Leveraging High-Resolution LiDAR and Stream Geomorphic Assessment Datasets to Expand Regional Hydraulic Geometry Curves for Vermont

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16 Abstract

In the two decades since Regional Hydraulic Geometry Curves (RHGCs) were first developed for Vermont streams, new remote-sensing data have been generated including digital elevation models derived from Light Detection and Ranging (lidar) data, and stream geomorphic assessments have been completed for more than 2,300 miles of river. Availability of these new data sets represented a cost-effective opportunity to revisit the analysis to update RHGCs for Vermont rivers without the need to engage in resource-intensive field work. We sought to improve upon the RHGCs, by (1) expanding the number of observations, and (2) reducing the variability in the relationships between drainage area and each of the response variables, bankfull width, mean depth, and cross-sectional area. To do so, we leveraged stream geomorphic data collected from 2005 through present; as well as high-resolution lidar data for estimation of basin characteristics. With the addition of 10 new sites, RHGCs have been expanded to cover drainage areas up to 396 (from 194) square miles. Additionally, stratification of the curves by channel slope at a threshold of 0.1% has improved prediction of bankfull width as a function of drainage area. Use of updated curves to design more geomorphically-compatible bridges and culverts will lead to greater resilience and durability of these transportation structures during extreme flood events. Greater longevity of structures translates to improved benefit-cost ratios when the full life cycle of these structures is analyzed and compared to that of undersized structures. Geomorphically-compatible structures also have co-benefits of supporting aquatic and terrestrial organism passage objectives.

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Abstract

In the two decades since Regional Hydraulic Geometry Curves (RHGCs) were first developed for Vermont streams, new remote-sensing data have been generated including digital elevation models derived from Light Detection and Ranging (lidar) data, and stream geomorphic assessments have been completed for more than 2,300 miles of river. Availability of these new data sets represented a cost-effective opportunity to revisit the analysis to update RHGCs for Vermont rivers without the need to engage in resource-intensive field work.

We sought to improve upon the RHGCs, by (1) expanding the number of observations, and (2) reducing the variability in the relationships between drainage area and each of the response variables, bankfull width, mean depth, and cross-sectional area. To do so, we leveraged stream geomorphic data collected from 2005 through present; as well as high-resolution lidar data for estimation of basin characteristics. With the addition of 10 new sites, RHGCs have been expanded to cover drainage areas up to 396 (from 194) square miles. Additionally, stratification of the curves by channel slope at a threshold of 0.1% has improved prediction of bankfull width as a function of drainage area. Use of updated curves to design more geomorphically-compatible bridges and culverts will lead to greater resilience and durability of these transportation structures during extreme flood events. Greater longevity of structures translates to improved benefit-cost ratios when the full life cycle of these structures is analyzed and compared to that of undersized structures. Geomorphically-compatible structures also have co-benefits of supporting aquatic and terrestrial organism passage objectives.

Chapter 1: Introduction and Background

Bankfull hydraulic geometry relationships are widely used in Vermont and other New England states by water resource and transportation engineers to predict stable width and depth of the bankfull channel, where bankfull is defined as that discharge with an approximate recurrence interval of 1.5 years (Leopold et al., 1995). In 2001, Vermont was one of the first states in New England to develop Regional Hydraulic Geometry Curves (RHGCs) for the bankfull channel to support river management and stream geomorphic assessments (Jaquith and Kline, 2001). These state-wide curves were subsequently updated and predict bankfull width, mean depth, and cross-sectional area each as a power function of drainage area, based on 20 observations of alluvial reaches in reference or stable condition (Jaquith and Kline, 2006).

RHGCs support flood-resilient sizing of bridges and culverts, so that the width and clearance are more compatible with river surroundings, lessening the risk of sediment and debris blockage (Furniss et al., 1998), and allowing for safe passage of fish and other aquatic organisms (Bates and Kirn, 2009; Furniss et al., 1998). We also use regional curves when repairing roads and railroads during flood recovery work to ensure that sufficient width is provided to the river to dissipate floodwater scour energy and improve long-term sustainability of that adjacent infrastructure (Schiff et al., 2015).

1.1 Project Motivation

Practitioners and agency personnel experienced in geomorphic assessments have reported that Vermont RHGCs do not well predict bankfull channel dimensions in all settings. In low-relief coastal settings along Lake Champlain with cohesive boundary materials, channels have a naturally low width-to-depth ratio (i.e., Rosgen E stream type) and RHGCs tend to overpredict bankfull width and underpredict bankfull depth (Jaquith and Kline, 2006). In other states with sufficient numbers of observations sites, regional curves have been stratified by geomorphic stream type (Mulvihill and Baldigo, 2012) or slope (Bent and Waite, 2013). Channel dimensions in Vermont's steeper-gradient headwater settings are also not always well predicted by the present curves despite a 2006 update that included steeper-gradient, small catchment settings (i.e., Rosgen B and Cb stream types), and some practitioners report using Connecticut "steep streams curves" as an additional source of design information (Jacobs, 2010). In other regions, research has successfully optimized RHGCs by grouping observations by geographic area (Dunne and Leopold, 1978) or hydrologic region (Mulvihill and Baldigo, 2012).

In the two decades since RHGCs were first developed for Vermont streams, new remote-sensing data have been generated including digital elevation models derived from Light Detection and Ranging (lidar) data, and stream geomorphic assessments have been completed for more than 2,300 miles of river. Availability of these new data sets represented a cost-effective opportunity to revisit the analysis, without the need to engage in resource-intensive field work, to expand and update RHGCs for Vermont rivers.

1.2 Research Objectives

Our research objectives were to improve upon the RHGCs, by (1) expanding the number of observations, and (2) reducing the variability in the relationships between drainage area and each of the response variables, bankfull width, mean depth, and cross-sectional area. To do so, we leveraged stream geomorphic data collected from 2005 through present; as well as high-resolution lidar data for estimation of basin characteristics. We also developed additional predictor variables (e.g., slope, elevation) and clustering factors (e.g., biogeophysical region, geomorphic stream type) that might better refine regression estimates.

Chapter 2: Methodology

2.1 Literature Review

With a focus on humid-temperate regions, a literature review was conducted to identify additional explanatory variables that could be incorporated in a co-variate regression model or considered for stratification of regression models. This review included studies that produced regional curves for either bankfull conditions or a suite of peak discharges for various design storms. A literature review was also conducted to identify geomorphic assessment data for candidate regional curve sites located in nearby regions of states bordering Vermont.

