MAINE ATLANTIC SALMON COMMISSION

DENNYS RIVER INSTREAM FLOW STUDY

REPORT

OCTOBER 2002

Prepared By:

Kleinschmidt

Energy & Water Resource Consultants

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1.0 INTRODUCTION

The survival of wild Atlantic salmon (*Salmo salar*) has exhibited a declining trend throughout most of its geographic range in North America since the mid-1980s (Maine Atlantic Salmon Task Force, 1997). Maine is the only state in the United States containing functioning wild Atlantic salmon populations (USFWS and NOAA, 2000). Within the State of Maine there are only eight rivers --Dennys, East Machias, Machias, Pleasant, Narraguagus, Ducktrap, Sheepscot and Cove Brook -- in which wild Atlantic salmon are known to be naturally reproducing. In 1999, the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), and National Oceanic and Atmospheric Administration (NOAA) concluded that wild stocks of Atlantic salmon were close to extinction in these eight Maine rivers (USFWS and NOAA, 2000). To protect wild Atlantic salmon in the Gulf of Maine, federal agencies listed them as endangered in the eight rivers in November 2000.

The Endangered Species Act (ESA) of 1973 defines an endangered species as one "in danger of extinction throughout all or a significant portion of its range". To protect wild Atlantic salmon from extinction in the Gulf of Maine, the ESA listing requires:

- That a Recovery Plan be developed by federal agencies to restore salmon to health. The State of Maine's Atlantic Salmon Conservation Plan (Maine Atlantic Salmon Task Force, 1997) will form the nucleus of the ESA Recovery Plan. The Federal Recovery Plan for Atlantic salmon should be finalized by May, 2003.

- That all federal agencies consult with the USFWS and NMFS to ensure that any action authorized, funded, or carried out by any federal agency is not likely to jeopardize the continued existence of the listed salmon.

- That Atlantic salmon not be disturbed in the Dennys, East Machias, Machias, Pleasant, Narraguagus, Ducktrap, Sheepscot Rivers and Cove Brook. As an endangered species, it is a federal violation to harm, harass, purse, hunt, shoot, wound, kill, trap, capture, or collect wild salmon in the eight Maine rivers.

The Maine Atlantic Salmon Commission (MASC) is charged with restoration and management of Atlantic salmon throughout its historical range in Maine. The MASC is working with federal agencies on the Federal Recovery Plan for Maine's Atlantic salmon and also manages the State of Maine's Atlantic Salmon Conservation Plan (Maine Atlantic Salmon Task Force, 1997). Since inception of the State Conservation Plan in 1997, the MASC has performed multiple research projects on the eight Maine rivers to protect Atlantic salmon and their habitat.

The MASC has managed the dam located on the outlet of Meddybemps Lake controlling Dennys River discharge since 1973. These discharges provide habitat for both stream resident and migratory life stages of Atlantic salmon in the Dennys River and also influence the lake levels of Meddybemps Lake. MASC has an obligation to ensure that the water management strategy employed for the Dennys River optimizes Atlantic salmon habitat and provides for adequate passage for migratory smolts and adults.

Dennys River water management has historically been based upon best professional judgment of MASC regional staff concerning the instream flow needs of Atlantic salmon. The purpose of this study is to develop a quantitative habitat-based water management strategy based on an Instream Flow Incremental Methodology (IFIM) model of the Dennys River.[1] This report presents the results of the IFIM study and will be utilized by MASC to manage Meddybemps Dam gate operation to target habitat-based flows in the Dennys River. The availability of water from the Meddybemps Lake watershed to meet target flows under dry/normal/wet years, and the

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[1] The IFIM was developed by the Instream Flow and Aquatic Systems Group of the USFWS (now a branch of the USGS) (Bovee, 1982; Milhous et al. (1989). The IFIM is one of the most widely used instruments in the world for assessing effects of flow manipulation on river habitat (Bovee et al., 1998). The IFIM provides decision-makers with information showing the amount of habitat available in a defined river reach, across a range of flows (Bovee 1982) by developing quantitative estimates of habitat from site-specific measurements of stream morphology, cover, substrate, depth, velocity and discharge gathered in study reaches along the river. These physical measurements are then rated for habitat suitability, based on objective habitat use data developed for the aquatic species and life stages of concern. IFIM studies have been used to evaluate and resolve salmonid habitat and flow issues in Maine, and throughout New England. Although IFIM does not compute a single "answer", it does provide a framework for decision-making in the realm of multiple-use water management (Bovee et al., 1998).

effect of meeting these targets on Meddybemps Lake levels have also been evaluated from a hydrologic water budget analysis and an engineering review of gate hydraulics.

2.0 DESCRIPTION OF THE STUDY AREA

2.1 <u>Dennys River</u>

The Dennys River is located in the eastern coastal river basin of Washington County, Maine and flows southeasterly for approximately 20 miles to Cobscook Bay on the Atlantic Ocean (Figure 1). The river drains an area of 132 square miles and originates at Meddybemps Lake in Washington County (MASC, 1982a). Sizable lakes in the watershed include Meddybemps Lake (6,765 acres), Pleasant Lake (339 acres), Cathance Lake (3,191 acres), Little Cathance Lake (140 acres) and Bearce Lake (>200 acres). Bearce Lake flows into Meddybemps Lake.

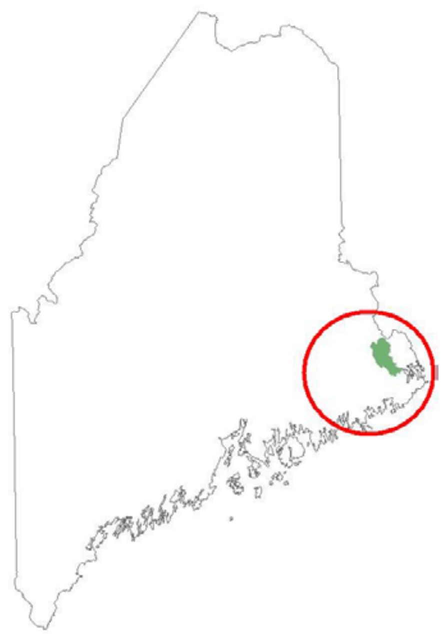


Figure 1. Location of the Dennys River watershed.

Topography of the Dennys River headwaters is characterized by hills and ridges largely forested by hardwoods and spruce-fir mixtures (MASC, 1982a). Drum and kettle topography produced by the melting ice and debris of the last glacier is common in the lower portions of the drainage. Lowland wetlands and bogs border some sections of the both the lower and upper drainage.

The soils of the upper drainage consist of a combination of deep excessively drained sandy and gravelly soil of a glacial outwash (MASC, 1982a). The blueberry barrens of the lower drainage consist of well-drained, sandy/gravely areas with some poorly drained soils occurring in peat bog and wetland areas. Forest types in the lower drainage are of mixed growth with alders and low bushes such as sweet fern. Bedrock of the Dennys watershed is varied, with granite, schist, metavolcanic, metasedimentary, and basalt flows as the river progresses to the ocean.

The upper six miles of the Dennys River, between the outlet of Meddybemps Lake and Gilman Falls, flows through a low, flat area characterized by deadwaters with sand and mud substrates (MASC, 1982a). Average channel width in the upper Dennys River is approximately 75 feet. A single, short riffle segment is located in the upper river immediately downstream of Meddybemps Lake outlet. Substrates in the riffle segment are largely cobble and boulders.

Between Gilman Falls and the confluence of Cathance Stream, the Dennys River is characterized by large deadwater areas separated by numerous riffle and pool areas (MASC, 1982a). This eleven mile section of the Dennys River averages over 40 feet in width. Cathance Stream, which is the only significant tributary to the Dennys River, originates at Cathance Lake and flows southeasterly fourteen miles to its confluence with the Dennys River.

Downstream of its confluence with Cathance Stream, the lower Dennys River flows approximately one mile where it then becomes tidal. This section of the Dennys is relatively narrow (stream widths average less than 30 feet) with increasing water velocities and depth (MASC, 1982a). Substrates consist largely of rubble and boulders in the lower Dennys River. In the lower tidal waters the river is extremely flat and becomes progressively wider as it approaches Dennys Bay. Tidal fluctuation ranges between 12-15 feet (MASC, 1982a).

The main stem of the Dennys River has been free of man-made obstructions from tidewater to the Meddybemps dam since 1930, when the Dennysville dam was destroyed (Bartlett and Robinson 1988). All other natural and artificial obstructions to fish passage in the watershed except two, are passable to migratory fishes. A 600-foot rock wall at the north end of Meddybemps Lake prevents outflow to Stony Brook. A natural falls below Pleasant Lake in Alexander prevents upstream migration on Sixteenth Stream (MASC, 1982a). Denil fishways are in operation on Cathance Stream, at the Cathance Lake dam, and the Meddybemps Lake outflow. An overflow roll dam at the Great Works Wildlife Management Area in Edmunds provides an overflow fishway for migratory species. As such, the entire Dennys River is available to most anadromous fish species for migration, spawning, and rearing of juveniles.

2.2 Fishery Management and Habitat Use

The statewide goal of MASC is to protect, conserve, restore, manage, and enhance Atlantic salmon habitat, populations, and fisheries within historical habitat in Maine. MASC has sole authority and responsibility to manage the anadromous (sea-run) Atlantic salmon fishery in the state of Maine including the sole authority to regulate the introduction of Atlantic salmon into Maine inland waters.

MASC has identified the Dennys River as one of seven rivers in the state of Maine with the highest priority for the restoration of Atlantic salmon (Baum, 1997). Since 1992, the overall management strategy adopted by the MASC and the USFWS for the Maine Atlantic salmon program is to maximize production of wild Atlantic salmon smolts by restocking with river-specific stocks, with an emphasis upon fry releases. The goal is to rebuild naturally-reproducing Atlantic salmon populations to levels where stocking will no longer be necessary on a continual basis (Maine Atlantic Salmon Task Force, 1997).

Hatchery raised salmon have been stocked in the Dennys River drainage since 1875. In 1992, MASC began stocking the Dennys River with river-specific Atlantic salmon raised at the Craig Brook National Fish Hatchery (Maine Atlantic Salmon Task Force, 1997). The hatchery raises Atlantic salmon progeny from wild salmon collected in the Denny's River. These progeny are then stocked in the Dennys River as fry, parr, smolt, and adults.

Based upon reported rod catch data and smolt production estimates, the Dennys River supported a historical (*i.e.*, pre-1980's) run size of 150-450 adult Atlantic salmon (MASC, 1982a). Commencing in the mid 1980s, a precipitous decline in the number of returning adult Atlantic salmon was documented throughout all Maine rivers including the Dennys. A portable weir has been seasonally operated in the Dennys River since 1992; in 2000, the MASC installed a more substantial weir at the head of tide on the Dennys River. The weir is a management tool operated to enumerate adult returns, collect broodstock, obtain biological data from individual salmon, and intercept escaped aquaculture salmon (Maine Atlantic Salmon Task Force, 1997).

MASC estimates that a minimum annual run of 170 adults is needed to sustain an Atlantic salmon run in the Dennys River (Maine Atlantic Salmon Task Force, 1997). A run size of 170 adult fish will provide sufficient progeny to fully utilize the freshwater habitat in the Dennys River (Maine Atlantic Salmon Task Force, 1997). MASC estimates that a total run size of 270 adult salmon would be needed in the Dennys River to provide a recreational fishery similar to that experienced historically.

The potential for any river to produce Atlantic salmon is limited by the habitat available during the riverine stages of the salmon's life cycle (MASC, 1982b). A salmon river must have adequate spawning habitat, ready access to these areas, suitable nursery areas for juvenile salmon, and holding pools for the adults. MASC has performed detailed habitat mapping of the Dennys River to document the amount of spawning and rearing habitat available for Atlantic salmon in support of management goals (Figure 2). Habitat suitable for each lifestage of Atlantic salmon can be found throughout the entire river basin, however, the majority of the nursery and spawning area in the Dennys River occurs downstream of Stoddard Rips. Tributaries to the Dennys River also provide additional rearing and spawning habitat for salmon. Additional units of rearing and spawning habitat also occurs in Cathance Stream.

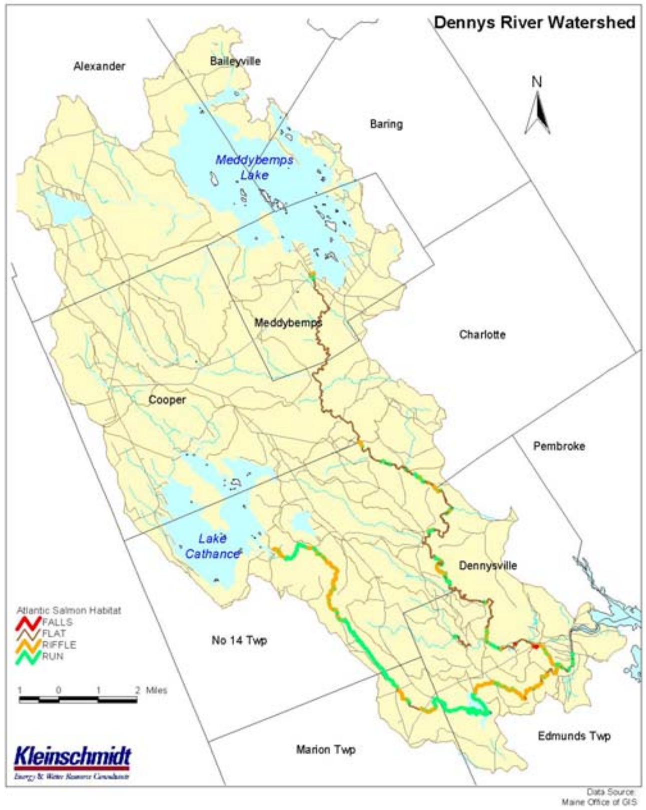


Figure 2. Distribution of Atlantic salmon habitat in the Dennys River, Maine.

Management of freshwater fisheries of the Dennys River and Meddybemps Lake is under the jurisdiction of the Maine Department of Inland Fisheries and Wildlife (MDIFW). MDIFW manages the river for wild populations of brook trout. Liberalized take regulations on competing species such as smallmouth bass and pickerel have been instituted on the Dennys River by the MDIFW for the protection of coldwater species such as brook trout and Atlantic salmon.

The MDIFW manages Meddybemps Lake for landlocked Atlantic salmon and smallmouth bass. Meddybemps Lake is recognized as an exceptional smallmouth bass fishery. Landlocked salmon are annually stocked in Meddybemps Lake to supplement natural reproduction. Other freshwater fish species found in the Dennys River basin include redbreast sunfish, pumpkinseed, brown bullhead, yellow perch, chain pickerel, white sucker, and various minnow species.

The Maine Department of Marine Resources manages an anadromous alewife run in the Dennys River. Alewives ascend the entire Dennys River mainstem in late spring and use a fish ladder to gain access to Meddybemps lake. YOY alewives exit Meddybemps Lake in late summer through fall and descend to tidewater.

2.3 Hydrology

The outlet dam on Meddybemps Lake in part, regulates flows in the Dennys River above the confluence of Cathance Stream. A constant minimum flow at the fishway of approximately 6 cfs is maintained at all seasons (MASC 1982a). Gaging and calculations by Kleinschmidt indicate that the fishway outflow is actually between 10 cfs and 30 cfs, depending on lake level. An additional 10 cfs is contributed below Meddybemps by small tributaries and springs. This is intermittent flow which is often unavailable during low flow periods. There are currently no water withdrawals for irrigation purposes occurring in the Dennys River.

Daily water discharge records for the Dennys River have been available since October 1955. Flow measurements are recorded at the U.S. Geological Survey gaging station (No. 01021200, "Dennys River at Dennysville, Maine"), which is located approximately 14 miles downstream of the Meddybemps Lake Dam. Table 1 presents the monthly mean and median flows for the Dennys River for the period of record of October 1, 1955 to September 30, 1998.

Table 1. Mean and median monthly flows in the Dennys River at Dennysville. Period of record: October 1955 to September 1998.

Month	Mean Discharge (cfs)	Median Discharge (cfs)
January	193	189
February	191	166
March	260	229
April	440	428
May	277	229
June	169	164
July	103	91
August	74.7	66
September	79.9	67
October	113	93
November	195	191
December	216	208

Monthly median flow is typically used to characterize water availability during a "typical" water year. This is because flow statistics often form skewed rather than bell-shaped frequency distributions. For example, during summer months low flows occur most frequently, with only a few brief high flow episodes occurring due to storm events. These occasional high flows tend to make the average monthly flow statistic higher, however, the median monthly flow statistic is less sensitive to such outliers, and is thus a better representation of typical monthly flows. For the period of record noted above, the average annual flow recorded at the Dennys River streamgage was 192 cfs, with the median annual flow being 162 cfs.

A USGS report provides additional information about the watershed represented by the Dennys River streamgage. The report "*A Technique for Estimating the Magnitude and Frequency of Floods in Maine*" (R.A. Morrill, 1975, USGS Open-File Report 75-292) notes that the drainage area at the gage is 92.4 mi^2 (this was revised to 92.9 mi^2 later), with a watershed slope of 5.4 feet per mile and a distance from the upper extents of the basin of 28.4 miles. The report also noted that 75.5% of the watershed was forested, with another 12.55% of the watershed occupied by lakes and ponds. Note that the 6,765-acre (10.6 mi^2) Meddybemps Lake itself accounts for over 11% of the drainage area at the Dennys River streamgage. The mean annual precipitation was noted as 42.15 inches of water.

The Dennys River streamgage has a contributing drainage area of 92.9 mi^2. Approximately 44.7 mi^2 (48%) of this drainage area is regulated by the Meddybemps Lake dam. Dam releases can be a significant part of streamflow recorded at the gage, especially during summer months when the lake is drawn down nearly three feet to augment low flow in the Dennys River. In the dry summer of 2001, flows recorded at the Dennys River streamgage were often higher than those in other watersheds, for a given drainage area such as the Narraguagus River, reflecting Meddybemps Lake storage and release. Numerous small tributaries run into the Dennys River downstream of Meddybemps Lake and include Dead Stream, Andrews Brook, Gilman Brook, Harrison Brook, Curry Brook, Preston Brook and Venture Brook.

For at least two decades, Meddybemps Lake (Figure 3) has been operated according to a "rule curve" based on drawdown measured from the chamfer on a concrete abutment at the dam. The rule curve, or lake level targets, are as follows:

Date	**Drawdown**
June 1	3" (essentially full)
June 10	6"
June 20	9"
June 30	12"
July 10	15"
July 20	18"
July 31	21"
August 10	24"
August 20	27"
August 31	30"
September 15	35"

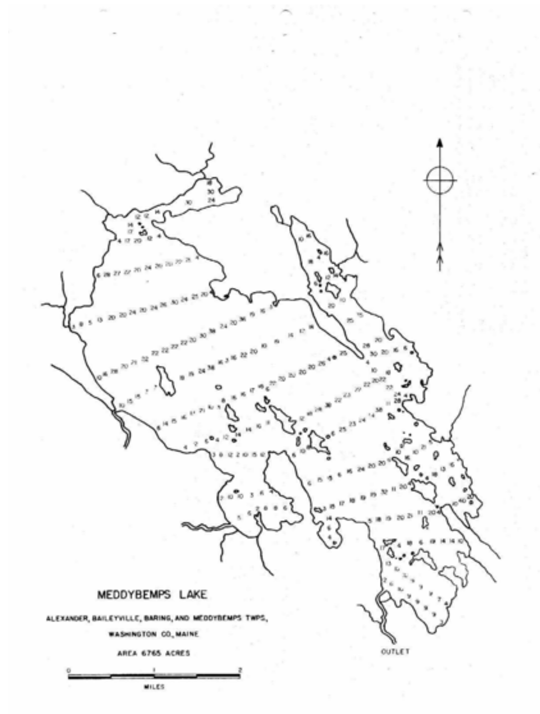


Figure 3. Bathymetric map of Meddybemps Lake (Maine DIFW data).

