Condition of culverts and fish passage at road-stream crossings on the Sumter National Forest, SC, summer 2004

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Background

Fish movement in streams prevents population fragmentation (Winston et al. 1991), allows for population recovery following disturbance (Detenbeck et al. 1992, Roghair and Dolloff 2005), and provides access to critical spawning habitats (Fausch and Young 1995). Road-stream crossings such as culverts can impede or prevent fish movement in streams (Warren and Pardew 1998). In May 2004 the U. S. Forest Service Southern Region and San Dimas Technology and Development Center co-sponsored a workshop in Harrisonburg, VA to present methods available to assess impacts of road-stream crossings on aquatic organism passage in National Forest streams. The Southern Region recognizes that a full inventory and assessment of road-stream crossings is needed to ensure biological integrity, to prioritize crossings for replacement, repair, or removal, and to meet provisions set forth in legislation such as the Endangered Species Act, National Lands Management Act, and Clean Water Act. In August 2004 the Forest Service Southern Research Station, Center for Aquatic Technology Transfer (CATT) conducted culvert inventories in the Andrew Pickens Ranger District of the Sumter National Forest (SNF), SC. Our primary purpose was to determine the degree to which culverts on the SNF act as impediments or barriers to fish passage. We also provide a comparison of the methods used to collect and analyze fish passage information.

Sites

The SNF requested information on stream crossings at 17 sites. We only examined eight of the 17 sites; three additional sites were bridges and six were out of Forest Service jurisdiction on state and county roads. The streams in the survey were: King Creek crossing FS708, Crane Creek crossings FS710 and FS709, west fork of unnamed tributary to Crane Creek crossing FS709, Townes Creek crossing FS710, Moody Creek crossing FS733, unnamed tributary to Moody Creek crossing FS733, and Tamassee Creek crossing FS715A.

Methods

Culvert type, material, dimensions, condition, and diversion potential were recorded at each site according to the National Inventory and Assessment Procedure (NIAP) for road-stream crossings (Clarkin et al. 2003). A tripod and transit were used to take several elevation measurements along the stream channel both upstream and downstream of the culvert, including the inlet and outlet of the culvert. A cross-section of the tailwater of the culvert was also measured along with five measurements of bankfull channel widths downstream of the site (Figure 2).

We subjected our data to three coarse filters of stream and culvert attributes to determine passage status for adult trout (Figure 3), minnows (Figure 4), and juvenile trout, darters, and sculpins (Figure 5) (Coffman 2005). The coarse filters enabled us to quickly determine if a culvert was passable to fish if certain characteristics were present. Each filter categorized culverts as Green (passable to fish), Red (impassable to fish), or Grey (indeterminate). Fish sampling or more intense culvert models, such as FishXing are needed to determine passage status at culverts classified as Grey.

We modeled fish passage at all sites using FishXing software v. 2.2.0 (Love et al. 1999) to determine passage status at Grey sites and for comparison purposes at Green and Red sites. FishXing software uses published swimming abilities of fish, hydraulic models, and measurements of the culvert and stream channel to evaluate stream crossings for fish passage. Model output determines passage status at a range of discharges and provides information as to the type of barrier a culvert presents, such as leap, velocity, exhaustion, or depth barriers.

Both prolonged and burst swimming abilities are used in FishXing to model fish passage. The FishXing software reported a prolonged swimming speed of 1.4 ft/sec for adult brook trout, but did not report burst swimming speed for adults, or prolonged or burst swimming speed for juvenile brook trout. Where necessary, we substituted default data reported in FishXing for other salmonid species, including a burst swim speed value of 8.0 ft/sec reported for cutthroat trout, and 2.5 ft/sec prolonged speed and 5.0 ft/sec burst speed reported for juvenile rainbow trout. We modeled fish passage at each crossing using the values reported for adult brook trout (prolonged), adult cutthroat trout (burst), and juvenile rainbow trout (prolonged and burst). Sufficient swim speed data were not available to model passage for minnows, darters or sculpin in the FishXing software.

The highest reported swim speeds for any adult trout found during our literature review were 11.5 ft/sec prolonged and 26.4 ft/sec burst (adult rainbow trout 640 mm; Webb 1971). Trout of this size are not likely to occur in SNF streams, however we modeled fish passage in the FishXing software at each crossing using these highest reported swim speeds as a best-case scenario to determine if a culvert would be passable to a 'super-trout' exhibiting optimal swimming performance.

In addition to modeling fish passage, we assessed the potential impact of each road crossing by measuring the distance of perennial mainstem and tributary upstream of the crossing site. We measured total amount of each stream type with map wheels on USGS 1:24,000 quadrangles.

Results

The coarse filter models classified three of the eight culverts as passable to adult trout, one culvert as impassable, and four culverts as indeterminate. Two of the eight culverts were classified as passable to juvenile trout, darters and sculpins, five of the culverts as impassable, and one culvert as indeterminate. One of eight culverts was classified as passable to minnows, with the remainder impassable (Table 2).