2.2 Selection and Filtering of Sites

Best engineering practice dictates that candidate regional curve sites are located proximal to a streamflow gauging station, so that the bankfull stage estimated from indicator features during field assessment can be validated. Thus, we used a two-stage data filtering strategy to provisionally identify regional curve sites: Filter A identified streamflow gauging stations with sufficiently robust record; Filter B then focused on reaches with geomorphic assessment data located reasonably close to a Filter A streamflow gauge.

2.2.1 Streamflow Gauging Stations (Filter A)

First, we compiled data for 163 streamflow gauging stations, both continuous-record and partial-record (i.e., crest-stage) gauges, located in Vermont and in neighboring portions of New Hampshire, Massachusetts, and New York. Data gathered for each station included drainage area, period of record, number of peak flow observations, whether flows were regulated or not by upstream impoundments or withdrawals, and percent of forest cover in the upstream catchment. The principal source for these initial data included the Data-Collection Station Reports accessed through USGS Streamstats (v. 4, https://streamstats.usgs.gov/ss/) (Ries et al., 2017), updated with reference to the respective National Water Information System (NWIS) page for the current period of record (USGS, 2019). While some of the streamflow gauging stations had been discontinued, most were current.

We then filtered these preliminary stations to *exclude*:

- Stations with less than 10 years of record in the most recent 30 years. This condition was set to minimize the potential for influence of climate-related, nonstationarity that has been observed regionally (Collins, 2009; Armstrong et al., 2012; Guilbert et al., 2015).
- Stations below flood-control dams or other substantial peak-flow regulation structures (a minor degree of low-flow diurnal fluctuation was noted for some stations but is not expected to substantially influence bankfull-discharge magnitude or associated channel dimensions).
- Stations with upstream drainage areas containing greater than 10% developed land uses.
- Stations that were unsuitable for slope-area calculations of discharge (Dalrymple and Benson, 1967).

2.2.2 Stream Geomorphic Assessments Reaches (Filter B)

A second filtering of streamflow gauging sites was performed based on whether suitable stream geomorphic assessment data (SGA) were available for reaches located at or nearby these gauges. Given budgetary constraints, no new field work was able to be conducted for this study, and we relied on previous studies for identification of bankfull channel dimensions at study sites.

For Vermont sites, these studies included the original work of Jaquith and Kline (2001, 2006) as well as various stream geomorphic assessments that generated data between 2005 and present. SGA data were exported from the web-based Data Management System (https://anrweb.vt.gov/DEC/SGA/Default.aspx) which stores SGA data gathered in accordance with VTANR protocols (Kline et al., 2009). An exported table of SGA data contained 5274 unique records with field-based geomorphic data. This table was then sub-set to contain only those reaches classified by assessors to be in Reference (n=157) or Good (n=1379) condition. As defined in VTANR protocols (Kline et al., 2009), reaches in Reference or Good condition were considered stable and undergoing minimal lateral and vertical adjustments.

These Reference and Good condition reaches were then reviewed in a geographical information system (GIS) for their spatial location relative to the above selected streamflow gauges. To maximize the number of potential regional curve sites, we selected reaches on the same river network and in proximity to a Filter A streamflow gauge if they:

- were laterally-unconfined alluvial reaches (i.e., not a bedrock reach);
- drained an upstream land area between 0.5 and 1.5 times the drainage area of the associated streamflow gauge; and
- did not have significant tributary(ies) joining the main channel between the location of the reach and the gauge.

Generally, reaches were not selected if they were immediately upstream or downstream of an existing RHGC site (Jaquith and Kline, 2006), unless the reach had a different geomorphic stream type classification (Rosgen, 1996).

In closely-bordering regions of NY, MA and NH, SGA data were gathered from studies published by US Geological Survey. Generally, USGS study reaches were defined as:

- dominantly alluvial (i.e., characterized by no or minimal exposures of bedrock);
- single-thread channels;
- approximately 20 channel widths in length (with a few exceptions);
- confined by valley walls or terraces on only one side (i.e., were located very broad to semi-confined valleys);
- stable (in quasi-equilibrium state) as defined by assessment.

2.2.3 Tiers of data robustness

Selected sites were then classified into four tiers of varying data robustness (Table 1).

Table 1. Tiers of data robustness for regional curve sites.

Tier	Gauging site relationship to subject alluvial reach	Bankfull Discharge Source
I	Co-located (USGS streamflow gauge)	Stage-discharge (USGS) or HEC-RAS model
Ia	Co-located (temporary streamflow gauge)	Stage-discharge model (Jaquith & Kline, 2006)
Ib	Co-located (USGS crest gauge)	Estimated from cross-section spreadsheet (VTANR SGA data)
II	Same watershed (USGS streamflow gauge)	Estimated from cross-section spreadsheet (VTANR SGA data)

2.3 Compilation of Bankfull Channel Dimensions from Geomorphic Assessments

To compile bankfull channel dimensions, we relied on published reports. In both VT, NY and MA studies, indicators of the bankfull discharge were assessed in the field using very similar approaches (Dunne & Leopold, 1978; Harrelson et al., 1994; Leopold, 1994; Kline et al., 2009; Mulvihill et al., 2009; Bent & Waite, 2013). Bankfull indicator features included:

- top surfaces of depositional bars on the inside of meander bends;
- base of perennial, woody vegetation (excepting willow, alder, dogwood species);
- transition, or break in slope, along the streambank profile from steep to shallow;
- changes in the dominant sediment grain size that may be coincident with the above features; and
- erosional scour on naturally-entrenched, steeper-gradient channels without significant floodplain.

Measurement of reach-scale bankfull channel dimensions at each study site varied somewhat between sites.

- At Tier I and Ia sites (VT, NY, MA) – bankfull indicators were surveyed using standard survey equipment along a longitudinal profile and at multiple cross sections
- At Tier Ib and II sites (VT), a cross section representative of the reach or segment was measured using a mix of methods, including i) laser-level and rod, ii) total station survey equipment and rod, or iii) fiberglass measuring tape or cam line and survey rod. The bankfull channel dimensions were estimated with reference to an arbitrary datum. The number of cross sections measured per reach or segment varied between 1 and 4; and one cross section was chosen as representative of the reach.

At each streamflow-gauging site, the bankfull discharge was estimated by reference to the stage-discharge rating curve to estimate the discharge corresponding to the average surveyed elevation of the bankfull channel features (Jaquith & Kline, 2001). MA study referenced the stage-discharge relationship for the water year in which SGAs were conducted (i.e, 2009), or the most recent available stage-discharge rating curve for those gages operated historically. Similarly, the stage-discharge rating curve for 2006 was used for NY stations, except for stations 01333500 and 04276500 which used a HEC-RAS model.

