Effects of Small Dams on Aquatic Biota in Two Connecticut Streams

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Cover photograph:

Connecticut Department of Energy and Environmental Protection file photo. Connecticut Department of Energy and Environmental Protection, Hartford, CT. Glenville Pond Dam in the Furnace Brook watershed, Stafford, Connecticut. Photo taken September 16, 2008.

Introduction

It is well documented that dams have an effect on the downstream habitat in several ways including; modification of the magnitude and timing of stream flow; alteration of quality and quantity of sediment; changes to water temperature regime; alteration of food/nutrient dynamics, and physical habitat; create barriers to organism movement (Graf, 2006; Magillian and Nislow, 2005; Ligon et al., 1995; Poff and Hart, 2002). These various effects on stream habitat depend on both the size of the dam size and the operation of the dam (Poff and Hart, 2002). Most studies have focused on the ecological effects of large dams since their impacts can greatly influence aquatic biota (Leopold et al., 1964).

In Connecticut, residents have been constructing dams for industrial use, water supply, fire protection and mechanical power since the early 1600's and as such, dams are a ubiquitous feature on the landscape. Over time, human needs have changed, resulting in numerous abandoned dams scattered throughout the state.

Connecticut has relatively few large dams and our understanding of how small surface-release dams may influence downstream aquatic life is incomplete. The Connecticut Department of Energy and Environmental Protection (DEEP) Dam Safety Program maintains a database of over 4,000 dams in Connecticut (Figure 1). Less than 5% of these are large dams (>10 m in height) (*sensu* Hayes *et al.*, 2006) and approximately 95% are smaller (< 10 m in height). The majority of small dams are run-of-river surface release dams that overflow when water levels in the impoundment exceed the dam height. Multiple stressors from these dams complicate the identification of most probable causes of aquatic life impairments using Connecticut's Stressor Identification Procedures, necessitating a greater understanding of small dam effects.

This study sought to characterize the effect of small dams on water temperature, macroinvertebrate and fish communities in Mill River, New Haven County, (a single dam in the study reach) and Furnace Brook, Windham County, (six dams are present in the study reach). Geographic information systems (GIS) and field checks were used to develop a list of suitable sampling locations. Water temperature data loggers were deployed at all study locations. Analysis focused on correlating environmental variables with aquatic biota to quantify relationships between variables to support the causal analysis step of Stressor Identification Work in Connecticut.

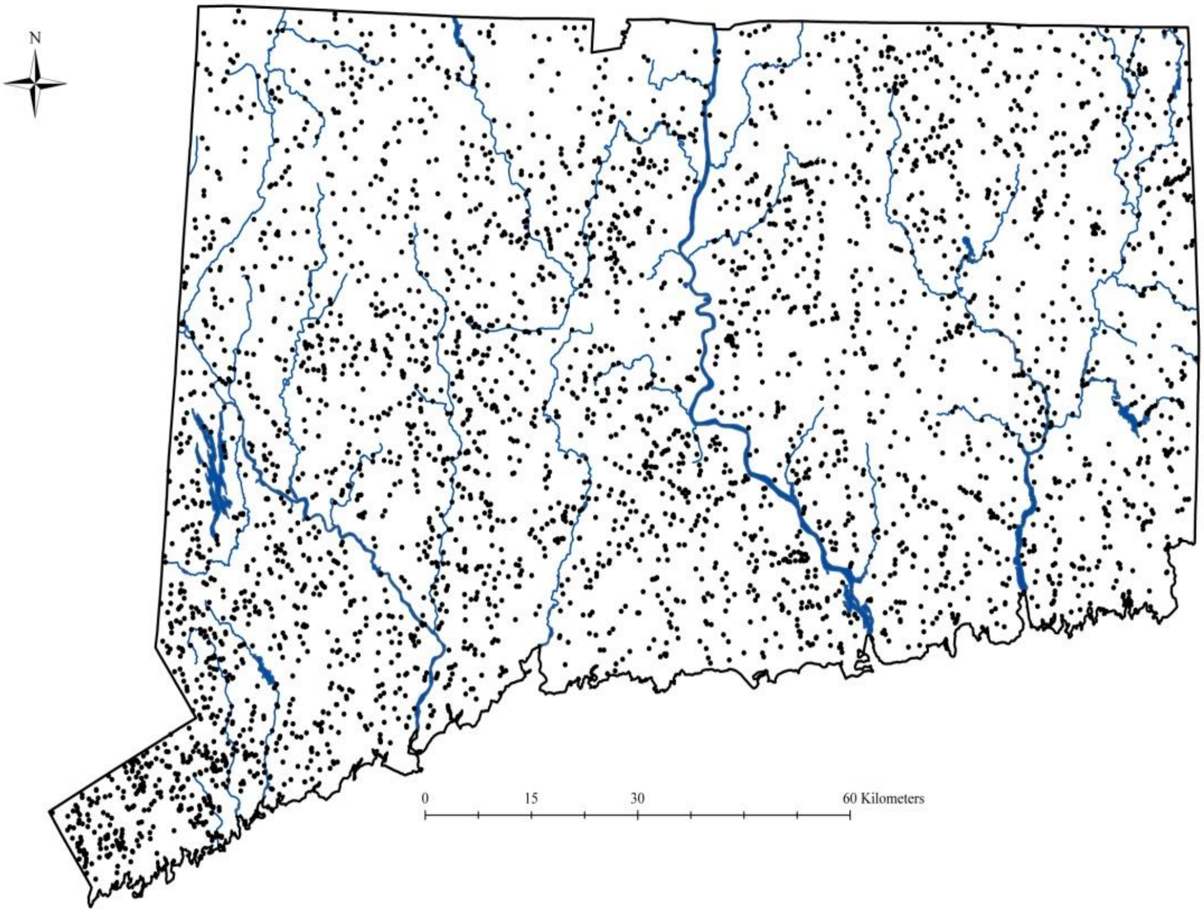

Figure 1. Locations of dams (solid black circles) in the Connecticut Department of Energy and Environmental Protection Dam Safety Project database.

Methods

Study Areas

Mill River is a fourth-order stream located in New Haven County, Connecticut (Figure 2). The Mill River watershed drains 66 km^2 and discharges into the New Haven Harbor. This study focused on a 5.25 km segment of the river with study sites (Table 1) spaced 0.5 to 1 km apart.

Clark's Pond Dam (Figure 3) is a 35 m long by 3 m high concrete dam that forms Clark's Pond (Figure 4), a shallow 0.9 hectare pond that has a surface release to the Mill River. Historic reports indicate that a dam has been present in this location since approximately the 1850's (Petry 1981). The river is well buffered by forest in the study section as the watershed is a protected water supply and contains few tributaries.

Furnace Brook is located in Windham County, Connecticut (Figure 5). The Furnace Brook watershed is 42 km^2 and joins Middle River to form the Willimantic River. Six dams (Figure 6, Table 2) are located on the study section of the river: Staffordville Reservoir Dam, Hydeville Pond Dam, Riverside Pond Dam, Glenville Pond Dam, Warren Pond Dam, and Cyril Dam.