The lake is then filled between September 15 and June 1. It is expected that most of the lake level recovery occurs during spring snowmelt periods in late March or April. The USGS lake elevation for full pond (no drawdown) is approximately 175.08', according to a survey conducted by Kleinschmidt using elevations for the dam abutment given on a drawings "Plan of Dennys River Dam on Meddybemps Lake, Meddybemps, Maine, Prepared for Meddybemps, Inc." (Almer Huntley, Jr. & Associates, Inc., June 23, 1989).

Releases from Meddybemps Lake are also governed by other parameters, not just the rule curve. As mentioned, the fish ladder at the dam contributes up to 30 cfs depending on lake level. The side outlet fishway may contribute up to 20 cfs with the lake full, although the flow quickly drops as the lake is drawn down, being completely dewatered as the drawdown approaches 30".

In general, Meddybemps Lake is not allowed to get above El. 175' and spill over the abutments. The 15.4' wide by 6.5' high wooden sluice gate at the outlet dam can be opened to pass flows during high runoff events, although the maximum allowable gate opening is unknown. While the gate is obviously sized for large flow events, it is virtually the only means of flow control from the lake. (Stoplogs or plywood can be used to block the fishway entrances, although they are not used to regulate flow.) As a consequence, during the summer this wide gate is only open 2" most of the time. For low flows, the control offered by the gate is imprecise. Leakage through the wooden gate and around the edge seals may be significant, and with small gate openings there is the potential for partial blockage by even small debris.

2.4 Surrounding Land Use

The Dennys River watershed is sparsely populated (MASC, 1982a). The small towns of Dennysville, Meddybemps, Alexander, Edmunds, and Baring are located within the Dennys watershed and have a combined population of about 1,500 (DeLorme, 1999).

Forestry is the dominant land use in the Dennys River watershed. The forest resources are managed primarily for the harvesting and production of pulp for paper manufacturing and other wood products. Lands are also managed for wildlife and public recreation. Wild blueberry culture is the primary form of agriculture in the Dennys River watershed. Other types of agricultural activities and/or products in the watershed includes: dairy farming, hay, silage corn, horse farming, sheep farming, beef cattle farming, Christmas trees, market vegetables, cranberries, and landscape and horticultural plants. These agricultural activities do not currently rely on irrigation withdrawals from the river.

In 2001, MASC in cooperation with the Lands for Maine's Future Program purchased most of the riparian habitat along the Dennys River and Cathance Stream owned by International Paper Company (MASC, 2001). Ownership of these lands by MASC will forever ensure the integrity of the streamside habitat along the Dennys River and Cathance Stream for the benefit to all fish and wildlife, especially Atlantic salmon.

3.0 METHODS

3.1 General Approach

The IFIM methodology combines modeling stream hydraulics of selected study reaches with pre-determined habitat suitability index (HSI) criteria for selected evaluation species to provide quantitative habitat values at stream flow increments. HSI criteria are based on depth, velocity, substrate, and cover preferences of each lifestage of the evaluation species.

YOY (fry), parr, and spawning Atlantic salmon habitat suitability were evaluated in the Denny's River using standard field procedures and habitat modeling techniques of the IFIM. Adult holding deadwater habitat was documented at three calibration flow, but not modeled. This study also evaluated the habitat-discharge relationship for *Stenonoma*, an aquatic macroinvertebrate, in order to assess forage production potential under various discharges in the Dennys River.

General modeling procedures involve collecting hydraulic data (*e.g*. bed profile, depth, current velocity, and water surface elevation at a series of known calibration flows) and habitat data (*i.e*. substrate and relevant cover characteristics) at a series of points (referred to as "verticals") along representative cross-sectional transects. Each pair of verticals along a transect defines the lateral boundaries of a "cell" that is assumed to be homogeneous with respect to depth, velocity, substrate, and cover.

The length of stream represented by each transect within a multi-transect study site was determined by field mapping. Hydraulic modeling predicts changes in depth and velocity in each cell as discharge varies. For each modeled discharge, the area of each cell is weighted relative to HSI criteria for each evaluation species life stage. Total units of habitat at each flow are calculated by summing weighted habitat area at all transect cells. Weighted Usable Area (WUA) is the standard unit of habitat calculated in standard IFIM computations: one unit of WUA is equal to one square foot of optimal habitat as defined by the habitat suitability criteria. Each study site represented a designated critical or representative mesohabitat type such as riffle, run, or spawning riffle. A habitat mapping database developed by the MASC and USFWS was queried to weight the WUA results of each study site according to the distribution of those habitats within each stream reach.

The WUA vs. flow relationship calculated by the IFIM process was used with a "water budget" analysis to determine if flow regulation can help optimize habitat. As noted previously, releases from Meddybemps Lake comprise a significant part of Dennys River flow, especially during summer months. By estimating unregulated inflow to the lake for a long period of record, dam releases can be calculated for different lake drawdown schedules to determine the effect on Dennys River flows and habitat.

3.2 Scoping

MASC provided input to the consultant (Kleinschmidt) on technical parameters, such as study area boundaries, evaluation lifestages, specific HSI criteria, and modeling approach. MASC and Kleinschmidt selected study site and transect locations in the field, based on MASC staff biologist professional judgment and knowledge of the river.

3.2.1 Study Area

The study area was defined as the Dennys River between Meddybemps Lake and the confluence with Cathance Stream in Dennysville (Figure 4).

3.2.2 Study Reaches

Five independent reaches were identified with boundaries based on pronounced changes in hydrology, and Atlantic salmon habitat (Table 2 and Figure 4). On August 8, 2001, the MASC and KA conducted a site visit to select representative study sites within each reach, based on channel characteristics and habitat known to support targeted lifestages of Atlantic salmon. Mesohabitat types for YOY and parr comprised low gradient riffles and runs with gravel, cobble, and boulder. Mesohabitat types for spawning and egg incubation were deep riffles and runs with gravel and cobble substrates. In addition, the hydraulic characteristics of a deadwater area that serves as adult holding habitat was surveyed, but not modeled.

Table 2. Dennys River Instream Flow Study. Summary description of Atlantic salmon habitat modeled in the Dennys River by reach and lifestage.

Reach	Description	Habitat	No. Transects	Represented Stream Reach (ft)	Atlantic Salmon Habitat		
					YOY	Parr	Spawning
1	Extended approximately 500 ft downstream of the Meddybemps Dam.	run	1	309.1	x	x	x
2	Deadwater extending from the confluence of Harrison Brook upstream approximately 1 mile.	deadwater	1	83,239.5	-	-	-
3	Referred to as School Bus Rips, extends downstream approximately ½ mile from the confluence of Gilmore Brook and the Dennys River.	riffle	1	166.7	x	x	x
4	Stoddard Rips downstream approximately 1 mile to the confluence of Preston Brook	riffle	2	2,968.8	x	x	x
5	Camp Rips downstream approximately 2 miles downstream to the confluence of Cathance Stream.	riffle and run	4	3,820.5	x	x	x

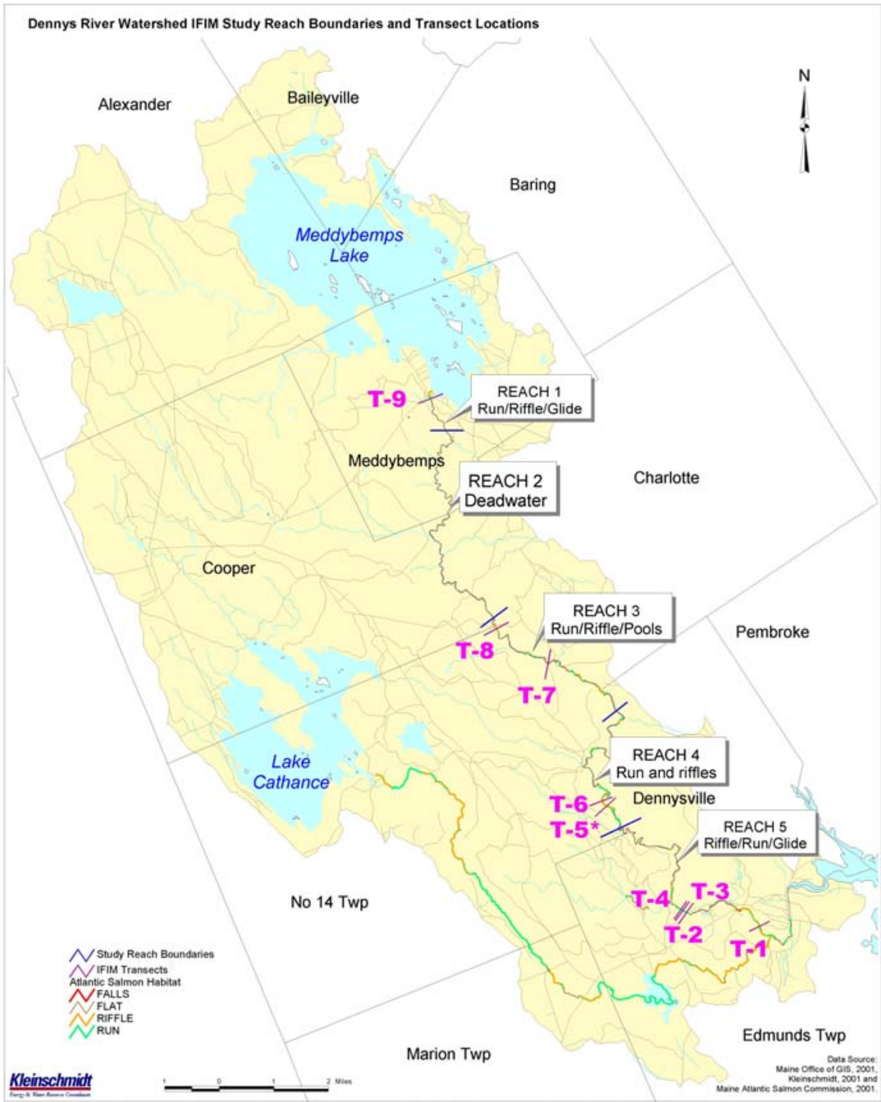
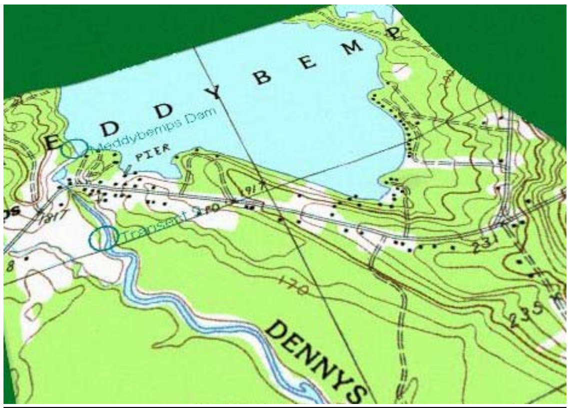


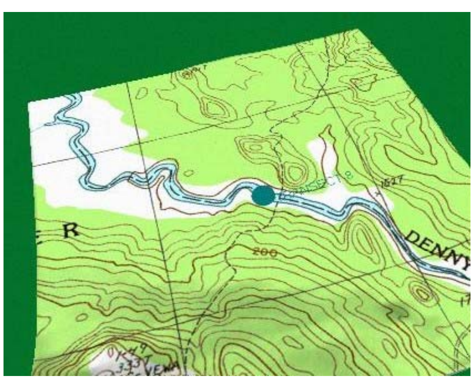
Figure 4. Dennys River IFIM study, location of reach boundaries and transects.

Each study site was selected to represent a given type of habitat within the subject reach. The number and location of transects were placed within each study site as necessary to represent channel configuration, slope, hydraulics and/or substrate and cover. Transects were numbered consecutively from downstream to upstream. The total length of study site represented by each transect was determined from MASC habitat mapping data for the Dennys River (Table 2). Photos characterizing study site habitat are found in Appendix A.

Reach 1 extends approximately 500 ft downstream from Meddybemps Dam. Habitat in this study reach generally consists of runs with small gravel substrate used for Atlantic salmon spawning. Stream widths in this study reach were also typically less than 100 ft wide with good forest cover canopy. One transect was established in this study reach.



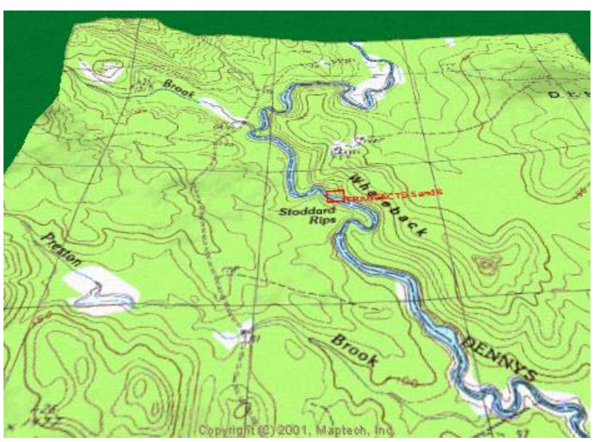
Reach 2 is a large deadwater extending approximately 5 miles downstream from Reach 1. This study reach is characterized by deep, slow-flowing riverine habitat suitable for adult Atlantic salmon. Because microhabitat characteristics in the deadwater would not be expected to change appreciably at alternative incremental flows, it was concluded that bed profile and depth data gathered at each calibration flow would adequately document habitat for adult holding suitability.



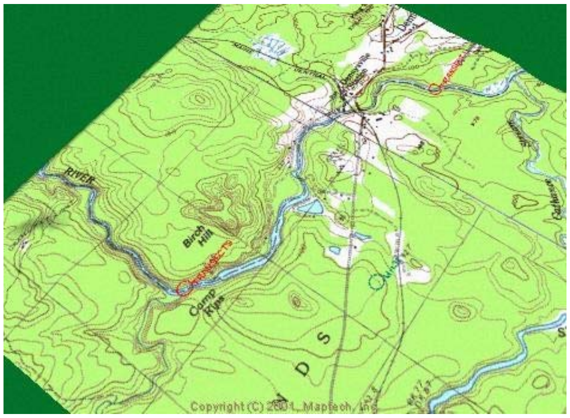
Reach 3, extends downstream to approximately one half mile from the confluence of Gilmore Brook and the Dennys River. Salmon habitat in this reach includes low gradient riffles with predominantly gravel and cobble substrates that can be

used by spawning, YOY and parr lifestages. Stream widths in this study reach were typically less than 100 ft wide with good forest cover canopy. One transect was established at "School Bus Rips".

<u>Reach 4</u> extends from Stoddard Rips downstream approximately 1 mile to the confluence of Preston Brook. Habitat throughout most of this reach consists of low and moderate gradient riffles with gravel, cobble, and small boulder substrates. Stream widths were typically less than 100 ft wide with good forest cover canopy. Two transects were established in this reach.



<u>Reach 5</u> extends from Preston Brook downstream to the confluence of Cathance Stream and the Dennys River, and includes Camp Rips. Venture Brook flows into the Dennys River in this study reach. Habitat in this reach consists primarily of low gradient riffles and runs with gravel, cobble and boulder substrates. Stream widths are typically 100-150 ft wide with fair forest cover canopy. Four transects were established to model rearing and spawning lifestages.



3.3 Evaluation Lifestages

Habitat-discharge relationships were modeled for young of year (YOY), parr, and spawning lifestages of Atlantic salmon.

The “spawning” or reproduction life stage refers to the deposition of eggs (October-November), through the incubation period of winter and early spring (May), when hatching occurs.

YOY refers to post-emergence life stages during the first calendar year post hatching (*i.e.* fry and 0+ parr).

Parr, as used in this study, refers to year 1 parr (Jan. 1- June 30 the calendar year after hatching), 1+ parr (July 1 - Dec. 31 one year after hatching).

A representative macroinvertebrate species (*Stenonoma*) was also employed to model at least one other ecological habitat function.

Each species and lifestage-specific habitat use is rated using Habitat Suitability Index (HSI) criteria, in which parameters such as depth, velocity, and substrate are independently assigned rating values (Bovee, 1982). Atlantic salmon HSI curves for this study were developed for use specifically on Maine streams (Appendix B). In addition, adult holding habitat was documented by depth preference criteria at each of the three flows for which field data were obtained (Appendix C). HSI criteria for Stenonoma used in this study were collaboratively developed by previous instream flow study teams for use in Maine and New England.

Although the primary focus of this analysis was low-flow management, high flow data were also obtained so that hydraulic simulation could be achieved to support future potential modeling of smolt migration, assessing channel forming flows, stream restoration, or support of a SALMOD model.

3.4 Field Methods

Field methods used in this study followed Bovee (1982). Transect data were collected in accordance with data requirements for completing hydraulic modeling with the IFG4 model using a single velocity calibration data set. This entailed the collection of transect bed profiles, cover and substrate data, water surface elevations (WSEL's) at a series of calibration flows, mean-column-velocity calibration data at one flow, and stream discharge at each WSEL calibration flow.

The location of each transect was marked with a Garmin model 12 GPS unit and on paper mapping. Lateral boundaries of each study transect were defined by head- and tailpins established above the crest of each bank. Headpins were located along the right bank (looking downstream). Pins were field-blazed and semi-permanently fixed with either rebar or by using a large tree or other fixed object. At sites with multiple transects, longitudinal cell distance was also measured by established upstream and downstream boundaries which were located at observed shifts in cover, depth, hydraulics, or stream channel shape. These were also field-blazed to facilitate mapping. All transect location and mapping work was done at a time of low stream discharge to facilitate examination of stream channel characteristics.

Transect measurements proceeded as follows: fiberglass survey tape (accurate to 0.1 ft) or graduated, high-strength lines were secured between headpin and tailpin at each transect. Streambed elevation, mean-column-velocity, dominant substrate and edge of water were recorded at intervals (verticals) along the tape to the nearest 0.1 ft. Verticals were established at intervals wherever an observed change in any of the above four parameters occurred along each transect. This typically resulted in about 30 to 40 verticals per transect. Verticals were also arranged so that not more than 10% of the total transect discharge passed between any pair, in order to optimize the accuracy of the hydraulic model. At each vertical, depth was measured to the nearest 0.1-ft and substrate type was recorded. Bed and water surface elevations were surveyed to the nearest 0.01-ft elevation using a surveying level and standard surveying techniques. When necessary to establish backwatering effects of downstream obstructions, the elevation of stage-of-zero-flow was surveyed to the nearest 0.01 ft at the downstream hydraulic control of the study site.

Hydraulic data were collected at three calibration discharges (low, middle, and high), to facilitate modeling in a range from below August median flow up to April median flow according to study objectives. At Transects 2-4, a fourth calibration WSEL was obtained to enhance the high-flow hydraulic model.

Bed profile, substrate and cover data were collected at the low calibration flow. Water surface elevation (stage) was surveyed at each transect at all three flows. Velocity data were collected at all transects at the mid-flow; at transects containing complex hydraulics, an additional velocity data set was also collected at the low flow to enhance hydraulic calibration. Stream stage (water height) was recorded at temporary staff gages installed in the vicinity of each transect or study site at the beginning and end of velocity measurements and before and after water surface elevation measurements at each transect. This verified that no significant changes in stage or discharge occurred during hydraulic measurements along each transect. At the velocity calibration flow, mean-column-velocity and depth were measured at all wetted verticals.

Depth was measured to the nearest 0.1-ft, and velocity was measured to the nearest 0.1-ft/s using a calibrated Marsh-McBirney Model 2000 Flowmate electronic current meter attached to a top-setting wading rod. In water less than 2.5-ft deep, mean-column-velocity was measured at 0.6 of the depth. In very turbulent areas less than 2.5 ft deep and in water greater than 2.5-ft deep, mean-column-velocity was taken as the average of the velocities measured at 0.2 and 0.8 of the depth.

Stream discharge at each study reach was determined by computations from collected depth, width and velocity data in an open channel location in the study site vicinity, using standard stream gaging techniques. In some cases it was possible to employ a habitat transect. Discharge at Transect 1 and Transects 2-4 (high flow only) was determined via the USGS stream gage (No. 01021200) located adjacent to the corresponding study site.

Flow on the Dennys River is unregulated, and therefore the low flow and high flow gaging calibration field schedule was dictated by precipitation-created river discharges in a target range required for model input. Because target flow conditions were ephemeral, the USGS gage for the Dennys River was monitored daily to indicate appropriate study flow conditions for the Dennys River. During high flow periods, Kleinschmidt consulted with MASC staff and other local contacts to confirm that suitable flow conditions were prevailing prior to mobilizing.

