installation of new culverts.

Bed failure is defined by Barnard (2003) as an event in which significant changes in the bed elevation and slope occur after construction. In the Washington stream simulation culvert study, two pipe culverts had bed failure, as did a pipe arch and an arch. Three of the failures had high slope as compared with the natural stream slope, (culvert bed slope to stream slope ratios of 1.7 to 3.2). All 4 installations with bed failure had width ratios close to unity, the width ratio being the ratio between the culvert bed width and the bankfull streambed width. These bed failure results support the design methodology presented by the Washington Department of Fish and Wildlife (2003) for stream simulation design culverts (required for stream slopes over 2.5%), that culvert bed width equal 1.2 x bankfull width + 2 ft (0.6 m) (Barnard 2003).

Based on this analysis it is certain that the small streams of the Etowah River Basin will require significantly larger culvert diameters and spans than are currently being installed. Commonly commercially available large pipe sizes may be insufficient for all but the smallest streams with Cherokee darter passage requirements.

Multiple cell box or pipe culverts may be an option if embedded according to stream simulation or no-slope designs. However, no examples of this design being used for fish passage were found in the literature, therefore options in which the stream is spanned would be preferable, and such designs should undergo continued study to determine long term suitability for fish passage.

### 4.4 Economic analysis of road crossing options

Selection of the best option for a given site must consider economic issues as well as site access and geomorphology. Total costs of crossings include several considerations. Costs of construction materials and labor as well as grading and paving are needed. The time it takes to install a crossing can also impact its economic viability. As expected, small metal pipe culverts are the lowest cost option for installation; however they are highly problematic for fish passage if not sized and embedded properly.

Larger pipes should be used as presented in Section 4.3. Embedded material is likely to increase the cost of construction materials for pipe culverts by 50% as well as require larger pipe sizes. Freespan bridges are approximately 40% more expensive than similarly sized concrete box culverts. A portion of the cost of freespans is due to additional design efforts to meet structural integrity requirements. Table 4.9 lists typical construction costs for various road crossing options compiled from commercially available data as well as cost data from the local counties. They are generally for construction materials only. The bridge costs include the added design costs.

With regard to construction time, some freespan bridges can be delivered and installed within a week, with total time to completion of construction approximately one month including road paving (Rod LeMasters, Ohio Bridge, personal communication, June 2004). This makes the time to install a bridge comparable to that for installing box culverts. A small pipe culvert, 1m in diameter, including labor could cost as little as $500 on a very small crossing whereas costs on small streams may increase significantly when larger diameters are required. A large diameter pipe culvert including labor may cost $10,000 - $20,000. A small freespan bridge could be installed for as little as $60,000. A large box culvert costs around $100,000 whereas a similarly sized freespan bridge would cost $140,000 or more. A freespan bridge in Bartow County cost $140,000. A large arch would cost $90,000 to $140,000. While freespan bridges are preferable, if a bridge does not completely clear the active channel, fish passage is usually assured due to the natural streambed providing resistance to flow, reducing velocity and also providing refuge from high flow behind rocks, etc.

Using freespans would increase the cost by approximately 40% or more for larger streams as opposed to box culverts. Although arches have been noted as problematic, this is likely to be more of an issue on small streams where construction costs must be minimized. Prefabricated arch culverts may provide passage and structural stability for similar costs to box culverts. As more case studies are developed with this option it is hoped it will become more acceptable for the GDOT and the counties involved in the Etowah HCP.

Table 4.9 Costs of construction materials for various road crossing options.

| Type | Size | Unit Cost of Materials / Linear Foot | Cost of Materials for Project (for 50 linear feet unless noted) | Notes |
|---|---|---|---|---|
| Concrete Pipe | 36” | $31 | $1,548 | materials only |
| Metal Pipe | 36” | $65 | $3,250 | materials only |
| Galvanized Arch Pipe | 75” x 112” | $75 | $3,750 | materials only |
| Aluminum Arch Pipe | 75” x 112” | $122 | $6,100 | materials only |
| Concrete Pipe | 96” | $194 | $9,718 | materials only |
| Metal Pipe | 84” | $215 | $10,750 | materials only |
| Embedded Metal Pipe | 84”, 1.5 cu yd/ft riprap | $290 | $14,500 | materials only |
| Single Box Culvert | 8’ x 5’ | $300 | $15,000 | materials only |
| Embedded Box Culvert | 8’ x 5’ 3 cu yd/ft riprap | $450 | $22,500 | materials only |
| Bottomless Box Culvert | Single 8’ x 8’ | $600 | $30,000 | materials only |
| Triple Precast Box Culvert | Triple 7’x7’ | $620 | $31,000 | materials only |
| Triple Precast Box Culvert | Triple 8’x5’ | $900 | $45,000 | materials only |
| Triple Precast Box Culvert | Triple 8’ x 7’ x 56’ | $1,731 | $96,911 | for structure – not grading work or pavement |
| Triple Precast Box Culvert | Triple 8’ x 8’ x 47’ | $2,089 | $98,166 | for structure – not grading work or pavement |
| Arch Bottomless Culvert | 57 lf | $2,446 | $136,976 | for structure – not grading work or pavement |
| Arch Bottomless Culvert SuperCor | 50’ span | | $90,000 | for structure – not grading work or pavement |
| Freespan Bridge | 50’ x 34’ | $2,800 | $140,000 | for parts, labor and incidentals |
| Arch Bottomless Culvert | 47’ | $3,023 | $142,081 | for structure – not grading work or pavement |
| Small Freespan Bridge US Bridge | 20’ x 25’ span | $3,025 | $60,500 | for structure – not grading work or pavement |
| Concrete Bridge | 50’ x 34’ | $3,960 | $198,000 | for parts and labor |

Note: Dimensions are given in imperial units because most commercial costing of these items in the United States of America is made in these units.

# CHAPTER 5

# DISCUSSION

## 5.1 Fish mark and recapture study (Ensign 2004, unpublished data)

A mark and recapture study of fish passage at 6 sites in the Etowah River Basin was carried out (Ensign, 2004, unpublished data) to assess movement of fish across freespan bridge, box culvert and tube culvert crossings (two of each). The 6 sites were part of an ongoing study of hydrologic alteration using Aquarods (Advanced Measurement and Controls) to measure stage levels and thus extra data such as stream slope is available for these sites (Roy 2004, unpublished data).

For each stream in the study, continuous reaches directly upstream and downstream of the crossings were divided into three contiguous cells. Each cell encompassed a single pool and riffle sequence (Ensign 2004, unpublished data). Fish in each cell were captured, tagged with fluorescent elastomer tags, and released. Unique combinations of tag color and tag position allowed assignment of all marked fish to the cell of original capture. One month later, fish were collected from the same cells and the tags inspected.

Across the six streams a total of 1407 fish were tagged and 418 tagged fish were recaptured during the second sampling period. Of the 418 fish recaptured, 132 were found outside their original cell of capture. The probability of upstream movement between contiguous cells was 6.3% (95% CI: +/- 2.8%) and the probability of downstream movement between contiguous cells was 3.5% (95% CI: +/- 1.9%) (Ensign 2004, unpublished data). Movement both upstream and downstream across box and tube culverts fell below the lower 95% confidence intervals of these estimates, indicating that these culverts act as impediments to fish movement. In each of the streams with box culverts, a single fish moved upstream through the culvert while a single fish moved upstream through one of the tube culverts. The study observed different fish species, although the Cherokee darter was not included.

The fish mark and recapture studies were carried out in summer, between June and August of 2003. The mark and recapture dates are given in Table 5.1. Physical measurements of the box and pipe culvert sites were obtained in June of 2004.

Ensign (2004, unpublished data) found no evidence that fish moved downstream through either box or tube culverts, although this does not imply they don't. Movement across the clear span crossings did not differ from movement between contiguous cells.

The physical parameters of the two box culverts and two pipe culvert crossings were measured as part of this thesis. A summary of the results of the physical measurements survey is given in Table 5.2. All crossings were shown to have excessive velocities for small stream fish passage on the day that measurements were taken, at low or base flow. No significant amount of sediment was found in any of these four crossings, except for a large boulder in the slower velocity pipe at the Possum Creek site, which would likely further impede passage due to localized turbulence.

Table 5.1. Mark and recapture dates for fish passage study in the Etowah River Basin (Ensign 2004, unpublished data).

| Site # | Stream | Crossing Type | Mark Date | Recapture Date |
|---|---|---|---|---|
| Aquarod 1 | Hickory Log Creek | Pipe Culvert | 7/7/03 | 8/7/03 |
| Aquarod 2 | Scott's Mill Creek | Box Culvert | 7/8/03 | 8/8/03 |
| Aquarod 3 | Sweat Mountain Trib. | Box Culvert | 6/25/03 | 7/24/03 |
| Aquarod 4 | Possum Creek | Pipe Culvert | 6/26/03 | 7/29/03 |
| Aquarod 5 | Upper Noonday Creek | Freespan | 7/9/03 | 8/11/03 |
| Aquarod 6 | Clark Creek | Freespan | 6/24/03 | 7/28/03 |

Table 5.2. Summary of physical and hydrologic parameters for the mark and recapture study sites

| Crossing Number | Aquarod 1 | Aquarod 2 | Aquarod 3 | Aquarod 4 | |
|---|---|---|---|---|---|
| Crossing Type | Pipe | Box | Box | Pipe | |
| Drainage Area ($km^2$): | 10.69 | 12.00 | 8.50 | 16.40 | |
| Culvert Slope (%): | 0.00% | 1.02% | 0.54% | -0.21% | |
| Stream Slope (%) *: | 0.26% | 0.75% | 0.53% | 0.30% | |
| Flowrate (m3/s): | 0.19 | 0.19 | 0.10 | 0.11 | |
| Culvert Outlet Velocity Calculated from Flowrate (m/s): | 3.51 | 1.34 | 0.74 | 0.64 | |
| Velocity measured in culvert today (m/s) inlet: | 0.56 | 0.78 | 0.34 | 0.09 | 0.4 |
| Velocity measured in culvert today (m/s) outlet: | 1.3 | 0.44 | 0.27 | 0.2 | 1 |
| Depth at Culvert Inlet (m): | 0.21 | 0.05 | 0.03 | 0.46 | 0.27 |
| Depth at Culvert Outlet (m): | 0.06 | 0.11 | 0.03 | 0.14 | 0.12 |
| Drop to Surface (m): | 0.00 | 0.00 | 0.30 | 0.00 | |
| Drop to Bottom (m): | 0.06 | 0.01 | 0.58 | 0.15 | 0.23 |

** Source: Roy 2004, unpublished data*

The two pipe culvert crossings were placed at approximately zero slope (0.0% and –0.2% measured slopes) with the box culverts at 0.5% and 1.0%. These slopes for the box culverts are at the limits of the recommended slopes for non-embedded or no-slope designed culverts used in Oregon. These crossings do not meet the most lenient of the literature values for small stream fish passage of velocities less than 0.4 m/s. The box culvert at 1.0% slope would not meet Oregon Department of Fish and Wildlife (2004) criteria for no-slope designs even without culvert sinking. The four road crossing sites studied for physical parameters and fish passage are pictured in Figure 5.1.

Culverts placed essentially flat with no embedding are options in Oregon on streams with slopes less than 2.5%. All stream slopes in mark and recapture fish passage study (Ensign 2004, unpublished data) are less than 1.0% (Roy 2004,unpublished data). For non-embedded crossings, Robison et al. (1999) point out that the 0.5% cut off is for pipe culverts with the added roughness attributed to the corrugation in the pipe. The bottoms of concrete box culverts are generally smoother than corrugated pipe and therefore velocities may be higher for similar slopes. This indicates that slopes for non-embedded box culverts should be less than 0.5%, and care should be taken to install them as close to 0.0% as possible. If considering the criteria that juvenile salmonid passage is lessened significantly through culverts with slopes greater than 0.2% (Powers and Bates, 1997), design slopes should be less than 0.2%.

If these culverts were instead placed with their bottoms below the streambed, excessive velocities may be avoided. The no-slope design with 20% embedding would be recommended for culverts in these locations due to the low stream slope, the difficulties in obtaining base flow velocities in non-embedded road crossings, and the impact on fish passage that the study crossings are noted to have.

*(a)*

*(b)*

*(c)*

*(d)*

Figure 5.1 Photos of fish mark and recapture study sites. (a). Aquarod Site 1. Hickory Log Ck; (b) Aquarod Site 2. Scott's Mill Ck; (c) Aquarod Site 3. Tributary of Sweat Mountain Ck; (d). Aquarod Site 4. Possum Ck.

5.2 New pipe designs

Larger pipes than those currently used on small streams, or other options instead of pipes, are likely to be required for adequate fish passage. No-slope and stream simulation test culverts are recommended to be installed and monitored as there do appear to be differences in Georgia stream flows compared with those in Washington State, where stream simulation has been well tested.

Because Cherokee darters are likely to move at low flows and not at high flows the hydraulic design for acceptable velocities doesn't necessarily apply. The need for prevention of any jump from downstream into a culvert, and the need for a culvert bed that models the natural streambed to provide the variation in substrate necessary to provide protection from high velocities, indicate that some bed fill in the culvert should be required in all cases. The stream simulation design is intended to ensure that there is streambed material in the culverts over the long term. If this can be provided at lower sinking depths, then that is acceptable.

The no-slope design is intended for use at zero-slope whereas stream simulation is recommended for slopes up to 8% (some extra precautions need to be taken at slopes greater than 4% (see Section 2.3.8 on sediment transport equilibrium in high slope streams). Once new designs are installed, tests will be needed to ensure that culvert beds in new culvert designs for fish passage in the Etowah River Basin remain stable over time.

Pipe culvert size increases on small streams (2 $km^2$ drainage areas and below) may be as much as 100% to 140%. This is partly because the smaller culverts appear to be undersized, even compared with current GDOT design guidelines. This could be a result of less stringent requirements in the past or because some of the road crossings were designed without considering current GDOT design criteria (which has been noted as a possibility especially for privately owned road crossings).

The larger streams have culverts that more closely match the active stream width, according to calculations in Section 4.3. Therefore, there will be less of a requirement to increase size, although embedding the culverts will increase their cross-sectional area requirement by 20% for box culverts in low slope streams (< 2.5%), and installations without multiple cell culverts (i.e. spanning the stream with a single opening) may be more costly for the same size crossing. Bridges, especially freespan bridges, are preferred over box and pipe culverts because there is less disruption of the natural stream profile. More frequent use of bridges below the GDOT drainage area threshold 20 $mi^2$ (51.8 $km^2$) would improve fish passage also, but would incur higher costs. However, freespan options are being used on drainage areas less than 20 $mi^2$ (51.8 $km^2$).

# CHAPTER 6

# IMPLEMENTATION OF NEW DESIGN CRITERIA

## 6.1 Technical committee meetings and recommendations

It was determined at the first technical committee meeting that the best format for implementation of the design criteria would be as Best Management Practices (BMPs). The criteria are listed in bullet form (as shown in Section 6.2). More detailed information should be given as to the technical aspects of the designs. The final BMP document will likely be a few pages to include technical design information. The Washington Department of Fish and Wildlife's (2003) 'Design of Road Culverts for Fish Passage' can be used as the required design guide as it provides design specifications for the recommendations made here.

The Georgia Department of Transportation was also contacted and their opinion sought on the design specifications. GDOT sets the standard for culvert design in Georgia and most counties use their design guidelines. County officials felt that wider acceptance of the recommendations for the Etowah HCP would be obtained if the GDOT received the recommendations positively. It has been pointed out that private culverts are not governed by the same requirements as county culverts to meet engineering design criteria and on some small streams pipe culverts are selected and installed with little if any design effort.

Maintenance options would be looked upon favorably for currently installed crossings. Maintenance to improve old structures may be an important part of an overall strategy that also requires developers to install appropriate new crossings. However, riprap addition is currently unproven as a useful technique if the hydrologic situation is causing significant scouring (see Section 2.3.20)

Education of counties and developers will be important. Costs that can be maintained at less than double current costs are looked upon more favorably. GIS mapping of roads with records of road crossings has begun, and poses an opportunity to record the state of each road crossing and develop a catalog of problem areas.

The view of the technical committee was that if there is a scientific basis to prove that these requirements are essential then they will be pleased to recommend the new design criteria. Clear instructions with examples showing costs and installation requirements are desirable.

## 6.2 Best management practices recommended for road crossings in the Etowah River Basin

The initial recommendations for road crossing criteria for fish passage resulting from this study are as follows:

- Bridges (especially freespan bridges) are the preferred option for all streams and are required for large streams and rivers. It is recommended that bridges be used to cross any stream with a drainage area equal to or greater than 20 $mi^2$ (51.8 $km^2$), following GDOT guidelines (i.e., only bridges are typically considered for streams draining over 20 $mi^2$ (51.8 $km^2$));
- If bridges are infeasible due to cost or other factors, bottomless culverts or embedded culverts shall be employed. Embedded culverts can be used for stream slopes up to 8%. Embedded culverts shall be sunk more deeply at the inlet than the outlet for slopes between 4% and 8%;
- Two embedded culvert design procedures are acceptable. The no-slope design option (on stream slopes less than 2.5%) and the stream simulation design option, as defined by the Washington Department of Wildlife (2003) on stream slopes up to 8%;
- The no-slope design option (Section 2.3.6.1) requires sizing the culvert so that the culvert bed width is equal to the bankfull width of the stream. The culvert must be sunk to a minimum of 20% of its diameter or rise. The cross sectional area must be sufficient to pass the 50 year flood. No-slope culverts should only be used on stream slopes less than 2.5% with culvert gradients less than or equal to 0.5%;
- The stream simulation design option (Section 2.3.6.3) requires sizing the culvert so that the culvert bed width is equal to 1.2 times the bankfull width of the stream plus an additional 2 ft (0.6

m). This requires sinking the culvert below the streambed by 30-50%. If the culvert does not naturally fill with streambed substrate, similar material should be placed in the culvert to match the natural streambed elevation. The slope in the culvert should be not greater than 1.25 times the upstream stream slope;

- For embedded culverts, fill shall consist of natural stream material or material of a similar size and composition as in the adjacent streambed. Structure may need be created using larger (D100) sized material interspersed with typical streambed material for stream simulation design culverts in alluvial channels (slopes up to 4%);
- Road crossing openings shall be sized to pass the 50-year flood and maintain structural integrity in the 100-year flood;
- Under no circumstances shall perched culverts be acceptable;
- Culverts shall be designed to minimize downstream scour, so they will not become perched over time. Size, slope relative to the stream, and embedding should ensure this;
- Velocity at base flow should be minimized. At base flow, water velocity through culverts should not exceed 0.3 m/s. However, although it is desirable that base flow velocity not exceed 0.3 m/s, so long as a culvert is bottomless or embedded, with streambed or similar material in it, velocities over 0.3 m/s may be acceptable if considered unavoidable (e.g. due to high stream slope);
- During construction, duration and extent of stream channel disturbance shall be minimized to the greatest extent practicable. All attempts shall be made to minimize erosion of banks and sedimentation of streams during construction;
- Variances to these requirements shall be considered for streams draining less than 0.3 $km^2$.

For further culvert design information, the Washington Department of Fish and Wildlife's 'Design of Road Culverts for Fish Passage' (2003) provides the most up to date and comprehensive guide to culvert installation suitable for passage of small-bodied small stream fish. Although they were developed for salmon passage, the no-slope and stream simulation design options presented therein are comprehensive and culverts designed accordingly should provide adequate passage for Cherokee darters.

It should be remembered that the recommendations made in this thesis are based on recommendations from Washington and Oregon. Differences in geomorphology and hydrology between these states and Georgia may require more stringent culvert design criteria or even allow less stringent slope, culvert width/size and embedding depth criteria. Only long-term studies of new installations will ensure the best solution for fish passage in the Etowah River Basin.

# CHAPTER 7

# CONCLUSIONS

While the evidence is at this point inconclusive as to whether road crossings are significantly impacting the survival of small stream anadromous fish, the evidence does indicate that this is highly likely. Road crossings, especially culverts, have been shown to act as barriers to passage of small stream fish, significantly reducing the likelihood of passage when compared with natural stream reaches, as shown by Ensign (2004, unpublished data), Warren and Pardew (1998) and Toepfer et al. (1999). Many of the culverts in the Etowah River Basin do not meet the most lenient of the requirements for passage of Cherokee darters, as determined from the available literature. The Cherokee darter is intolerant of impoundment and its population is fragmented throughout the Etowah, indicating that darter populations are impacted negatively by habitat fragmentation. Even with further studies of fish movements across road crossings in the Etowah River Basin, the indicators of impacts of road crossings are likely to remain indirect and difficult to separate from other impacts of urbanization. But this should not be sufficient reason to avoid the implementation of relatively cost effective measures to protect the federally threatened species. Long-term assessment of new culverts designed according to the recommendations in this thesis is recommended because hydrological and geomorphological conditions in the Etowah River Basin are different from those in other states where new design recommendations have been tested.

The main difference in requirements for fish passage of the Cherokee darter as compared with salmon is that streambed simulation strategies (the no-slope design option with 20% embedding and the stream simulation design option with 30-50% embedding) are given a higher priority because even zero-slope non-embedded designs are seen to reduce fish passage. Further studies may refine the required % embedding, but at this time, 20% for no-slope designs and 30-50% for stream simulation designs (at higher slopes than no-slope) are required.

Implementation of the recommended best management practices for new road crossing installations should reduce habitat fragmentation of the Cherokee darter habitat and promote the survival and thriving of the Cherokee darter, along with the other fish in the Etowah River Basin. It will be much more cost effective than requiring replacement of culverts in the future.

### 7.1 Recommended future directions

The following areas require further investigation. The following culvert options may be trailed but if trailed should receive ongoing monitoring.

- Multiple culverts to provide the same overall stream width as a single opening culvert designed by the no-slope design method or the stream simulation design method, as long as distance between two separate openings is minimized to avoid excessive alteration of stream width;
- Culverts designed to the same width and countersinking dimensions as no-slope design but installed in locations with slopes greater than 2.5%;
- Culverts designed to meet requirements of 50-year storm flow passage with 20% embedding but not specifically designed to meet bankfull (if 50-year flood passage design size is smaller);
- Be mindful that these recommendations are based on Washington and Oregon’s recommendations and differences in geomorphology and hydrology between these states and Georgia may require more stringent or even allow less stringent slope, culvert width/size and embedding depth criteria. Only long-term studies of new installations will provide answers;
- Maintenance of existing culverts;
- Ongoing fish passage studies and genetics research will also add weight to the validity of the recommendations, especially if it is determined in the future that old road crossings may need to be replaced for better fish passage.

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# APPENDICES

## APPENDIX A. SITE STRATIFICATION CUT OFF DETERMINATION

**2 Year Flood** http://ga2.er.usgs.gov/floodfrequency/analysisinfo.cfm

Constant*Drainage Area^Power

Constant =

207

*

drainage area ^ (miles) Conversion factor:

Power:

0.654

| | | | |
|---|---|---|---|
| 0.6214 | miles = | 1 km | |
| 0.38613796 | miles ^ 2 = | 1 km^2 | |

Calculating Flood Discharges in cubic feet per second

| Drainage Area (km^2) | Drainage Area (miles^2) | Flood (2 Year) Flow | Doubling from 1km^2 | Cut offs |
|---|---|---|---|---|
| 1 | 0.38613796 | 111.0963879 | 111.0963879 | 1) 1 km^2 |
| 2 | 0.77227592 | 174.8129317 | 1.573524891 | |
| 3 | 1.15841388 | 227.8962818 | 2.051338356 | 2) 3 km^2 |
| 4 | 1.54455184 | 275.0724992 | 2.475980582 | |
| 5 | 1.9306898 | 318.2924388 | 2.865011588 | |
| 6 | 2.31682776 | 358.6004719 | 3.227831963 | |
| 7 | 2.70296572 | 396.6377604 | 3.570212927 | |
| 8 | 3.08910368 | 432.8334243 | 3.896017074 | |
| 9 | 3.47524164 | 467.4923841 | 4.207989051 | 3) 9 km^2 |
| 10 | 3.8613796 | 500.841075 | 4.508167045 | |
| 11 | 4.24751756 | 533.0534459 | 4.798116804 | |
| 12 | 4.63365552 | 564.2667684 | 5.079073936 | |
| 13 | 5.01979348 | 594.591767 | 5.352035093 | |
| 14 | 5.40593144 | 624.1193886 | 5.617818906 | |
| 14.5 | 5.59900042 | 638.608379 | 5.748237101 | |
| 15 | 5.7920694 | 652.9254882 | 5.877108161 | |
| 16 | 6.17820736 | 681.0741667 | 6.130479841 | |
| 17 | 6.56434532 | 708.6202088 | 6.378427075 | |
| 18 | 6.95048328 | 735.6109026 | 6.621375512 | |
| 19 | 7.33662124 | 762.0874225 | 6.85969577 | |
| 20 | 7.7227592 | 788.0858978 | 7.093713057 | |
| 21 | 8.10889716 | 813.6382514 | 7.323714717 | |
| 22 | 8.49503512 | 838.7728651 | 7.549956219 | |
| 23 | 8.88117308 | 863.5151148 | 7.772665978 | |
| 24 | 9.26731104 | 887.8878051 | 7.99204926 | |
| 25 | 9.653449 | 911.9115255 | 8.208291398 | 4) 25 km^2 |
| 26 | 10.03958696 | 935.6049452 | 8.421560435 | |
| 27 | 10.42572492 | 958.9850588 | 8.632009343 | |
| 28 | 10.81186288 | 982.0673927 | 8.83977788 | |
| 29 | 11.19800084 | 1004.86618 | 9.044994157 | |
| 30 | 11.5841388 | 1027.394507 | 9.247775976 | |
| 31 | 11.97027676 | 1049.664445 | 9.448231978 | |
| 32 | 12.35641472 | 1071.687154 | 9.646462622 | |
| 33 | 12.74255268 | 1093.472979 | 9.842561037 | |
| 34 | 13.12869064 | 1115.031537 | 10.03661377 | |
| 35 | 13.5148286 | 1136.37178 | 10.22870141 | |
| 36 | 13.90096656 | 1157.502065 | 10.41889918 | |
| 37 | 14.28710452 | 1178.430208 | 10.60727742 | |
| 37.5 | 14.4801735 | 1188.820781 | 10.70080498 | |
| 38 | 14.67324248 | 1199.163528 | 10.79390204 | |
| 39 | 15.05938044 | 1219.708898 | 10.97883487 | |
| 40 | 15.4455184 | 1240.072776 | 11.16213406 | |
| 41 | 15.83165636 | 1260.261245 | 11.34385436 | |
| 42 | 16.21779432 | 1280.280041 | 11.5240474 | |
| 43 | 16.60393228 | 1300.134579 | 11.70276192 | |
| 44 | 16.99007024 | 1319.829981 | 11.88004404 | |
| 45 | 17.3762082 | 1339.371098 | 12.05593739 | |
| 46 | 17.76234616 | 1358.762527 | 12.23048338 | |
| 47 | 18.14848412 | 1378.008632 | 12.40372129 | |
| 48 | 18.53462208 | 1397.113562 | 12.57568844 | |
| 49 | 18.92076004 | 1416.08126 | 12.74642035 | |
| 50 | 19.306898 | 1434.915483 | 12.91595082 | |

