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RESEARCH ARTICLE

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Model estimated baseflow for streams with endangered Atlantic Salmon in Maine, USA

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Abstract

We present a regression model for estimating mean August baseflow per square kilometer of drainage area to help resource managers assess relative amounts of baseflow in Maine streams with Atlantic Salmon habitat. The model was derived from mean August baseflows computed at 31 USGS streamflow gages in Maine. We use an ordinary least squares regression model to estimate mean August baseflow per unit drainage area from two explanatory variables: percentage of the basin underlain by sand and gravel aquifers and mean July precipitation in the basin. This model provides the ability to estimate mean August baseflow in cubic meters per second per square kilometer of basin area on user-selected, ungaged sites throughout Maine south of 46° 21′55″ N latitude. The model has an adjusted R^2 of 0.78 and a mean 95% prediction interval of plus or minus 0.002 cubic meters per second per square kilometer. A map of the Narraguagus watershed in eastern coastal Maine shows reaches color coded by relative amounts of baseflow predicted by the model as an example of how this method could be applied throughout Maine. The map can be used to identify reaches with relatively higher amounts of baseflow during summer low flows for habitat conservation and restoration work. These areas have the potential to be high-quality habitat for Atlantic salmon and other cold-water fish because baseflows are known to moderate stream temperatures in summer low-flow periods.

KEYWORDS

Atlantic salmon, baseflow, habitat, Maine, streamflow

1 | INTRODUCTION

The last populations of Atlantic salmon in the United States are found in Maine, where remnant populations are in dire conditions. The Gulf of Maine Distinct Population Segment (GOM DPS) of Atlantic Salmon was jointly listed as endangered by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (USOFR, 2009a). The freshwater range of the GOM DPS includes all watersheds from the Androscoggin River northward along the Maine coast to the Dennys River (USOFR, 2009a) (Figure 1). Diminished habitat quality and accessibility are among the leading threats identified by the services in the listing rule and addressed in the Final Recovery Plan (USFWS and NMFS, 2018). As with other salmonids, Atlantic salmon must have access to cold water throughout the warmest parts of the summer, particularly in the southern portions of their range (Kurylyk, Mac Quarrie, Linnansaari, Cunjak, & Curry, 2015).