FishXing models classified five of the eight culverts as passable to adult trout, and one culvert as passable to juvenile trout, all at discharges less than 10 cfs (Table 2). Sufficient swim speed data were not available to model darter, sculpin, and minnow passage using FishXing software.

King Creek (708 – 0.632)

The road crossing at King Creek consists of a concrete box culvert in good condition with no blockage and low overwash and diversion potential (Table 1). Coarse filter results were indeterminate for adult trout, impassable for minnows, and impassable for juvenile trout, darters, and sculpins (Table 2). FishXing results were passable for adult trout at discharges between 2.63 and 8.21 cfs, and impassable for juvenile trout at all discharges (Table 2). The culvert presents depth and velocity barriers to both adult and juvenile trout. The culvert is passable to a 'super-trout' at all discharges. There are 2.1 km of perennial mainstem and 0.8 km of perennial tributary upstream of the road crossing (Table 3).

Crane Creek (709 – 0.36)

The road crossing at Crane Creek consists of a circular annular CMP culvert in good condition with no blockage and low overwash and diversion potential (Table 1). Coarse filter results were indeterminate for adult trout, impassable for minnows, and impassable for juvenile trout, darters, and sculpins (Table 2). FishXing results were passable for adult trout at discharges between 1.30 and 2.38 cfs, and impassable for juvenile trout at all discharges (Table 2). The culvert presents velocity, leap, and outlet pool depth barriers to adult trout and velocity and leap barriers to juvenile trout. The culvert is passable to a 'super-trout' at discharges greater than 1.3 cfs. There are 1.8 km of perennial mainstem and 0.0 km of perennial tributary upstream of the road crossing (Table 3).

West Fork Tributary of Crane Creek (709 – 0.45)

The road crossing at the West Fork Tributary of Crane Creek consists of a circular annular CMP culvert in good condition with no blockage and low overwash and diversion potential (Table 1). Coarse filter results were indeterminate for adult trout, impassable for minnows, and indeterminate for juvenile trout, darters, and sculpins (Table 2). FishXing results were passable for adult trout at discharges between 1.00 and 4.55 cfs, and impassable for juvenile trout at all discharges (Table 2). The culvert presents velocity, leap, and outlet pool depth barriers to adult trout and velocity and leap barriers to juvenile trout. The culvert is passable to a 'super-trout' at all discharges. There are 1.3 km of perennial mainstem and 0.0 km of perennial tributary upstream of the road crossing (Table 3).

Crane Creek (710 – 3.17)

The road crossing at Crane Creek consists of a concrete box culvert in poor condition due to deteriorating concrete. There was no blockage and overwash and diversion potential are low (Table 1). Coarse filter results were passable for adult trout, impassable for minnows, and impassable for juvenile trout, darters, and sculpins (Table 2). FishXing results were impassable for adult trout at all discharges, and impassable for juvenile trout at all discharges (Table 2). The culvert presents depth, velocity, and leap barriers to adult trout and juvenile trout. The culvert is passable to a 'super-trout' at all discharges.

There are 3.2 km of perennial mainstem and 1.8 km of perennial tributary upstream of the road crossing (Table 3).

Townes Creek (710 – 3.34)

The road crossing at Townes Creek consists of a concrete box culvert in poor condition due to water undercutting the left upstream wingwall and flowing under the culvert. There was no blockage and overwash and diversion potential are low (Table 1). Coarse filter results were passable for adult trout, impassable for minnows, and passable for juvenile trout, darters, and sculpins (Table 2). FishXing results were passable for adult trout at discharges between 1.03 and 6.07 cfs, and impassable for juvenile trout at all discharges (Table 2). The culvert presents depth, velocity, and leap barriers to adult trout and juvenile trout. The culvert is passable to a 'super-trout' at all discharges. There are 3.7 km of perennial mainstem and 1.0 km of perennial tributary upstream of the road crossing (Table 3).

Tamassee Creek (715A – 0.66)

The road crossing at Tamassee Creek consists of an oval concrete culvert in poor condition due to a beaver dam backing water into the culvert. There was no blockage inside the culvert, but overwash and diversion potential are high and sediment from previous high water events is on the road (Table 1). Coarse filter results were passable for adult trout, passable for minnows, and passable for juvenile trout, darters, and sculpins (Table 2). FishXing results were passable for adult trout at all discharges, and passable for juvenile trout discharges less than 5.72 cfs (Table 2). The culvert presents no barriers to adult trout and velocity barriers to juvenile trout. The culvert is passable to a 'super-trout' at all discharges. High water caused by the beaver dam made accurate measurements difficult at this site. Model results may change if the culvert is inventoried again during when the beaver dam is removed and water levels are lower. There are 4.1 km of perennial mainstem and 2.6 km of perennial tributary upstream of the road crossing (Table 3).