# APPENDIX B. ROAD CROSSING SURVEY DATA

| Final ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 |
| **Culvert #:** | 0(a) | 1 | 2(a) | 4(a) | 5 (a) | 6 (a) | 7 (b) | 8(b) |
| **Storm or Base (Low) Flow** | | | | | | | | |
| **Stream:** | Flat Creek | trib Stamp Ck | unnamed | Cochran Rd | trib Buzzard Flapper | trib Hickory Log Ck | trib Yellow Ck | Conn Ck |
| **Road:** | SR9 | Brookes Rd | Iron Moutain Rd | Marable Ck | Hube Turner Dr | Worley Rd | Roscoe Collett Rd | Mountain Breeze Rd |
| **County:** | Dawson | Bartow | Cherokee | Paulding | Cherokee | Cherokee | Cherokee | Cherokee |
| **Culvert Size km^2:** | 1.62 | 1.15 | 2.24 | 2.24 | 1.8 | 2.4 | 1.54 | 2.27 |
| **Date (Month, Day, Year):** | 25-Jun-03 | 14-Apr-04 | 17-Jul-03 | 21-Oct-03 | 3-Jul-03 | 24-Jul-03 | 28-Jul-03 | 28-Jul-03 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Box | Bottomless Arch | Pipe | Pipe | Pipe | Pipe | Pipe | Pipe |
| **Concrete/Metal/PVC/Other:** | Concrete | Concrete | Metal | Metal | Metal | Metal | Metal | Metal |
| **Number of Openings:** | 2 | 1 | 3 | 1 | 3 | 1 | 1 | 3 |
| **Number of Openings with Flow:** | 2 | 1 | 0 | 1 | 3 | 1 | 1 | 1 |
| **Number of Openings with Partial Flow** | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| **Road Surface Paved/Gravel:** | Paved | Paved | Paved | Gravel | Paved | Paved | Gravel | Paved |
| **Number of Lanes:** | 2 | 2 | 2 | 1.5 | 1 | 2 | 2 | 2 |
| **Culvert Diameter (m):** | n/a | - | 1.05 | 1.85 | 1.54 | 1.3208 | 1.24 | 2.05 |
| **Corrugated?** | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| **Corrugation Wavelenth:** | n/a | - | 2.5 | 0.075 | 0.0889 | 0.0635 | 0.0889 | 0.0762 |
| **Corrugation Height:** | n/a | - | 0.5 | 0.035 | 0.0254 | 0.0127 | 0.0254 | 0.0254 |
| **Culvert Opening Width (m):** | 2.43 | 1.4478 | n/a | n/a | n/a | n/a | n/a | n/a |
| **Width of Culvert Internal Walls (m):** | 0.25 | | n/a | n/a | 0.3 | n/a | n/a | n/a |
| **Total Culvert Width (m):** | 5.11 | 1.4478 | - | - | 5.22 | n/a | n/a | n/a |
| **Total Culvert Opening Width (m):** | 4.86 | 1.4478 | 3.8 | 1.85 | 4.62 | 1.321 | 1.24 | 6.15 |
| **Apron: Yes/No** | Yes | No | - | No | No | Yes - rocks | No | No |
| **Culvert Height (m):** | 2.15 | 0.9144 | n/a | n/a | n/a | n/a | n/a | n/a |
| **Culvert Length (m):** | 15.00 | 9.60 | 25.00 | 12.30 | 12.30 | 11.00 | 14.00 | 28.50 |
| **Culvert Slope (%):** | 1.12% | 0.00% | 1.32% | 0.00% | 2.18% | 0.01% | 0.00% | 0.87% |
| **Overhang (m):** | 0.30 | 0.00 | 0.57 | 0.05 | 0.08 | 0.15 | 0.05 | 0.05 |
| **Drop to Bottom Min (m):** | 0.30 | 0.20 | 0.19 | 0.01 | 0.01 | 0.22 | 0.03 | 0.05 |
| **Drop to Bottom Max (m):** | - | - | - | 0.38 | - | - | - | - |
| **Drop to Water Surface (m):** | 0.30 | 0.13 | 0.08 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| **Drop to Surface > 2 cm** | Yes | Yes | Yes | No | No | No | No | No |
| **Drop to Bottom > 2 cm** | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes |
| **Drop to Surface > 6 inches (0.15 m)** | Yes | No | No | No | No | No | No | No |
| **Velocity Greater Than 0.25 m/s** | Yes | No | No | No | Yes | Yes | Yes | Yes |
| **Velocity Greater Than 0.4 m/s** | No | No | No | No | No | No | No | Yes |
| **Upstream 'Jump' (m):** | 0.23 | 0.00 | 0.00 | -0.33 | 0.03 | 0.10 | 0.06 | 0.10 |
| **Impassable wrt US Drop / Jump** | | | | Drop US | | | | |
| **Impassable Road Crossing (lenient criteria)** | 1 | | | 1 | | | | 1 |
| **Impassable Road Crossing (strict criteria)** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Maybe Impassable - Type** | | small bottomless arch | | | | | | |
| **Max water depth in culvert today (m) inlet:** | 0.02 | 0.06 | 0.01 | 0.20 | 0.10 | 0.13 | 0.07 | 0.13 |
| **Max water depth in culvert today (m) outlet:** | - | 0.06 | - | 0.20 | - | 0.10 | 0.13 | 0.18 |
| **Typical Width Upstream (m):** | 3.20 | | 1.55 | 1.75 | - | 1.30 | 1.00 | - |
| **Typical Width Downstream (m):** | - | 1.10 | 3.65 | 3.00 | 1.30 | 3.00 | 1.38 | 2.50 |
| **Total Width at water level today (m)** | 4.86 | 1.45 | 2.22 | 1.16 | 2.29 | 0.70 | 0.75 | 1.15 |
| **Flowrate (m3/s) :** | 0.0339 | 0.0033 | 0.0373 | 0.0044 | 0.0435 | 0.0138 | 0.0248 | 0.0594 |
| **Average Culvert Outlet Velocity (m/s) :** | 0.34 | 0.04 | 0.01 | 0.03 | 0.28 | 0.28 | 0.38 | 0.43 |
| **Velocity in culvert today (m/s) inlet:** | - | - | - | - | - | - | - | - |
| **Velocity in culvert today (m/s) outlet:** | - | 0.12 | - | 0.03 | - | - | - | - |
| **Velocity in Culvert (average) (m/s):** | 0.09 | | | | | | | |
| **Depth of Sediment in main channels (m):** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total Opening CSA (m3) no fill** | 10.45 | 1.32 | 3.84 | 2.69 | 5.59 | 1.37 | 1.21 | 9.90 |
| **Scour Pool** Length (m): | - | n/a | 6.60 | 11.00 | n/a | 10.00 | 7.00 | 6.00 |
| **Scour Pool Max Depth (m):** | 0.30 | n/a | 0.97 | 0.36 | n/a | 0.51 | 0.43 | 0.25 |
| **Scour Pool Width (m):** | 7.70 | n/a or slight widening to 1.5 m | 6.50 | 5.00 | n/a | 5.00 | 1.80 | 3.00 |
| **Common Flood Water Mark (above water surface):** | 0.37 | 0.15 | 1.22 | 0.10 | 0.30 | 0.15 | 0.15 | 0.46 |
| **Max Flood High water mark (above water surface):** | - | | - | 0.36 | 0.91 | 0.91 | - | 1.22 |
| **Sediment in Culvert Yes/No:** | No | Yes | Yes | No | Yes - a little in lhs | No | No | No |
| **Sediment in Main Flow Section of Culvert Yes/No:** | | Yes - stream bottom | Yes | No | No | No | No | No |
| **Stream Gradient Very Low/Low/Med/High:** | Low-Med | Low-Med | Low | Very Low | Med | Low/Low-Med | Med | Med |

| Final ID | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 |
| **Culvert #:** | 9 (a) | 10(a) | 11b | 12 (b) | 13(a) | 14 | 15(a) | 16(b) |
| **Storm or Base (Low) Flow** | | | Unnatural - pump fed feeds to dam | | | | | |
| **Stream:** | trib Hickory Log Ck | trib Etowah | trib East Branch | Coopers Sandy Ck | trib of Noonday Ck | trib Pumpkinvine | Virgil Rd | Picketts Mill Ck |
| **Road:** | Worley Rd | Liberty Lane | Harrington Rd | Cogburn Rd | White Circle | Hulseytown Rd | trib Raccoon Ck | Wiscassett Parkway |
| **County:** | Cherokee | Dawson | Pickens | Fulton | Cobb | Paulding | Paulding | Cobb |
| **Culvert Size km^2:** | 1.04 | 1.44 | 2.82 | 2.49 | 2.36 | 2.95 | 2.48 | 2.58 |
| **Date (Month, Day, Year):** | 24-Jul-03 | 26-Jun-03 | 14-Apr-04 | 15-Jul-03 | 31-Jul-03 | 15-Apr-04 | 21-Oct-03 | 31-Jul-03 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Pipe | Pipe | Pipe | Bridge - spans stream | Pipe | Pipe | Pipe | Pipe |
| **Concrete/Metal/PVC/Other:** | Concrete | Metal | Metal | Wood and cement | Cement | Metal | Metal | Metal |
| **Number of Openings:** | 1 | 1 | 2 | 1 | 1 | 5 | 1 | 2 |
| **Number of Openings with Flow:** | 1 | 1 | 2 | 1 | 1 | 4 | 1 | 2 |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Road Surface Paved/Gravel:** | Paved | Paved | Paved | Paved | Paved | Paved | Cemented Gravel | Paved |
| **Number of Lanes:** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **Culvert Diameter (m):** | 0.9144 | 2.5 | 0.9144 | n/a | 1.23 | 1.6 | 1.75 | 1.65 |
| **Corrugated?** | No | Yes | Yes | No | No | Yes | Yes | Yes |
| **Corrugation Wavelenth:** | n/a | 0.127 | 0.0635 | n/a | n/a | | 0.0762 | 0.127 |
| **Corrugation Height:** | n/a | 0.0254 | 0.0127 | n/a | n/a | | 0.0254 | 0.0254 |
| **Culvert Opening Width (m):** | n/a | n/a | - | 4.2 | n/a | - | n/a | n/a |
| **Width of Culvert Internal Walls (m):** | n/a | n/a | - | n/a | n/a | - | n/a | 0.3302 |
| **Total Culvert Width (m):** | n. | n/a | 1.82 | 3.5904 | n/a | 11.4 | - | - |
| **Total Culvert Opening Width (m):** | 0.91 | 2.5 | 1.52 | 4.2 | 1.23 | 8 | 1.75 | 3.3 |
| **Apron: Yes/No** | No | No | No | Yes | Yes | 1.524 | No | Yes |
| **Culvert Height (m):** | n/a | n/a | - | 3.00 | n/a | - | n/a | n/a |
| **Culvert Length (m):** | 11.00 | 18.20 | 12.35 | 9.90 | 11.15 | 12.10 | 12.20 | 28.30 |
| **Culvert Slope (%):** | 3.00% | 1.61% | 0.87% | n/a | 3.19% | 1.05% | 0.00% | 0.81% |
| **Overhang (m):** | 0.25 | 0.00 | 1.00 | n/a | 0.10 | 0.00 | 0.03 | 0.91 |
| **Drop to Bottom Min (m):** | 0.30 | 0.00 | fence | n/a | 0.11 | 0.04 | 0.01 | 0.81 |
| **Drop to Bottom Max (m):** | - | - | - | - | | - | 0.10 | - |
| **Drop to Water Surface (m):** | 0.17 | 0.00 | 0.00 | n/a | 0.00 | 0.00 | 0.00 | 0.28 |
| **Drop to Surface > 2 cm** | Yes | No | Yes | No | No | No | No | Yes |
| **Drop to Bottom > 2 cm** | Yes | No | Yes | No | Yes | Yes | Yes | Yes |
| **Drop to Surface > 6 inches (0.15 m)** | Yes | No | No | No | No | No | No | Yes |
| **Velocity Greater Than 0.25 m/s** | No | Yes | Yes | No | Yes | Yes | No | No |
| **Velocity Greater Than 0.4 m/s** | No | Yes | Yes | No | No | Yes | No | No |
| **Upstream 'Jump' (m):** | 0.08 | 0.00 | -0.20 | n/a | 0.00 | 0.00 | 0.08 | -0.03 |
| **Impassable wrt US Drop / Jump** | | | Drop US = passable | | | | | |
| **Impassable Road Crossing (lenient criteria)** | 1 | 1 | 1 | | | 1 | | 1 |
| **Impassable Road Crossing (strict criteria)** | 1 | 1 | 1 | | 1 | 1 | 1 | 1 |
| **Maybe Impassable - Type** | | | | | | | | |
| **Max water depth in culvert today (m) inlet:** | - | 0.08 | 0.13 | 0.70 | - | - | 0.13 | 0.08 |
| **Max water depth in culvert today (m) outlet:** | 0.05 | - | - | - | 0.10 | 0.04 | 0.20 | 0.08 |
| **Typical Width Upstream (m):** | - | 2.30 | 2.20 | 3.30 | 1.80 | | | 2.50 |
| **Typical Width Downstream (m):** | 3.50 | 1.95 | | 3.60 | 1.80 | 2.10 | | 2.50 |
| **Total Width at water level today (m)** | 0.42 | 0.86 | 0.97 | 4.20 | 0.66 | 2.06 | 1.12 | 1.53 |
| **Flowrate (m3/s) :** | -0.0033 | 0.0258 | 0.0861 | 0.1191 | 0.0148 | 0.0514 | 0.0381 | 0.0190 |
| **Average Culvert Outlet Velocity (m/s) :** | -0.23 | 0.59 | 1.40 | 0.04 | 0.35 | 0.20 | 0.24 | 0.16 |
| **Velocity in culvert today (m/s) inlet:** | Close to zero | - | - | - | - | - | - | - |
| **Velocity in culvert today (m/s) outlet:** | - | - | - | - | - | 0.48 | 0.08 | - |
| **Velocity in Culvert (average) (m/s):** | | 0.80 | | | | | | |
| **Depth of Sediment in main channels (m):** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total Opening CSA (m3) no fill** | 0.66 | 4.91 | 0.95 | 12.60 | 1.19 | 10.05 | 2.41 | 4.28 |
| **Scour Pool** Length (m): | 8.00 | n/a | n/a | n/a | 7.00 | n/a | 10.00 | 11.00 |
| **Scour Pool Max Depth (m):** | 0.79 | n/a | n/a | n/a | 1.17 | n/a | 0.65 | 0.66 |
| **Scour Pool Width (m):** | 5.00 | n/a | constructed | 3.59 | 7.00 | width of culvert | 7.00 | 7.00 |
| **Common Flood Water Mark (above water surface):** | 0.15 | - | | 0.46 | - | 0.61 | 0.23 | 0.10 |
| **Max Flood High water mark (above water surface):** | - | - | 1.83 | 1.22 | 0.91 | | 0.61 | 1.07 |
| **Sediment in Culvert Yes/No:** | No | - | No | Yes | No | Yes | Yes | Yes |
| **Sediment in Main Flow Section of Culvert Yes/No:** | No | | No | Yes - stream bottom | No | Yes | No | Yes |
| **Stream Gradient Very Low/Low/Med/High:** | Low | Low-Med | med-high | Med-Low | Med / Med-High | Low-Med | Low | Low |

| Final ID | 17 | 18 | 19 | 20 | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| STRATCLASS | 1-3 | 1-3 | 1-3 | 1-3 | | |
| Culvert #: | 17 (b) | 27(a) | 19 | 22 (a) | | |
| Storm or Base (Low) Flow | AFTER STORM | | | | | |
| Stream: | trib Thalley Ck | trib Mill Ck | trib Rock Ck | trib Rubes Ck | | |
| Road: | Spot Rd | Mill Creek Dr | Gregory Rd | Netherstone Dr | | |
| County: | Forsyth | Dawson | Pickens | Cobb | | |
| Culvert Size km^2: | 1.98 | 1.26 | 1.31 | 2.65 | 2.03 | 0.59 |
| Date (Month, Day, Year): | 2-Jul-03 | 26-Jun-03 | 14-Apr-04 | 8-Jul-03 | | |
| Culvert Type - Box/Pipe/Feespan/Other | Pipe | Pipe | Pipe | Pipe | | |
| Concrete/Metal/PVC/Other: | Metal | Metal | Metal | Metal | | |
| Number of Openings: | 1 | 1 | 1 | 3 | 1.75 | 1.12 |
| Number of Openings with Flow: | 1 | 1 | 1 | 2 | | |
| Number of Openings with Partial Flow | 0 | 0 | 0 | 0 | | |
| Road Surface Paved/Gravel: | Paved | Gravel | Gravel | Paved | | |
| Number of Lanes: | 2 | 1 | 2 | 2 | | |
| Culvert Diameter (m): | 1.9 | 1.1 | 1.15 | 2.15 | | |
| Corrugated? | Yes | Yes | Yes | Yes | | |
| Corrugation Wavelenth: | 0.0889 | 0.0508 | 0.0635 | 0.0762 | | |
| Corrugation Height: | 0.0127 | 0.0127 | 0.0127 | 0.0381 | | |
| Culvert Opening Width (m): | n/a | n/a | - | n/a | | |
| Width of Culvert Internal Walls (m): | n/a | n/a | - | 0.5 | | |
| Total Culvert Width (m): | n/a | n/a | 1.15 | 6.4 | | |
| Total Culvert Opening Width (m): | 1.9 | 1.1 | 1.15 | 6.4 | | |
| Apron: Yes/No | No | No | No | Yes | | |
| Culvert Height (m): | n/a | n/a | - | n/a | | |
| Culvert Length (m): | 22.00 | 8.85 | 9.30 | 24.50 | 15.38 | 6.56 |
| Culvert Slope (%): | 0.00% | 0.00% | 0.00% | 1.49% | 0.92% | 1.02% |
| Overhang (m): | 0.00 | 0.00 | 0.00 | 0.23 | 0.20 | 0.30 |
| Drop to Bottom Min (m): | 0.00 | 0.00 | 0.00 | 0.46 | 0.15 | 0.21 |
| Drop to Bottom Max (m): | - | - | 0.00 | - | 0.16 | 0.20 |
| Drop to Water Surface (m): | 0.00 | 0.00 | 0.00 | 0.36 | 0.07 | 0.12 |
| Drop to Surface > 2 cm | No | No | No | Yes | | |
| Drop to Bottom > 2 cm | No | No | No | Yes | | |
| Drop to Surface > 6 inches (0.15 m) | No | No | No | Yes | | |
| Velocity Greater Than 0.25 m/s | No | No | No | Yes | | |
| Velocity Greater Than 0.4 m/s | No | No | No | Yes | | |
| Upstream 'Jump' (m): | 0.00 | 0.20 | 8" drop to bottom, 3" drop to water surface | 0.00 | 0.02 | 0.13 |
| Impassable wrt US Drop / Jump | | | | | | |
| Impassable Road Crossing (lenient criteria) | | | | 1 | | |
| Impassable Road Crossing (strict criteria) | | | | 1 | | |
| Maybe Impassable - Type | | | | | | |
| Max water depth in culvert today (m) inlet: | 1.01 | 0.40 | 0.20 | - | 0.21 | 0.27 |
| Max water depth in culvert today (m) outlet: | - | - | 0.10 | 0.10 | 0.11 | 0.06 |
| Typical Width Upstream (m): | 6.00 | - | 1.30 | - | 2.35 | 1.36 |
| Typical Width Downstream (m): | 6.00 | 1.40 | 1.60 | 2.10 | 2.50 | 1.23 |
| Total Width at water level today (m) | 1.90 | 1.06 | 0.88 | 2.20 | 1.62 | 1.15 |
| Flowrate (m3/s) : | 0.1561 | 0.0252 | 0.0247 | 0.0439 | 0.0411 | 0.0394 |
| Average Culvert Outlet Velocity (m/s) : | 0.10 | 0.16 | 0.20 | 0.70 | 0.29 | 0.34 |
| Velocity in culvert today (m/s) inlet: | 0.20 | - | 0.19 | - | 0.20 | 0.01 |
| Velocity in culvert today (m/s) outlet: | - | - | 0.27 | - | 0.19 | 0.18 |
| Velocity in Culvert (average) (m/s): | | | | | 0.44 | 0.50 |
| Depth of Sediment in main channels (m): | 0.00 | 0.25 | 28" wide sed at outlet. No sed at inlet | 0.00 | 0.01 | 0.06 |
| Total Opening CSA (m3) no fill | 2.84 | 0.95 | 1.04 | 6.93 | 4.26 | 3.78 |
| Scour Pool Length (m): | 8.00 | - | n/a | n/a | 8.46 | 1.88 |
| Scour Pool Max Depth (m): | 0.94 | - | n/a | n/a | 0.64 | 0.30 |
| Scour Pool Width (m): | 6.00 | - | 2.50 | n/a | 5.16 | 1.93 |
| Common Flood Water Mark (above water surface): | 0.30 | 30m wide floodplain | 0.61 | 0.61 | 0.37 | 0.29 |
| Max Flood High water mark (above water surface): | - | - | - | - | 1.00 | 0.41 |
| Sediment in Culvert Yes/No: | Yes | Yes | Not at inlet but at outlet | No | | |
| Sediment in Main Flow Section of Culvert Yes/No: | Yes | | Yes | No | | |
| Stream Gradient Very Low/Low/Med/High: | Very Low | Low | Low | Med | | |

| Final ID | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|---|
| STRATCLASS | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 |
| Culvert #: | 20 (a) | 21 (a) | 22 (b) | 23 | 24(b) | 25 (b) | 26 (b) | 27(b) |
| Storm or Base (Low) Flow | | | | | | | STORM | STORM |
| Stream: | trib of Allatoona | trib Canton Ck | trib Rubes Ck | trib Pickets Mill Ck | trib Etowah | trib Mill Ck | trib to Shoal Ck or Lake Arrowhead | Mill Ck |
| Road: | Paul Samuel Rd | Epperson Rd | Landing Way | Dogwood Trail | Ckers Chapel Rd | Brickmill Rd | Arrowhead Lake Drive | Thompson Rd |
| County: | Cobb | Cherokee | Cobb | Paulding | Cherokee | Cherokee | Cherokee | Dawson |
| Culvert Size km^2: | 4.41 | 3.16 | 8.16 | 4.8 | 4.04 | 8.48 | 4.65 | 6.74 |
| Date (Month, Day, Year): | 31-Jul-03 | 17-Jul-03 | 8-Jul-03 | 15-Apr-04 | 3-Jul-03 | 17-Jul-03 | 24-Jul-03 | 27-Jun-03 |
| Culvert Type - Box/Pipe/Feespan/Other | Bridge - Freespan with boulders | Bridge - spans stream | Box | Pipe | Bridge - Freespan with rocks | Box | Pipe | Box |
| Concrete/Metal/PVC/Other: | Cement with exposed steel bolts | Metal with concrete walls | Concrete | Metal | Metal and Cement | Concrete | Metal | Concrete |
| Number of Openings: | 1 | 1 | 4 | 3 | 1 | 3 | 2 | 2 |
| Number of Openings with Flow: | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| Number of Openings with Partial Flow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road Surface Paved/Gravel: | Paved | Paved | Paved | Paved | Paved | Paved | Paved | Paved |
| Number of Lanes: | 2 | 2 | 2 | 1.5 | 2 | 2 | 2 | 2 |
| Culvert Diameter (m): | n/a | n/a | n/a | 1.75 | n/a | n/a | 2.5 | n/a |
| Corrugated? | No | No | No | Yes | No | No | Yes | No |
| Corrugation Wavelenth: | n/a | n/a | n/a | 0.0762 | n/a | n/a | 0.0635 | n/a |
| Corrugation Height: | n/a | n/a | n/a | 0.0254 | n/a | n/a | 0.0254 | n/a |
| Culvert Opening Width (m): | 2.45 | 5.7 | 3 | - | 9.4 | 3.05 | n/a | 3.04 |
| Width of Culvert Internal Walls (m): | n/a | n/a | 0.24 | - | n/a | 0.25 | n/a | 0.24 |
| Total Culvert Width (m): | 2.45 | 5.7 | 12.72 | 6.6 | 4.2 | 9.65 | n/a | 6.32 |
| Total Culvert Opening Width (m): | 2.45 | 5.7 | 12 | 5.25 | 4.2 | 9.15 | 5 | 6.08 |
| Apron: Yes/No | Yes | Yes | Yes | No | Yes | Yes | No | Yes |
| Culvert Height (m): | 2 | 2.24 | n/a | - | 1.22 | 3.00 | n/a | 3.04 |
| Culvert Length (m): | 9.80 | 7.40 | 17.50 | 15.30 | - | 12.85 | 50.00 | 17.40 |
| Culvert Slope (%): | n/a | n/a | 0.00% | 1.33% | n/a | 0.00% | greater than slope of stream | 0.87% |
| Overhang (m): | n/a | n/a | 0.00 | 0.20 | n/a | 0.00 | 1.22 | 0.00 |
| Drop to Bottom Min (m): | n/a | n/a | 0.00 | 0.09 | n/a | 0.01 | 0.15 | 0.57 |
| Drop to Bottom Max (m): | - | - | - | - | - | - | - | - |
| Drop to Water Surface (m): | n/a | n/a | 0.00 | 0.00 | n/a | 0.00 | 0.00 | 0.29 |
| Drop to Water Surface > 2 cm | No | No | No | No | No | No | No | Yes |
| Drop to Bottom > 2 cm | No | No | No | Yes | No | No | Yes | Yes |
| Drop to Surface > 6 inches (0.15 m) | No | No | No | No | No | No | No | Yes |
| Velocity Greater Than 0.25 m/s | No | No | No | Yes | No | Yes | No | Yes |
| Velocity Greater Than 0.4 m/s | No | No | No | Yes | No | Yes | No | Yes |
| Upstream 'Jump' (m): | n/a | n/a | 0.14 | 0.38 | n/a | 0.48 | 0.00 | 0.91 |
| Impassable due to US Jump? | | | | | | | | |
| Impassable Road Crossing (lenient criteria) | | | | 1 | | 1 | | 1 |
| Impassable Road Crossing (strict criteria) | | | | 1 | | 1 | 1 | 1 |
| Maybe Impassable - Type | | | | | | | | |
| Max water depth in culvert today (m) inlet: | 0.48 | 0.46 | 0.46 | - | 0.15 | 0.10 | 0.10 | 0.08 |
| Max water depth in culvert today (m) outlet: | - | - | - | 0.16 | - | 0.13 | 0.05 | 0.05 |
| Typical Width Upstream (m): | 2.20 | 2.50 | 7.70 | | 1.50 | 3.80 | 3.00 | 3.50 |
| Typical Width Downstream (m): | 2.20 | 2.50 | 7.70 | 6.00 | 1.50 | 3.80 | 4.50 | - |
| Total Width at water level today (m) | 2.45 | 5.70 | 6.00 | 2.98 | 9.40 | 3.05 | 2.72 | 6.08 |
| Flowrate (m3/s) : | 0.045 | 0.050 | 0.125 | 0.063 | 0.223 | 0.166 | 0.079 | 0.184 |
| Average Culvert Outlet Velocity (m/s) : | 0.126 | 0.111 | 0.074 | 0.191 | 0.242 | 0.429 | 0.023 | 0.398 |
| Velocity in culvert today (m/s) inlet: | - | - | - | - | - | - | - | - |
| Velocity in culvert today (m/s) outlet: | - | - | - | 0.53 | - | - | - | - |
| Velocity in Culvert (average) (m/s): | | | | | | | | |
| Depth of Sediment (m): | SB | SB | 0.18 | 0.00 | SB | 0.00 | 0.00 | 0.00 |
| Total Opening CSA (m3) no fill | 4.90 | 12.74 | 32.92 | 7.22 | 11.46 | 27.42 | 9.82 | 18.48 |
| Scour Pool Length (m): | n/a | n/a | n/a | 11.00 | 0.00 | n/a | 20.00 | 4.30 |
| Scour Pool Max Depth (m): | n/a | n/a | n/a | 0.89 | n/a | n/a | 1.22 | 0.61 |
| Scour Pool Width (m): | Bridge = stream width | n/a | n/a | 9.00 | n/a | n/a | 14.00 | 6.20 |
| Common Flood Water Mark (above water surface): | 1.22 | - | 0.61 | 0.10 | 0.61 | 0.30 | 0.15 | 0.46 |
| Max Flood High water mark (above water surface): | - | 1.22 | 0.91 | 0.91 | - | 0.91 | 0.91 | 1.83 |
| Sediment in Culvert Yes/No: | Yes | Yes | Yes | No | Yes | Yes | Yes US in B | No |
| Sediment in Main Flow Section of Culvert Yes/No: | Yes - stream bottom | Yes - stream bottom | Yes | No | Yes - stream bed | Yes - little in main but ignore | Yes US in B | |
| Stream Gradient Very Low/Low/Med/High: | Med-High | Low | Low | High DS Low US | Med-High | Med | Low/Low-Med | - |