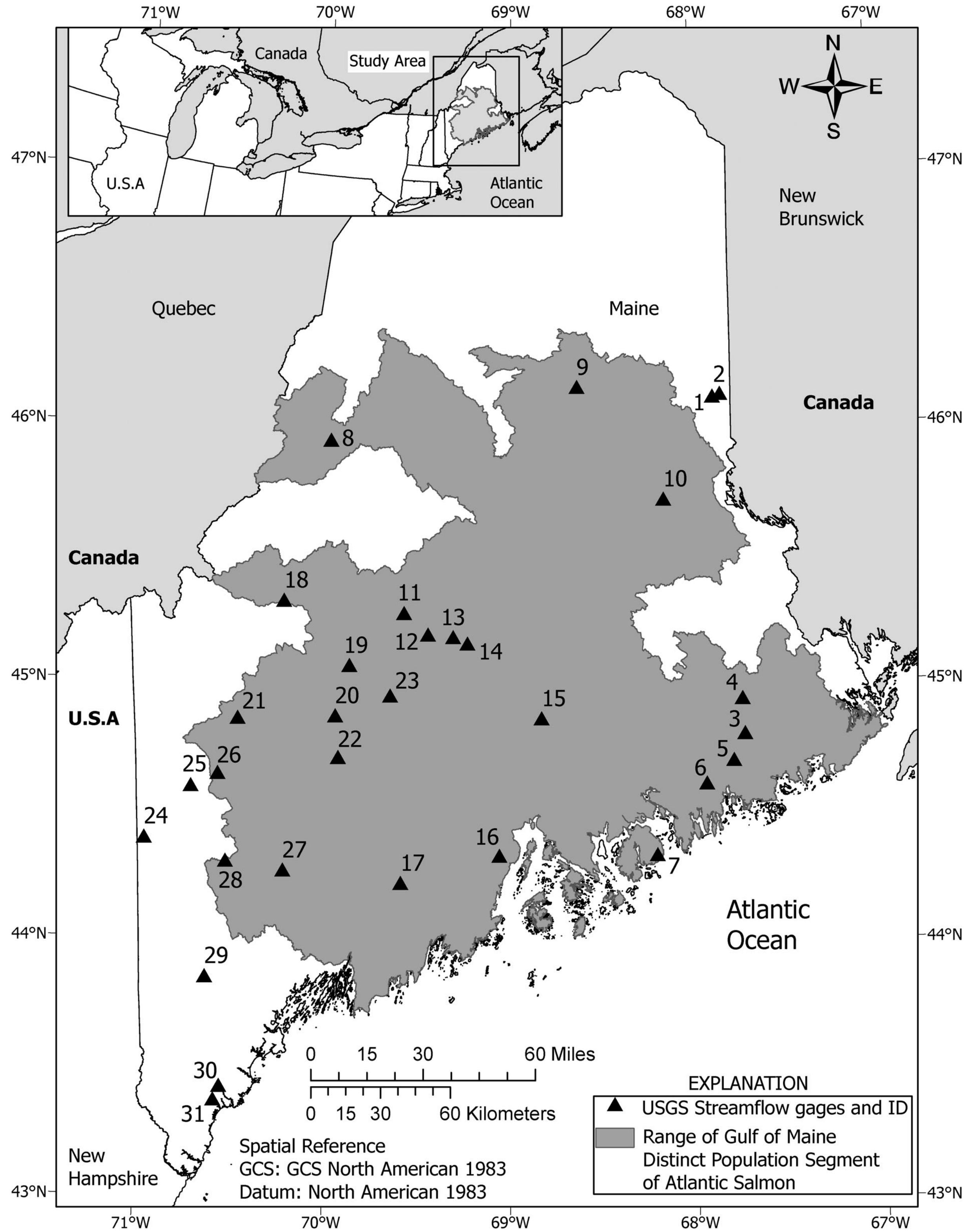


FIGURE 1 Map showing locations of U.S. Geological Survey (USGS) streamflow gages used in this study and range of the Gulf of Maine Distinct Population Segment of Atlantic Salmon in Maine

Recently, the services identified a need to "inventory and prioritize freshwater habitats that provide the best opportunity for salmon recovery, including climate resilient habitats" in the Final Recovery Plan for the GOM DPS of Atlantic Salmon (USFWS and NMFS, 2018). Borggaard et al. (2019) specifically identified mapping cold-water habitats as a priority action. A key assumption of this strategy is that areas containing abundant cold water will be of higher habitat quality. While this assumption has yet to be tested empirically with demographic data, the abundance of cold-water habitat is widely regarded as a limiting factor of Atlantic salmon populations, given (a) well-established thermal maxima for the species and (b) the lack of evidence of adaptation to warmer temperatures (Elliott & Elliott, 2010).

Baseflow is a component of streamflow composed of the delayed storage release of groundwater but also can include surface water sources such as lakes, wetlands, and snow and ice melt (Smakhtin, 2001). It is especially important for habitat for Atlantic salmon and other aquatic species because of its influence on water quantity and river temperatures during the summer low-flow period in Maine and Atlantic Canada (Hodgkins & Dudley, 2011; Kurylyk et al., 2015). The importance of the baseflow has received considerable attention recently with four broad patterns emerging: (a) low flows control the amount of physical aquatic habitat available to aquatic biota; (b) low flows mediate habitat conditions and water quality (especially temperature and dissolved oxygen), which strongly influence fish and invertebrate communities; (c) low flows influence energy and nutrient flow; and (d) low flows restrict connectivity and diversity of habitat (Rolls, Leigh, & Sheldon, 2012).

Low flow is widely regarded as a key factor in limiting juvenile production of Atlantic salmon in rivers, particularly during hot, dry summers (Havey & Davis, 1970; Poff & Huryn, 1998). Recently, Hvidsten et al. (2015) reported increased smolt production with increased minimum discharge over 27 years in the river Orkla in Norway. During periods of little to no precipitation, seasonal low streamflow may be almost entirely comprised of outflows from aquifers and other slow-release sources (Brutsaert, 2008). Groundwater-derived baseflow is typically cooler than surface water in summer and thus can be important for buffering streams from increasing air temperatures and maintaining cold-water habitat (Erickson & Stefan, 2000; Meisner, Rosenfeld, & Regier, 1988). Stream temperatures are expected to increase with anthropogenic climate change, and thus the seasonal need may become more acute and/or occur over a longer duration each year (Isaak, Wollrab, Horan, & Chandler, 2012; Mohseni, Stefan, & Eaton, 2003). Briggs et al. (2018) found that streams that were influenced by groundwater discharge in Virginia and coastal Massachusetts may serve as “climate refugia” for sensitive fish species—due to groundwater discharges attenuating surface water temperatures. The identification of areas that have relatively high amounts of baseflow during the low-flow season is one first step in assessing factors that likely affect river temperature and the relative abundance of habitat for Atlantic salmon and other aquatic species (Erickson & Stefan, 2000; Mather, Parrish, Campbell, McMenemy, & Smith, 2008).

There are multiple studies that develop regression equations relating baseflow to watershed characteristics at sites that do not have a streamflow gage (Neff, Day, Piggott, & Fuller, 2005; Santhi, Allen, Muttiah, Arnold, & Tuppad, 2008; Zhang, Ahiablame, Engel, & Liu, 2013). Watershed characteristics that are often good baseflow predictors include basin size, topography, rainfall, geologic and hydrologic variables, and soils (Zhang et al., 2013). The amount of baseflow at a site is typically dominated by drainage area, thus, it can be helpful to standardize baseflow values by drainage area prior to developing regression equations.

A number of regression equations have previously been developed to estimate low streamflow values in Maine. Equations to estimate August median flow in eastern coastal Maine and in southern Maine use drainage area and percent sand and gravel aquifers (Lombard, 2004, 2010). Equations to estimate statewide 7Q10 (lowest 7-day average flow that occurs once every 10 years) also reference drainage area and sand and gravel aquifers (Dudley, 2004). Equations to estimate monthly means and medians during summer months throughout the state of Maine use drainage area, sand and gravel aquifers, and precipitation (Dudley, 2015). Models developed by Detenbeck (2018) use slope, percent imperviousness, watershed storage, glacial geology, and soils to estimate August median flow in New England streams and rivers.

This paper presents a model that can be applied to ungaged stream basins to estimate baseflow per unit of drainage area throughout Maine south of 46° 21′55″ N latitude (approximately Houlton, Maine). Estimated normalized baseflows can, in turn, support the identification of stream reaches richer in cold-water habitat to be prioritized for restoration and/or conservation.