2.4 Flow Frequency Analysis

For each of the gages associated with Tier I to II sites, we determined the bankfull discharge recurrence interval by examination of the record of annual instantaneous peak discharge using a log-Pearson Type III analysis following Bulletin 17C procedures (England et al., 2015). This method uses the Expected Moments Algorithm to estimate the moments and parameters of the log-Pearson Type III distribution. We used a weighted skew approach that considered the Vermont regional skew coefficient (0.44) and mean square error (0.078) developed by Olson (2014) to mitigate the sensitivity to outliers of site skew coefficients (Interagency Advisory Committee on Water Data, 1982). Low outliers were detected and identified using the Multiple Grubbs-Beck method (Cohn et al., 2013). Plotting positions were calculated by the Hirsch-Stedinger method (Hirsch and Stedinger, 1987). Peak annual discharge data were retrieved from the USGS NWIS from the approved records through water year 2018 (USGS, 2019). Flow frequency analysis was performed using Hydrologic Engineering Center's Statistical Software Package (HEC-SSP) software (USACE, 2019).

2.5 Compilation and Development of Catchment Characteristics

Upstream drainage areas were delineated from point locations identified by coordinates reported in the USGS Gages II data set (Falcone, 2011) or from previous reports (Bent & Wait, 2013; Lumia, 2006; Olson, 2014) using USGS Streamstats v.4.3.8 (Reis et al., 2017). Topographical dimensions of the catchments were calculated in GIS based on digital elevation models of 1/3 arc second resolution (approx. 10 m), and stream networks of the hydro-corrected National Hydrography Dataset. Land cover land use data were sourced from the 30m-resolution 2016 National Land Cover Data set (available at www.mrlc.gov).

2.6 Statistical Analysis

Exploratory data analysis included Pearson and Spearman correlations among catchment properties and bankfull channel dimensions. Regressions between predictor and response variables were explored using ordinary least squares methods, multiple linear regression and penalized linear regression. Performance of regression equations was assessed by comparing predicted (P) bankfull dimensions to those observed (O) during stream geomorphic assessments for 464 sites distributed across the state of Vermont, using Root Mean Square Error (RMSE), calculated as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i + O_i)^2}{n}}$$

Statistical analyses were executed in JMP, R and Excel.

As part of her Masters project, co-author Roberge also used geostatistical methods to explore whether clustering of these RHGC stations based on temporal structure revealed in instantaneous discharge time series records, might indicate a meaningful method to group the stations (see Appendix B).

Chapter 3: Results and Discussion

3.1 Expanded Observation Sites and Catchment Characteristics

A total of 30 observation sites was identified, expanding the number of observations by 10 (Figure 1). Twenty-three Tier 1 sites were identified, located proximal to a USGS continuous-recording streamflow gauging station. This listing includes 15 of the original 20 RHGC sites in Vermont, as well as four sites from New York (Mulvihill et al., 2009) and four sites from Massachusetts (Bent and Waite, 2013). For each of these Tier 1 sites, field-based survey estimates of bankfull discharge were confirmed with bankfull discharge estimated from a stage-discharge relationship developed by USGS personnel. Recurrence intervals of the bankfull discharges ranged from 1.4 to 3.8 years with a median of 1.5 years (Table A-1).

Tier 1a sites comprise five of the original 20 RHGC sites in Vermont, where bankfull discharge estimates were developed by Jaquith & Kline (2006) based on field surveys and a co-located temporary streamflow gauging station. Only two additional Vermont stations were able to be identified where stream geomorphic assessment data were paired with streamflow gauging data. One site was co-located with a USGS crest gauge station (Tier 1b), and one was located nearby to a USGS streamflow gauge (Tier II), and represented a different stream type than the reach co-located with that gauge.

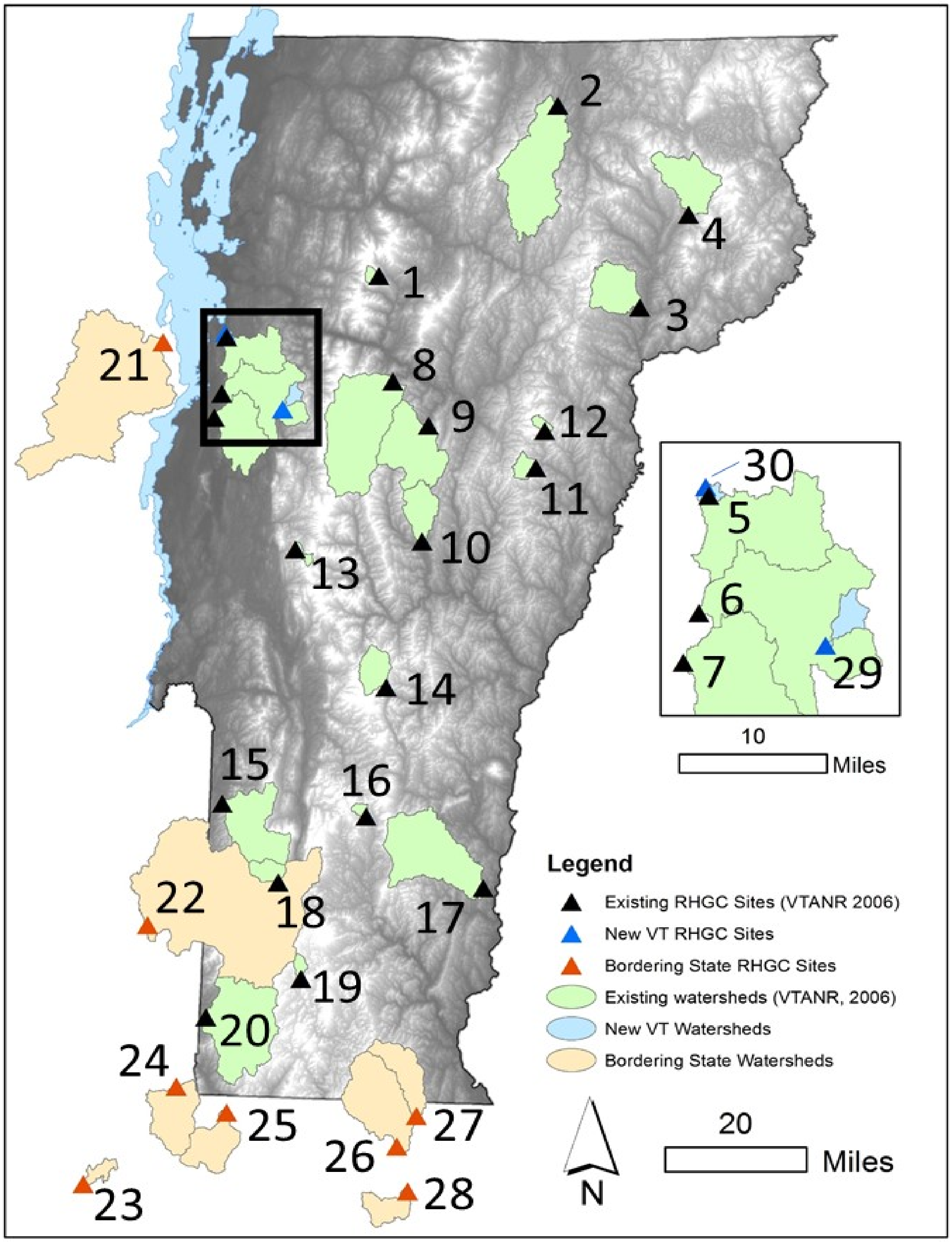
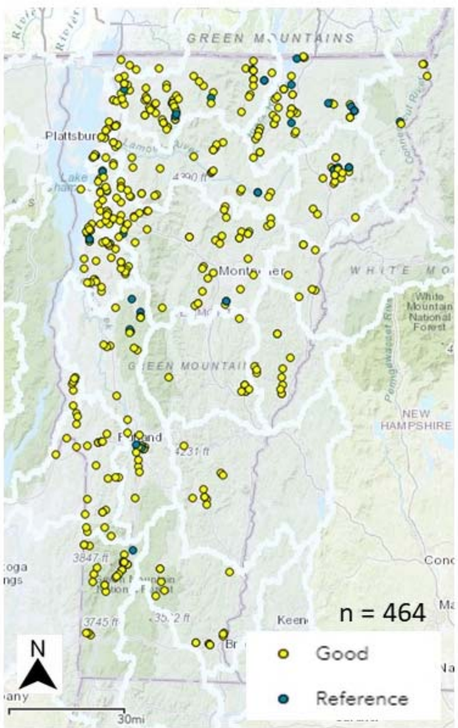