3.5 Hydraulic Modeling

All modeling was conducted using PHABSIM for Windows (Mid-continent Ecological Science Center of the USGS). In general, the IFG4 and MANSQ hydraulic models are used in calibrating the hydraulic model component of PHABSIM (Milhous, *et al*., 1989). The choice of specific model(s) was based on the hydraulic characteristics of each transect. MANSQ or WSP and a log-log fit were compared to select the model which best established the stage-discharge relationship across the flow range of interest, and IFG4 was run to simulate velocity in each cell along each transect at the flow increments of interest. Model runs were QC'd by a hydraulic engineer experienced in stream channel modeling.

The first step of modeling involved establishing the stage-discharge relationship for each transect. Next, calibration of the model for velocities consisted of calculating the Mannings equation roughness coefficient, given field measured velocities and stream slope values to allow the predicted velocity values to correlate in the model as closely as possible to each corresponding velocity recorded during calibration flows.

3.6 Habitat Modeling

Habitat area was computed independently for each study site using the HABTAE option in PHABSIM. HABTAE is the standard program applied to calculate habitat availability at each specified flow increment by combining hydraulic output with HSI criteria. Habitat and wetted area output for each site is expressed in standardized units of area (square feet) available per 1,000 ft. of similar stream reach for each lifestage and flow increment. One unit of Weighted Usable Area (WUA) corresponds to 1 square foot of optimal habitat. This habitat area estimate was then extrapolated for the actual area represented by the study site within the reach based on interpretation of MASC habitat mapping data.

The specific discharge (cfs) simulation steps selected varied among reaches, but were based on the relative estimated discharges (cfsm) for each reach, based on drainage area. Drainage area estimates for each study reach were developed by obtaining basin mapping data (MGS web site) and sub-basin boundaries. Finer flow increments were employed at simulated discharges below 200 cfs to give relatively high resolution in the lower end of the flow range.

3.7 Water Budget Analysis

A water budget (or conservation of mass) analysis, was used for modeling the effects of flow regulation in a river.

The basic conservation of mass relationship for a reservoir is:

inflow – outflow = change in storage

Inflow is the net unregulated or "natural" discharge to a lake. Inflow is computed on a net, rather than gross, basis because flow losses due to evaporation, interception and evapotranspiration are extremely difficult to measure, let alone predict.

Outflow is the regulated release from the lake.

Change in storage is the variation in lake volume associated with lake level fluctuations.

In the summer, when Meddybemps Lake is drawn down, the conservation of mass equation indicates that dam releases exceed natural inflow coming into the lake. Similarly, refilling the lake requires dropping lake outflow below inflow to increase the volume (storage).

The effects of a revised rule curve (lake level targets) for Meddybemps Lake on Dennys River flow and habitat were assessed using a monthly water budget model. With monthly outflow (dam release) as the dependent variable, it was necessary to estimate unregulated monthly inflow and route it through the lake for a given rule curve.

3.7.1 Estimating Unregulated Inflow

To estimate unregulated inflow, data were prorated from the USGS Narraguagus gage, a nearby watershed that is unregulated, with a similar drainage area and hydrologic characteristics. [2]

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[2] We selected the Narraguagus gage for the following reasons. Ideally, the regulated and unregulated watersheds should be adjacent (or within the same region) and have similar hydrologic characteristics, e.g. percent surface water and wetlands, drainage area, slope, land cover type and use, and rainfall. When gages occur in both watersheds, the coefficient, a, is also important in determining how well the two watersheds correspond. Given that Meddybemps Lake essentially refills every year, the average annual flow for the Dennys River streamgage does reflect unregulated flow in the basin. (i.e. the effect of regulation is to change the timing and size of daily and monthly flows, rather than the total annual volume of water.) Ideally, the coefficient would be consistent from year to year, and would be close to 1.00 (reflecting similar hydrologic characteristics). It is also important that the streamgage have a sufficiently long period of record that includes wet, dry and normal years, with some droughts and floods in the record.

For each month, unregulated inflow was calculated as follows:

$$Q_2 = Q_1 (DA_2/DA_1)^a$$

Four candidate gages were selected for closer scrutiny:

USGS Streamgage No. 01022260, "Pleasant River near Epping, Maine", has a drainage area of 60.6 mi^2. The period of record is from August 1980 through September 1991, with 10 calendar years (1981-1990) that overlapped with the period of record for the Dennys River streamgage. According to the report "Estimating the Magnitude of Peak Flows for Streams in Maine for Selected Recurrence Intervals" (Glenn Hodgkins, 1999, Water-Resources Investigations Report 99-4008) the "areal percentage of wetlands in drainage basin" is 26.7%. As defined in that report, "wetlands" includes surface waters as well as wetlands listed on National Wetlands Inventory maps. Using mean annual flow, the drainage area coefficient (a) for the Pleasant River and Dennys River gages varied between 0.214 and 0.968, with an average coefficient of 0.657. Given the short period of record, and the wide range in coefficients, it was felt that the Pleasant River gage data would not provide a good approximation of unregulated flow in the Dennys River watershed.

USGS Streamgage No. 01021500, "Machias River at Whitneyville, Maine", has a drainage area of 458 mi^2. The continuous period of record for this streamgage is from September 1929 through September 1977, with 21 calendar years (1956-1976) that overlapped with the period of record for the Dennys River streamgage. According to the two USGS reports cited earlier, the Machias River watershed has a slope of 5.76 feet per mile, a watershed length of 57.7 miles, and mean annual precipitation of 42.00 inches of water. The watershed reportedly was 89.1% forested, with 3.79% of the basin comprised of surface water and an "areal percentage of wetlands in the drainage basin" of 15.5%. The calculated coefficients (a) for the overlapping period of gage record ranged from 0.879 to 1.109, with an average coefficient of 0.977.

USGS Streamgage No. 01023000, "West Branch Union River at Amherst, Maine", has a drainage area of 148 mi^2. The continuous period of record for this streamgage is from July 1929 through September 1979, with 23 calendar years (1956-1978) that overlapped with the period of record for the Dennys River streamgage. According to the two USGS reports cited earlier, the West Branch Union River watershed has a slope of 7.77 feet per mile, a watershed length of 31.8 miles, and mean annual precipitation of 41.33 inches of water. The watershed reportedly was 93.3% forested, with 3.14% of the basin comprised of surface water and an "areal percentage of wetlands in the drainage basin" of 18.9%. The calculated coefficients (a) for the overlapping period of gage record ranged from 0.269 to 1.516, with an average coefficient of 0.787. Since it was felt that this range of coefficients was too broad to reliably model unregulated flow in the Dennys River watershed, this streamgage was dropped from consideration.

USGS Streamgage No. 01022500, "Narraguagus River at Cherryfield, Maine", has a drainage area of 227 mi^2. The streamgage has been continuously recording since February 1948, with 42 calendar years (1956-1997) that overlapped with the period of record for the Dennys River streamgage. According to the two USGS reports cited earlier, the Narraguagus River watershed has a slope of 10.94 feet per mile, a watershed length of 38.4 miles, and mean annual precipitation of 41.98 inches of water. The watershed reportedly was 81.3% forested, with 1.59% of the basin comprised of surface water and an "areal percentage of wetlands in the drainage basin" of 15.0%. The calculated coefficients (a) for the overlapping period of gage record ranged from 0.845 to 1.369, with an average coefficient of 1.049. While the Machias River streamgage correlated well with the Dennys River streamgage—and many basin characteristics were similar between the two watersheds—it was felt that the Narraguagus River streamgage was ultimately more useful for two primary reasons. The first reason is that the drainage area of the Narraguagus River streamgage is smaller than that of the Machias River streamgage, and is thereby closer to the drainage area of Meddybemps Lake and the Dennys River. This minimizes the variability in runoff that can occur with localized storms in small versus large watersheds. The second reason is that the Narraguagus River streamgage is still active, and the gage record includes 2001, an extreme drought year in which historic low flows occurred in many unregulated rivers and streams in Maine.

Q_2 = unregulated monthly inflow to Meddybemps Lake (cfs)

Q_1 = unregulated monthly flow from streamgage outside basin (cfs)

DA_1 = contributing drainage area of streamgage outside basin (mi^2)

DA_2 = Meddybemps Lake watershed (44.7 mi^2)

a = coefficient

For estimating unregulated inflow to Meddybemps Lake, therefore,

$$Q_{Meddybemps} = Q_{Narraguagus} (DA_{Meddybemps}/DA_{Narraguagus})^a$$

$Q_{Meddybemps}$ = unregulated monthly inflow to Meddybemps Lake (cfs)

$Q_{Narraguagus}$ = recorded monthly flow at the Narraguagus River streamgage (cfs)

$DA_{Meddybemps}$ = 44.7 mi^2

$DA_{Narraguagus}$ = 227 mi^2

a = 1.05 (rounded)

Downstream of Meddybemps Lake, additional drainage area contributes unregulated flow to the Dennys River. This unregulated flow—most of it delivered by tributaries to the Dennys River—was also prorated from the Narraguagas River streamgage. That is,

$$Q_{unregulated} = Q_{Narraguagus} (DA_{unregulated}/DA_{Narraguagus})^a$$

$Q_{unregulated}$ = unregulated monthly inflow from additional drainage area downstream of Meddybemps Lake (cfs)

$Q_{Narraguagus}$ = recorded monthly flow at the Narraguagas River streamgage (cfs)

$DA_{unregulated}$ = varies (up to 48.2 mi^2 of unregulated drainage area at the Dennys River streamgage)

$DA_{Narraguagus}$ = 227 mi^2

a = 1.05 (rounded)

Prorating flows from the Narraguagus River streamgage—or any streamgage—is an approximation. Seasonal variability in runoff, localized storms, and differences in basin characteristics lend some degree of uncertainty to the analysis. One of the biggest differences between the Dennys River and Narraguagus River basins is Meddybemps Lake, which is a large part of the Dennys River watershed. Meddybemps Lake would tend to decrease flows in the summer (through lake evaporation), yet increase precipitation available for runoff after storms. The drainage area coefficient (> 1) implies that each square mile of drainage area in the Dennys River watershed contributes slightly less runoff than each square mile of drainage area in the Narraguagus River watershed, perhaps due to the net effect of increased lake evaporation from Meddybemps Lake.

For water budget analysis purposes, the coefficient effectively adjusts the prorated Narraguagus River flows for a long period of record, implicitly accounting for some of this variability. Since Meddybemps Lake is operated on an annual cycle of drawdown and refill, the prorated Narraguagus River flows would give a good estimate of the drawdowns and lake releases that would occur year after year. The water budget analysis is especially valuable for comparing different rule curves or operating scenarios; it is less reliable for predicting flows for a given month or year.

Other potential methods for estimating unregulated stream flow that were considered but rejected included:

1. **Recorded data about natural inflow (precipitation, groundwater infiltration, runoff, interception, lake evaporation and evapotranspiration.** Sufficiently detailed data does not exist for Meddybemps Lake.
2. **Conservation of mass relationship to calculate unregulated inflow.** This requires detailed lake level records and accurate outflow records, which were also not available. (While lake levels are often measured by the Maine Atlantic Salmon Commission during summer, the levels are not necessarily measured every month. Also, changes in gate setting and fishway operation were frequently recorded, although the corresponding outflows were unknown.)
3. **The Dennys River gage** is located nearly 14 miles downstream of the dam, and gage records reflect regulated releases from Meddybemps Lake, as well as unregulated contributions from additional drainage area (tributaries). Therefore, Dennys River gage records cannot simply be prorated to calculate flows for the smaller drainage area of Meddybemps Lake.

3.7.2 Calculating Change in Storage

Meddybemps Lake reportedly has a surface area of 6,765 acres at full pond (El. 175'). While a stage-area curve was not available for the lake, a depth map roughly indicated that the surface area would change by less than 5% with a 3-foot drawdown. For purposes of the water budget analysis, it was decided that a refined stage-area relationship would not significantly increase the accuracy of the model. (Most of the model's uncertainty is driven by the proration of Narraguagus River flows to the Dennys River basin, not lake volume calculations.) Over the range of drawdowns studied (up to 3 ft.), the lake area was assumed to remain at 6,765 acres. Therefore, each 1 in. change in lake elevation represents a change in volume (storage) of nearly 564 acre-feet, or 24.6 million cubic feet of water.

3.7.3 Water Budget Analysis

The water budget model was run on a monthly basis by prorating mean monthly Narraguagus streamgage flows for the period June 1948 through December 2001 (53 full years of record). Detailed analyses were performed for three operating scenarios: run-of-river, the existing rule curve, and a flow-optimized, revised rule curve as described below. For each run, a different rule curve was input to the model, setting lake level targets for each month. Other independent variables included unregulated inflow, and a minimum flow below the Meddybemps Lake dam. The spreadsheet model calculated lake outflow as the dependent variable, and also calculated flow at three other reaches downstream of the dam.

Monthly flows were computed for four reaches corresponding to those used in the IFIM study.

- Reach 1 (Transect 9), immediately downstream of the Meddybemps Lake dam, has an approximate drainage area of 45 mi^2. Virtually all of the flow in Reach 1 is regulated by Meddybemps Lake.
- Reach 3 (Transect 7) has an approximate drainage area of 67 mi^2, including 22 mi^2 of unregulated drainage area.
- Reach 4 (Transects 5 and 6) has an approximate drainage area of 78 mi^2, including 33 mi^2 of unregulated drainage area.
- Reach 5 (Transects 1, 2, 3 and 4) has an approximate drainage area of 93 mi^2, including 48 mi^2 of unregulated drainage area. Reach 5 is represented by the USGS Dennysville streamgage.

For each model run, a flow duration analysis was performed for each month, ranking the flows from the 53 calendar years studied in the model. These computations included median, maximum and minimum flows that would occur in each month. This methodology—determining the flow distribution for a long period of record—is more reliable than looking at “wet”, “dry” and “normal” years for two reasons. The first reason is that years that are critical from a habitat standpoint—such as the 2001 drought year—have a wide range of variability in monthly flows, and include some months that may have had normal or above-normal precipitation. The second reason is that the effects of high or low flows can be cumulative. For example, if Meddybemps Lake doesn't refill in a given year, lake levels and dam outflows will be affected in subsequent months.

Since each flow in a given reach has an associated WUA ("habitat") value, the flow distributions predicted by the water budget model can be used to assess the variability in WUA for each month, over a range of years. This allows a quantitative assessment of the effect of lake regulation on habitat throughout Dennys River.

A description of each of the three model runs follows.

Run-of-River

The run-of-river condition assumes only unregulated flow occurs in the Dennys River watershed for all reaches. For Meddybemps Lake, the model assumes that lake level remains constant, with monthly outflow equaling monthly inflow. Although this is a simplistic assumption, it does provide a baseline of how Atlantic salmon habitat would be affected if the Dennys River were an unregulated system.

Existing Rule Curve

This model was run for the existing rule curve, or lake level targets maintained by MASC. This run contained some key assumptions that were important for simplifying the model.

- **A minimum flow of 40 cfs would occur downstream of the Meddybemps Lake dam, even if it meant not meeting the rule curve target**. This is a realistic assumption, since 40 cfs roughly corresponds to actual operation during low flow (*i.e.* summer) months, when the fishway is open, the lake is drawn down, and the gate is open 2".
- **Monthly lake level targets are met, if possible, by varying lake outflow**. In actuality, the gate opening may be reset weekly, or even daily, to try to stay on the rule curve, and the rule curve may not be met exactly. For example, a gate operator may open the gate wider expecting

a big runoff event, only to have less precipitation delivered than expected, thereby missing the lake level target.

- **The refill schedule is linear between September 15th and June 1st.** In actuality, the gate may be set and left for weeks or months in the winter, with most of the refill occurring in discrete events during spring runoff (late March or April). However, lake level records were not historically kept in the winter and early spring, so it is difficult to calibrate the model to historic refill rates.

Revised, or Flow-Optimized Rule Curve

The third run attempts to "improve" the existing rule curve by revising lake level and flow targets to optimize habitat in the Dennys River as determined from IFIM modeling. Reach weighting analyses indicate that reaches 4 and 5 contained most available habitat for Atlantic salmon spawning, parr and YOY. Optimizing flows in these reaches for habitat is therefore akin to optimizing flows in the Dennys River.

Optimal flows varied by month, depending on the life stages of concern, as well as reach. Reach 5, with a slightly greater drainage area than Reach 4, would receive slightly more unregulated inflow, especially during high flow events. Three other conditions were assumed for this revised operation model.

- The lake not be allowed to spill.
- The existing informal minimum flow downstream of the dam (40 cfs), mainly resulting from fishway operation, be maintained.
- The drawdown not exceed the current target drawdown (35"), and be less if possible.

4.0 RESULTS

4.1 Discharge Measurements

Field data for low- and mid-calibration flows were collected during August 13-16, and high flow data were gathered April 4-5, 2002 (Table 3 and Figures 5 - 6). Low flow data were collected under prevailing Meddybemps Dam rule curve gate settings; mid-flow field conditions were temporarily provided by opening the gate for 24 hours. High flow data were gathered during unregulated spring run-off. A fourth (high) calibration flow was opportunistically surveyed in reach 5. Discharge varied by study reach, but ranged from 50 to 61 cfs for the low flow, 83 to 105 for the mid flow, and 204 to 486 cfs for the high flow.

Table 3. Summary of field calibration data collected for Dennys River PHABSIM hydraulic model.

Study	Low Flow Measurements		Mid Flow Measurements		High Flow Measurements	
Reach	Date(s)	Discharge (cfs)	Date(s)	Discharge (cfs)	Date (s)	Discharge (cfs)
1	8/13/2001	61	8/15/2001	105	4/5/2002	278
2	8/13/2001	57	8/15/2001	103	4/4/2002	204
3	8/13/2001	57	8/15/2001	103	4/5/2002	204
4	8/13/2001	50	8/15/2001	83	4/4/2002	384
5	8/14/2001	52-59	8/16/2001	84-89	4/4/2002	342-486*

*Two sets of high flow calibration data

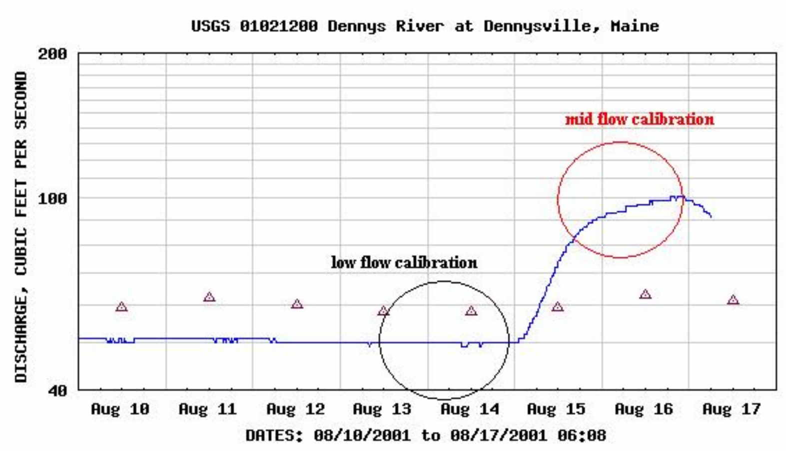


Figure 5. Dennys River stream flow at the USGS gage (reach 5) during low and mid-flow calibration data collection.