2 | METHODS

2.1 | Data

Streamflow gages were selected for this study based on their inclusion in, or proximity to, the freshwater range of the GOM DPS of Atlantic salmon in Maine (Figure 1). The surficial geologic materials in the basins are predominantly glacial till and fine and coarse-grained glaciomarine deposits with some ice-contact glaciofluvial deposits, such as eskers (Thompson & Borns, 1985). High flows in this region typically occur in early spring and late fall, and low flows generally occur in the summer and early fall.

Observed daily mean streamflow data from 31 USGS continuous-record streamflow gages are from the USGS National Water Information System (U.S. Geological Survey, 2020; Lombard & Sturtevant, 2021). These gages contained 9–31 years of data from 1989 through 2019. Data prior to 1989 were not used as studies have indicated that low-flow statistics based on the recent past rather than the full record may more satisfactorily represent present or near-future values (Blum et al., 2019). The study basins used in the development of the regression equations ranged from 3 to 1,340 km^2 (km^2) (1.30–516 $mile^2$). These basins have minimal human alterations such as dams or withdrawals during summer months, as outlined in the USGS database NWIS (U.S. Geological Survey, 2020). Water years were not included if there were missing daily values during August.

More than 80 basin characteristics were tested as potential explanatory variables in the regression analyses based on their potential physical relation to baseflow, their public availability as digital datasets, and their ease of calculation using GIS. Variables types include topography, climate, hydrology, geology, soils, and land use. Basin characteristics used and their data sources are documented in a USGS data release (Table 1; Lombard & Sturtevant, 2021).

TABLE 1 Basin characteristics and baseflows at streamflow gages used to develop the final regression equations

ID	Streamgage number	Streamgage name	Drainage area (km[2a])	Percentage of sand and gravel aquifers in basin[b]	Mean July precipitation (mm)[a]	August mean baseflow per square kilometer ($m^3/s/km^a$)
1	01017960	Meduxnekeag River near Houlton, ME	226	2.02	96.6	0.00440
2	01018009	Pearce Brook at Route 1 at Houlton, ME	17.9	0.00	93.5	0.00339
3	01021470	Libby Brook near Northfield, ME	16.6	73.0	85.4	0.00942
4	01021480	Old Stream near Wesley, ME	77.7	22.0	83.5	0.00379
5	01022260	Pleasant River near Epping, ME	161	33.8	86.2	0.00724
6	01022500	Narraguagus River at Cherryfield, ME	588	15.2	86.9	0.00438
7	01022840	Otter Creek near Bar Harbor, ME	3.52	0.00	91.1	0.00373
8	01027200	North Branch Penobscot River near Pittston farm, ME	580	0.03	125	0.00688
9	01029200	Seboeis River near Shin Pond, ME	448	0.86	103	0.00492
10	01030350	Wytopitlock Stream near Wytopitlock ME	127	0.14	97.7	0.00408
11	01031300	Piscataquis River at Blanchard, ME	298	1.19	103	0.00317
12	01031450	Kingsbury Stream at Abbot Village, ME	247	0.89	95.7	0.00280
13	01031500	Piscataquis River near Dover-Foxcroft, ME	769	1.80	97.7	0.00298
14	01031510	Black Stream near Dover-Foxcroft, ME	68.4	2.60	93.8	0.00331
15	01037000	Kenduskeag Stream near Bangor, ME	505	2.80	85.8	0.00136
16	01037380	Ducktrap River near Lincolnville, ME	39.1	1.00	84.6	0.00152
17	01038000	Sheepscot River at North Whitefield, ME	378	4.39	84.8	0.00283
18	01044550	Spencer Stream near Grand Falls, ME	513	4.06	111	0.00518
19	01046000	Austin Stream at Bingham, ME	234	2.41	103	0.00417
20	01047000	Carrabassett River near North Anson, ME	912	8.35	108	0.00432
21	01047200	Sandy River near Madrid, ME	65.0	0.57	110	0.00536
22	01048000	Sandy River near Mercer, ME	1,340	4.98	101	0.00394
23	01048220	East Branch Wesserunsett Stream near Athens, ME	50.8	0.62	96.4	0.00407
24	01054200	Wild River at Gilead, ME	181	0.64	119	0.00608
25	01054300	Ellis River at South Andover, ME	339	5.71	110	0.00512
26	01055000	Swift River near Roxbury, ME	250	1.17	112	0.00460
27	01055500	Nezinscot River at Turner Center, ME	440	8.92	100	0.00389
28	01057000	Little Androscoggin River near South Paris, ME	191	2.91	92.0	0.00327
29	01063310	Stony Brook at East Sebago, ME	3.37	4.65	106	0.00327
30	01067950	Kennebunk River near Kennebunk, ME	67.6	16.3	97.4	0.00281
31	01069700	Branch Brook near Kennebunk, ME	23.8	70.8	98.1	0.01160

Note: km^2, square kilometer; mm, millimeters; $m^3/s/km^2$, cubic meter per second per square kilometer; ME, Maine.
[a]PRISM Climate Group (2012).
[b]Maine Geological Survey (2018).