Figure 1. Location of Regional Hydraulic Geometry Curve stations for Vermont streams (n=30). Additional observation sites (n=10) include two new stations in Vermont, and eight stations in bordering regions of Massachusetts and New York State. Map numbers correspond to Table A-1.

Table 2. Summary of 2021 Regional Hydraulic Geometry Curve stations by data tier.

Tier	Gauging site relationship to subject alluvial reach	Bankfull Discharge Source	Number of Sites
I	Co-located (USGS streamflow gauge)	Stage-discharge (USGS) **	VT (15); NY (4); MA (4)
Ia	Co-located (temporary streamflow gauge)	Stage-discharge (Jaquith & Kline, 2006)	VT (5)
Ib	Co-located (crest gauge)	Estimated from cross-section spreadsheet (VTANR SGA data)	VT (1)
II	Same watershed (USGS streamflow gauge)	Estimated from cross-section spreadsheet (VTANR SGA data)	VT (1)

***except for NY stations 01333500 and 04276500, which used a HEC-RAS model (Mulvihill et al., 2009)*



Stream geomorphic assessment data identified a total of 464 stream reaches in reference or good condition (Figure 2). However, availability of a co-located or nearby streamflow gauging record proved to be a limiting condition for the identification of suitable RHGC stations.

Figure 2. Location of stream reaches assessed in reference or good condition by VTANR Stream Geomorphic Assessment protocols (Kline et al., 2009) between 2005 and 2019 (n=464).

Stations developed through site selection methods described in Section 2.2 included mostly channels of C(15) or Bc(7) stream type (Rosgen, 1994); remaining stations were located on Cb(2), B(2), F(2) and Gc(1) stream types, with only one E stream type identified (Table A-1). An opportunity exists for a future research effort employing establishment of temporary streamflow gauging stations and channel surveys to expand curve development for E stream types, as 24 SGA records were identified for stable E stream types lacking adequate streamflow gauging records.

3.2 Updated Regional Curves

With the addition of 10 new sites, RHGCs have been expanded to cover drainage areas up to 396 (from 194) square miles (Fig. 3).