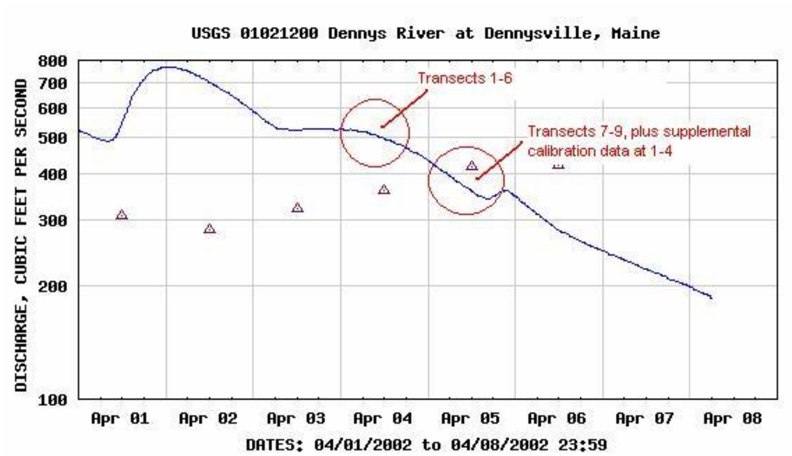
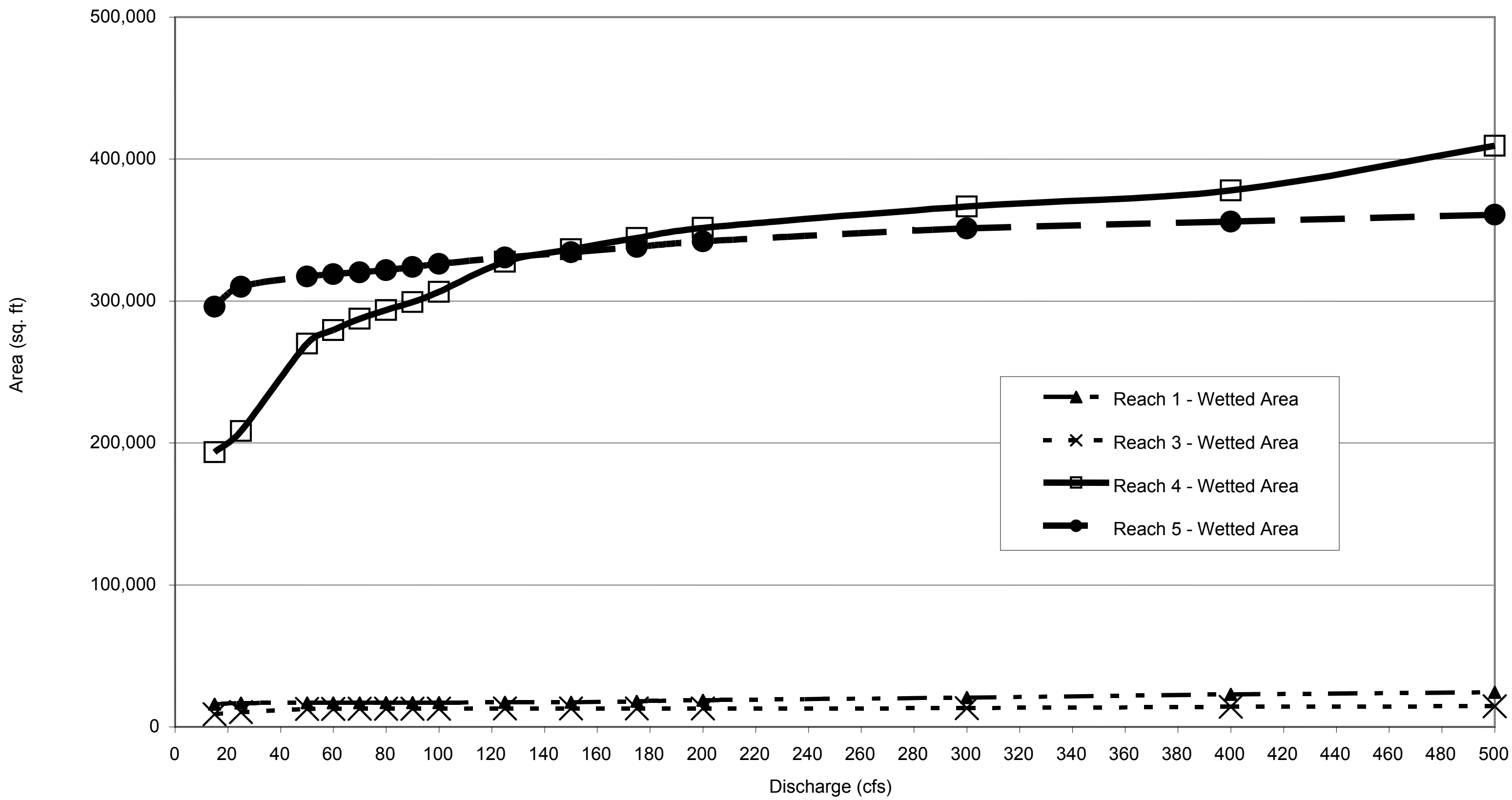


Figure 6. Dennys River stream flow at the USGS gage (reach 5) during high-flow calibration data collection.

4.2 Wetted Area

Figure 7 illustrates changes to wetted area in reaches 1,3, 4 and 5 based on the hydraulic model component of PHABSIM. Note that wetted area in Reach 4 increases rapidly up to 50 cfs and then wets more gradually after that. Reaches 1,3 and 5 are lower gradient, primarily run habitat, and therefore do not change in wetted area as significantly as do the riffle habitat modeled in reach 4. Reaches 4 and 5 represent the greatest amount of modeled wetted area within the watershed.

Figure 7. Dennys River Instream Flow Study. Total wetted area (sq. ft.) in study reaches in the Dennys River.



4.3 Weighted Usable Area

Figures 8-10 and tables 4 – 7 summarize habitat-discharge relationships in each study reach for YOY, parr and spawning/incubation lifestages of Atlantic salmon. Figures 11 and 12 depict habitat-discharge relationships for all three salmon lifestages and also the macroinvertebrate *Stenonema* for reaches 4 and 5 where most habitat occurs. The results consistently indicate that the majority of habitat for these species exists in the lower half of the river (reaches 4 and 5), and that the greatest volatility of habitat gain and loss across flows also occurs in these reaches. For these reasons, the following narrative focuses on these reaches unless otherwise noted.

4.3.1 YOY

Young of year habitat increases rapidly as flows ascend between 15 and 25 cfs in both reaches 4 and 5. Although the absolute peak WUA count is achieved at 50 cfs in Reach 5, WUA for this lifestage remains essentially unchanged between 25 and 60 cfs. At higher flows, habitat suitability for this lifestage declines at a constant and rapid rate indicative of increasing velocities and depth in riffle areas. WUA reaches an inflection point in Reach 4 at approximately 60 (94.3% of optimal), and remains essentially unchanged to 175 cfs, with an absolute peak in WUA at 150 cfs. Suitability declines at a gradual rate at higher flows.

4.3.2 Parr

Parr habitat increases rapidly as flows ascend to 50 cfs in Reach 5, and 100 cfs in reach 4. Although the absolute peak WUA count is achieved at 70 cfs in Reach 5, WUA for this lifestage remains above 95% of optimal between 50 and 100 cfs. At higher flows, habitat suitability for this lifestage declines at a constant and rapid rate. WUA reaches an inflection point in Reach 4 at approximately 90 cfs (90.2% of optimal), and reaches an absolute peak at 175 cfs. A flow as high as 300 cfs provides 94.7 % of the optimal WUA units.

4.3.3 Spawning and Incubation

Spawning and incubation habitat was greater in reach 4 than in any other reach, with reach 5 providing slightly more than that in reaches 1 and. In reach 4, habitat suitability changes in an arc-shaped curve rather than a linear curve, with increases featuring no pronounced inflection point. A flow range between 175 and 300 cfs produces 94 -100% of optimal habitat, with 200 cfs providing the absolute optimal. (Table 10, Figure 5). In reach 5, a range of 175-200 cfs produces 97.7 to 100% of optimal habitat.

4.3.4 Stenonema

Stenonema habitat increases rapidly as flows ascend to 60 cfs in both reaches 4 and 5. In reach 5 there is a pronounced inflection point at 60 cfs (92.1% of optimal), with the absolute peak WUA count achieved at 125 cfs followed by a gradual decrease at higher flow increments. WUA for *Stenonema* in Reach 4 achieves 92.3% of optimal at 125 cfs, and continues to ascend in an arc until reaching optimal at 300 cfs. At higher flows, habitat suitability for *Stenonema* declines only slightly.

4.3.5 Inter-lifestage Comparison

The dynamics of habitat changes among lifestages within reaches 4 and 5 are compared in figures 11 and 12, respectively. The trends indicate:

- The YOY lifestage tends to optimize at a lower flow than parr
- Both parr and *Stenonema* tend to optimize at a higher flow range than YOY (and there is a generally sympatric relationship between habitat changes for both parr and *Stenonema*)

- In Reach 4, spawning and incubation suitability tends to optimize at a flow that is in agreement with good parr and *Stenonema* conditions, and
- In Reach 5, spawning habitat optimizes at a flow that is higher than that which optimizes for YOY or parr, but is in reasonable agreement with *Stenonema* suitability.

Table 4. Dennys River Instream Flow Study. Wetted area and weighted usable area (WUA) for lifestages of Atlantic salmon and *Stenonema* in Study Reach 1 in the Dennys River.

Note: Shading denotes maximum WUA.

	Wetted	Atlantic salmon YOY		Atlantic salmon parr		Atlantic salmon spawning		Stenonema	
Discharge	Area (sq.ft.)	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA
15	15,914	11,200	91.5%	7,686	58.7%	1,489	12.6%	4,405	48.3%
25	16,726	12,245	100.0%	10,368	79.2%	3,999	33.9%	5,609	61.5%
50	16,899	11,783	96.2%	13,004	99.4%	7,589	64.3%	8,568	93.9%
60	16,957	11,155	91.1%	13,073	99.9%	8,595	72.9%	8,871	97.2%
70	17,011	10,592	86.5%	13,086	100.0%	9,530	80.8%	8,996	98.6%
80	17,062	10,062	82.2%	13,008	99.4%	10,383	88.0%	9,079	99.5%
90	17,112	9,565	78.1%	12,762	97.5%	11,107	94.2%	9,126	100.0%
100	17,158	9,074	74.1%	12,451	95.1%	11,553	97.9%	9,067	99.4%
125	17,268	7,874	64.3%	11,705	89.4%	11,797	100.0%	8,794	96.4%
150	17,370	6,760	55.2%	10,948	83.7%	10,823	91.7%	8,495	93.1%
175	18,122	5,834	47.6%	10,204	78.0%	9,555	81.0%	8,173	89.6%
200	18,793	5,271	43.0%	9,195	70.3%	8,134	69.0%	7,884	86.4%
300	20,684	4,588	37.5%	5,034	38.5%	3,248	27.5%	7,273	79.7%
400	22,863	5,393	44.0%	3,685	28.2%	1,279	10.8%	7,276	79.7%
500	24,368	6,161	50.3%	3,950	30.2%	383	3.2%	7,434	81.5%

Table 5. Dennys River Instream Flow Study. Wetted area and weighted usable area (WUA) for lifestages of Atlantic salmon and *Stenonema* in Study Reach 3 in the Dennys River.

Note: Shading denotes maximum WUA.

	Wetted	Atlantic salmon fry		Atlantic salmon parr		Atlantic salmon spawning		Stenonema	
Discharge	Area (sq.ft.)	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA
15	8,915	4,422	76.6%	4,276	63.1%	0	0.0%	3,919	51.8%
25	10,384	5,178	89.7%	5,152	76.0%	845	12.4%	5,043	66.6%
50	12,650	5,775	100.0%	6,602	97.4%	3,583	52.4%	6,222	82.2%
60	12,743	5,647	97.8%	6,768	99.9%	4,336	63.4%	6,697	88.5%
70	12,784	5,445	94.3%	6,776	100.0%	5,111	74.8%	7,072	93.5%
80	12,822	5,122	88.7%	6,700	98.9%	5,835	85.4%	7,326	96.8%
90	12,856	4,737	82.0%	6,578	97.1%	6,441	94.3%	7,519	99.4%
100	12,887	4,306	74.5%	6,402	94.5%	6,770	99.1%	7,566	100.0%
125	12,957	3,289	57.0%	5,809	85.7%	6,833	100.0%	7,270	96.1%
150	13,016	2,518	43.6%	4,993	73.7%	5,766	84.4%	6,794	89.8%
175	13,068	2,066	35.8%	4,222	62.3%	4,242	62.1%	6,303	83.3%
200	13,115	1,744	30.2%	3,605	53.2%	3,082	45.1%	5,873	77.6%
300	13,240	1,252	21.7%	2,493	36.8%	1,523	22.3%	4,766	63.0%
400	14,170	937	16.2%	2,083	30.7%	1,311	19.2%	3,974	52.5%
500	14,457	750	13.0%	1,841	27.2%	1,169	17.1%	3,249	42.9%

Table 6. Dennys River Instream Flow Study. Wetted area and weighted usable area (WUA) for lifestages of Atlantic salmon and *Stenonema* in Reach 4 of the Dennys River.

Note: Shading denotes maximum WUA.

	Wetted	Atlantic salmon fry		Atlantic salmon parr		Atlantic salmon spawning		Stenonema	
Discharge	Area (sq.ft.)	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA
15	193,506	79,855	48.1%	71,605	31.9%	5,647	4.5%	49,156	25.2%
25	208,374	111,976	67.4%	104,231	46.4%	11,248	9.0%	76,958	39.4%
50	269,984	149,160	89.8%	160,691	71.5%	32,496	26.1%	127,774	65.4%
60	279,524	156,571	94.3%	176,256	78.4%	44,162	35.5%	140,908	72.2%
70	287,432	162,107	97.6%	187,962	83.6%	56,094	45.1%	151,009	77.3%
80	293,564	164,219	98.9%	197,340	87.8%	66,476	53.5%	158,842	81.4%
90	299,170	164,279	98.9%	202,737	90.2%	74,556	60.0%	165,332	84.7%
100	306,479	163,502	98.5%	207,594	92.4%	82,199	66.1%	170,037	87.1%
125	327,771	164,556	99.1%	217,633	96.8%	97,635	78.5%	180,179	92.3%
150	336,456	166,042	100.0%	223,741	99.6%	108,593	87.3%	187,491	96.0%
175	344,344	162,308	97.8%	224,744	100.0%	117,193	94.2%	191,076	97.9%
200	351,532	157,612	94.9%	224,423	99.9%	124,358	100.0%	193,586	99.2%
300	366,561	138,771	83.6%	212,905	94.7%	120,648	97.0%	195,237	100.0%
400	377,975	118,927	71.6%	191,005	85.0%	101,822	81.9%	192,181	98.4%
500	409,385	106,347	64.0%	165,955	73.8%	80,166	64.5%	191,788	98.2%

Table 7. Dennys River Instream Flow Study. Wetted area and weighted usable area (WUA) for lifestages of Atlantic salmon and *Stenonema* in Reach 5 of the Dennys River.

Note: Shading denotes maximum WUA.

	Wetted	Atlantic salmon fry		Atlantic salmon parr		Atlantic salmon spawning		Stenonema	
Discharge	Area (sq.ft.)	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA	WUA	% Max. WUA
15	295,974	163,332	84.0%	140,063	56.1%	197	0.7%	79,689	36.1%
25	309,992	189,508	97.4%	188,454	75.5%	1,253	4.5%	127,627	57.9%
50	317,348	194,482	100.0%	241,041	96.5%	5,967	21.2%	190,542	86.4%
60	318,857	191,483	98.5%	248,236	99.4%	8,559	30.4%	203,200	92.1%
70	320,309	187,045	96.2%	249,660	100.0%	11,187	39.8%	211,126	95.7%
80	321,791	181,937	93.5%	248,502	99.5%	13,866	49.3%	214,349	97.2%
90	324,034	176,331	90.7%	246,229	98.6%	16,261	57.8%	216,510	98.2%
100	326,128	170,584	87.7%	243,516	97.5%	18,295	65.1%	218,139	98.9%
125	330,616	156,024	80.2%	234,129	93.8%	22,566	80.2%	220,589	100.0%
150	334,479	140,007	72.0%	221,293	88.6%	25,567	90.9%	220,166	99.8%
175	338,018	123,618	63.6%	207,141	83.0%	27,472	97.7%	218,489	99.0%
200	342,007	107,659	55.4%	193,013	77.3%	28,120	100.0%	215,417	97.7%
300	351,079	63,255	32.5%	121,168	48.5%	23,789	84.6%	197,882	89.7%
400	355,942	42,118	21.7%	71,881	28.8%	14,677	52.2%	182,576	82.8%
500	360,874	32,689	16.8%	46,268	18.5%	6,179	22.0%	169,296	76.7%

Figure 8. Dennys River Instream Flow Study. Weighted usable area (sq. ft) for Atlantic salmon YOY compared among reaches in the Dennys River.

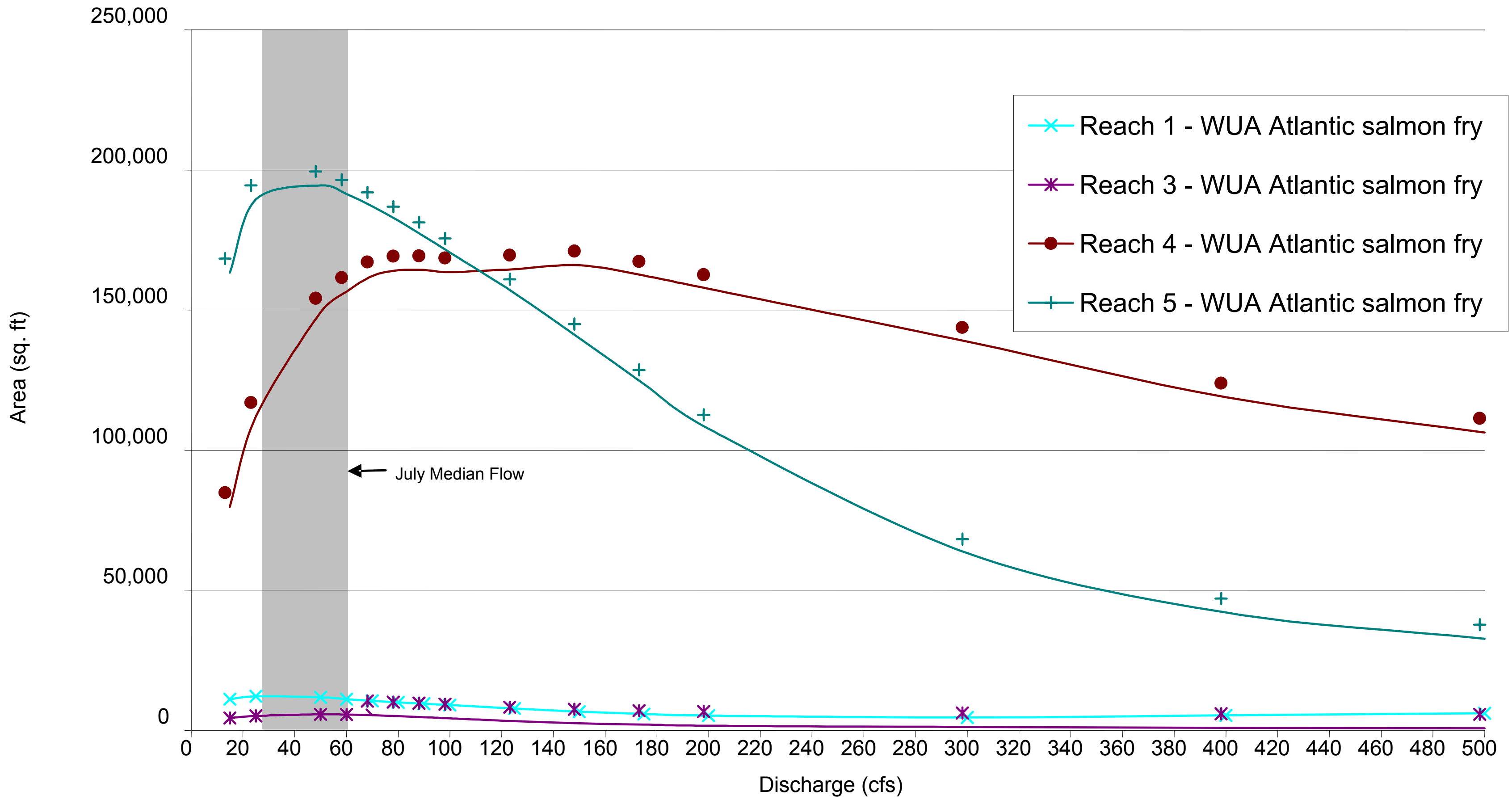


Figure 9. Dennys River Instream Flow Study. Weighted usable area (sq. ft) for Atlantic salmon parr at study reaches in the Dennys River.