Stream Water Temperature

Stream water temperatures were collected hourly using data loggers (TidBit ® v2 Data Logger, ONSET ® Computer Corporation, Bourne, MA) deployed each site's thalweg from January 1, 2009 - December 31, 2009. Mean summer (June-August) water temperature was calculated for each site. This allowed for quantification of the warmest, and thus potentially biologically limiting, water temperatures at the sites.

Biological Sampling

Fish sampling was conducted during June 2009 at Furnace Brook and during July 2009 at Mill River. Sampling was performed during a period of low stream flow to maximize sampling efficiency. Typically, 150 meters of stream were electrofished using single tow barge electro fishing unit (Hagstrom et al. 1995). A single pass was completed at each location and all species were measured to the nearest centimeter (total length), counted, and immediately released into the stream.

Benthic macroinvertebrate samples were collected from all sites on two consecutive years in October 2008 and September 2009 using an 800 *u*m-mesh kick net. A total of 2 m^2 of riffle habitat (12 kicks composited from multiple riffles of a stream reach) was sampled at each location. Samples were preserved in 70% ethyl alcohol and brought back to the laboratory for subsampling. A 200-organism subsample was taken using a random grid design (Plafkin et al. 1989) from each sampling location. Organisms were identified to the lowest practical taxonomic level.

Data Analysis

A fish multimetric index (MMI) score was calculated using the mixed water MMI since it was the most appropriate (Kanno et al., 2010) for these study locations. A macroinvertebrate MMI score for each site was calculated using a 200 organism subsample at the genus level (Gerritsen and Jessup 2007). The MMI is composed of 7 metrics: Ephemeroptera (E) taxa, Plecoptera (P) taxa, Trichoptera (T) taxa, percent sensitive EPT, scraper taxa, BCG taxa biotic index, and percent dominant genus.

The MMI score is the average score of all seven metrics and ranges from 0-100 with low values representing high stress and high values representing least stressed sites. Graphs of temperature, macroinvertebrate and fish data were prepared using MiniTab®16 statistical software.

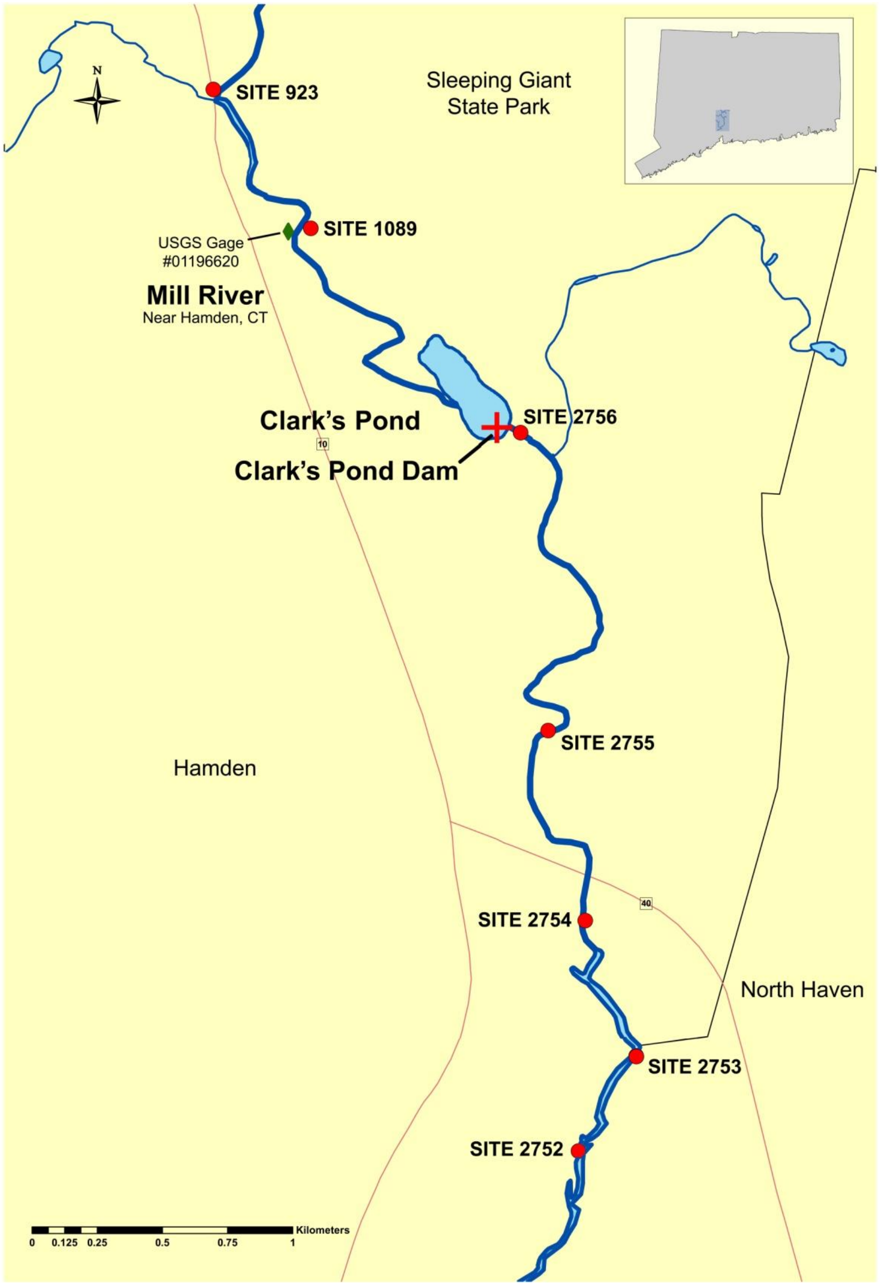

Figure 2. Study site locations on the Mill River, New Haven County (Subregional Basin Number 5302).

Figure 3. Clark's Pond Dam on the Mill River, 2008.

Figure 4. Clark's Pond, 2008.

Figure 5. Furnace Brook Dams. From top left to bottom right: Staffordville Reservoir Dam, Hydeville Pond Dam, Riverside Pond Dam, Glenville Pond Dam, Warren Pond Dam, and Cyril Dam.

Table 1: Mill River study sites and site descriptions. Negative values are upstream from Clark's Pond Dam and Reservoir Dam and positive values are downstream.

Station ID	Site Description	Distance to Dam (km)	Latitude	Longitude
923	at first pull-off Route 10 downstream Tuttle Ave	-1.90	41.4259	-72.9055
1089	Upstream Mount Carmel Ave in Sleeping Giant State Park	-1.20	41.4211	-72.9022
	Clark's Pond Dam	0		
2756	downstream New Road (Clarke's Pond)	0.05	41.4140	-72.8949
2755	Upstream Ives Street	1.52	41.4037	-72.894
2754	adjacent Route 22 (Broadway)	2.35	41.3972	-72.8927
2753	adjacent Riverside Drive	2.93	41.3925	-72.8909
2752	Adjacent Legion athletic field	3.35	41.3892	-72.8929

Table 2: Furnace Brook study sites and site descriptions. Distances are from Staffordville Reservoir Dam. Negative values are upstream of the Staffordville Reservoir Dam and positive values are downstream.