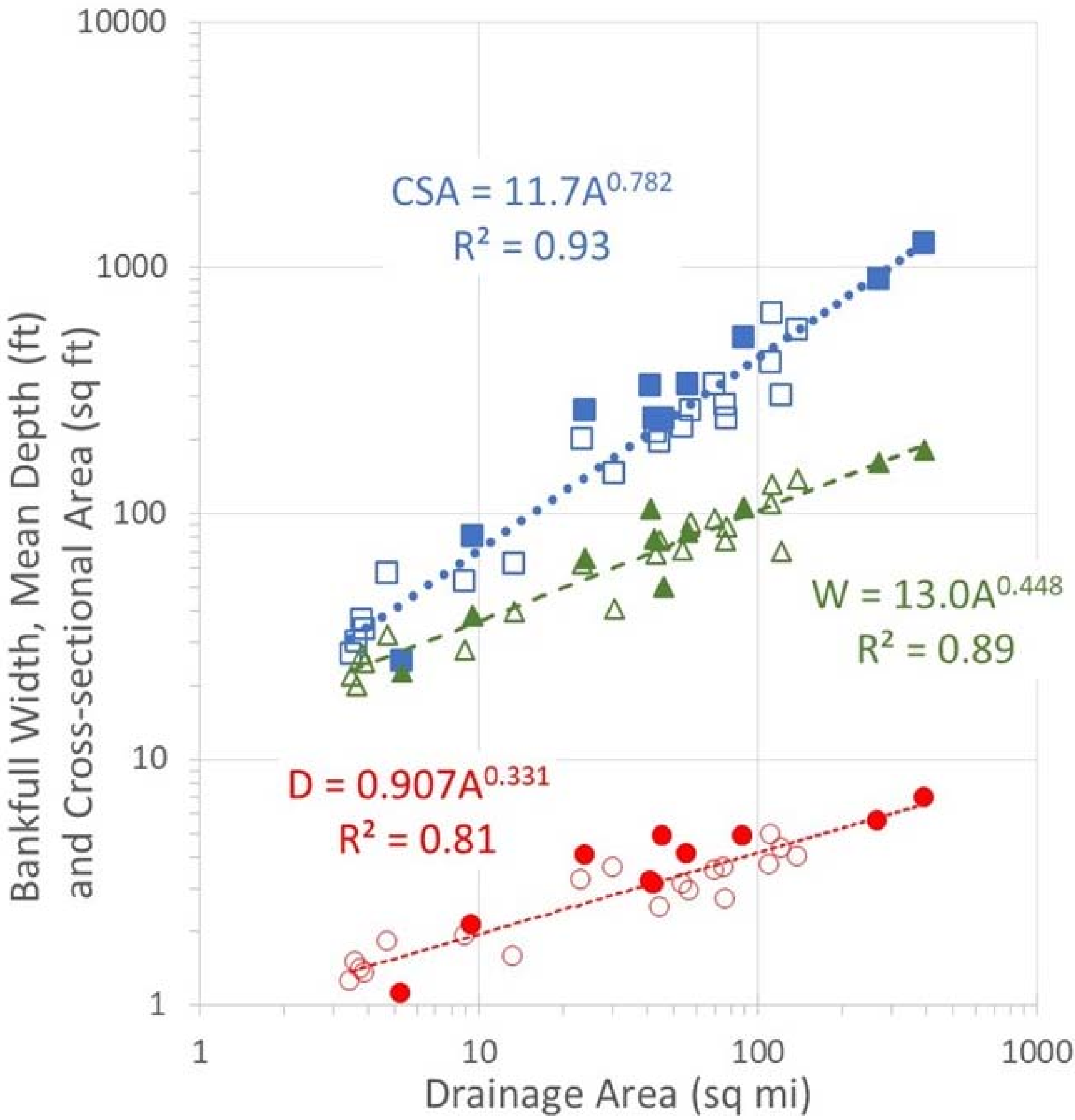


Figure 3. 2021 Regional Hydraulic Geometry Curves (RHGCs) for Vermont streams, including bankfull cross-sectional area (CSA), bankfull width (W) and bankfull mean depth (D). Open symbols signify sites included in the 2006 RHGCs (Jaquith & Kline, 2006); solid symbols reflect new data points. Trend lines are fit through all data (n=30).

The 2021 edition of the curves is more broadly applicable than the 2006 curves, which were limited to sites with drainage areas between 3.5 and 196 square miles (Table 3).

Table 3. Regression model coefficients of determination.

		Linear Regression Model Coefficient of Determination, R^2		
Model	n	W	D	CSA
2001 RHGCs	14	0.78	0.59	0.85
2006 RHGCs	20	0.91	0.87	0.95
2021 RHGCs	30	0.89	0.81	0.93
2021 Slope Stratified RHGCs				
Slopes > 0.1%	23	0.95	0.81	0.92
Slopes ≤0.1%	7	0.89	0.72	0.96

Catchment characteristics were explored as additional predictor variables in multiple linear regression models and penalized linear regression approaches, but there was little additional statistical power gained by including additional watershed characteristics. Moreover, sub-setting the relatively few numbers of observations (n=30) limited the statistical power of the resulting predictive models. In the end, for ease of use, and consistency with prior versions of the curves, we offer a set of simple linear regression models, but with an option for stratification by channel slope for the most frequently used bankfull width equation (next section).

3.3 Stratifying by Slope Improves Model Performance

An increasing proportion of the variation in bankfull width explained by drainage area was achieved when stratifying the curves by channel slopes at a threshold of 0.1% (Figure 4). These lower-gradient stations are composed of sand- and fine-gravel-bed channels classified as E(1), C(4), Gc(1) and Bc(1) stream types distributed across physiographic provinces, including the Champlain Valley and Northern Vermont Piedmont (Thompson and Sorenson, 2000).

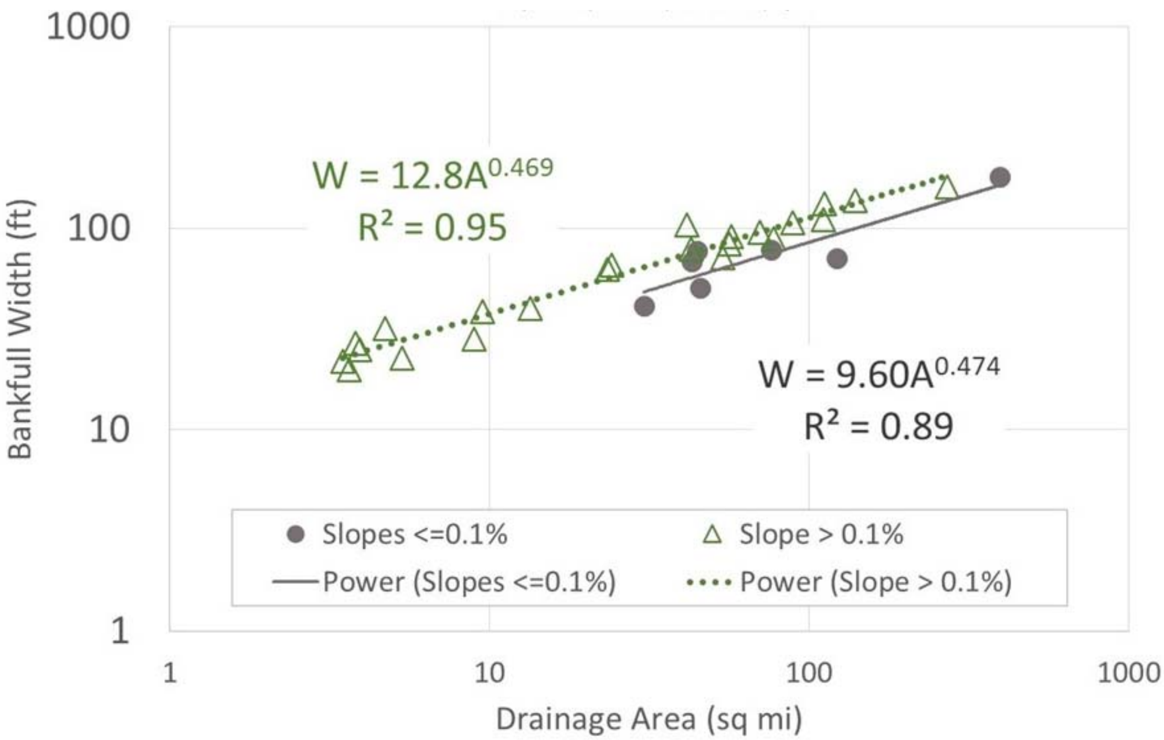


Figure 4. Slope-stratified linear prediction models for bankfull width as a function of drainage area. Open green triangles denote RHGC stations with channel slopes greater than 0.1% (n=23); solid gray circles denote stations with slopes less than or equal to 0.1% (n=7).