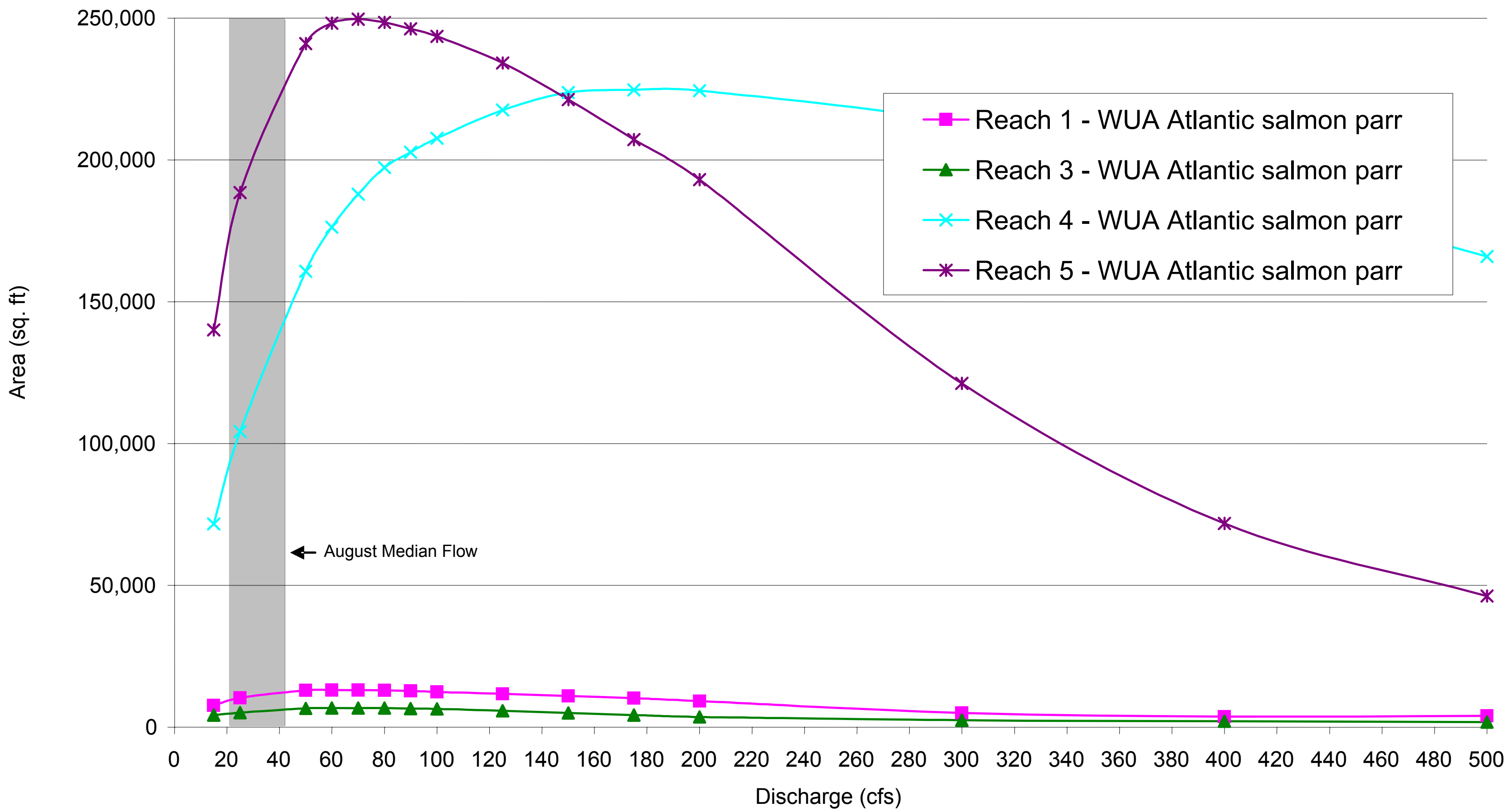


Figure 10. Dennys River Instream Flow Study. Weighted usable area (sq. ft) for Atlantic salmon spawning at study reaches in the Dennys River.

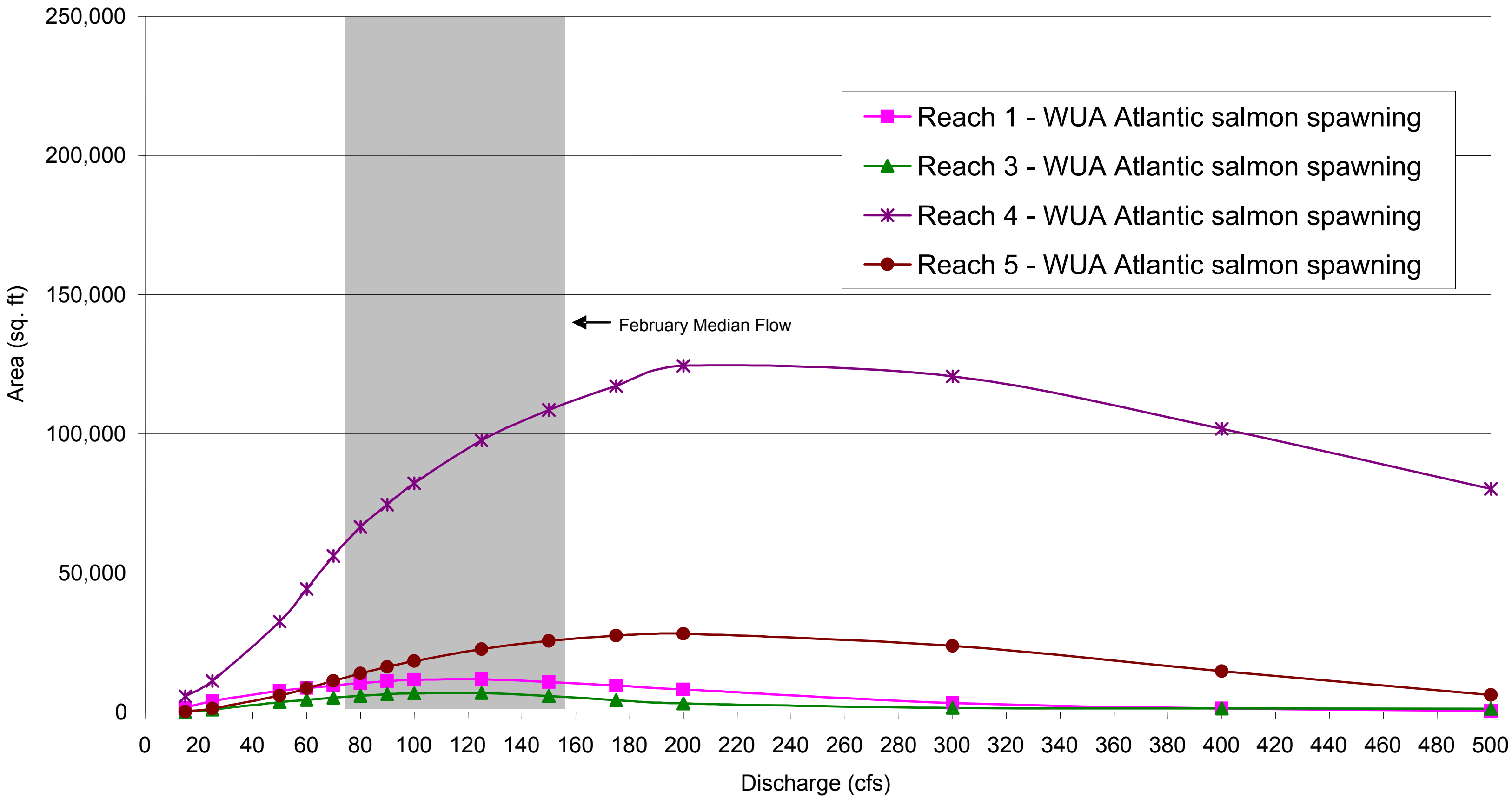


Figure 11. Dennys River Instream Flow Study. Weighted usable area (sq. ft) for lifestages of Atlantic salmon and *Stenonema* in Reach 4 of the Dennys River.

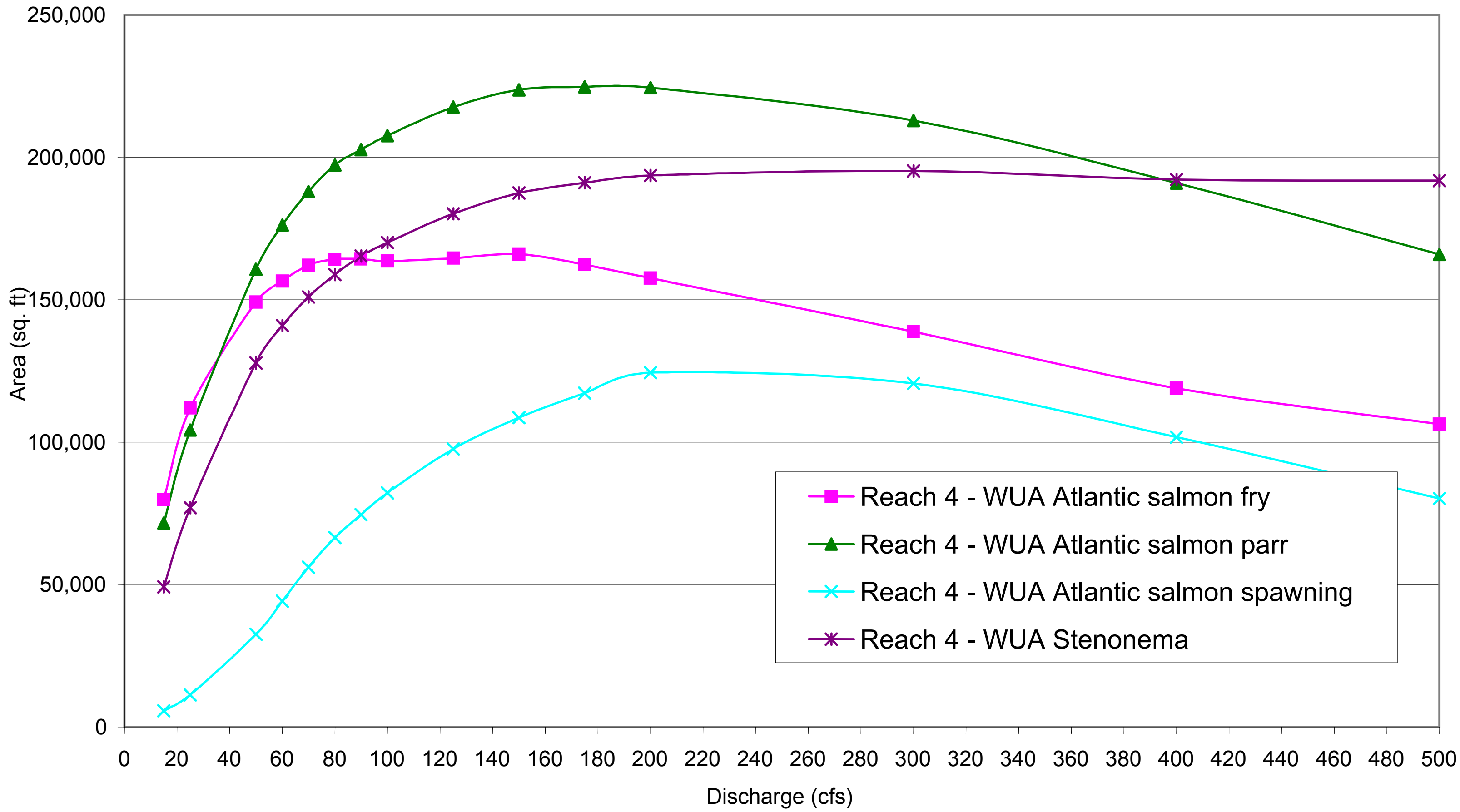
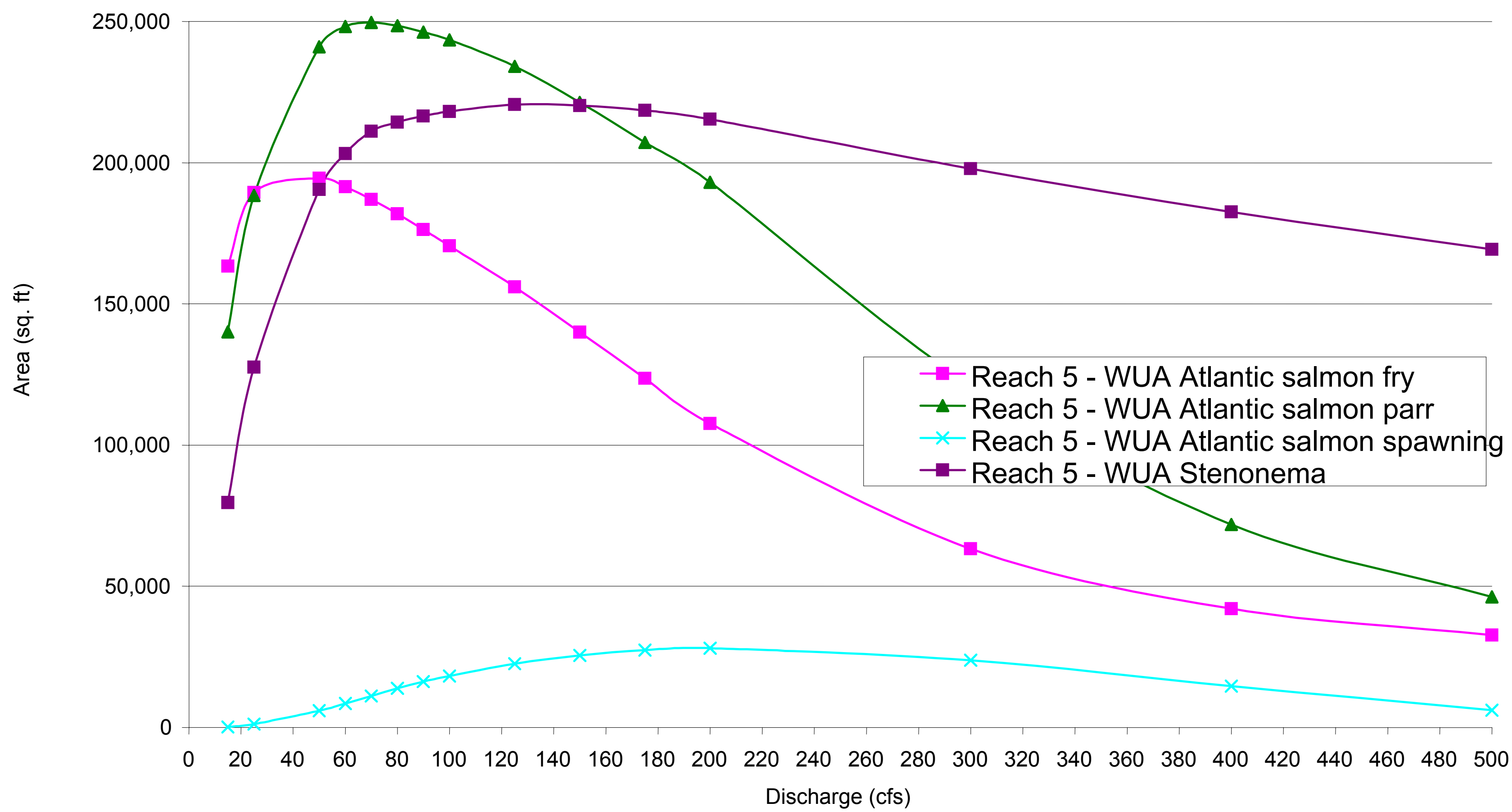


Figure 12. Dennys River Instream Flow Study. Weighted usable area (sq. ft) for lifestages of Atlantic salmon and *Stenonema* in Reach 5 of the Dennys River.



4.4 Water Budget Analysis

Reaches 4 and 5 provide most of the strategic Atlantic salmon rearing habitat in the Dennys River and thus best illustrate how regulation of Meddybemps Lake affects habitat. The water budget modeling provides a comparison of the effects of flow regulation on Atlantic salmon habitat in the Dennys River. Table 8a summarizes the median monthly flows for Reach 4. Table 8b indicates what the flow release at Meddybemps should be to achieve corresponding habitat targets downstream in reaches 4 and 5. Because flows exceed or fall below a median flow half the time, this value should be considered as a general target rather than an absolute flow requirement. Flows and habitat suitability can and will fluctuate around these targets.

4.4.1 Run of River

Under a scenario in which the Meddybemps Dam was operated to provide no stream flow storage or augmentation (*i.e.* unregulated), median discharge in Reach 4 would range from 32 cfs (August) to 378 cfs (April). August and September would both have similar low flows (32 and 35 cfs respectively)

4.4.2 Existing Rule Curve

Under the existing rule curve, the water budget model indicates that Reach 4 would experience monthly median flows ranging from 61 cfs (September) up to 318 cfs (April). The two consecutive low flow months are shifted to September and October (61 and 67 cfs respectively), although the historical gage data indicates some deviation; low flow months are August/September (66/67 cfs).

4.4.3 Revised, or Flow-Optimized Rule Curve

For January, February, March, April, November and December, the life stage of concern is spawning/incubation. For Reach 4, the optimal flow is 200 cfs, which would correspond to a slightly greater flow in Reach 5. Because 200 cfs is not feasible, then flows should be as close to 200 cfs as possible without violating lake level rules. Flows may exceed, but should not fall below, those occurring during the lowest flow month of the lifestage season (105 cfs in February).

For May and June, the optimal habitat for fry and parr occurs at 70 cfs in Reach 4 (with a corresponding flow of 80 cfs in Reach 5). However, on most years more flow will need to be released to stay within lake level rules.

In July, August, September and October, optimizing parr habitat means targeting 100 cfs in Reach 4 (125 cfs in Reach 5). Most years a range of median monthly flows of 92-128 cfs should be feasible. However, if flows must be reduced to 80 cfs on dry years, there is only a relatively small reduction in habitat (<0.5%).

We also modeled the effects of managing lake outflow strictly to maintain optimal habitat flows (*i.e.,* spawning flow of 200 cfs January- April, November-December, YOY flow of 70 cfs May-June, and parr flow of 100 cfs July-October). Under this scenario the lake will not refill annually. An initial model run showed that the lake level would steadily drop year after year because the optimal flows could not be sustained. Specifically, the spawning flow (200 cfs) could not be maintained for six months out of every year. Therefore, the existing rule curve was revised to maximize habitat, knowing that conditions would be closer to optimum in May, June, July August, September and October (for fry and/or parr) than in January, February, March, April, November and December (for spawning).

An assessment of the run-of-river and existing rule curve models indicated that optimizing habitat required an approach of:

1) reducing lake outflow in April, May and June, and using this period for the bulk of lake refill,

2) starting the lake drawdown later than June 1 and ending it after September 15, thereby reducing flows in June and providing more flow in October, and

3) relying less on November through March for lake refill, thereby providing more winter flow for spawning considerations.

The revised rule curve used in the model was therefore as follows:

Date	**Drawdown**
June 1	3" (lake essentially full)
July 1	3"
August 1	10"
September 1	17"
October 1	23"
November 1	30"
December 1	30"
January 1	30"
February 1	30"
March 1	30"
April 1	24"
May 1	12"
June 1	3" (lake refilled)

Table 8a. Modeled and historic median monthly flow targets for Dennys River IFIM Reach 4

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Run-of-river	140	124	215	378	166	89	47	32	35	64	162	174
Existing Rule Curve (Model)	103	92	147	318	131	177	129	115	61	67	109	129
Historical (1955-2001)	189	166	229	428	229	164	91	66	67	93	191	208
Revised Rule Curve	121	105	183	261	110	84	100	95	92	128	162	174
Optimal (IFIM)	***200***	***200***	***200***	***200***	***70***	***70***	***100****	***100****	***100****	***100****	***200***	***200***

***80 cfs provides < 0.5% less habitat than optimal**

Table 8b. Discharge (cfs) from Meddybemps Lake required to meet run-of-river, existing rule curve, and revised rule curve targets at reaches 4/5 under median monthly flow conditions.