Tributary of Moody Creek (733 – 0.60)

The road crossing at the tributary of Moody Creek consists of a circular concrete culvert in poor condition due to debris and sediment partially blocking the inlet to the culvert. Overwash and diversion potential are high due to this 50 percent blockage (Table 1). Coarse filter results were indeterminate for adult trout, impassable for minnows, and impassable for juvenile trout, darters, and sculpins (Table 2). FishXing results were passable for adult trout at discharges less than 1.00 cfs, and impassable for juvenile trout at all discharges (Table 2). The culvert presents velocity and leap barriers to adult trout and velocity barriers to juvenile trout. The culvert is passable to a 'super-trout' at discharges less than 127 cfs. There are 1.0 km of perennial mainstem and 0.0 km of perennial tributary upstream of the road crossing (Table 3).

Moody Creek (733 – 1.44)

The road crossing at Moody Creek consists of a circular annular CMP culvert in poor condition due to blockage with sediment and debris. Overwash and diversion potential are high due to the nearly complete blockage with sediment (Table 1). Coarse filter results were impassable for adult trout, impassable for minnows, and impassable for juvenile trout, darters, and sculpins (Table 2). We were unable to collect data needed to run the FishXing model because of the amount of sediment blocking the culvert. The upstream end was not visible and only the top of the downstream end was exposed. There are 0.5 km of perennial mainstem and 0.0 km of perennial tributary upstream of the road crossing (Table 3).

Discussion

The coarse filter provides a quick way of determining fish passage based on simple 'yes/no' responses to questions regarding characteristics of the culvert such as slope, outlet drop, length, and substrate. However, the filters are in the preliminary stages of development and values used to categorize culverts are subject to change as more information on fish swimming and leaping capabilities becomes available. The filters work well when culverts are clearly passable or impassable, but leave a large 'grey' area of uncertainty. These sites must undergo additional analysis in FishXing or biological sampling to determine passage status.

FishXing is capable of modeling fish passage at a range of stream discharges, recognizing that the hydraulic conditions within the channel and culvert can change dramatically with variation in discharge. Several additional measurements must be recorded at each culvert for input into FishXing software. The software has few default swim speed values for the primary species and swim speeds of most non-game species such as minnows are not available. The wide range of swim speeds reported for individual species or for species of similar body types tested in different manners highlights the difficulty in determining the 'true' swimming abilities of fish in a laboratory setting.

Although FishXing and the coarse filter classified culverts similarly in most cases, there were some notable differences. For example, the coarse filter classified two culverts as passable to juvenile trout, but FishXing classified one of these as impassable at all discharges. At the other crossing a beaver dam had backed water into the culvert making it difficult to accurately inventory. Removal of the beaver dam could change the results. Lack of swim speed data for minnow, darter and sculpin species commonly present in trout streams precluded comparison between FishXing and the coarse filter for these species. The coarse filter classified three sites as passable, and four sites as indeterminate, and one as impassable for adult trout. Analysis with the FishXing software classified all four of the indeterminate culverts as passable at a narrow range of discharges. Of the three culverts classified as passable by the coarse filter one was classified by FishXing as passable at all discharges, one was passable at a narrow range of discharges, and one was impassable at all discharges in the FishXing model. All of the culverts were passable to trout at optimal swimming performance ('super-trout'), but fish of this size and swimming ability (rainbow trout 640 mm or greater) do not occur in these streams. Clearly more information on the swimming ability of fishes is needed before we can reliably model fish passage capabilities. However, even with the limitations discussed above, there seems to be agreement among the models as to which culverts are impassable to juvenile trout.

An alternative to models is to use fish sampling to determine fish passage. Mark-recapture sampling designs can vary in complexity and effort depending on project goals (Coffman 2005, Warren and Pardew 1998) and provide direct evidence of fish passage without the numerous assumptions of fish passage models. To begin, a sample of fish downstream of a culvert site are marked and released. Marked fish captured upstream of the culvert during subsequent sampling indicate that the culvert is passable for that species and size/age class of fish. Such sampling can provide important information for biological evaluations at crossing sites and can generally be accomplished with little expense relative to the cost of stream crossing installation.

Since many of the culverts were considered either complete or partial barriers to fish passage at all or some flows, the SNF may consider repairing or replacing some of the structures to improve aquatic organism passage. Several factors must be considered when proposing such projects (Clarkin et al. 2003). First, lack of fish passage is not bad in all situations. Barriers to movement can provide protection to fish populations by keeping exotic species out (Thompson and Rahel 1998). This is especially true in the case of native brook trout streams with wild populations of introduced brown and rainbow trout (Larson and Moore 1985, Habera and Strange 1993). Second, the relative benefit of replacement must be considered. For example, several of the streams had more than 70% of their total perennial waters potentially blocked by impassable culverts, whereas others had much less (Table 3). In addition to the quantity of upstream habitat, the quality must also be considered. Some streams with relatively little habitat upstream of culverts may serve as important spawning areas or refuges during high water events. The quality of upstream habitat could be quantified with supplemental stream habitat or fish inventories.