| Final ID | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|
| STRATCLASS | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 |
| Culvert #: | 28 (a) | 29 | 31 (a) | 33 (b) | 34 | 35 (b) | 36 (a) | 37 (a) |
| Storm or Base (Low) Flow | | | | AFTER STORM | | | | |
| Stream: | Shut In Ck | trib Pumkinvine Ck | Puckett Ck | trib Settingdown Ck | trib Etowah nr Allatoona Dam | Williams Rd | Rubes Ck | Canton Ck |
| Road: | Arrowhead Lake Dr | Spring Rd | Shoal Ck Rd | Concord Rd | Allatoona Dam Rd | Dunnaway Branch | E. Brandon Dr | Beavers Rd |
| County: | Cherokee | Paulding | Cherokee | Forsyth | Bartow | Paulding | Cobb | Cherokee |
| Culvert Size km^2: | 6.53 | 3.5 | 4.81 | 3.47 | 3.77 | 3.25 | 4.75 | 4.08 |
| Date (Month, Day, Year): | 22-Jul-03 | 15-Apr-04 | 21-Jul-03 | 1-Jul-03 | 14-Apr-04 | 21-Oct-03 | 8-Jul-03 | 17-Jul-03 |
| Culvert Type - Box/Pipe/Feespan/Other | Pipe | Pipe | Pipe | Pipe | Box | Pipe | Pipe | Pipe |
| Concrete/Metal/PVC/Other: | Metal | Metal | Concrete | Metal | Concrete | Metal | Metal | Metal |
| Number of Openings: | 2 | 1 | 4 | 2 | 2 | 2 | 3 | 3 |
| Number of Openings with Flow: | 2 | 1 | 2 | 2 | 1 | 2 | 3 | 2 |
| Number of Openings with Partial Flow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road Surface Paved/Gravel: | Paved | Paved | Paved | Paved | Paved | Gravel | Paved | Paved |
| Number of Lanes: | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Culvert Diameter (m): | 3.05 | 1.75 | 1.15 | 0.8636 | - | 1.8 | 2.3 | 2.25 |
| Corrugated? | Yes | Yes | No | Yes | No | Yes | Yes | Yes |
| Corrugation Wavelenth: | 0.0635 | 0.0762 | n/a | 0.0635 | - | 0.0762 | 0.0762 | 0.0635 |
| Corrugation Height: | 0.0254 | 0.0254 | n/a | 0.0127 | - | 0.0254 | 0.0254 | 0.0127 |
| Culvert Opening Width (m): | n/a | - | n/a | n/a | 4.5 | n/a | n/a | n/a |
| Width of Culvert Internal Walls (m): | n/a | - | n/a | n/a | 0.36 | - | 0.4064 | n/a |
| Total Culvert Width (m): | n/a | 1.75 | n/a | n/a | 9.36 | - | 7.7128 | n/a |
| Total Culvert Opening Width (m): | 6.1 | 1.75 | 6.99 | 1.7272 | 9 | 3.6 | 6.9 | 6.75 |
| Apron: Yes/No | No | No | Yes | No | Yes | No | Yes | - |
| Culvert Height (m): | n/a | - | n/a | n/a | 3.18 | n/a | n/a | n/a |
| Culvert Length (m): | 100.00 | 13.20 | 18.40 | 13.00 | 19.68 | 10.80 | 15.20 | 18.40 |
| Culvert Slope (%): | 0.76% | 2.50% | 2.47% | 0.87% | 0.22% | 0.00% | 0.00% | 0.01% |
| Overhang (m): | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Drop to Bottom Min (m): | 0.00 | 0.61 | 0.00 | 0.00 | 0.05 | 0.00 | 0.01 | 0.00 |
| Drop to Bottom Max (m): | - | - | - | - | 0.05 | 0.00 | - | - |
| Drop to Water Surface (m): | 0.00 | 0.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Drop to Water Surface > 2 cm | No | Yes | No | No | No | No | No | No |
| Drop to Bottom > 2 cm | No | Yes | No | No | Yes | No | No | No |
| Drop to Surface > 6 inches (0.15 m) | No | Yes | No | No | No | No | No | No |
| Velocity Greater Than 0.25 m/s | Yes | Yes | No | Yes | Yes | No | Yes | No |
| Velocity Greater Than 0.4 m/s | Yes | Yes | No | Yes | Yes | No | Yes | No |
| Upstream 'Jump' (m): | 0.00 | 0.00 | -0.30 | - | 0.05 | 0.00 | 0.15 | 0.13 |
| Impassable due to US Jump? | | | Yes | | | | | |
| Impassable Road Crossing (lenient criteria) | 1 | 1 | 1 | 1 | 1 | | 1 | |
| Impassable Road Crossing (strict criteria) | 1 | 1 | 1 | 1 | 1 | | 1 | |
| Maybe Impassable - Type | | | | | | | | |
| Max water depth in culvert today (m) inlet: | - | 0.18 | 0.00 | 0.25 | 0.05 | 0.71 | - | 0.00 |
| Max water depth in culvert today (m) outlet: | 0.46 | 0.09 | 0.00 | - | 0.03 | 0.71 | 0.06 | - |
| Typical Width Upstream (m): | - | | 4.00 | 2.65 | 4.00 | 4.00 | 4.25 | 2.00 |
| Typical Width Downstream (m): | 10.00 | 2.15 | 4.00 | - | 3.00 | 1.00 | - | 3.00 |
| Total Width at water level today (m) | 4.01 | 0.77 | 3.17 | 1.57 | 4.50 | 3.35 | 2.26 | 3.08 |
| Flowrate (m3/s) : | 0.069 | 0.048 | 0.154 | 0.214 | 0.030 | 0.004 | 0.096 | 0.109 |
| Average Culvert Outlet Velocity (m/s) : | 0.065 | 1.046 | 0.228 | 0.744 | 0.260 | 0.003 | 1.002 | 0.00 |
| Velocity in culvert today (m/s) inlet: | - | 0.85 | - | - | 0.35 | - | - | - |
| Velocity in culvert today (m/s) outlet: | 0.45 | 1.30 | - | - | 0.40 | 0.01 | - | - |
| Velocity in Culvert (average) (m/s): | | | | | 1.05 | | | |
| Depth of Sediment (m): | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 |
| Total Opening CSA (m3) no fill | 14.61 | 2.41 | 10.59 | 1.17 | 28.58 | 5.09 | 12.46 | 11.93 |
| Scour Pool Length (m): | 20.00 | n/a | n/a | 8.00 | n/a | 8.00 | n/a | n/a |
| Scour Pool Max Depth (m): | 1.22 | bedrock | n/a | 3.00 | n/a | 0.33 | n/a | n/a |
| Scour Pool Width (m): | 14.00 | boulders on sides | width of culverts | 9.00 | width of stream | 5.00 | n/a | n/a |
| Common Flood Water Mark (above water surface): | 0.15 | 0.10 | - | - | 0.61 | 0.08 | 0.15 | - |
| Max Flood High water mark (above water surface): | - | 0.20 | - | 0.91 | 1.83 | 0.15 | 1.22 | 1.83 |
| Sediment in Culvert Yes/No: | No | No | Yes | No | Yes | Yes | Yes | Yes |
| Sediment in Main Flow Section of Culvert Yes/No: | No | No | Yes - small amount | No | No | Yes | Yes | Yes - little bit |
| Stream Gradient Very Low/Low/Med/High: | Low/Low-Med | Med-High | Med | Med | Low-Med | Low-Med | Low | Low |

| Final ID | 37 | 38 | 39 | 40 | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| STRATCLASS | 3-9 | 3-9 | 3-9 | 3-9 | | |
| Culvert #: | 38 (b) | 39 (b) | 160 | 161 | | |
| Storm or Base (Low) Flow | | | | | | |
| Stream: | Burt Creek | trib Westbrook C | trib Etowah R. | Camp Ck | | |
| Road: | SR 136 | Cedar Crest Rd | Pink Williams Rd | Ben Higgins Rd | | |
| County: | Dawson | Paulding | Lumpkin | Lumkpin | | |
| Culvert Size km^2: | 8.41 | 3.41 | 4.14 | 4.514 | 4.95 | 1.74 |
| Date (Month, Day, Year): | 27-Jun-03 | 21-Oct-03 | 22-Apr-04 | 22-Apr-04 | | |
| Culvert Type - Box/Pipe/Feespan/Other | Freespan Arch | Box | Ford | Pipe | | |
| Concrete/Metal/PVC/Other: | Concrete and Metal | Concrete | Natural rock and gravel bottom | Metal | | |
| Number of Openings: | 1 | 2 | 1 | 2 | | |
| Number of Openings with Flow: | 1 | 1 | 1 | 2 | | |
| Number of Openings with Partial Flow | 0 | 0 | 0 | 0 | | |
| Road Surface Paved/Gravel: | Paved | Paved | Gravel | Paved | | |
| Number of Lanes: | 2 | 2 | 2 | 2 | | |
| Culvert Diameter (m): | n/a | n/a | n/a | 2.1 | | |
| Corrugated? | Yes | No | No | Yes | | |
| Corrugation Wavelenth: | 0.1524 | n/a | n/a | 0.1016 | | |
| Corrugation Height: | 0.0762 | n/a | n/a | 0.0254 | | |
| Culvert Opening Width (m): | 9.9 | 2.45 | 5.7 | - | | |
| Width of Culvert Internal Walls (m): | - | 0.26 | n/a | - | | |
| Total Culvert Width (m): | 9.9 | 5.16 | 5.7 | 4.5 | | |
| Total Culvert Opening Width (m): | 9.9 | 4.9 | 5.7 | 4.2 | | |
| Apron: Yes/No | No | Yes | No | No | | |
| Culvert Height (m): | 6.00 | 1.85 | n/a | - | | |
| Culvert Length (m): | 30.00 | 12.80 | 10.00 | 18.50 | 21.59 | 21.16 |
| Culvert Slope (%): | n/a | 0.00% | n/a | 0.69% | 0.69% | 0.88% |
| Overhang (m): | n/a | 0.00 | 0.00 | 0.36 | 0.13 | 0.31 |
| Drop to Bottom Min (m): | n/a | 0.01 | 0.00 | 0.41 | 0.12 | 0.21 |
| Drop to Bottom Max (m): | - | 0.10 | 0.00 | - | 0.04 | 0.05 |
| Drop to Water Surface (m): | n/a | 0.00 | 0.00 | 0.22 | 0.07 | 0.16 |
| Drop to Water Surface > 2 cm | No | No | No | Yes | | |
| Drop to Bottom > 2 cm | No | No | No | Yes | | |
| Drop to Surface > 6 inches (0.15 m) | No | No | No | Yes | | |
| Velocity Greater Than 0.25 m/s | No | No | No | Yes | | |
| Velocity Greater Than 0.4 m/s | No | No | No | Yes | | |
| Upstream 'Jump' (m): | n/a | 0.13 | 0.00 | 0.00 | 0.14 | 0.28 |
| Impassable due to US Jump? | | | | | | |
| Impassable Road Crossing (lenient criteria) | | | | 1 | | |
| Impassable Road Crossing (strict criteria) | | | | 1 | | |
| Maybe Impassable - Type | | | | | | |
| Max water depth in culvert today (m) inlet: | n/a | 0.04 | 0.18 | - | 0.22 | 0.21 |
| Max water depth in culvert today (m) outlet: | - | 0.04 | 0.18 | 0.05 | 0.15 | 0.20 |
| Typical Width Upstream (m): | 5.00 | 2.25 | 5.70 | 2.50 | 3.56 | 1.55 |
| Typical Width Downstream (m): | 5.00 | 2.25 | 5.70 | 1.50 | 3.87 | 2.41 |
| Total Width at water level today (m) | 9.90 | 2.45 | 5.70 | 1.53 | 4.03 | 2.45 |
| Flowrate (m3/s) : | 0.132 | 0.008 | 0.052 | 0.069 | 0.10 | 0.07 |
| Average Culvert Outlet Velocity (m/s) : | 0.043 | 0.089 | 0.051 | 0.593 | 0.29 | 0.32 |
| Velocity in culvert today (m/s) inlet: | - | - | - | - | 0.60 | 0.35 |
| Velocity in culvert today (m/s) outlet: | - | 0.07 | - | 0.35 | 0.44 | 0.42 |
| Velocity in Culvert (average) (m/s): | | | | | 1.05 | #DIV/0! |
| Depth of Sediment (m): | SB | 0.00 | SB | 0.00 | 0.02 | 0.05 |
| Total Opening CSA (m3) no fill | 59.40 | 9.07 | | 6.93 | 15.12 | 13.81 |
| Scour Pool Length (m): | n/a | - | n/a | 9.00 | 10.04 | 6.99 |
| Scour Pool Max Depth (m): | n/a | 0.28 | n/a | 1.19 | 1.09 | 0.86 |
| Scour Pool Width (m): | n/a | 5.16 | n/a | 10.00 | 9.05 | 3.58 |
| Common Flood Water Mark (above water surface): | - | 0.10 | 0.15 | 0.10 | 0.33 | 0.32 |
| Max Flood High water mark (above water surface): | 1.52 | 0.28 | - | 0.30 | 1.00 | 0.59 |
| Sediment in Culvert Yes/No: | Yes | Yes | Yes | Yes | | |
| Sediment in Main Flow Section of Culvert Yes/No: | Yes - stream bottom | No | Yes - stream bottom | Yes -big rocks and cobbles (deliberately put there) | | |
| Stream Gradient Very Low/Low/Med/High: | Low | Low | Low-Med | Med | | |

| Final ID | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
|---|---|---|---|---|---|---|---|---|
| STRATCLASS | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 |
| Culvert #: | 40 | 41 (b) | 42 (b) | 43 (a) | 44 (b) | 45 (b) | 46 (b) | 47 (b) |
| Storm or Base (Low) Flow | | STORM | | | | | | |
| Stream: | Bluffy Ck | Squattingdown Ck | Conn Ck | Moriah Rd | Pucket Ck | Lee Rd | trib Rubes Ck | Dannell Ck |
| Road: | Hulseytown Rd | Oak Grove | Conn Ck Rd | West Fork | Old Hwy 41 | Pegamore Ck | Jameson Rd | Hwy 53 |
| County: | Paulding | Forsyth | Cherokee | Paulding | Cobb | Paulding | Cobb | Pickens |
| Culvert Size km^2: | 21.19 | 9.37 | 18.01 | 9.16 | 19.65 | 21.88 | 11.25 | 9.14 |
| Date (Month, Day, Year): | 15-Apr-04 | 1-Jul-03 | 28-Jul-03 | 21-Oct-03 | 31-Jul-03 | 21-Oct-03 | 21-Jul-03 | 28-Jul-03 |
| Culvert Type - Box/Pipe/Feespan/Other | Box | Pipe | Box | Box | Bridge - Freespan with pilons | Pipe | Box | Box |
| Concrete/Metal/PVC/Other: | Concrete | Metal | Concrete | Concrete | Cement, metal | Metal | Concrete | Concrete |
| Number of Openings: | 3 | 1 | 3 | 1 | 1 | 6 | 2 | 4 |
| Number of Openings with Flow: | 2 | 1 | 3 | 1 | 1 | 6 | 1 | 2 |
| Number of Openings with Partial Flow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road Surface Paved/Gravel: | Paved | Paved | Paved | Gravel | Paved | Paved | Paved | Paved |
| Number of Lanes: | 2 | 2 | 2 | 2 | 4 | 2 | 2 | 2 |
| Culvert Diameter (m): | - | 3 | n/a | n/a | n/a | 0.6 | n/a | n/a |
| Corrugated? | No | Yes | No | No | No | Yes | No | No |
| Corrugation Wavelenth: | - | 0.1651 | n/a | n/a | n/a | 0.0635 | n/a | n/a |
| Corrugation Height: | - | 0.1016 | n/a | n/a | n/a | 0.0254 | n/a | n/a |
| Culvert Opening Width (m): | 2.75 | n/a | 3.05 | 3.1 | 24 | n/a | 3.06 | 3.05 |
| Width of Culvert Internal Walls (m): | | n/a | 0.25 | n/a | 1.7 | 0.508 | 0.25 | 0.25 |
| Total Culvert Width (m): | 14 | n/a | 9.65 | 3.1 | 31.5 | 6.14 | 6.37 | 13.2 |
| Total Culvert Opening Width (m): | 8.25 | 3 | 9.15 | 3.1 | 31.5 | 3.6 | 6.12 | 12.2 |
| Apron: Yes/No | Yes 5m | No | Yes | Yes 7.3 m | No | Yes | Yes | Yes |
| Culvert Height (m): | 2.5019 | n/a | 3.0988 | 1.8 | 2.55 | n/a | 3.0734 | 1.8796 |
| Culvert Length (m): | 26.70 | 34.14 | 17.00 | 13.70 | 12.50 | 6.00 | 15.65 | 15.65 |
| Culvert Slope (%): | 0.48% | Too deep to measure and raining | slight - sediment and hard to measure.. | 0.00% | n/a | 0.00% | 1.70% | 0.00% |
| Overhang (m): | 0.00 | 0.30 | 0.00 | 0.00 | n/a | 0.06 | 0.00 | 0.00 |
| Drop to Bottom Min (m): | 0.25 | 0.15 | 0.00 | 0.64 | n/a | 0.01 | 0.00 | 0.00 |
| Drop to Bottom Max (m): | 0.61 | - | - | 0.64 | - | 0.05 | - | - |
| Drop to Water Surface (m): | 0.01 | 0.00 | 0.00 | 0.09 | n/a | 0.00 | 0.00 | 0.00 |
| Drop to Water Surfaced > 2 cm | No | No | No | Yes | No | No | No | No |
| Drop to Bottom > 2 cm | Yes | Yes | No | Yes | No | Yes | No | No |
| Drop to Surface > 6 inches (0.15 m) | No | No | No | No | No | No | No | No |
| Velocity Greater Than 0.25 m/s | Yes | Yes | No | No | No | Yes | No | No |
| Velocity Greater Than 0.4 m/s | Yes | No | No | No | No | Yes | No | No |
| Upstream 'Jump' (m): | 0.00 | n/a | 0.00 | -0.51 | n/a | -0.20 | 0.08 | 0.00 |
| Impassable due to US Jump? | | | | Yes | | Yes | | |
| Impassable Road Crossing (lenient criteria) | 1 | | | 1 | | 1 | | |
| Impassable Road Crossing (strict criteria) | 1 | 1 | | 1 | | 1 | | |
| Maybe Impassable - Type | | | | | | | | |
| Max water depth in culvert today (m) inlet: | - | 0.58 | 0.15 | 0.03 | 0.91 | - | 0.28 | - |
| Max water depth in culvert today (m) outlet: | 0.03 | - | - | 0.03 | - | 0.19 | - | 0.20 |
| Typical Width Upstream (m): | 6.00 | 2.60 | - | 4.00 | 10.75 | | 3.50 | 3.00 |
| Typical Width Downstream (m): | 4.20 | - | 4.90 | 2.00 | - | | 3.50 | 3.00 |
| Total Width at water level today (m) | 5.50 | 2.38 | 9.15 | 3.10 | 24.00 | 2.63 | 3.06 | 6.10 |
| Flowrate (m3/s) : | 0.401 | 0.357 | 0.333 | 0.013 | 0.148 | 0.138 | 0.121 | 0.115 |
| Average Culvert Outlet Velocity (m/s) : | 1.11 | 0.37 | 0.24 | 0.17 | 0.01 | 0.94 | 0.22 | 0.19 |
| Velocity in culvert today (m/s) inlet: | 1.63 | - | - | - | - | - | - | - |
| Velocity in culvert today (m/s) outlet: | 0.90 | - | - | - | - | 0.83 | - | - |
| Velocity in Culvert (average) (m/s): | | | | | | | | |
| Depth of Sediment (m): | 0.00 | 0.00 | SB sim | 0.00 | SB | 0.00 | 0.10 | 0.10 |
| Total Opening CSA (m3) no fill | 20.64 | 7.07 | 28.35 | 5.58 | 61.20 | 1.70 | 18.81 | 22.93 |
| Scour Pool Length (m): | 20.00 | - | n/a | 15.00 | n/a | 5.00 | 13.00 | 13.00 |
| Scour Pool Max Depth (m): | 0.91 | 0.81 | - | 0.79 | 0.91 | 0.61 | n/a | - |
| Scour Pool Width (m): | 18.00 | n/a | 9.65 | 9.00 | WOB | 6.14 | 6.37 | Width of culvert but island of grass in middle |
| Common Flood Water Mark (above water surface): | 0.05 | - | 0.15 | - | 1.22 | 0.08 | 1.52 | 0.30 |
| Max Flood High water mark (above water surface): | 1.83 | - | 0.61 | 0.61 | 1.83 | 1.50 | - | - |
| Sediment in Culvert Yes/No: | Yes middle | Yes | Yes | No | Yes | No | Yes | Yes |
| Sediment in Main Flow Section of Culvert Yes/No: | No | Yes | Yes | No | Yes | No | Yes | Yes |
| Stream Gradient Very Low/Low/Med/High: | Low-Med | Med | Low/Low-Med | Low | Low / Low-Med | Low-Med | - | Low-Med |

| Final ID | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 |
|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 |
| **Culvert #:** | 49 (b) | 50 (b) | 51 (b) | 52 (b) | 53 (b) | 54 | 56(b) | 57 |
| **Storm or Base (Low) Flow** | | | STORM | STORM | | | | |
| **Stream:** | Mill Ck | Long Swamp Ck | Brewton Ck | Thalley Ck | Butler Ck | trib Long Swamp Ck | Pigeon Creek | Boston Ck |
| **Road:** | Union Hill Rd | Grandview Rd | Mt Tabor Rd | John Burrows | Mack Dobbs Rd | Georgia Baptist Rd | Cleve Right Rd | Hwy 20 |
| **County:** | Cherokee | Pickens | Forsyth | Forsyth | Cobb | Pickens | Dawson | Bartow |
| **Culvert Size km^2:** | 17.14 | 22.45 | 18.17 | 14.87 | 9.62 | 9.063 | 14.26 | 17.28 |
| **Date (Month, Day, Year):** | 17-Jul-03 | 28-Jul-03 | 27-Jun-03 | 1-Jul-03 | 31-Jul-03 | 22-Apr-04 | 26-Jun-03 | 14-Apr-04 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Box | Bridge or bottomless culvert | Box | Pipe | Bridge - spans stream concrete walls | Pipe | Bridge - Freespan | Bridge - Freespan |
| **Concrete/Metal/PVC/Other:** | Concrete | Concrete, Slate | Concrete | Metal | Concrete | Metal pipes in dirt with concrete bank reinforcement. | Wooden, Bolted | Huge construction |
| **Number of Openings:** | 3 | 2 | 2 | 2 | 1 | 4 | 1 | 1 |
| **Number of Openings with Flow:** | 3 | 1 | 2 | 2 | 1 | 3 | 1 | 1 |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Road Surface Paved/Gravel:** | Paved | Paved | Paved | Paved | Paved | Paved | Gravel | Paved |
| **Number of Lanes:** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **Culvert Diameter (m):** | n/a | n/a | n/a | 2.5 | n/a | 0.77 | n/a | - |
| **Corrugated?** | No | No | No | Yes | No | Yes | No | No |
| **Corrugation Wavelenth:** | n/a | n/a | n/a | 0.0889 | n/a | 0.0635 | n/a | |
| **Corrugation Height:** | n/a | n/a | n/a | - | n/a | 0.0127 | n/a | |
| **Culvert Opening Width (m):** | 3.05 | 5 | 3 | n/a | 5.4 | - | 5 | 8 |
| **Width of Culvert Internal Walls (m):** | 0.25 | 1 | 0.24 | n/a | n/a | 0 | n/a | |
| **Total Culvert Width (m):** | 9.65 | 11 | 6.24 | n/a | 8.2 | 3.8 | 5 | 40 |
| **Total Culvert Opening Width (m):** | 9.15 | 11 | 6 | 5 | 8.2 | 4.35 | 5 | 40 |
| **Apron: Yes/No** | Yes | Yes | Yes | No | Yes | No but concrete bank support | No | |
| **Culvert Height (m):** | 3.12 | 3.0988 | 3.05 | n/a | - | - | - | 50 |
| **Culvert Length (m):** | 16.00 | 9.80 | 11.58 | 19.90 | 13.50 | 18.00 | - | |
| **Culvert Slope (%):** | 0.01% | n/a | 0.88% | 0.88% | n/a | 1.83% | n/a | n/a |
| **Overhang (m):** | 0.00 | n/a | 0.00 | - | n/a | 0.81 | n/a | - |
| **Drop to Bottom Min (m):** | 0.64 | n/a | 0.00 | 0.58 | 5 " drop over bedrock | 0.27 | n/a | - |
| **Drop to Bottom Max (m):** | - | - | - | - | - | - | - | - |
| **Drop to Water Surface (m):** | 0.18 | n/a | 0.00 | 0.20 | n/a | 0.33 | n/a | - |
| **Drop to Water Surfaced > 2 cm** | Yes | No | No | Yes | No | Yes | No | No |
| **Drop to Bottom > 2 cm** | Yes | No | No | Yes | No | Yes | No | No |
| **Drop to Surface > 6 inches (0.15 m)** | Yes | No | No | Yes | No | Yes | No | No |
| **Velocity Greater Than 0.25 m/s** | Yes | Yes | No | Yes | No | Yes | Yes | n/a |
| **Velocity Greater Than 0.4 m/s** | Yes | Yes | No | Yes | No | Yes | No | n/a |
| **Upstream 'Jump' (m):** | 0.39 | n/a | 0.00 | - | n/a | 0.03 | n/a | - |
| **Impassable due to US Jump?** | | | | | | | | |
| **Impassable Road Crossing (lenient criteria)** | 1 | 1 | | 1 | | 1 | | |
| **Impassable Road Crossing (strict criteria)** | 1 | 1 | | 1 | | 1 | 1 | |
| **Maybe Impassable - Type** | | Bridge over bedrock | | | | | Bridge | |
| **Max water depth in culvert today (m) inlet:** | 0.15 | 0.10 | 0.36 | - | 0.15 | - | - | - |
| **Max water depth in culvert today (m) outlet:** | - | - | 0.20 | 0.46 | - | 0.13 | 0.30 | - |
| **Typical Width Upstream (m):** | 6.60 | 4.80 | - | 5.00 | 4.50 | 3.00 | 4.70 | |
| **Typical Width Downstream (m):** | 6.60 | - | 5.10 | - | 5.00 | 3.05 | 4.70 | |
| **Total Width at water level today (m)** | 9.15 | 5.00 | 6.00 | 3.87 | 5.40 | 2.15 | 5.00 | |
| **Flowrate (m3/s) :** | 0.589 | 0.498 | 0.359 | 0.600 | 0.079 | 0.135 | 0.399 | 0 |
| **Average Culvert Outlet Velocity (m/s) :** | 0.42 | 0.98 | 0.24 | 0.49 | 0.09 | 0.72 | 0.26 | - |
| **Velocity in culvert today (m/s) inlet:** | - | - | - | 0.59 | - | - | - | - |
| **Velocity in culvert today (m/s) outlet:** | - | - | - | - | - | 0.91 | - | - |
| **Velocity in Culvert (average) (m/s):** | | | | | | | | |
| **Depth of Sediment (m):** | 0.00 | BR | 0.10 | 0.00 | SB | 0.00 | SB | SB |
| **Total Opening CSA (m3) no fill** | 28.59 | 30.99 | 18.29 | 9.82 | | 4.06 | | 400 |
| **Scour Pool** Length (m): | 9.00 | n/a | n/a | - | n/a | 8.00 | n/a | |
| **Scour Pool Max Depth (m):** | 0.46 | n/a | n/a | 0.43 | n/a | 0.66 | n/a | |
| **Scour Pool Width (m):** | 9.00 | n/a | 7.15 | 0.61 | WOB | 8.00 | n/a | |
| **Common Flood Water Mark (above water surface):** | - | 0.91 | 0.60 | 0.61 | - | 0.05 | - | |
| **Max Flood High water mark (above water surface):** | - | 1.52 | - | - | 1.22 | 0.61 | At top of bridge | |
| **Sediment in Culvert Yes/No:** | No | Yes - only a little, mostly bed rock | Yes | Yes | Yes | No | Yes | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sediment in Main Flow Section of Culvert Yes/No:** | No | Yes | | Yes | Yes | No | Yes - Stream Bed | |
| **Stream Gradient Very Low/Low/Med/High:** | Low to Low-Med | Med | Low | Low | Low-Med | Med | Low-Med | |

| Final ID | 57 | 58 | 59 | 60 | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| **STRATCLASS** | 9-25 | 9-25 | 9-25 | 9-25 | | |
| **Culvert #:** | 59 (b) | 60(b) | 61 (b) | 121 | | |
| **Storm or Base (Low) Flow** | | | | | | |
| **Stream:** | trib Little River | Black Mill Ck | Blankets Ck | Mill Ck | | |
| **Road:** | River Chase Rd | Dawson Forest Hwy | Sixes Rd | Ben West Rd | | |
| **County:** | Cherokee | Dawson | Cherokee | Lumkpin | | |
| **Culvert Size km^2:** | 9.85 | 15.54 | 11.56 | 10.31 | 14.49 | 4.74 |
| **Date (Month, Day, Year):** | 21-Jul-03 | 26-Jun-03 | 21-Jul-03 | 22-Apr-04 | | |
| **Culvert Type - Box/Pipe/Feespan/Other** | Box | Box | Box | Bridge - spans stream, concrete walls | | |
| **Concrete/Metal/PVC/Other:** | Concrete | Concrete | Concrete | concrete with steal beams | | |
| **Number of Openings:** | 3 | 3 | 3 | 1 | | |
| **Number of Openings with Flow:** | 2 | 3 | 3 | 1 | | |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | | |
| **Road Surface Paved/Gravel:** | Paved | Paved | Paved | Paved | | |
| **Number of Lanes:** | 2 | 2 | 2 | 2 | | |
| **Culvert Diameter (m):** | n/a | n/a | n/a | n/a | | |
| **Corrugated?** | No | No | No | No | | |
| **Corrugation Wavelenth:** | n/a | n/a | n/a | n/a | | |
| **Corrugation Height:** | n/a | n/a | n/a | n/a | | |
| **Culvert Opening Width (m):** | 3 | 3.05 | 3.06 | 4.85 | | |
| **Width of Culvert Internal Walls (m):** | 0.3048 | - | 0.25 | n/a | | |
| **Total Culvert Width (m):** | 9.6096 | - | 9.93 | 4.85 | | |
| **Total Culvert Opening Width (m):** | 9 | 9.15 | 9.18 | 4.85 | | |
| **Apron: Yes/No** | Yes | Yes | Yes | Yes | | |
| **Culvert Height (m):** | 2.4384 | 3.66 | 2.1082 | 2.5 | | |
| **Culvert Length (m):** | 18.60 | 28.80 | 25.00 | 4.90 | 17.08 | 7.67 |
| **Culvert Slope (%):** | 0.27% | 0.27% | 1.26% | n/a | 0.63% | 0.67% |
| **Overhang (m):** | 0.18 | 0.00 | 0.00 | 0.00 | 0.10 | 0.22 |
| **Drop to Bottom Min (m):** | 0.30 | 0.61 | 0.00 | 0.00 | 0.23 | 0.26 |
| **Drop to Bottom Max (m):** | - | - | - | 0.00 | 0.32 | 0.35 |
| **Drop to Water Surface (m):** | 0.25 | 0.00 | 0.00 | 0.00 | 0.07 | 0.11 |
| **Drop to Water Surfaced > 2 cm** | Yes | No | No | No | | |
| **Drop to Bottom > 2 cm** | Yes | Yes | No | No | | |
| **Drop to Surface > 6 inches (0.15 m)** | Yes | No | No | No | | |
| **Velocity Greater Than 0.25 m/s** | Yes | Yes | No | No | | |
| **Velocity Greater Than 0.4 m/s** | No | Yes | No | No | | |
| **Upstream 'Jump' (m):** | 0.15 | 0.91 | 0.28 | 0.00 | 0.09 | 0.33 |
| **Impassable due to US Jump?** | | | | | | |
| **Impassable Road Crossing (lenient criteria)** | 1 | 1 | | | | |
| **Impassable Road Crossing (strict criteria)** | 1 | 1 | | | | |
| **Maybe Impassable - Type** | | | | | | |
| **Max water depth in culvert today (m) inlet:** | 0.051 | 0.051 | 0.043 | 0.24 | 0.24 | 0.26 |
| **Max water depth in culvert today (m) outlet:** | 0.06 | - | 0.20 | - | 0.18 | 0.13 |
| **Typical Width Upstream (m):** | 4.00 | 6.00 | 2.00 | 3.40 | 4.62 | 2.09 |
| **Typical Width Downstream (m):** | 2.65 | 7.75 | 2.00 | 3.40 | 4.13 | 1.67 |
| **Total Width at water level today (m)** | 6.00 | 9.15 | 9.18 | 4.85 | 6.40 | 4.86 |
| **Flowrate (m3/s) :** | 0.098 | 0.312 | 0.180 | 0.094 | 0.25 | 0.18 |
| **Average Culvert Outlet Velocity (m/s) :** | 0.26 | 0.67 | 0.10 | 0.08 | 0.40 | 0.33 |
| **Velocity in culvert today (m/s) inlet:** | - | - | - | - | 1.11 | 0.74 |
| **Velocity in culvert today (m/s) outlet:** | - | - | - | - | 0.88 | 0.04 |
| **Velocity in Culvert (average) (m/s):** | | | | | - | - |
| **Depth of Sediment (m):** | 0.00 | 0.00 | 0-6" (don't substract from depth) | SB | 0.03 | 0.05 |
| **Total Opening CSA (m3) no fill** | 21.95 | 33.47 | 19.35 | 12.13 | 41.38 | 90.57 |
| **Scour Pool** Length (m): | n/a | - | 13.00 | n/a | 12.00 | 4.63 |
| **Scour Pool Max Depth (m):** | n/a | - | n/a | n/a | 0.70 | 0.19 |
| **Scour Pool Width (m):** | n/a | 11.00 | 3.06 | n/a | 8.00 | 4.47 |
| **Common Flood Water Mark (above water surface):** | 0.08 | 1.00 | - | 0.05 | 0.51 | 0.51 |
| **Max Flood High water mark (above water surface):** | - | - | - | - | 1.22 | 0.54 |
| **Sediment in Culvert Yes/No:** | Yes | No | Yes | Yes | | |
| **Sediment in Main Flow Section of Culvert Yes/No:** | No | | Yes - lots | Yes | | |
| **Stream Gradient Very Low/Low/Med/High:** | Low | Low | Low | Med-High | | |

