Connecticut Department of
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Brook Trout Fish Passage Assessment and Monitoring Study
Culvert Sliplining Project, Tributary to Lyman Brook
Marlborough, CT

Final Report May 2020

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Project Need and Background

Many aging corrugated metal culverts that convey streams under major Connecticut highways require repair or replacement. In many cases, culverts are covered by significant amounts (greater than 20 ft) of earthen fill. Complete culvert removal can be expensive and present a multitude of construction and traffic issues since removal of culverts under large amounts of fill require large open trench cuts.

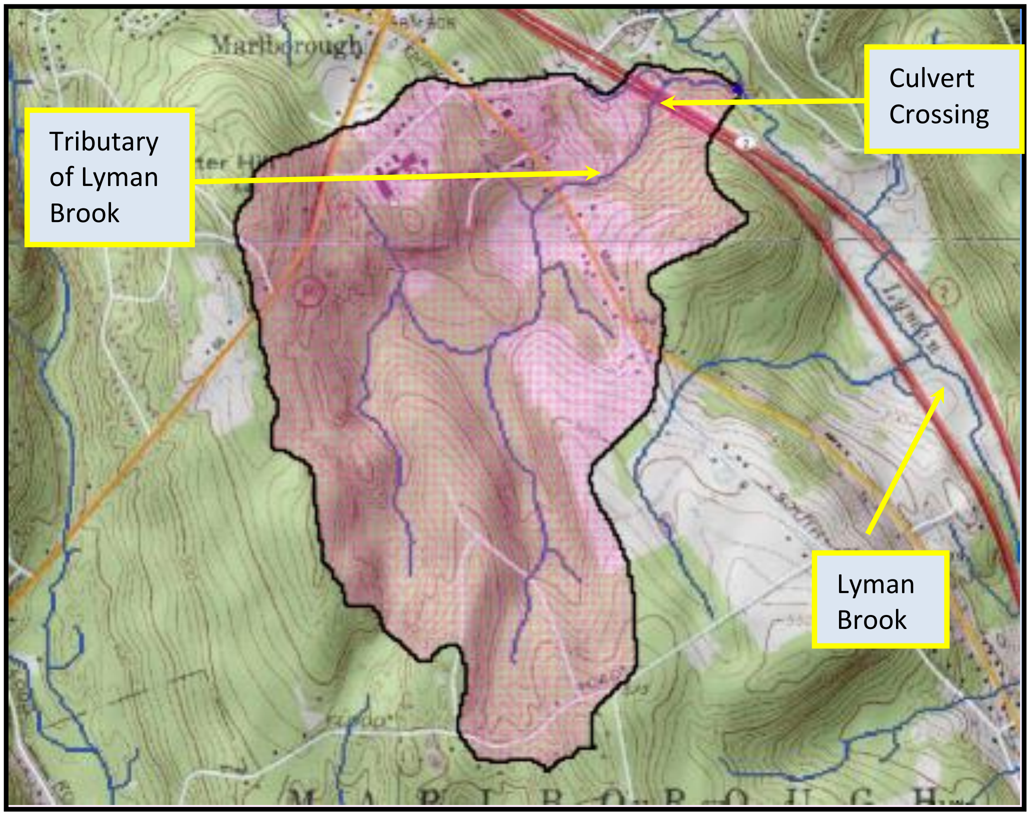
Often referred to as “baby- boomer” culverts since they have approached or exceeded their design lives (Webb 2009), these culverts are being rehabilitated with a method called “sliplining”. This technique involves placement of a smaller diameter culvert within the larger diameter failing culvert. The new sliplined culvert is subsequently stabilized with grout. In most cases, the invert elevation of the sliplined culvert is raised approximately 3-4 inches in height. Unfortunately, sliplining is typically not “fish-passage friendly”. Conditions such as perched outlets, shallow water depth or increased water velocities are exacerbated, making upstream fish passage challenging. A search of fish passage literature and consultation with other fishery agency biologists revealed a lack of institutional knowledge and limited experience with modifying sliplined culverts to provide upstream fish passage.

The Fisheries Division (FD) was first presented with a list of projects in 2008 proposed for sliplining by the Connecticut Department of Transportation (CTDOT) entitled “List 21”. Given their location on major highways, total culvert replacement alternatives were not feasible. Thus, FD and CTDOT staff were challenged to solve fish passage issues at several proposed slipline projects.

Once such rehabilitation sliplining project involved replacement of twin 72 inch corrugated metal culverts that convey a tributary of Lyman Brook under Route 2 in Marlborough, CT (Figure 1). This infrastructure blocks and fragments the wild Brook Trout population in the stretch of stream above the culvert due to the presence of an outlet perch exceeding 1.5 ft in height (Figure 2). CTDOT proposed to slipline these failing culverts with 60 inch diameter polymer coated round metal culverts.

The FD proposed design modifications to provide upstream fish passage, including the installation of a corner baffle system in one culvert and the installation of a concrete pool/weir fishway at the outlet. In addition, the two agencies signed a Memorandum of Agreement (MOA) to evaluate the effectiveness of project design features and assess the ability for wild Brook Trout (*Salvelinus fontinalis*) to pass through this infrastructure by conducting a remote monitoring fish passage study utilizing passive integrated transponder (PIT) methodology. The MOA required the CTDOT to purchase the PIT study equipment and the FD to conduct the study over a three year period. This final report outlines the design features of this culvert rehabilitation project and results of the three-year fish passage monitoring and assessment study, 2016-2018.

Figure 1. Topographic map of study area, Tributary to Lyman Brook, Marlborough, CT.



Project Engineering and Design

The twin 72 inch corrugated metal culverts were 262 feet in length and set at a 4.5% slope. Culverts were sliplined with 60 inch diameter polymer coated round corrugated metal culverts. The smaller diameter pipes were required due to pipe deformities. The existing culvert invert elevations were raised approximately three inches. A complete summary of project design metrics can be found in Appendix A. A complete set of the engineered plans is included in Appendix B.

The concrete pool/weir fishway constructed at the east culvert outlet was comprised of 6 pools/weirs designed with a four inch drop in elevation per pool (Figure 3, Appendix B). Weirs included notches (2 ft x 1 ft) with slots to accept weirboards to allow flexibility in manipulation of water levels in the pools. Fishway Pool #6 created a minimum four inch backwater into the culvert. A fish diversion wall was constructed at the west culvert outlet to help guide fish into the fishway. The west culvert outlet included a riprap scour hole to dissipate outlet energy during flooding. A boulder weir was installed to create a holding pool (mean water depth of 2.5 ft) to facilitate fish passage into Fishway Entrance-Pool #1. Change in water surface elevation between the holding pool and Fishway Entrance #1 weir varied with discharge; however, the difference in maximum water surface elevation during low flows was approximately four inches. The east culvert was retrofitted with a corner baffle system (Figure 4, Appendix B).

Figure 2. Photograph of culvert outlet depicting perched conditions and physical barrier to upstream fish passage.

Studies have shown that angled baffles provide regions of lower velocity and adequate water depths which are key features of flow diversity necessary for passage (Thurman and Horner-Devine 2007). The baffle angled at 4 degrees from horizontal ranged from 0.5 to 1.04 ft in height. Spacing between baffles was 5 ft. Mean daily flows were directed into the inlet of the baffled east culvert via a low flow diversion wall installed at the west culvert inlet (Figure 6). Flood flows were conveyed into both culverts.

Figure 3. Upstream view of concrete pool and weir fishway, diversion wall and boulder weir holding pool.

A custom deflect and collect trash rack system was constructed at the inlet to minimize debris accumulation in the baffled culvert (Figure 5, Appendix B). The primary trash rack was designed to collect and deflect large wood whereas the secondary trash rack comprised of 2 inch diameter rebar functioned to collect small brush, branches and other smaller size debris (Figure 6). This custom system was constructed to ensure minimal debris accumulation within the baffled culvert, minimizing seasonal maintenance. Culverts of this diameter are defined as confined space and require special training to enter.

Figure 4. Upstream view of corner baffle system at moderate stream discharge.

Figure 5. View of primary inlet trashrack and collection of woody debris after storm event.

Figure 6. View of secondary rebar trashrack and concrete diversion wall at inlet.

Estimated Design Hydraulic Conditions

CTDOT engineering staff conducted a HEC-RAS hydraulic modelling analysis to predict and estimate water depth and water velocity metrics within the baffled culvert and the pool-weir fishway during seasonal bioperiods (Appendix B; Table 1). These data were compared to target swim speed and water depth criteria for Brook Trout. Based upon a review of fisheries literature and the Fishing Xing Software Program, fish passage design target parameters were defined as: prolonged swim speed of 1.3 ft/s, burst swim speed of 3.1 ft/s and minimum water depth of 0.5 ft (Fish Xing 2014).

These hydraulic data summarized in Table 1 provided some confidence that the design's estimated water depth and water velocity were mostly within range of acceptable target criteria limits and that fish passage needs were likely to be provided. The only exception was average water depth which was lower than the minimum depth of 0.5 ft. It should be noted that the estimated mean water depth of 0.4 ft in the upstream channel was lower than the target level. It is not necessary for the culvert/fishway to be passable year-round but it is most important to provide passable conditions when fish are motivated to move upstream during spawning. Inherent to survival, Brook Trout will have to take advantage of periodic higher stream flow events that provide fish with an opportunity to access spawning habitats that perhaps may not always be accessible during typical low flow conditions at the end of summer/early fall.

Table 1. Hydraulic analysis summary of estimated fish passage metrics by bioperiod.*

	BIOPERIODS			
Hydraulic Conditions	**Habitat Forming** (March-April Q50) 4.0 CFS	**Resident Spawning** (June Q75) 0.4 CFS	**Rearing and Growth** (July-October Q75) 0.1 CFS	**Salmonid Spawning** (November Q75) 0.5 CFS
Over Culvert Baffles				
Maximum Depth (ft.)	0.8	0.3	0.2	0.4
Mean Depth (ft.)	0.5	0.2	0.1	0.2
Mean Velocity (ft/s)	1.9	1.0	0.8	1.1
Between Culvert Baffles				
Mean Depth (ft.)	1.2	0.7	0.5	0.7
Mean Velocity (ft/s)	1.1	0.3	0.1	0.3
Over Fishway Weir Notch				
Maximum Depth (ft.)	0.8	0.2	0.1	0.2
Mean Depth (ft.)	0.8	0.2	0.1	0.2
Mean Velocity (ft/s)	2.4	1.1	0.7	1.2
Upstream Channel				
Mean Depth (ft.)	0.8	0.5	0.4	0.5
Mean Velocity (ft/s)	1.8	0.6	0.4	0.7

**Design parameters: prolonged swim speed of 1.3 ft/s, burst swim speed of 3.1 ft/s and minimum water depth of 0.5 ft.*

Fish Passage Monitoring and Assessment

Objectives

1. Evaluate fish passage performance within the modified baffled culvert and pool/weir fishway through passive integrated transponder (PIT) tag monitoring over a three year period (2016-2018).

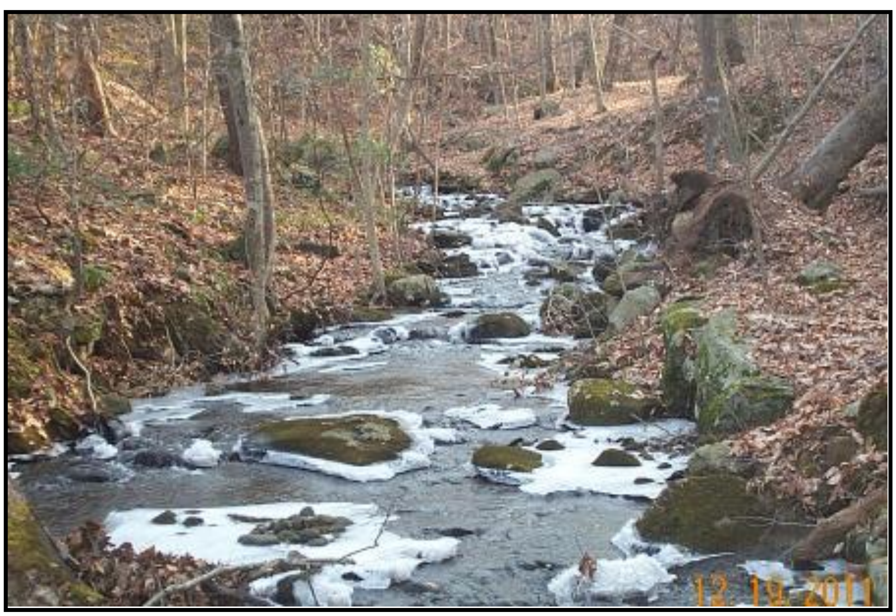
2. Utilize study findings to facilitate fish passage design for future culvert sliplining or other culvert rehabilitation projects that require infrastructure modifications to achieve upstream fish passage.

Study Area Characteristics

The linear length of the Tributary to Lyman Brook from its confluence upstream to its headwaters is approximately 1.12 miles (Figure 1). Length of stream from the confluence up to the Route 2 culvert outlets that block upstream fish passage is only 0.17 miles; thus, these culverts impact connectivity to much of the upper portion of the watershed. Watershed size of the Tributary to Lyman Brook was calculated as 0.94 mi^2 (Connecticut Stream Stats 2014). Approximately 5.3% of the watershed is comprised of coarse-grained stratified drift. The stream grade from its confluence upstream to the culvert outlet is relatively moderate at 2%. Mesohabitats are comprised of alternating riffle/run/pool features (Figure 7). Gravel/cobble substrates are dominant with lesser amounts of smaller boulders. The stream grade above the culvert is much steeper at 6.5% with large boulder step-pools being the dominant mesohabitat feature (Figure 8). Gravel/cobble substrates are less prevalent than within downstream areas. Step-pool tailwaters provide favorable Brook Trout spawning habitat.

Figure 7. Example of low-moderate grade mesohabitats below culverts.

Figure 8. Example of steep grade large boulder step pool mesohabitats above culverts.



Methods

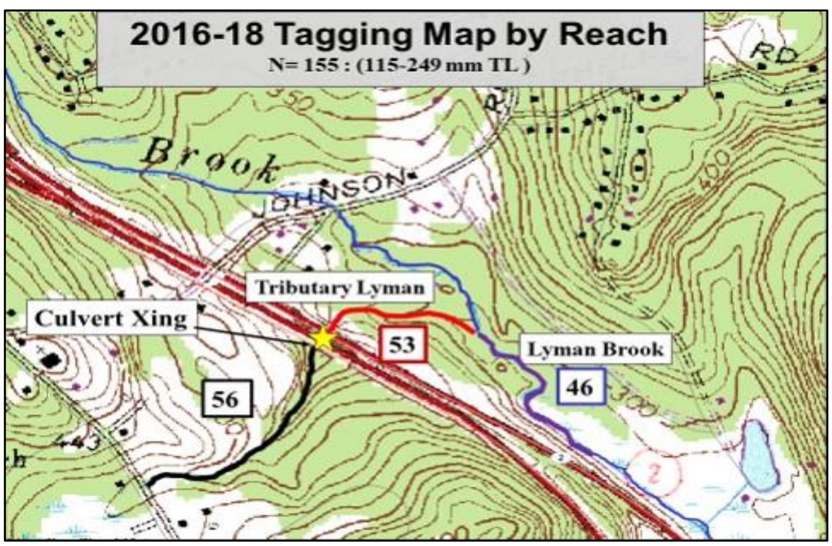
Study Time Period

Brook Trout movement and activity in small streams are known to be greatest in the fall associated with the onset of spawning and the presence of colder water temperatures (Mollenhauer et al. 2013; Goerig et. al. 2016). The PIT tag monitoring study period included the period from mid-September through early November to encompass movements and behavior through pre-, during and post-fish spawning life stages. The study encompassed three consecutive annual spawning periods from 2016 to 2018.

Fish Collection and Tagging

Brook Trout were collected using Smith-Root LR-24 backpack electrofishing gear each year in late June. After capture, fish were measured to the nearest millimeter (total length) and tagged via the peritoneal cavity with Half Duplex System (HDX) PIT tags, 12 mm length x 2 mm diameter and weight of 0.1 gram. Fish were tagged and returned in place to the stretch of brook in which they were collected (Figure 9). Three reaches were sampled as follows: mainstem Lyman Brook below confluence of Tributary to Lyman Brook (purple line), Tributary of Lyman Brook from confluence upstream to culvert outlet (red line) and Tributary of Lyman Brook above the culverts (black line). During the study period, 155 fish were tagged that ranged from 115-249 mm in total length with a mean length of 165 mm TL.

Figure 9. Total number of Brook Trout tagged by reach from 2016-18.



PIT System Antenna Setup

A (HDX) system utilizing Oregon RFID components was deployed powered by a 12 volt deep cycle marine battery. Freshly charged batteries were switched off approximately every 1.5 days. The HDX system reader energizes an antenna array and creates an electromagnetic field that causes the PIT tag to discharge a radio signal carrying the unique identification number of the tag to the antenna. When a PIT tagged fish is detected by an antenna, the date, time, fish identification number and antenna number is recorded by the reader and data logger. Typically, data from the readers were uploaded to a laptop computer at the time when batteries were switched. Attempts to set up a solar charged system were unsuccessful at the site due to: (1)

extreme noise interference generated by the solar panel controller that significantly decreased the tag detection field and, (2) lack of open and secure areas to sufficiently charge the panels.

Specific antenna locations were as follows: (A) fishway entrance: pool-weir #1, (B) culvert entrance headwall, (C) culvert inlet headwall and (D) approximately 15 meters upstream from inlet headwall.

While the use of remote PIT tag detection monitored tagged fish passively, it was also the intent of the study to conduct periodic mobile searches using a portable backpack reader to identify locations of tagged fish within the mainstem and the Tributary of Lyman Brook. Mobile searches were not conducted in 2018 due to equipment malfunction.

RESULTS AND DISCUSSION

2016 Monitoring: Culvert Movements

During 2016 the first year of monitoring, we tagged 61 Brook Trout in the study area. There were 40 movements documented through the culvert. This included 22 separate upstream movements and 18 downstream movements involving nine fish (Figure 10, Table 2). Of note, Fish #336 was extremely active making a total of 18 combined upstream/downstream movements. This behavior resulted in 45% of all observed culvert movements in 2016.

The State of Connecticut was declared to be in a D4 exceptional drought from June 21, 2016 through May 2, 2017 (CTGOV 2017). Given that the frequency of movements appeared to be coincident with rain events, we decided to plot 2016 movements versus the Salmon River USGS gage 01193500 located in East Hampton, CT to determine general movement trends (Figure 10). Our first documented movement (Fish #336) occurred 9 days into monitoring September 27 after a 0.5 inch rain event. A 0.5 inch rain event results in a significant increase in discharge and availability of useable habitat in this second order stream. Brook Trout movement through culverts tend to occur more frequently at higher discharges (Goerig and T. Castro-Santos 2016). Mollenhauer et al. 2013 also documented increased activity and large upstream movements for wild Brook Trout during a high flow event in central Pennsylvania headwater streams. Subsequent movements in 2016 also appeared to be correlated with rain events and increased discharge. In general, most movement activity occurred from late September to mid-October when fish are seeking suitable spawning habitats.