The culvert inventories performed on the SNF in summer 2004 are the first step in determining the impacts of road crossings on aquatic organism passage in SNF streams. A full inventory of all stream crossings would provide the basis for meeting many provisions and policies set forth in legislation such as the Endangered Species Act, National Forest Management Act, and Clean Water Act. In addition it would provide the foundation for interdisciplinary discussion during project planning, such as prioritization of culvert replacements. We look forward to working with the SNF to meet their future stream crossing inventory goals.

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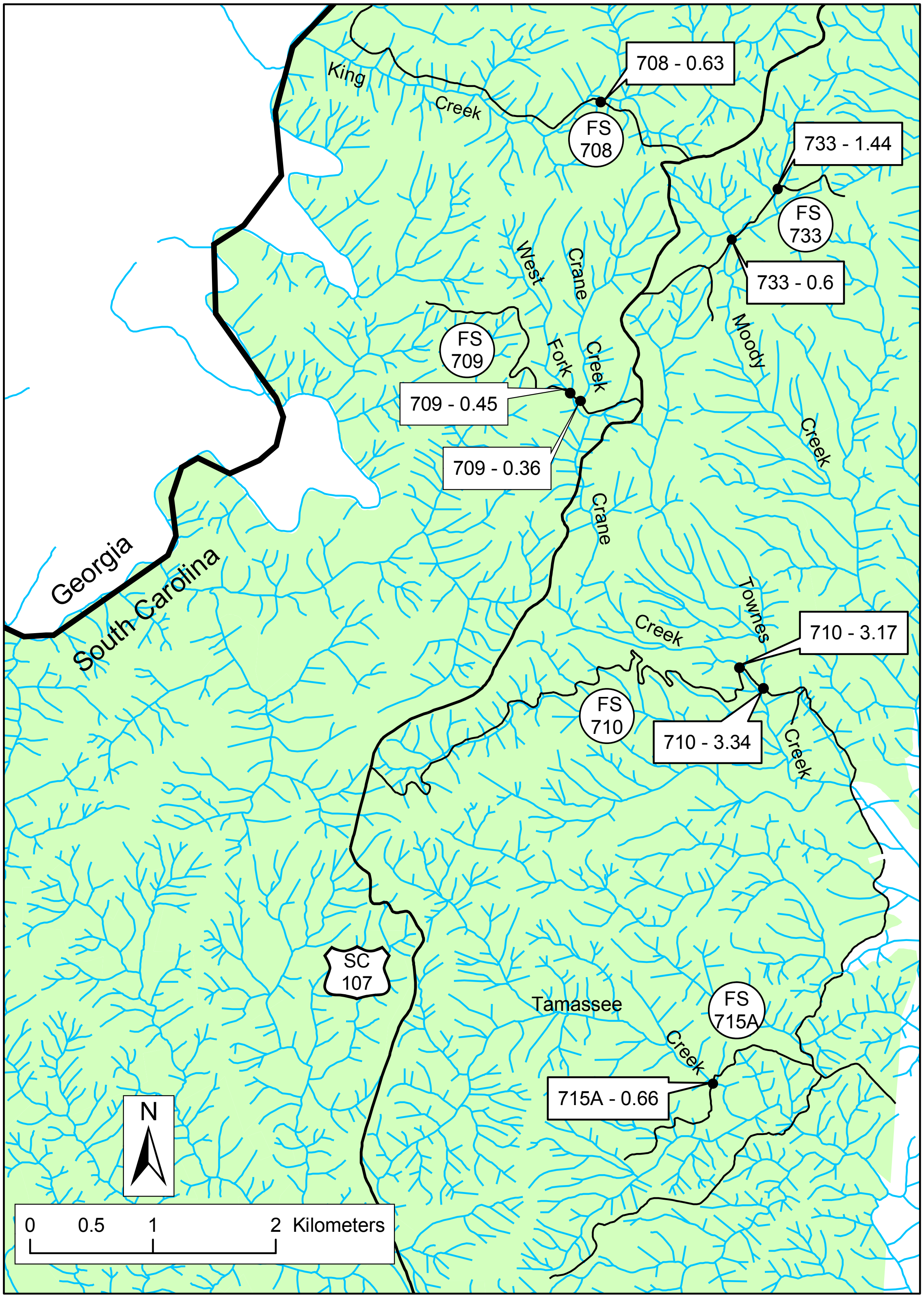

Figure 1. Location of culverts inventoried in the Sumter National Forest (shaded) during summer 2004.