| Final ID | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 |
|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 |
| **Culvert #:** | 63 (b) | 65 (b) | 66 (b) | 67 (b) | 70 (b) | 71 (b) | 72 | 74 |
| **Storm or Base (Low) Flow** | Unnatural - Dam Upstream | | | AFTER STORM | | | AFTER STORM | |
| **Stream:** | Yellow Ck | Canton Ck | East Brach | Chicken Ck | Shoal Ck | Rubes Ck | Nancy Ck | Shoal Ck |
| **Road:** | Cowart Rd-Shiloh Church Rd | Hwy 575 | Old Mill White Rd | Freemanville Rd | Pleasant Arbour Rd | Alabama Rd | Mission Rd or Cherokee Ave | Shoal Ck Rd |
| **County:** | Dawson | Cherokee | Pickens | Fulton | Cherokee | Cherokee | Bartow | Dawson |
| **Culvert Size km^2:** | 39.29 | 35.8 | 42.53 | 49.17 | 45.22 | 28.87 | 35.49 | 30.86 |
| **Date (Month, Day, Year):** | 28-Jul-03 | 22-Jul-03 | 28-Jul-03 | 15-Jul-03 | 24-Jul-03 | 8-Jul-03 | 14-Apr-04 | 22-Apr-04 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Box | Box | Bridge - freespan | Bridge - Freespan with pilons | Bridge - Freespan with pilons | Box | Bridge - Freespan with pilons | Bridge - Freespan with pilons |
| **Concrete/Metal/PVC/Other:** | Concrete | Concrete | Metal and Wood | wooden pylons and cement | Concrete with Steel Poles | Concrete | Concrete and Steel | concrete only thing exposed. |
| **Number of Openings:** | 3 | 4 | 1 | 1 | 1 | 6 | 5 (3 pylons) | 1 |
| **Number of Openings with Flow:** | 1 | 4 | 1 | 1 | 1 | 6 | 1 | 1 |
| **Number of Openings with Partial Flow** | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Road Surface Paved/Gravel:** | Paved | Paved | Gravel | Paved | Paved | Paved | Paved | Paved |
| **Number of Lanes:** | 2 | 4 + Median Strip | 2 | 2 | 2 | 4 | 2 | 2 |
| **Culvert Diameter (m):** | n/a | n/a | n/a | n/a | n/a | n/a | - | n/a |
| **Corrugated?** | No | No | No | No | No | No | No | No |
| **Corrugation Wavelenth:** | n/a | n/a | n/a | n/a | n/a | n/a | - | n/a |
| **Corrugation Height:** | n/a | n/a | n/a | n/a | n/a | n/a | - | n/a |
| **Culvert Opening Width (m):** | 3.05 | 3.01 | 6.1 | 13 | 7.3 | 3.05 | 19 | 11.65 |
| **Width of Culvert Internal Walls (m):** | 0.3302 | 0.3429 | n/a | - | n/a | 0.3048 | pylons 1.2 m | n/a |
| **Total Culvert Width (m):** | 9.81 | 13.41 | 10 | 13 | 7.3 | 20.13 | 30 | 11.65 |
| **Total Culvert Opening Width (m):** | 9.15 | 12.04 | 10 | 13 | 7.3 | 18.3 | 30 | 11.65 |
| **Apron: Yes/No** | Yes | Yes | No | No | No | Yes | No | No |
| **Culvert Height (m):** | - | 2.4384 | 3 | 10.00 | 3.0734 | 1.80 | 2m above water | 6 |
| **Culvert Length (m):** | 20.30 | 74.25 | 3.50 | 7.70 | 8.50 | 43.90 | 12.00 | 8.90 |
| **Culvert Slope (%):** | 0.53% | 0.53% | n/a | n/a | n/a | 0.00% | n/a | n/a |
| **Overhang (m):** | 0.00 | 0.00 | n/a | n/a | n/a | 0.00 | 0.00 | 0.00 |
| **Drop to Bottom Min (m):** | 0.25 | 0.51 | n/a | n/a | n/a | 0.38 | 0.00 | 0.00 |
| **Drop to Bottom Max (m):** | - | - | - | - | - | - | 0.00 | 0.00 |
| **Drop to Water Surface (m):** | 0.00 | 0.10 | n/a | n/a | n/a | 0.13 | 0.00 | 0.00 |
| **Drop to Water Surface > 2 cm** | No | Yes | No | No | No | Yes | No | No |
| **Drop to Bottom > 2 cm** | Yes | Yes | No | No | No | Yes | No | No |
| **Drop to Surface > 6 inches (0.15 m)** | No | No | No | No | No | No | No | No |
| **Velocity Greater Than 0.25 m/s** | Yes | Yes | Yes | n/a | Yes | Yes | No | No |
| **Velocity Greater Than 0.4 m/s** | Yes | Yes | Yes | n/a | No | Yes | No | Yes |
| **Upstream 'Jump' (m):** | 0.43 | 0.43 | n/a | n/a | n/a | 0.10 | 0.00 | 0.00 |
| **Impassable due to US Jump?** | No | No | No | No | No | No | No | No |
| **Impassable Road Crossing (lenient criteria)** | 1 | 1 | 1 | | | 1 | | |
| **Impassable Road Crossing (strict criteria)** | 1 | 1 | 1 | | 1 | 1 | | 1 |
| **Maybe Impassable - Type** | | | Bridge | | Bridge | | | Bridge |
| **Max water depth in culvert today (m) inlet:** | 0.25 | 0.10 | 0.22 | - | 0.29 | 0.12 | 0.46 | 0.15 |
| **Max water depth in culvert today (m) outlet:** | 0.13 | 0.20 | - | - | - | 0.05 | 0.46 | - |
| **Typical Width Upstream (m):** | n/a | - | 6.95 | 13.00 | 6.40 | 14.00 | | - |
| **Typical Width Downstream (m):** | 9.00 | 7.00 | 6.95 | 13.00 | - | 13.90 | 6.00 | 9.60 |
| **Total Width at water level today (m)** | 3.05 | 12.04 | 6.10 | 13.00 | 7.30 | 18.30 | 19.00 | 11.65 |
| **Flowrate (m3/s) :** | 0.84 | 0.57 | 0.62 | 0 | 0.71 | 0.49 | 0 | 0.46 |
| **Average Culvert Outlet Velocity (m/s) :** | 2.16 | 0.47 | 0.46 | - | 0.34 | 0.23 | 0 | 0.26 |
| **Velocity in culvert today (m/s) inlet:** | - | - | - | - | - | 0.21 | - | - |
| **Velocity in culvert today (m/s) outlet:** | - | - | - | - | - | 0.43 | - | - |
| **Velocity in Culvert (average) (m/s):** | | | | | | | 0.09 | |
| **Depth of Sediment (m):** | 0.00 | 0.10 | SB | SB | SB | 0.00 | SB | SB |
| **Total Opening CSA (m3) no fill** | 27.45 | 29.36 | 18.30 | 130.00 | 22.44 | 32.94 | | 69.90 |
| **Scour Pool** Length (m): | n/a | 13.00 | n/a | n/a | 5.00 | n/a | - | n/a |
| **Scour Pool Max Depth (m):** | 0.71 | - | n/a | - | same as stream | n/a | - | n/a |
| **Scour Pool Width (m):** | 11.81 | 13.41 | may be slight scouring DS of bridge to LHS | n/a | width of bridge | n/a | 19.00 | bridge = widest point |
| **Common Flood Water Mark (above water surface):** | - | - | 0.61 | 0.61 | 0.15 | - | 0.30 | 0.02 |
| **Max Flood High water mark (above water surface):** | 0.61 | 2.44 | 1.52 | 3.05 | 1.22 | - | floodplain | 0.91 |
| **Sediment in Culvert Yes/No:** | No | Yes | Yes | Yes | Yes | No | Yes | Yes |
| **Sediment in Main Flow Section of Culvert Yes/No:** | No | Yes - cobbles in 2 openings | Yes | Yes | Yes | No | Yes | Yes |
| **Stream Gradient Very Low/Low/Med/High:** | Med | Low-Med/Med | Med | Med | Low | Low | Low | Med |

| Final ID | 69 | 70 | Mean | Standard Deviation |
|---|---|---|---|---|
| STRATCLASS | 25-50 | 25-50 | | |
| Culvert #: | 75 | 41 (a) | | |
| Storm or Base (Low) Flow | | STORM | | |
| Stream: | East Branch | Settingdown Cr | | |
| Road: | McArthur Rd | Hubert Martin Rd | | |
| County: | Pickens | Forsyth | | |
| Culvert Size km^2: | 42.51 | 26.92 | 37.67 | 7.35 |
| Date (Month, Day, Year): | 14-Apr-04 | 1-Jul-03 | | |
| Culvert Type - Box/Pipe/Feespan/Other | Box | Box | | |
| Concrete/Metal/PVC/Other: | Concrete | Concrete | | |
| Number of Openings: | 4 | 3 | | |
| Number of Openings with Flow: | 4 | 3 | | |
| Number of Openings with Partial Flow | 2 | 0 | | |
| Road Surface Paved/Gravel: | Gravel | Paved | | |
| Number of Lanes: | 2 | 2 | | |
| Culvert Diameter (m): | - | n/a | | |
| Corrugated? | No | No | | |
| Corrugation Wavelenth: | - | n/a | | |
| Corrugation Height: | - | n/a | | |
| Culvert Opening Width (m): | 4.05 | 2.81 | | |
| Width of Culvert Internal Walls (m): | 0.2413 | - | | |
| Total Culvert Width (m): | 20.67 | 9.1 | | |
| Total Culvert Opening Width (m): | 16.2 | 8.43 | | |
| Apron: Yes/No | Yes | Yes | | |
| Culvert Height (m): | 1.5494 | - | | |
| Culvert Length (m): | 11.70 | 10.40 | 20.12 | 22.16 |
| Culvert Slope (%): | 0.00% | 1.31% | 0.47% | 0.54% |
| Overhang (m): | 0.00 | n/a | 0.00 | 0.00 |
| Drop to Bottom Min (m): | 0.00 | n/a | 0.19 | 0.22 |
| Drop to Bottom Max (m): | 0.00 | - | 0.00 | 0.00 |
| Drop to Water Surface (m): | 0.00 | n/a | 0.04 | 0.06 |
| Drop to Water Surface > 2 cm | No | No | | |
| Drop to Bottom > 2 cm | No | No | | |
| Drop to Surface > 6 inches (0.15 m) | No | No | | |
| Velocity Greater Than 0.25 m/s | Yes | Yes | | |
| Velocity Greater Than 0.4 m/s | Yes | Yes | | |
| Upstream 'Jump' (m): | 0.00 | 0.30 | 0.18 | 0.20 |
| Impassable due to US Jump? | No | No | | |
| Impassable Road Crossing (lenient criteria) | 1 | | | |
| Impassable Road Crossing (strict criteria) | 1 | 1 | | |
| Maybe Impassable - Type | | Box - high vel at high flow | | |
| Max water depth in culvert today (m) inlet: | - | 0.25 | 0.23 | 0.12 |
| Max water depth in culvert today (m) outlet: | 0.44 | 0.25 | 0.26 | 0.17 |
| Typical Width Upstream (m): | | 7.30 | 9.53 | 3.66 |
| Typical Width Downstream (m): | 10.00 | 6.15 | 9.07 | 2.89 |
| Total Width at water level today (m) | 12.15 | 8.43 | 11.10 | 5.07 |
| Flowrate (m3/s) : | 1.68 | 0.92 | 0.63 | 0.48 |
| Average Culvert Outlet Velocity (m/s) : | 0.35 | 0.43 | 0.52 | 0.63 |
| Velocity in culvert today (m/s) inlet: | - | - | 0.21 | - |
| Velocity in culvert today (m/s) outlet: | 0.55 | - | 0.49 | 0.08 |
| Velocity in Culvert (average) (m/s): | | | 0.09 | - |
| Depth of Sediment (m): | 0.28 | 0.00 | 0.08 | 0.12 |
| Total Opening CSA (m3) no fill | 25.10 | | 44.44 | 38.09 |
| Scour Pool Length (m): | 20.00 | n/a | 12.67 | 7.51 |
| Scour Pool Max Depth (m): | - | n/a | 0.71 | - |
| Scour Pool Width (m): | 20.67 | n/a | 16.22 | 4.27 |
| Common Flood Water Mark (above water surface): | 0.18 | 0.61 | 0.35 | 0.25 |
| Max Flood High water mark (above water surface): | 0.91 | - | 1.52 | 0.90 |
| Sediment in Culvert Yes/No: | Yes | Yes | | |
| Sediment in Main Flow Section of Culvert Yes/No: | Yes (but not in one of middle culverts) | No - 1 channel has sediment, but not all | | |
| Stream Gradient Very Low/Low/Med/High: | Med | Med | | |

The following two pages contain the details gathered in the field for the multiple openings at culverts (the parameters of extra openings that differ from the first one listed in the main tables).

| **Final ID** | 3 | 11 | 14 | 16 | 20 | 24 | 27 | 29 |
|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 3-9 | 3-9 | 3-9 |
| **Culvert #:** | 2(a) | 11b | 14 | 16(b) | 22 (a) | 23 | 26 (b) | 28 (a) |
| **Culvert diameter (m): (Opening 2)** | 1.4 | 0.610 | - | 1.65 | 2.05 | - | 2.5 | 3.05 |
| **Slope (%) (2)** | - | 2.18% | - | - | - | - | - | - |
| **Overhang (m): (2)** | 0.00 | - | - | 0.23 | - | 0.23 | 0.61 | 0.10 |
| **Drop to bottom min (m): (2)** | 0.00 | - | 0.04 | 0.25 | - | 0.06 | 0.05 | 0.06 |
| **Drop to Bottom Max (m): (2)** | - | - | - | - | - | - | - | - |
| **Drop to water Surface (m): (2)** | 0.00 | 0.30 | 0.04 | 0.09 | - | - | - | - |
| **Water depth in Culvert today inlet (m): 2** | 0.34 | 0.05 | - | - | - | - | 0.48 | - |
| **Water depth in Culvert today outlet (m): 2** | - | - | 0.00 | 0.1143 | 0.2286 | 0.19 | 0.51 | 0.30 |
| **Average Culvert Outlet Velocity (m/s) : (2)** | 0.114 | 0.759 | 0 | 0.207 | 0.218 | 0.21 | 0.109 | 0.065 |
| **Velocity at inlet (m/s): (2)** | - | - | - | - | - | - | - | - |
| **Velocity at outlet (m/s): (2)** | - | - | 0.00 | - | - | 0.02 | - | 0.10 |
| **Depth of Sediment in main channels (m): (2)** | 0.114 | 0 | 0 | 0 | 0 | 0 | - | - |
| **Upstream 'Jump' (m): (2)** | - | - | 0.00 | - | - | - | - | - |
| **Culvert diameter (m): (3)** | 1.35 | | - | | | - | | |
| **Slope (%) (3)** | - | | - | | | - | | |
| **Overhang (m): (3)** | 1.17 | | - | | | 0.36 | | |
| **Drop to bottom min (m): (3)** | 0.58 | | 0.04 | | | 0.10 | | |
| **Drop to Bottom Max (m): (3)** | - | | - | | | - | | |
| **Drop to water Surface (m): (3)** | 0.36 | | 0.00 | | | - | | |
| **Water depth in Culvert today inlet (m): 3** | 0.13 | | - | | | - | | |
| **Water depth in Culvert today outlet (m): 3** | - | | 0.07 | | | 0.12 | | |
| **Average Culvert Outlet Velocity (m/s) : (3)** | 0.059 | | 0.291 | | | 0.158 | | |
| **Velocity at outlet (m/s): (3)** | - | | - | | | - | | |
| **Velocity at inlet (m/s): (3)** | - | | 0.52 | | | 0.12 | | |
| **Depth of Sediment in main channels (m): (3)** | 0.0508 | | 0 | | | 0 | | |
| **Upstream 'Jump' (m): (3)** | - | | 0.0254 | | | - | | |
| **Culvert diameter (m): (4)** | | | - | | | | | |
| **Slope (%) (4)** | | | - | | | | | |
| **Overhang (m): (4)** | | | - | | | | | |
| **Drop to bottom min (m): (4)** | | | 0.00 | | | | | |
| **Drop to Bottom Max (m): (4)** | | | - | | | | | |
| **Drop to water Surface (m): (4)** | | | 0.00 | | | | | |
| **Water depth in Culvert today inlet (m): 4** | | | - | | | | | |
| **Water depth in Culvert today outlet (m): 4** | | | 0.14 | | | | | |
| **Average Culvert Outlet Velocity (m/s) : (4)** | | | 0.4624683 | | | | | |
| **Velocity at outlet (m/s): (4)** | | | - | | | | | |
| **Velocity at inlet (m/s): (4)** | | | 0.13 | | | | | |
| **Depth of Sediment in main channels (m): (4)** | | | 0.0508 | | | | | |
| **Upstream 'Jump' (m): (4)** | | | 0.0254 | | | | | |
| **Culvert diameter (m): (5)** | | | - | | | | | |
| **Slope (%) (5)** | | | - | | | | | |
| **Overhang (m): (5)** | | | - | | | | | |
| **Drop to bottom min (m): (5)** | | | 0.00 | | | | | |
| **Drop to Bottom Max (m): (5)** | | | - | | | | | |
| **Drop to water Surface (m): (5)** | | | 0.00 | | | | | |
| **Water depth in Culvert today inlet (m): 5** | | | - | | | | | |
| **Water depth in Culvert today outlet (m): 5** | | | 0 | | | | | |
| **Average Culvert Outlet Velocity (m/s) : (5)** | | | 0 | | | | | |
| **Velocity at outlet (m/s): (5)** | | | - | | | | | |
| **Velocity at inlet (m/s): (5)** | | | 0 | | | | | |
| **Depth of Sediment in main channels (m): (5)** | | | 0.0508 | | | | | |
| **Upstream 'Jump' (m): (5)** | | | 0.0254 | | | | | |

| Final ID | 31 | 34 | 36 | 40 | 41 | 46 | 54 | 69 |
|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 3-9 | 3-9 | 3-9 | 3-9 | 9-25 | 9-25 | 9-25 | 25-50 |
| **Culvert #:** | 31 (a) | 35 (b) | 37 (a) | 161 | 40 | 45 (b) | 54 | 75 |
| **Culvert diameter (m): (Opening 2)** | 2.45 | 1.8 | 2.25 | 2.1 | - | 0.6 | 1.55 | - |
| **Slope (%) (2)** | - | - | - | - | - | - | 3.01% | - |
| **Overhang (m): (2)** | - | - | - | 0.71 | - | - | 0.91 | - |
| **Drop to bottom min (m): (2)** | - | - | - | 0.76 | - | - | 0.30 | - |
| **Drop to Bottom Max (m): (2)** | - | - | - | - | - | - | - | - |
| **Drop to water Surface (m): (2)** | - | - | - | 0.05 | - | - | 0.20 | - |
| **Water depth in Culvert today inlet (m): 2** | 0.09 | 0.48 | 0.50 | - | - | - | - | - |
| **Water depth in Culvert today outlet (m): 2** | 0.30 | 0.48 | - | 0.10 | 0.00 | 0.10 | 0.10 | 0.44 |
| **Average Culvert Outlet Velocity (m/s) : (2)** | 0.216 | 0.0023817 | 0.1510459 | 0.94 | 0 | 0.62 | 0.61 | 0.67 |
| **Velocity at inlet (m/s): (2)** | - | - | - | - | - | - | - | - |
| **Velocity at outlet (m/s): (2)** | - | 0.01 | - | 0.83 | - | 0.50 | 1.12 | 0.95 |
| **Depth of Sediment in main channels (m): (2)** | - | - | 0.0508 | - | blocked with sed | - | - | 0 |
| **Upstream 'Jump' (m): (2)** | - | - | - | -0.10 | - | - | 0.00 | - |
| **Culvert diameter (m): (3)** | 2.15 | | 2.25 | | - | 0.6 | 0.78 | - |
| **Slope (%) (3)** | - | | - | | - | - | - | - |
| **Overhang (m): (3)** | - | | - | | - | - | - | - |
| **Drop to bottom min (m): (3)** | - | | - | | - | - | - | - |
| **Drop to Bottom Max (m): (3)** | - | | - | | - | - | - | - |
| **Drop to water Surface (m): (3)** | - | | - | | - | - | - | - |
| **Water depth in Culvert today inlet (m): 3** | 0.22 | | 0.18 | | - | - | - | - |
| **Water depth in Culvert today outlet (m): 3** | 0.33 | | - | | 0.06 | 0.08 | - | 0.44 |
| **Average Culvert Outlet Velocity (m/s) : (3)** | 0.23 | | 0.076 | | 1.96 | 0.51 | 0 | 0.35 |
| **Velocity at outlet (m/s): (3)** | - | | - | | - | - | - | - |
| **Velocity at inlet (m/s): (3)** | - | | - | | 0.25 | 0.79 | - | 0.44 |
| **Depth of Sediment in main channels (m): (3)** | - | | 0 | | 0 | - | - | 0.28 |
| **Upstream 'Jump' (m): (3)** | - | | - | | - | - | - | - |
| **Culvert diameter (m): (4)** | 1.24 | | | | | 0.6 | 1.25 | - |
| **Slope (%) (4)** | - | | | | | - | 3.01% | - |
| **Overhang (m): (4)** | - | | | | | - | 0.36 | - |
| **Drop to bottom min (m): (4)** | - | | | | | - | 0.13 | - |
| **Drop to Bottom Max (m): (4)** | - | | | | | - | - | - |
| **Drop to water Surface (m): (4)** | - | | | | | - | 0.00 | - |
| **Water depth in Culvert today inlet (m): 4** | 0.00 | | | | | - | - | - |
| **Water depth in Culvert today outlet (m): 4** | 0.00 | | | | | 0.08 | 0.15 | blocked |
| **Average Culvert Outlet Velocity (m/s) : (4)** | 0 | | | | | 0.51 | 0.80 | 0 |
| **Velocity at outlet (m/s): (4)** | - | | | | | - | - | - |
| **Velocity at inlet (m/s): (4)** | - | | | | | 0.61 | 1.38 | 0.00 |
| **Depth of Sediment in main channels (m): (4)** | - | | | | | - | - | blocked |
| **Upstream 'Jump' (m): (4)** | - | | | | | - | 0.01 | - |
| **Culvert diameter (m): (5)** | | | | | | 0.6 | | |
| **Slope (%) (5)** | | | | | | - | | |
| **Overhang (m): (5)** | | | | | | - | | |
| **Drop to bottom min (m): (5)** | | | | | | - | | |
| **Drop to Bottom Max (m): (5)** | | | | | | - | | |
| **Drop to water Surface (m): (5)** | | | | | | - | | |
| **Water depth in Culvert today inlet (m): 5** | | | | | | - | | |
| **Water depth in Culvert today outlet (m): 5** | | | | | | 0.08 | | |
| **Average Culvert Outlet Velocity (m/s) : (5)** | | | | | | 0.51 | | |
| **Velocity at outlet (m/s): (5)** | | | | | | - | | |
| **Velocity at inlet (m/s): (5)** | | | | | | 0.40 | | |
| **Depth of Sediment in main channels (m): (5)** | | | | | | - | | |
| **Upstream 'Jump' (m): (5)** | | | | | | - | | |
| **Culvert diameter (m): (6)** | | | | | | 0.6 | | |
| **Slope (%) (6)** | | | | | | - | | |
| **Overhang (m): (6)** | | | | | | - | | |
| **Drop to bottom min (m): (6)** | | | | | | - | | |
| **Drop to Bottom Max (m): (6)** | | | | | | - | | |
| **Drop to water Surface (m): (6)** | | | | | | - | | |
| **Water depth in Culvert today inlet (m): 6** | | | | | | - | | |
| **Water depth in Culvert today outlet (m): 6** | | | | | | 0.09 | | |
| **Average Culvert Outlet Velocity (m/s) : (6)** | | | | | | 0.56 | | |
| **Velocity at outlet (m/s): (6)** | | | | | | - | | |
| **Velocity at inlet (m/s): (6)** | | | | | | 0.18 | | |
| **Depth of Sediment in main channels (m): (6)** | | | | | | - | | |
| **Upstream 'Jump' (m): (6)** | | | | | | - | | |

# APPENDIX C. FLOWRATE CALCULATIONS

The following tables show the width, depth and velocity data collected at each site and the calculations to determine the flowrate at each site. These calculations are included for completeness.