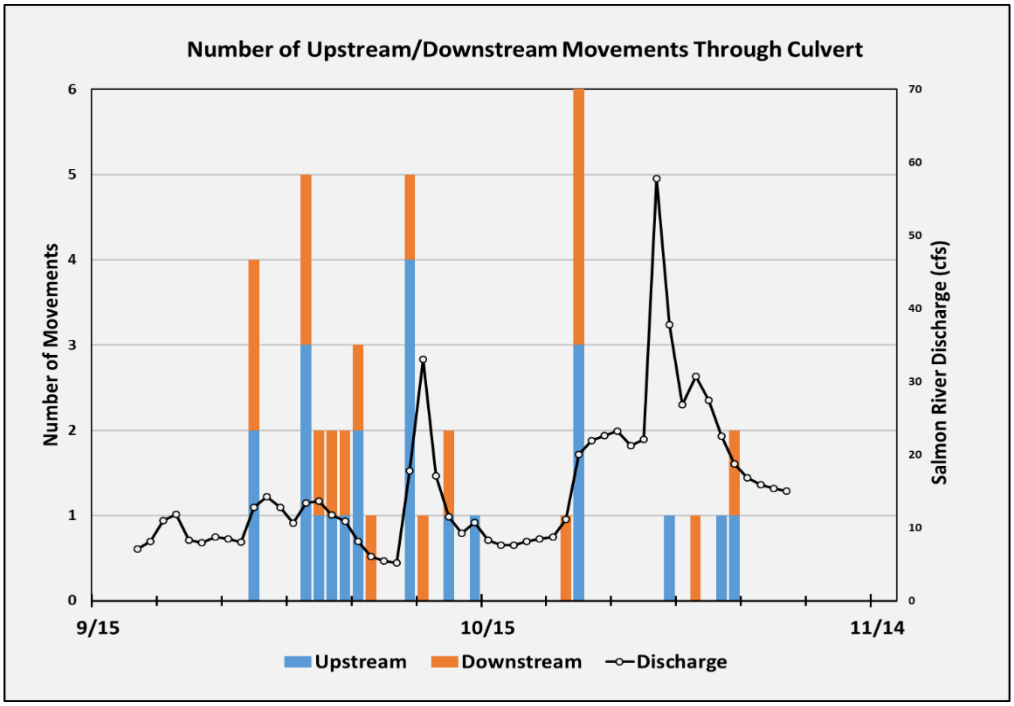
Transit Times

Transit Time or net total time (expressed as hours:minutes) for fish to travel upstream or downstream through the baffled culvert was determined by calculating the difference in detection times recorded at both the outlet and inlet antennas (Table 2, Figure 11). For example, upstream movement transit time is the time between the last detection at the outlet antenna and first detection at the inlet antenna.

Table 2. Summary of upstream and downstream metrics through the baffled culvert during study years 2016-18.

Study Year	Fish ID #	Length (mm)	Upstream Passage Date	Upstream Transit Duration (Hours:Minutes)	Downstream Passage Date	Downstream Transit Duration (Hours:Minutes)
2016	302	186	10/9/2016	1:06	10/21/2016	1:47
	328	161	11/2/2016	1:28	11/3/2016	3:13
	330	137	10/14/2016	1:03		
	333	145	9/27/2016	1:25	9/27/2016	6:24
			10/01/2016	1:57		
	336	171	9/27/2016	1:21	9/27/2016	9:04
			10/1/2016	0:46	10/1/2016	0:57
			10/2/2016	1:39	10/2/2016	0:47
			10/3/2016	1:23	10/3/2016	0:29
			10/4/2016	2:36	10/4/2016	0:42
			10/5/2016	1:00	10/6/2016	0:20
			10/9/2016	4:11	10/10/2016	4:12
			10/12/2016	7:55	10/12/2016	0:45
			10/22/2016	0:26	10/22/2016	0:13
	337	175	10/1/2016	1:04	10/1/2016	0:15
			10/5/2016	1:10	10/5/2016	0:22
			10/9/2016	0:38		
	351	137	11/3/2016	5:25		
	373	145	10/22/2016	0:35	10/22/2016	0:21
	376	166	10/9/2016	3:44	10/9/2016	1:25
			10/22/2016	3:42	10/22/2016	0:58
			10/29/2016	15:40	10/31/2016	0:34
2017	302	226	9/7/2017	3:03	9/7/2017	11:44
			10/24/2017	0:40	10/24/2017	0:20
			10/24/2017	0:45	10/25/2017	0:06
	346	187	9/6/2017	1:03		
	484	208			10/25/2017	0:09
	486	145	10/8/2017	2:39	10/8/2017	0:16
			10/24/2017	0:38	10/24/2017	0:09
2018	544	153	9/25/2018	2:01	9/25/2018	30:14
			9/28/2018	1:51	9/28/2018	0:19
			10/10/2018	0:26	10/11/2018	0:53
			10/13/2018	0:25	10/13/2018	1:53
			10/17/2018	2:27	10/24/2018	0:50
			10/24/2018	0:33		
	556	146			9/25/2018	0:19
	561	181	11/6/2018	4:41	11/9/2018	4:18
	586	155	10/12/2018	2:25		

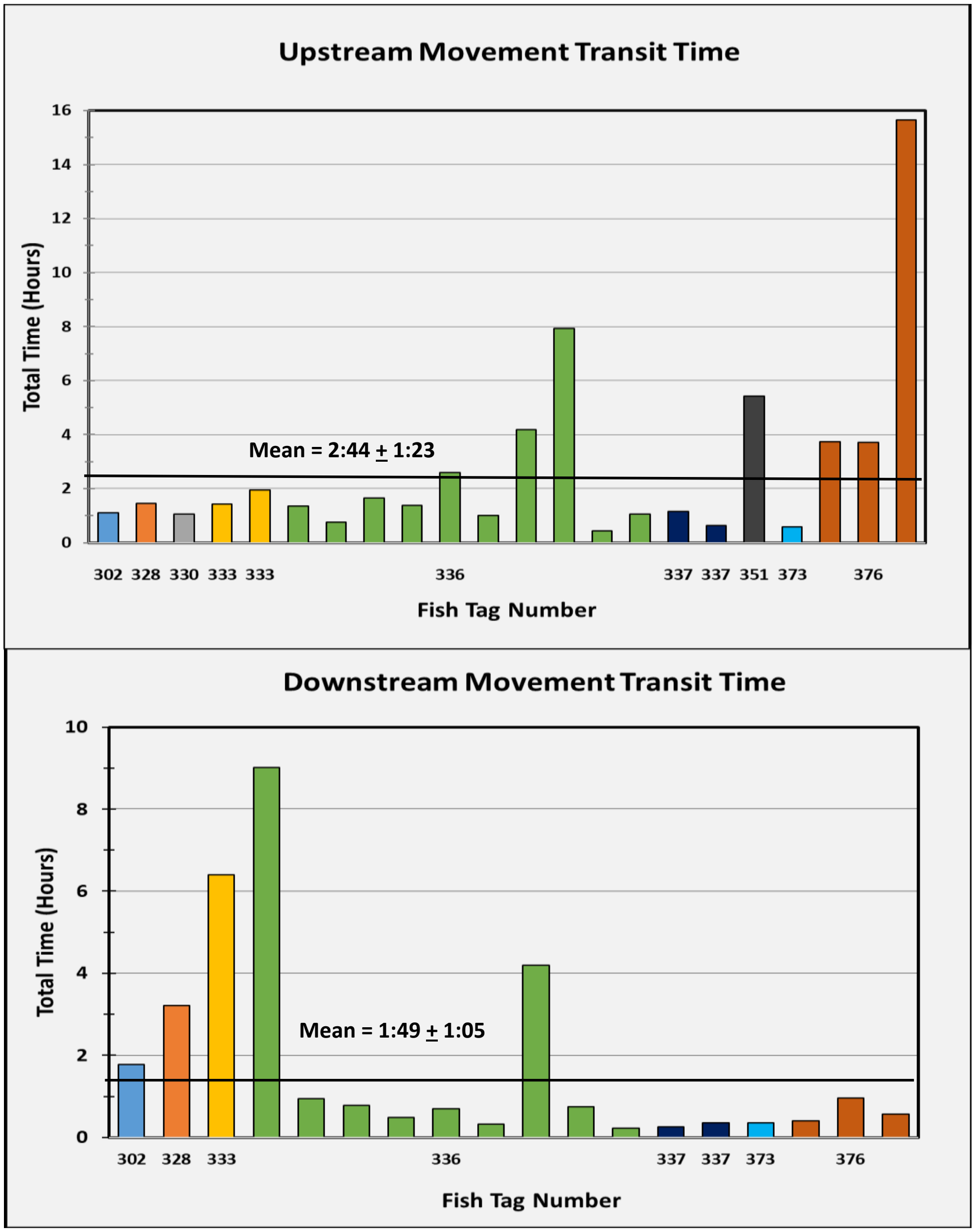
Figure 10. Total number of upstream and downstream movements through the culvert versus Salmon River discharge at USGS gage in 2016.



In 2016, the majority (68%) of upstream movements occurred within a two hour timeframe. The mean transit time of upstream movements was 2:44 ± 1:23 (Figure 11). The minimum and maximum transit times were 0:26 and 15:40, respectively, indicating a wide range in movement time extremes. While Fish #376 spent 15:40 to move upstream, this event occurred during a one inch rain event October 28 and 29, 2016 when Salmon River discharge reached 57 cfs. Corner baffles are known to create varying velocity refugia, including eddies in which fish encounter more favorable hydraulic conditions to rest and reduce sustained swimming speeds (Thurman and Horner-Devine 2007).

Conversely in 2016, the majority (67%) of downstream movements occurred within a one hour timeframe. The mean transit time of downstream movements was 1:49 ± 1:05 (Figure 11). The minimum and maximum transit times were 0:13 and 9:04, respectively again indicating a wide range in movement time extremes. These ranges in movement were exhibited by Fish #336. The reduced mean downstream movement transit time as compared to upstream by approximately one hour appears to be somewhat intuitive since fish are moving downstream with streamflow as opposed to moving upstream against flow.

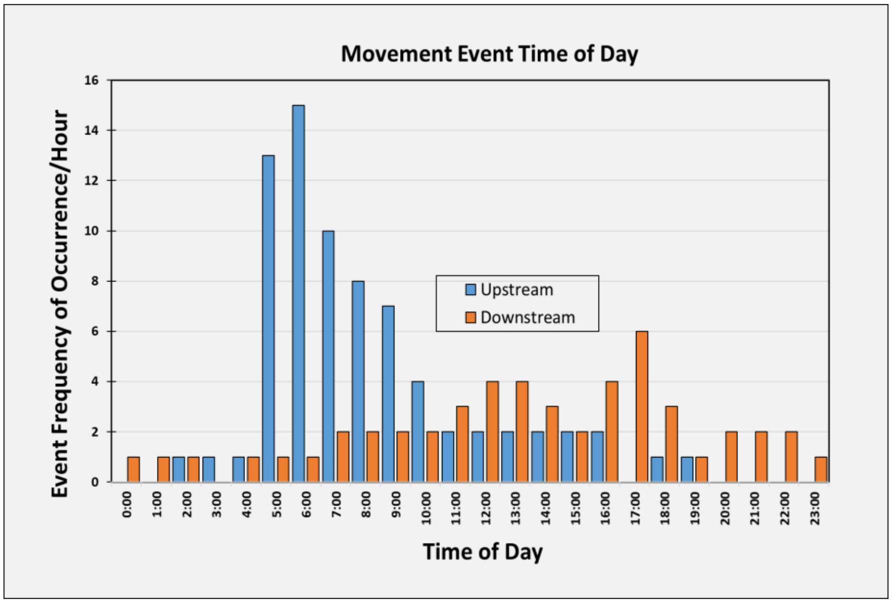
Figure 11. Transit time or net total time (expressed as hours:minutes) for fish to travel upstream or downstream through the culvert during 2016.



Movement Time of Day

While movements through the culvert occurred throughout the day, Brook Trout were less active after sunset and during the overnight hours (Figure 12). Activity increased in twilight hours when the most frequent upstream movements were observed in the early morning during the 5:00 through 10:00 timeframe. Patterns of increased activity for downstream movements were not as pronounced with the frequency of movement events occurring over a longer period from 11:00 to 18:00.

Figure 12. Movement event frequency of occurrence by time of day in 2016.



Fishway Only Residency

Fish #341 was found throughout the entire 2016 study season to inhabit either the fishway or outlet pool. A spawning redd was observed with the outlet pool the weekend of October 25, 2016. It is suspected that this fish had spawned in the outlet pool (Figure 13). This was the only fish that had spent residence time in the fishway but did not move upstream through the culvert.

Figure 13. Spawning redd discovered within fishway outlet pool.

2017 Monitoring: Culvert Movements

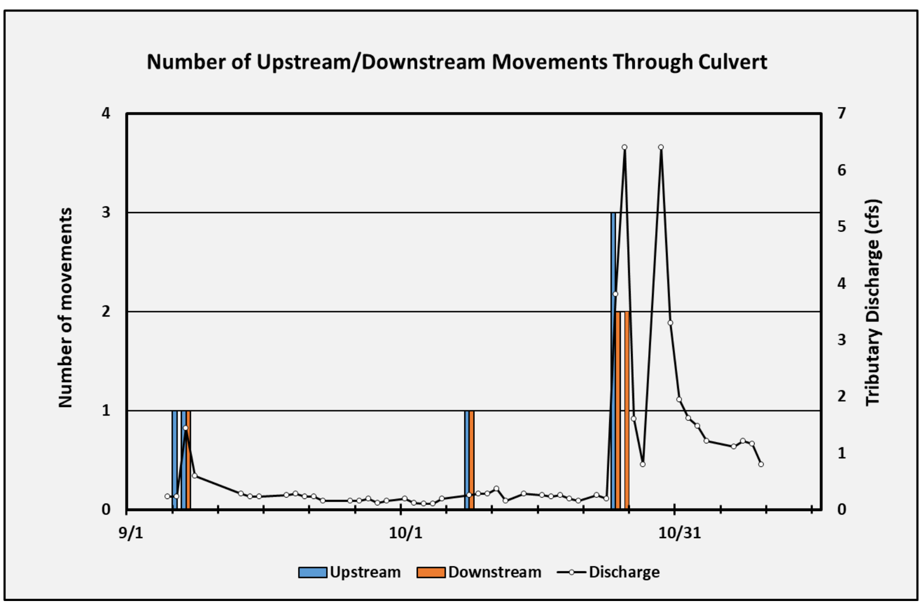
During 2017 the second year of monitoring, we tagged 33 Brook Trout in the study area. In addition, eight fish tagged in 2016 were recaptured. We documented 12 movements through the culvert, fewer than observed during the 2016 monitoring season. This included six separate upstream movements and six downstream movements involving four fish. (Figure 14, Table 2).

Two (Fish #302 and Fish #346) of the four fish recorded moving upstream through the culvert were tagged in 2016. Of interest, Fish #346 was originally tagged in the stretch of stream above the culverts. The fact that this fish moved upstream through the culvert on September 6, 2017 indicated that the fish had previously moved downstream through the culvert sometime outside the annual September-November monitoring period. Also of note, Fish #333 which had been originally tagged in the mainstem of Lyman Brook below the Tributary to Lyman Brook confluence was recaptured upstream above the culvert in 2017, indicating a net movement through the culvert outside our monitoring period. These movements support the conclusion that Brook Trout can readily access habitats within this stream system network after the installation of the baffled culvert and fishway.

In 2017, we recorded water levels through the Fishway Weir #6 rectangular notch and developed a weir and discharge relationship using the Kindsvater-Carter formula (Kindsvater and Carter 1959). As such, we obtained daily onsite discharge measurements during the time of day when batteries were switched. We also verified the accuracy of weir/discharge measurements by conducting several random streamflow measurements using a Marsh McBirney flow meter and the USGS mid-section method (Buchanan and Somers 1969).

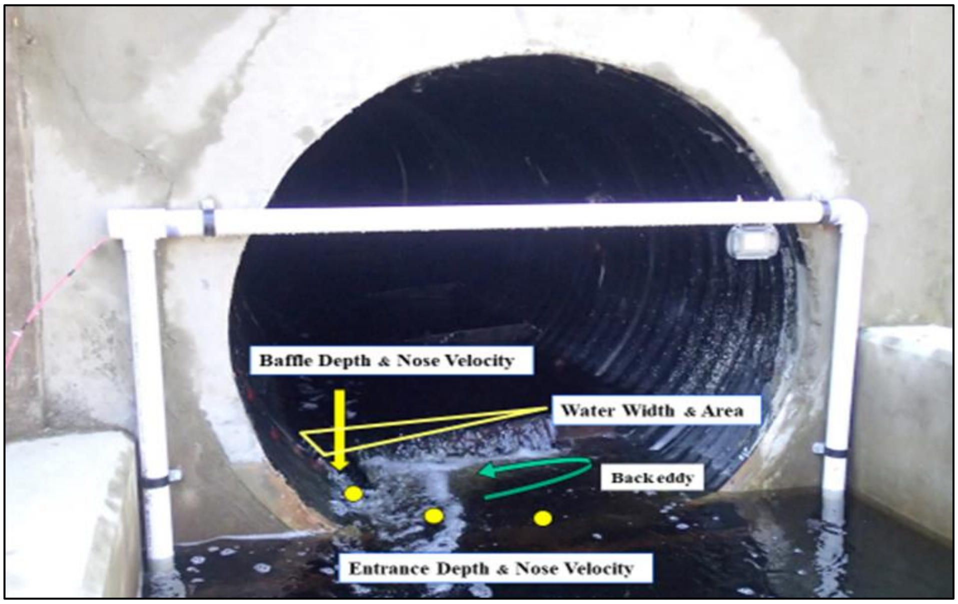
While the State of Connecticut was no longer in a declared drought during the 2017 monitoring season, rainfall events were fairly limited in number. Streamflow during the season was generally less than 0.3 cfs (Figure 14). Movement occurrence still appeared to be associated with increases in discharge, all except the movement of Fish #486, which made a relatively quick upstream and subsequent downstream movement through the culvert on October 8, 2017 (Figure 14).

Figure 14. Total number of upstream and downstream movements through the culvert versus Unnamed Tributary to Lyman Brook Discharge in 2017.



Fish Movement and Culvert Hydraulic Conditions
In addition to developing a weir/discharge relationship at the fishway, we began to measure water velocity and water depth metrics during a wide range of discharge events to develop predictive relationships between discharge and correspondent hydraulic metrics. Measurements were recorded at the following locations: Fishway Weir #6, culvert entrance and the 1st upstream corner baffle (Figure 15). The goal of this data collection was to help define hydraulic conditions during fish passage events. Results of these hydraulic relationships are presented in Appendix C.

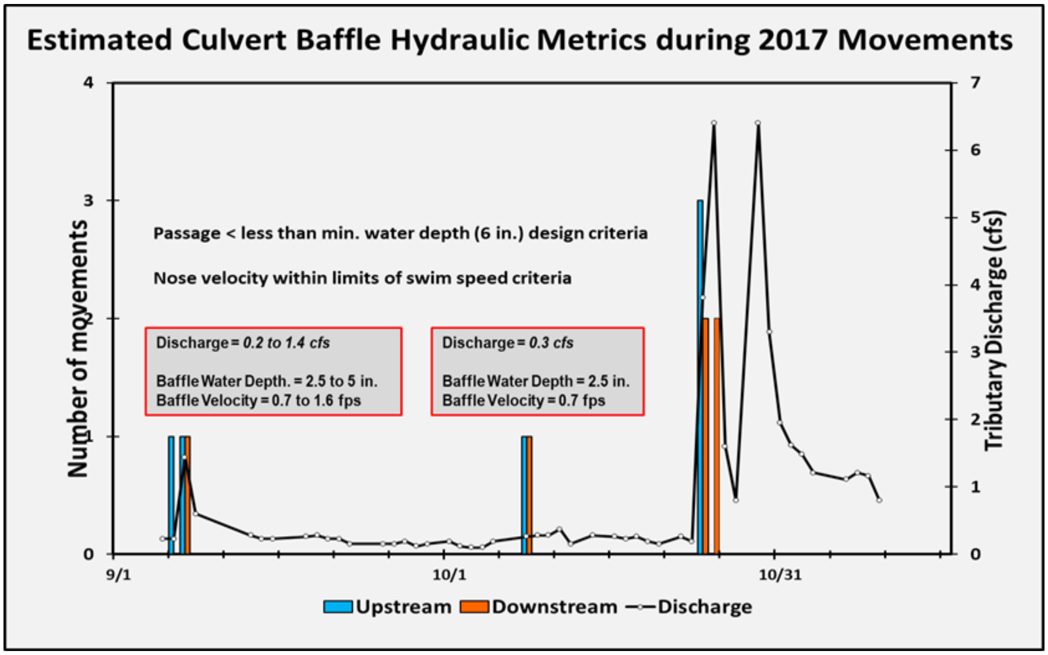
Figure 15. Collection of hydraulic condition data at 1st baffle and culvert entrance in 2017.



As previously discussed, we designed a 4 inch backwater from Fishway Weir #6 that provided suitable depths for Brook Trout to be able to gain access to the 1st upstream most baffle within the culvert. In addition, while hydraulic conditions were variable below this baffle, there was usually a back-eddy effect from flows flowing over the baffle which created low water velocity conditions. In summary, hydraulic conditions except during large discharge events were more or less suitable for Brook Trout at the culvert entrance, therefore while we collected metrics at the entrance (Appendix C) it was determined that "culvert entrance" hydraulic metrics were not critical for fish passage analysis.