Meddybemps Operation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Run of River	81	72	125	219	96	51	27	19	20	37	94	101
Existing Rule Curve	40	40	47	161	61	139	109	101	46	40	40	42
Revised Rule Curve	81	72	66	94	40	40	80	78	82	100	94	101

4.5 Habitat Suitability Under Different Rule Curves

Table 9 compares how each rule curve scenario affects habitat suitability based on combined WUA values for reaches 4 and 5.

Parr. The existing rule curve consistently provides a higher percentage of optimal habitat than what would exist in an unregulated river for parr during all months of the year. A "revised rule curve" modeled on the suggested scenario in this report should increase that habitat further during most months other than November and December.

YOY. The existing rule curve does not consistently provide better habitat for YOY salmon over a run-of-river condition. Under run-of-river 76-95% of optimal habitat occurs across various months; under the existing rule curve the range is 75-87%. However, an approach following the "revised rule curve" model will, however increase these reaches so that habitat suitability performs in the 85-94% of optimal range.

Spawning and incubation. The existing rule curve produces similar to inferior habitat suitability for spawning and incubation (69-90% optimal) relative to an unregulated run-of-river scenario (75-99%). The "revised rule curve" approach should produce spawning habitat suitability close to that in the unregulated scenario.

Table 9a. Dennys River Instream Flow Study. Percent optimal WUA (reaches 4 and 5 combined) attained for lifestages of Atlantic salmon under run-of-river, existing rule curve, and revised rule curve.

lifestage	Meddybemps Operation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
YOY	Run of River	-	-	-	-	76%	91%	95%	-	-	-	-	-
	Existing Rule Curve	-	-	-	-	81%	75%	87%	-	-	-	-	-
	Revised Rule Curve	-	-	-	-	85%	94%	92%	-	-	-	-	-
parr	Run of River	91%	92%	78%	54%	88%	77%	86%	73%	87%	92%	88%	84%
	Existing Rule Curve	92%	93%	88%	57%	90%	88%	94%	94%	90%	92%	91%	90%
	Revised Rule Curve	91%	92%	88%	69%	91%	93%	94%	94%	95%	94%	88%	84%
Egg incubation	Run of River	89%	82%	98%	75%	-	-	-	-	-	-	95%	99%
	Existing Rule Curve	74%	69%	90%	84%	-	-	-	-	-	-	76%	86%
	Revised Rule Curve	86%	82%	90%	95%	-	-	-	-	-	-	95%	99%

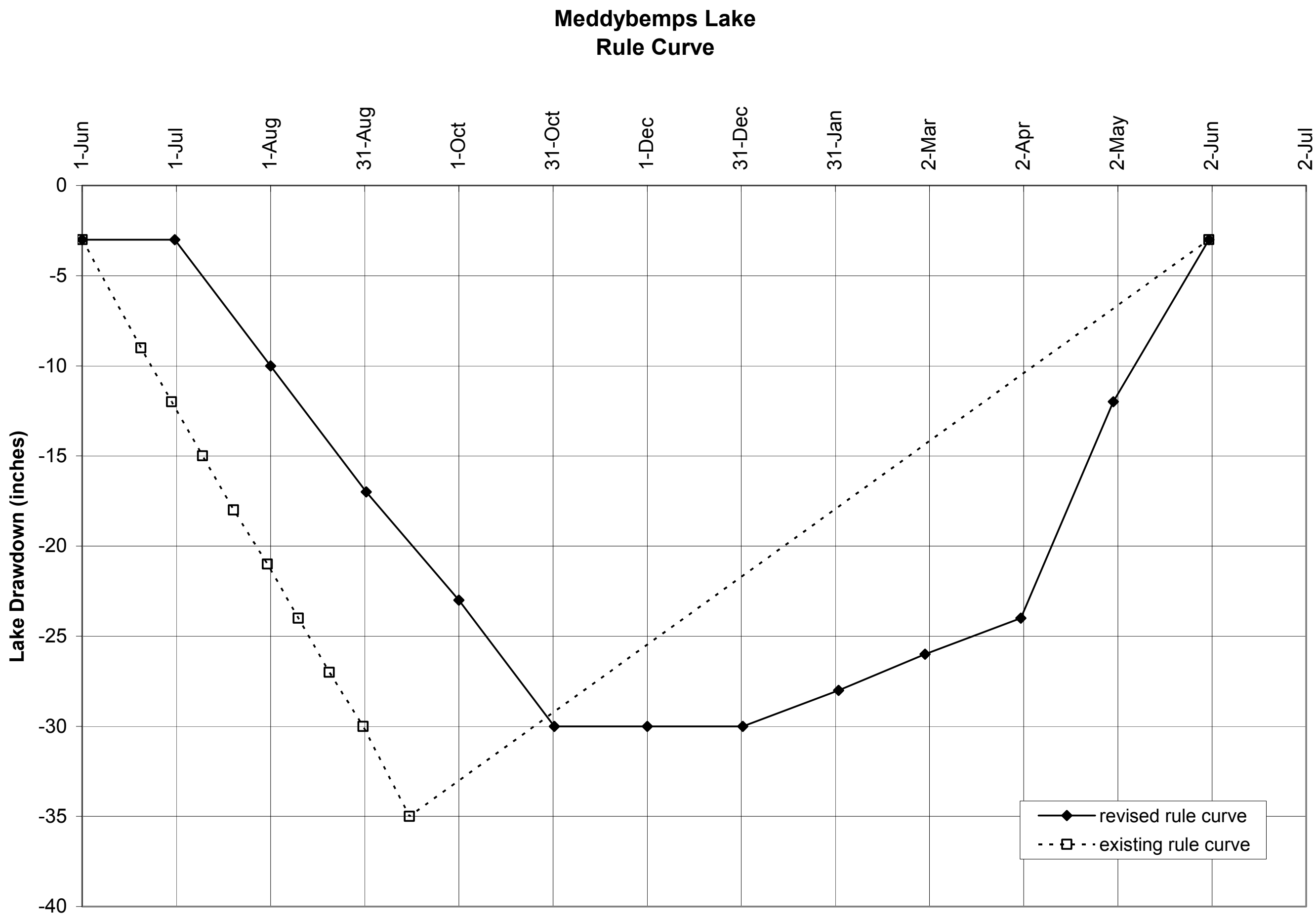
4.6 Lake Level Effects

Since there is a lot of interest in the maximum drawdown of Meddybemps Lake by lake stakeholders, it is important to note that the revised rule curve approach not only better maximizes habitat in the Dennys River but would typically provide higher lake levels during the summer recreation season. The following is a comparison of existing and revised rule curves for June through September.

Date	Lake Drawdown (Existing Rule Curve)	Lake Drawdown (Revised Rule Curve)
June 1	-3”	-3”
July 1	-12”	-3”
August 1	-21”	-10”
September 1	-30”	-17”
October 1	-35”	-23”

The comparison of the existing rule curve with the revised rule curve is also portrayed in Figure 13.

Figure 13. Revised Rule Curve



5.0 DISCUSSION

5.1 Deviations Between Model and Historic Flows

Differences exist between the existing rule curve model and historic USGS gaging data.

For Reach 5, the *median* monthly flows estimated by the water budget model for the existing rule curve can be compared with the *median* monthly flows from the Dennysville gage (also located within Reach 5) records for the period 1955-2001.

Median Monthly Flows: Reach 5

Month	Exist. Rule Curve (Model)	Historical (Gaged)	% Difference
January	133	189	+ 42%
February	118	166	+ 41%
March	186	229	+ 23%
April	395	428	+ 8%
May	164	229	+ 40%
June	195	164	- 16%
July	138	91	- 34%
August	121	66	- 45%
September	68	67	- 1%
October	80	93	+ 16%
November	142	191	+ 35%
December	168	208	+ 24 %
Annual	141	187	+ 33%

Similarly, for Reach 5, the *mean* monthly flows calculated by the water budget model for the existing rule curve can be compared with the *mean* monthly flows from the Dennys River streamgage records for the period 1955-2001.

Mean Monthly Flows: Reach 5

Month	Exist. Rule Curve (Model)	Historical (Gaged)	% Difference
January	159	193	+ 21%
February	152	191	+ 26%
March	228	260	+ 14%
April	399	440	+ 10%
May	215	277	+ 29%
June	211	169	- 20%
July	153	103	- 33%
August	132	74.7	- 43%
September	89	79.9	- 10%
October	98	113	+ 15%
November	176	195	+ 11%
December	204	216	+ 6 %
Annual	184	192	+ 4%

The differences in median flow between the existing rule curve (model) and gage records for several months may be partly due to the fact that the existing rule curve and dam configuration do not date all the way back to 1955. Also, it is not known how well the existing rule curve has historically been met, and the model assumes good compliance.

Differences in mean monthly flows imply that the model may be overestimating flow in the summer and underestimating flow in the winter. This may be due to uncertainty of proration of Narraguagus River flows to the Dennys River; on an annual basis the proration looks good (note the 4% difference in mean annual flow for the period of record), but it breaks down at the monthly level. For summer months, the effect may indeed be caused by increased evaporative loss in Meddybemps Lake, compared to the Narraguagus River basin. While it is expected that coefficient “a” on the drainage area ratio would vary seasonally as well as annually, this seasonal variation cannot be predicted without comparing Narraguagus flows with unregulated Dennys River flows for an overlapping period of record. As explained earlier, the historic gage data for the Dennys River includes regulated flow.

Another possible reason for the differences between modeled and gaged median monthly flows is that dam operators have historically exhibited some flexibility in dam operation. For example, the rule curve might have purposefully been violated if there was a desire to increase river flows or to refill the lake. The model, obviously, could not calibrate to the historic week-by-week decision making of operators.

Ultimately, the operation of Meddybemps Lake—on an annual drawdown and refill cycle—makes the monthly differences less significant than they initially appear. That is, an additional drawdown to provide summer flows would be offset by additional flow available for refill in the winter and early spring. More important are the incremental differences in monthly flow and habitat between the modeled run-of-river, existing rule curve and revised rule curve scenarios. All of these scenarios have the same annual water budgets, and also have the same systematic uncertainty.

5.2 Meddybemps Lake Water Budget

As discussed earlier, Meddybemps Lake has historically been operated with an annual drawdown of approximately 35" between June 1st and September 15th, with refill of the lake between September 15th and June 1st. Although no interim monthly targets were set for the refill period, it is expected that the refill mostly occurred from fall runoff (large rain events), a midwinter (January or February) thaw, and spring runoff.

Using monthly flows prorated from the unregulated Narraguagus River streamgage, three operating conditions were modeled for the Meddybemps Lake and the Dennys River system. The first condition is the run-of-river, or unregulated condition, which assumes that there would be no lake drawdown. While this is a good approximation for a baseline condition, it is not perfect. In actuality, without the dam, Meddybemps Lake levels would still fluctuate seasonally, with this fluctuation largely determined by hydraulic conditions at the outlet.

The second condition is the existing rule curve. The water budget model assumes that the existing lake level targets are met, if possible, by varying lake outflow. This includes some constraints: the lake is not allowed to spill over the dam, and a minimum flow of 40 cfs is maintained below the dam at all times. In actuality, operation of the dam is more complex than simply meeting lake level targets. For example, in any given month an operator may decide to provide more outflow to the Dennys River and let the lake fall below the rule curve target. Then, the refill is made up in another month. Also, gate changes at the dam can be made daily or weekly, and the model assumes an average monthly inflow and outflow.

The third condition is a revised rule curve. Based on the PHABSIM habitat model and hydrologic data, it appears as though habitat management goals in the Dennys River can be maximized by beginning the drawdown later in the year (July 1st), extending the drawdown through October, and doing most of the refill in March, April, May and June. Based on discussions with the Maine Atlantic Salmon Commission, this revised rule curve was tweaked to provide for some refill during midwinter thaws in January and/or February. The lowest target lake level for the revised rule curve is -30 inches, which is slightly higher than the existing minimum lake level target (-35 inches). Smaller lake drawdowns (-12 inches or -24 inches) were not extensively modeled, except to verify that drawdowns of less than -30 inches did not significantly increase flows during summer months (July, August and September). Also, it was evident that providing the absolute optimum flows identified by PHABSIM model output in all months was not sustainable; the lake level would drop year after year, as the volume of seasonal drawdowns exceeded the volume of seasonal refills.

As discussed previously, the water budget models attempt to meet monthly target lake levels by varying outflow. In actuality, both lake level and outflow targets will be used in the future to manage flow in the Dennys River basin. While optimal river flows will be targeted, it is expected that flows above or below optimal may at times be unavoidable, or allowed via management if the lake is too far from its seasonal targets. This balancing, which may involve week-by-week adjustments by MASC staff, is too complex to model on a monthly basis. Since the “allowable” deviations from the rule curve and optimal flows have not been determined, it is not possible at this time to build this logic into the water budget model. Therefore, it is not meaningful to ask “What is the maximum lake level drawdown in any given year?", since this drawdown can be affected by revising dam outflow up or down.

During dry summers, the revised rule curve will not provide optimal flows. Dam operation could meet the rule curve by reducing outflow below the habitat target flow, or increase the lake drawdown by keeping outflow at the habitat-based target. In actuality, the operator would probably do both—reduce outflow and allow a little more drawdown of the lake. The data in this report should provide the operator with a sense of what trade-offs exist under various choices.

The revised rule curve, in which the drawdown would occur between July 1st and October 31st (five months), has two intended consequences. The first is to maximize habitat availability during critical low flow periods, such as July-September and even October. For Reach 4 on the Dennys River, the optimal flows are 100 cfs for July, August, September and October. Since a flow of 80 cfs for July, August, September and October results in less than a 0.5% reduction in total habitat, targeting a flow range between 80 and 100 cfs should provide good summer rearing habitat conditions.

The second intended consequence is to reduce spring flows (March-May) closer to optimal levels for egg incubation (< 200 cfs in Reach 4) by providing volume to capture spring runoff.

Note that the revised rule curve scenario does not imply that a lake drawdown to -30 inches will be required every year. In fact, in most years the drawdown could be less than -30 inches and still provide optimal summer flows in the Dennys River. However, the tradeoff would be less volume available to capture spring runoff, which may result in higher-than-optimal flows in the following spring. One way to deal with "wet" summers may be to provide the optimal flow and minimize the lake drawdown, recognizing that some drawdown would have to occur in November, December, January and February in order to have storage volume available for spring runoff. This could be achieved by releasing more flow in these months, although care should be given not to provide a flow that entices redd formation in river bed areas that cannot be sustainably wetted during the incubation months. This may entail some field observation at specific spawning areas. Another option is to simply allow high flow releases in a spring (prior to YOY emergence) following a wet summer when the lake is not drawn down appreciably.

This revised rule curve is not necessarily a specific endorsement for revising the existing operation. Other factors (*e.g*. competing priorities for fish and wildlife management in Meddybemps Lake, recreation, *etc*.) outside the scope of this analysis may influence decisions regarding lake level regulation. Although it may be possible to optimize riverine habitat even further, no rule curve/flow release schedule is going to be met all of the time, due to operating constraints, vagaries in climate, and the uncertainty of predicting unregulated inflow. However, this revised rule curve suggests a starting point for refined flow regulation in the Dennys River basin.

The revised rule curve tends to increase habitat for several months compared to the run-of-river and existing rule curve scenarios. As noted previously, the water budget model may overestimate flow in the summer and underestimate flow in the winter and early spring. For the revised rule curve, the implication of this would be that the maximum drawdown may have to be closer to the current target of -35 inches, rather than -30 inches, and that a modest amount of refill (say 6 in.) may have to occur between November 1 and March 1. However, this does not invalidate the model results that show that shifting the timing of the current June 1-September 15 drawdown to a July 1-November 1 drawdown may help optimize habitat.

6.0 RECOMMENDATIONS

To optimize Dennys River salmon habitat, we recommend managing flow based on habitat targets in reaches 4 and 5. A revised rule curve similar to the one illustrated in this analysis should sustainably maximize habitat suitability for rearing and spawning lifestages of salmon while maintaining Meddybemps Lake level targets and existing overall water level fluctuation ranges. The recommended revised rule curve is a starting point, final operating guidelines for the Meddybemps Dam will ultimately be refined through experience across a range of dry, normal and wet water years.

The extent to which a modified rule curve should be followed or modified during a given month will be governed by prevailing field conditions, which will vary year to year. These adjustments will be refined as operation experience is gained over time. As general guidance, a table relating gate discharge in Reach 1 to discharge in Reach 5 (as represented by the USGS Dennysville gage) under hydrologic conditions ranging from “extremely wet” to “extremely dry” is provided as Appendix D.

7.0 LITERATURE CITED

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APPENDIX A

PHOTOGRAPHS OF IFIM TRANSECTS AT EACH CALIBRATION FLOW

Transect 1 Low Flow

Transect 1 Mid Flow

Transect 1 High Flow

Transect 2 Low Flow

Transect 2 Mid Flow

Transect 2 High Flow (Looking across transect toward headpin)

Transect 3 Low Flow

Transect 3 Mid Flow

Transect 3 High Flow (Looking across transect toward headpin)

Transect 4 Low Flow

Transect 4 Mid Flow

Transect 4 High Flow (Looking across transect toward headpin)

Transect 5 Side Channel at Low Flow (Looking across from headpin side)

Transect 5 Side Channel at Mid Flow (Looking across from headpin side)

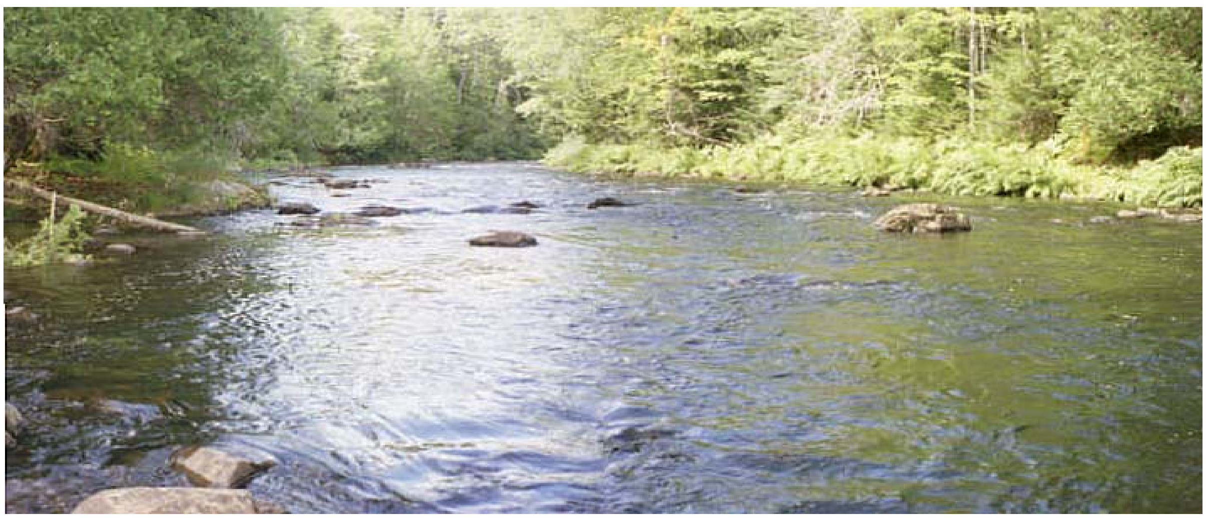
Transect 5 Side Channel at High Flow (Looking across from headpin side)