| Final ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 11 | 12 | 13 | 14 | 14 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 |
| **Culvert #:** | 0(a) | 1 | 2 | 4 | 5 (a) | 6 (a) | 7 (b) | 8(b) | 9 (a) | 10(a) | 11b | 11b o.s. | 12 (b) | 13 | 14 | 14 | 14 | 15 | 16 |
| **Notes** | | | | 60 cm under bank | | | | | | | | | | | | | | | |
| Width Corrected - zero at bank (m) 1 | 0.3 | 0.25 | 0.25 | 0.6 | 0.15 | 0.05 | 0.1 | 0.2 | 0.15 | 0.2 | 0.1 | 0.1 | 0.3 | 0 | 0.3 | 0.1 | 0.5 | 0.8 | 0.2 |
| 2 | 0.6 | 0.35 | 0.35 | 0.9 | 0.25 | 0.25 | 0.3 | 0.5 | 0.5 | 0.4 | 0.4 | 0.2 | 0.6 | 0.2 | 0.6 | 0.3 | 0.7 | 1.1 | 0.4 |
| 3 | 0.9 | 0.45 | 0.45 | 1.2 | 0.35 | 0.45 | 0.5 | 0.8 | 0.8 | 0.6 | 0.7 | 0.3 | 0.9 | 0.4 | 0.75 | 0.5 | 0.9 | 1.4 | 0.6 |
| 4 | 1.2 | 0.55 | 0.55 | 1.5 | 0.45 | 0.55 | 0.7 | 1.1 | 1.1 | 0.8 | 0.9 | | 1.2 | 0.6 | 0.9 | 0.7 | 1.1 | 1.7 | 0.8 |
| 5 | 1.5 | 0.65 | 0.65 | 1.8 | 0.55 | 0.75 | 0.9 | 1.4 | 1.4 | 1 | 1.3 | | 1.5 | 0.8 | 1 | 0.9 | 1.3 | 2 | 1 |
| 6 | 1.8 | 0.7 | 0.75 | 2.1 | 0.65 | 0.85 | 1.1 | 1.7 | 1.7 | 1.2 | 1.8 | | 1.8 | 1 | 1.1 | 1.1 | 1.5 | 2.3 | 1.2 |
| 7 | 2.1 | 0.75 | 0.85 | 2.4 | 0.75 | 1.05 | 1.3 | 2 | 2.1 | 1.4 | 2 | | 2.1 | 1.2 | 1.4 | 1.3 | 1.7 | 2.6 | 1.4 |
| 8 | 2.4 | 0.85 | 0.95 | 2.7 | 0.85 | 1.15 | 1.5 | 2.3 | 2.4 | 1.6 | 2.2 | | 2.4 | 1.4 | 1.7 | 1.5 | 1.9 | 2.8 | 1.6 |
| 9 | 2.7 | 0.95 | 1.05 | 3 | 0.95 | 1.3 | 1.7 | 2.5 | 2.7 | 1.8 | | | 2.7 | 1.8 | 1.85 | 1.7 | 2.1 | 3.1 | 1.8 |
| 10 | 3 | 1.05 | 1.15 | 3.3 | 1.05 | | 1.8 | | 3 | 2 | | | 3 | | 2 | 1.8 | | 3.4 | 2 |
| 11 | 3.2 | 1.1 | 1.55 | 3.6 | 1.15 | | | | 3.5 | 2.2 | | | 3.3 | | 2.3 | | | 3.8 | 2.2 |
| 12 | | | | 3.9 | 1.25 | | | | | 2.3 | | | | | 2.6 | | | | 2.4 |
| 13 | | | | 4.2 | 1.3 | | | | | | | | | | 2.9 | | | | 2.6 |
| 14 | | | | 4.5 | | | | | | | | | | | 3.3 | | | | |
| 15 | | | | 4.9 | | | | | | | | | | | | | | | |
| **Depth (ft) (unless** | | **(cm)** | | | | | | | | | **(cm)** | **(cm)** | | | **(cm)** | **(cm)** | **(cm)** | | |
| **indicated cm) 1** | 1 | 4 | 0.15 | 1.08 | 0.5 | 0.5 | 0.35 | 0.2 | 0.35 | 0.083 | 17 | 4 | 0.2 | 0.2 | 29 | 30 | 6 | 0.33 | 0.2 |
| 2 | 1.1 | 8 | 0.2 | 1.31 | 0.6 | 0.6 | 0.25 | 0.55 | 0.3 | 0.35 | 18 | 3 | 0.55 | 0.35 | 31 | 33 | 11 | 0.39 | 0.15 |
| 3 | 1.2 | 10 | 0.2 | 1.51 | 0.55 | 0.55 | 0.2 | 1.1 | 0.4 | 0.4 | 7 | 0 | 0.6 | 0.5 | 29 | 35 | 13 | 0.52 | 0.15 |
| 4 | 1.1 | 10 | 0.3 | 1.51 | 0.5 | 0.5 | 0.5 | 1 | 0.4 | 0.6 | 4 | | 0.5 | 0.425 | 29 | 33 | 9 | 0.56 | 0.15 |
| 5 | 1.15 | 10 | 0.3 | 1.31 | 0.45 | 0.5 | 0.6 | 0.7 | 0.25 | 0.45 | 0 | | 0.6 | 0.35 | 26 | 30 | 8 | 0.56 | 0.15 |
| 6 | 1.05 | 5 | 0.35 | 1.31 | 0.4 | 0.25 | 0.8 | 0.5 | 0.2 | 0.45 | 12 | | 0.6 | 0.4 | 26 | 26 | 7 | 0.26 | 0.2 |
| 7 | 1.15 | 9 | 0.3 | 1.31 | 0.4 | 0.85 | 1.05 | 0.5 | 0.2 | 0.4 | 12 | | 0.7 | 0.2 | 15 | 21 | 4 | 0.00 | 0.15 |
| 8 | 1.75 | 6 | 0.2 | 1.31 | 0.3 | 0.25 | 1.2 | 0.35 | 0.2 | 0.3 | 0 | | 0.7 | 0 | 15 | 15 | 4 | 0.20 | 0.25 |
| 9 | 1.15 | 4 | 0.2 | 1.35 | 0.25 | 0 | 0.3 | 0 | 0.2 | 0.2 | | | 0.35 | 0 | 12 | 9 | 0 | 0.26 | 0.2 |
| 10 | 1.25 | 6 | 0.15 | 1.15 | 0.25 | | 0 | | 0.15 | 0.1 | | | 0.375 | | 9 | 0 | | 0.20 | 0.15 |
| 11 | 0 | 0 | 0 | 0.92 | 0.3 | | | | 0 | 0.1 | | | 0 | | 7 | | | 0.00 | 0.15 |
| 12 | | | | 0.98 | 0.2 | | | | | 0 | | | | | 7 | | | | 0.15 |
| 13 | | | | 1.15 | 0 | | | | | | | | | | 8 | | | | 0 |
| 14 | | | | 0.13 | | | | | | | | | | | 0 | | | | |
| 15 | | | | 0.00 | | | | | | | | | | | | | | | |
| | | (cm) | | | | | | | | | (cm) | (cm) | | | (cm) | (cm) | (cm) | | |
| Average Depth (ft) | 1.0818182 | 6.5454545 | 0.2136364 | 1.0892388 | 0.3615385 | 0.4444444 | 0.525 | 0.5444444 | 0.2409091 | 0.2860833 | 8.75 | 2.3333333 | 0.4704545 | 0.2694444 | 17.357143 | 23.2 | 6.8888889 | 0.2982582 | 0.1576923 |
| Velocity (m/s) 1 | 0.02 | -0.02 | 0.3 | 0 | 0.22 | -0.01 | 0.03 | 0.03 | -0.05 | 0 | 0.58 | 0.2 | 0.02 | -0.01 | 0.05 | -0.09 | 0.16 | 0.02 | 0.1 |
| 2 | 0.02 | 0.03 | 0.31 | 0.01 | 0.28 | -0.02 | 0.03 | 0.09 | -0.05 | 0.06 | 0.69 | 0.04 | 0.19 | 0.05 | -0.03 | -0.05 | 0.25 | 0.03 | 0.15 |
| 3 | 0.05 | 0.07 | 0.54 | 0.01 | 0.38 | 0.08 | 0 | 0.08 | 0 | 0.14 | 0.24 | 0 | 0.3 | 0.1 | 0 | 0.28 | 0.5 | 0.025 | 0.15 |
| 4 | 0.01 | 0.12 | 0.71 | 0 | 0.39 | 0.23 | 0.01 | 0.19 | -0.03 | 0.11 | 0.32 | | 0.33 | 0.1 | 0.29 | 0.39 | 0.6 | 0.02 | 0.2 |
| 5 | 0.03 | 0.24 | 0.53 | 0 | 0.38 | -0.02 | 0.05 | 0.2 | 0.06 | 0.12 | 0 | | 0.33 | 0.09 | 0.29 | 0.11 | 0.48 | 0.015 | 0.19 |
| 6 | 0.04 | 0.02 | 0.59 | 0.005 | 0.34 | 0.43 | 0.08 | 0.18 | 0.11 | 0.13 | 0.65 | | 0.31 | 0.17 | 0 | 0 | 0.4 | -0.03 | 0.17 |
| 7 | 0.04 | 0.03 | 0.62 | 0.01 | 0.3 | 0.01 | 0.09 | 0.17 | -0.03 | 0.21 | 0.57 | | 0.33 | 0.24 | -0.03 | -0.03 | 0.43 | 3.8 | 0.2 |
| 8 | 0.05 | -0.03 | 0.4 | 0.01 | 0.32 | -0.2 | 0.13 | 0.04 | -0.06 | 0.21 | 0 | | 0.26 | 0 | -0.05 | -0.08 | 0.17 | -0.01 | 0.11 |
| 9 | 0.03 | -0.04 | 0.5 | 0.01 | 0.34 | 0 | 0.19 | 0 | -0.06 | 0.11 | | | 0.2 | 0 | 0.12 | -0.07 | 0 | 0.015 | 0.25 |
| 10 | 0.03 | -0.05 | 0.31 | -0.01 | 0.31 | | 0 | | -0.06 | 0 | | | 0.01 | | 0.42 | 0 | | -0.015 | 0.16 |
| 11 | 0 | 0 | 0 | 0 | 0.22 | | | | 0 | 0.11 | | | 0 | | 0.53 | | | 0 | 0.1 |
| 12 | | | | -0.01 | 0.07 | | | | | 0 | | | | | 0.7 | | | | 0.08 |
| 13 | | | | 0 | 0 | | | | | | | | | | 0.62 | | | | 0 |
| 14 | | | | -0.01 | | | | | | | | | | | 0 | | | | |
| 15 | | | | 0 | | | | | | | | | | | | | | | |
| Average Velocity (m/s) | 0.0290909 | 0.0336364 | 0.4372727 | 0.0016667 | 0.2730769 | 0.0555556 | 0.061 | 0.1088889 | -0.0154545 | 0.1 | 0.38125 | 0.08 | 0.2072727 | 0.0822222 | 0.2078571 | 0.046 | 0.3322222 | 0.3518182 | 0.1430769 |
| Flowrate (m3/s) | | | | | | | | | | | | | | | | | | | |
| 1 | 0.0004572 | -0.00005 | 0.0008573 | 0 | 0.0012573 | -1.905E-05 | 8.001E-05 | 9.144E-05 | -0.0002 | 0 | 0.002465 | 0.0002 | 9.144E-05 | 0 | 0.0010875 | -0.000675 | 0.0012 | 0.0004 | 0.0003048 |
| 2 | 0.0019202 | 0.00003 | 0.0016269 | 0.0005475 | 0.004191 | -0.0005029 | 0.0005486 | 0.0020574 | -0.0017336 | 0.0003959 | 0.0333375 | 0.00042 | 0.0036005 | 0.0003353 | 0.0009 | -0.00441 | 0.003485 | 0.000825 | 0.0013335 |
| 3 | 0.0036805 | 0.00045 | 0.0025908 | 0.00129 | 0.0057836 | 0.0010516 | 0.0002057 | 0.0064122 | -0.0008001 | 0.002286 | 0.0174375 | 0.00003 | 0.0128816 | 0.0019431 | -0.000675 | 0.00782 | 0.009 | 0.001155 | 0.0013716 |
| 4 | 0.0031547 | 0.00095 | 0.0047625 | 0.00069 | 0.0061608 | 0.0024803 | 0.0001067 | 0.0129616 | -0.0005486 | 0.00381 | 0.00308 | 0 | 0.015842 | 0.0028194 | 0.0063075 | 0.02278 | 0.0121 | 0.0011138 | 0.0016002 |
| 5 | 0.0020574 | 0.0018 | 0.0056693 | 0 | 0.005574 | 0.0032004 | 0.0010058 | 0.0151562 | 0.0004458 | 0.0036805 | 0.00128 | 0 | 0.0165964 | 0.0022441 | 0.007975 | 0.01575 | 0.00918 | 0.0008925 | 0.0017831 |
| 6 | 0.0035204 | 0.0004875 | 0.0055474 | 0.0003 | 0.0046634 | 0.0023432 | 0.0027737 | 0.0104242 | 0.0017488 | 0.003429 | 0.00975 | 0 | 0.0175565 | 0.0029718 | 0.00377 | 0.00308 | 0.0066 | -0.0002813 | 0.0019202 |
| 7 | 0.0040234 | 8.75E-05 | 0.0059931 | 0.0009 | 0.0039014 | 0.0073762 | 0.004793 | 0.008001 | 0.0009754 | 0.0044044 | 0.01464 | 0 | 0.0190195 | 0.003749 | -0.0009225 | -0.000705 | 0.004565 | 0.02262 | 0.0019736 |
| 8 | 0.0059665 | 0 | 0.0038862 | 0.0012 | 0.0033071 | -0.0015926 | 0.0075438 | 0.0040805 | -0.000823 | 0.0044806 | 0.00342 | 0 | 0.0188824 | 0.0007315 | -0.0018 | -0.00198 | 0.0024 | 0.01137 | 0.0018898 |
| 9 | 0.0053035 | -0.000175 | 0.0027432 | 0.001215 | 0.0027661 | -0.0005715 | 0.0073152 | 0.0002134 | -0.0010973 | 0.0024384 | 0 | 0 | 0.0110414 | 0 | 0.0007088 | -0.0018 | 0.00034 | 0.0000525 | 0.0024689 |
| 10 | 0.0032918 | -0.000225 | 0.0021603 | 0 | 0.0024765 | 0 | 0.0004343 | 0 | -0.0009601 | 0.0005029 | 0 | 0 | 0.0034804 | 0 | 0.0042525 | -0.0001575 | 0 | 0 | 0.0021869 |
| 11 | 0.0005715 | -0.0000375 | 0.0014173 | -0.0004725 | 0.0022212 | 0 | 0 | 0 | -0.0003429 | 0.0003353 | 0 | 0 | 8.573E-05 | 0 | 0.0114 | 0 | 0 | -0.00009 | 0.0011887 |
| 12 | 0 | 0 | 0 | -0.000435 | 0.0011049 | 0 | 0 | 0 | 0 | 8.382E-05 | 0 | 0 | 0 | 0 | 0.012915 | 0 | 0 | 0 | 0.000823 |
| 13 | 0 | 0 | 0 | -0.0004875 | 5.334E-05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01485 | 0 | 0 | 0 | 0.0001829 |
| 14 | 0 | 0 | 0 | -0.0002925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00496 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | -0.00004 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Flowrate (m3/s) | 0.0339471 | 0.0033175 | 0.0372542 | 0.004415 | 0.0434607 | 0.0137655 | 0.0248069 | 0.0593979 | -0.0033357 | 0.0258467 | 0.08541 | 0.00065 | 0.1190777 | 0.0147942 | 0.0657288 | 0.0397025 | 0.04887 | 0.0380575 | 0.0190271 |
| | | | | | | | | | | | | | | | Use average | | 0.0514338 | | |

| Final ID | 17 | 18 | 19 | 20 | 21 | 22 | 23 | | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 3-9 | 3-9 | 3-9 | | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 |
| **Culvert #:** | 17 (b) | 27(a) | 19 | 22 (a) | 20 | 21 (a) | 22 (b) | 22 (b) o.s. | 23 | 24(b) | 25 (b) | 26 (b) | 27(b) | 28 (a) | 29 | 31 (a) | 33 (b) | 34 | 35 |
| **Notes** | measured in culvert | | | | | | | 2nd side of DS 23 | | | | | | | | | | | |
| Width Corrected - zero at bank (m) 1 | 0.3 | -1.2 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.7 | 0.35 | 0.2 | 0.05 | 0.2 | 0.2 | 0 | 0.2 | 0.1 |
| 2 | 0.4 | -1 | 0.4 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.4 | 0.6 | 0.9 | 0.5 | 0.4 | 0.25 | 0.4 | 0.6 | 0.25 | 0.4 | 0.2 |
| 3 | 0.5 | -0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.3 | 0.4 | 0.5 | 0.8 | 1.1 | 0.8 | 0.6 | 0.45 | 0.6 | 1 | 0.45 | 0.6 | 0.3 |
| 4 | 0.6 | -0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.4 | 0.5 | 0.7 | 1 | 1.3 | 1.1 | 0.8 | 0.65 | 0.8 | 1.4 | 0.65 | 0.8 | 0.4 |
| 5 | 0.7 | -0.4 | 0.7 | 0.9 | 0.9 | 0.9 | 0.5 | 0.6 | 0.8 | 1.2 | 1.5 | 1.4 | 1 | 0.85 | 1 | 1.8 | 0.85 | 1 | 0.5 |
| 6 | 0.8 | -0.2 | 0.8 | 1.1 | 0.95 | 1.1 | 0.6 | 0.7 | 0.9 | 1.4 | 1.7 | 1.7 | 1.2 | 1.05 | 1.2 | 2.2 | 1.05 | 1.2 | 0.6 |
| 7 | 0.9 | 0 | 0.9 | 1.3 | 1 | 1.3 | 0.7 | 0.8 | 1.1 | 1.6 | 1.9 | 2 | 1.4 | 1.25 | 1.4 | 2.6 | 1.25 | 1.4 | 0.7 |
| 8 | 1 | 0.1 | 1 | 1.5 | 1.1 | 1.5 | 0.8 | 0.9 | 1.3 | 1.8 | 2.1 | 2.3 | 1.6 | 1.45 | 1.6 | 3 | 1.45 | 1.6 | 0.85 |
| 9 | 1.1 | 0.2 | 1.1 | 1.7 | 1.2 | 1.7 | 0.9 | 1 | 1.5 | 2 | 2.3 | 2.6 | 1.8 | 1.65 | 1.8 | 3.4 | 1.65 | 1.8 | |
| 10 | 1.2 | | 1.2 | 1.9 | 1.3 | 1.9 | 1 | 1.1 | 1.8 | 2.2 | 2.5 | 2.9 | 2 | 1.85 | 2.15 | 3.8 | 1.85 | 2 | |
| 11 | 1.3 | | 1.3 | 2.1 | 1.5 | 2.1 | 1.1 | 1.2 | 2.1 | 2.4 | 2.7 | 3 | 2.2 | 2.05 | | 4.2 | 2.05 | 2.2 | |
| 12 | 1.4 | | | 2.2 | 1.7 | 2.3 | 1.2 | 1.3 | | 2.6 | 2.9 | | 2.4 | 2.25 | | 4.4 | 2.25 | 2.4 | |
| 13 | 1.5 | | | | 1.9 | 2.5 | 1.3 | 1.4 | | 2.8 | 3.1 | | 2.6 | 2.35 | | | 2.45 | 2.6 | |
| 14 | 1.6 | | | | 2.2 | 2.8 | 1.4 | 1.5 | | 3 | 3.3 | | 2.8 | | | | 2.65 | 2.9 | |
| 15 | 1.7 | | | | | | 1.5 | 1.6 | | 3.2 | 3.5 | | 3 | | | | | | |
| 16 | 1.9 | | | | | | 1.6 | 1.7 | | 3.4 | 3.8 | | 3.2 | | | | | | |
| 17 | | | | | | | 1.7 | 1.8 | | 3.6 | | | 3.4 | | | | | | |
| 18 | | | | | | | 1.8 | | | 3.2 | | | 3.6 | | | | | | |
| 19 | | | | | | | | | | 4.2 | | | 3.7 | | | | | | |
| Depth (ft) (unless indicated cm) | | | (cm) | | | | | | (cm) | | | | | | (cm) | | | (cm) | |
| 1 | 1.45 | 0.1 | 7 | 0.55 | 0.35 | 0.3 | 0.35 | 0.25 | 25 | 0.2 | 0.25 | 0.3 | 0.5 | 0.15 | 24 | 0.2 | 0 | 8 | 0.2952756 |
| 2 | 2.25 | 0.3 | 8 | 0.55 | 0.35 | 0 | 0.35 | 0.4 | 26 | 0.3 | 0.7 | 0.3 | 0.5 | 0.75 | 23 | 0.6 | 0.7 | 9 | 0.3116798 |
| 3 | 2.6 | 0.35 | 13 | 0.6 | 0.4 | 0.3 | 0.35 | 0.4 | 33 | 0.35 | 0.9 | 0.3 | 0.55 | 1.2 | 24 | 0.6 | 0.7 | 8 | 0.2952756 |
| 4 | 2.9 | 0.35 | 16 | 0.75 | 0.4 | 0.3 | 0.35 | 0.45 | 46 | 0.3 | 0.7 | 0.3 | 0.5 | 1.5 | 23 | 0.5 | 0.7 | 11 | 0.328084 |
| 5 | 3.1 | 0.35 | 16 | 0.2 | 0.475 | 0.4 | 0.5 | 0.475 | 47 | 0.45 | 1 | 0.3 | 0.55 | 1.65 | 15 | 0.375 | 0.7 | 10 | 0.2952756 |
| 6 | 3.2 | 0.25 | 20 | 0.5 | 0.45 | 0.4 | 0.5 | 0.5 | 47 | 0.4 | 0.5 | 0.45 | 0.5 | 1.55 | 13 | 0.8 | 0.75 | 8 | 0.2788714 |
| 7 | 3.25 | 0.3 | 20 | 0.5 | 0.5 | 0.4 | 0.5 | 0.5 | 29 | 0.5 | 0.8 | 0.45 | 0.5 | 1.5 | 12 | 0.8 | 0.7 | 7 | 0.1968504 |
| 8 | 3.3 | 0.25 | 20 | 0.5 | 0.4 | 0.3 | 0.3 | 0.5 | 24 | 0.35 | 0.7 | 0.8 | 0.45 | 1.3 | 6 | 0.7 | 0.7 | 6 | 0 |
| 9 | 3.3 | 0 | 15 | 0.4 | 0.4 | 0.35 | 0.4 | 0.45 | 24 | 0.35 | 0.65 | 0.9 | 0.4 | 1.15 | 4 | 0.65 | 0.55 | 1.5 | |
| 10 | 3.25 | | 8 | 0.475 | 0.3 | 0.2 | 0.35 | 0.4 | 15 | 0.5 | 0.6 | 0.7 | 0.35 | 0.85 | 0 | 0.5 | 0.6 | 2 | |
| 11 | 3.15 | | 0 | 0.15 | 0.4 | 0.3 | 0.35 | 0.3 | 0 | 0.5 | 0.45 | 0 | 0.25 | 0.45 | | 0.2 | 0.55 | 3 | |
| 12 | 2.85 | | | 0 | 0.35 | 0.2 | 0.35 | 0.25 | | 0.4 | 0.35 | | 0.2 | 0.2 | | 0 | 0.5 | 5 | |
| 13 | 2.6 | | | | 0.25 | 0.2 | 0.35 | 0.25 | | 0.4 | 0.2 | | 0.25 | 0 | | | 0.3 | 6 | |
| 14 | 2.3 | | | | 0 | 0 | 0.35 | 0.2 | | 0.5 | 0.2 | | 0.2 | | | | 0 | 0 | |
| 15 | 2.1 | | | | | | 0.3 | 0.15 | | 0.2 | 0.15 | | 0.25 | | | | | | |
| 16 | 0 | | | | | | 0.25 | 0.042 | | 0.2 | 0 | | 0.3 | | | | | | |
| 17 | | | | | | | 0.083 | 0 | | 0.2 | | | 0.4 | | | | | | |
| 18 | | | | | | | 0 | | | 0 | | | 0.25 | | | | | | |
| 19 | | | | | | | | | | 0 | | | 0 | | | | | | |
| | | | (cm) | | | | | | (cm) | | | | | | (cm) | | | (cm) | |
| | 2.6 | 0.25 | 13 | 0.43125 | 0.3589286 | 0.2607143 | 0.3323889 | 0.3245294 | 28.727273 | 0.3210526 | 0.509375 | 0.4363636 | 0.3631579 | 0.9423077 | 14.4 | 0.49375 | 0.5321429 | 6.04 | 0.250164 |
| Velocity (m/s) 1 | -0.01 | 0.05 | 0.06 | 0.08 | 0 | 0.15 | 0.04 | 0.11 | 0 | 0.36 | 0.25 | 0.4 | 0.2 | 0.2 | 0.21 | 0.12 | 0 | 0.19 | 0.09 |
| 2 | 0.02 | 0.22 | 0.16 | 0.13 | 0.19 | 0.5 | 0.1 | 0.17 | 0.19 | 0.38 | 0.38 | 0.12 | 0.25 | 0.19 | 0.23 | 0.14 | 0.17 | 0.15 | 0.22 |
| 3 | 0.02 | 0.31 | 0.24 | 0.27 | 0.27 | 0.19 | 0.28 | 0.21 | 0.43 | 0.57 | 0.5 | 0.03 | 0.46 | 0.11 | 0.22 | 0.1 | 0.23 | 0.04 | 0.09 |
| 4 | 0.07 | 0.21 | 0.25 | 0.2 | 0.44 | 0.33 | 0.42 | 0.25 | 0.25 | 0.84 | 0.37 | 0.18 | 0.44 | 0.12 | 0.19 | 0.23 | 0.45 | 0.04 | 0.05 |
| 5 | 0.13 | 0.26 | 0.25 | 0.27 | 0.25 | 0.14 | 0.74 | 0.29 | 0.08 | 0.5 | 0.21 | 0.5 | 0.5 | 0.09 | 0.14 | 0.25 | 0.63 | 0.26 | 0 |
| 6 | 0.22 | 0.18 | 0.19 | 0.27 | 0.09 | 0.21 | 0.9 | 0.27 | 0.24 | 0.78 | 0.41 | 0.07 | 0.61 | 0.07 | 0.11 | 0.24 | 0.56 | 0.38 | 0.02 |
| 7 | 0.15 | 0.16 | 0.18 | 0 | 0.02 | 0.04 | 0.79 | 0.23 | 0.08 | 0.83 | 0.27 | -0.02 | 0.56 | 0.1 | 0.1 | 0.17 | 0.51 | 0.38 | 0.01 |
| 8 | 0.2 | 0.1 | 0.13 | 0 | 0.03 | 0.22 | 0.77 | 0.25 | -0.04 | 0.82 | 0.35 | 0.2 | 0.61 | 0.08 | 0.09 | 0.29 | 0.61 | 0.28 | 0 |
| 9 | 0.17 | 0 | 0.13 | 0.05 | 0.14 | 0.24 | 0.82 | 0.2 | -0.04 | 0.75 | 0.36 | 0.37 | 0.55 | 0.1 | 0.06 | 0.34 | 0.67 | | |
| 10 | 0.19 | | 0.02 | 0.21 | 0.36 | 0.3 | 0.7 | 0.18 | -0.03 | 0.46 | 0.45 | 0.14 | 0.58 | 0.05 | 0 | 0.29 | 0.59 | | |
| 11 | 0.17 | | 0 | 0.05 | 0.42 | 0.41 | 0.67 | 0.16 | 0 | 0.82 | 0.5 | 0 | 0.5 | 0 | | 0.07 | 0.57 | | |
| 12 | 0.09 | | | 0 | 0 | 0.34 | 0.51 | 0.15 | | 0.29 | 0.2 | | 0.59 | -0.03 | | 0 | 0.4 | 0.18 | |
| 13 | 0.11 | | | | 0.05 | 0.17 | 0.4 | 0.13 | | 0.37 | -0.08 | | 0.59 | 0 | | | 0.27 | 0.20 | |
| 14 | 0.08 | | | | 0 | 0 | 0.26 | 0.13 | | 0.67 | -0.012 | | 0.4 | | | | 0 | 0.00 | |
| 15 | 0.08 | | | | | | 0.12 | 0.08 | | 0.77 | -0.009 | | 0.35 | | | | | | |
| 16 | 0 | | | | | | 0.05 | 0 | | 0.53 | 0 | | 0.5 | | | | | | |
| 17 | | | | | | | 0 | 0 | | 0.4 | | | 0.25 | | | | | | |
| 18 | | | | | | | 0 | | | 0 | | | -0.03 | | | | | | |
| 19 | | | | | | | | | | 0 | | | 0 | | | | | | |
| Average Velocity (m/s) | 0.105625 | 0.1655556 | 0.1463636 | 0.1275 | 0.1614286 | 0.2314286 | 0.4205556 | 0.1652941 | 0.1054545 | 0.5336842 | 0.2593125 | 0.1809091 | 0.4163158 | 0.0830769 | 0.135 | 0.1866667 | 0.4042857 | 0.1909091 | 0.06 |
| Flowrate (m3/s) | | | | | | | | | | | | | | | | | | | |
| 1 | -0.0003315 | -0.0004572 | 0.000315 | 0.0003353 | 0 | 0.0003429 | 0.0001067 | 0.0004191 | 0 | 0.0021946 | 0.0033338 | 0.0032004 | 0.001524 | 0.0001143 | 0.00252 | 0.0003658 | 0 | 0.00076 | 0.0002025 |
| 2 | 0.0002819 | 0.0016459 | 0.000825 | 0.0035204 | 0.0020269 | 0.0029718 | 0.0007468 | 0.0013868 | 0.0024225 | 0.0056388 | 0.0091211 | 0.0035662 | 0.006858 | 0.0053492 | 0.01034 | 0.0063398 | 0.002267 | 0.00289 | 0.0014338 |
| 3 | 0.0014783 | 0.0052502 | 0.0021 | 0.0070104 | 0.0052578 | 0.0031547 | 0.0020269 | 0.0023165 | 0.009145 | 0.0094107 | 0.0214579 | 0.0020574 | 0.0113614 | 0.0089154 | 0.010575 | 0.0087782 | 0.0085344 | 0.001615 | 0.0014338 |
| 4 | 0.0037719 | 0.0055474 | 0.0035525 | 0.0096698 | 0.0086563 | 0.0047549 | 0.0037338 | 0.0029794 | 0.02686 | 0.0139675 | 0.0212141 | 0.0028804 | 0.0144018 | 0.009464 | 0.009635 | 0.0110642 | 0.0145085 | 0.00076 | 0.000665 |
| 5 | 0.009144 | 0.005014 | 0.004 | 0.0068047 | 0.0092012 | 0.005014 | 0.0075133 | 0.0038062 | 0.0076725 | 0.0153162 | 0.0150266 | 0.0093269 | 0.0150419 | 0.0100813 | 0.00627 | 0.0128016 | 0.0230429 | 0.00315 | 0.0002375 |
| 6 | 0.0168021 | 0.0040234 | 0.00396 | 0.0057607 | 0.0011982 | 0.0042672 | 0.0124968 | 0.0041605 | 0.00752 | 0.0165811 | 0.0141732 | 0.0097727 | 0.0177622 | 0.0078029 | 0.0035 | 0.0175489 | 0.0262966 | 0.00576 | 0.0000875 |
| 7 | 0.0181851 | 0.0028499 | 0.0037 | 0.0041148 | 0.0003981 | 0.003048 | 0.0128778 | 0.00381 | 0.01216 | 0.0220828 | 0.0134722 | 0.0010287 | 0.0178308 | 0.0079019 | 0.002625 | 0.0199949 | 0.0236449 | 0.0057 | 0.0001088 |
| 8 | 0.0174689 | 0.0010897 | 0.0031 | 0 | 0.0003429 | 0.0027737 | 0.0095098 | 0.0036576 | 0.00106 | 0.0213741 | 0.0141732 | 0.0051435 | 0.0169393 | 0.007681 | 0.00171 | 0.0210312 | 0.0238963 | 0.00429 | 0.0000225 |
| 9 | 0.018608 | 0.0001905 | 0.002275 | 0.0006858 | 0.0010363 | 0.0045568 | 0.0084811 | 0.0032576 | -0.00192 | 0.0167488 | 0.0146075 | 0.0221513 | 0.0150266 | 0.0067208 | 0.00075 | 0.0259232 | 0.024384 | 0.00105 | 0 |
| 10 | 0.017968 | 0 | 0.0008625 | 0.0034671 | 0.002667 | 0.0045263 | 0.0086868 | 0.0024613 | -0.0020475 | 0.0156743 | 0.0154305 | 0.0186538 | 0.0129159 | 0.004572 | 0.00021 | 0.0220828 | 0.0220828 | 0 | 0 |
| 11 | 0.0175565 | 0 | 0.00004 | 0.0024765 | 0.008321 | 0.0054102 | 0.0073076 | 0.0018136 | -0.0003375 | 0.0195072 | 0.0152019 | 0.0007468 | 0.0098755 | 0.0009906 | 0 | 0.007681 | 0.0203302 | 0 | 0 |
| 12 | 0.0118872 | 0 | 0 | 5.715E-05 | 0.0048006 | 0.005715 | 0.0062941 | 0.0012992 | 0 | 0.0152248 | 0.0085344 | 0 | 0.0074752 | -0.0002972 | 0 | 0.0002134 | 0.0155219 | 0.00072 | 0 |
| 13 | 0.0083058 | 0 | 0 | 0 | 0.0004572 | 0.003109 | 0.0048539 | 0.0010668 | 0 | 0.0080467 | 0.0010058 | 0 | 0.0080924 | -4.572E-05 | 0 | 0 | 0.0081686 | 0.00209 | 0 |
| 14 | 0.0070942 | 0 | 0 | 0 | 0.0002858 | 0.0007772 | 0.0035204 | 0.0008915 | 0 | 0.0142646 | -0.0005608 | 0 | 0.0067894 | 0 | 0 | 0 | 0.0012344 | 0.0009 | 0 |
| 15 | 0.0053645 | 0 | 0 | 0 | 0 | 0 | 0.0018821 | 0.0005601 | 0 | 0.0153619 | -0.000112 | 0 | 0.0051435 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0.0025603 | 0 | 0 | 0 | 0 | 0 | 0.0007125 | 0.000117 | 0 | 0.0079248 | -3.086E-05 | 0 | 0.0071247 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001269 | 0 | 0 | 0.0056693 | 0 | 0 | 0.008001 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.0024384 | 0 | 0 | 0.0021793 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -5.715E-05 | 0 | 0 | 0 | 0 | 0 | 0 |
| Flowrate (m3/s) | 0.1561452 | 0.0251536 | 0.02473 | 0.0439026 | 0.0446494 | 0.0504215 | 0.0908773 | 0.0340032 | 0.062535 | 0.2225497 | 0.1660486 | 0.0785279 | 0.1842859 | 0.0692506 | 0.048135 | 0.1538249 | 0.2139125 | 0.029685 | 0.0041913 |