Relative to baffle metrics and fish passage, Fish #346 moved upstream on September 6, 2017 during a rain event taking 1:03 to move upstream through the culvert. While we don't know hydraulic conditions during that "specific hour" of movement (19:43-20:46), the daily recorded metrics during this period were estimated to range as follows: stream discharge 0.2 to 1.4 cfs, baffle water depth 2.5 to 5 inches and nose water velocity 0.7 to 1.6 fps (Table 3; Figure 16). Fish #486 moved upstream on October 8, 2017 (8:02-10:41) and subsequently downstream from (11:28 to 11:44). Conditions were very static during this time frame with a low stream discharge of 0.3 cfs, baffle water depth of 2.5 inches and nose water velocity of 0.7 fps (Table 3; Figure 16). The main takeaway from these movements was that passage occurred at less than the minimum design water depth of 0.5 ft. (6 inches) and within the defined design ranges of prolonged and burst swim speed criteria. Researchers have shown a positive correlation between successful passage and elevated motivation, e.g. spawning (Goerig and Castro-Santos 2016) which may explain successful passage at less than desirable water depths. We could not with confidence delineate the specific hydraulic conditions that fish experienced during passage events on October 24-25, 2017 as discharge rapidly increased from 0.2 cfs to 6.4 cfs during a storm event.

Figure 16. Estimated hydraulic metrics at the 1st baffle during movement events in 2017.



Transit Times

In 2017, the mean transit time of upstream movements was 1:28 ± 1:00 (Figure 17), with the minimum and maximum times being 0:38 and 3:03, respectively. Conversely, the mean transit time of downstream movements was 2:00 ± 4:00 (Figure 17) with the minimum and maximum times being 0:09 and 11:44, respectively. The downstream movement mean was highly skewed due to the 11:44 movement time of Fish #302 on September 7, 2017. If this outlier movement event is eliminated from the data set, the downstream mean transit time for 2017 is reduced to 0:12 ± 0:05 and appears to be more representative of downstream transit times for the monitoring season.

Movement Time of Day

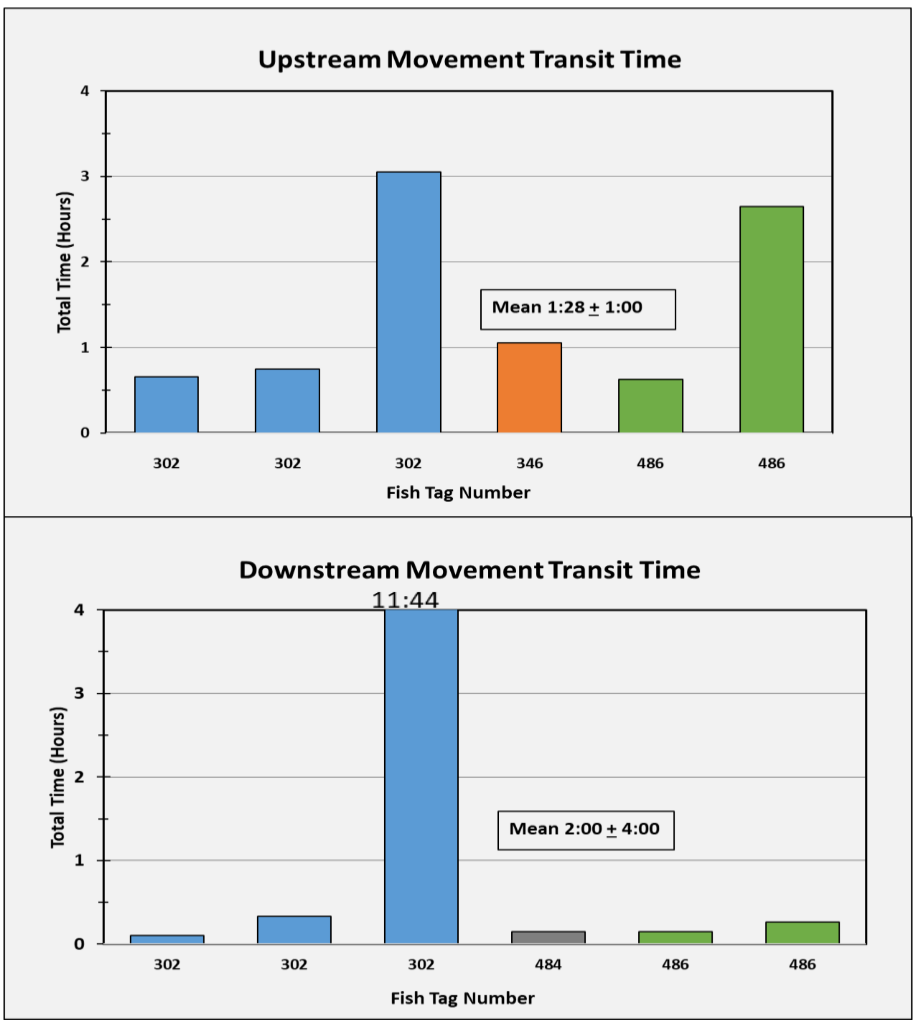
Unlike 2016, general trends in movement by time of day were not that apparent in 2017 due to a limited amount of data (Figure 18). Downstream movements were somewhat more pronounced during the 11:00 to 14:00 timeframe, a trend also observed in 2016.

Fishway Only Residency

Fish #442 was found throughout the entire 2017 study season to move within the fishway being located at either Fishway Pool #1 or Fishway Pool #6. This was the only fish in 2017 that had spent residence time within the fishway and did not move upstream through the culvert. Fish #477 was found by monthly mobile searches to reside within the fishway outlet pool.

A spawning redd was discovered in Fishway Pool #6 on October 21, 2017 (Figure 19). It is suspected that spawning involved at least two tagged fish, Fish #302 and Fish #486 which were located in Fishway Pool #6 at similar times during the October 18 through October 21 timeframe. Fish #442 was not thought to have been involved in spawning with Fish #302 and Fish #486 since it was found only at Fishway Pool #1 during the October 18-21 timeframe.

Figure 17. Transit time or net total time (expressed as hours:minutes) for fish to travel upstream or downstream through the culvert in 2017.



While spawning within the fishway was unexpected, this event documented the benefit of introducing natural substrates into the fishway to make this infrastructure more habitable for fish. In addition, deep water available within the fishway pools also provided habitat that generally was not abundant within the Tributary to Lyman Brook; thus, encouraging Brook Trout to readily reside in the fishway.

All three fish (#302,#442,#486) left the fishway during the rain event from October 23-25 when the fishway overtopped. In general, there was a trend in downstream dispersal of fish after October spawning.

2018 Monitoring: Culvert Movements
During 2018, the third year of monitoring, we tagged 61 Brook Trout in the study area. No prior PIT tagged fish were recaptured. We documented 15 movements through the culvert; again, fewer events than observed during the 2016 monitoring season. This included eight separate upstream movements and seven downstream movements involving four fish. (Figure 20, Table 2). Most (73%) of the movements in 2018 involved Fish #544 which made a total of 11 movements through the culvert; six upstream and five downstream.

Fish #544 moved upstream and subsequently downstream within a 24 hour period at four different occasions. This fish was able to navigate through the culvert during a variety of hydraulic conditions, exhibiting an almost learned behavior as the culvert did not provide an impediment to passage.

Similar to prior years, activity and movements trended with increases in streamflow (Figure 20). Monitoring year 2018 was extremely wet as indicated by the saw-tooth hydrograph with the fishway being overtopped a total of 6 times. Amazingly, flows exceeded 1.2 cfs for the entire month of October, representing a value four times greater than the average discharge of 0.3 cfs observed in 2017. As seen in 2016, there was increased activity in late September through mid-October when fish were seeking suitable spawning habitats.

Figure 18. Movement event frequency of occurrence by time of day in 2017.

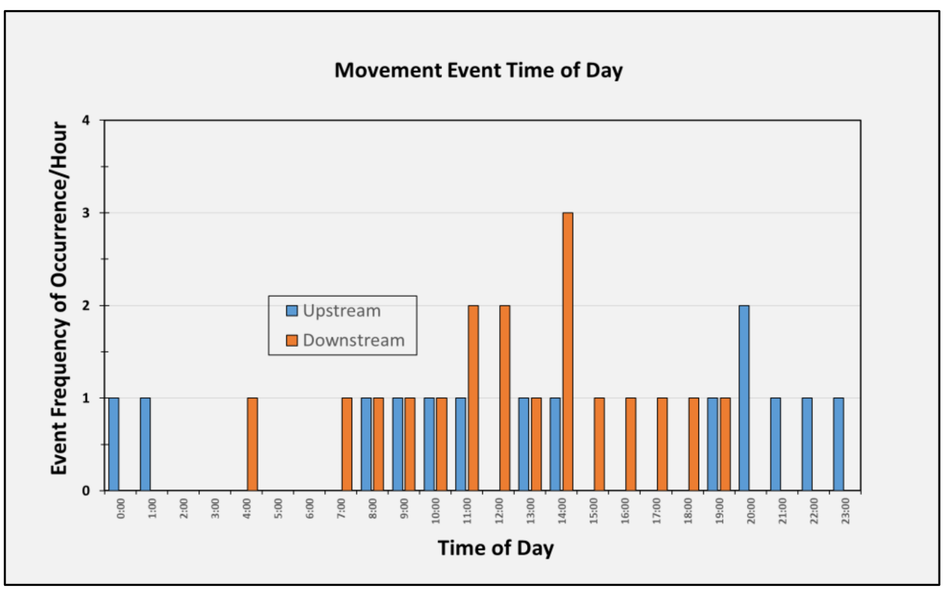
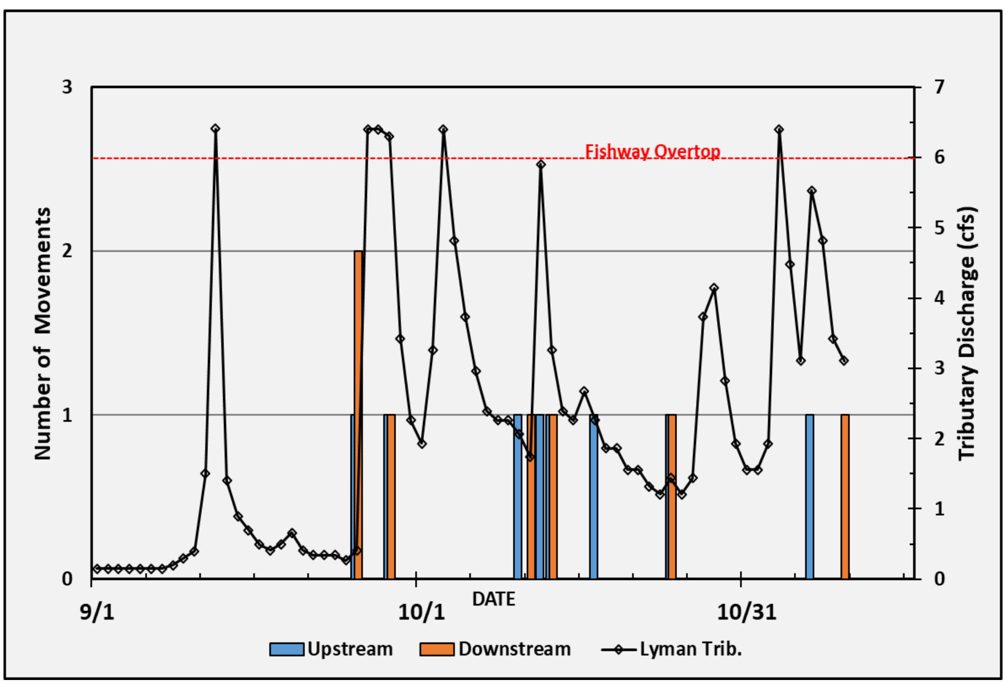


Figure 19. Spawning redd found within Fishway Pool #6 on October 21, 2017.

Figure 20. Total number of upstream and downstream movements through the culvert versus Unnamed Tributary to Lyman Brook Discharge in 2018.



Fish Movement and Culvert Hydraulic Conditions

We documented several fish moving upstream through the culvert during high discharge events in 2018 as opposed during 2017 when fish passage occurred at lower discharges. Fish #544 moved upstream on September 28 when the daily discharge reading was 6.3 cfs, a flow in which the fishway is overtopped and the culvert experiences full width "streaming flow" conditions over the baffles. Streaming flow occurs when the predominant flow skims the baffle tops creating an isolated circulation cell between baffles (Lang and Cashman 2009; Thurman and Horner-Devine 2007). Culvert baffle metrics at this flow were estimated as: water depth of 14.1 inches and nose velocity of 2.35 fps (Table 3). Fish #586 moved upstream on October 12 at a discharge of 5.9 cfs and water depth of 13.3 inches and nose velocity of 2.2 fps whereas Fish #561 moved upstream on November 6 at a discharge of 5.5 cfs, water depth of 12.2 inches and nose velocity of 2.2 fps. The take-away from these results were that Brook Trout were able to successfully move upstream through the culvert through fairly rigorous hydraulic conditions. Back-eddying below the baffles most likely provided resting areas with lower than predictive nose velocities that helped fish ascend the culvert.

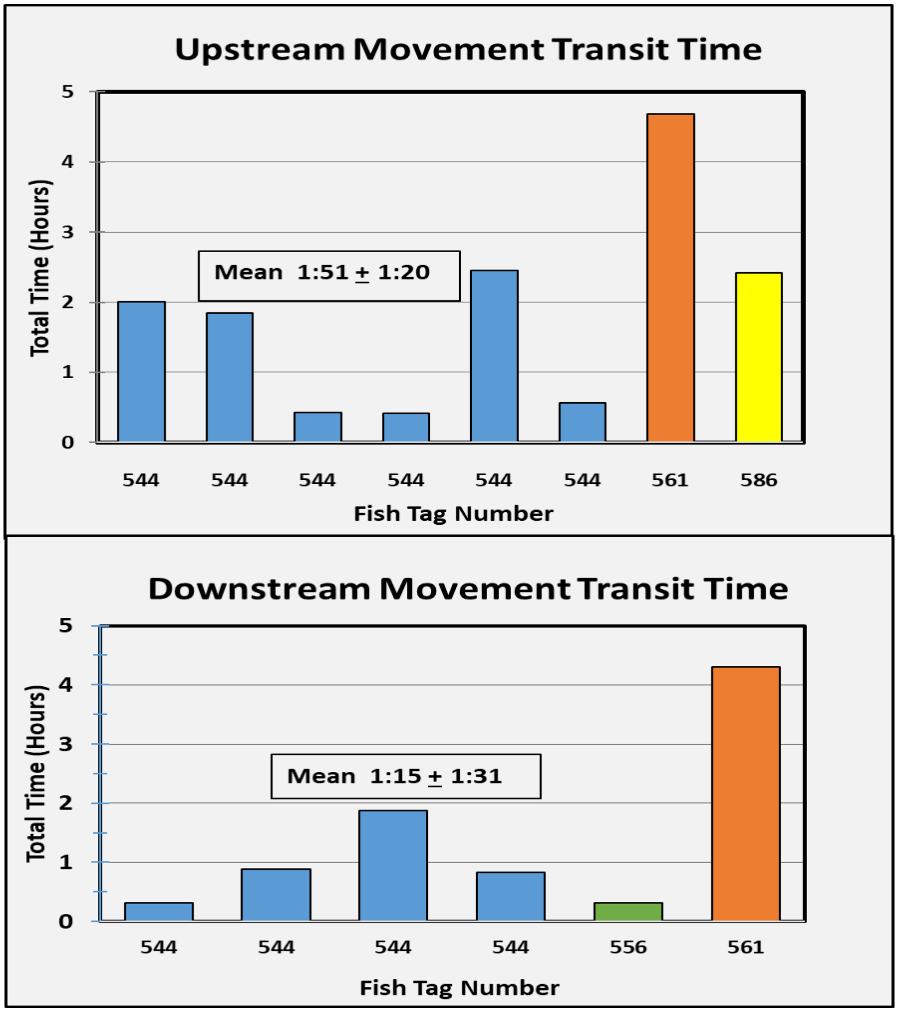
Transit Times

In 2018, the mean transit time of upstream movements was 1:51 ± 1:20 (Figure 21), with the minimum and maximum times being 0:25 and 4:41, respectively. Mean transit time of downstream movements was skewed by the individual movement of Fish #544, which took 30:14 during September 25-26, 2018. It was our opinion that this extended passage event represented more of a "within culvert residence" behavior. As such, this outlier movement was eliminated from the calculation of the mean that resulted in the mean transit time of downstream movements being 1:15 ± 1:31 (Figure 21).

Table 3. Summary of predicted hydraulic metrics during upstream fish passage in 2017-18.

			Baffle Metrics	
Fish ID	**Dates of Fish Movement**	**Weir Discharge (cfs)**	**Water Depth (in.)**	**Nose Velocity (fps)**
302	9/6/2017	0.2	2.4	0.7
346	9/7/2017	1.4	4.7	1.6
486	10/8/2017	0.3	2.5	0.7
302/486	10/24/2017	3.8	9.1	2.1
544	9/25/2018	0.4	2.7	0.9
544	9/28/2018	6.3	14.1	2.3
544	10/10/2018	2.0	5.9	1.7
586	10/12/2018	5.9	13.3	2.2
544	10/13/2018	3.2	8.2	2.0
544	10/17/2018	2.2	6.3	1.7
544	10/24/2018	1.4	4.7	1.6
561	11/6/2018	5.5	12.2	2.2
561	11/9/2018	3.1	7.9	1.9

Figure 21. Transit time or net total time (expressed as hours:minutes) for fish to travel upstream or downstream through the culvert in 2018.



Movement Time of Day

Brook Trout were less active after sunset and during the overnight hours as observed in prior years (Figure 22). While movements through the culvert occurred throughout the day, downstream movements were more pronounced over a longer period from 10:00 to 18:00. There was a minor peak in upstream movement activity during the early morning 6:00 to 7:00.

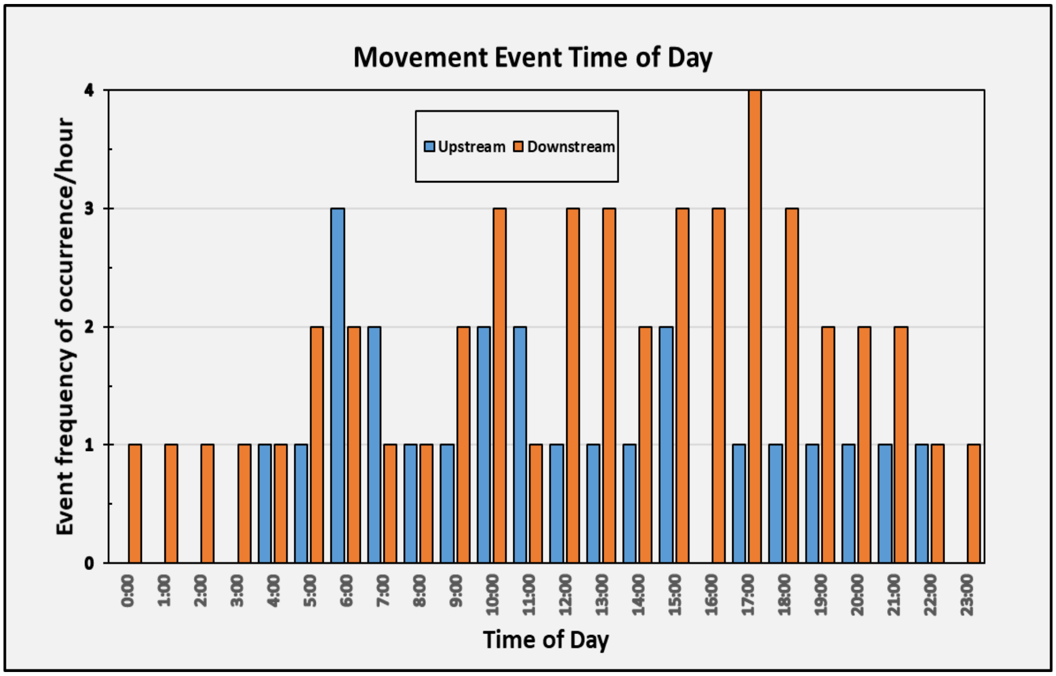
Fishway Only Residency

There were three Brook Trout that only resided within the fishway in 2018. Fish #553 entered the fishway on September 10 and left on October 31, spending 51 days within the fishway. Fish #558 was found within the fishway on August 28 during the beginning of 2018 monitoring and left on September 16 for a residence time of 20 days. Fish #590 was also found on August 28 within the fishway and left on November 14 for a total residence time of 79 days. While Fish #553 and #590 were located within the fishway during the expected spawning timeframe, we did not observe the construction of any redds within the fishway as we had found in Fishway Pool #6 in 2017. It should be noted that high flow events that occurred during the spawning period created unfavorable observation conditions.