Transect 5 Main Channel at Low Flow

Transect 5 Main Channel at Mid Flow

Transect 5 Main Channel at High Flow

Transect 6 Low Flow



Transect 6 Mid Flow

Transect 6 High Flow


Transect 7 Low Flow


Transect 7 Mid Flow


Transect 7 High Flow

Transect 8 Low Flow

Transect 8 Mid Flow

Transect 8 High Flow

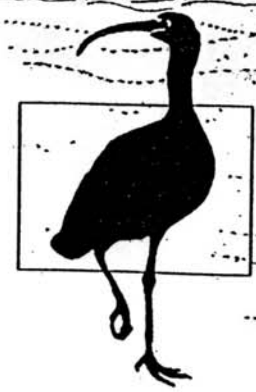
Transect 9 Low Flow

Transect 9 Mid Flow

Transect 9 High Flow

APPENDIX B

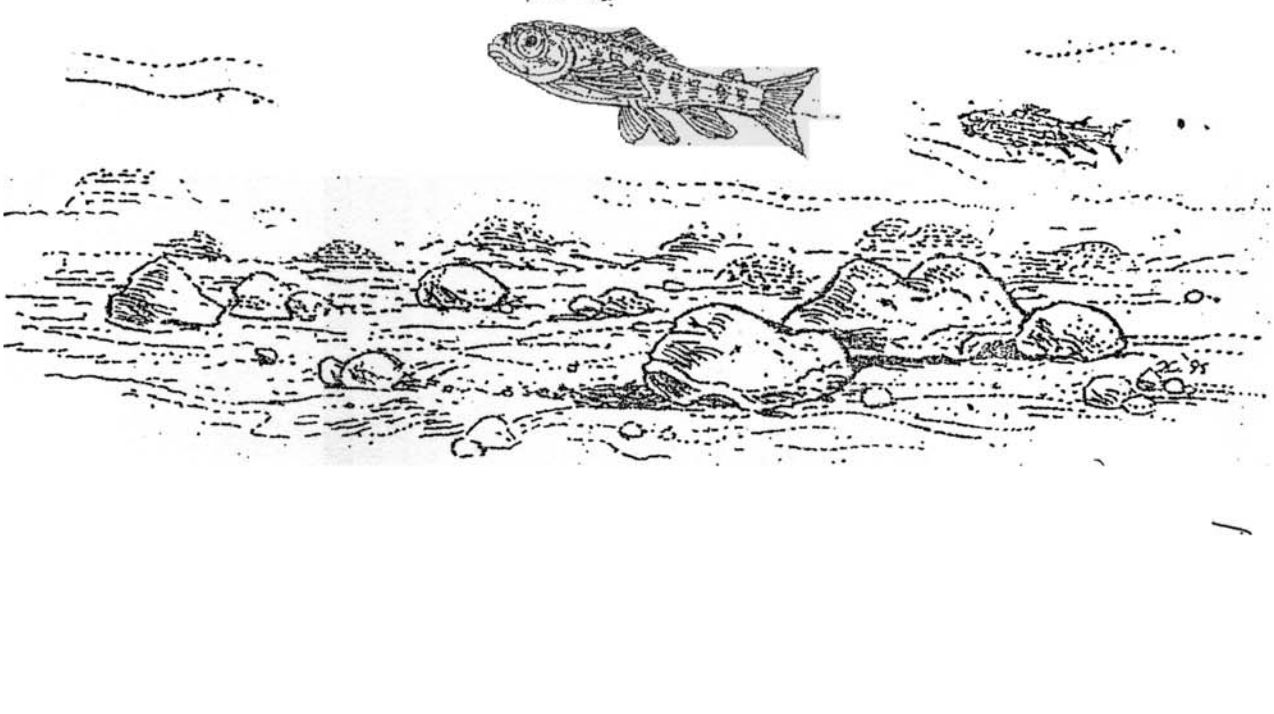
HABITAT SUITABILITY INDICES



U.S. DEPARTMENT OF THE INTERIOR
NATIONAL BIOLOGICAL SERVICE

BIOLOGICAL SCIENCE REPORT 3

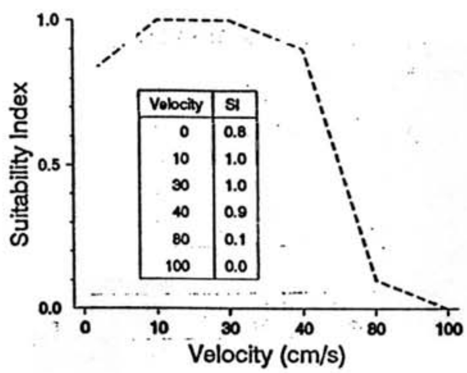
HABITAT SUITABILITY INDEX MODELS: NONMIGRATORY FRESHWATER LIFE STAGES OF ATLANTIC SALMON



Fry Component

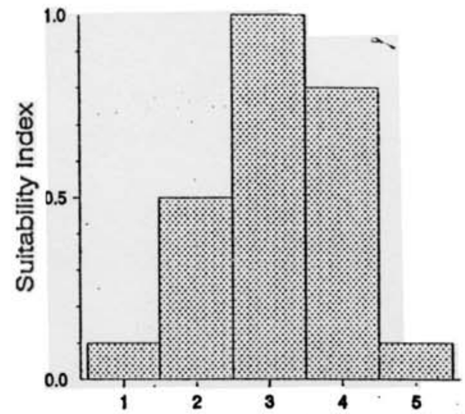
If mean stream depth is greater than 50 cm, divide the stream into fourths. Because fry occur mostly in the shallower sections, average the variables for the two shallowest fourths of the section to arrive at a mean value for each SI of the fry component. In streams shallower than 50 cm, simply average the entire stream.

V6: Mean column velocity for fry during base summer flow. Measuring at a point 0.6 x total depth from the surface approximates mean column velocity.



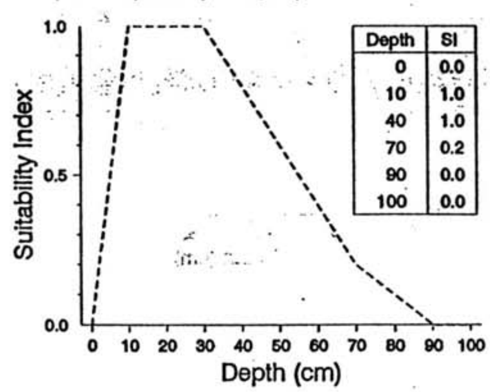
Velocity	SI
0	0.8
10	1.0
30	1.0
40	0.9
80	0.1
100	0.0

V7: Dominant substrate for fry.



Substrate Code	Substrate Type	Size (mm)	SI
1	Fines	< 0.5	0.1
2	Sand	0.5 - 2.2	0.5
3	Pebble-gravel	> 2.2 - 22.2	1.0
4	Cobble	> 22.2 - 256	0.8
5	Boulder	> 256	0.1

V8: Mean depth for fry during base summer flow.

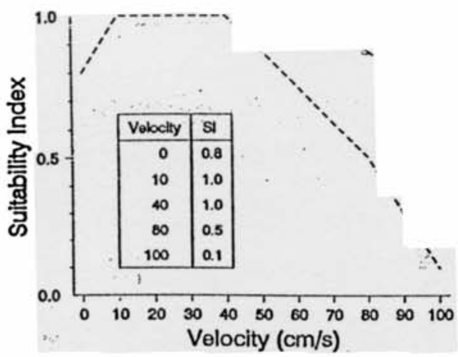


Depth	SI
0	0.0
10	1.0
40	1.0
70	0.2
90	0.0
100	0.0

Parr Component

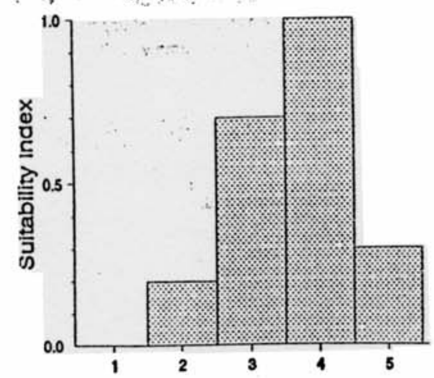
If mean stream depth is over 50 cm, divide the stream into fourths, and average the variables in the two deepest fourths to arrive at the mean value for each SI. In streams shallower than 50 cm, use the mean values for the entire stream.

V9: Mean column velocity for parr during base summer flows.



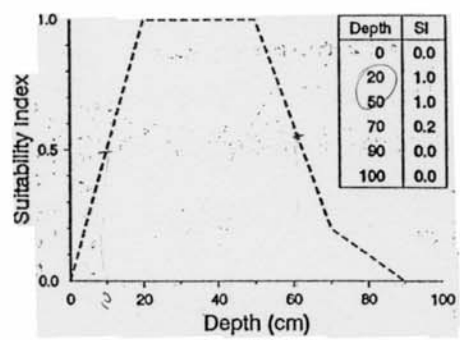
Velocity	SI
0	0.8
10	1.0
40	1.0
80	0.5
100	0.1

V10: Dominant substrate for parr.



Substrate Code	Substrate Type	Size (mm)	SI
1	Fines	< 0.5	0.0
2	Sand	0.5 - 2.2	0.2
3	Pebble-gravel	> 2.2 - 22.2	0.7
4	Cobble	> 22.2 - 256	1.0
5	Boulder	> 256	0.3

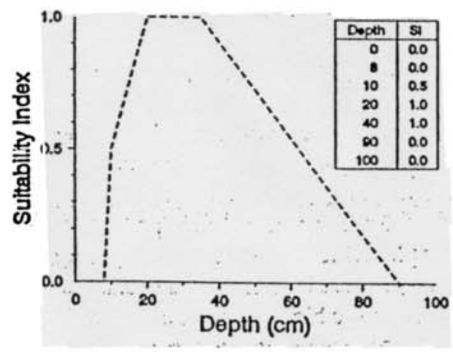
V11: Mean depth for parr during base summer flows.



Depth	SI
0	0.0
20	1.0
50	1.0
70	0.2
90	0.0
100	0.0

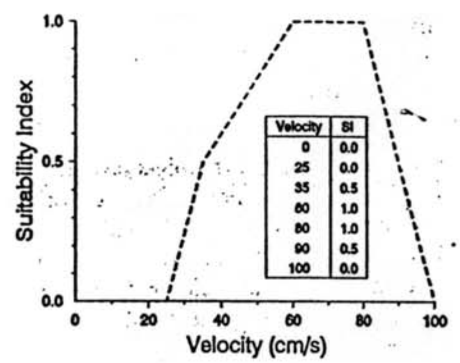
Reproductive Component

Evaluate at the head or tail of pools only if the substrate material is > 2.2 to 256 mm in diameter and water is at least 15 cm deep. The best time to conduct the field work would be in the fall, when Atlantic salmon are selecting spawning areas. Otherwise, attempt to estimate fall conditions by historical information on seasonal variation.



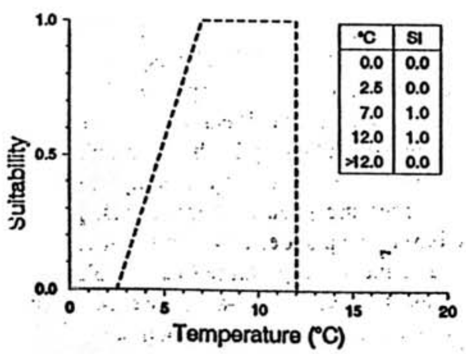
Depth	SI
0	0.0
8	0.0
10	0.5
20	1.0
40	1.0
90	0.0
100	0.0

V13: Mean column velocity for reproduction during fall, or at flow conditions approximating those occurring during fall.

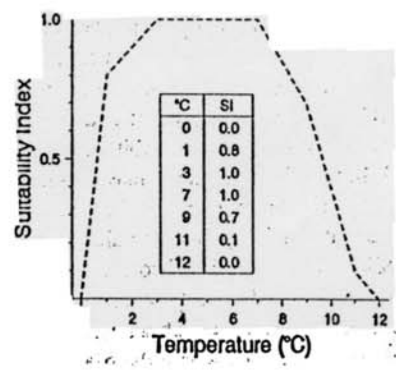


Velocity	SI
0	0.0
25	0.0
35	0.5
60	1.0
80	1.0
90	0.5
100	0.0

V14: Spawning temperature - If water temperature reaches then declines below 12°C in late October and early November, SI=1.0. Spawning will follow the date that water temperature reaches and maintains a temperature between 12° and 7°C.

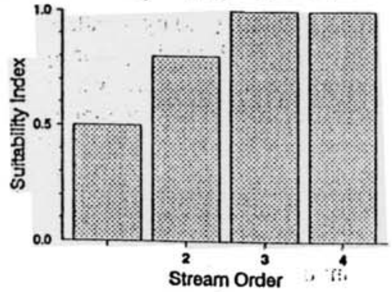


°C	SI
0.0	0.0
2.5	0.0
7.0	1.0
12.0	1.0
>12.0	0.0



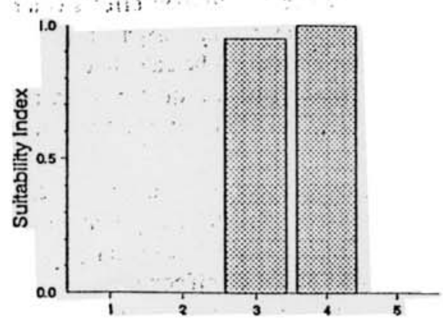
°C	SI
0	0.0
1	0.8
3	1.0
7	1.0
9	0.7
11	0.1
12	0.0

V16: Stream order, based on stream branches having permanent water flow.



Stream Order	SI
1	0.5
2	0.8
3	1.0
4	1.0

V17: Dominant substrate for spawning and embryo incubation.



Substrate Code	Substrate Type	Size (mm)	SI
1	Fines	< 0.5	0.00
2	Sand	0.5 - 2.2	0.00
3	Pebble-gravel	> 2.2 - 22.2	0.95
4	Cobble	> 22.2 - 256	1.00
5	Boulder	> 256	0.00

APPENDIX C

BED ELEVATION AND CALIBRATION FLOW WATER SURFACE ELEVATIONS - SURVEYED AT IFIM TRANSECTS

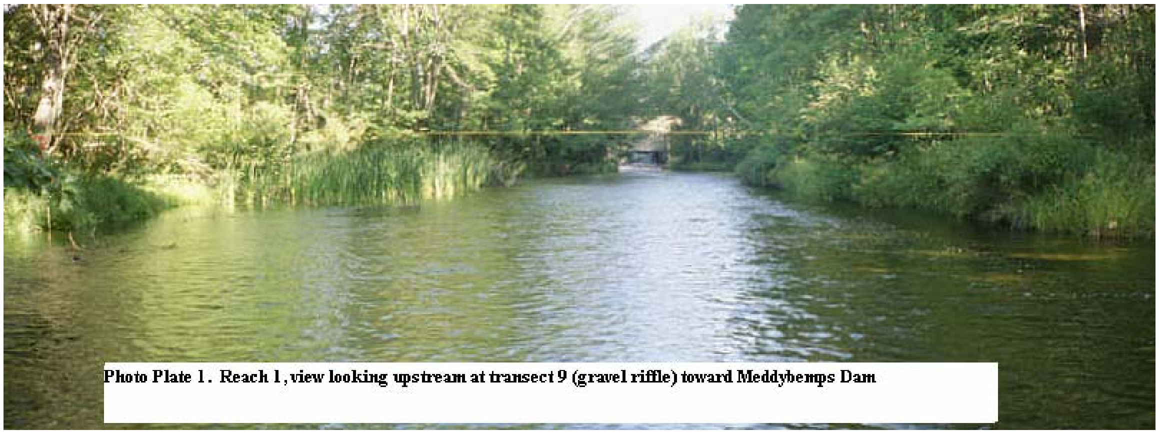


Photo Plate 1. Reach 1, view looking upstream at transect 9 (gravel riffle) toward Meddybemps Dam

Denny's River Instream Flow Study. Transect 9 bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.

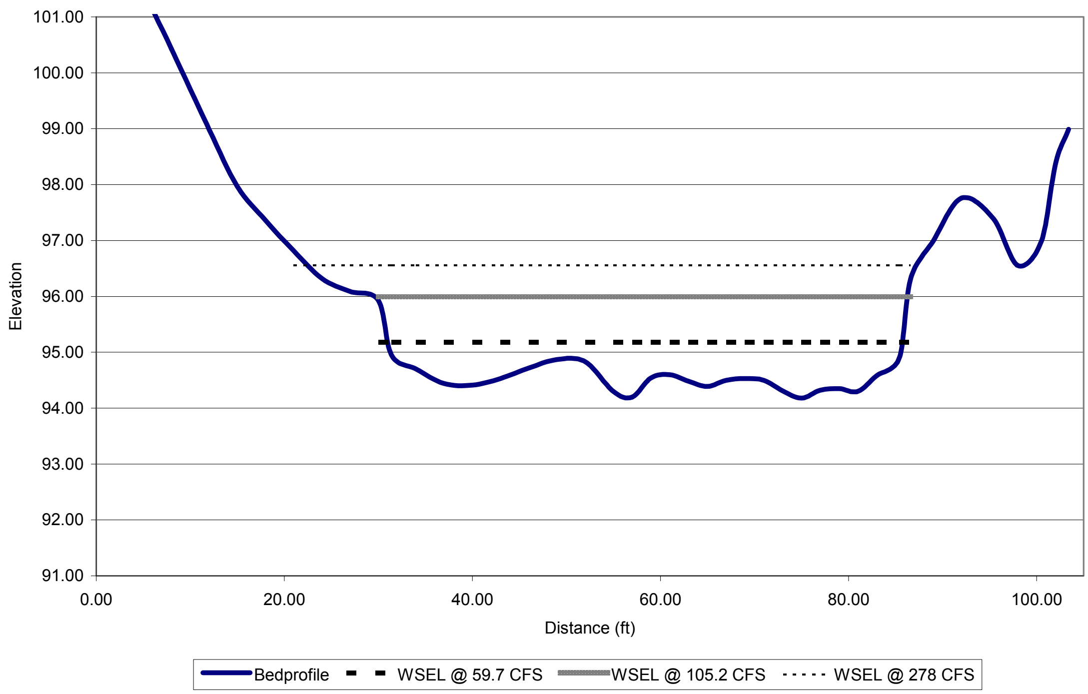


Photo Plate 2. View of Deadwater habitat, transect 8, reach 2.

Denny's River Instream Flow Study. Deadwater bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.