We assessed performance of these curves by reference to the VTANR stream geomorphic data set. For the 464 alluvial reaches classified in reference or good condition following assessment protocols (Figure 2), we compared the bankfull width predicted by the 2006 RHGCs to the actual field-measured values in Figure 5a. On this top plot we have used the general 2006 regression equation to predict channel width for all sites. In other words, there is no separate prediction for low-gradient sites; they are simply visualized separately on the plot in Figure 5a. The Root Mean Square Error (RMSE) value of 18.8 ft indicates that, overall, the curves somewhat overpredict channel width. This is not an unexpected result, given that a majority of assessed reaches are located in settings impacted by close encroachments. Given a history of channel and floodplain manipulations (Kline and Cahoon, 2010), even those reaches assessed in stable, good condition may have channel widths lesser than regime predictions as a result of historic dredging or channel armoring (Underwood, et al., 2021).

However, some degree of scatter about the 1:1 line in Figure 5a is a reflection of the uncertainty in the regional curves for width prediction. The overall RMSE value improves when the 2021 slope-stratified RHGCs for bankfull width are used for predictions (Figure 5b). A closer fit to the 1:1 line is evident particularly for low-gradient channels, and the overall RMSE value decreases to 17.7 feet.

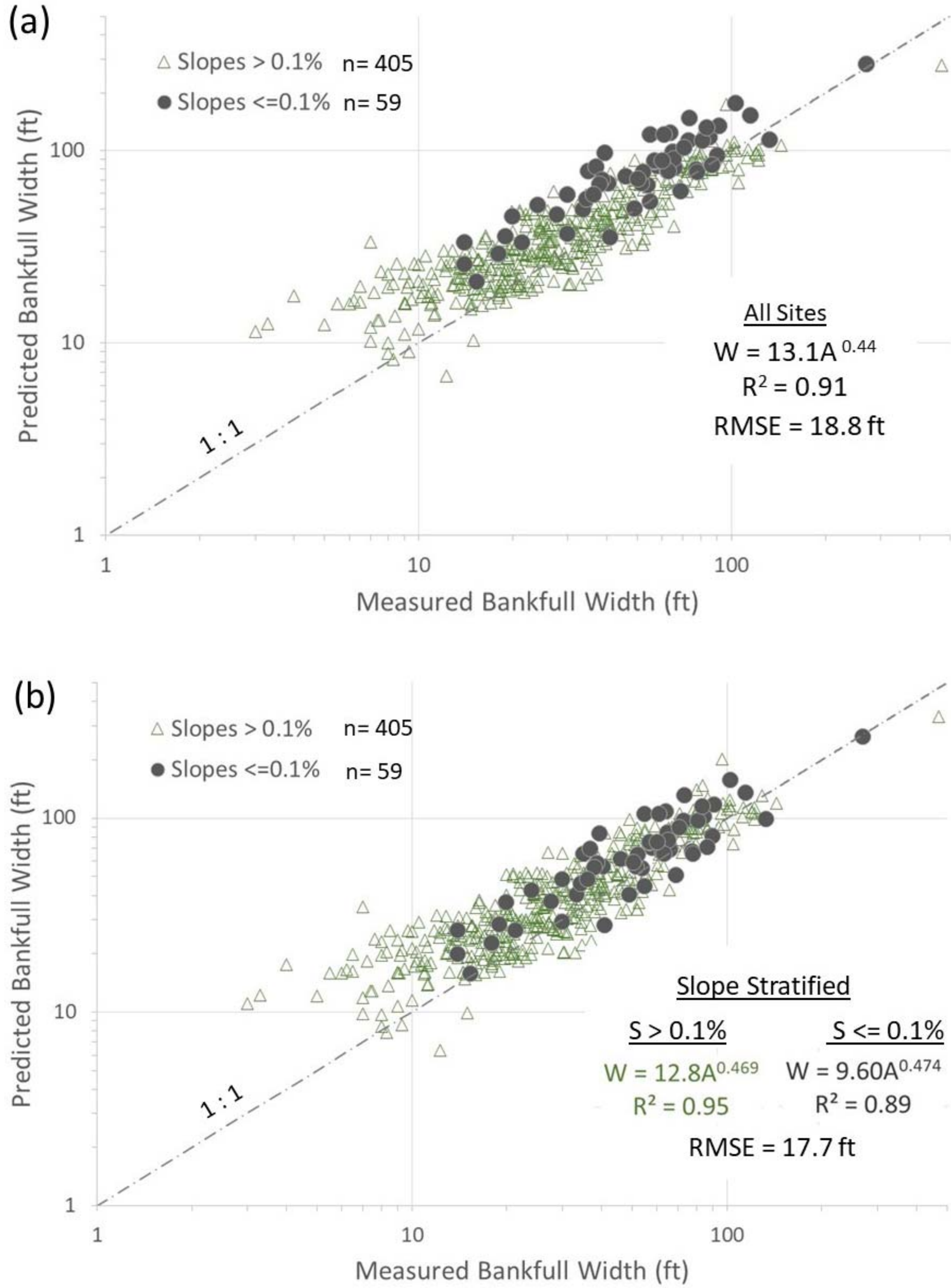


Figure 5. Comparison of bankfull width value measured during geomorphic assessments vs. bankfull width predicted by (a) 2006 RHGCs and (b) 2021 Slope-Stratified RHGCs. Observations have been symbolized with open green triangles for the channels with slopes greater than 0.1%, and solid gray circles for slopes ≤ 0.1 %. The dashed diagonal line represents a 1-to-1 relationship.

Chapter 5: Conclusions and Recommendations

Regional Hydraulic Geometry Curves for the state of Vermont have been updated to improve predictions of bankfull channel dimensions, by reference to stream geomorphic assessment data that have been compiled over the last 15 years. Despite limited overlap of these assessment data with available streamflow gauging records that led to only two new usable stations identified within Vermont, reliance on published data for eight stations in neighboring states has produced a set of updated regional curves that are more broadly applicable. RHGCs have been expanded to cover drainage areas up to 396 (from 194) square miles. Additionally, stratification of the curves by channel slope at a threshold of 0.1% has improved prediction of bankfull width as a function of drainage area.

Data analysis has identified targeted reaches where establishment of temporary streamflow monitoring stations and additional channel survey work under future funding would enable further expansion of the RHGCs to better address very-low-gradient channels and add coverage for steep-gradient streams.