Upstream of Culvert Movements

Unlike prior years, we documented PIT tagged fish that were detected at the inlet culvert headwall and upstream antennas that never moved downstream through the baffled culvert. These were usually very brief detections. Fish #554 was located at the inlet upstream antenna for 16 minutes on November 11th. Fish #576 was located at either the inlet culvert headwall or upstream antenna intermittently over a 24 hour period. Fish #592 was detected twice on September 4 at the upstream antenna. Of interest, all three of these fish had been tagged in the stretch of brook “above“ the culverts.

Figure 22. Movement event frequency of occurrence by time of day in 2018.



Monitoring Culvert Movements Summary (2016-2018)

Over the three year monitoring period, we documented a total of 67 movements upstream and downstream through the culvert that involved a total of 17 tagged fish (Figure 23). As previously mentioned, the increased frequency of movement occurred in late September to mid-October when Brook Trout were seeking suitable spawning habitat (Figure 23).

Movement Group Type

It became apparent that there were definitive trends in Brook Trout movement through the baffled culvert over the three year monitoring period that could be characterized. Ten fish (59%) only made a single upstream and/or downstream movement for a total of less than 2 overall movements (Table 4.) An example of this type of behavior is shown in Figure 24, in which Fish #302 spent 21 days in the fishway, made a single movement upstream through the culvert, spent 12 days upstream during the spawning period, and moved back downstream through the culvert subsequently spending time within the fishway before dispersal in early November.

Figure 23. Total number of upstream and downstream movements through the culvert from 2016-2018.

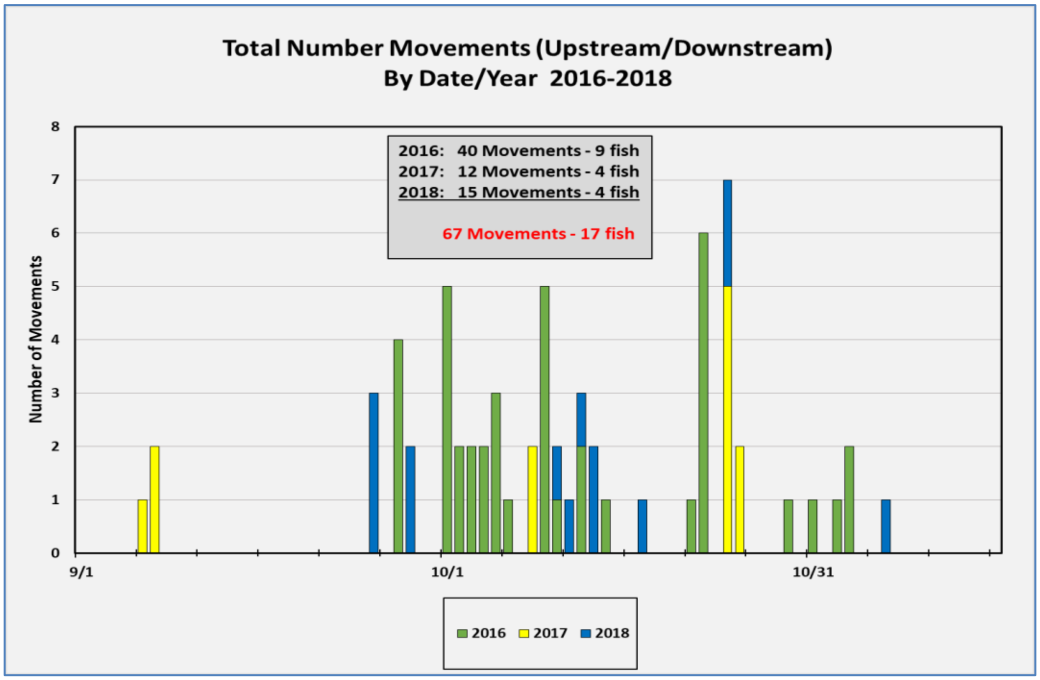
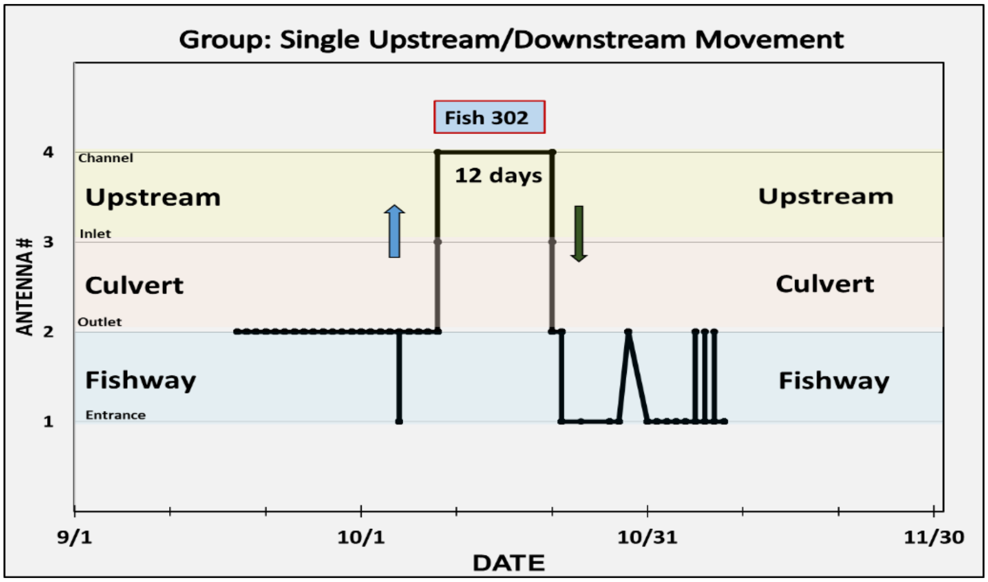


Table 4. Summary of Culvert Movement Group from 2016-2018

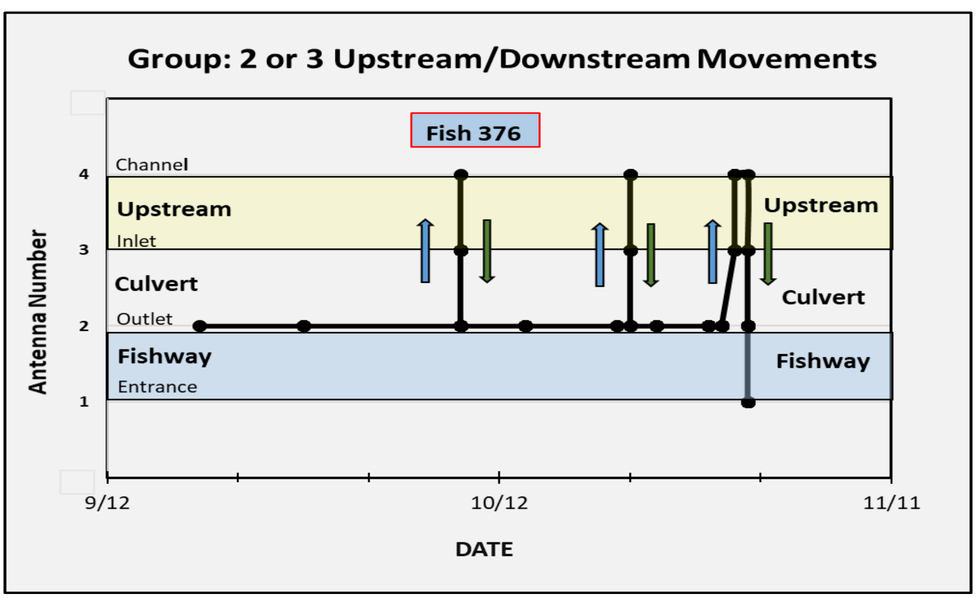
Culvert Movement Type Groups	2016	2017	2018	Total
Group A Single upstream and/or downstream movement, < than 2 total movements	5	2	3	10
Group B Two to Three upstream and/or downstream movements < than 6 total movements	3	2	0	5
Group C Multiple upstream and downstream movements >10 total movements	1	0	1	2
Total	9	4	4	17

Figure 24. Example of single upstream/downstream movement group, Fish #302 in 2016. Antenna number as follows: 1 (Entrance to fishway), 2 (culvert outlet : Fishway Pool #6), 3 (culvert inlet) and 4 (upstream channel).



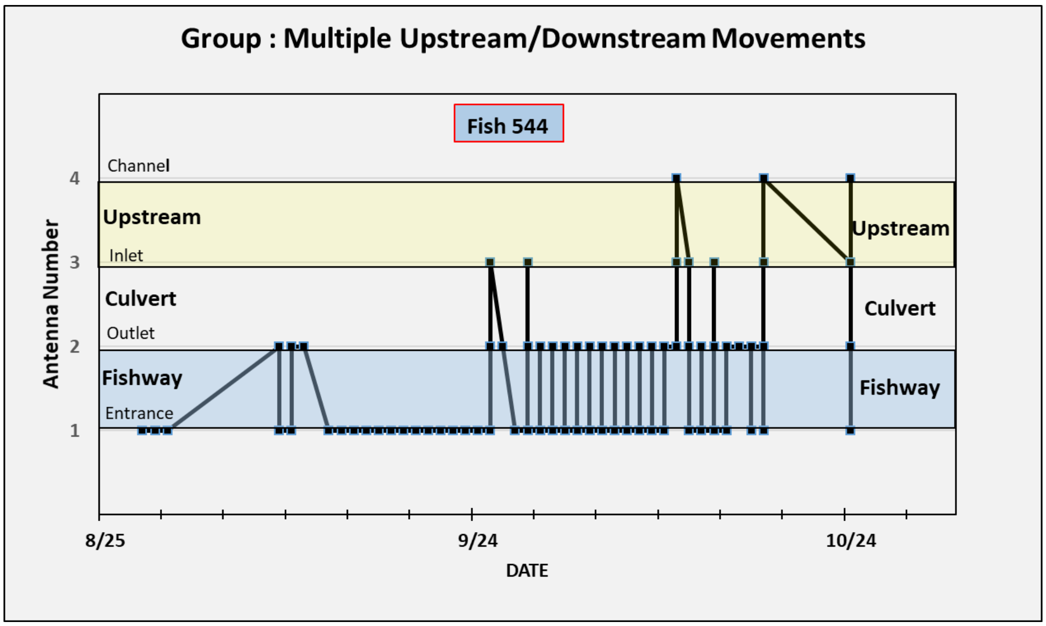
Five fish (29%) made only two to three upstream and/or downstream movements for less than six overall movements (Table 4). This group typically moved upstream and subsequently back downstream through the culvert within a 24 hour period. An example of this type of behavior is shown in Figure 25, in which Fish #376, which mainly resided in Fishway Pool #6 throughout the monitoring period, made relatively quick upstream and downstream movements with a 1-2 day period before downstream dispersal in late October.

Figure 25. Example of two to three upstream/downstream movement group, Fish #376 in 2016. Antenna number as follows: 1 (Entrance to fishway), 2 (culvert outlet : Fishway Pool #6), 3 (culvert inlet) and 4 (upstream channel).



Two fish (12%) often moved upstream and downstream within the culvert multiple times over the monitoring period for more than ten overall movements (Table 4.) An example of this type of behavior is shown in Figure 26, in which Fish #544 made eleven movements through the culvert within a one month period. While this type of behavior was atypical, it indicated the fact that these fish could readily move upstream and downstream under very variable streamflow conditions.

Figure 26. Example of multiple movements for Fish #544 in 2018. Antenna number as follows: 1 (Entrance to fishway), 2 (culvert outlet : Fishway Pool #6), 3 (culvert inlet) and 4 (upstream channel).



Transit Times

Approximately 72% of all upstream movements through the culvert during the three year monitoring period occurred within a 2.5 hour period (Figure 27). Conversely, 65% of all downstream movements through the culvert occurred with a one hour period. We suspect that this apparent difference in transit time was due to fish movement against streamflow (upstream) versus movement with streamflow (downstream). There were a few data points when fish took much longer periods to move through the culvert. These Brook Trout (Fish #376, Fish #302 and Fish #544) were most likely spending residence time within the culvert rather than actively swimming against or with streamflow since they had previously made several positive movements through the culvert in time periods less than one hour in length (Table 2).

Movement Time of Day

While movements through the culvert occurred throughout the day, Brook Trout were less active after sunset and during the overnight hours, especially from midnight until 4 am in the morning (Figure 28). Activity increased in twilight hours when the most frequent upstream movements were observed in the early morning during the 5:00 through 10:00 timeframe. Patterns of increased activity for downstream movements were not as pronounced with the frequency of movement events occurring over a much longer period from 10:00 to 18:00.

These trends were different than observed in other studies, which have found that salmonid activity and movements can be more pronounced after dusk with a sharp decline in activity during the day (Goerig and Castro-Santos 2016; Roy at al. 2013).

Figure 27. Transit time frequency of occurrence or net total time (expressed as hours:minutes) for fish to travel upstream or downstream through the culvert from 2016-2018.

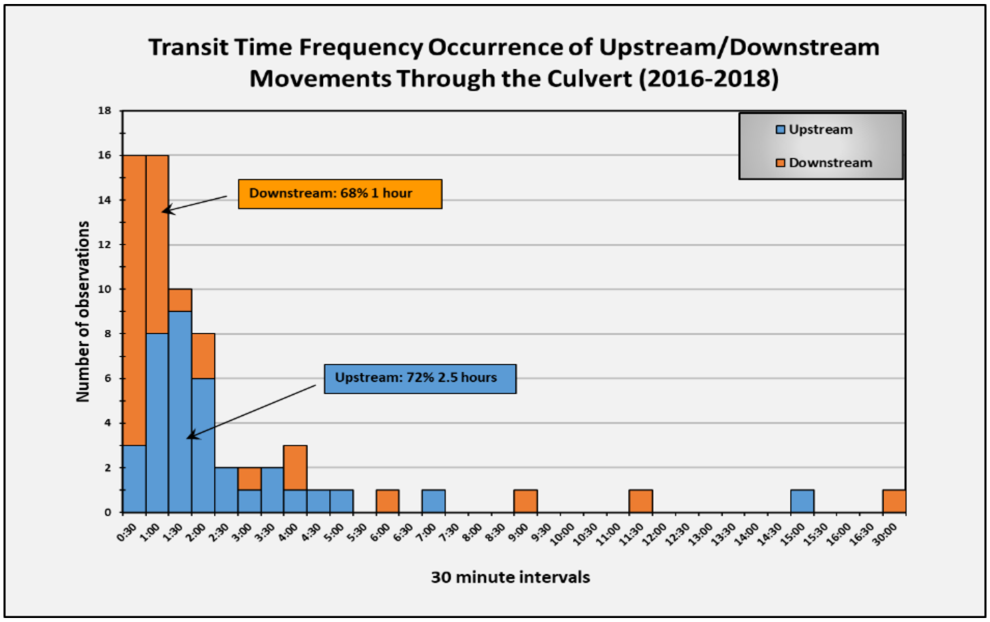
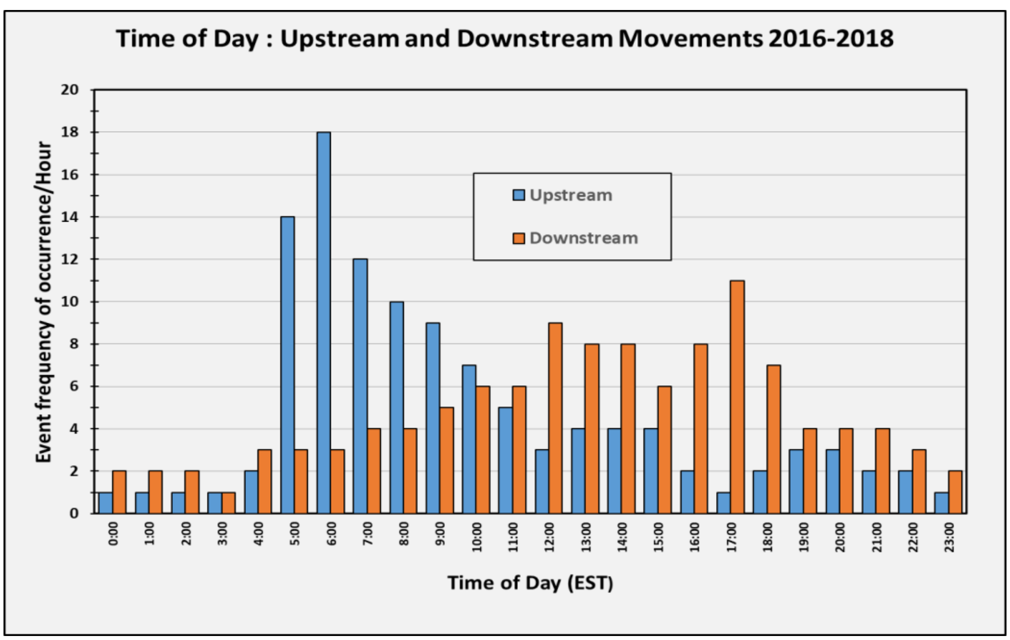


Figure 28. Movement event frequency of occurrence by time of day from 2016-2018.



Trash Rack Performance at Inlet
As mentioned, a deflect and collect trash rack system was constructed at the inlet to minimize debris accumulation in the baffled culvert. The trash rack system experienced its first test after a large storm event in late October of 2017. Heavy winds associated with this event resulted in many downed trees in Connecticut. The primary trash rack was observed to effectively collect large woody debris that would have otherwise blocked the inlet of both culverts (Figure 29). In addition, the secondary trash rack comprised of rebar was effective in collecting smaller debris that would have otherwise ended up within the baffled culvert potentially become lodged and negative impacting fish passage (Figure 30).

Based upon our evaluation over the three year monitoring period, it is our recommendation that the simple vertical rebar trash rack installed at the inlet of baffled culverts would help minimize “within culvert” debris accumulation, especially for smaller diameter culverts, less than 5 feet in diameter. That being said, periodic maintenance by Fisheries and/or DOT will still be required to ensure removal of debris from the trash rack.

Figure 29. Accumulation of large woody debris on primary trash rack after October 2017 storm event.

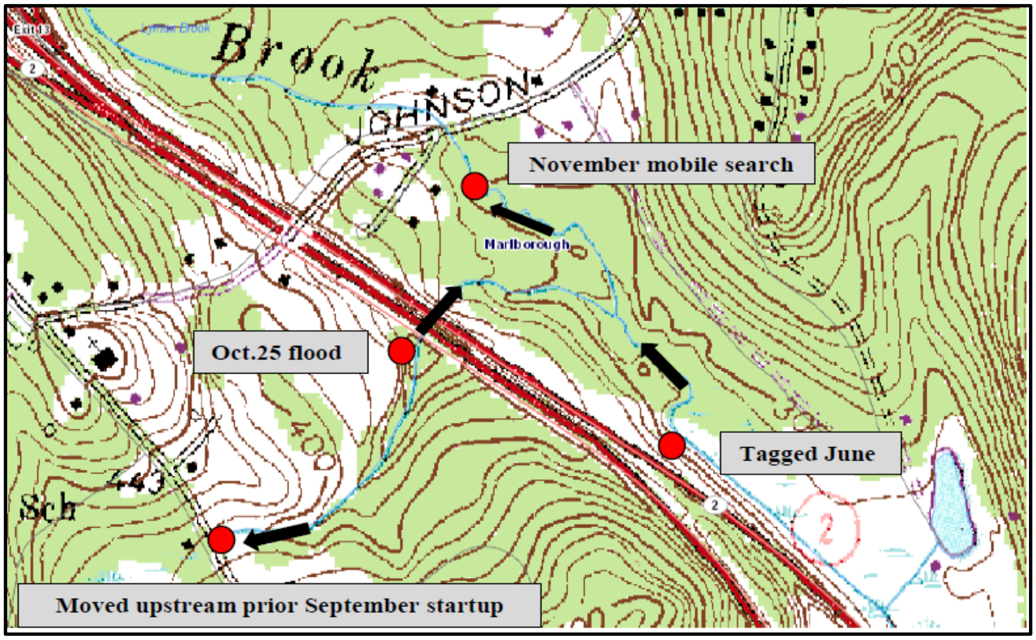
Figure 30. Accumulation of smaller woody debris on secondary rebar trash rack after October 2017 storm event.