2.2 | Baseflow separation

In order to assess relative amounts of groundwater-derived baseflow, it was important to use a baseflow separation technique that removed most of the direct runoff and thus did not conflate aquifer outflows and direct runoff. Partington et al. (2012) found that HYSEP local minimum underestimated baseflow up to 23% and did not overestimate baseflow in any of his models. In addition, HYSEP local minimum does not require the estimation of additional parameters such as a baseflow recession constant that add potential additional sources of errors, since the calibration of such parameters was beyond the scope of this work. Daily August baseflows were separated from total daily mean streamflows by use of the HYSEP (HYdrograph SEParation) local minimum method (Pettyjohn & Henning, 1979; Sloto & Crouse, 1996). This is a graphical baseflow separation technique that connects local minima along the hydrograph with straight lines (Sloto & Crouse, 1996).

We analyze August baseflows because August exhibits consistently low streamflow values in Maine. We computed mean monthly

August baseflows for each year from daily values obtained from the baseflow separation computation. August means from each year of record were averaged and divided by the drainage area to yield a normalized mean August baseflow for each site.

2.3 | Statistical analyses

We regionalized the mean August baseflow streamflow statistic using multiple linear regression. Streamflow statistics are quantitative characterizations of hydrology that are often derived from observed streamflow records. In the absence of observations, as at ungaged locations, multiple linear regression can be used to regionalize or transfer information from gaged to ungaged locations (Farmer, Kiang, Feaster, & Eng, 2019). We related variations in the mean August baseflows per square kilometer of drainage area to variations in drainage-basin characteristics through ordinary least squares regression (OLS; Helsel, Hirsch, Ryberg, Archfield, & Gilroy, 2020).

An all-subsets regression using the smwrStats package (accessed at https://github.com/USGS-R/smwrStats) for statistical software R (https://www.R-project.org/) was used to determine the best combination of explanatory variables for the final equation. Variables for the final OLS model maximized the adjusted R^2 and minimized the standard error and the Mallow's Cp statistic. The adjusted R^2 indicates the variability observed in the response variable that is accounted for by the model after it has been adjusted for the number of explanatory variables. Mallow's Cp statistic helps achieve a parsimonious model, a compromise between explaining the variance in the response by including all relevant explanatory variables and minimizing the standard error of the estimates by restricting the number of explanatory variables. The 95% prediction interval is the measure of the expected accuracy of a regression model when it is applied at an ungaged location.

2.4 | Mapping

We applied the baseflow regression model throughout a single watershed, the Narraguagus in eastern coastal Maine (44°32′30″ N latitude, 67°52′53″E longitude), as an example of how the equation could be applied and visualized. The stream network for this application included reaches from the National Hydrography Dataset flow accumulation grid greater than 2.59 km^2 (1 mi^2) (U.S. Geological Survey, 2019). We computed the basin characteristics needed for the regression model, applied the regression model to those reaches, and then mapped reaches colored by their relative amounts of baseflow.

3 | RESULTS

3.1 | Statistical analyses

Percentage of sand and gravel aquifers in the basin and basin-wide mean July precipitation produced the model to predict mean August baseflow with the best fit, the lowest standard error, and lowest Mallow's Cp value (Equation [1]).

$$BF_{aug} = -0.006765 + 0.0001074\,AQ + 0.0001033\,JULAVEPRE, \quad (1)$$

where BF_{aug} is the mean August baseflow in cubic meters per second per square kilometer of drainage area; AQ is the fraction of the basin underlain by sand and gravel aquifers as mapped by the Maine Geological Survey (2018) statewide at a scale of 1:24,000; and JULAVEPRE is the basin-wide average of the mean July precipitation in mm based on gridded PRISM data for the period 1980–2010 (PRISM climate group, 2012).

Percent sand and gravel aquifers in the basins ranged from 0 to 73% (Table 1; Figure 2). Only eight of the streamflow gages had greater than 9% sand and gravel aquifers (Table 1). For these gages, the percent sand and gravel aquifers correlated well with mean August baseflow ($R^2 = 0.79$). Mean July precipitation ranged from 83.5 to 125 mm (3.29–4.93 in.) (Table 1; Figure 3). For streamflow gages with less than 9% sand and gravel aquifers, mean July precipitation had a high correlation with August baseflow ($R^2 = 0.81$). Both AQ and JULAVPRE were positively related to baseflows ($p < .05$), thus, the higher the percentage of sand and gravel aquifers in the basin, or the higher the mean July precipitation in the basin, the higher the mean August baseflows.

Residual diagnostic plots indicated that the residuals from this model were independent, homoscedastic, and normally distributed. All Cook's D values at individual sites were less than 0.5, indicating that none of the observations had high influence (Cook, 1977; Helsel et al., 2020). Variance inflation factor was less than 2 for both explanatory variables, thus multicollinearity between the two variables was unlikely (Helsel et al., 2020). The nonsignificance of the Durbin–Watson test statistic for the model indicated that model residuals were independent and serial correlation was not an issue.

The regression equation presented in Equation (1) can be applied to unregulated rural streams in Maine (south of 46° 21′55″ N latitude) when watershed variables are within the range of the explanatory variables used to fit the regression (Figure 4). The fitted regression has a mean 95% prediction interval of plus or minus 0.002 cubic meters per second per square kilometer. If the equation is applied outside the range of explanatory variables or drainage areas used to develop the equations, on a regulated stream, or outside of the geographic region of our study, the accuracy of the estimated flows would be unknown. Furthermore, determining the basin characteristics for use in the regression equation with data sources other than those listed in Table 1 or using different computational methods than those outlined in this report will produce estimates with unknown accuracy.