Station ID	Site Description	Distance to Dam (km)	Latitude	Longitude
2757	Adjacent to Delphi Rd.	-2.93	42.0211	-72.2517
	Staffordville Reservoir Dam	0		
2758	Adjacent to Rt. 19	1.17	41.9934	-72.2695
	Hydeville Pond Dam	1.77		
2759	Upstream of Hydeville Rd.	1.81	41.9937	-72.2767
	Riverside Pond Dam	3.70		
89	Upstream of Orcuttville Rd.	4.20	41.9841	-72.2947
	Glenville Pond Dam	6.32		
90	Downstream of Glenville Pond	6.33	41.4037	-72.2979
	Warren Pond Dam	7.25		
2760	Downstream of Warren Pond	7.27	41.9599	-72.2994
	Cyril Dam	7.80		
543	Upstream of concrete channel	7.82	41.9554	-72.3013

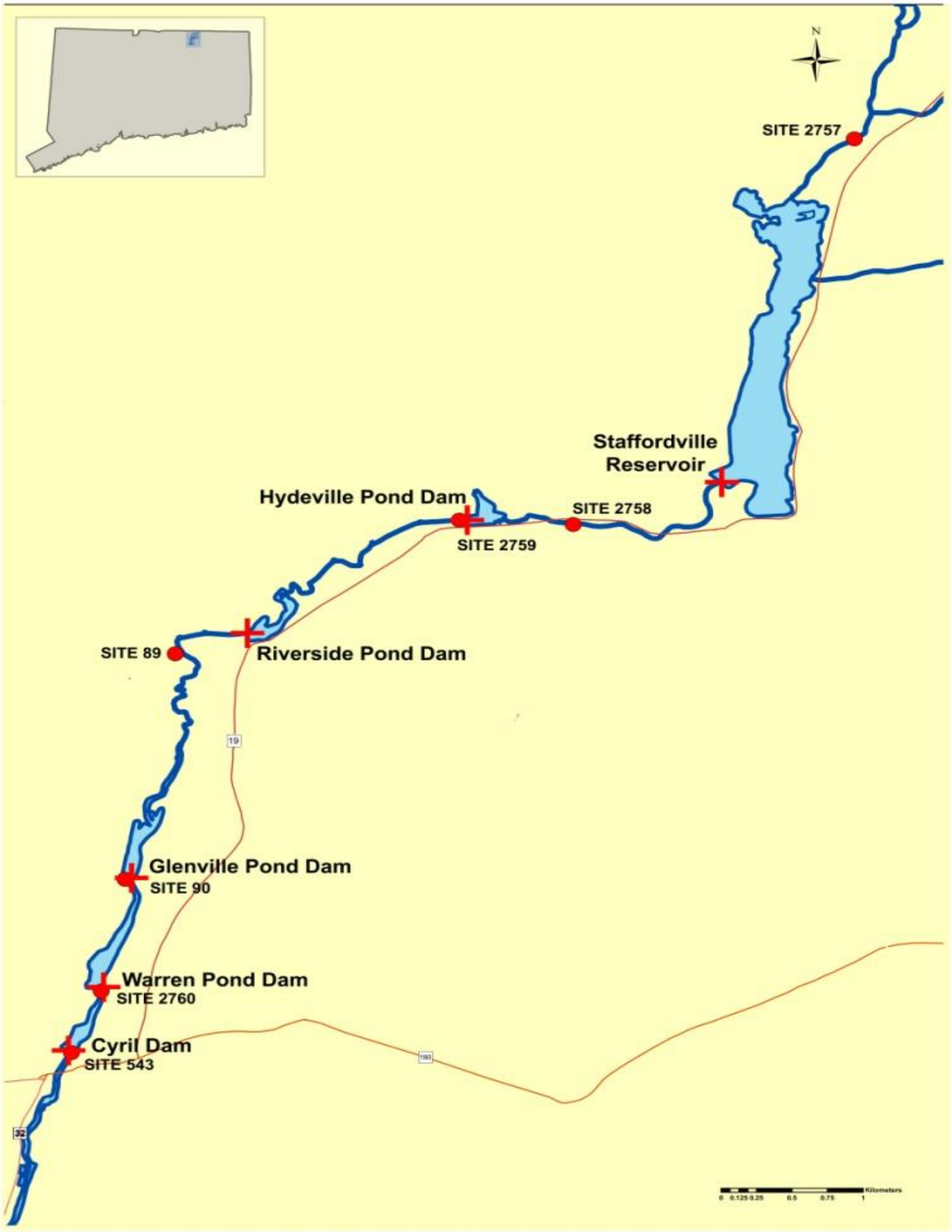

Figure 6. Study site locations on Furnace Brook, Windham County (Subregional Basin Number 3103)

Results

Summer (June-August) and mean annual stream flows during the study period were between the median and 75th percentile of flows for a 31 year period of record, 1978-2009 at USGS Station 01196620, Mill River near Hamden, Connecticut (Fig. 7). This location is in the Mill River study reach (Fig. 2) and is a good representation of flow conditions for years the study was conducted.

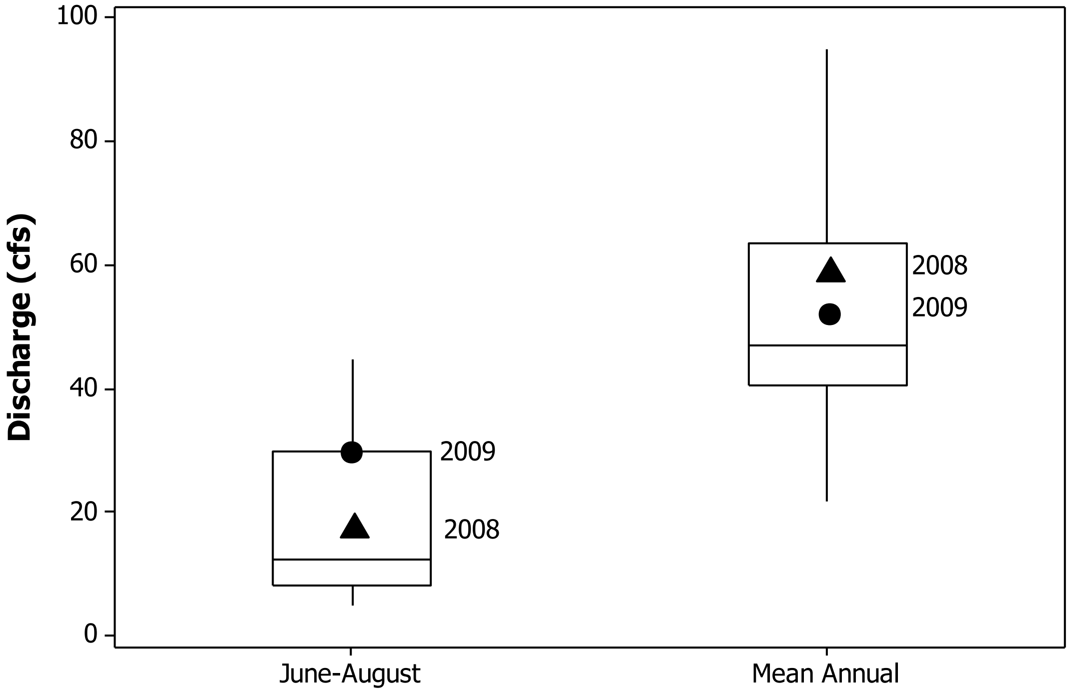

Figure 7. Summer (June- August) and mean annual stream flow during 2008 (solid triangles) and 2009 (solid circles) compared to the period of record 1978-2009 at USGS Station 01196620, Mill River near Hamden, Connecticut.