Mobile Search Results

Although fish movement downstream of the culvert was not a primary study objective, we attempted to document any large scale movements for Brook Trout moving between the mainstem of Lyman Brook and the Tributary of Lyman Brook. For study year 2016, we conducted a monthly mobile search in September and November and in 2017 during the months of July, August, September and November. Mobile searches were not conducted in 2018 due to equipment malfunction. Each search involved an approximate 0.6 mile study length in the mainstem of Lyman Brook and a 0.5 mile stretch in the Tributary of Lyman Brook.

We documented only a small number of fish (Fish #306, #333, #349 and #484) that moved between the mainstem of Lyman Brook and the Tributary of Lyman Brook or vice versa. This was somewhat contrary to a study conducted by Kanno et al. 2014 in the West Brook stream network, Massachusetts that showed Brook Trout emigration from tributaries was common with about a third of individuals (28-33%) moved between the mainstem and tributary habitats within their life cycle. Our results were not that conclusive given the lack of effort and also the fact that fish may have escaped mobile detection during higher stream flow events when detection efficacy is lower. Kanno et al. 2014 determined that higher movement rates were detected when individuals were tracked over longer time periods and larger study lengths. One noteworthy track was the movements of Fish #484 in 2017 which exhibited some large scale movements (Figure 31). This fish had been tagged in the mainstem of Lyman Brook in June, moved into the tributary to Lyman Brook and upstream through the baffled culvert sometime prior to the 2017 startup to monitoring, was discovered moving downstream through the culvert during the October 25 flood event and subsequently found upstream in the mainstem of Lyman Brook in November. This track involved a minimum travel length of 0.9 miles.

Figure 31. Summary of widespread movements of Fish #484 between mainstem of Lyman Brook and the Tributary to Lyman Brook in 2017.



STUDY CONCLUSIONS AND KEY FINDINGS

Main takeaways for this study are as follows:

1. Over the three year monitoring period, we documented a total of 67 movements upstream and downstream through the baffled culvert that involved a total of 17 PIT tagged fish. Increased frequency of movement occurred in late September to mid-October when Brook Trout were seeking suitable spawning habitat. Movement events tended to be associated with rain events and subsequent increases in stream discharge.

2. In general, there was a trend in downstream dispersal of fish within the Tributary to Lyman Brook after the October spawning period. This may indicate that Brook Trout were seeking more viable overwintering habitats in the mainstem of Lyman Brook where deeper waters are available and less likely to be impacted by anchor ice.

3. Corner or sloped baffle design for round culverts successfully passed Brook Trout at this location. It is recommended that sloped baffles be utilized at future culvert modification projects since sloped baffles appear to offer more favorable passage conditions under a variety of streamflow conditions as opposed to simple v-notch baffles that have been utilized at several past culvert modification projects in Connecticut.

4. This study attempted to identify specific hydraulic conditions Brook Trout experience at the culvert baffles during passage. In 2017, fish were documented at moving through the culvert during very static low flow conditions with a stream discharge of 0.3 cfs,

baffle water depth of 2.5 inches and nose water velocity of 0.7 fps. These movements occurred at less than the minimum design water depth of 0.5 ft (6 inches).

5. Spawning within the fishway documented the benefit of introducing natural substrates and providing deep water within the fishway to make this infrastructure more habitable for utilization by Brook Trout, especially as a staging area prior to spawning.

6. It is apparent that there were definitive trends in Brook Trout movement through the baffled culvert that could be characterized. Ten fish (59%) only made a single upstream and/or downstream movement for a total of less than two overall movements. Five fish (29%) made only two to three upstream and/or downstream movements for a total of less than six overall movements. This group typically moved upstream and subsequently back downstream through the culvert within a 24 hour period. Two fish (12%) often moved upstream and downstream within the culvert multiple times over the monitoring period for a total of more than 10 overall movements. While this type of behavior was atypical, it indicated the fact that these fish could readily move upstream and downstream under variable streamflow conditions.

7. Approximately 72% of all upstream movements through the culvert occurred within a 2.5 hour period. Conversely, 65% of all downstream movements through the culvert occurred with a one hour period. This apparent difference in transit time was due to fish movement against streamflow (upstream) versus movement with streamflow (downstream).

8. While movements through the culvert occurred throughout the day, Brook Trout were less active after sunset and during the overnight hours, especially from midnight until 4 am in the morning. Activity increased in twilight hours when the most frequent upstream movements were observed in the early morning during the 5:00 through 10:00 timeframe.

9. Results of this study will help guide fish passage design features at future culvert modification and sliplining projects. Based upon the success of this collaboration, both DOT and DEEP should continue joint efforts to pursue innovative culvert design modifications. Specifically, consideration should be given to installing pre-fabricated fishways at culverts that are severely perched. The use of pre-fabricated rather than cast-in-place concrete fishways will reduce overall project cost and expedite construction. It is recommended to find a suitable site(s) to install a pre-fabricated fishway (type to be determined) and monitor fish movements via PIT tag technology.

Acknowledgements
Special thanks to Steve Gephard DEEP Fisheries Division for design and technical support throughout all phases of the project. Numerous fisheries staff graciously provided field survey assistance including Tim Wildman, Dave Ellis and Neal Hagstrom. Dr. Alex Haro, S.O. Conte Anadromous Fish Research Laboratory helped fine tune our PIT detection system at the culverts. This project is a testament to the excellent cooperation between two state agencies in finding a balance between protecting natural resources and transportation infrastructure at the same time. Department of Transportation staff involved in this project from design to

implementation include Andrew Davis, Amanda Saul, Kevin Carifa, Salvatore Aresco, Won Song, Joe Whewell, John Dunn, Bob Beauchesne and Paul Dickey.

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Appendix A. Summary of Culvert Design Features

Culverts

Length: 262 feet/Slope at 4.5 percent
Diameter: Twin 72 inch corrugated metal culverts
Outlet: Perched freefall: 1.5 ft.

Watershed

Watershed size at crossing: 0.94 mi^2
Stream grade: Above: 6.5% Below: 2%

Culvert Rehabilitation Proposal:

Slipline with 60 inch polymer coated round corrugated metal culverts. Smaller 60 inch pipe required due to pipe deformities. Invert to be raised 3 inches.

Fish Passage Features

Target species: Brook Trout

Prolonged swim speed=1.3 ft/s
Burst swim speed= 3.1 ft/s
Minimum depth of 0.5 ft.

Corner baffle system

Angled Height: 0.5 to 1.04 ft.
Spacing between baffle = 5ft.

Average daily flows

Directed into baffled east culvert.

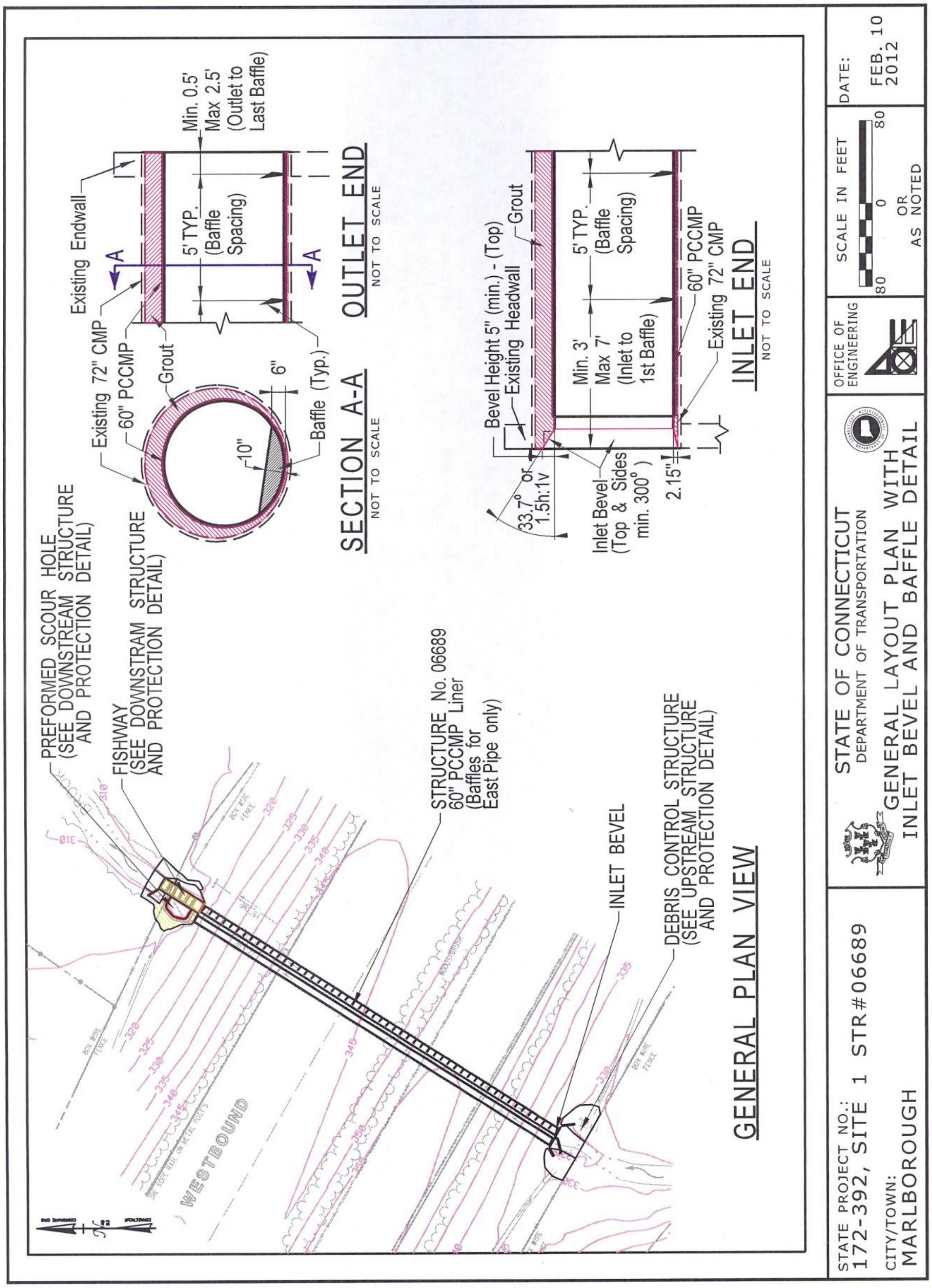
Flood flows

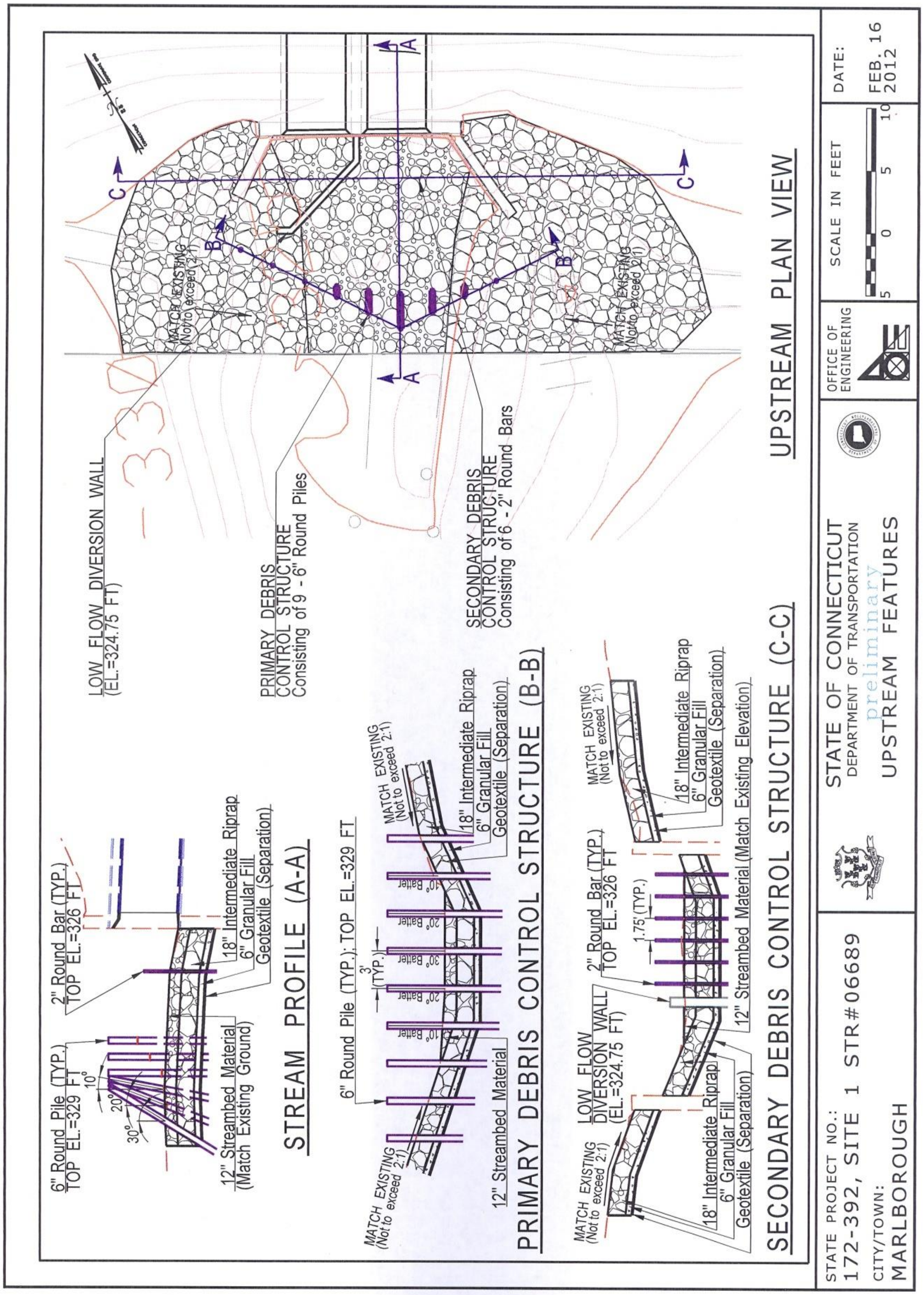
Conveyed into both culverts.

Concrete pool/weir fishway at outlet

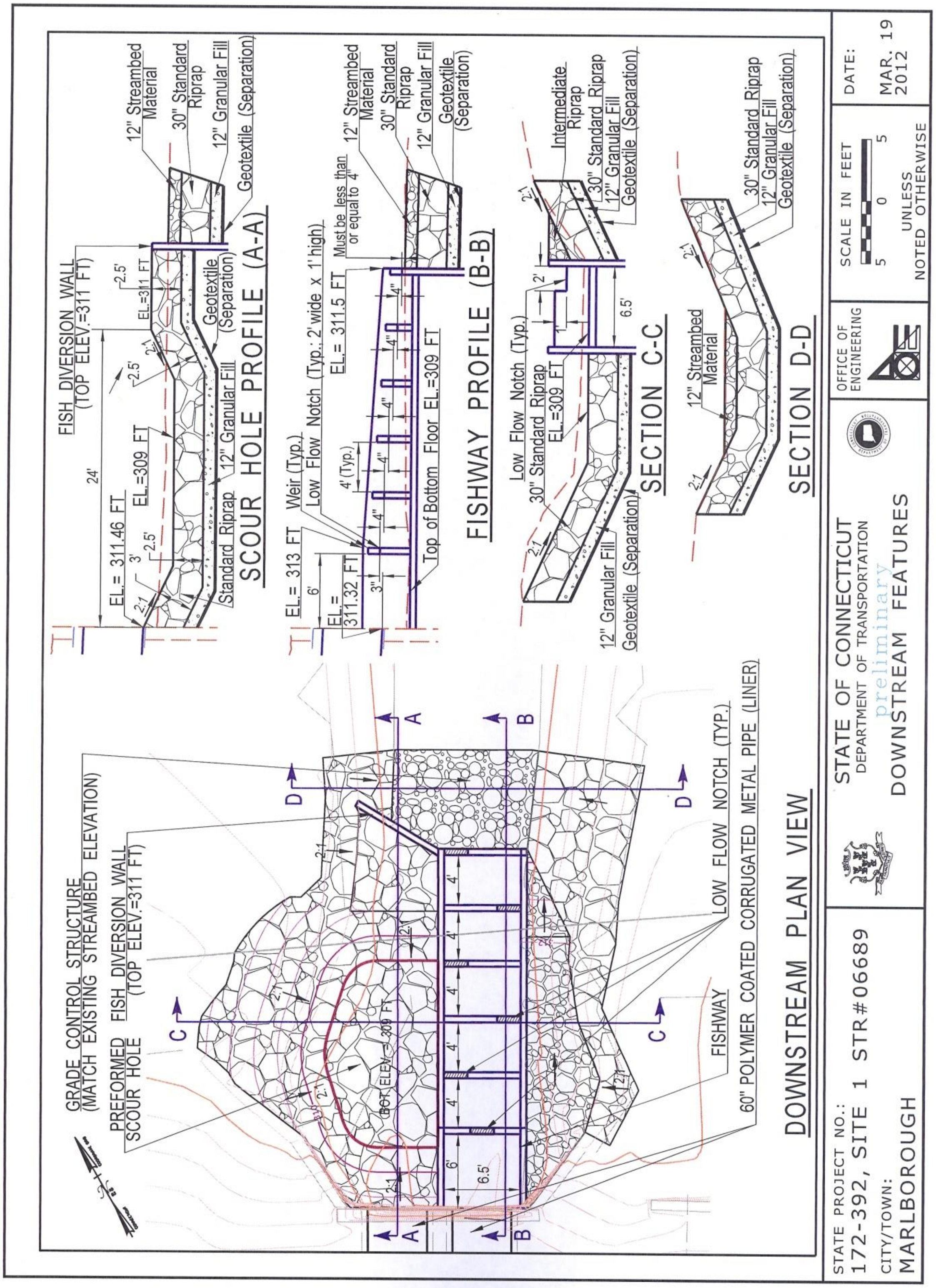
6 pools/weirs at 4 inch drop per pool.
Three inch backwater into culvert.
Weirs notched (2 ft. x 1 ft.) with weir board slots.
Fish diversion wall and scour hole at west culvert.
Boulder grade control weir below fishway entrance to prevent headcutting.
Custom deflect and collect trash rack system at inlet to minimize debris accumulation in baffles.