Use of updated curves to design more geomorphically-compatible bridges and culverts will lead to greater resilience and durability of these transportation structures during extreme flood events, as demonstrated in Vermont during Tropical Storm Irene. Greater longevity of structures translates to improved benefit-cost ratios when the full life cycle of these structures is analyzed and compared to that of undersized structures. Geomorphically-compatible structures also have co-benefits of supporting aquatic and terrestrial organism passage objectives. Updated regional curves are publicly-available for use by transportation departments of the New England states, as well as engineers and scientists working at private firms, non-governmental organizations and state and federal agencies.

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Appendices

Appendix A. Oversize tables.

Table A-1. Geomorphic data set for Regional Hydraulic Geometry Curve stations.

Data Source	Data Tier	Map No.	State	Reference USGS Stn	Description	Drainage Area [mi^2]	Station Altitude [ft]	Average Bankfull Channel Dimensions: Width [ft]	Mean Depth [ft]	Cross-sectional Area [ft]	Entrench-ment Ratio [--]	Width to Depth Ratio [--]	Water Surface Slope [ft/ft]	D50 [mm]	Reach Stream Type	D50 (cat)	Bankfull Discharge [c] [$ft^3 sec^{-1}$]
4	I	1	VT	04288230	Ranch Brook at Ranch Camp near Stowe VT	3.8	1,240 [a]	27	1.4	37	1.48	24.88	0.0193	53	B4	gravel	147 [h]
3	I	2	VT	04296000	Black River at Coventry VT	122	710.0 [a]	70.6	4.3	303.7	2.8	16	0.0004	9.9	C4	gravel	1726
3	I	3	VT	01135300	Sleepers River (Site W-5) near St. Johnsbury VT	42.9	641.7 [a]	68.6	3.1	213.5	3	22	0.0007	16.8	C4	gravel	1312
3	I	4	VT	01133000	East Branch Passumpsic River near East Haven VT	53.8	943.9 [a]	71.5	3.1	224.3	2.7	23	0.0053	56	C4	gravel	1122
3	I	5	VT	04282795	Laplatte River at Shelburne Falls VT	44.6	150 [a]	77.4	2.5	197.2	1.6	30	0.001	16.2	B4c	gravel	734
3	I	6	VT	04282780	Lewis Creek at North Ferrisburg VT	77.2	117.6 [b]	88.7	2.7	244	4.2	32	0.0044	52.4	C4	gravel	1850
3	I	7	VT	04282650	Little Otter Creek at Ferrisburg VT	57.1	146.8 [b]	91.7	2.9	264.6	2.5	32	0.002	0.8	C5	sand	853.6
3	I	8	VT	04288000	Mad River near Moretown VT	139	543.9 [a]	138	4	559	2.8	34	0.002	20.5	C4	gravel	4960
3	I	9	VT	04287000	Dog River at Northfield Falls VT	76.1	603 [a]	78	3.6	277	2.3	22	0.0008	37	C4	gravel	1537
3	I	10	VT	01142500	Ayers Brook at Randolph VT	30.5	630.5 [a]	41.0	3.6	146.0	1.2	11	0.0008	0.3	G5c	sand	621
3	I	11	VT	01139800	East Orange Branch at East Orange VT	8.95	1,180 [a]	28.1	1.9	52.8	4.8	15	0.0132	15.7	C4	gravel	186.5
4	Ia	12	VT	NA	Waits River	3.92	1630 [j]	25	1.34	34	4.18	16	0.0195	35	C4b	gravel	131 [h]
4	Ia	13	VT	NA	Sucker Brook	3.48	1540 [j]	22	1.25	27	1.74	16.5	0.0292	32	B4	gravel	79 [h]
3	I	14	VT	01150900	Ottauquechee River near West Bridgewater VT	23.4	1,148.6 [b]	62.5	3.2	201.3	3.1	19	0.0017	10.4	C4	gravel	661
3	I	15	VT	04280350	Mettawee River near Pawlet VT	70.2	525 [a]	95.3	3.5	337	2.4	27	0.0058	27.4	C4	gravel	3300
4	Ia	16	VT	NA	Greendale Brook	3.65	1620 [j]	20	1.49	30	1.64	20.78	0.0184	31	B4c	gravel	171 [h]
3	I	17	VT	01153550	Williams River near Rockingham VT	112	303.7 [a]	132.5	4.9	650.3	1.4	22	0.0025	58.9	B4c	gravel	5490
4	Ia	18	VT	NA	West Branch Batten Kill	13.4	810 [j]	40	1.58	63	4.89	25.22	0.007	43	C4	gravel	206 [h]
4	Ia	19	VT	NA	Deerfield River	4.72	2060 [j]	32	1.80	57	1.88	21	0.0104	74	B3c	cobble	104 [h]
3, 5	I	20	VT	01334000	Walloomsac River near North Bennington VT	111	525.4 [b]	110	3.7	410	1.5	33.5	0.0027	75	F3	cobble	1879
1	I	21	NY	04276500	Bouquet River at Willsboro NY	270	150.9 [a]	161.3	5.6	905.5	1.7	28.9	0.003	122.2	B3c	cobble	6,200 [d]
1	I	22	NY	01329490	Batten Kill Below Mill at Battenville NY	396	373.1 [a]	180.3	7.0	1,258	2.5	26.8	0.001	39.1	C4	gravel	6,320
1	I	23	NY	01360640	Valatie Kill near Nassau NY	9.48	492.2 [b]	38.6	2.1	80.8	5.6	18.6	0.002	24.9	C4	gravel	227
1	I	24	NY	01333500	Little Hoosic River at Petersburg NY	56.1	587.4 [a]	83.7	4.1	337.3	5.3	21.1	0.004	65.5	C3	cobble	2,500 [d]
2	I	25	MA	01333000	Green River at Williamstown MA	42.6	613 [b]	79	3.09	244.12	1.33	25.6	0.0107	59.56	B4c	gravel	1220
2	I	26	MA	01169000	North River at Shattuckville MA	89.0	461 [b]	106.3	4.9	515.99	4.34	21.9	0.0052	66.95	C3	cobble	3070
2	I	27	MA	01170100	Green River near Colrain MA	41.4	432.3 [b]	104.75	3.19	332.54	1.14	32.8	0.0075	92.81	F3	cobble	2110
2	I	28	MA	01169900	South River near Conway MA	24.1	456 [b]	65.55	4.04	264.18	1.45	16.2	0.0052	30.21	B4c	gravel	1710
5	Ib	29	VT	04282700	Lewis Creek Tributary at Starksboro VT	5.31	640.0 [a]	22.67	1.11	25.11	6.84	20.46	0.0293	22	C4b	gravel	153.3 [i]
5	II	30	VT	04282795	Laplatte River downstream of Shelburne Falls VT	45.82	98 [j]	50.5	4.85	245.02	13.86	10.41	0.0002	0.55	E5	sand	870.34 [i]

Abbreviations: NA Not Available

NR Not Recorded

Table A-1 (continued). Geomorphic data set for Regional Hydraulic Geometry Curve stations.