Effect of a Single Dam- Mill River

Water Temperature

Figure 8 illustrates average daily water temperature for all Mill River study sites during 2009. Site 923 has signals of groundwater input, leading to cooler water temperatures during the summer months, and warmer temperatures during the winter, relative to other study sites. Average site temperatures peaked at around 24°C in August, which had the warmest water temperatures (Fig. 9). Figure 10 shows Mill River mean summer water temperatures at points relative to Clark’s Pond Dam. Negative downstream distance (e.g. station ID 923, 1089) indicates site locations upstream of Clark’s Pond Dam.

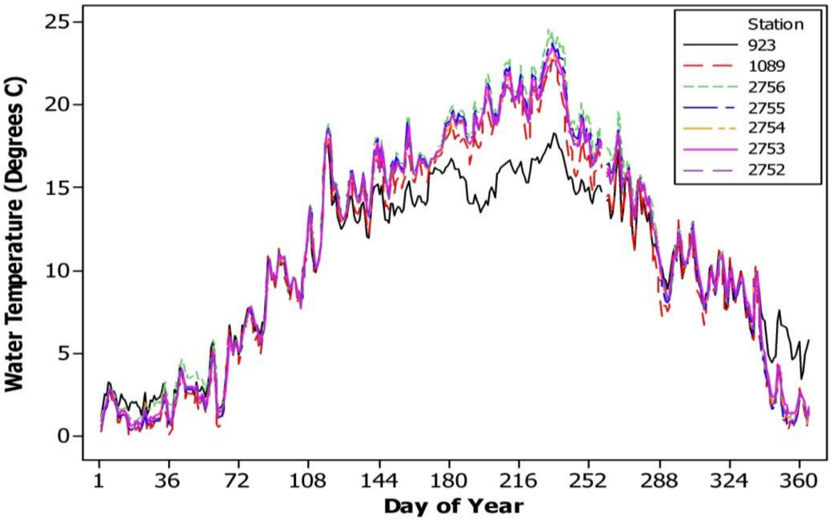

Figure 8. Mill River average daily water (degrees C), 2009 calendar year.

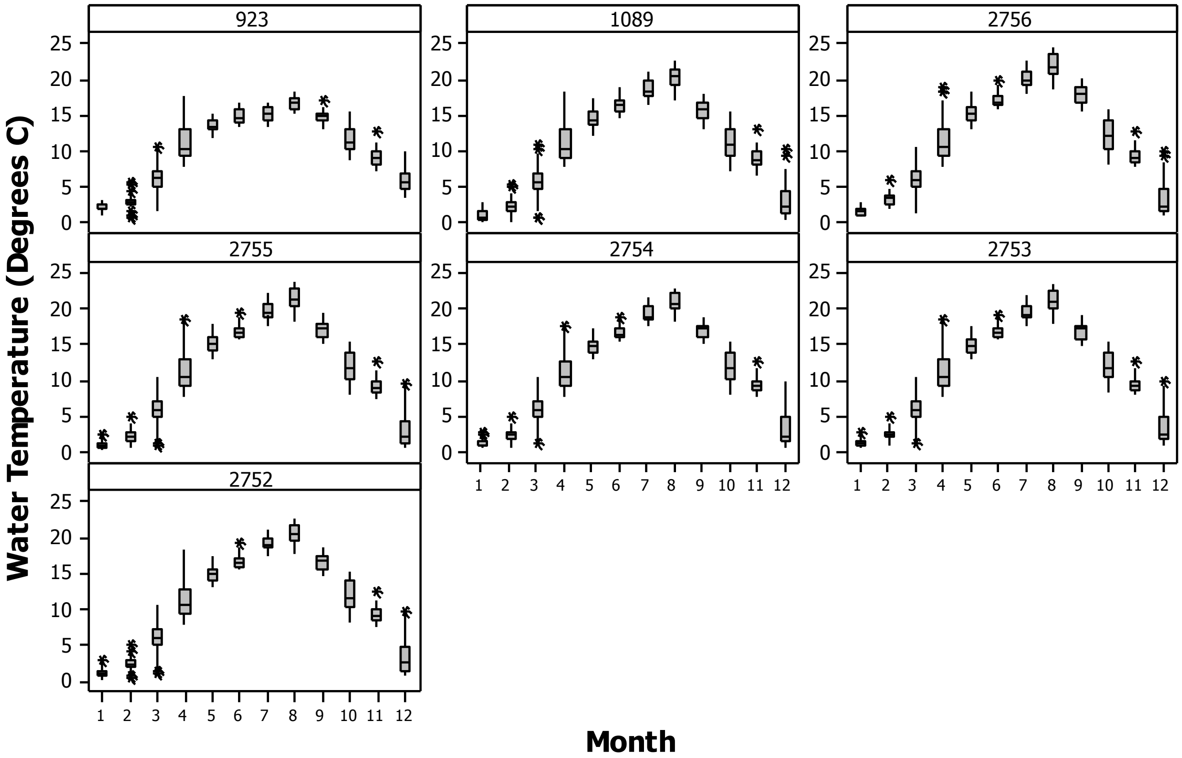

Figure 9. Boxplots of average daily temperature for each site in the Mill River study area by month. Sites are listed upstream (top left) to downstream. Station ID's 923 and 1089 are upstream of Clark's Pond Dam and all other sites are downstream of Clark's Pond Dam.

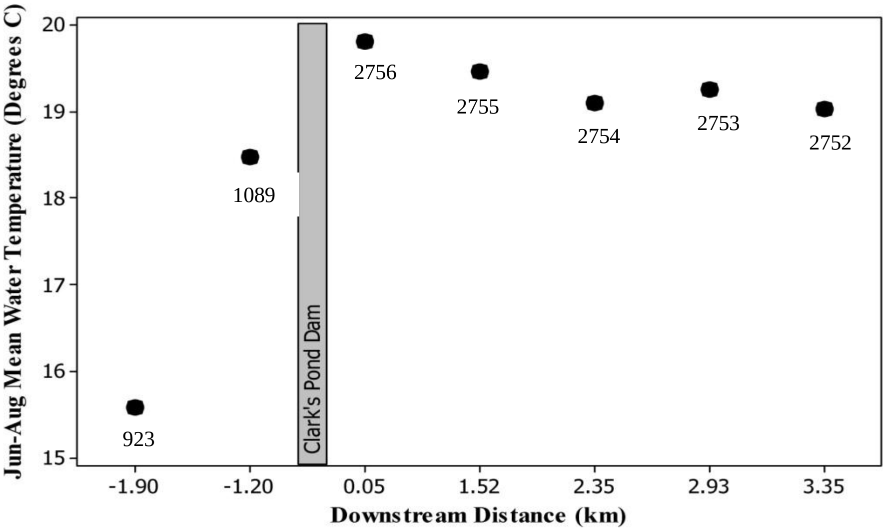

Figure 10. 2009 Mill River mean summer (June-August) temperature by proximity to Clark's Pond Dam. Station ID's 923 and 1089 are upstream of Clark's Pond Dam and all other sites are downstream of Clark's Pond Dam.