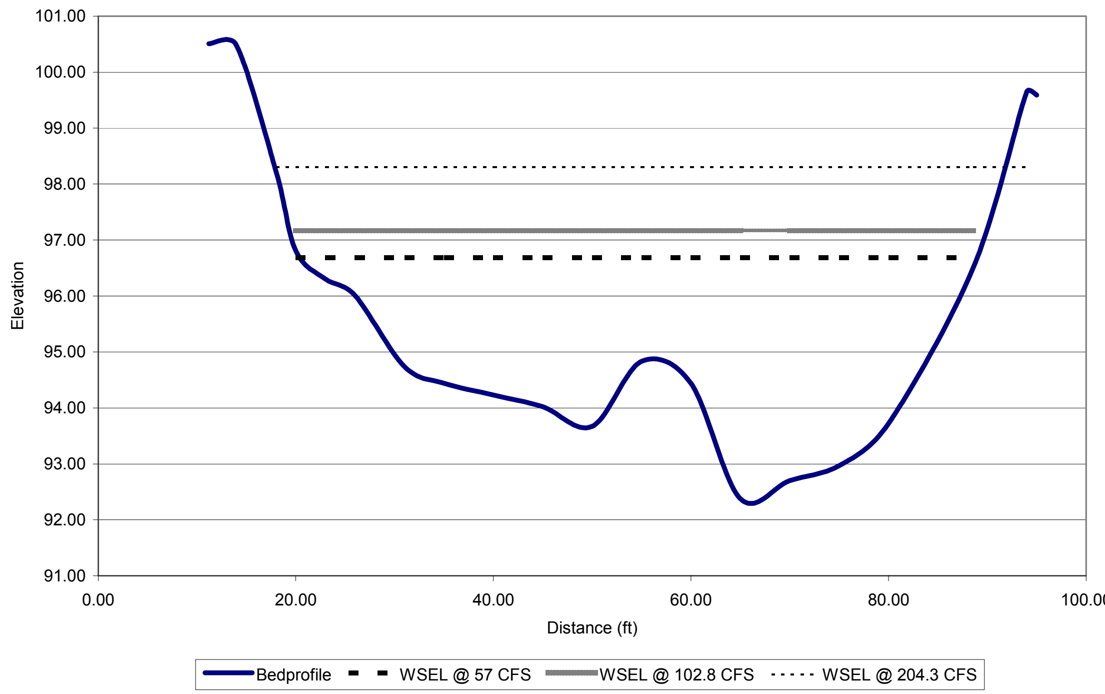
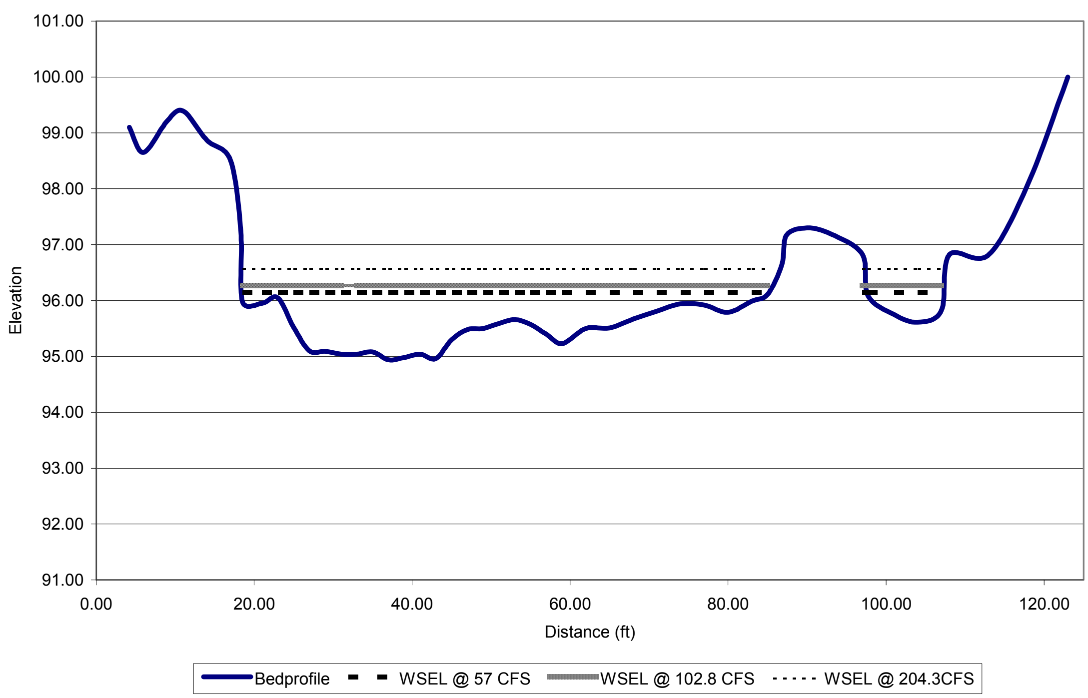


Photo Plate 3. View of riffle transect in Reach 3 near "School Bus Rips".

Denny's River Instream Flow Study. School Bus Rips riffle bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.



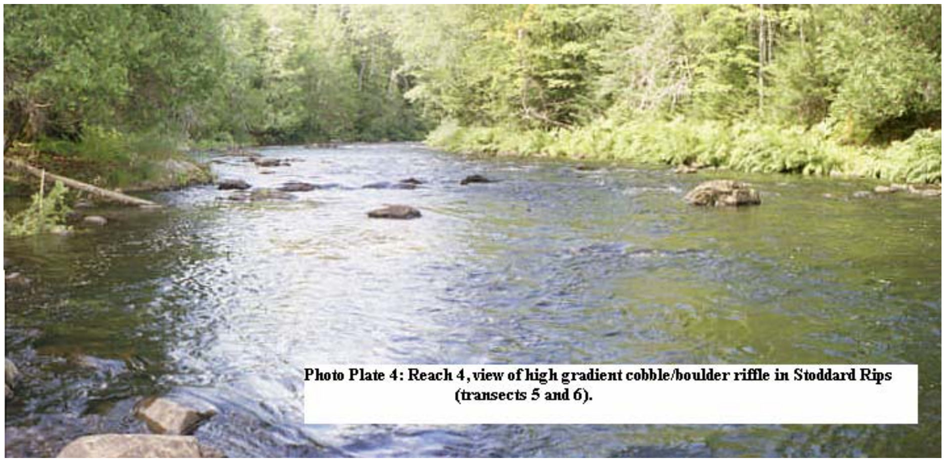
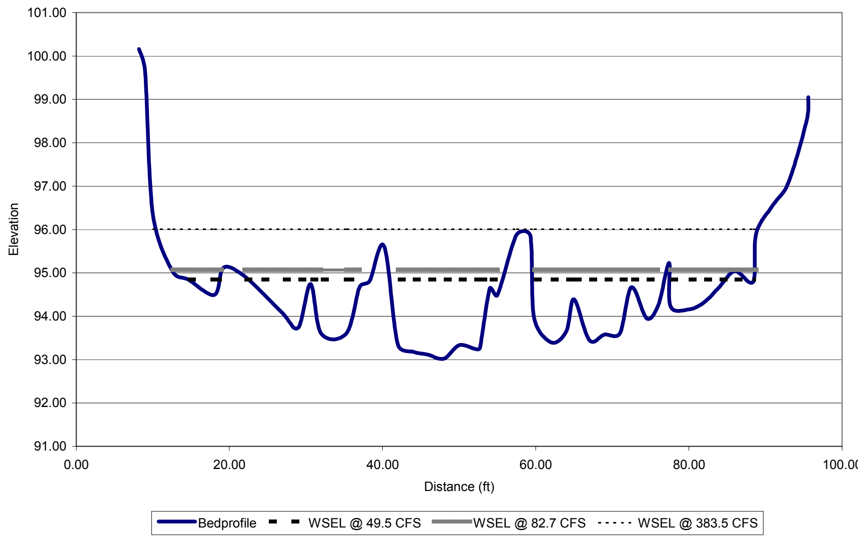
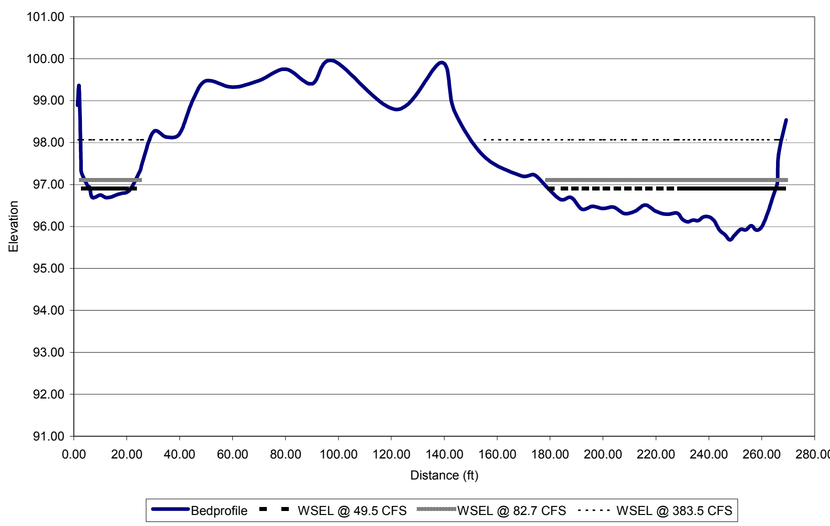


Photo Plate 4: Reach 4, view of high gradient cobble/boulder riffle in Stoddard Rips (transects 5 and 6).

Denny's River Instream Flow Study. Transect 6 bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.



Denny's River Instream Flow Study. Transect 5 bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.



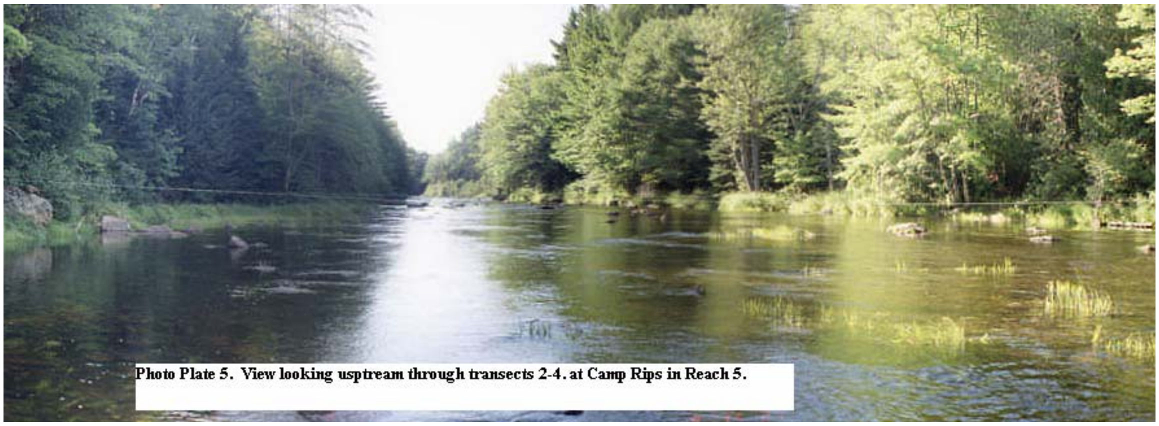
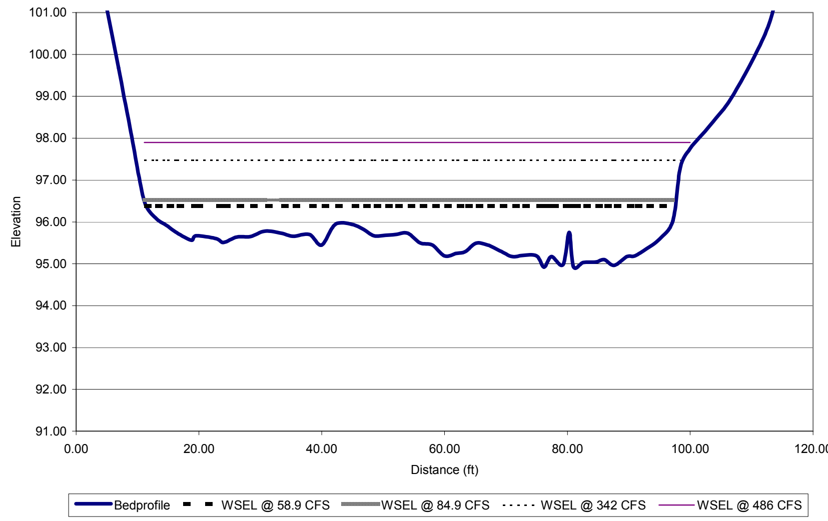
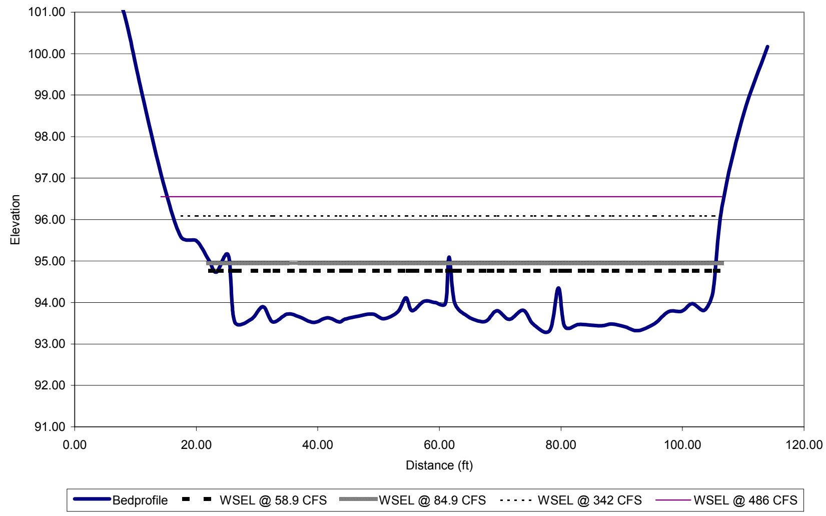


Photo Plate 5. View looking usptream through transects 2-4. at Camp Rips in Reach 5.

Denny's River Instream Flow Study. Transect 4 bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.



Denny's River Instream Flow Study. Transect 3 bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.



Denny's River Instream Flow Study. Transect 2 bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.

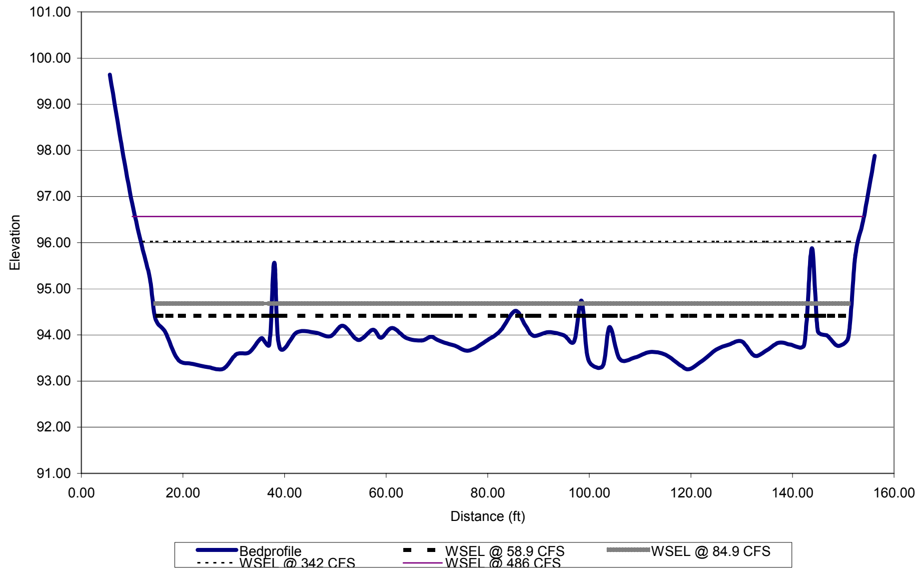
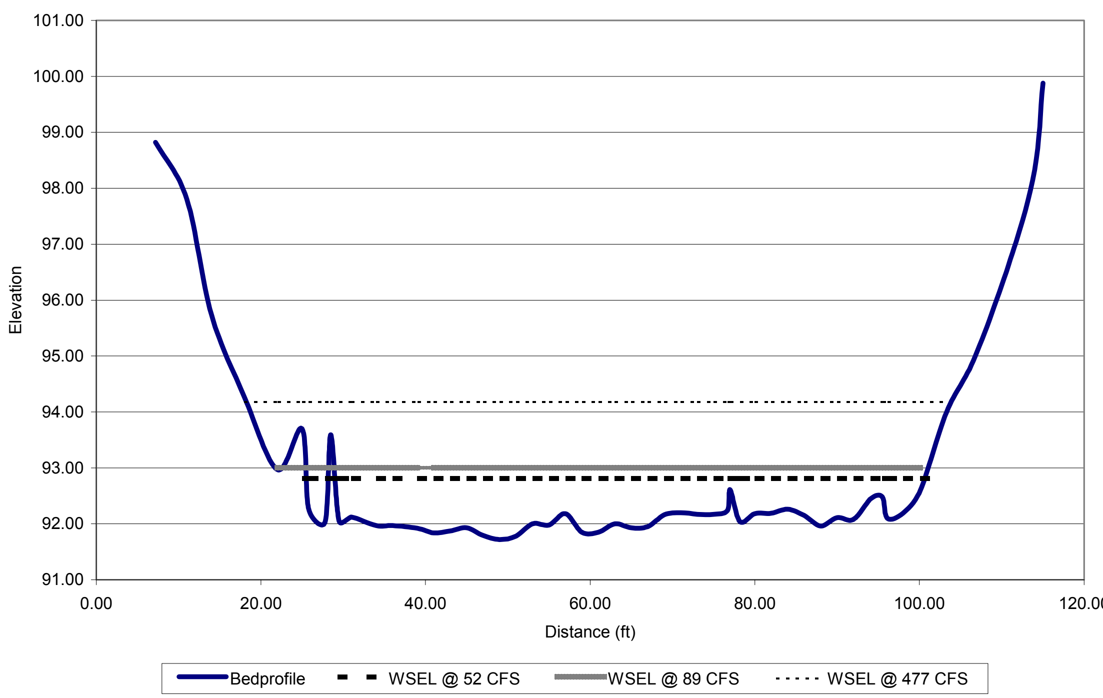


Photo Plate 6: View looking upstream of run/riffle transect (1) located upstream from confluence with Cathance Stream in reach five.

Denny's River Instream Flow Study. Transect 1 bed profile and water surface elevations (WSEL) at low, mid, and high calibration discharges.



APPENDIX D

RELATIONSHIP OF MEDDYBEMPS DAM OUTFLOW TO CORRESPONDING DISCHARGE AT THE DENNYSVILLE GAGE

Difference = Streamgage Flow - Meddybemps Lake Dam Outflow

Notes:

1. Meddybemps Dam Outflow includes all gate flow, fishway flow and leakage.
2. Streamgage flow from USGS Streamgage No. 01021200, "Dennys River at Dennysville, Maine"
3. "Below Normal (Dry)" means flow difference is exceeded more than 90% of the time for unregulated conditions.
4. "Normal" means flow difference occurs between 25% and 75% of the time for unregulated conditions.
5. "Above Normal (Wet)" means flow difference is exceeded less than 10% of the time for unregulated conditions.

Difference (cfs)	January	February	March	April	May	June	July	August	September	October	November	December
0	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)
5	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)
10	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)
15	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	normal	normal	below normal (dry)	below normal (dry)	below normal (dry)
20	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	**median**	**median**	below normal (dry)	below normal (dry)	below normal (dry)
25	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	normal	normal	normal	below normal (dry)	below normal (dry)	below normal (dry)
30	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	**median**	above normal (wet)	normal	normal	below normal (dry)	below normal (dry)
35	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	normal	normal	below normal (dry)	below normal (dry)
40	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	above normal (wet)	above normal (wet)	normal	**median**	below normal (dry)	below normal (dry)
45	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	normal	below normal (dry)	below normal (dry)
50	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	normal	below normal (dry)	below normal (dry)
55	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	below normal (dry)	**median**	above normal (wet)	above normal (wet)	above normal (wet)	normal	below normal (dry)	below normal (dry)
60	below normal (dry)	normal	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	normal	below normal (dry)	below normal (dry)
65	below normal (dry)	normal	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	below normal (dry)	below normal (dry)
70	normal	normal	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
75	normal	normal	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
80	normal	**median**	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
85	normal	normal	below normal (dry)	below normal (dry)	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
90	**median**	normal	below normal (dry)	below normal (dry)	normal	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
95	normal	normal	below normal (dry)	below normal (dry)	normal	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	**median**	normal
100	normal	normal	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
105	normal	normal	normal	below normal (dry)	**median**	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
110	normal	normal	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	**median**
115	normal	normal	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
120	normal	normal	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
125	normal	above normal (wet)	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
130	normal	above normal (wet)	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
135	normal	above normal (wet)	**median**	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
140	above normal (wet)	above normal (wet)	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
145	above normal (wet)	above normal (wet)	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
150	above normal (wet)	above normal (wet)	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
155	above normal (wet)	above normal (wet)	normal	below normal (dry)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal	normal
160	above normal (wet)	above normal (wet)	normal	below normal (dry)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal
165	above normal (wet)	above normal (wet)	normal	below normal (dry)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal
170	above normal (wet)	above normal (wet)	normal	below normal (dry)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal
175	above normal (wet)	above normal (wet)	above normal (wet)	below normal (dry)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	normal
180	above normal (wet)	above normal (wet)	above normal (wet)	below normal (dry)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
185	above normal (wet)	above normal (wet)	above normal (wet)	below normal (dry)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
190	above normal (wet)	above normal (wet)	above normal (wet)	below normal (dry)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
195	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
200	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
205	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
210	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
215	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
220	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
225	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
230	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
235	above normal (wet)	above normal (wet)	above normal (wet)	**median**	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
240	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
245	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
250	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
255	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
260	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
265	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
270	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
275	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
280	above normal (wet)	above normal (wet)	above normal (wet)	normal	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
285	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
290	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
295	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
300	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)
300 +	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)	above normal (wet)