3.2 | Mapping baseflows for an example watershed

We show relative amounts of mean August baseflow by reach in the Narraguagus watershed in Figure 5. Stream segments over the sand and gravel aquifer in the central portion of the watershed show the highest amounts of estimated mean August baseflow (between

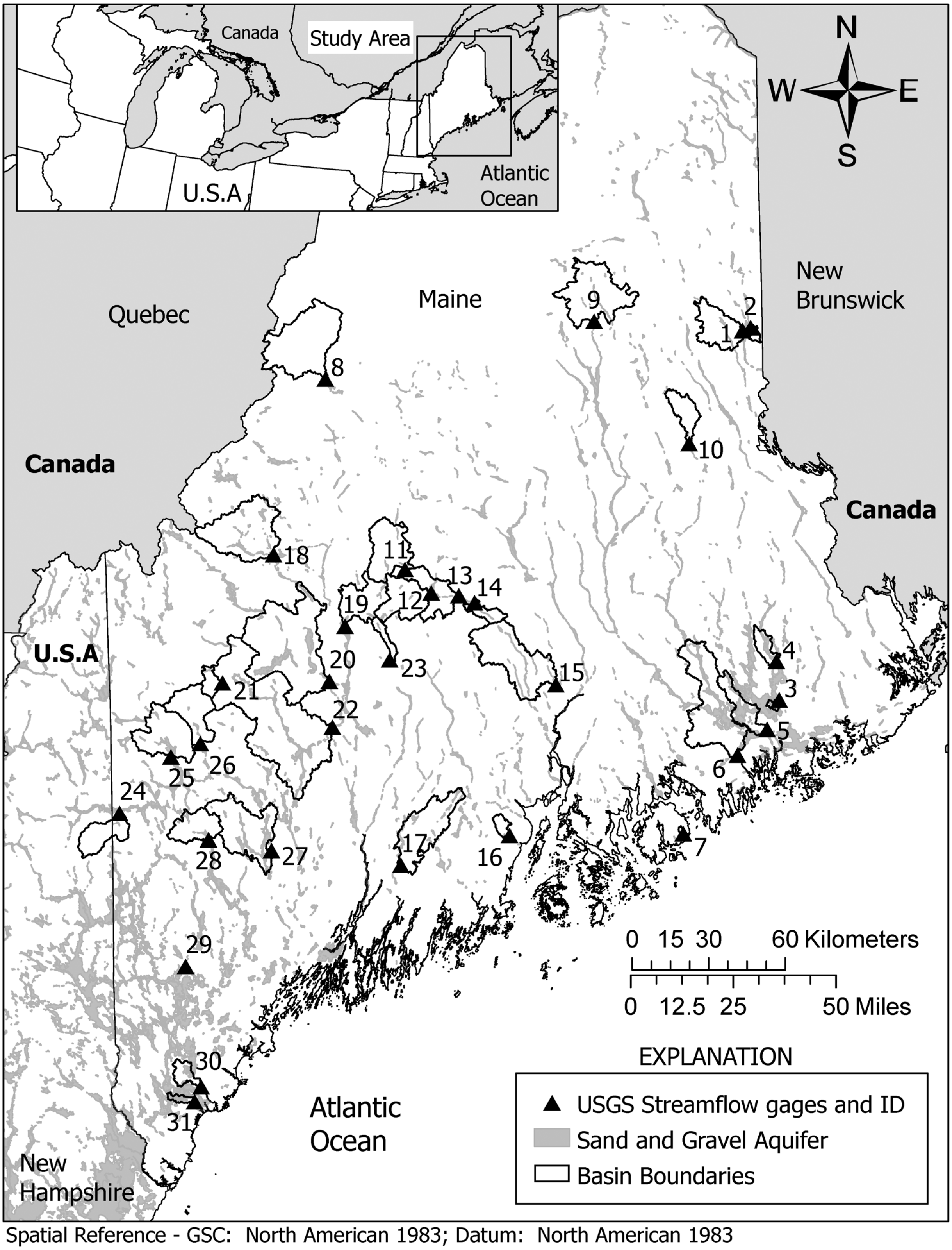
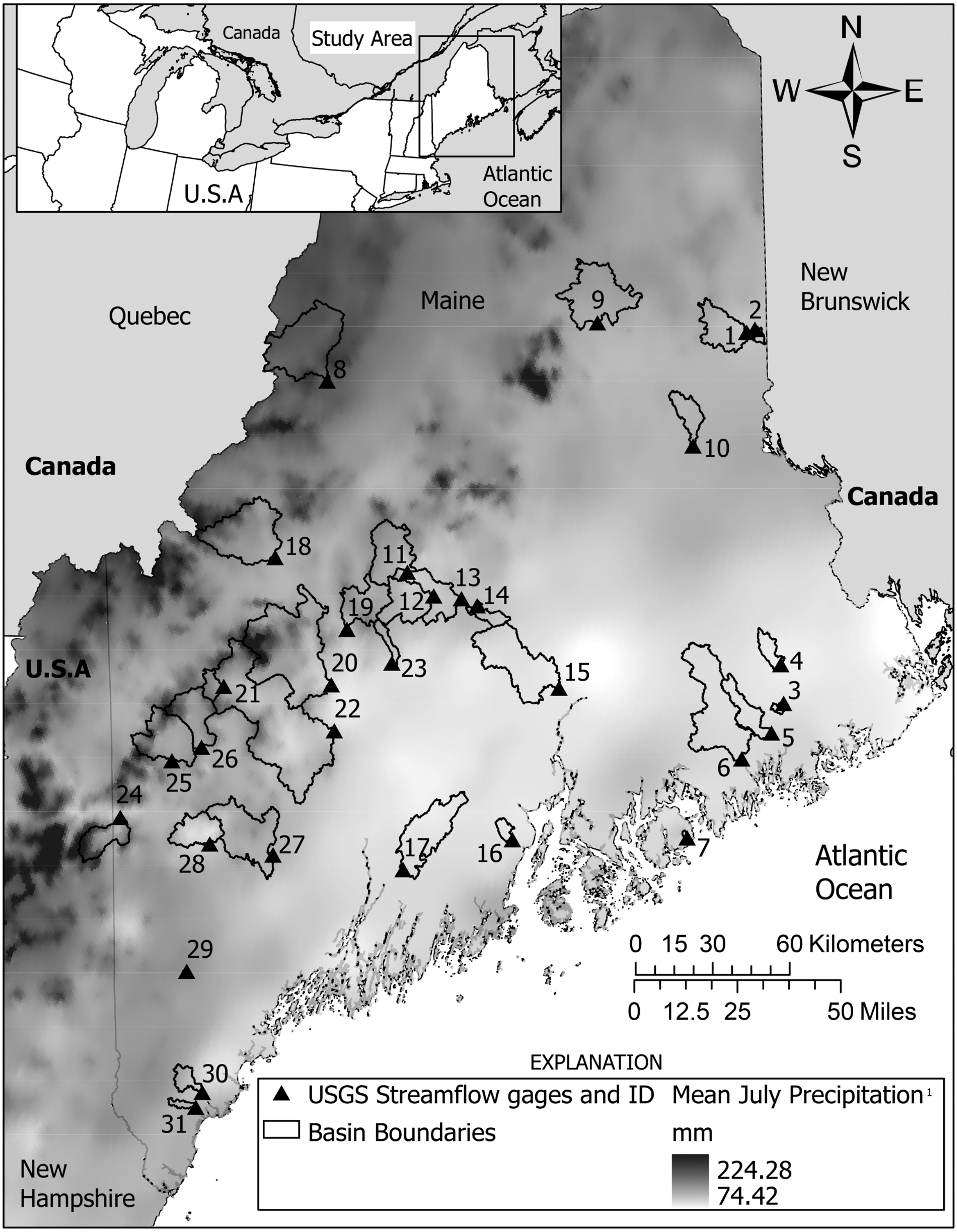