Macroinvertebrate Communities

Figure 11 shows macroinvertebrate MMIs at locations relative to Clark's Pond Dam for 2008 and 2009. The dashed line at an MMI value of 55 indicates the threshold typically used by DEEP to judge impairment to aquatic life in streams. MMI scores greater than 55 typically meet Connecticut's aquatic life goals and reflect healthy stream communities.

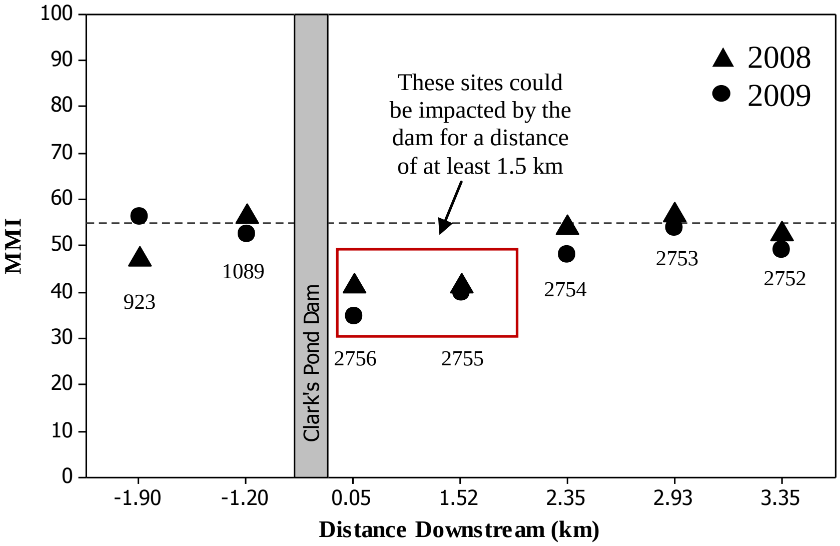

Figure 11. Mill River macroinvertebrate multi-metric indices (MMI) by proximity to Clark's Pond Dam for 2008 and 2009. Station ID's 923 and 1089 are upstream of Clark's Pond Dam and all other sites are downstream of Clark's Pond Dam.

Fish Communities

Figure 12 illustrates mixed water MMI scores calculated for fish communities at points relative to Clark's Pond Dam. Little change in fish MMI scores relative to the dam was observed. Figure 13 shows species counts for points relative to the Clark's Pond Dam. The observed increase in species below Clark's Pond Dam may be attributed to the presence of pond species including pumpkinseed, bluegill, and yellow perch (Table 3).

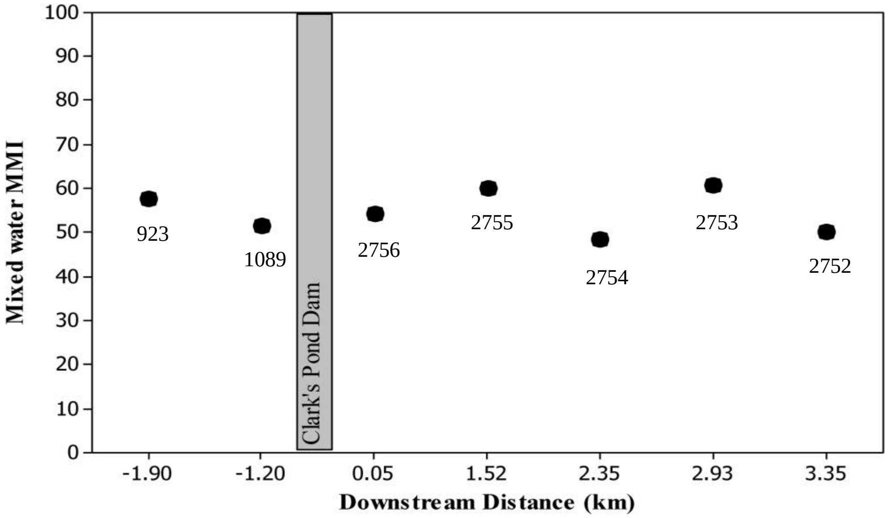

Figure 12. 2009 Mill River fish mixed-water multi-metric indices (MMI) by proximity to Clark's Pond Dam. Station ID's 923 and 1089 are upstream of Clark's Pond Dam and all other sites are downstream of Clark's Pond Dam.

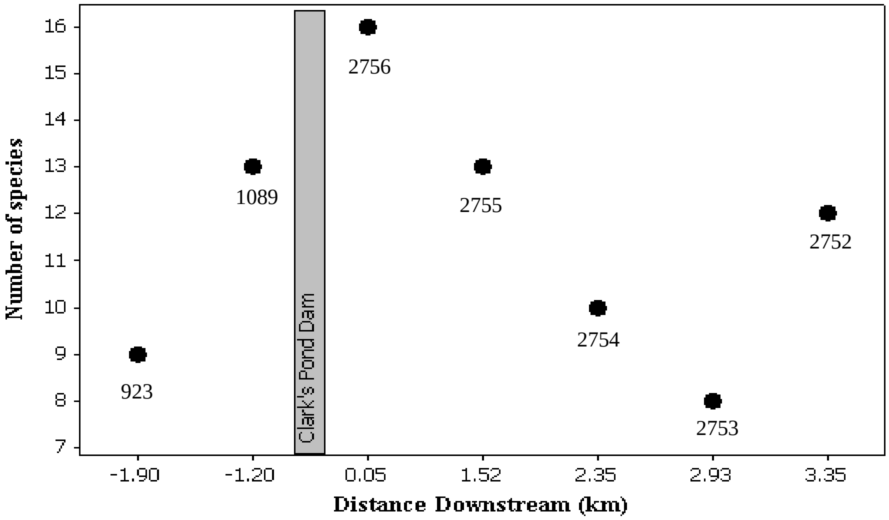

Figure 13. 2009 fish species count (excluding stocked species) for points relative to Clark's Pond Dam. Station ID's 923 and 1089 are upstream of Clark's Pond Dam and all other sites are downstream of Clark's Pond Dam.