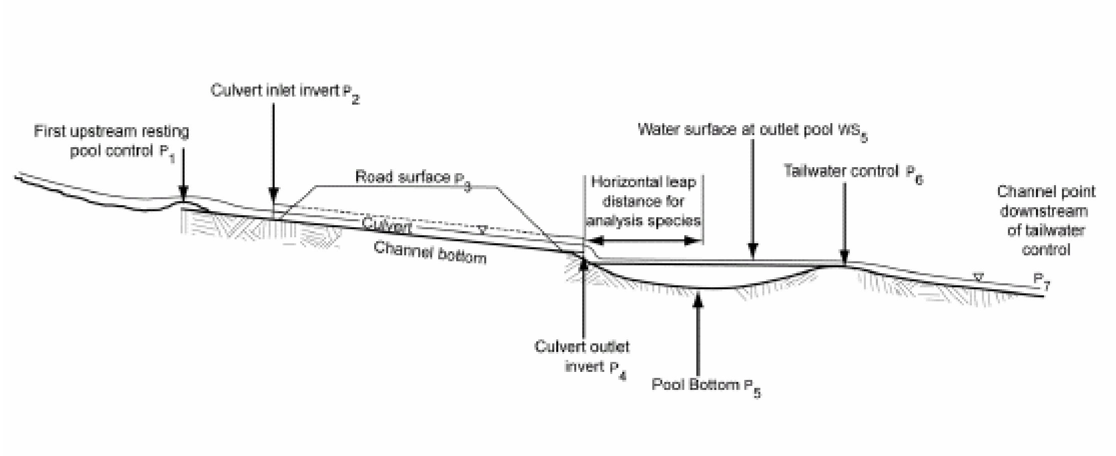

Figure 2. Location of measurements taken at each SNF culvert during summer 2004 (Clarkin et al. 2003). Tailwater cross-section measurements were taken at the tailwater control (P_6).

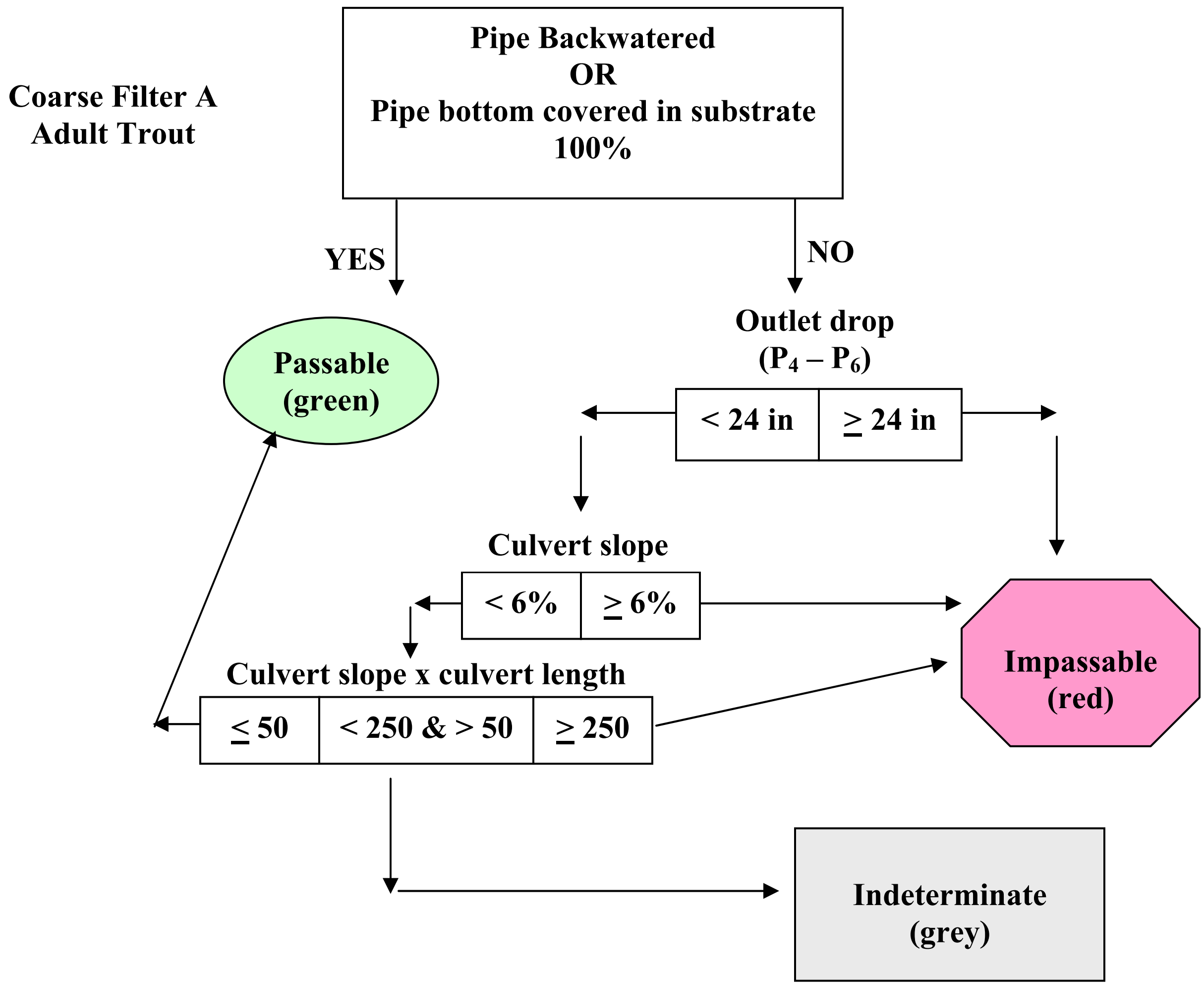

Figure 3. Coarse Filter A (Coffman 2005): Model used to determine passage status for adult trout.