FIGURE 2 Map showing sand and gravel aquifers in Maine, U.S. Geological Survey (USGS) streamflow gages used in this study, and their associated basin boundaries

0.0022 and 0.01 cubic meters per second per square kilometer). Areas with higher amounts of mean July precipitation in the southwestern portion of the basin had reaches with slightly higher amounts of mean August baseflow; however, mean July precipitation did not have as great an impact on mean August baseflow as did the percentage of sand and gravel aquifers (Equation [1]). A shapefile that includes these



Spatial Reference - GSC: North American 1983; Datum: North American 1983
Credits:
[1] PRISM Climate Group, 2012a, United States average monthly or annual precipitation, 1981–2010, 30 arc-second normal, created July 10, 2012: Oregon State University, PRISM

FIGURE 3 Map showing geographic variability in mean July precipitation in Maine, U.S. Geological Survey (USGS) streamflow gages used in this study, and their associated basin boundaries

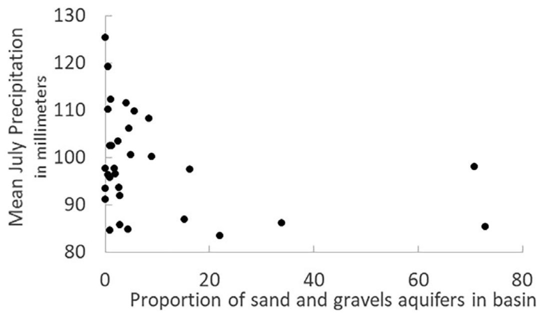


FIGURE 4 Range of percentage of sand and gravel aquifers and mean July precipitation in the basins used to develop the regression equation for estimating baseflows for streams in Maine south of 46° 21′55″ N latitude

reaches, the percentage sand and gravel aquifer in the basin and mean July precipitation for each, and their August mean baseflows is available in an associated data release (Lombard & Sturtevant, 2021).

4 | DISCUSSION

4.1 | Baseflow prediction

We present a baseflow estimation equation to help water resource managers identify and prioritize stream reaches with potential Atlantic Salmon habitat for conservation and restoration. By identifying basin characteristics that explain much of the variability of baseflow in gaged reaches, we are able to better understand baseflow in ungaged reaches. The map of the Narraguagus watershed in Figure 5 shows an example of how the baseflow equation developed here could be used to map watersheds throughout Atlantic salmon watersheds in Maine south of 46° 21′55″ N latitude in order to quickly and easily identify and prioritize areas relatively rich in baseflow with the potential to provide high quality aquatic habitat. These stream reaches in the Narraguagus watershed (available as a GIS coverage at Lombard & Sturtevant, 2021) can be overlain with fish population maps to better understand the link between relatively high baseflow and fish populations in Maine.