Table 3. Catch per unit effort (number per hour) of fish collected in the Mill River on 7/1-2/2009

			Station ID						
Family	Scientific Name	Common Name	923	1089	2756	2755	2754	2753	2752
Anguillidae	*Anguilla rostrata*	American eel	15.00	25.45	21.82	23.08	24.00	18.00	27.86
Catostomidae	*Catostomus commersoni*	White sucker	81.00	136.36	54.55	39.23	120.00	3.00	55.71
Centrarchidae	*Lepomis auritus*	Redbreast sunfish		1.82	7.27	16.15	27.00	6.00	15.00
	Lepomis gibbosus	Pumpkinseed			1.82	2.31			
	Lepomis macrochirus	Bluegill sunfish		3.64	58.18				8.57
	Micropterus salmoides	Largemouth bass		1.82	1.82	6.92	6.00		
Cyprinidae	*Luxilus cornutus*	Common shiner			1.82	23.08	3.00		40.71
	Notemigonus crysoleucas	Golden shiner			12.73				
	Notropis hudsonius	Spottail shiner							62.14
	Rhinichthys atratulus	Blacknose dace	177.00	61.82	30.91	30.00	21.00	108.00	83.57
	Rhinichthys cataractae	Longnose dace	234.00	181.82	181.82	193.85	249.00	216.00	85.71
	Semotilus corporalis	Fallfish		1.82	16.36	4.62			
Esocidae	*Esox americanus*	Redfin pickerel	9.00	14.55	9.09	4.62	12.00	6.00	2.14
	Esox niger	Chain pickerel							
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead							
Percidae	*Etheostoma olmstedi*	Tesselated darter	105.00	61.82	43.64	20.77	66.00	48.00	47.14
	Perca flavescens	Yellow perch			16.36	4.62			
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout, Stocked	12.00		5.45	4.62	6.00	3.00	10.71
	Salmo trutta	Brown trout, naturalized	15.00	5.45	3.64			6.00	8.57
	Salmo trutta hatcheryis	Brown trout, stocked	3.00		10.91	13.85	3.00	3.00	8.57
	Salvelinus fontinalis	Brook trout, wild	21.00	7.27					2.14
	Salvelinus fontinalis	Brook trout, stocked	6.00	3.64	7.27	9.23	24.00		
Total			678.00	507.27	485.45	396.92	561.00	417.00	458.57

Effect of Multiple Dams- Furnace Brook

Water Temperature

Figure 14 illustrates average daily water temperature series for all Furnace Brook study sites during 2009. Average site temperatures peak at around 25°C in August, which had the warmest water temperatures at all 7 sites (Fig. 15). At site 2759, water temperatures were cooler than average during summer. Water temperatures fluctuate and are therefore not thought to indicate groundwater input despite being lower than average. Figure 16 shows Furnace Brook mean summer water temperatures at points relative to dams.

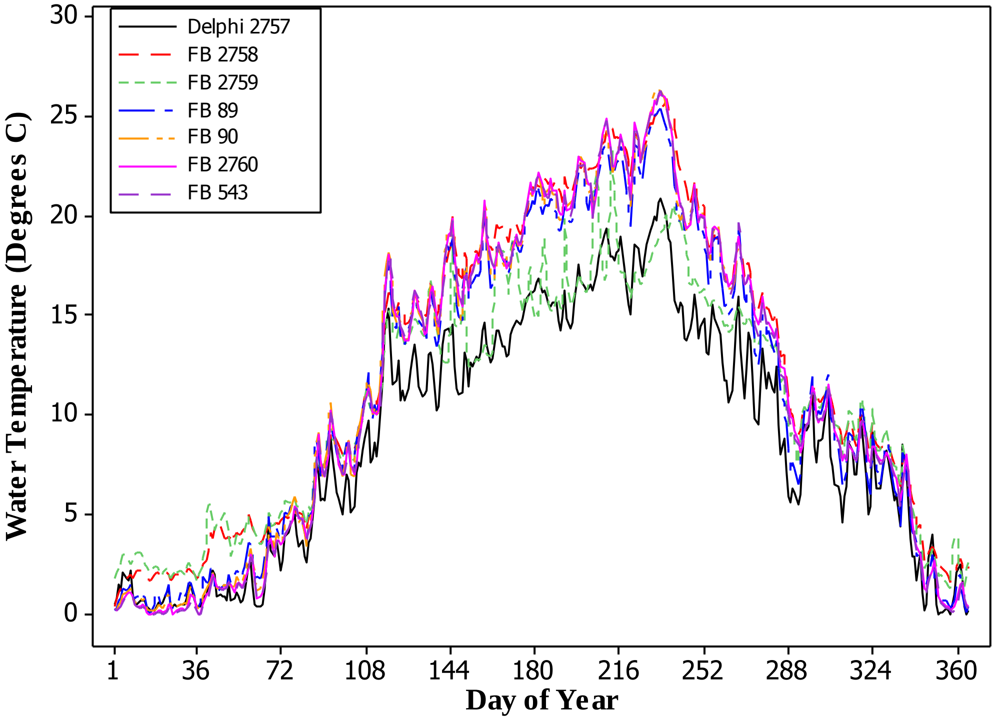

Figure 14. Furnace Brook average daily water temperature (degrees C), 2009 calendar year.

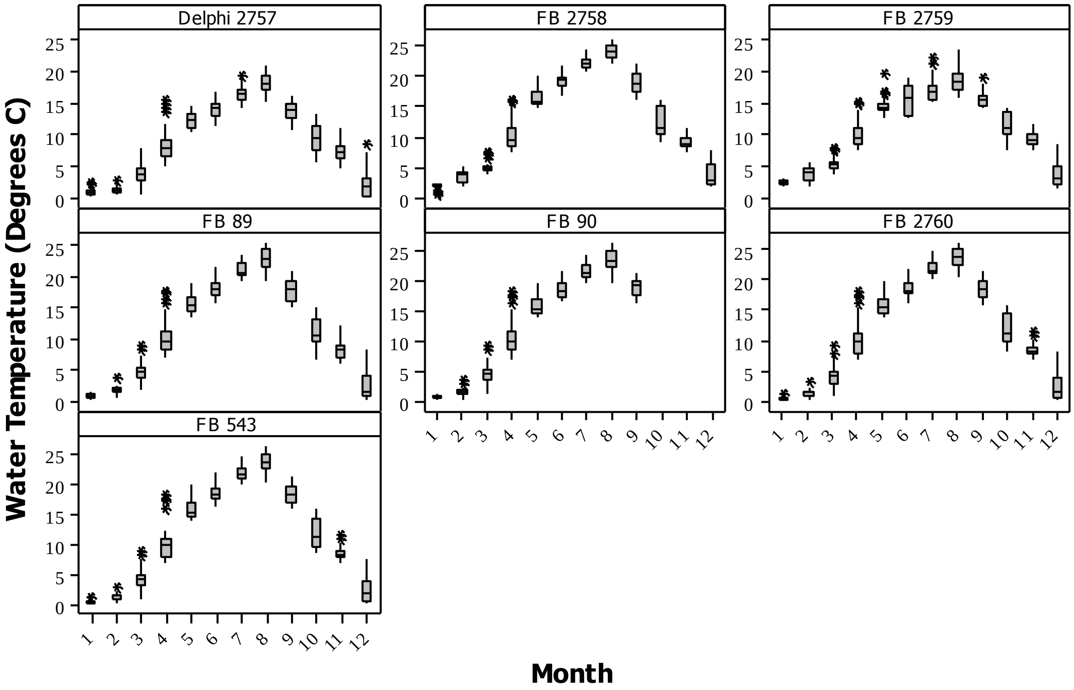

Figure 15. Boxplots of average daily temperature for each site in the Furnace Brook study area. Sites are listed upstream (Delphi 2757) to downstream (FB543). Delphi Brook is upstream of Staffordville Reservoir Dam.