APPENDIX B. CULVERT MODIFICATION AND FISHWAY DESIGN


GENERAL PLAN VIEW
PREFORMED SCOUR HOLE (SEE DOWNSTREAM STRUCTURE AND PROTECTION DETAIL)
FISHWAY (SEE DOWNSTRAM STRUCTURE AND PROTECTION DETAIL)
STRUCTURE No. 06689 60" PCCMP Liner (Baffles for East Pipe only)
INLET BEVEL
DEBRIS CONTROL STRUCTURE (SEE UPSTREAM STRUCTURE AND PROTECTION DETAIL)
WESTBOUND
SECTION A-A
NOT TO SCALE
Existing 72" CMP
60" PCCMP
Grout
Baffle (Typ.)
10"
6"
OUTLET END
NOT TO SCALE
Existing Endwall
5' TYP. (Baffle Spacing)
Min. 0.5' Max 2.5' (Outlet to Last Baffle)
INLET END
NOT TO SCALE
Bevel Height 5" (min.) - (Top)
Existing Headwall
33.7° or 1.5h:1v
Inlet Bevel (Top & Sides min. 300°)
2.15"
Min. 3' Max 7' (Inlet to 1st Baffle)
60" PCCMP
Existing 72" CMP
STATE PROJECT NO.: 172-392, SITE 1 STR#06689
CITY/TOWN: MARLBOROUGH
STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION
GENERAL LAYOUT PLAN WITH INLET BEVEL AND BAFFLE DETAIL
OFFICE OF ENGINEERING
SCALE IN FEET
80 0 80
OR AS NOTED
DATE: FEB. 10 2012



UPSTREAM PLAN VIEW
LOW FLOW DIVERSION WALL (EL.=324.75 FT)
PRIMARY DEBRIS CONTROL STRUCTURE Consisting of 9 - 6" Round Piles
SECONDARY DEBRIS CONTROL STRUCTURE Consisting of 6 - 2" Round Bars
MATCH EXISTING (Not to exceed 2:1)
STREAM PROFILE (A-A)
6" Round Pile (TYP.) TOP EL.=329 FT
2" Round Bar (TYP.) TOP EL.=326 FT
12" Streambed Material (Match Existing Ground)
18" Intermediate Riprap
6" Granular Fill
Geotextile (Separation)
PRIMARY DEBRIS CONTROL STRUCTURE (B-B)
6" Round Pile (TYP.); TOP EL.=329 FT
12" Streambed Material
SECONDARY DEBRIS CONTROL STRUCTURE (C-C)
LOW FLOW DIVERSION WALL (EL.=324.75 FT)
2" Round Bar (TYP.) TOP EL.=326 FT
12" Streambed Material (Match Existing Elevation)
STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION
preliminary
UPSTREAM FEATURES
OFFICE OF ENGINEERING
SCALE IN FEET
DATE: FEB. 16 2012
STATE PROJECT NO.: 172-392, SITE 1 STR#06689
CITY/TOWN: MARLBOROUGH



GRADE CONTROL STRUCTURE
(MATCH EXISTING STREAMBED ELEVATION)
PREFORMED SCOUR HOLE
FISH DIVERSION WALL
(TOP ELEV.=311 FT)
FISHWAY
LOW FLOW NOTCH (TYP.)
60" POLYMER COATED CORRUGATED METAL PIPE (LINER)
BOT. ELEV.=309 FT
DOWNSTREAM PLAN VIEW
FISH DIVERSION WALL
(TOP ELEV.=311 FT)
EL.= 311.46 FT
EL.=309 FT
EL.=311 FT
12" Streambed Material
30" Standard Riprap
12" Granular Fill
Geotextile (Separation)
Standard Riprap
SCOUR HOLE PROFILE (A-A)
EL.= 313 FT
EL.= 311.32 FT
Weir (Typ.)
Low Flow Notch (Typ.: 2' wide x 1' high)
EL.= 311.5 FT
Must be less than or equal to 4"
Top of Bottom Floor EL.=309 FT
FISHWAY PROFILE (B-B)
Low Flow Notch (Typ.)
30" Standard Riprap
EL.=309 FT
Intermediate Riprap
SECTION C-C
SECTION D-D
STATE PROJECT NO.:
172-392, SITE 1 STR#06689
CITY/TOWN:
MARLBOROUGH
STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION
preliminary
DOWNSTREAM FEATURES
OFFICE OF ENGINEERING
SCALE IN FEET
UNLESS NOTED OTHERWISE
DATE:
MAR. 19 2012

Fish Passage Flows

(from FishXing)

Maintaining fish passage through culverts during flood flows is often impracticable and unnecessary. Extreme low flow periods may also present problems for providing fish passage, and short-term barriers to movement may or may not be important to the survival of species present. It may not be necessary to provide passage at extreme low flows if fish are not attempting to move during this period or if naturally occurring stream conditions limits passage between stream reaches. For any particular species and lifestage the Low Passage Flow (QLP) and High Passage Flow (QHP) define the range of flows to be analyzed by FishXing. These are determined locally or regionally based on knowledge of movement patterns of the species present.

Some states have developed guidelines for determining Fish Passage Flows. For examples of guidelines see the "State and Agency Flow Guidelines for Fish Passage Flows" table in the Flow Guidelines for Fish Passage Flows section.

Low Flow guidelines determine the depth threshold for passage and are based on annual or migration period exceedance percentage from a flow duration curve for the 2-year, 7-day low flow.

High Flow guidelines determine the velocity threshold for passage and are typically based on annual or migration period exceedance percentage from a flow duration curve.

State and Agency Flow Guidelines for Fish Passage Flows

State / Agency	High Flow Capacity	High Fish Passage Flow	Low Fish Passage Flow
Alaska	Q_{50} or Q_{100}	"Q2d2" the flow 24 hours before or after the 2-yr flood	None
Washington	Q_{100} w/ debris	10% exceedance flow during migration period: species specific	2-yr, 7-day low flow
Oregon	Q_{100}	10% exceedance flow during migration period: species specific. Approximate by Q10% = 0.18*(Q2)+36 where Q2>44 cfs. where Q2<44 cfs use Q2	2-yr, 7-day low flow or 95% exceedance flow for migration period: species specific
NMFS SW Region	Q_{100} at HW/D =1	for adult salmon & steelhead 1% annual exceedance flow or 50% Q2. For juveniles, 10% annual exceedance flow	for adult salmon & steelhead, the greater of 3 cfs or 50% annual exceedance flow. For juveniles, the greater of 95% annual exceedance flow or 1 cfs.
California Dept. Fish & Game	Q_{100} at HW/D =1.5	standards vary from 1%-10% annual exceedance for various groups of fish	standards vary from 50%-95% annual exceedance for various groups of fish
NMFS NW Region		5% exceedance flow for period of upstream migration	95% exceedance flow during months of upstream migration

Although the above table shows different criteria for different States and regions, they seem to be generally close. The most commonly used criteria appear to be 10% and 95% exceedance flows (during the migration periods) for the high and low fish passage design flows respectively. As Connecticut does not have specific guidelines on determining the fish passage flows, it was determined to use these most common values.

Fish Low Flow: ***95% exceedance during the migration period.***
Fish High Flow: ***10% exceedance during the migration period.***

State Project No. 172-392, Str.06689

KNOWN DATA

Probability of Exceedance	Discharge (CFS) from StreamStat	Discharge (CFS) Computed	Use
99%	0.69	0.67	
95%	0.98	0.99	F.P. Low
90%		1.23	**1**
75%	1.68	1.75	
50%	2.51	2.59	
25%	4.02	3.83	
10%		5.46	**5.5**
5%		6.74	F.P. High
1%		10.02	

y = C x EXP(p x F) = $2.5872e^{0.5821x}$

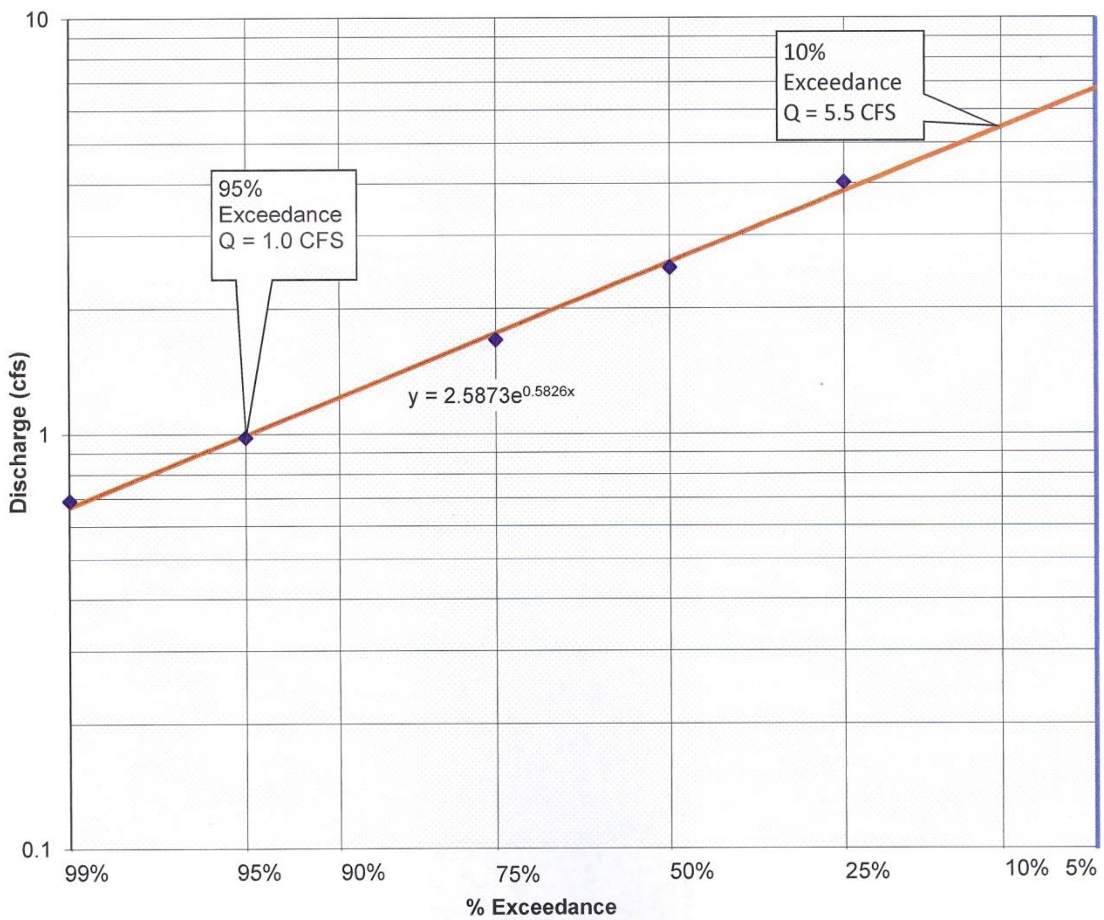
= 5.46 cfs

for 10% Exceedance

C =	2.5872
p =	0.5821
y =	discharge
F =	x-axis value of return frequency
=	1.2816

F of 1.2816 equals to Prob. Of Exceedance of 10%

Habitat Forming (Mar.-Apr Flows)



AVERAGE SPRING FLOW

Hydraulic Condiiton Between Baffles/Weirs

	Reach	River S	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Hydr Dept (ft)	Max Chl Dpth (ft)
Downstream 23.3 ft Section of the Culvert	main	911.*	AveSpring	4	312.35	313.52	1.14	3.5	4.23	0.83	1.17
	main	910.*	AveSpring	4	312.31	313.53	1.09	3.67	4.29	0.86	1.22
	main	909.*	AveSpring	4	312.26	313.53	1.03	3.89	4.36	0.89	1.27
	main	908.9		Inl Struct							
	main	908.*	AveSpring	4	312.22	313.29	1.3	3.08	4.09	0.75	1.07
	main	907.*	AveSpring	4	312.17	313.3	1.21	3.3	4.17	0.79	1.13
	main	906.*	AveSpring	4	312.13	313.3	1.15	3.47	4.22	0.82	1.17
	main	905.*	AveSpring	4	312.08	313.3	1.09	3.69	4.3	0.86	1.22
	main	904.*	AveSpring	4	312.04	313.3	1.04	3.86	4.35	0.89	1.26
	main	903.9		Inl Struct							
	main	903.*	AveSpring	4	311.99	313.07	1.28	3.12	4.11	0.76	1.08
	main	902.*	AveSpring	4	311.95	313.07	1.22	3.29	4.16	0.79	1.12
	main	901.*	AveSpring	4	311.9	313.08	1.14	3.5	4.24	0.83	1.18
	main	900.*	AveSpring	4	311.86	313.08	1.09	3.68	4.29	0.86	1.22
	main	899.*	AveSpring	4	311.81	313.08	1.03	3.9	4.36	0.89	1.27
	main	898.9		Inl Struct							
	main	898.*	AveSpring	4	311.77	312.84	1.3	3.08	4.09	0.75	1.07
	main	897.*	AveSpring	4	311.72	312.85	1.21	3.29	4.17	0.79	1.13
	main	896.*	AveSpring	4	311.68	312.85	1.15	3.47	4.22	0.82	1.17
	main	895.*	AveSpring	4	311.63	312.85	1.09	3.68	4.3	0.86	1.22
	main	894.*	AveSpring	4	311.59	312.85	1.04	3.86	4.35	0.89	1.26
	main	893.9		Inl Struct							
	main	893.*	AveSpring	4	311.54	312.63	1.27	3.16	4.12	0.77	1.09
	main	892.*	AveSpring	4	311.5	312.63	1.2	3.33	4.18	0.8	1.13
	main	891.*	AveSpring	4	311.45	312.64	1.13	3.54	4.25	0.83	1.19
	main	890.*	AveSpring	4	311.41	312.64	1.08	3.72	4.31	0.86	1.23
	main	889.*	AveSpring	4	311.36	312.64	1.02	3.94	4.37	0.9	1.28
	main	888.9		Inl Struct							
	main	888	AveSpring	4	311.32	312.39	1.31	3.06	4.09	0.75	1.07
Fishway	main	887	AveSpring	4	309	312.41	0.18	22.18	6.52	3.4	3.41
	main	882	AveSpring	4	309	312.41	0.18	22.18	6.52	3.4	3.41
	main	881.8		Inl Struct							
	main	878	AveSpring	4	309	312.09	0.2	20.08	6.52	3.08	3.09
	main	877.8		Inl Struct							
	main	873	AveSpring	4	309	311.74	0.22	17.83	6.52	2.74	2.74
	main	872.8		Inl Struct							
	main	869	AveSpring	4	309	311.41	0.25	15.71	6.52	2.41	2.41
	main	868.8		Inl Struct							
	main	864	AveSpring	4	309	311.08	0.3	13.55	6.51	2.08	2.08
	main	863.8		Inl Struct							
	main	860	AveSpring	4	309	310.74	0.35	11.31	6.51	1.74	1.74
	main	859.8		Inl Struct							
	main	858.98	AveSpring	4	309.62	309.87	1.38	2.89	12.54	0.23	0.25
	main	848	AveSpring	4	309.42	309.6	2.27	1.77	12.63	0.14	0.18

Hydraulic Data at Weirs/Baffles

	Reach	River Sta	Profile	E.G. Elev (ft)	W.S. Elev (ft)	Q Total (cfs)	Q Weir (cfs)	Weir Flow Area (sq ft)	Weir Max Depth (ft)	Weir Avg Depth (ft)	Ave Vel. over Weir (ft/s)
Over Baffles inside the culvert	main	908.9	AveSpring	313.54	313.53	4	4	2.13	0.78	0.49	1.88
	main	903.9	AveSpring	313.32	313.3	4	4	2.14	0.78	0.49	1.87
	main	898.9	AveSpring	313.09	313.08	4	4	2.14	0.78	0.49	1.87
	main	893.9	AveSpring	312.87	312.85	4	4	2.14	0.78	0.49	1.87
	main	888.9	AveSpring	312.65	312.64	4	4	2.17	0.79	0.5	1.84
Over the weir notches	main	881.8	AveSpring	312.41	312.41	4	4	1.68	0.84	0.84	2.38
	main	877.8	AveSpring	312.09	312.09	4	4	1.69	0.85	0.85	2.37
	main	872.8	AveSpring	311.74	311.74	4	4	1.68	0.84	0.84	2.38
	main	868.8	AveSpring	311.41	311.41	4	4	1.69	0.84	0.84	2.37
	main	863.8	AveSpring	311.08	311.08	4	4	1.68	0.84	0.84	2.38
	main	859.8	AveSpring	310.74	310.74	4	4	1.68	0.84	0.84	2.38

Brook Trout	prolonged speed	**1.3** ft/s	Min. depth	**0.5 ft**
	burst speed	**3.1** ft/s		

Over baffles & weirs: Velocity < burst speed; ave. depth close to min. depth
Areas between baffles and weirs: Velocity close to or less than prolonged speed; flow depth > min. depth

The computed velocity and depth are within the acceptable range for Brook Trout

FISH PASSAGE LOW DESIGN FLOW (95% EXCEEDANCE DURING MIGRATION PERIOD: MAR-APR)

Hydraulic Condiiton Between Baffles/Weirs

	Reach	River S	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Hydr Dept (ft)	Max Chl Dpth (ft)
Downstream 23.3 ft Section of the Culvert	main	911.*	Fish Low	1	312.35	313.21	0.45	2.24	3.76	0.6	0.86
	main	910.*	Fish Low	1	312.31	313.21	0.42	2.39	3.83	0.63	0.9
	main	909.*	Fish Low	1	312.26	313.21	0.39	2.59	3.91	0.66	0.95
	main	908.9		Inl Struct							
	main	908.*	Fish Low	1	312.22	312.98	0.53	1.88	3.6	0.52	0.76
	main	907.*	Fish Low	1	312.17	312.98	0.48	2.06	3.68	0.56	0.81
	main	906.*	Fish Low	1	312.13	312.98	0.45	2.21	3.75	0.59	0.85
	main	905.*	Fish Low	1	312.08	312.98	0.42	2.4	3.83	0.63	0.9
	main	904.*	Fish Low	1	312.04	312.98	0.39	2.56	3.9	0.66	0.94
	main	903.9		Inl Struct							
	main	903.*	Fish Low	1	311.99	312.76	0.52	1.91	3.61	0.53	0.77
	main	902.*	Fish Low	1	311.95	312.76	0.49	2.06	3.68	0.56	0.81
	main	901.*	Fish Low	1	311.9	312.76	0.45	2.25	3.76	0.6	0.86
	main	900.*	Fish Low	1	311.86	312.76	0.42	2.4	3.83	0.63	0.9
	main	899.*	Fish Low	1	311.81	312.76	0.39	2.59	3.91	0.66	0.95
	main	898.9		Inl Struct							
	main	898.*	Fish Low	1	311.77	312.54	0.52	1.91	3.61	0.53	0.77
	main	897.*	Fish Low	1	311.72	312.54	0.48	2.09	3.69	0.57	0.82
	main	896.*	Fish Low	1	311.68	312.54	0.45	2.24	3.76	0.6	0.86
	main	895.*	Fish Low	1	311.63	312.54	0.41	2.43	3.84	0.63	0.91
	main	894.*	Fish Low	1	311.59	312.54	0.39	2.59	3.91	0.66	0.95
	main	893.9		Inl Struct							
	main	893.*	Fish Low	1	311.54	312.32	0.52	1.93	3.62	0.53	0.78
	main	892.*	Fish Low	1	311.5	312.32	0.48	2.08	3.69	0.56	0.82
	main	891.*	Fish Low	1	311.45	312.32	0.44	2.26	3.77	0.6	0.87
	main	890.*	Fish Low	1	311.41	312.32	0.41	2.42	3.84	0.63	0.91
	main	889.*	Fish Low	1	311.36	312.32	0.38	2.61	3.92	0.67	0.96
	main	888.9		Inl Struct							
	main	888	Fish Low	1	311.32	311.9	0.8	1.24	3.17	0.39	0.58
Fishway	main	887	Fish Low	1	309	311.9	0.05	18.89	6.51	2.9	2.9
	main	882	Fish Low	1	309	311.9	0.05	18.89	6.51	2.9	2.9
	main	881.8		Inl Struct							
	main	878	Fish Low	1	309	311.57	0.06	16.74	6.51	2.57	2.57
	main	877.8		Inl Struct							
	main	873	Fish Low	1	309	311.24	0.07	14.56	6.51	2.24	2.24
	main	872.8		Inl Struct							
	main	869	Fish Low	1	309	310.9	0.08	12.39	6.51	1.9	1.9
	main	868.8		Inl Struct							
	main	864	Fish Low	1	309	310.57	0.1	10.23	6.51	1.57	1.57
	main	863.8		Inl Struct							
	main	860	Fish Low	1	309	310.23	0.12	8.02	6.51	1.23	1.23
	main	859.8		Inl Struct							
	main	858.98	Fish Low	1	309.62	309.73	0.82	1.22	11.95	0.1	0.11
	main	848	Fish Low	1	309.42	309.52	1.29	0.77	11.95	0.06	0.1

Hydraulic Data at Weirs/Baffles

	Reach	River Sta	Profile	E.G. Elev (ft)	W.S. Elev (ft)	Q Total (cfs)	Q Weir (cfs)	Weir Flow Area (sq ft)	Weir Max Depth (ft)	Weir Avg Depth (ft)	Ave Vel. over Weir (ft/s)
Over Baffles inside the culvert	main	908.9	Fish Low	313.21	313.21	1	1	0.78	0.45	0.23	1.28
	main	903.9	Fish Low	312.99	312.98	1	1	0.79	0.45	0.23	1.27
	main	898.9	Fish Low	312.76	312.76	1	1	0.79	0.45	0.23	1.27
	main	893.9	Fish Low	312.54	312.54	1	1	0.81	0.46	0.23	1.23
	main	888.9	Fish Low	312.32	312.32	1	1	0.8	0.46	0.23	1.25
Over the weir notches	main	881.8	Fish Low	311.9	311.9	1	1	0.66	0.33	0.33	1.52
	main	877.8	Fish Low	311.57	311.57	1	1	0.66	0.33	0.33	1.52
	main	872.8	Fish Low	311.24	311.24	1	1	0.68	0.34	0.34	1.47
	main	868.8	Fish Low	310.9	310.9	1	1	0.67	0.33	0.33	1.49
	main	863.8	Fish Low	310.57	310.57	1	1	0.66	0.33	0.33	1.52
	main	859.8	Fish Low	310.23	310.23	1	1	0.66	0.33	0.33	1.52

Brook Trout	prolonged speed	**1.3** ft/s	Min. depth	**0.5 ft**
	burst speed	**3.1** ft/s		

Over baffles & weirs: Velocity < burst speed; flow depth over weir is less than min. depth requiring jump over the baffles & we
Areas between baffles and weirs: Velocity < prolonged speed; flow depth > min. depth

The computed velocity and depth are within the acceptable range for Brook Trout.