Both percentage of sand and gravel aquifers and mean July precipitation were important in explaining the variability of the August baseflow. This makes sense physically as sand and gravel aquifers tend to be correlated with relatively coarse-grained surficial sediments and thus high infiltration rates and groundwater storage and also tend to have good connectivity with the streams. Additional streamflow gages in basins with high percentages of sand and gravel aquifers would help to refine the equation and could improve its accuracy, should those data become available in the future.

Mountainous sites in the western portion of Maine with higher mean July precipitation tended to have relatively high amounts of baseflow (Figure 3). Mean July precipitation in a basin correlates fairly well with mean basin elevation (R^2 is equal to 0.63), indicating an orographic effect on mean July precipitation. Elevation alone did not, however, explain variability as well as July precipitation. Therefore, July precipitation may be also describing geographic variability in seasonal climate during a season when convective storms are common. Hodgkins and Dudley (2011) observed interannual baseflows in the northeast correlated most strongly with seasonal (summer) precipitation.

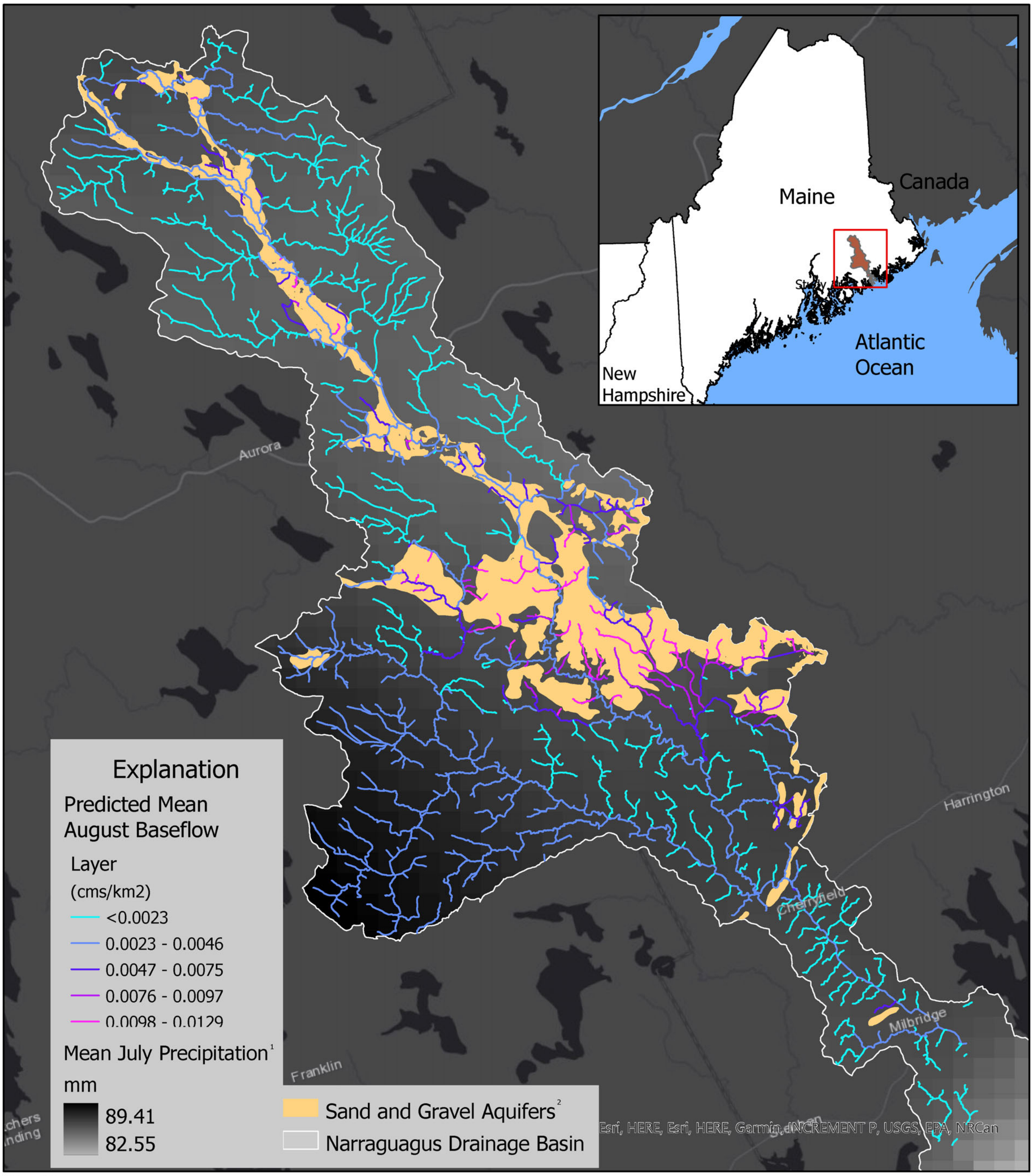
Statewide equations to estimate mean and median August streamflows used a similar combination of explanatory variables: drainage area, percentage of sand and gravel aquifers in the basin, and mean basin elevation (Dudley, 2015). Studies to estimate August median flow in Maine subregions also used drainage area and percentage of sand and gravel aquifers for the eastern coastal and southern parts of Maine (Lombard, 2004, 2010). Note that the equation presented in this report standardized baseflows by drainage area, and thus drainage area was not an explicit component of the equation as it was in the statewide and subregional low-flow studies for Maine. In the future, localized baseflow studies may increase the accuracy of estimates of baseflow at ungaged basins where sufficient gaging-station data are unavailable.