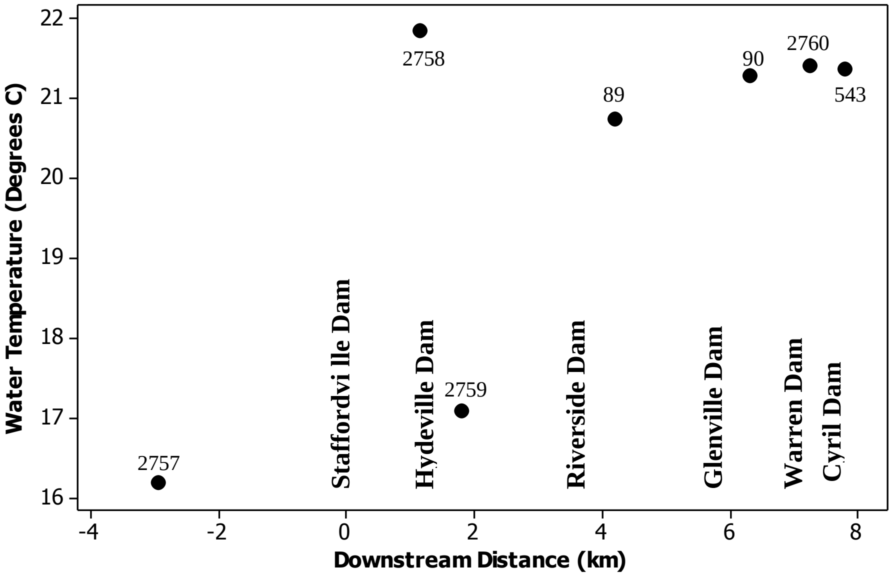

Figure 16. 2009 Furnace Brook mean summer (June-August) temperature by proximity to Furnace Brook Dams. Distances are downstream from Staffordville Reservoir Dam and used for plotting position. Other dams in the Furnace Brook watershed are shown as text in the appropriate location longitudinally along the watershed.

Macroinvertebrate Communities

Figure 17 shows macroinvertebrate MMIs at locations relative to Furnace Brook dams for 2008 and 2009. The dashed line at MMI 55 indicates the threshold typically used by DEEP to judge impairment. MMI scores greater than 55 typically meet Connecticut's aquatic life goals and reflect healthy stream communities. MMI scores approximate a passing value of 55 below Staffordville Dam, Hydeville Dam and Riverside Dam (2008 only), but remain below what is considered good stream health as we proceed downstream.

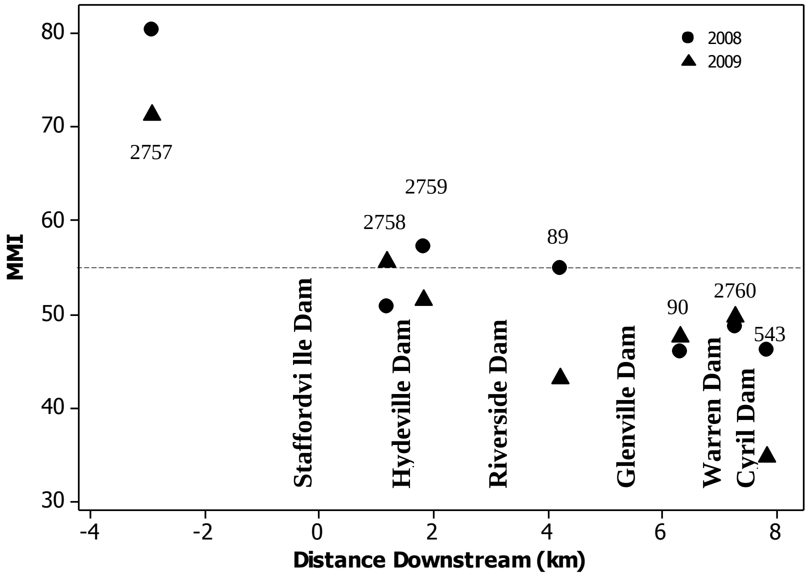

Figure 17. Furnace Brook macroinvertebrate multi-metric (MMI) indices by proximity to dams in Furnace Brook watershed. Distances are downstream from Staffordville Reservoir Dam and used for plotting position. Other dams in the Furnace Brook watershed are shown as text in the appropriate location longitudinally along the watershed.

Fish Communities

Figure 18 illustrates MMI scores calculated for fish communities at points relative to the dams in the system and Figure 19 shows species counts for points relative to the dams. The sample size at sites 2758 (n= 20) and 2759 (n=8) were less than the recommended number of 30 fish needed to calculate the MMI (Kanno et. al., 2010) and therefore are not plotted.

Fish species collected from the Furnace Brook watershed are listed in Table 4. It is interesting to note that the system of dams in Furnace Brook may limit distribution for at least some fish species. For example, common shiner (*Luxilus cornutus*) was only collected from the lowest of the study sites, 543. This site joins with the Middle River about 0.25 km downstream to form the Willimantic River where populations of common shiner have been collected by DEEP staff. Cyril Dam may prevent this species from populating the upper reaches of the Furnace Brook watershed. Brook trout (*Salvelinus fontinalis*) was only collected from the uppermost site 2757, Delphi Brook.

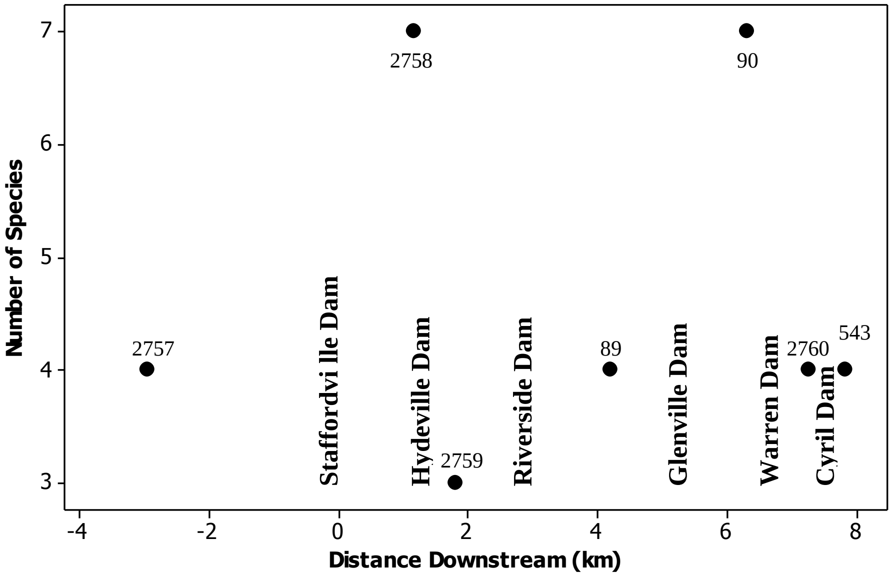

Figure 18. 2009 fish species count (excluding stocked species) for points relative to Furnace Brook Dams. Distances are downstream from Staffordville Reservoir Dam and used for plotting position. Other dams in the Furnace Brook watershed are shown as text in the appropriate location longitudinally along the watershed.