| Final ID | 35 | 36 | 37 | 38 | 39 | 40 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | | 49 | 50 | 51 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STRATCLASS | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | | 9-25 | 9-25 | 9-25 |
| Culvert #: | 36 (a) | 37 (a) | 38 (b) | 39 | 160 | 161 | 161 ii sub | 40 | 41 (b) | 42 (b) | 43 | 44 | 45 | 46 (b) | 47 | 47 o.s. | 49 (b) | 50 (b) | 51 (b) |
| Notes | 9cm under bank | | | | | | Subtract side stream | | | | | | | | | 2nd side | | | |
| Width Corrected - zero at bank (m) 1 | 0.05 | 0.15 | 0.2 | 0.1 | 0.5 | 0 | 0.1524 | 0.2 | 0 | 0.1 | 0.05 | 0.15 | 0.1 | 0.1 | 0.3 | 0.25 | 0 | 0.2 | 1 |
| 2 | 0.45 | 0.55 | 0.4 | 0.3 | 1 | 0.3 | 0.254 | 0.6 | 0.2 | 0.35 | 0.15 | 1.15 | 0.4 | 0.3 | 0.6 | 0.55 | 0.6 | 0.5 | 1.2 |
| 3 | 0.85 | 0.95 | 0.6 | 0.5 | 1.5 | 0.6 | 0.4064 | 1 | 0.4 | 0.6 | 0.25 | 2.15 | 0.7 | 0.5 | 0.9 | 0.85 | 1.2 | 0.8 | 1.4 |
| 4 | 1.25 | 1.35 | 0.8 | 0.7 | 2 | 0.9 | 0.508 | 1.4 | 0.6 | 0.85 | 0.35 | 3.15 | 1 | 0.7 | 1.2 | 1.15 | 1.8 | 1.1 | 1.6 |
| 5 | 1.65 | 1.75 | 0.9 | 0.9 | 2.5 | 1.2 | 0.6096 | 1.8 | 0.8 | 1.1 | 0.45 | 4.15 | 1.3 | 0.9 | 1.5 | 1.45 | 2.4 | 1.4 | 1.8 |
| 6 | 2.05 | 2.15 | 1 | 1.1 | 3 | 1.5 | 0.7366 | 2.2 | 1 | 1.35 | 0.55 | 5.15 | 1.6 | 1.1 | 1.65 | 1.75 | 3 | 1.7 | 2 |
| 7 | 2.45 | 2.55 | 1.2 | 1.3 | 3.5 | 1.8 | 0.8636 | 2.6 | 1.2 | 1.6 | 0.65 | 6.15 | 1.9 | 1.3 | 1.8 | 2.05 | 3.6 | 2 | 2.2 |
| 8 | 2.85 | 2.95 | 1.4 | 1.5 | 4 | 2.1 | 1.016 | 3 | 1.4 | 2.1 | 0.75 | 7.15 | 2.2 | 1.5 | 2.1 | 2.25 | 4.2 | 2.3 | 2.4 |
| 9 | 3.25 | 3.35 | 1.6 | 1.7 | 4.5 | 2.4 | | 3.4 | 1.6 | 2.6 | 0.85 | 8.15 | 2.5 | 1.7 | 2.25 | | 4.8 | 2.6 | 2.6 |
| 10 | 3.65 | 3.75 | 1.8 | 1.9 | 5 | 2.7 | | 3.8 | 1.8 | 3.1 | 0.95 | 9.15 | 2.8 | 1.9 | 2.4 | | 5.4 | 2.9 | 2.8 |
| 11 | 4.05 | 4.15 | 2 | 2.1 | 5.5 | 3 | | 4.2 | 2 | 3.6 | 1.05 | 10.15 | 3.1 | 2.1 | 2.7 | | 6 | 3.2 | 3 |
| 12 | 4.25 | 4.55 | 2.2 | 2.3 | 5.7 | 3.3 | | | 2.2 | 4.1 | 1.15 | 10.75 | 3.4 | 2.7 | | | 6.6 | 3.5 | 3.2 |
| 13 | | | 2.4 | 2.5 | | 3.65 | | | | 4.6 | 1.25 | | 3.7 | | | | | 3.8 | 3.4 |
| 14 | | | 2.6 | | | | | | | 4.9 | 1.35 | | 4 | | | | | 4.1 | 3.6 |
| 15 | | | 2.9 | | | | | | | | 1.6 | | | | | | | 4.4 | 3.8 |
| 16 | | | 3 | | | | | | | | | | | | | | | 4.8 | 4 |
| 17 | | | 3.2 | | | | | | | | | | | | | | | | 4.2 |
| 18 | | | 3.3 | | | | | | | | | | | | | | | | 4.4 |
| 19 | | | 3.5 | | | | | | | | | | | | | | | | 4.6 |
| 20 | | | | | | | | | | | | | | | | | | | 4.8 |
| 21 | | | | | | | | | | | | | | | | | | | 5 |
| 22 | | | | | | | | | | | | | | | | | | | 5.2 |
| 23 | | | | | | | | | | | | | | | | | | | 5.4 |
| 24 | | | | | | | | | | | | | | | | | | | 5.5 |
| Depth (ft) (unless indicated cm) | | | | | (cm) | (cm) | (cm) | (cm) | | | | | | | | | | | |
| 1 | 0.75 | 0.35 | 0.25 | 0.35 | 2 | 30 | 4 | 57 | 0 | 0.25 | 0.4593176 | 0.85 | 2.2965879 | 0.2 | 0.5 | 0.2 | 1.1 | 0.2 | 0.45 |
| 2 | 0.9 | 0.5 | 0.3 | 0.65 | 10 | 27 | 5 | 70 | 0.7 | 0.4 | 0.4593176 | 1.5 | 2.2309711 | 0.45 | 0.4 | 0.5 | 1.5 | 0.15 | 0.6 |
| 3 | 1.15 | 0.55 | 0.2 | 0.8 | 15 | 17 | 8 | 70 | 1.1 | 0.8 | 0.3937008 | 2 | 2.1653543 | 0.6 | 0.4 | 0.6 | 1.6 | 0.2 | 0.55 |
| 4 | 1.05 | 0.5 | 0.55 | 0.9 | 16 | 15 | 8 | 69 | 1.5 | 0.8 | 0.3608924 | 2.1 | 1.9028871 | 0.7 | 0.5 | 0.55 | 1.5 | 0.4 | 0.5 |
| 5 | 1.1 | 0.6 | 0.5 | 0.9 | 18 | 12 | 7.5 | 60 | 1.8 | 0.4 | 0.2952756 | 2.75 | 1.6404199 | 0.55 | 0.6 | 0.65 | 1.5 | 0.5 | 0.5 |
| 6 | 0.975 | 0.6 | 0.45 | 0.9 | 18 | 12 | 6 | 52 | 1.8 | 0.45 | 0.328084 | 2.55 | 1.3779528 | 0.5 | 0.6 | 0.5 | 1.3 | 0.9 | 0.5 |
| 7 | 0.9 | 0.4 | 0.55 | 0.8 | 17 | 16 | 6 | 46 | 1.8 | 0.4 | 0.328084 | 1.6 | 1.312336 | 0.3 | 0.7 | 0.3 | 1.1 | 0.8 | 0.5 |
| 8 | 0.75 | 0.6 | 0.4 | 0.5 | 15.5 | 12 | 0 | 40 | 1.5 | 0.5 | 0.2296588 | 1.5 | 1.1154856 | 0.3 | 0.7 | 0 | 0.9 | 0.9 | 0.5 |
| 9 | 0.55 | 0.8 | 0.3 | 0.45 | 14 | 11 | | 34 | 1.15 | 0.6 | 0.164042 | 1.1 | 0.9186352 | 0.25 | 0.75 | | 0.9 | 1 | 0.55 |
| 10 | 0.55 | 0.9 | 0.35 | 0.3 | 14 | 9 | | 28 | 0.85 | 0.7 | 0.1312336 | 1.075 | 0.9186352 | 0.15 | 0.5 | | 0.4 | 0.85 | 0.6 |
| 11 | 0.4 | 0.8 | 0.35 | 0.35 | 2 | 7 | | 0 | 0.2 | 0.5 | 0.1312336 | 0.25 | 0.7874016 | 0.15 | 0 | | 0.4 | 0.8 | 0.6 |
| 12 | 0 | 0 | 0.35 | 0.3 | 0 | 4 | | | 0 | 0.7 | 0.1968504 | 0 | 0.5905512 | 0 | | | 0 | 0.6 | 0.55 |
| 13 | | | 0.3 | 0 | | 0 | | | | 0.35 | 0.1312336 | | 0.2624672 | | | | | 0.4 | 0.4 |
| 14 | | | 0.2 | | | | | | | 0 | 0.1312336 | | 0 | | | | | 0.25 | 0.5 |
| 15 | | | 0.25 | | | | | | | | 0 | | | | | | | 0.25 | 0.5 |
| 16 | | | 0.25 | | | | | | | | | | | | | | | 0 | 0.55 |
| 17 | | | 0.2 | | | | | | | | | | | | | | | | 0.6 |
| 18 | | | 0.2 | | | | | | | | | | | | | | | | 0.6 |
| 19 | | | 0 | | | | | | | | | | | | | | | | 0.5 |
| 20 | | | | | | | | | | | | | | | | | | | 0.5 |
| 21 | | | | | | | | | | | | | | | | | | | 0.6 |
| 22 | | | | | | | | | | | | | | | | | | | 0.5 |
| 23 | | | | | | | | | | | | | | | | | | | 0.45 |
| 24 | | | | | | | | | | | | | | | | | | | 0 |
| | | | | | (cm) | (cm) | (cm) | (cm) | | | | | | | | | | | |
| | 0.75625 | 0.55 | 0.3131579 | 0.5538462 | 11.791667 | 13.230769 | 5.5625 | 47.818182 | 1.03 | 0.4892857 | 0.25 | 1.4395833 | 1.2514061 | 0.3458333 | 0.5136364 | 0.4125 | 1.0166667 | 0.5125 | 0.5041667 |
| Velocity (m/s) 1 | 0.01 | 0.02 | 0.15 | -0.02 | 0.01 | 0.05 | 0.16 | 0.1 | 0.00 | 0.42 | 0.11 | 0.01 | 0.06 | 0.35 | 0.03 | 0.05 | 0.03 | 0 | 0.12 |
| 2 | 0.05 | 0.04 | 0.51 | 0 | 0.02 | 0.04 | 0.16 | 0.14 | 0.40 | 0.77 | 0.08 | -0.01 | 0.04 | 0.6 | 0.06 | 0.19 | 0.14 | 0 | 0.16 |
| 3 | 0.03 | 0.05 | 0.42 | 0.005 | 0.04 | 0.08 | 0.13 | 0.19 | 0.38 | 1.03 | 0.08 | 0 | 0.085 | 0.61 | -0.03 | 0.27 | 0.24 | 0.05 | 0.13 |
| 4 | 0.1 | 0.15 | 0.63 | 0.02 | 0.04 | 0.13 | 0.09 | 0.27 | 0.50 | 0.93 | 0.09 | 0.04 | 0.13 | 0.71 | 0.03 | 0.32 | 0.49 | 0.17 | 0.19 |
| 5 | 0.14 | 0.21 | 0.6 | 0.04 | 0.06 | 0.17 | 0.12 | 0.28 | 0.46 | 0.83 | 0.08 | 0.04 | 0.135 | 0.65 | 0.08 | 0.31 | 0.36 | 0.42 | 0.36 |
| 6 | 0.16 | 0.15 | 0.51 | 0.07 | 0.08 | 0.22 | 0.05 | 0.32 | 0.51 | 0.75 | 0.15 | 0.05 | 0.115 | 0.51 | 0.19 | 0.24 | 0.5 | 0.55 | 0.38 |
| 7 | 0.15 | 0 | 0.49 | 0.06 | 0.16 | 0.23 | 0.03 | 0.26 | 0.53 | 0.02 | 0.09 | 0.06 | 0.15 | 0.36 | 0.3 | 0.14 | 0.42 | 0.7 | 0.58 |
| 8 | 0.1 | 0.04 | 0.5 | 0.02 | 0.09 | 0.24 | 0 | 0.24 | 0.50 | 0.04 | 0.04 | 0.04 | 0.12 | 0.27 | 0.28 | 0 | 0.15 | 0.8 | 0.56 |
| 9 | 0.06 | 0.23 | 0.49 | -0.02 | 0.07 | 0.21 | | 0.02 | 0.52 | 0.31 | 0.06 | 0.02 | 0.08 | 0.13 | 0.075 | | 0.09 | 0.64 | 0.52 |
| 10 | 0.09 | 0.32 | 0.45 | -0.03 | 0.12 | 0.15 | | -0.01 | 0.49 | 0.34 | -0.03 | 0 | 0.05 | 0.05 | 0.09 | | 0.06 | 0.95 | 0.56 |
| 11 | 0.02 | 0.14 | 0.46 | -0.02 | 0.04 | 0.11 | | 0 | 0.33 | 0.5 | 0.14 | -0.015 | 0.06 | -0.01 | 0 | | 0.01 | 0.85 | 0.73 |
| 12 | 0 | 0 | 0.33 | -0.03 | 0 | 0.15 | | | 0.00 | 0.24 | 0.44 | 0 | 0.055 | 0 | | | 0 | 1.15 | 0.68 |
| 13 | | | 0.34 | 0 | | 0 | | | | 0.15 | 0.41 | | 0.025 | | | | | 0.93 | 0.64 |
| 14 | | | 0.18 | | | | | | | 0 | 0.25 | | 0 | | | | | 0.58 | 0.57 |
| 15 | | | 0.12 | | | | | | | | 0 | | | | | | | 0.34 | 0.8 |
| 16 | | | 0.23 | | | | | | | | | | | | | | | 0 | 0.73 |
| 17 | | | 0.38 | | | | | | | | | | | | | | | | 0.85 |
| 18 | | | 0.16 | | | | | | | | | | | | | | | | 0.82 |
| 19 | | | 0 | | | | | | | | | | | | | | | | 0.73 |
| 20 | | | | | | | | | | | | | | | | | | | 0.66 |
| 21 | | | | | | | | | | | | | | | | | | | 0.19 |
| 22 | | | | | | | | | | | | | | | | | | | 0.01 |
| 23 | | | | | | | | | | | | | | | | | | | 0.01 |
| 24 | | | | | | | | | | | | | | | | | | | 0 |
| Average Velocity (m/s) | 0.0758333 | 0.1125 | 0.3657895 | 0.0073077 | 0.0608333 | 0.1369231 | 0.0925 | 0.1645455 | 0.385 | 0.4521429 | 0.132 | 0.0195833 | 0.0789286 | 0.3525 | 0.1004545 | 0.19 | 0.2075 | 0.508125 | 0.4575 |
| Flowrate (m3/s) 1 | 2.858E-05 | 8.001E-05 | 0.0005715 | -5.334E-05 | 0.000025 | 0 | 0.0002438 | 0.00285 | 0 | 0.0008001 | 0.0001925 | 9.716E-05 | 0.00105 | 0.0005334 | 0.0003429 | 0.0001905 | 0 | 0 | 0.0041148 |
| 2 | 0.0030175 | 0.0015545 | 0.0055321 | -0.0003048 | 0.00045 | 0.0038475 | 0.0007315 | 0.03048 | 0.0042672 | 0.0147352 | 0.00133 | 0 | 0.01035 | 0.0094107 | 0.0018517 | 0.0038405 | 0.0202082 | 0 | 0.0044806 |
| 3 | 0.0049987 | 0.0028804 | 0.0070866 | 0.0001105 | 0.001875 | 0.00396 | 0.0014364 | 0.0462 | 0.021397 | 0.041148 | 0.00104 | -0.002667 | 0.0125625 | 0.0193624 | 0.0005486 | 0.0115672 | 0.0538582 | 0.0004001 | 0.0050825 |
| 4 | 0.0087173 | 0.0064008 | 0.0120015 | 0.0006477 | 0.0031 | 0.00504 | 0.0008941 | 0.06394 | 0.0348691 | 0.0597408 | 0.0009775 | 0.0124968 | 0.019995 | 0.0261518 | 0 | 0.0155105 | 0.1034644 | 0.0030175 | 0.0051206 |
| 5 | 0.0157277 | 0.0120701 | 0.0098412 | 0.0016459 | 0.00425 | 0.006075 | 0.0008268 | 0.07095 | 0.0482803 | 0.0402336 | 0.000825 | 0.0295656 | 0.021465 | 0.025908 | 0.0027661 | 0.0172822 | 0.116586 | 0.0121387 | 0.008382 |
| 6 | 0.0189738 | 0.0131674 | 0.0080353 | 0.0030175 | 0.0063 | 0.00702 | 0.0007287 | 0.0672 | 0.0532181 | 0.0255842 | 0.0010688 | 0.0363474 | 0.01725 | 0.0185623 | 0.0037033 | 0.014459 | 0.1100938 | 0.0310439 | 0.0112776 |
| 7 | 0.0177165 | 0.004572 | 0.01524 | 0.003368 | 0.0105 | 0.00945 | 0.0003048 | 0.05684 | 0.0570586 | 0.0124682 | 0.0012 | 0.0347853 | 0.0162975 | 0.010607 | 0.0072809 | 0.0069494 | 0.1009498 | 0.0485775 | 0.0146304 |
| 8 | 0.012573 | 0.0012192 | 0.0143332 | 0.001585 | 0.0101563 | 0.00987 | 6.858E-05 | 0.043 | 0.0518008 | 0.0020574 | 0.0005525 | 0.023622 | 0.014985 | 0.0057607 | 0.0185623 | 0.0006401 | 0.0521208 | 0.058293 | 0.0173736 |
| 9 | 0.0063398 | 0.0115214 | 0.0105613 | 0 | 0.0059 | 0.0077625 | 0 | 0.01924 | 0.0411937 | 0.0146685 | 0.000285 | 0.0118872 | 0.0093 | 0.0033528 | 0.0058836 | 0 | 0.019751 | 0.062545 | 0.0172822 |
| 10 | 0.0050292 | 0.0284988 | 0.0093116 | -0.0005715 | 0.00665 | 0.0054 | 0 | 0.00062 | 0.0307848 | 0.0321945 | 5.625E-05 | 0.0033147 | 0.00546 | 0.0010973 | 0.0023574 | 0 | 0.0089154 | 0.0672427 | 0.0189281 |
| 11 | 0.0031852 | 0.0238354 | 0.0097079 | -0.0004953 | 0.0032 | 0.00312 | 0 | -0.00028 | 0.0131216 | 0.0384048 | 0.00022 | -0.0015145 | 0.00429 | 0.0001829 | 0.0010287 | 0 | 0.0025603 | 0.0678942 | 0.0235915 |
| 12 | 0.0001219 | 0.0034138 | 0.0084277 | -0.0004953 | 0.00004 | 0.002145 | 0 | 0 | 0.0010058 | 0.0338328 | 0.00145 | -0.0001715 | 0.0036225 | -6.858E-05 | 0 | 0 | 0.0001829 | 0.064008 | 0.0247117 |
| 13 | 0 | 0 | 0.006637 | -0.0001372 | 0 | 0.000525 | 0 | 0 | 0 | 0.015602 | 0.002125 | 0 | 0.00156 | 0 | 0 | 0 | 0 | 0.0475488 | 0.019111 |
| 14 | 0 | 0 | 0.0039624 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0012002 | 0.00132 | 0 | 0.00015 | 0 | 0 | 0 | 0 | 0.0224371 | 0.0165964 |
| 15 | 0 | 0 | 0.0030861 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000625 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0105156 | 0.0208788 |
| 16 | 0 | 0 | 0.0013335 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0025908 | 0.0244831 |
| 17 | 0 | 0 | 0.0041834 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0276911 |
| 18 | 0 | 0 | 0.0016459 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.030541 |
| 19 | 0 | 0 | 0.0004877 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0259842 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0211836 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0142494 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0033528 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0002896 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.429E-05 |
| Flowrate (m3/s) | 0.0964292 | 0.1092137 | 0.131986 | 0.0083172 | 0.0524463 | 0.064215 | 0.0052346 | 0.40104 | 0.356997 | 0.3326702 | 0.0132675 | 0.1477632 | 0.1383375 | 0.1208608 | 0.0443255 | 0.0704393 | 0.5886907 | 0.4982528 | 0.3593706 |