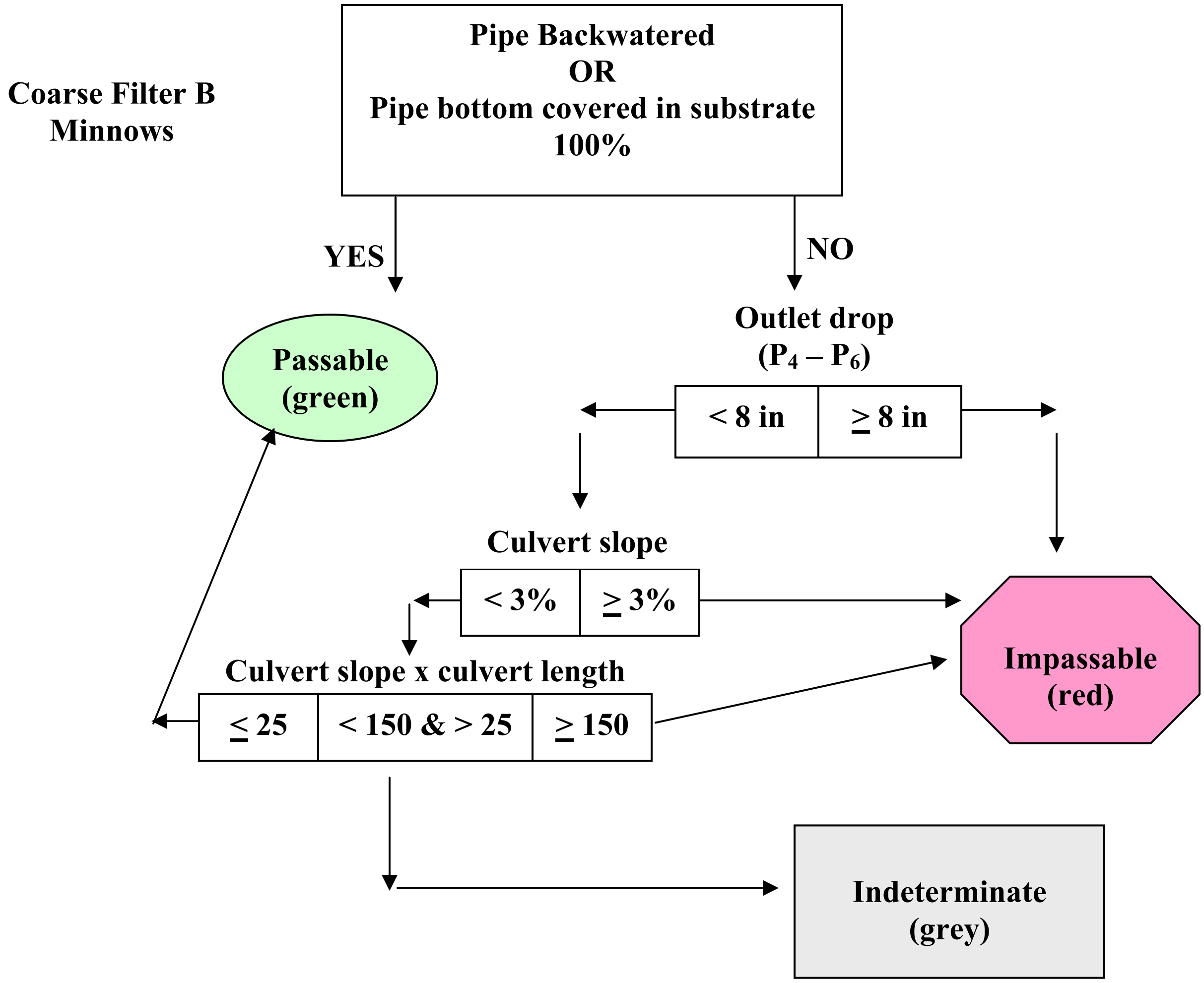

Figure 4. Coarse Filter B (Coffman 2005): Model used to determine passage status for Cyprinids (minnows).