FISH PASSAGE HIGH DESIGN FLOW (10% EXCEEDANCE DURING MIGRATION PERIOD: MAR-APR)

Hydraulic Condiiton Between Baffles/Weirs

Section	Reach	River S	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Hydr Dept (ft)	Max Chl Dpth (ft)
Downstream 23.3 ft Section of the Culvert	main	911.*	Fish High	5.5	312.35	313.64	1.38	4	4.38	0.91	1.29
	main	910.*	Fish High	5.5	312.31	313.64	1.32	4.18	4.42	0.95	1.33
	main	909.*	Fish High	5.5	312.26	313.64	1.25	4.41	4.47	0.99	1.38
	main	908.9		Inl Struct							
	main	908.*	Fish High	5.5	312.22	313.41	1.55	3.56	4.25	0.84	1.19
	main	907.*	Fish High	5.5	312.17	313.41	1.45	3.78	4.33	0.87	1.24
	main	906.*	Fish High	5.5	312.13	313.41	1.39	3.96	4.37	0.91	1.28
	main	905.*	Fish High	5.5	312.08	313.41	1.31	4.19	4.42	0.95	1.33
	main	904.*	Fish High	5.5	312.04	313.41	1.26	4.37	4.46	0.98	1.37
	main	903.9		Inl Struct							
	main	903.*	Fish High	5.5	311.99	313.18	1.54	3.58	4.26	0.84	1.19
	main	902.*	Fish High	5.5	311.95	313.18	1.47	3.75	4.32	0.87	1.23
	main	901.*	Fish High	5.5	311.9	313.19	1.38	3.98	4.37	0.91	1.29
	main	900.*	Fish High	5.5	311.86	313.19	1.32	4.16	4.41	0.94	1.33
	main	899.*	Fish High	5.5	311.81	313.19	1.25	4.39	4.46	0.98	1.38
	main	898.9		Inl Struct							
	main	898.*	Fish High	5.5	311.77	312.95	1.55	3.54	4.25	0.83	1.18
	main	897.*	Fish High	5.5	311.72	312.96	1.46	3.76	4.32	0.87	1.24
	main	896.*	Fish High	5.5	311.68	312.96	1.39	3.94	4.37	0.9	1.28
	main	895.*	Fish High	5.5	311.63	312.96	1.32	4.17	4.42	0.94	1.33
	main	894.*	Fish High	5.5	311.59	312.96	1.26	4.35	4.46	0.98	1.37
	main	893.9		Inl Struct							
	main	893.*	Fish High	5.5	311.54	312.74	1.53	3.6	4.27	0.84	1.2
	main	892.*	Fish High	5.5	311.5	312.74	1.46	3.77	4.32	0.87	1.24
	main	891.*	Fish High	5.5	311.45	312.74	1.38	4	4.38	0.91	1.29
	main	890.*	Fish High	5.5	311.41	312.74	1.32	4.18	4.42	0.95	1.33
	main	889.*	Fish High	5.5	311.36	312.74	1.25	4.41	4.47	0.99	1.38
	main	888.9		Inl Struct							
	main	888	Fish High	5.5	311.32	312.58	1.43	3.85	4.35	0.88	1.26
Fishway	main	887	Fish High	5.5	309	312.6	0.23	23.41	6.52	3.59	3.6
	main	882	Fish High	5.5	309	312.6	0.23	23.41	6.52	3.59	3.6
	main	881.8		Inl Struct							
	main	878	Fish High	5.5	309	312.26	0.26	21.25	6.52	3.26	3.26
	main	877.8		Inl Struct							
	main	873	Fish High	5.5	309	311.93	0.29	19.08	6.52	2.93	2.93
	main	872.8		Inl Struct							
	main	869	Fish High	5.5	309	311.6	0.33	16.91	6.52	2.59	2.6
	main	868.8		Inl Struct							
	main	864	Fish High	5.5	309	311.27	0.37	14.75	6.52	2.26	2.27
	main	863.8		Inl Struct							
	main	860	Fish High	5.5	309	310.93	0.44	12.56	6.52	1.93	1.93
	main	859.8		Inl Struct							
	main	858.98	Fish High	5.5	309.62	309.91	1.6	3.43	12.72	0.27	0.29
	main	848	Fish High	5.5	309.42	309.64	2.4	2.3	12.98	0.18	0.22

Hydraulic Data at Weirs/Baffles

Section	Reach	River Sta	Profile	E.G. Elev (ft)	W.S. Elev (ft)	Q Total (cfs)	Q Weir (cfs)	Weir Flow Area (sq ft)	Weir Max Depth (ft)	Weir Avg Depth (ft)	Ave Vel. over Weir (ft/s)
Over Baffles inside the culvert	main	908.9	Fish High	313.67	313.64	5.5	5.5	2.68	0.91	0.6	2.05
	main	903.9	Fish High	313.44	313.41	5.5	5.5	2.68	0.91	0.6	2.05
	main	898.9	Fish High	313.21	313.19	5.5	5.5	2.66	0.9	0.59	2.07
	main	893.9	Fish High	312.99	312.96	5.5	5.5	2.66	0.9	0.59	2.07
	main	888.9	Fish High	312.77	312.74	5.5	5.5	2.68	0.91	0.6	2.05
Over the weir notches	main	881.8	Fish High	312.6	312.6	5.5	5.5	2.18	1.03	0.33	2.52
	main	877.8	Fish High	312.27	312.26	5.5	5.5	2.17	1.03	0.33	2.53
	main	872.8	Fish High	311.93	311.93	5.5	5.5	2.21	1.03	0.34	2.49
	main	868.8	Fish High	311.6	311.6	5.5	5.5	2.19	1.03	0.34	2.51
	main	863.8	Fish High	311.27	311.27	5.5	5.5	2.18	1.03	0.33	2.52
	main	859.8	Fish High	310.93	310.93	5.5	5.5	2.21	1.03	0.34	2.49

Brook Trout	prolonged speed	**1.3**	ft/s	Min. depth	**0.5 ft**
	burst speed	**3.1**	ft/s		

Over baffles & weirs: Velocity < burst speed; depth close to min. requiring jump over the weirs (adequate for baffles)
Areas between baffles and weirs: Velocity slight above prolonged speed downstream of baffles but becomes lower as approaches the baffles; flow depth > min. depth

The computed velocity and depth are within the acceptable range for Brook Trout

172-392 Str06689 Determination of Summer Low and Fall Flows

Use Discharges from StreamStat:

Although some parameters used in StreamStat are outside the suggested range, the results for the low flow conditions seem to be within an acceptable range of the actual observed site conditions. Therefore, the StreamStat low flows are directly used in the hydraulic computations. However, for the higher storm events (2-year and up), the flows are computed using the NRCS/SCS hydrographic method.

The selected discharges from the results are:

JUND75 (June streamflow exceeded 75 percent of the time) ------------ 0.38 cfs
D75_07_10 (July to October flow exceeded 75 percent of the time.) --- 0.09 cfs
NOVD75 (November streamflow exceeded 75 percent of the time) ---- 0.52 cfs
**75%-tile flows are selected as it is deemed most reflective of the site condition.*

The summarized tables from StreamStat are shown below for the low flows.

RESIDENT SPAWNING Streamflow Statistics					
Statistic	Flow (ft^3/s)	Estimation Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
				Minimum	Maximum
JUND25	1.47	22			
JUND50	0.72	25			
JUND75	0.38	32			
JUND90	0.21	41			
JUND99	0.0831	67			

REARING AND GROWTH Streamflow Statistics					
Statistic	Flow (ft^3/s)	Estimation Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
				Minimum	Maximum
D25_07_10	0.56	31			
D50_07_10	0.21	41			
D75_07_10	0.0876	54			
D80_07_10	0.07	59			
D99_07_10	0.00692	160			

SALMONID SPAWNING Streamflow Statistics					
Statistic	Flow (ft^3/s)	Estimation Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
				Minimum	Maximum
NOVD25	2.11	21			
NOVD50	1.16	21			
NOVD75	0.52	27			
NOVD90	0.24	36			
NOVD99	0.0778	55			

Computed Depth:

The SteamStat low flows were applied in the existing condition model to determine the flow depth for comparison. The computed flow depths in the east barrel of the culvert (also at outlet) are:

JUND75:	East Cell.	0.13 ft or	1.56 in.	{June}
	West Cell.	0.05 ft or	0.6 in.	
D75_07_10:	East Cell.	0.07 ft or	0.84 in.	{Jul. ~ Oct.}
	West Cell.	n/a(dry)		
NOVD75:	East Cell.	0.15 ft or	1.8 in.	{Nov.}
	West Cell.	0.06 ft or	0.72 in.	

Actual observed depth:

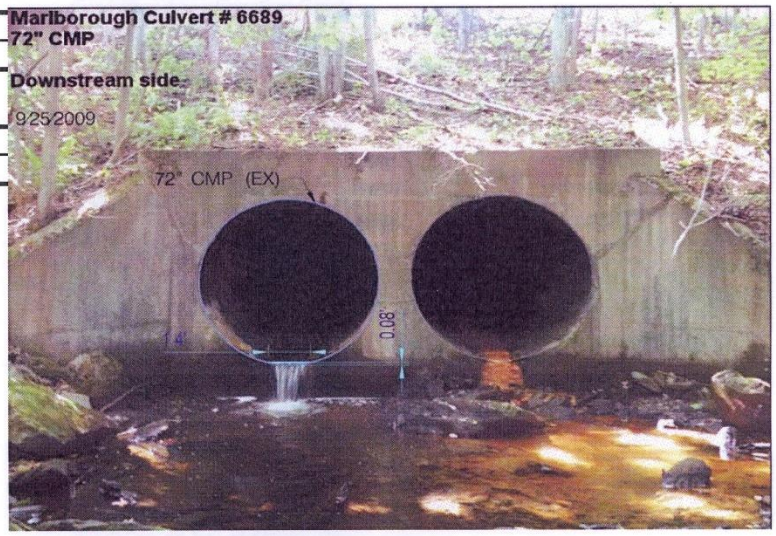
9/25/2009:

East Cell.	0.08 ft
West Cell.	0 ft

or

E	0.96 in.
W	0 in.

**Computed depth match closely.*



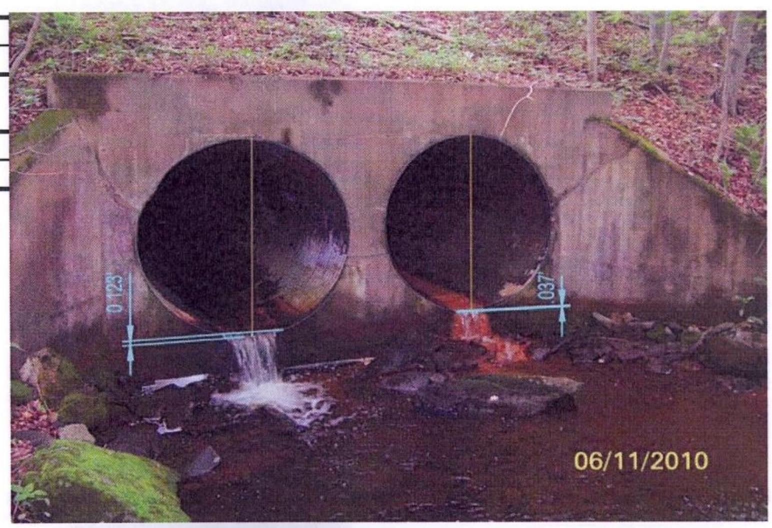
6/11/2010:

East Cell.	0.123 ft
West Cell.	0.037 ft

or

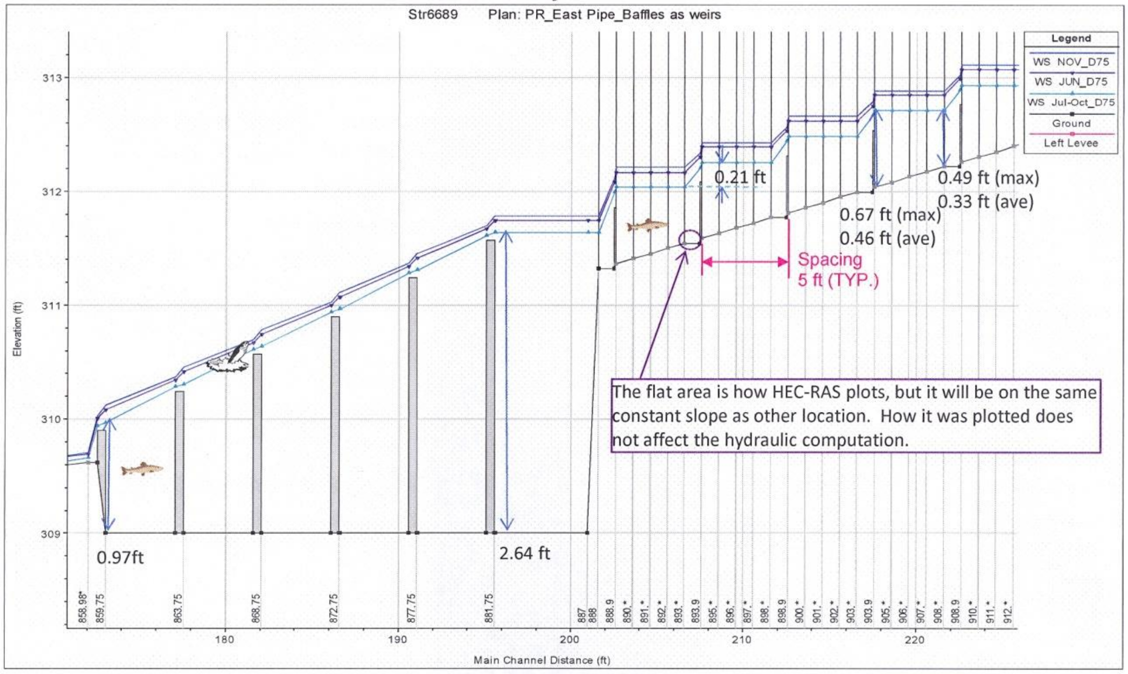
E	1.48 in.
W	0.44 in.

**Computer and observe depths match closely.*

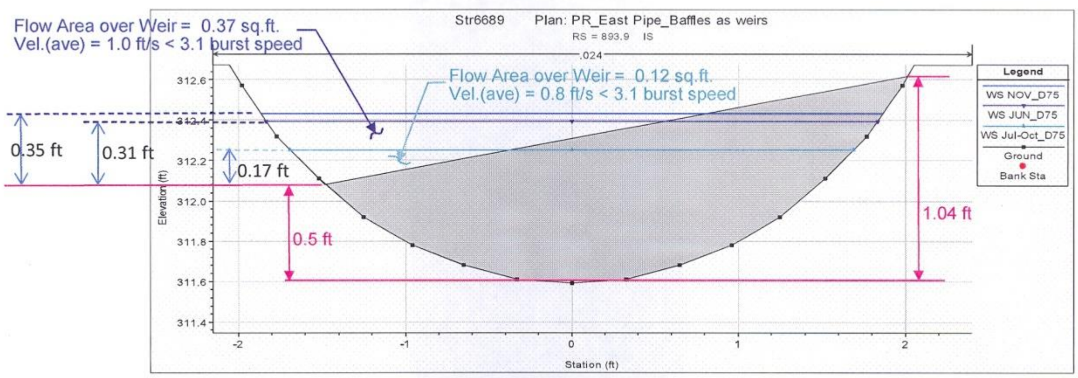


172-392 Str06689 Summer Low and Fall Flows

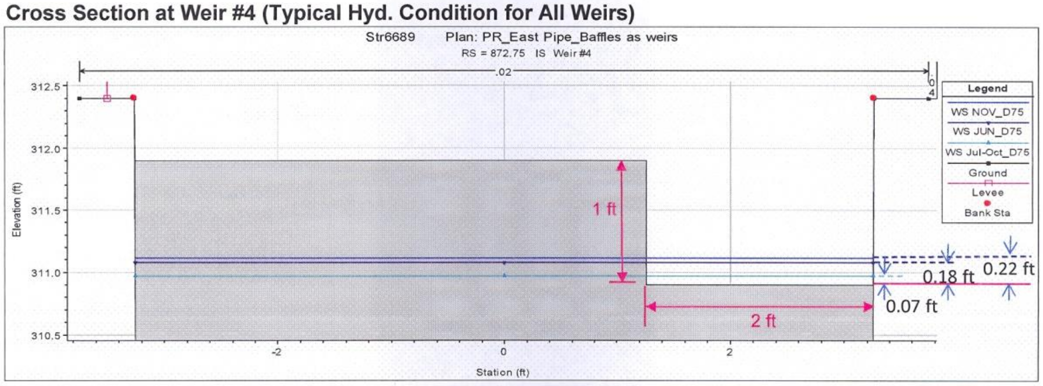
Profile - Downstream End of Culvert and Fishway



Typical Cross Section at A Baffle Inside The Culvert



Cross Section at Weir #4 (Typical Hyd. Condition for All Weirs)



NOVEMBER FLOW (75%-tile)

Hydraulic Condiiton Between Baffles/Weirs

	Reach	River S	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Hydr Dept (ft)	Max Chl Dpth (ft)
Downstream 23.3 ft Section of the Culvert	main	911.*	NOV_D75	0.52	312.35	313.11	0.28	1.87	3.59	0.52	0.76
	main	910.*	NOV_D75	0.52	312.31	313.11	0.26	2.01	3.66	0.55	0.8
	main	909.*	NOV_D75	0.52	312.26	313.11	0.24	2.2	3.74	0.59	0.85
	main	908.9		Inl Struct							
	main	908.*	NOV_D75	0.52	312.22	312.88	0.34	1.53	3.38	0.45	0.66
	main	907.*	NOV_D75	0.52	312.17	312.88	0.31	1.7	3.5	0.49	0.71
	main	906.*	NOV_D75	0.52	312.13	312.88	0.28	1.85	3.58	0.52	0.75
	main	905.*	NOV_D75	0.52	312.08	312.88	0.26	2.03	3.66	0.55	0.8
	main	904.*	NOV_D75	0.52	312.04	312.88	0.24	2.18	3.73	0.58	0.84
	main	903.9		Inl Struct							
	main	903.*	NOV_D75	0.52	311.99	312.66	0.34	1.55	3.4	0.46	0.67
	main	902.*	NOV_D75	0.52	311.95	312.66	0.31	1.69	3.49	0.48	0.71
	main	901.*	NOV_D75	0.52	311.9	312.66	0.28	1.87	3.59	0.52	0.76
	main	900.*	NOV_D75	0.52	311.86	312.66	0.26	2.01	3.66	0.55	0.8
	main	899.*	NOV_D75	0.52	311.81	312.66	0.24	2.2	3.74	0.59	0.85
	main	898.9		Inl Struct							
	main	898.*	NOV_D75	0.52	311.77	312.43	0.34	1.52	3.37	0.45	0.66
	main	897.*	NOV_D75	0.52	311.72	312.43	0.31	1.69	3.49	0.48	0.71
	main	896.*	NOV_D75	0.52	311.68	312.43	0.28	1.83	3.57	0.51	0.75
	main	895.*	NOV_D75	0.52	311.63	312.43	0.26	2.01	3.66	0.55	0.8
	main	894.*	NOV_D75	0.52	311.59	312.43	0.24	2.16	3.72	0.58	0.84
	main	893.9		Inl Struct							
	main	893.*	NOV_D75	0.52	311.54	312.21	0.33	1.57	3.41	0.46	0.67
	main	892.*	NOV_D75	0.52	311.5	312.22	0.3	1.71	3.5	0.49	0.71
	main	891.*	NOV_D75	0.52	311.45	312.22	0.28	1.89	3.6	0.52	0.77
	main	890.*	NOV_D75	0.52	311.41	312.22	0.26	2.03	3.67	0.55	0.81
	main	889.*	NOV_D75	0.52	311.36	312.22	0.23	2.22	3.75	0.59	0.86
	main	888.9		Inl Struct							
	main	888	NOV_D75	0.52	311.32	311.78	0.58	0.9	2.88	0.31	0.46
Fishway	main	887	NOV_D75	0.52	309	311.79	0.03	18.13	6.51	2.78	2.79
	main	882	NOV_D75	0.52	309	311.79	0.03	18.13	6.51	2.78	2.79
	main	881.8		Inl Struct							
	main	878	NOV_D75	0.52	309	311.46	0.03	15.98	6.51	2.45	2.46
	main	877.8		Inl Struct							
	main	873	NOV_D75	0.52	309	311.12	0.04	13.76	6.51	2.11	2.12
	main	872.8		Inl Struct							
	main	869	NOV_D75	0.52	309	310.79	0.04	11.62	6.51	1.78	1.79
	main	868.8		Inl Struct							
	main	864	NOV_D75	0.52	309	310.46	0.05	9.48	6.51	1.46	1.46
	main	863.8		Inl Struct							
	main	860	NOV_D75	0.52	309	310.12	0.07	7.28	6.51	1.12	1.12
	main	859.8		Inl Struct							
	main	858.98	NOV_D75	0.52	309.62	309.71	0.58	0.89	11.83	0.08	0.09
	main	848	NOV_D75	0.52	309.42	309.49	1.24	0.42	11.7	0.04	0.07