| Final ID | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STRATCLASS | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 |
| Culvert #: | 52 (b) | 53 | 54 | 56(b) | 57 | 59 (b) | 60(b) | 61 (b) | 121 | 63 (b) | 65 (b) | 66 (b) | 67 (b) | 70 (b) | 71 (b) | 72 | 74 | 75 | 41 (a) |
| Notes | | | | | Huge Bridge Steep Hill Didn't get flow | | | | | | | | bridge too wide and strong to measure | | | Flow through bridge too hard to measure | | | measured on apron |
| Width Corrected - zero at bank (m) 1 | 0.2 | 0.35 | 0.3 | 0 | | 0.25 | 0.55 | 0.3 | 0.1 | 1 | -0.15 | 0.7 | | 0.5 | 0.7 | | 1 | 0.1 | 1 |
| 2 | 0.5 | 0.45 | 0.5 | 0.3 | | 0.45 | 0.95 | 0.8 | 0.5 | 2 | 0.35 | 1.4 | | 1.1 | 1.7 | | 2 | 1.1 | 2 |
| 3 | 0.8 | 0.6 | 0.6 | 0.6 | | 0.65 | 1.35 | 1.3 | 0.9 | 3 | 0.85 | 2.1 | | 1.7 | 2.7 | | 2.3 | 2.1 | 3 |
| 4 | 1.1 | 0.85 | 0.9 | 0.9 | | 0.85 | 1.75 | 1.8 | 1.3 | 3.2 | 1.35 | 2.8 | | 2.3 | 3.7 | | 3.9 | 3.1 | 4 |
| 5 | 1.4 | 1.35 | 1.2 | 1.2 | | 1.05 | 2.15 | 2.3 | 1.7 | 4 | 1.85 | 3.5 | | 2.9 | 4.7 | | 4 | 4.1 | 5 |
| 6 | 1.7 | 1.6 | 1.5 | 1.5 | | 1.25 | 2.55 | 2.8 | 2.1 | 5 | 2.35 | 4.2 | | 3.5 | 5.2 | | 5 | 5.1 | 6 |
| 7 | 3.1 | 1.85 | 1.8 | 1.8 | | 1.45 | 2.95 | 3.3 | 2.5 | 5.4 | 2.85 | 4.9 | | 4.1 | 6.4 | | 6 | 6.1 | 6.15 |
| 8 | 3.4 | 2.35 | 2.1 | 2.1 | | 1.65 | 3.35 | 3.8 | 2.9 | 6 | 3.35 | 5.6 | | 4.7 | 6.7 | | 7 | 7.1 | |
| 9 | 3.7 | 2.85 | 2.4 | 2.4 | | 1.85 | 3.75 | 4.3 | 3.3 | 7 | 3.85 | 6.3 | | 5.3 | 7.7 | | 8 | 8.1 | |
| 10 | 4 | 3.35 | 2.7 | 2.7 | | 2.05 | 4.15 | 4.8 | 3.7 | 7.4 | 4.35 | 7 | | 5.9 | 8.7 | | 9 | 9.1 | |
| 11 | 4.3 | 3.85 | 2.85 | 3 | | 2.25 | 4.55 | 5.3 | 4.1 | 8 | 4.85 | 7.1 | | 6.5 | 9.7 | | 10 | 10.1 | |
| 12 | 4.6 | 4.35 | 3.05 | 3.3 | | 2.45 | 4.95 | 5.5 | 4.5 | 9 | 5.35 | | | | 10.7 | | 11 | 10.9 | |
| 13 | 5 | 4.85 | | 3.6 | | 2.65 | 5.35 | | | 9.1 | 5.85 | | | | 11.7 | | 12 | | |
| 14 | | 5.25 | | 3.9 | | | 5.75 | | | | 5.95 | | | | 12.7 | | 12.8 | | |
| 15 | | | | 4.2 | | | 6.15 | | | | | | | | 13.7 | | | | |
| 16 | | | | 4.5 | | | 6.55 | | | | | | | | 13.9 | | | | |
| 17 | | | | 4.7 | | | 6.95 | | | | | | | | | | | | |
| 18 | | | | | | | 7.55 | | | | | | | | | | | | |
| 19 | | | | | | | 7.75 | | | | | | | | | | | | |
| Depth (ft) (unless indicated cm) | | | (cm) | | | | | | (cm) | | | | | | | | (cm) | (cm) | |
| 1 | 0.2 | 0.5 | 26 | 0 | | 0.4 | 0.55 | 0.2 | 8 | 0.55 | 1.35 | 0.4 | | 1.1 | 0.4 | | 6 | 14 | 0.6 |
| 2 | 1.1 | 0.5 | 19 | 0.55 | | 0.6 | 0.8 | 0.75 | 20 | 1.05 | 1.4 | 0.7 | | 1.3 | 0.5 | | 10 | 30 | 0.65 |
| 3 | 1.35 | 0.6 | 16 | 0.7 | | 0.85 | 0.6 | 0.85 | 24 | 0.8 | 1.4 | 0.95 | | 1.5 | 0.8 | | 0 | 28 | 0.65 |
| 4 | 1.4 | 0.7 | 32 | 0.9 | | 0.8 | 0.7 | 1.45 | 32 | 0.75 | 1.3 | 1 | | 1.4 | 0.4 | | 0 | 27 | 0.65 |
| 5 | 0.7 | 0.7 | 30 | 1.25 | | 0.7 | 0.75 | 1.475 | 52 | 0.8 | 1.2 | 1 | | 1.25 | 0.041 | | 25 | 27 | 0.6 |
| 6 | 0.2 | 0.7 | 31 | 1.2 | | 0.5 | 0.8 | 1.2 | 42 | 1.1 | 1 | 1.1 | | 1.25 | 0 | | 26 | 30 | 0.55 |
| 7 | 1 | 0.7 | 26 | 1.3 | | 0.6 | 0.9 | 0.9 | 33 | 1.3 | 0.95 | 1 | | 0.95 | 0 | | 37 | 33 | 0 |
| 8 | 1 | 0.8 | 29 | 1.1 | | 0.5 | 1.1 | 0.9 | 25 | 0.9 | 0.8 | 0.7 | | 0.75 | 0.041 | | 32 | 39 | |
| 9 | 1.4 | 0.65 | 38 | 1.4 | | 0.55 | 1.3 | 0.5 | 20.5 | 1 | 0.65 | 0.6 | | 0.55 | 0.35 | | 22 | 39 | |
| 10 | 1.5 | 0.15 | 27 | 1.5 | | 0.5 | 1.4 | 0.3 | 14.5 | 1 | 0.425 | 0.45 | | 0.5 | 0.9 | | 24 | 34 | |
| 11 | 1.3 | 0.2 | 17 | 1.5 | | 0.4 | 1.5 | 0.3 | 9 | 0.85 | 0.4 | 0 | | 0 | 1.2 | | 8 | 38 | |
| 12 | 0.6 | 0.4 | 0 | 1.5 | | 0.25 | 1.6 | 0 | 4 | 0.5 | 0.15 | | | | 0.8 | | 11 | 0 | |
| 13 | 0 | 0.5 | | 1.1 | | 0 | 1.85 | | | 0 | 0.2 | | | | 0.8 | | 11 | | |
| 14 | | 0 | | 1.05 | | | 2.1 | | | | 0 | | | | 0.6 | | 0 | | |
| 15 | | | | 1 | | | 2.2 | | | | | | | | 0.45 | | | | |
| 16 | | | | 0.8 | | | 2.25 | | | | | | | | 0 | | | | |
| 17 | | | | 0 | | | 2.1 | | | | | | | | | | | | |
| 18 | | | | | | | 0.6 | | | | | | | | | | | | |
| 19 | | | | | | | 0 | | | | | | | | | | | | |
| | | | (cm) | | | | | | (cm) | | | | | | | | (cm) | (cm) | |
| | 0.9038462 | 0.5071429 | 24.25 | 0.9911765 | | 0.5115385 | 1.2157895 | 0.7354167 | 23.666667 | 0.8153846 | 0.8017857 | 0.7181818 | #DIV/0! | 0.9590909 | 0.455125 | | 15.142857 | 28.25 | 0.5285714 |
| Velocity (m/s) 1 | 0.67 | -0.03 | 0.15 | 0 | | 0.03 | 0.07 | 0.05 | -0.02 | 0.13 | 0.08 | 0.2 | | 0.03 | 0.06 | | 0.23 | 0.15 | 0.9 |
| 2 | 0.48 | 0.02 | 0.27 | 0.05 | | 0.07 | 0.07 | 0.08 | -0.01 | 0.35 | 0.31 | 0.4 | | 0.24 | 0.2 | | 0.45 | 0.36 | 1.255 |
| 3 | 0.67 | 0.15 | 0.26 | 0.15 | | 0.36 | 0.09 | 0.12 | 0.03 | 0.5 | 0.31 | 0.47 | | 0.43 | 0.17 | | 0 | 0.48 | 0.99 |
| 4 | 0.63 | 0.41 | 0.26 | 0.27 | | 0.2 | 0.08 | 0.13 | 0.16 | 0.28 | 0.5 | 0.46 | | 0.56 | 0.22 | | 0 | 0.51 | 0.88 |
| 5 | 0.57 | 0.31 | 0.26 | 0.3 | | 0.14 | 0.08 | 0.14 | 0.1 | 0.51 | 0.48 | 0.45 | | 0.48 | 0 | | 0.34 | 0.44 | 0.96 |
| 6 | 0.53 | 0.2 | 0.2 | 0.42 | | 0.22 | 0.11 | 0.17 | 0.1 | 0.21 | 0.38 | 0.41 | | 0.5 | 0 | | 0.34 | 0.68 | 0.08 |
| 7 | 0.25 | 0.1 | 0.18 | 0.51 | | 0.23 | 0.11 | 0.17 | 0.12 | 0.42 | 0.43 | 0.39 | | 0.4 | 0 | | 0.19 | 0.88 | 0 |
| 8 | 0.46 | 0.03 | 0.2 | 0.36 | | 0.39 | 0.12 | 0.18 | 0.07 | 0.39 | 0.46 | 0.33 | | 0.4 | 0 | | 0.23 | 0.7 | |
| 9 | 0.51 | -0.04 | 0.1 | 0.37 | | 0.42 | 0.11 | 0.16 | 0.08 | 0.6 | 0.37 | 0.19 | | 0.35 | 0.2 | | 0.21 | 0.5 | |
| 10 | 0.43 | 0 | 0.04 | 0.27 | | 0.3 | 0.13 | 0.05 | 0.07 | 0.65 | 0.3 | 0.13 | | 0.21 | 0.37 | | 0.23 | 0.37 | |
| 11 | 0.38 | -0.03 | 0 | 0.33 | | 0.34 | 0.16 | 0.08 | 0.04 | 0.25 | 0.14 | 0 | | 0 | 0.37 | | 0.24 | 0.33 | |
| 12 | 0.34 | 0.02 | 0 | 0.15 | | 0.25 | 0.13 | 0 | 0 | 0.08 | 0.18 | | | | 0.3 | | 0.18 | 0 | |
| 13 | 0 | -0.04 | | 0.17 | | 0 | 0.15 | | | 0 | 0.05 | | | | 0.17 | | 0.04 | | |
| 14 | | 0 | | 0.13 | | | 0.14 | | | | 0 | | | | 0.16 | | 0 | | |
| 15 | | | | 0.08 | | | 0.14 | | | | | | | | 0.015 | | | | |
| 16 | | | | 0.06 | | | 0.09 | | | | | | | | 0 | | | | |
| 17 | | | | 0 | | | 0.03 | | | | | | | | | | | | |
| 18 | | | | | | | 0.06 | | | | | | | | | | | | |
| 19 | | | | | | | 0 | | | | | | | | | | | | |
| Average Velocity (m/s) | 0.4553846 | 0.0785714 | 0.16 | 0.2129412 | | 0.2269231 | 0.0984211 | 0.1108333 | 0.0616667 | 0.3361538 | 0.285 | 0.3118182 | #DIV/0! | 0.3272727 | 0.1396875 | | 0.1914286 | 0.45 | 0.7235714 |
| Flowrate (m3/s) 1 | 0.0020422 | -0.0004001 | 0.002925 | 0 | | 0.0002286 | 0.0016135 | 0.0002286 | -0.00004 | 0.0054483 | -0.0012344 | 0.0042672 | 0 | 0.0012573 | 0.0012802 | | 0.00345 | 0.000525 | 0.041148 |
| 2 | 0.0341757 | -0.0000762 | 0.00945 | 0.0006287 | | 0.001524 | 0.0057607 | 0.0047054 | -0.00084 | 0.0585216 | 0.0408623 | 0.0352044 | 0 | 0.0296266 | 0.0178308 | | 0.0272 | 0.0561 | 0.2052638 |
| 3 | 0.0644081 | 0.0021374 | 0.0046375 | 0.005715 | | 0.0095021 | 0.0068275 | 0.012192 | 0.00088 | 0.1198245 | 0.0661416 | 0.0765696 | 0 | 0.0857707 | 0.0366522 | | 0.003375 | 0.1218 | 0.2223897 |
| 4 | 0.0817245 | 0.0138684 | 0.01872 | 0.0153619 | | 0.0140818 | 0.0067361 | 0.0219075 | 0.01064 | 0.0184252 | 0.0833247 | 0.0967321 | 0 | 0.1312621 | 0.0356616 | | 0 | 0.136125 | 0.1852422 |
| 5 | 0.0576072 | 0.0384048 | 0.02418 | 0.0280149 | | 0.0077724 | 0.0070714 | 0.0300895 | 0.02184 | 0.0746455 | 0.093345 | 0.0970788 | 0 | 0.1260043 | 0.0073929 | | 0.002125 | 0.12825 | 0.17526 |
| 6 | 0.0226314 | 0.0136017 | 0.021045 | 0.040325 | | 0.0065837 | 0.0089764 | 0.0315944 | 0.0188 | 0.1042416 | 0.0720852 | 0.096332 | 0 | 0.112014 | 0 | | 0.0867 | 0.1596 | 0.0911352 |
| 7 | 0.0998525 | 0.008001 | 0.016245 | 0.0531495 | | 0.0075438 | 0.0113995 | 0.0272034 | 0.0165 | 0.0460858 | 0.060179 | 0.0896112 | 0 | 0.0905256 | 0 | | 0.083475 | 0.2457 | 0.0005029 |
| 8 | 0.0324612 | 0.0074295 | 0.015675 | 0.0477317 | | 0.0103937 | 0.0140208 | 0.024003 | 0.01102 | 0.081473 | 0.0593408 | 0.0652882 | 0 | 0.0621792 | 0 | | 0.07245 | 0.2844 | 0 |
| 9 | 0.0532181 | -0.0005525 | 0.015075 | 0.0417195 | | 0.0129616 | 0.016825 | 0.0181356 | 0.006825 | 0.1433322 | 0.0458534 | 0.0360578 | 0 | 0.044577 | 0.0059588 | | 0.0594 | 0.234 | 0 |
| 10 | 0.0623164 | -0.0012192 | 0.006825 | 0.0424282 | | 0.0115214 | 0.019751 | 0.0064008 | 0.00525 | 0.0762 | 0.0274415 | 0.0179222 | 0 | 0.0268834 | 0.0542925 | | 0.0506 | 0.158775 | 0 |
| 11 | 0.0518465 | -0.0004001 | 0.00066 | 0.041148 | | 0.0087782 | 0.0256337 | 0.0029718 | 0.002585 | 0.0761238 | 0.0138303 | 0.0004458 | 0 | 0.0048006 | 0.1184148 | | 0.0376 | 0.126 | 0 |
| 12 | 0.0312725 | -0.0002286 | 0 | 0.0329184 | | 0.0058445 | 0.0274015 | 0.0003658 | 0.00052 | 0.0339471 | 0.0067056 | 0 | 0 | 0 | 0.102108 | | 0.01995 | 0.02508 | 0 |
| 13 | 0.0062179 | -0.0006858 | 0 | 0.0190195 | | 0.0009525 | 0.0294437 | 0 | 0 | 0.0003048 | 0.0030671 | 0 | 0 | 0 | 0.0573024 | | 0.0121 | 0 | 0 |
| 14 | 0 | -0.0006096 | 0 | 0.0147447 | | 0 | 0.0349148 | 0 | 0 | 0 | 7.62E-05 | 0 | 0 | 0 | 0.0352044 | | 0.00088 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0.0098412 | | 0 | 0.0366979 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0140018 | | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0.0057607 | | 0 | 0.0311963 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001029 | | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0.0007315 | | 0 | 0.0159106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | | 0 | 0.01111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | | 0 | 0.0005486 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| Flowrate (m3/s) | 0.599774 | 0.0792709 | 0.1354375 | 0.3992385 | | 0.0976884 | 0.311839 | 0.1797977 | 0.09398 | 0.8385734 | 0.571018 | 0.6155093 | 0 | 0.7149008 | 0.4862032 | | 0.459305 | 1.676355 | 0.9209418 |

# APPENDIX D. VELOCITY CALCULATIONS

The following tables show the calculations to determine the velocity in the road crossings. Pipe culvert cross sectional area of flow was determined as a segment of a circle using the formulas given by The Math Forum (1994-2004). Box culverts were treated as rectangular cross sectional areas as were bridges and arches. These calculations were done because of the difficulty in determining velocity in culverts in the fields due to shallow water, difficulty of access and/or excessive turbulence making readings difficult at many sites. Where there are multiple openings of different depth, flowrate is apportioned in proportion to the value of $AR^{2/3}$ (see Equation 1 in the main text for the definitions of these parameters).  While in some cases this is not accurate it provides velocities comparable to measured velocities in most cases where obtained. Low flowrates in streams and shallow depths in culverts will incur the highest errors in velocity determination. The width at the water surface in each crossing on the day measured is also determined (summation of surface water widths openings with flow).

| Final ID | 1 | 2 | *3* | *3* | *3* | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 |
| **Culvert #:** | 0(a) | 1 | 2 | 2ii | 2iii | 4 | 5 (a) | 6 (a) | 7 (b) | 8 (a) | 9 (a) | 10(a) |
| **Drainage Area (km2):** | 1.62 | 1.15 | 2.24 | | | 2.24 | 1.8 | 2.4 | 1.54 | 2.27 | 1.04 | 1.44 |
| **Drainage Area (mi2):** | 0.6255 | 0.4441 | 0.8649 | | | 0.8649 | 0.6950 | 0.9267 | 0.5947 | 0.8765 | 0.4016 | 0.5560 |
| **Flowrate (m3/s)** | 0.0339 | 0.0033 | 0.0373 | | | 0.0044 | 0.0435 | 0.0138 | 0.0248 | 0.0594 | -0.0033 | 0.0258 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Box | Bottomless Arch | Pipe | *Pipe* | *Pipe* | Pipe | Pipe | Pipe | Pipe | Pipe | Pipe | Pipe |
| **Number of Openings:** | 2 | 1 | 3 | | | 1 | 3 | 1 | 1 | 3 | 1 | 1 |
| **Number of Openings with Flow:** | 2 | 1 | 0 | | | 1 | 3 | 1 | 1 | 1 | 1 | 1 |
| **Number of Openings with Partial Flow** | 0 | 0 | 3 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Opening Number** | 0 | 0 | a | b | c | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Culvert Diameter (m):** | n/a | - | 1.05 | 1.4 | 1.35 | 1.85 | 1.54 | 1.3208 | 1.24 | 2.05 | 0.9144 | 2.5 |
| **Culvert Opening Width (m):** | 2.43 | 1.4478 | n/a | | | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| **Max water depth in culvert today (m) inlet/outlet:** | 0.02 | 0.06 | 0.01 | 0.34 | 0.13 | 0.20 | 0.10 | 0.13 | 0.07 | 0.13 | - | 0.08 |
| **Max water depth in culvert today (m) outlet:** | - | 0.06 | - | - | - | 0.20 | - | 0.10 | 0.13 | 0.18 | 0.05 | - |
| **Average Water Depth from Cross Section (m):** | | | | | | | | | | | | |
| **Depth of Sediment (m):** | 0.00 | 0.00 | 0.00 | 0.11 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *AR^(2/3) for Apportioning* | | | *0.00000* | *0.14323* | *0.01721* | | | | | | | |
| Diameter (m) | | | 1.05 | 1.4 | 1.35 | 1.85 | 1.54 | 1.3208 | 1.24 | 2.05 | 0.9144 | 2.5 |
| Depth (m) | | | 0.01 | 0.34 | 0.13 | 0.20 | 0.10 | 0.10 | 0.13 | 0.18 | 0.05 | 0.08 |
| d (m) | | | 0.5123 | 0.3571 | 0.548 | 0.7218 | 0.6684 | 0.5588 | 0.493 | 0.8472 | 0.4064 | 1.1738 |
| Radius (m) | | | 0.525 | 0.7 | 0.675 | 0.925 | 0.77 | 0.6604 | 0.62 | 1.025 | 0.4572 | 1.25 |
| theta (central angle) (rad) | | | | 2.0709 | 1.2470 | 1.3512 | 1.0391 | 1.1241 | 1.3030 | 1.1957 | 0.9518 | 0.7019 |
| Area of flow today (m^2) | | | 0.0000 | 0.2924 | 0.0681 | 0.1605 | 0.0525 | 0.0485 | 0.0651 | 0.1393 | 0.0144 | 0.0439 |
| Width at Streambed Intersection (Culvert Outlet) (m) | | | 0.0000 | 1.2041 | 0.7882 | 1.1569 | 0.7646 | 0.7039 | 0.7519 | 1.1539 | 0.4189 | 0.8595 |
| Width (m) | 2.43 | 1.4478 | | | | | | | | | | |
| Depth (m) | 0.02032 | 0.05588 | | | | | | | | | | |
| Average depth (m) from flowrate calcs: | | | | | | | | | | | | |
| Height of opening (m) | 2.15 | 0.9144 | | | | | | | | | | |
| Area of flow today (m^2) | 0.0494 | 0.0809 | | | | | | | | | | |
| Inlet Velocity (Measured) | - | - | - | - | - | - | - | - | - | - | - | - |
| Outlet Velocity (Measured) | - | 0.12 | - | - | - | 0.03 | - | - | - | - | - | - |
| Average Velocity (Measured) | 0.09 | | | | | | | | | | | 0.80 |
| Calculated Typical Average Velocity (m/s) | 0.3438 | 0.0410 | 0.0000 | 0.1138 | 0.0587 | 0.0275 | 0.2759 | 0.2840 | 0.3811 | 0.4263 | -0.2324 | 0.5883 |
| Using Avg Depth not Max Depth Velocity (m/s) = | | | | | | | | | | | | |
| Data Reliable? | | | | | | | | | | | flow rate must be overall approx. 0 | |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | 10.4490 | 1.3239 | | | | | | | | | | |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | | | 3.8367 | | | 2.6880 | 5.5880 | 1.3701 | 1.2076 | 9.9019 | 0.6567 | 4.9087 |
| Total Opening CSA (m2) no fill | 10.4490 | 1.3239 | 3.8367 | | | 2.6880 | 5.5880 | 1.3701 | 1.2076 | 9.9019 | 0.6567 | 4.9087 |
| Total Width at water level (m) | 4.8600 | 1.4478 | 1.9923 | | | 1.1569 | 2.2937 | 0.7039 | 0.7519 | 1.1539 | 0.4189 | 0.8595 |
| Total Width at water level (ft) | 15.9449 | 4.7500 | 6.5366 | | | 3.7957 | 7.5253 | 2.3094 | 2.4670 | 3.7858 | 1.3744 | 2.8199 |

| Final ID | *11* | *11* | 12 | 13 | *14* | *14* | *14* | *14* | *14* | 15 | *16* | *16* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 |
| **Culvert #:** | 11b | 11 b ii | 12 (b) | 13 | 14 | 14 ii | 14 iii | 14 iv | 14 v | 15 | 16 | 16 ii |
| **Drainage Area (km2):** | 2.82 | | 2.49 | 2.36 | 2.95 | | | | | 2.48 | 2.58 | |
| **Drainage Area (mi2):** | 1.0889 | | 0.9615 | 0.9113 | 1.1391 | | | | | 0.9576 | 0.9962 | |
| **Flowrate (m3/s)** | 0.0861 | | 0.1191 | 0.0148 | 0.0514 | | | | | 0.0381 | 0.0190 | |
| **Culvert Type - Box/Pipe/Feespan/Other** | Pipe | | Bridge | Pipe | Pipe | | | | | Pipe | Pipe | *Pipe* |
| **Number of Openings:** | 2 | 0 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 1 | 2 | 0 |
| **Number of Openings with Flow:** | 2 | | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 1 | 2 | |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Opening Number** | a | b | 0 | 0 | a | b | c | d | e | 0 | a | b |
| **Culvert Diameter (m):** | 0.9144 | 0.6096 | n/a | 1.23 | 1.6 | - | - | - | - | 1.75 | 1.65 | 1.65 |
| **Culvert Opening Width (m):** | - | 0 | 4.2 | n/a | - | 0 | 0 | 0 | 0 | n/a | n/a | 0 |
| **Max water depth in culvert today (m) inlet/outlet:** | 0.13 | 0.05 | 0.21 | - | - | - | - | - | - | 0.13 | 0.08 | - |
| **Max water depth in culvert today (m) outlet:** | - | - | - | 0.10 | 0.04 | 0.00 | 0.07 | 0.14 | 0.00 | 0.20 | 0.08 | 0.11 |
| **Average Water Depth from Cross Section (m):** | | | | | | | | | | | | |
| **Depth of Sediment (m):** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 | 0.00 | 0.00 | 0.00 |
| *AR^(2/3) for Apportioning* | *0.01396* | *0.00159* | | | *0.00157* | *0.00000* | *0.00524* | *0.02318* | *0.00000* | | *0.00638* | *0.01526* |
| Diameter (m) | 0.9144 | 0.6096 | | 1.23 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.75 | 1.65 | 1.65 |
| Depth (m) | 0.13 | 0.05 | | 0.10 | 0.04 | 0.00 | 0.07 | 0.14 | 0.00 | 0.20 | 0.08 | 0.11 |
| d (m) | 0.3302 | 0.254 | | 0.51975 | 0.76 | 0.8 | 0.73 | 0.66 | 0.8 | 0.6718 | 0.7488 | 0.7107 |
| Radius (m) | 0.4572 | 0.3048 | | 0.615 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.875 | 0.825 | 0.825 |
| theta (central angle) (rad) | 1.5276 | 1.1714 | | 1.1280 | 0.6351 | 0.0000 | 0.8429 | 1.2012 | 0.0000 | 1.3909 | 0.8664 | 1.0653 |
| Area of flow today (m^2) | 0.0552 | 0.0116 | | 0.0424 | 0.0134 | 0.0000 | 0.0308 | 0.0860 | 0.0000 | 0.1558 | 0.0355 | 0.0648 |
| Width at Streambed Intersection (Culvert Outlet) (m) | 0.6325 | 0.3370 | | 0.6575 | 0.4996 | 0.0000 | 0.6545 | 0.9042 | 0.0000 | 1.1213 | 0.6926 | 0.8379 |
| Width (m) | | | 4.2 | | | | | | | | | |
| Depth (m) | | | 0.21 | | | | | | | | | |
| Average depth (m) from flowrate calcs: | | | 0.14 | | | | | | | | | |
| Height of opening (m) | | | 3.00 | | | | | | | | | |
| Area of flow today (m^2) | | | 0.8961 | | | | | | | | | |
| Inlet Velocity (Measured) | - | - | - | - | - | - | - | - | - | - | - | - |
| Outlet Velocity (Measured) | - | - | - | - | 0.48 | 0.00 | 0.52 | 0.13 | 0.00 | 0.08 | - | - |
| Average Velocity (Measured) | | | | | | | | | | | | |
| Calculated Typical Average Velocity (m/s) | 1.3983 | 0.7591 | 0.1329 | 0.3485 | 0.2006 | 0.0000 | 0.2913 | 0.4625 | 0.0000 | 0.2443 | 0.1580 | 0.2070 |
| Using Avg Depth not Max Depth Velocity (m/s) = | | | 0.1977 | | | | | | | | | |
| Data Reliable? | | | | | | | | | | | | |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | | | 12.6000 | | | | | | | | | |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | 0.9486 | | | 1.1882 | 10.0531 | | | | | 2.4053 | 4.2765 | |
| Total Opening CSA (m2) no fill | 0.9486 | | 12.6000 | 1.1882 | 10.0531 | | | | | 2.4053 | 4.2765 | |
| Total Width at water level (m) | 0.9694 | | 4.2000 | 0.6575 | 2.0583 | | | | | 1.1213 | 1.5305 | |
| Total Width at water level (ft) | 3.1805 | | 13.7795 | 2.1572 | 6.7531 | | | | | 3.6787 | 5.0214 | |

| **Final ID** | 17 | 18 | 19 | *20* | *20* | 21 | 22 | 23 | *24* | *24* | *24* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 1-3 | 1-3 | 1-3 | 1-3 | 1-3 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 |
| **Culvert #:** | 17 (b) | 27(a) | 19 | 22 (a) | 22 (a) | 20 | 21 (a) | 22 (b) | 23 | 23 ii | 23 iii |
| **Drainage Area (km2):** | 1.98 | 1.26 | 1.31 | 2.65 | | 4.41 | 3.16 | 8.16 | 4.8 | | |
| **Drainage Area (mi2):** | 0.7646 | 0.4865 | 0.5058 | 1.0233 | | 1.7029 | 1.2202 | 3.1509 | 1.8535 | | |
| **Flowrate (m3/s)** | 0.1561 | 0.0252 | 0.0247 | 0.0439 | | 0.0446 | 0.0504 | 0.1249 | 0.0625 | | |
| **Culvert Type - Box/Pipe/Feespan/Other** | Pipe | Pipe | Pipe | Pipe | *Pipe* | Bridge | Bridge | Box | Pipe | | |
| **Number of Openings:** | 1 | 1 | 1 | 3 | 0 | 1 | 1 | 4 | 3 | 0 | 0 |
| **Number of Openings with Flow:** | 1 | 1 | 1 | 2 | 0 | 1 | 1 | 2 | 2 | 0 | 0 |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Opening Number** | 0 | 0 | 0 | a | b | 0 | 0 | 0 | a | b | c |
| **Culvert Diameter (m):** | 1.9 | 1.1 | 1.15 | 2.15 | 2.05 | n/a | n/a | n/a | 1.75 | - | - |
| **Culvert Opening Width (m):** | n/a | n/a | - | n/a | 0 | 2.45 | 5.7 | 3 | - | 0 | 0 |
| **Max water depth in culvert today (m) inlet/outlet:** | 1.01 | 0.40 | 0.20 | - | - | 0.14 | 0.08 | 0.46 | - | - | - |
| **Max water depth in culvert today (m) outlet:** | - | - | 0.10 | 0.10 | 0.23 | - | - | - | 0.16 | 0.19 | 0.12 |
| **Average Water Depth from Cross Section (m):** | | | | | | | | | | | |
| **Depth of Sediment (m):** | 0.00 | 0.25 | sed at outlet | 0.00 | 0.00 | SB | SB | 0.18 | 0.00 | 0.00 | 0.00 |
| *AR^(2/3) for Apportioning* | | | | *0.01359* | *0.07535* | | | | *0.03234* | *0.04667* | *0.01747* |
| Diameter (m) | 1.9 | 1.1 | 1.15 | 2.15 | 2.05 | | | | 1.75 | 1.75 | 1.75 |
| Depth (m) | 1.01 | 0.40 | 0.20 | 0.10 | 0.23 | | | | 0.16 | 0.19 | 0.12 |
| d (m) | -0.05584 | 0.15 | 0.3718 | 0.9734 | 0.7964 | | | | 0.715 | 0.685 | 0.755 |
| Radius (m) | 0.95 | 0.55 | 0.575 | 1.075 | 1.025 | | | | 0.875 | 0.875 | 0.875 |
| theta (central angle) (rad) | 3.2592 | 2.5891 | 1.7353 | 0.8765 | 1.3619 | | | | 1.2287 | 1.3431 | 1.0598 |
| Area of flow today (m^2) | 1.5237 | 0.3122 | 0.1238 | 0.0624 | 0.2015 | | | | 0.1097 | 0.1412 | 0.0718 |
| Width at Streambed Intersection (Culvert Outlet) (m) | 1.8967 | 1.0583 | 0.8772 | 0.9124 | 1.2905 | | | | 1.0088 | 1.0889 | 0.8845 |
| Width (m) | | | | | | 2.45 | 5.7 | 3 | | | |
| Depth (m) | | | | | | 0.14 | 0.08 | 0.28 | | | |
| Average depth (m) from flowrate calcs: | | | | | | 0.11 | 0.08 | | | | |
| Height of opening (m) | | | | | | 2.00 | 2.24 | 2.75 | | | |
| Area of flow today (m^2) | | | | | | 0.3547 | 0.4530 | 0.8382 | | | |
| Inlet Velocity (Measured) | 0.20 | - | 0.19 | - | - | - | - | - | - | - | - |
| Outlet Velocity (Measured) | - | - | 0.27 | - | - | - | - | - | 0.53 | 0.02 | 0.12 |
| Average Velocity (Measured) | | | | | | | | | | | |
| Calculated Typical Average Velocity (m/s) | 0.1025 | 0.1611 | 0.1998 | 0.7035 | 0.2178 | 0.1259 | 0.1113 | 0.0745 | 0.1910 | 0.2142 | 0.1577 |
| Using Avg Depth not Max Depth Velocity (m/s) = | | | | | | 0.1666 | 0.1113 | | | | |
| Data Reliable? | | Note: vel doubled to account for sediment volume in pipe | | | | | | | | | |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | | | | | | 4.9000 | 12.7406 | 33.0000 | | | |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | 2.8353 | 0.9503 | 1.0387 | 6.9311 | | | | | 7.2158 | | |
| Total Opening CSA (m2) no fill | 2.8353 | 0.9503 | 1.0387 | 6.9311 | | 4.9000 | 12.7406 | 33.0000 | 7.2158 | | |
| Total Width at water level (m) | 1.8967 | 1.0583 | 0.8772 | 2.2029 | | 2.4500 | 5.7000 | 6.0000 | 2.9821 | | |
| Total Width at water level (ft) | 6.2228 | 3.4721 | 2.8781 | 7.2275 | | 8.0381 | 18.7008 | 19.6850 | 9.7840 | | |