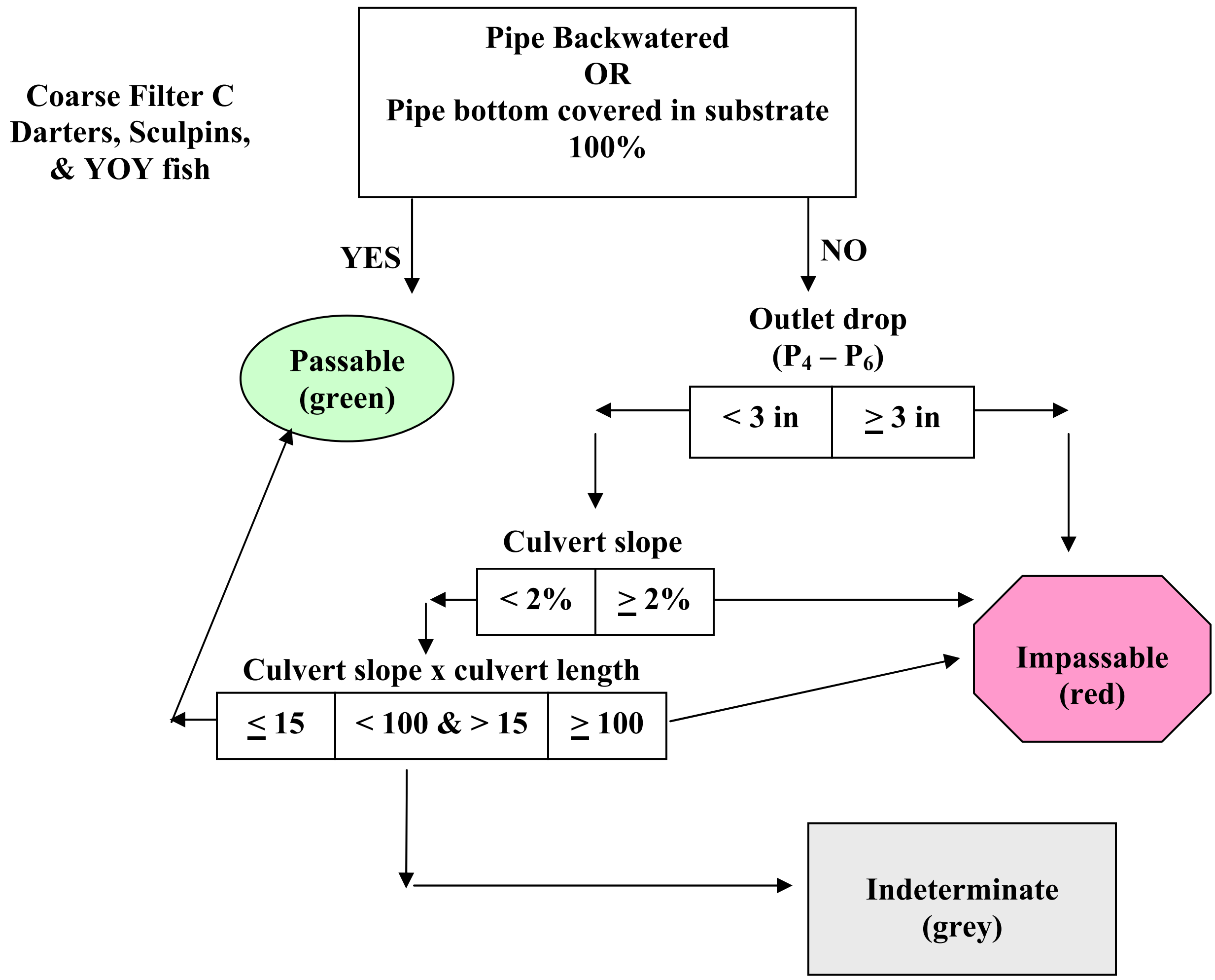

Figure 5. Coarse Filter C (Coffman 2005): Model used to determine passage status for young-of-the-year (YOY) fish (age-0).

Table 1. Description of culverts inventoried in SNF, summer 2004. Culverts were considered to be blocked if sediment, woody debris, or other materials closed culvert by 50% or more at any point. Overwash and diversion potential were considered high if evidence of previous overwash (sediment or debris deposits over road) was present or if inlets were blocked by sediment or other debris.

Crossing ID	**Stream**	**Material**	**General Condition**	**Inlet Blocked**	**Overwash Potential**	**Diversion Potential**
708 - 0.632	King Creek	Concrete Box	Good	No	Low	Low
709 - 0.36	Crane Creek	Annular CMP	Good	No	Low	Low
709 - 0.45	West Fork Tributary of Crane Creek	Annular CMP	Good	No	Low	Low
710 - 3.17	Crane Creek	Concrete Box	Poor	No	Low	Low
710 - 3.34	Townes Creek	Concrete Box	Poor	No	Low	Low
715A - 0.66	Tamassee Creek	Oval Concrete	Poor	No	High	High
733 - 0.60	Tributary of Moody Creek	Circular concrete	Poor	Yes	High	High
733 - 1.44	Moody Creek	Annular CMP	Poor	Yes	High	High

Table 2. Results for coarse filter and FishXing models. See Figures 3 - 5 for coarse filter descriptions. Filter A was developed for adult trout, filter B for minnows (Cyprinidae), and filter C for darters, sculpins, and age-0 fish; green = passable, red = impassable, grey = indeterminate. FishXing results presented as range of discharges (cfs) for which culvert was passable or impassable due to insufficient water depth, excessive water velocity, excessive leap into culvert, or insufficient outlet pool depth. FishXing model for adults based on prolonged swim speed for 150 mm adult brook trout and burst swim speed for 150 mm adult cutthroat trout. No swim speed data were available to model minnow passage. Model for juveniles based on prolonged and burst swim speeds for 50 mm age-0 rainbow trout. Model for ‘super-trout’ based on prolonged and burst swim speeds for 640 mm adult rainbow trout. Data were not collected at Moody Creek.