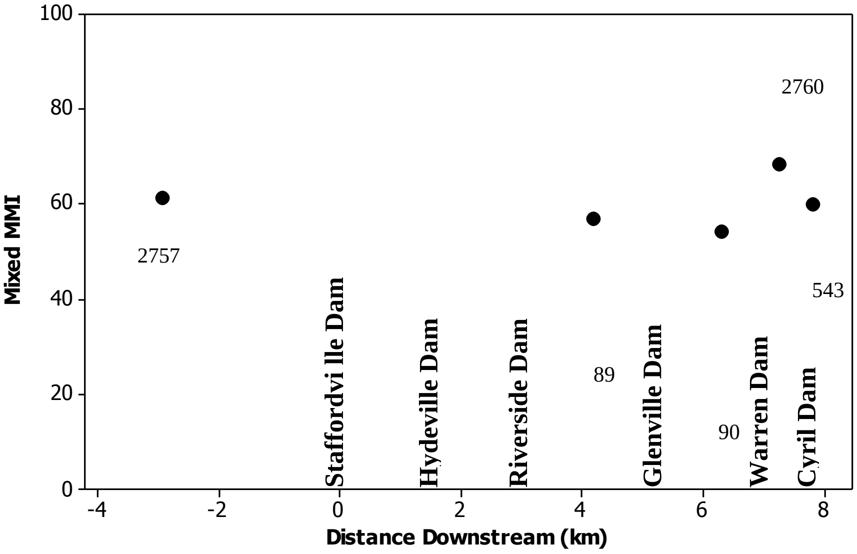

Figure 19. 2009 Furnace Brook fish mixed water multi-metric indices (MMI) by proximity to Furnace Brook dams. Sample sizes for sites 2758 and 2759 were too small to calculate an MMI for fish. Distances are downstream from Staffordville Reservoir Dam and used for plotting position. Other dams in the Furnace Brook watershed are shown as text in the appropriate location longitudinally along the watershed.

Table 4. Catch per unit effort (number per hour) of fish collected in the Furnace Brook Watershed on 06/01/2009

			Station ID						
Family	Scientific Name	Common Name	2757	2758	2759	89	90	2760	543
Anguillidae	*Anguilla rostrata*	American eel						3.90	
Catostomidae	*Catostomus commersoni*	White sucker	2.30	16.65	37.99	48.11			95.36
Centrarchidae	*Lepomis auritus*	Redbreast sunfish							
	Lepomis gibbosus	Pumpkinseed		6.66	9.50	4.01	18.56		
	Lepomis macrochirus	Bluegill sunfish		3.33			176.29	39.00	
	Micropterus salmoides	Largemouth bass					18.56		
Cyprinidae	*Luxilus cornutus*	Common shiner							166.89
	Notemigonus crysoleucas	Golden shiner		3.33					
	Notropis hudsonius	Spottail shiner							
	Rhinichthys atratulus	Blacknose dace	6.89	23.31		44.10	9.28		39.74
	Rhinichthys cataractae	Longnose dace							
	Semotilus corporalis	Fallfish			28.50	80.18	120.62	175.51	166.89
Esocidae	*Esox americanus*	Redfin pickerel							
	Esox niger	Chain pickerel					9.28	3.90	
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead		3.33					
Percidae	*Etheostoma olmstedi*	Tesselated darter							
	Perca flavescens	Yellow perch		6.66			9.28		
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout, Stocked					9.28		
	Salmo trutta	Brown trout, naturalized	41.33						
	Salmo trutta hatcheryis	Brown trout, stocked		3.33		12.03		23.40	15.89
	Salvelinus fontinalis	Brook trout, wild	80.36						
	Salvelinus fontinalis	Brook trout, stocked							
Total			130.87	66.60	75.99	188.42	371.13	245.72	484.77

Discussion

Water Temperature

There is limited literature available that describe the impact of small surface-release dams on downstream temperature. Analysis of Mill River temperature data indicated that mean summer water temperatures increase to at least 1.5 km downstream of Clark's Pond Dam but are decrease further downstream so the effect of Clark's Pond dam may be localized. The lower temperatures at Site 923, inconsistent with those of the other sites, were probably due to localized groundwater input. Average water temperatures for sites in Furnace Brook ranged more than those measured at Mill River sites, perhaps as a result of the presence of more several consecutive small dams. Temperatures at Furnace Brook site 2759 were cooler than those of other Furnace Brook sites during summer months. However, unlike Site 923 on Mill River, these temperature patterns were not consistent with a signal from groundwater input due to the pulsed pattern perhaps from dam releases.

The temperature pattern downstream of dams seems variable among studies. In this study, water temperatures in Mill River were similar to upstream of dam temperatures at a distance of 8 km downstream of Clark's Pond Dam. Lessard and Hayes (2003) studied three dammed streams in Michigan's Lower Peninsula and reported that water temperatures did not decrease to upstream-of-dam levels, even at the furthest downstream sites (60-80 m downstream of dams). Another study (Saila et al., 2005) conducted in southwestern Rhode Island's Pawcatuck River Watershed observed mean summer water temperatures increasing by 4° to 5°C directly downstream of a small dam. It is important to note that locations with cooler summer water temperatures (Clark's Pond site 923 and Furnace Brook site 2759) may provide important thermal refugia for aquatic species and therefore may be especially important for streams segments with dams.

Macroinvertebrates

Santucci et al. (2005) used a multimetric macroinvertebrate community index to characterize stream macroinvertebrate communities and found that free-flowing (non-dammed) areas supported higher-quality macroinvertebrate communities than areas close to dams (as indicated by multimetric index scores). Mill River macroinvertebrate data corroborate these findings. MMI decreases downstream of the dam to at least 1.5 km and begins to approximate upstream-of-dam levels at 2.3 km downstream.

Fish

Fish species richness in Mill River increased directly downstream of Clarks Pond Dam due to the addition of pond species, a phenomenon also noted by Lessard and Hayes (2003). Little change in fish mixed MMI scores relative to Clark's Pond Dam was observed. Consecutive dams on the Furnace Brook watershed may serve to fragment fish populations as documented by the presence of brook trout only in the upper reaches, and common shiner only in the lower reaches. Other sites between the multiple dams varied considerably in fish species richness and mixed MMI scores.

Stream sections below dams may warrant separate treatment when evaluating stressor relationships. Our study has shown that small run-of-river dams can impact on water temperature and aquatic life in Connecticut streams. Based on our observations, it is unlikely that stream segments downstream of dams can be expected to meet targets of stream health established for free-flowing sections (unless the dams are removed).

A possible approach to this problem could be to map stream segments influenced by small dams (dam shadow segments). Dam shadow segments could be thought of as similar to patches (Thoms et. al, 2005) or functional process zones (Thorp et al., 2006) and be used to test hypothesis and better understand the “best attainable conditions” (BAC) for stream reaches below small dams. This could be accomplished by designing a study to collect additional data such as water temperature and biological communities within 1.5 km downstream of dams at numerous locations in Connecticut and use these data to determine thresholds to meet BAC in the dam shadow.

Acknowledgments

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