4.2 | Importance of baseflow to freshwater habitat

We focused on developing models to predict summer baseflows because it is an important component for good salmon habitat in the summer. In addition, we anticipate that results could be used to explore the links between baseflow and water temperature in Atlantic salmon rivers to support in-stream temperature modeling and projections.

The links between baseflow and water temperature are especially important, as water temperature is one of the key parameters that control the geographic distribution of fish and other aquatic organisms, most of which are adapted to a specific range of temperatures (Beitinger, Bennett, & McCauley, 2000). Native salmonids need cold water distributed over space and time to thrive in freshwater (Poole et al., 2001; Wilbur, O'Sullivan, MacQuarrie, Linnansaari, & Curry, 2020). Furthermore, where salmonid populations are healthy, habitat conditions are likely to be suitable for other native aquatic species. Summer stream temperature has been shown to be a critical characteristic of habitat quality in Atlantic and Pacific salmon as increasing summer temperatures have contributed to the decline of native salmonid populations (Breau, Cunjak, & Peake, 2011; Poole et al., 2001). Studies in the Pacific Northwest have shown that baseflow index and stream channel slope were two of the most important factors that explain summer stream temperatures (Mayer, 2012).

With respect to recovery of the GOM DPS of Atlantic salmon, the U.S. Fish and Wildlife Service and National Marine Fisheries Service designated critical habitat at the time of listing in 2009 (USOFR, 2009b). However, it is widely recognized that much of this habitat is too warm for Atlantic salmon to survive during the hottest parts of summer. In the Miramichi River in New Brunswick, Canada, Kurylyk et al. (2015) emphasize the need to preserve, augment, and even create cold-water thermal refuges if the vitality of this world-renowned salmon river is to be maintained in the face of changing



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[1] PRISM Climate Group, 2012a, United States average monthly or annual precipitation, 1981–2010, 30 arc-second normal, created July 10, 2012: Oregon State University, PRISM Climate Group web page, accessed September 16, 2013, at http://www.prism.oregonstate.edu/
[2] Maine Geological Survey, 2018, Data catalog: Maine Geological Survey web page, accessed May 2020 at https://mgs-maine.opendata.arcgis.com/datasets/maine-aquifers.
Base Map: Esri, HERE, Garmin, (c) OpenStreetMap contributors and the GIS user community

FIGURE 5 Map of the Narraguagus watershed in eastern coastal Maine showing predicted relative amounts of baseflow normalized by drainage area for each stream reach in the watershed [Color figure can be viewed at wileyonlinelibrary.com]

climatic conditions. Thus, ensuring that Atlantic salmon can access cold-water habitat is a key part of the overall recovery strategy for the GOM DPS. By providing a means to identify and map baseflow-rich stream reaches in these watersheds, this study is an important first step in prioritizing freshwater habitats that provide the best opportunity for salmon recovery, including climate-resilient habitats (action F3.2 in the Final Recovery Plan for the GOM DPS; USFWS and NMFS, 2018).

Although it has been established that baseflows moderate stream temperatures and this study can help inform predictive models of stream temperatures, the relation between stream temperatures and baseflows is complex due to additional factors such as inflows, riparian cover, and watershed size. Many of the challenges with determining the links between baseflows and stream temperatures are outlined by Detenbeck, Morrison, Abele, and Kopp (2016)—including the lack of available stream-temperature data, the differing time intervals of data collection, and the differences between discrete readings versus continuous data. It would be useful to instrument more streamflow gages with continuous water-temperature gages to better define the importance of baseflows to stream temperature without having to take differences in location into account. A better understanding of the links between baseflow and temperature will be critical for predicting how stream temperatures will change with changing climate in the baseflow-rich reaches of Atlantic salmon watersheds.

5 | SUMMARY AND CONCLUSIONS

Maine is home to the GOM DPS of Atlantic Salmon, the last remnant population of Atlantic Salmon in the United States. The identification and conservation of high-quality habitat, including areas rich in baseflow to provide cold-water habitat during the summer, is critical to their survival as a species. We present a regression model to estimate relative amounts of baseflow in any stream reach in Maine south of 46° 21′55″ N latitude. The equation uses percentage of sand and gravel aquifers and the mean July precipitation in the basin to predict mean August baseflow per square kilometer of drainage area (baseflow) for any user-selected watershed in this region. The equation applies to watersheds in Maine within ranges of the explanatory variables used to develop the Equation (0–73% sand and gravel aquifers and 83.5–125 mm mean July precipitation). In addition, user-selected sites should have drainage areas between 3 and 1,340 km^2 and not be affected by substantial amounts of streamflow regulation or basin water withdrawals.

The model developed here to estimate mean August baseflow per square kilometer of basin drainage area can help resource managers assess relative amounts of baseflow within rivers in Maine. Maps derived from the model, such as the one included here for the Narraguagus River basin, would allow resource managers to predict areas rich in baseflow in order to quickly identify areas with potentially high-quality habitat in the state. Low water temperatures are an important aspect of good Atlantic salmon habitat during summer low-flow periods, and further work is needed to verify the link between baseflow amounts and water temperatures because of potentially complicating factors such as the amount of riparian cover in a watershed. The development of this model is an important step toward creating links between baseflow and water temperature.

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DATA AVAILABILITY STATEMENT

All USGS streamflow data are available from the USGS National Water Information System database (http://doi.org/10.5066/F7P55KJN) and in a USGS data release (Lombard & Sturtevant, 2021).

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