	Coarse Filter	**FishXing**	**FishXing Impassable (cfs)**			
		Passable (cfs)	**Depth**	**Velocity**	**Leap**	**Outlet pool depth**
King Creek						
FS708-0.632						
Adult	Filter A: indeterminate	2.63 - 8.21	<2.63	>8.21	None	None
Minnows	Filter B: impassable	--	--	--	--	--
Juvenile	Filter C: impassable	None	<2.63	All	None	None
Super trout	--	All	None	None	None	None
Crane Creek						
FS709-0.36						
Adult	Filter A: indeterminate	1.30 - 2.38	None	>2.38	<1.30	<0.55
Minnows	Filter B: impassable	--	--	--	--	--
Juvenile	Filter C: impassable	None	None	All	<1.30	None
Super trout	--	> 1.3	None	None	<1.3	None
W. Fork Crane Creek						
FS709-0.45						
Adult	Filter A: indeterminate	1.00 - 4.55	None	>4.55	4.55 - 15.49	<1.00
Minnows	Filter B: impassable	--	--	--	--	--
Juvenile	Filter C: indeterminate	None	None	>0.10	<15.49	None
Super trout	--	All	None	None	None	None
Crane Creek						
FS710-3.17						
Adult	Filter A: passable	None	<2.15	>110.33	<110.33	None
Minnows	Filter B: impassable	--	--	--	--	--
Juvenile	Filter C: impassable	None	<1.00	All	<110.33	None
Super trout	--	All	None	None	None	None

Table continued next page…

	Coarse Filter	FishXing Passable (cfs)	FishXing Impassable (cfs) Depth	Velocity	Leap	Outlet pool depth
Townes Creek FS710-3.34						
Adult	Filter A: passable	1.03 – 6.07	<1.03	>6.07	6.07 – 38.39	None
Minnows	Filter B: impassable	--	--	--	--	--
Juvenile	Filter C: passable	None	<1.00	All	<38.39	None
Super trout	--	All	None	None	None	None
Tamassee Creek* FS715A-0.66						
Adult trout	Filter A: passable	All	None	None	None	None
Minnows	Filter B: passable	--	--	--	--	--
Juvenile trout	Filter C: passable	<5.72	None	>5.72	None	None
Super trout	--	All	None	None	None	None
Moody Creek Tributary FS733-0.6						
Adult	Filter A: indeterminate	<1.00	None	>1.00	3.47 - 6.37	None
Minnows	Filter B: impassable	--	--	--	--	--
Juvenile	Filter C: impassable	None	None	>1.00	None	None
Super trout	--	<127.00	None	>127.00	None	None
Moody Creek FS733-1.44						
Adult	Filter A: impassable	--	--	--	--	--
Minnows	Filter B: impassable	--	--	--	--	--
Juvenile	Filter C: impassable	--	--	--	--	--
Super trout	--	--	--	--	--	--

* The culvert at Tamassee Creek was backwatered by a beaver dam making accurate measurements difficult. Results may change with removal of the dam.

Table 3. Location of culverts relative to total stream length for sites inventoried in SNF, summer 2004. Length = total perennial stream length of mainstem; Culvert location (km) = kilometers upstream from confluence; Upstream main (km) = kilometers of perennial mainstem upstream of culvert; Upstream main (%) = percent of perennial mainstem upstream of culvert; Upstream trib (km) = total kilometers of perennial tributary upstream of culvert location. Perennial stream distance determined from USGS 1:24,000 quadrangles.

Crossing ID	Stream	Length (km)	Culvert Location	Upstream Main (km)	Upstream Main (%)	Upstream Trib (km)
708 - 0.632	King Creek	5.0	2.8	2.1	42	0.8
709 - 0.36	Crane Creek	5.2	3.4	1.8	34	0.0
709 - 0.45	West Fork Trib of Crane Creek	1.4	0.1	1.3	99	0.0
710 - 3.17	Crane Creek	3.5	0.3	3.2	91	1.8
710 - 3.34	Townes Creek	5.2	1.5	3.7	71	1.0
715A - 0.66	Tamassee Creek	8.7	4.6	4.1	47	2.6
733 - 0.60	Tributary of Moody Creek	1.0	0.0	1.0	100	0.0
733 - 1.44	Moody Creek	3.2	2.7	0.5	16	0.0

Appendix A – Culvert photos


708-0.632, King Creek, outlet from downstream


709-0.36, Crane Creek, outlet from downstream


709-0.45, West Fork Crane Tributary, outlet from downstream


710-3.17, Crane Creek, outlet from downstream


710-3.34, Townes Creek, outlet from downstream


715A-0.66, Tamassee Creek, outlet from downstream

733-0.60, Tributary to Moody Creek, inlet from upstream

733-1.44, Moody Creek, inlet from upstream