| **Final ID** | 25 | 26 | *27* | *27* | 28 | *29* | *29* | 30 | *31* | *31* | *31* | *31* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 |
| **Culvert #:** | 24(b) | 25 (b) | 26 (b) | 26 (b) ii | 27(b) | 28 (a) | 28 (a) ii | 29 | 31 (a) | 31 (a) ii | 31 (a) iii | 31 (a) iv |
| **Drainage Area (km2):** | 4.04 | 8.48 | 4.65 | | 6.74 | 6.53 | | 3.5 | 4.81 | | | |
| **Drainage Area (mi2):** | 1.5600 | 3.2744 | 1.7955 | | 2.6026 | 2.5215 | | 1.3515 | 1.8573 | | | |
| **Flowrate (m3/s)** | 0.2225 | 0.1660 | 0.0785 | | 0.1843 | 0.0693 | | 0.0481 | 0.1538 | | | |
| **Culvert Type - Box/Pipe/Feespan/Other** | Bridge | Box | Pipe | *Pipe* | Box | Pipe | *Pipe* | Pipe | Pipe | *Pipe* | *Pipe* | *Pipe* |
| **Number of Openings:** | 1 | 3 | 2 | 0 | 2 | 2 | 0 | 1 | 4 | 0 | 0 | 0 |
| **Number of Openings with Flow:** | 1 | 1 | 2 | 0 | 2 | 2 | 0 | 1 | 2 | 0 | 0 | 0 |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Opening Number** | 0 | 0 | a | b | 0 | a | b | 0 | a | b | c | d |
| **Culvert Diameter (m):** | n/a | n/a | 2.5 | 2.5 | n/a | 3.05 | 3.05 | 1.75 | 1.15 | 2.45 | 2.15 | 1.24 |
| **Culvert Opening Width (m):** | 9.4 | 3.05 | n/a | 0 | 3.04 | n/a | 0 | - | n/a | 0 | 0 | 0 |
| **Max water depth in culvert today (m) inlet/outlet:** | 0.10 | 0.10 | 0.10 | 0.48 | 0.08 | - | - | 0.18 | 0.00 | 0.09 | 0.22 | 0.00 |
| **Max water depth in culvert today (m) outlet:** | - | 0.13 | 0.05 | 0.51 | 0.05 | 0.46 | 0.30 | 0.09 | 0.00 | 0.30 | 0.33 | 0.00 |
| **Average Water Depth from Cross Section (m):** | | | | | | | | | | | | |
| **Depth of Sediment (m):** | SB | 0.00 | 0.00 | - | 0.00 | 0.00 | - | 0.00 | 0.03 | - | - | - |
| *AR^(2/3) for Apportioning* | | | *0.00329* | *0.45518* | | *0.40746* | *0.17205* | | *0.00000* | *0.15298* | *0.16881* | *0.00000* |
| Diameter (m) | | | 2.5 | 2.5 | | 3.05 | 3.05 | 1.75 | 1.15 | 2.45 | 2.15 | 1.24 |
| Depth (m) | | | 0.05 | 0.51 | | 0.46 | 0.30 | 0.09 | 0.00 | 0.30 | 0.33 | 0.00 |
| d (m) | | | 1.1992 | 0.742 | | 1.0678 | 1.2202 | 0.7861 | 0.575 | 0.9202 | 0.7448 | 0.62 |
| Radius (m) | | | 1.25 | 1.25 | | 1.525 | 1.525 | 0.875 | 0.575 | 1.225 | 1.075 | 0.62 |
| theta (central angle) (rad) | | | 0.5721 | 1.8705 | | 1.5902 | 1.2866 | 0.9094 | 0.0000 | 1.4419 | 1.6108 | 0.0000 |
| Area of flow today (m^2) | | | 0.0240 | 0.7149 | | 0.6866 | 0.3799 | 0.0460 | 0.0000 | 0.3378 | 0.3534 | 0.0000 |
| Width at Streambed Intersection (Culvert Outlet) (m) | | | 0.7055 | 2.0119 | | 2.1775 | 1.8295 | 0.7686 | 0.0000 | 1.6172 | 1.5504 | 0.0000 |
| Width (m) | 9.4 | 3.05 | | | 3.04 | | | | | | | |
| Depth (m) | 0.10 | 0.13 | | | 0.08 | | | | | | | |
| Average depth (m) from flowrate calcs: | 0.10 | | | | | | | | | | | |
| Height of opening (m) | 1.22 | 3.00 | | | 3.04 | | | | | | | |
| Area of flow today (m^2) | 0.9199 | 0.3874 | | | 0.2316 | | | | | | | |
| Inlet Velocity (Measured) | - | - | - | - | - | - | - | 0.85 | - | - | - | - |
| Outlet Velocity (Measured) | - | - | - | - | - | 0.45 | 0.10 | 1.30 | - | - | - | - |
| Average Velocity (Measured) | | | | | | | | | | | | |
| Calculated Typical Average Velocity (m/s) | 0.2419 | 0.4287 | 0.0235 | 0.1090 | 0.3978 | 0.0649 | 0.0649 | 1.0456 | 0.0000 | 0.2165 | 0.2284 | 0.0000 |
| Using Avg Depth not Max Depth Velocity (m/s) = | 0.2419 | | | | | | | | | | | |
| Data Reliable? | | | | | | | | | | | | |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | 11.4605 | 27.4244 | | | 18.4832 | | | | | | | |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | | | 9.8175 | | | 14.6123 | | 2.4053 | 10.5912 | | | |
| Total Opening CSA (m2) no fill | 11.4605 | 27.4244 | 9.8175 | | 18.4832 | 14.6123 | | 2.4053 | 10.5912 | | | |
| Total Width at water level (m) | 9.4000 | 3.0500 | 2.7174 | | 6.0800 | 4.0070 | | 0.7686 | 3.1676 | | | |
| Total Width at water level (ft) | 30.8399 | 10.0066 | 8.9152 | | 19.9475 | 13.1464 | | 2.5215 | 10.3923 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Final ID** | 32 | 33 | 34 | 34 | 35 | *36* | *36* | *36* | 37 | 38 | 39 |
| **STRATCLASS** | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 | 3-9 |
| **Culvert #:** | 33 (b) | 34 | 35 | 35 ii | 36 (a) | 37 (a) | 37 (a) ii | 37 (a) iii | 38 (b) | 39 | 160 |
| **Drainage Area (km2):** | 3.47 | 3.77 | 3.25 | | 4.75 | 4.08 | | | 8.41 | 3.41 | 4.14 |
| **Drainage Area (mi2):** | 1.3399 | 1.4557 | 1.2549 | | 1.8342 | 1.5754 | | | 3.2474 | 1.3167 | 1.5986 |
| **Flowrate (m3/s)** | 0.2139 | 0.0297 | 0.0042 | | 0.0964 | 0.1092 | | | 0.1320 | 0.0083 | 0.0524 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Pipe | Box | Pipe | *Pipe* | Pipe | Pipe | *Pipe* | *Pipe* | Freespan Arch | Box | Ford |
| **Number of Openings:** | 2 | 2 | 2 | 0 | 3 | 3 | 0 | 0 | 1 | 2 | 1 |
| **Number of Openings with Flow:** | 2 | 1 | 2 | 0 | 3 | 2 | 0 | 0 | 1 | 1 | 1 |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Opening Number** | 0 | 0 | a | b | 0 | a | b | c | 0 | 0 | 0 |
| **Culvert Diameter (m):** | 0.8636 | - | 1.8 | 1.8 | 2.3 | 2.25 | 2.25 | 2.25 | n/a | n/a | n/a |
| **Culvert Opening Width (m):** | n/a | 4.5 | n/a | 0 | n/a | n/a | 0 | 0 | 9.9 | 2.45 | 5.7 |
| **Max water depth in culvert today (m) inlet/outlet:** | 0.25 | 0.05 | 0.71 | 0.48 | - | 0.00 | 0.50 | 0.18 | n/a | 0.04 | 0.18 |
| **Max water depth in culvert today (m) outlet:** | - | 0.03 | 0.71 | 0.48 | 0.06 | - | - | - | - | 0.04 | 0.18 |
| **Average Water Depth from Cross Section (m):** | | | | | | | | | 0.10 | | |
| **Depth of Sediment (m):** | 0.00 | 0.00 | 0.08 | - | 0.00 | 0.00 | 0.05 | 0.00 | SB | 0.00 | SB |
| *AR^(2/3) for Apportioning* | | | *0.74498* | *0.33772* | | *0.00000* | *0.40636* | *0.04627* | | | |
| Diameter (m) | 0.8636 | | 1.8 | 1.8 | 2.3 | 2.25 | 2.25 | 2.25 | | | |
| Depth (m) | 0.25 | | 0.71 | 0.48 | 0.06 | 0.00 | 0.50 | 0.18 | | | |
| d (m) | 0.1778 | | 0.1888 | 0.4174 | 1.0865 | 1.125 | 0.6297 | 0.9472 | | | |
| Radius (m) | 0.4318 | | 0.9 | 0.9 | 1.15 | 1.125 | 1.125 | 1.125 | | | |
| theta (central angle) (rad) | 2.2928 | | 2.7189 | 2.1771 | 0.6677 | 0.0000 | 1.9535 | 1.1398 | | | |
| Area of flow today (m^2) | 0.1438 | | 0.9350 | 0.5489 | 0.0321 | 0.0000 | 0.6491 | 0.1463 | | | |
| Width at Streambed Intersection (Culvert Outlet) (m) | 0.7870 | | 1.7599 | 1.5947 | 0.7537 | 0.0000 | 1.8645 | 1.2140 | | | |
| Width (m) | | 4.5 | | | | | | | 9.9 | 2.45 | 5.7 |
| Depth (m) | | 0.03 | | | | | | | 0.10 | 0.04 | 0.18 |
| Average depth (m) from flowrate calcs: | | | | | | | | | 0.10 | | |
| Height of opening (m) | | 3.18 | | | | | | | 6.00 | 1.85 | n/a |
| Area of flow today (m^2) | | 0.1143 | | | | | | | 0.9450 | 0.0933 | 1.0260 |
| Inlet Velocity (Measured) | - | 0.35 | - | - | - | - | - | - | - | - | - |
| Outlet Velocity (Measured) | - | 0.40 | 0.01 | 0.01 | - | - | - | - | - | 0.07 | - |
| Average Velocity (Measured) | | 1.05 | | | | | | | | | |
| Calculated Typical Average Velocity (m/s) | 0.7439 | 0.2597 | 0.0031 | 0.0024 | 1.0017 | 0.0000 | 0.1510 | 0.0763 | 0.1397 | 0.0891 | 0.0511 |
| Using Avg Depth not Max Depth Velocity (m/s) = | | | | | | | | | 0.1397 | | |
| Data Reliable? | | | | | | | | | | | |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | | 28.5750 | | | | | | | 59.4000 | 9.0650 | #VALUE! |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | 1.1715 | | 5.0894 | | 12.4643 | 11.9282 | | | | | |
| Total Opening CSA (m2) no fill | 1.1715 | 28.5750 | 5.0894 | | 12.4643 | 11.9282 | | | 59.4000 | 9.0650 | #VALUE! |
| Total Width at water level (m) | 1.5740 | 4.5000 | 3.3547 | | 2.2611 | 3.0785 | | | 9.9000 | 2.4500 | 5.7000 |
| Total Width at water level (ft) | 5.1640 | 14.7638 | 11.0061 | | 7.4184 | 10.1000 | | | 32.4803 | 8.0381 | 18.7008 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Final ID** | *46* | *46* | *46* | *46* | *46* | *46* | 47 | 48 | 49 | 50 | 51 | 52 |
| **STRATCLASS** | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 |
| **Culvert #:** | 45 | 45 ii | 45 iii | 45 iv | 45 v | 45 vi | 46 (b) | 47 | 49 (b) | 50 (b) | 51 (b) | 52 (b) |
| **Drainage Area (km2):** | 21.88 | | | | | | 11.25 | 9.14 | 17.14 | 22.45 | 18.17 | 14.87 |
| **Drainage Area (mi2):** | 8.4487 | | | | | | 4.3441 | 3.5293 | 6.6184 | 8.6688 | 7.0161 | 5.7419 |
| **Flowrate (m3/s)** | 0.1383 | | | | | | 0.1209 | 0.1148 | 0.5887 | 0.4983 | 0.3594 | 0.5998 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Pipe | *Pipe* | *Pipe* | *Pipe* | *Pipe* | *Pipe* | Box | Box | Box | Bridge | Box | Pipe |
| **Number of Openings:** | 6 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 3 | 2 | 2 | 2 |
| **Number of Openings with Flow:** | 6 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 1 | 2 | 2 |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Opening Number** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Culvert Diameter (m):** | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | n/a | n/a | n/a | n/a | n/a | 2.5 |
| **Culvert Opening Width (m):** | n/a | 0 | 0 | 0 | 0 | 0 | 3.06 | 3.05 | 3.05 | 5 | 3 | n/a |
| **Max water depth in culvert today (m) inlet/outlet:** | - | - | - | - | - | - | 0.28 | - | 0.15 | 0.10 | 0.36 | - |
| **Max water depth in culvert today (m) outlet:** | 0.19 | 0.10 | 0.08 | 0.08 | 0.08 | 0.09 | - | 0.20 | - | - | 0.20 | 0.46 |
| **Average Water Depth from Cross Section (m):** | | | | | | | | | | | | |
| **Depth of Sediment (m):** | 0.00 | - | - | - | - | - | 0.10 | 0.10 | 0.00 | BR | 0.10 | 0.00 |
| *AR^(2/3) for Apportioning* | *0.02555* | *0.00690* | *0.00375* | *0.00375* | *0.00375* | *0.00520* | | | | | | |
| Diameter (m) | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | | | | | | 2.5 |
| Depth (m) | 0.19 | 0.10 | 0.08 | 0.08 | 0.08 | 0.09 | | | | | | 0.46 |
| d (m) | 0.1095 | 0.1984 | 0.2238 | 0.2238 | 0.2238 | 0.2111 | | | | | | 0.7928 |
| Radius (m) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | | | | | | 1.25 |
| theta (central angle) (rad) | 2.3943 | 1.6964 | 1.4575 | 1.4575 | 1.4575 | 1.5805 | | | | | | 1.7675 |
| Area of flow today (m^2) | 0.0772 | 0.0317 | 0.0209 | 0.0209 | 0.0209 | 0.0261 | | | | | | 0.6147 |
| Width at Streambed Intersection (Culvert Outlet) (m) | 0.5586 | 0.4501 | 0.3996 | 0.3996 | 0.3996 | 0.4263 | | | | | | 1.9328 |
| Width (m) | | | | | | | 3.06 | 3.05 | 3.05 | 5 | 3 | |
| Depth (m) | | | | | | | 0.18 | 0.10 | 0.15 | 0.10 | 0.25 | |
| Average depth (m) from flowrate calcs: | | | | | | | | | | 0.16 | | |
| Height of opening (m) | | | | | | | 3.07 | 1.88 | 3.12 | 3.10 | 3.05 | |
| Area of flow today (m^2) | | | | | | | 0.5441 | 0.3099 | 0.4648 | 0.5080 | 0.7620 | |
| Inlet Velocity (Measured) | - | - | - | - | - | - | - | - | - | - | - | 0.59 |
| Outlet Velocity (Measured) | 0.83 | 0.50 | 0.79 | 0.61 | 0.40 | 0.18 | - | - | - | - | - | - |
| Average Velocity (Measured) | | | | | | | | | | | | |
| Calculated Typical Average Velocity (m/s) | 0.9365 | 0.6159 | 0.5084 | 0.5084 | 0.5084 | 0.5634 | 0.2221 | 0.1852 | 0.4222 | 0.9808 | 0.2358 | 0.4878 |
| Using Avg Depth not Max Depth Velocity (m/s) = | | | | | | | | | | 0.6379 | | |
| Data Reliable? | Deepest and shallowest of 6 given | | | | | | | | | | | measured in culvert. 2 culverts. check vel… fairly right! |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | | | | | | | 18.8092 | 22.9311 | 28.5864 | 30.9880 | 18.2880 | |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | 1.6965 | | | | | | | | | | | 9.8175 |
| Total Opening CSA (m2) no fill | 1.6965 | | | | | | 18.8092 | 22.9311 | 28.5864 | 30.9880 | 18.2880 | 9.8175 |
| Total Width at water level (m) | 2.6337 | | | | | | 3.0600 | 6.1000 | 9.1500 | 5.0000 | 6.0000 | 3.8657 |
| Total Width at water level (ft) | 8.6407 | | | | | | 10.0394 | 20.0131 | 30.0197 | 16.4042 | 19.6850 | 12.6827 |

| Final ID | 53 | *54* | *54* | *54* | *54* | 55 | 56 | 57 | 58 | 59 | 60 | 61 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 9-25 | 25-50 |
| **Culvert #:** | 53 | 54 | 54 ii | 54 iii | 54 iv | 56(b) | 57 | 59 (b) | 60(b) | 61 (b) | 121 | 63 (b) |
| **Drainage Area (km2):** | 9.62 | 9.063 | | | | 14.26 | 17.28 | 9.85 | 15.54 | 11.56 | 10.31 | 39.29 |
| **Drainage Area (mi2):** | 3.7146 | 3.4996 | | | | 5.5063 | 6.6725 | 3.8035 | 6.0006 | 4.4638 | 3.9811 | 15.1714 |
| **Flowrate (m3/s)** | 0.0793 | 0.1354 | | | | 0.3992 | 0.0000 | 0.0977 | 0.3118 | 0.1798 | 0.0940 | 0.8386 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Bridge | Pipe | | | | Bridge | Bridge | Box | Box | Box | Bridge | Box |
| **Number of Openings:** | 1 | 4 | 0 | 0 | 0 | 1 | 1 | 3 | 3 | 3 | 1 | 3 |
| **Number of Openings with Flow:** | 1 | 3 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 3 | 1 | 1 |
| **Number of Openings with Partial Flow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Opening Number** | 0 | a | b | c | d | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Culvert Diameter (m):** | n/a | 0.77 | 1.55 | 0.78 | 1.25 | n/a | - | n/a | n/a | n/a | n/a | n/a |
| **Culvert Opening Width (m):** | 5.4 | - | 0 | 0 | 0 | 5 | 8 | 3 | 3.05 | 3.06 | 4.85 | 3.05 |
| **Max water depth in culvert today (m) inlet/outlet:** | 0.15 | - | - | - | - | - | - | 0.05 | 0.05 | 0.04 | 0.24 | 0.25 |
| **Max water depth in culvert today (m) outlet:** | - | 0.13 | 0.10 | 0.00 | 0.15 | 0.30 | - | 0.06 | - | 0.20 | - | 0.13 |
| **Average Water Depth from Cross Section (m):** | | | | | | 0.30 | | | | | | |
| **Depth of Sediment (m):** | SB | 0.00 | - | - | - | SB | SB | 0.00 | 0.00 | 0-6" | SB | 0.00 |
| *AR^(2/3) for Apportioning* | | *0.01334* | *0.01109* | *0.00000* | *0.02355* | | | | | | | |
| Diameter (m) | | 0.77 | 1.55 | 0.78 | 1.25 | | | | | | | |
| Depth (m) | | 0.13 | 0.10 | 0.00 | 0.15 | | | | | | | |
| d (m) | | 0.255 | 0.675 | 0.39 | 0.475 | | | | | | | |
| Radius (m) | | 0.385 | 0.775 | 0.39 | 0.625 | | | | | | | |
| theta (central angle) (rad) | | 1.6937 | 1.0273 | 0.0000 | 1.4150 | | | | | | | |
| Area of flow today (m^2) | | 0.0520 | 0.0515 | 0.0000 | 0.0834 | | | | | | | |
| Width at Streambed Intersection (Culvert Outlet) (m) | | 0.5769 | 0.7616 | 0.0000 | 0.8124 | | | | | | | |
| Width (m) | 5.4 | | | | | 5 | 8 | 3 | 3.05 | 3.06 | 4.85 | 3.05 |
| Depth (m) | 0.15 | | | | | 0.30 | - | 0.06 | 0.05 | 0.20 | 0.24 | 0.13 |
| Average depth (m) from flowrate calcs: | 0.15 | | | | | 0.30 | - | | | | 0.24 | |
| Height of opening (m) | 3.50 | | | | | 3.50 | 50.00 | 2.44 | 3.66 | 2.11 | 2.50 | 3.00 |
| Area of flow today (m^2) | 0.8347 | | | | | 1.5106 | #VALUE! | 0.1905 | 0.1549 | 0.6218 | 1.1478 | 0.3874 |
| Inlet Velocity (Measured) | - | - | - | - | - | - | - | - | - | - | - | - |
| Outlet Velocity (Measured) | - | 0.91 | 1.12 | - | 1.38 | - | - | - | - | - | - | - |
| Average Velocity (Measured) | | | | | | | | | | | | |
| Calculated Typical Average Velocity (m/s) | 0.0950 | 0.7245 | 0.6082 | 0.0000 | 0.7970 | 0.2643 | #VALUE! | 0.2564 | 0.6709 | 0.0964 | 0.0819 | 2.1649 |
| Using Avg Depth not Max Depth Velocity (m/s) = | 0.0950 | | | | | 0.2643 | | | | | 0.0819 | |
| Data Reliable? | | | | | | | Stream a long way below bridge. Didn't get flow data | | | | | |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | 18.9000 | | | | | 17.5000 | 400.0000 | 21.9456 | 33.4670 | 19.3533 | 12.1250 | 27.4500 |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | | 4.0576 | | | | | | | | | | |
| Total Opening CSA (m2) no fill | 18.9000 | 4.0576 | | | | 17.5000 | 400.0000 | 21.9456 | 33.4670 | 19.3533 | 12.1250 | 27.4500 |
| Total Width at water level (m) | 5.4000 | 2.1509 | | | | 5.0000 | 8.0000 | 6.0000 | 9.1500 | 9.1800 | 4.8500 | 3.0500 |
| Total Width at water level (ft) | 17.7165 | 7.0567 | | | | 16.4042 | 26.2467 | 19.6850 | 30.0197 | 30.1181 | 15.9121 | 10.0066 |

| Final ID | 62 | 63 | 64 | 65 | 66 | 67 | 68 | *69* | *69* | *69* | *69* | 70 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STRATCLASS** | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 | 25-50 |
| **Culvert #:** | 65 (b) | 66 (b) | 67 (b) | 70 (b) | 71 (b) | 72 | 74 | 75 | 75 ii | 75 iii | 75 iv | 41 (a) |
| **Drainage Area (km2):** | 35.8 | 42.53 | 49.17 | 45.22 | 28.87 | 35.49 | 30.86 | 42.51 | | | | 26.92 |
| **Drainage Area (mi2):** | 13.8237 | 16.4224 | 18.9864 | 17.4612 | 11.1478 | 13.7040 | 11.9162 | 16.4147 | | | | 10.3948 |
| **Flowrate (m3/s)** | 0.5710 | 0.6155 | 0.0000 | 0.7149 | 0.4862 | 0.0000 | 0.4593 | 1.6764 | | | | 0.9209 |
| **Culvert Type - Box/Pipe/Feespan/Other** | Box | Bridge | Bridge | Bridge | Box | Bridge | Bridge | Box | | | | Box |
| **Number of Openings:** | 4 | 1 | 1 | 1 | 6 | 1 | 1 | 4 | | | | 3 |
| **Number of Openings with Flow:** | 4 | 1 | 1 | 1 | 6 | 1 | 1 | 4 | 0 | 0 | 0 | 3 |
| **Number of Openings with Partial Flow** | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| **Opening Number** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | a | b | c | d | 0 |
| **Culvert Diameter (m):** | n/a | n/a | n/a | n/a | n/a | - | n/a | - | - | - | - | n/a |
| **Culvert Opening Width (m):** | 3.01 | 6.1 | 13 | 7.3 | 3.05 | 19 | 11.65 | 4.05 | 0 | 0 | 0 | 2.81 |
| **Max water depth in culvert today (m) inlet/outlet:** | 0.10 | 0.22 | - | 0.29 | 0.12 | 0.46 | 0.15 | - | - | - | - | 0.25 |
| **Max water depth in culvert today (m) outlet:** | 0.20 | - | - | - | 0.05 | 0.46 | - | 0.44 | 0.44 | 0.44 | blocked | 0.25 |
| **Average Water Depth from Cross Section (m):** | | | | | | | | | | | | |
| **Depth of Sediment (m):** | 0.10 | SB | SB | SB | 0.00 | SB | SB | 0.28 | 0.00 | 0.28 | blocked | 0.00 |
| *AR^(2/3) for Apportioning* | | | | | | | | *0.20123* | *1.04851* | *0.20123* | *0.00000* | |
| Diameter (m) | | | | | | | | | | | | |
| Depth (m) | | | | | | | | | | | | |
| d (m) | | | | | | | | | | | | |
| Radius (m) | | | | | | | | | | | | |
| theta (central angle) (rad) | | | | | | | | | | | | |
| Area of flow today (m^2) | | | | | | | | | | | | |
| Width at Streambed Intersection (Culvert Outlet) (m) | | | | | | | | | | | | |
| Width (m) | 3.01 | 6.1 | 13 | 7.3 | 3.05 | 19 | 11.65 | 4.05 | 4.05 | 4.05 | 4.05 | 2.81 |
| Depth (m) | 0.10 | 0.22 | - | 0.29 | 0.12 | 0.46 | 0.15 | 0.17 | 0.44 | 0.17 | blocked | 0.25 |
| Average depth (m) from flowrate calcs: | | 0.22 | - | 0.29 | | - | 0.15 | | | | | |
| Height of opening (m) | 2.44 | 3.00 | 10.00 | 3.07 | 1.80 | 3.00 | 6.00 | 1.55 | | | | 3.00 |
| Area of flow today (m^2) | 0.3058 | 1.3353 | #VALUE! | 2.1340 | 0.3533 | 8.6868 | 1.7641 | 0.6687 | 1.8002 | 0.6687 | 0.0000 | 0.7137 |
| Inlet Velocity (Measured) | - | - | - | - | 0.21 | - | - | - | - | - | - | - |
| Outlet Velocity (Measured) | - | - | - | - | 0.43 | - | - | 0.55 | 0.95 | 0.44 | 0.00 | - |
| Average Velocity (Measured) | | | | | | 0.09 | | | | | | |
| Calculated Typical Average Velocity (m/s) | 0.4668 | 0.4610 | #VALUE! | 0.3350 | 0.2294 | - | 0.2604 | 0.3477 | 0.6729 | 0.3477 | 0.0000 | 0.4301 |
| Using Avg Depth not Max Depth Velocity (m/s) = | | 0.4610 | | 0.3350 | | | 0.2604 | | | | | |
| Data Reliable? | | | Bridge: No Flow Data | | | No flow data - too deep to measure | | | | | | |
| Box or Bridge Total Opening Cross Sectional Area (m3) (no fill material) | 29.3583 | 18.3000 | 130.0000 | 22.4358 | 32.9400 | 57.0000 | 69.9000 | 25.1003 | | | | 25.2900 |
| Pipe Total Opening Cross Sectional Area (m3) (no fill material) | | | | | | | | | | | | |
| Total Opening CSA (m2) no fill | 29.3583 | 18.3000 | 130.0000 | 22.4358 | 32.9400 | 57.0000 | 69.9000 | 25.1003 | | | | 25.2900 |
| Total Width at water level (m) | 12.0400 | 6.1000 | 13.0000 | 7.3000 | 18.3000 | 19.0000 | 11.6500 | 12.1500 | | | | 8.4300 |
| Total Width at water level (ft) | 39.5013 | 20.0131 | 42.6509 | 23.9501 | 60.0394 | 62.3360 | 38.2218 | 39.8622 | | | | 27.6575 |

# APPENDIX E. PHOTOS OF ROAD CROSSINGS IN THE ETOWAH RIVER BASIN

The following photographs are of the sites in the Etowah River Basin road crossing study. Below each photograph is the final identification number corresponding to that road crossing, which corresponds to the data in Appendices A to D, listed under the same ‘Final I.D.’. The ‘Final I.D.’ number is different to the culvert number. Brief descriptions of the pictures are only added where it is felt that the picture is not self-explainatory.


1


1


2


3


3 LHS pipe


3 – upstream

4 – no photo


5


5 – middle pipe


6 downstream


6 upstream


7


7 close up view


8


9


10


10 – close up downstream


10 – upstream


11


12
13 – no photo

14 – downstream

14 – upstream

14

14
15 – no photo
16 – no photo

17

17


18

19

20

21 - no photo

22

23 – upstream

23 – downstream


24

25

25

26

27 – downstream opening 1

27 – downstream opening 2

27 – upstream opening 1

27 – upstream opening 2


28


29 – downstream – both openings


29 – downstream opening 1


29 – upstream opening 2


30


31


31

32 – no photo
33 – no photo
34 – no photo



35 – upstream 35 – downstream


36


37

38 – no photo



39


40

41

41 - Apron

42

42

43

43

43 – log jam upstream

44 – no photo

45 – no photo

46 – no photo

47


48

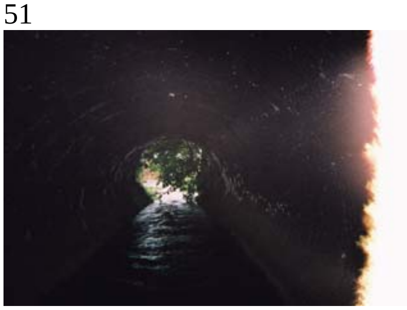
48

49

50

50 – opening 1 from upstream

50 – downstream opening

51

52

52 – levied banks downstream

53 – no photo


54

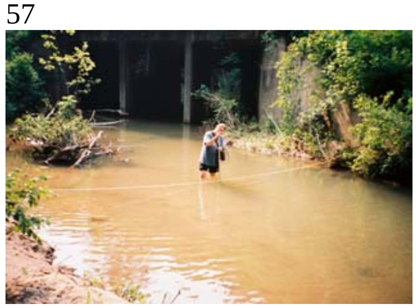
55

55 – under bridge

56

57

57

58

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