Hydraulic Data at Weirs/Baffles

	Reach	River Sta	Profile	E.G. Elev (ft)	W.S. Elev (ft)	Q Total (cfs)	Q Weir (cfs)	Weir Flow Area (sq ft)	Weir Max Depth (ft)	Weir Avg Depth (ft)	Ave Vel. over Weir (ft/s)
Over Baffles inside the culvert	main	908.9	NOV_D75	313.11	313.11	0.52	0.52	0.47	0.35	0.18	1.11
	main	903.9	NOV_D75	312.88	312.88	0.52	0.52	0.48	0.35	0.18	1.08
	main	898.9	NOV_D75	312.66	312.66	0.52	0.52	0.47	0.35	0.18	1.11
	main	893.9	NOV_D75	312.43	312.43	0.52	0.52	0.47	0.35	0.18	1.11
	main	888.9	NOV_D75	312.22	312.22	0.52	0.52	0.49	0.35	0.18	1.06
Over the weir notches	main	881.8	NOV_D75	311.79	311.79	0.52	0.52	0.43	0.22	0.22	1.21
	main	877.8	NOV_D75	311.46	311.46	0.52	0.52	0.43	0.22	0.22	1.21
	main	872.8	NOV_D75	311.12	311.12	0.52	0.52	0.43	0.22	0.22	1.21
	main	868.8	NOV_D75	310.79	310.79	0.52	0.52	0.43	0.22	0.22	1.21
	main	863.8	NOV_D75	310.46	310.46	0.52	0.52	0.43	0.22	0.22	1.21
	main	859.8	NOV_D75	310.12	310.12	0.52	0.52	0.44	0.22	0.22	1.18

Brook Trout	prolonged speed	**1.3** ft/s	Min. depth	**0.5 ft**
	burst speed	**3.1** ft/s		

Over baffles & weirs: Velocity < burst speed; ave. depth close to min. depth
Areas between baffles and weirs: Velocity close to prolonged speed; flow depth > min. depth

The computed velocity and depth are within the acceptable range for Brook Trout

JUNE FLOW (75%-tile)

Hydraulic Condiiton Between Baffles/Weirs

	Reach	River S	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Hydr Dept (ft)	Max Chl Dpth (ft)
Downstream 23.3 ft Section of the Culvert	main	911.*	JUN_D75	0.38	312.35	313.07	0.22	1.72	3.51	0.49	0.72
	main	910.*	JUN_D75	0.38	312.31	313.07	0.2	1.86	3.59	0.52	0.76
	main	909.*	JUN_D75	0.38	312.26	313.07	0.19	2.05	3.67	0.56	0.81
	main	908.9		Inl Struct							
	main	908.*	JUN_D75	0.38	312.22	312.85	0.27	1.41	3.29	0.43	0.63
	main	907.*	JUN_D75	0.38	312.17	312.85	0.24	1.58	3.41	0.46	0.68
	main	906.*	JUN_D75	0.38	312.13	312.85	0.22	1.72	3.51	0.49	0.72
	main	905.*	JUN_D75	0.38	312.08	312.85	0.2	1.89	3.6	0.53	0.77
	main	904.*	JUN_D75	0.38	312.04	312.85	0.19	2.04	3.67	0.56	0.81
	main	903.9		Inl Struct							
	main	903.*	JUN_D75	0.38	311.99	312.62	0.27	1.42	3.3	0.43	0.63
	main	902.*	JUN_D75	0.38	311.95	312.62	0.24	1.55	3.39	0.46	0.67
	main	901.*	JUN_D75	0.38	311.9	312.62	0.22	1.72	3.51	0.49	0.72
	main	900.*	JUN_D75	0.38	311.86	312.62	0.2	1.87	3.59	0.52	0.76
	main	899.*	JUN_D75	0.38	311.81	312.62	0.19	2.05	3.67	0.56	0.81
	main	898.9		Inl Struct							
	main	898.*	JUN_D75	0.38	311.77	312.39	0.27	1.4	3.29	0.43	0.62
	main	897.*	JUN_D75	0.38	311.72	312.39	0.24	1.57	3.41	0.46	0.67
	main	896.*	JUN_D75	0.38	311.68	312.39	0.22	1.71	3.5	0.49	0.71
	main	895.*	JUN_D75	0.38	311.63	312.39	0.2	1.88	3.6	0.52	0.76
	main	894.*	JUN_D75	0.38	311.59	312.39	0.19	2.03	3.66	0.55	0.8
	main	893.9		Inl Struct							
	main	893.*	JUN_D75	0.38	311.54	312.17	0.27	1.41	3.3	0.43	0.63
	main	892.*	JUN_D75	0.38	311.5	312.17	0.25	1.55	3.39	0.46	0.67
	main	891.*	JUN_D75	0.38	311.45	312.17	0.22	1.72	3.51	0.49	0.72
	main	890.*	JUN_D75	0.38	311.41	312.17	0.2	1.86	3.59	0.52	0.76
	main	889.*	JUN_D75	0.38	311.36	312.17	0.19	2.05	3.67	0.56	0.81
	main	888.9		Inl Struct							
	main	888	JUN_D75	0.38	311.32	311.74	0.48	0.79	2.76	0.29	0.42
Fishway	main	887	JUN_D75	0.38	309	311.75	0.02	17.86	6.51	2.74	2.75
	main	882	JUN_D75	0.38	309	311.75	0.02	17.86	6.51	2.74	2.75
	main	881.8		Inl Struct							
	main	878	JUN_D75	0.38	309	311.41	0.02	15.7	6.51	2.41	2.41
	main	877.8		Inl Struct							
	main	873	JUN_D75	0.38	309	311.08	0.03	13.5	6.51	2.07	2.08
	main	872.8		Inl Struct							
	main	869	JUN_D75	0.38	309	310.75	0.03	11.36	6.51	1.74	1.75
	main	868.8		Inl Struct							
	main	864	JUN_D75	0.38	309	310.42	0.04	9.21	6.51	1.41	1.42
	main	863.8		Inl Struct							
	main	860	JUN_D75	0.38	309	310.08	0.05	7.02	6.51	1.08	1.08
	main	859.8		Inl Struct							
	main	858.98	JUN_D75	0.38	309.62	309.69	0.52	0.73	11.73	0.06	0.07
	main	848	JUN_D75	0.38	309.42	309.48	1.03	0.37	11.66	0.03	0.06

Hydraulic Data at Weirs/Baffles

	Reach	River Sta	Profile	E.G. Elev (ft)	W.S. Elev (ft)	Q Total (cfs)	Q Weir (cfs)	Weir Flow Area (sq ft)	Weir Max Depth (ft)	Weir Avg Depth (ft)	Ave Vel. over Weir (ft/s)
Over Baffles inside the culvert	main	908.9	JUN_D75	313.07	313.07	0.38	0.38	0.37	0.31	0.16	1.03
	main	903.9	JUN_D75	312.85	312.85	0.38	0.38	0.38	0.31	0.16	1.00
	main	898.9	JUN_D75	312.62	312.62	0.38	0.38	0.37	0.31	0.16	1.03
	main	893.9	JUN_D75	312.39	312.39	0.38	0.38	0.38	0.31	0.16	1.00
	main	888.9	JUN_D75	312.17	312.17	0.38	0.38	0.37	0.31	0.16	1.03
Over the weir notches	main	881.8	JUN_D75	311.75	311.75	0.38	0.38	0.35	0.18	0.18	1.09
	main	877.8	JUN_D75	311.41	311.41	0.38	0.38	0.35	0.17	0.17	1.09
	main	872.8	JUN_D75	311.08	311.08	0.38	0.38	0.35	0.18	0.18	1.09
	main	868.8	JUN_D75	310.75	310.75	0.38	0.38	0.35	0.18	0.18	1.09
	main	863.8	JUN_D75	310.42	310.42	0.38	0.38	0.35	0.18	0.18	1.09
	main	859.8	JUN_D75	310.08	310.08	0.38	0.38	0.36	0.18	0.18	1.06

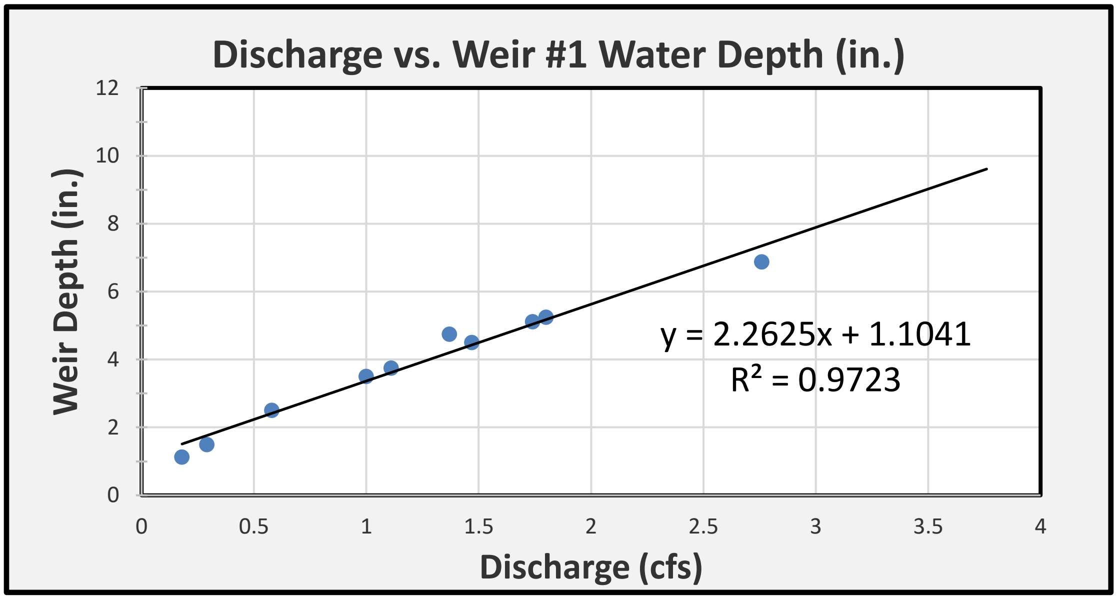
Brook Trout	prolonged speed	**1.3** ft/s	Min. depth	**0.5 ft**
	burst speed	**3.1** ft/s		

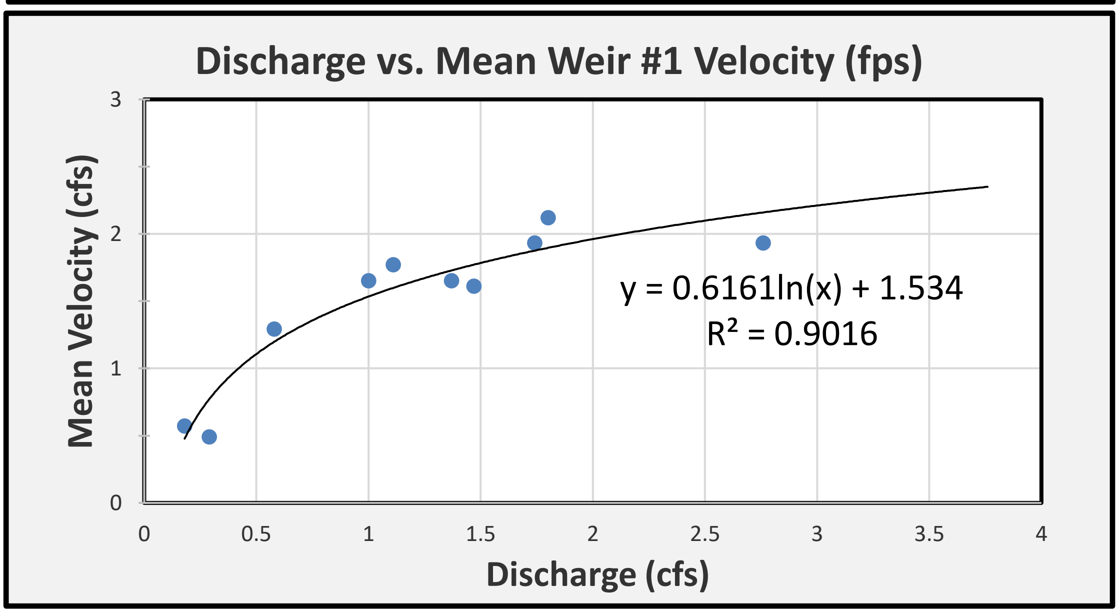
Over baffles & weirs: Velocity < burst speed; depth close to min.
Areas between baffles and weirs: Velocity slight above prolonged speed; flow depth > min. depth

The computed velocity and depth are within the acceptable range for Brook Trout

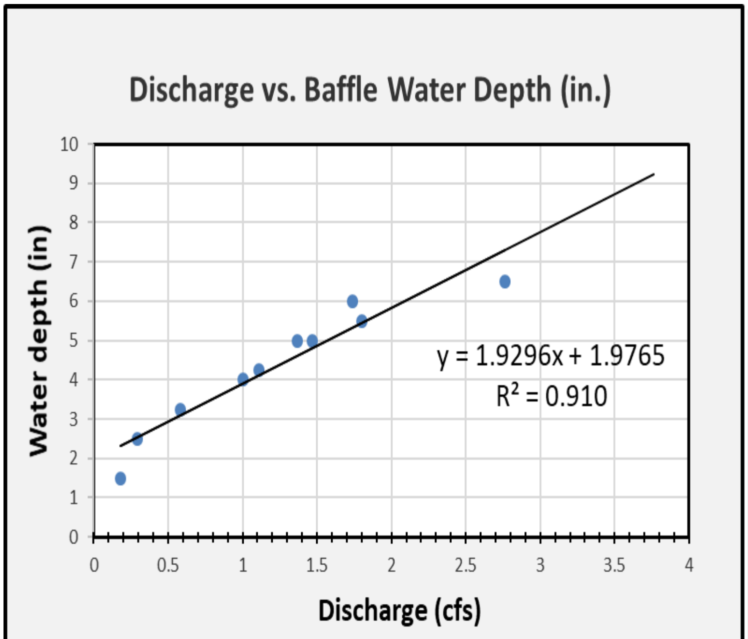
APPENDIX C

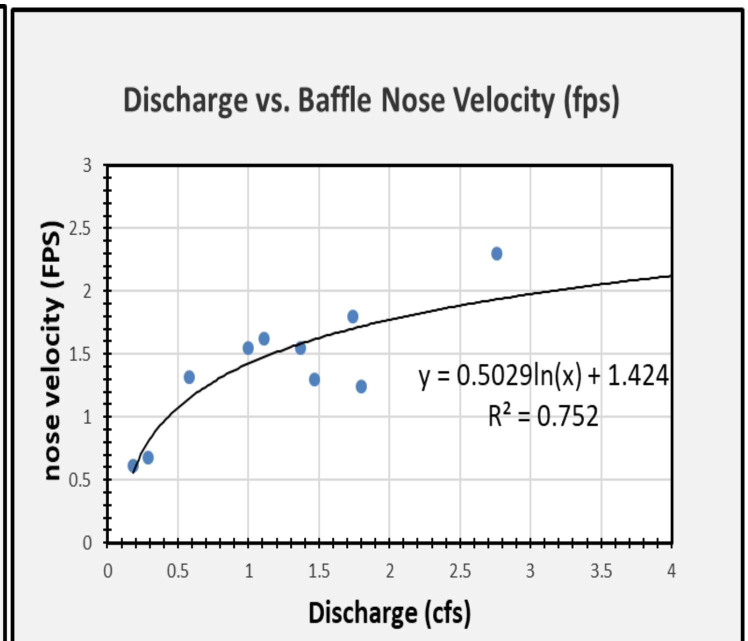
Weir # 6 Metrics

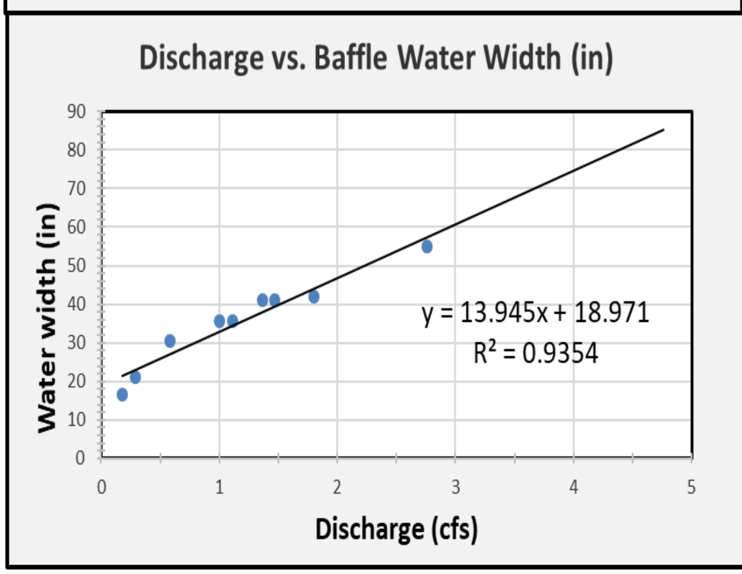


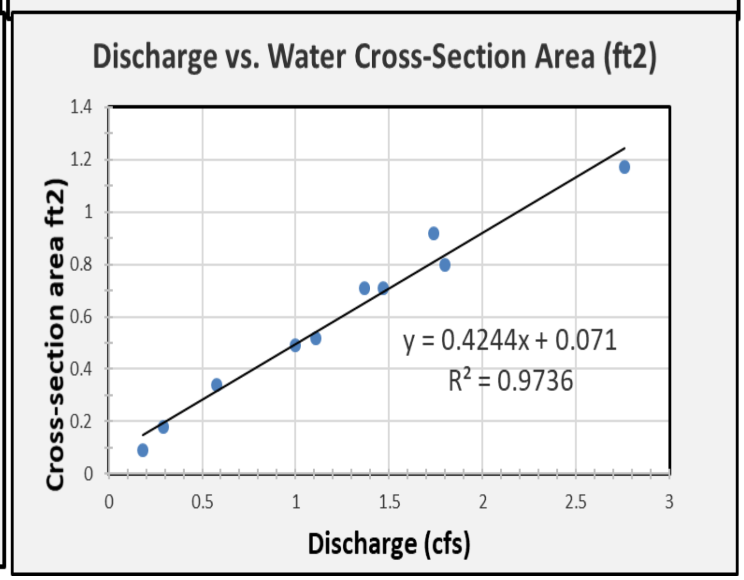


Baffle # 1 Metrics









Culvert Entrance Metrics