Data Sources:	1	Mulvihill et al., 2009 with original data from Mulvihill et al., 2007a (Regions 1 & 2) and Mulvihill et al., 2007b (Region 3)
	2	Bent and Waite, 2013
	3	Jaquith and Kline, 2001
	4	Jaquith and Kline, 2006
	5	VT ANR Stream Geomorphic Assessment Data Management System, accessed 1/12/2020
Notes:	a	Altitude datum: NGVD29
	b	Altitude datum: NAVD88
	c	Bankfull discharge obtained from review of gaging station stage-discharge rating curve, unless otherwise noted.
	d	Bankfull discharge obtained from HEC-RAS analysis, per Mulvihill et al., 2009
	e	Mean annual runoff obtained from Randall, 1996, unless otherwise noted.
	f	Mean annual runoff calculated from continuous record streamflow-gaging station through water year, 2006, per Mulvihill et al., 2009
	g	RI calculated through wy2006 (for Mulvihill et al 2009), or through wy2009 (for Bent & Waite, 2013) except for discontinued gauges.
	h	Bankfull discharge extrapolated from temporary stage-discharge rating curve (2004-2005)
	i	Bankfull discharge and dimensions obtained from field measurements stored in VTANR Data Management System for stream geomorphic assessment data.
	j	Altitude values from Vermont Contours State Plane Cache, https://maps.vcgi.vermont.gov/arcgis/rest/services/EGC_services/MAP_VCGI_CONTOURS_SP_CACHE/MapServer

Table A-2. Land cover/ land use in upstream drainage area for each Regional Hydraulic Geometry Curve station.

Map No.	State	Description	Waterbodies & Wetlands	Developed	Forested	Scrub/Shrub	Barren	Grassland	Agricultural	Total
			Percent Land Cover/ Land Use							
1	VT	Ranch Brook at Ranch Camp near Stowe VT	0.0	0.8	97.8	1.2	0.0	0.1	0.0	100
2	VT	Black River at Coventry VT	8.1	4.8	65.2	1.5	0.1	1.7	18.6	100
3	VT	Sleepers River (Site W-5) near St. Johnsbury VT	2.9	4.8	74.3	3.3	0.0	1.2	13.5	100
4	VT	East Branch Passumpsic River near East Haven VT	5.6	3.0	86.0	3.2	0.0	1.1	1.0	100
5	VT	Laplatte River at Shelburne Falls VT	7.2	7.5	43.4	0.2	0.0	0.3	41.5	100
6	VT	Lewis Creek at North Ferrisburg VT	8.3	4.2	62.6	0.2	0.3	0.4	24.0	100
7	VT	Little Otter Creek at Ferrisburg VT	10.2	4.8	35.4	0.1	0.2	0.3	49.0	100
8	VT	Mad River near Moretown VT	0.7	4.6	86.0	1.0	0.1	0.8	6.9	100
9	VT	Dog River at Northfield Falls VT	1.6	5.4	84.7	1.4	0.1	0.8	5.9	100
10	VT	Ayers Brook at Randolph VT	2.5	6.2	72.1	1.0	0.1	0.5	17.6	100
11	VT	East Orange Branch at East Orange VT	1.2	1.0	94.3	2.8	0.0	0.6	0.0	100
12	VT	Waits River	0.8	4.3	90.2	2.1	0.0	0.4	2.2	100
13	VT	Sucker Brook	3.1	0.4	96.1	0.3	0.0	0.1	0.0	100
14	VT	Ottauquechee River near West Bridgewater VT	5.1	9.4	83.3	0.2	1.1	0.3	0.6	100
15	VT	Mettawee River near Pawlet VT	2.0	3.5	79.7	0.2	0.1	2.4	12.0	100
16	VT	Greendale Brook	3.6	2.0	93.9	0.5	0.0	0.0	0.0	100
17	VT	Williams River near Rockingham VT	1.8	5.2	82.5	2.3	0.1	1.6	6.6	100
18	VT	West Branch Batten Kill	4.4	5.0	83.8	0.3	0.1	1.4	4.7	100
19	VT	Deerfield River	15.6	0.6	82.8	0.9	0.0	0.0	0.0	100
20	VT	Walloomsac River near North Bennington VT	6.2	9.2	76.3	0.2	0.4	0.9	6.7	100
21	NY	Bouquet River at Willsboro NY	5.4	3.1	82.7	1.0	0.5	0.5	6.6	100
22	NY	Batten Kill Below Mill at Battenville NY	6.4	4.9	74.8	0.3	0.1	1.3	12.1	100
23	NY	Valatie Kill near Nassau NY	6.1	8.3	71.4	1.1	0.0	0.7	12.5	100
24	NY	Little Hoosic River at Petersburg NY	1.1	3.9	87.0	0.8	0.0	1.1	6.0	100
25	MA	Green River at Williamstown MA	2.2	5.2	81.2	0.5	0.0	2.3	8.6	100
26	MA	North River at Shattuckville MA	2.8	4.8	83.9	0.9	0.1	0.7	6.8	100
27	MA	Green River near Colrain MA	2.2	4.2	88.5	1.1	0.0	0.9	3.1	100
28	MA	South River near Conway MA	3.1	6.3	82.1	0.2	0.0	0.4	7.8	100
29	VT	Lewis Creek Tributary at Starksboro VT	0.7	5.0	90.8	0.2	0.0	0.6	2.7	100
30	VT	Laplatte River downstream of Shelburne Falls VT	7.1	8.0	43.3	0.2	0.0	0.3	41.1	100

Table A-3. Physical characteristics of upstream drainage area for each Regional Hydraulic Geometry Curve station.

Map No.	State	Station	Type	Description	Drainage Area [mi^2}	Altitude [ft]	Minimum Elevation [ft]	Maximum Elevation [ft]	Mean Elevation [ft]	Mean Basin Slope [deg]	Main Channel Slope [ft/ft]	Main Channel Length [ft]	Catchment Perimeter [ft]
1	VT	04288230	USGS	Ranch Brook at Ranch Camp near Stowe VT	3.8	1240	1296	4042	2298	18.5	0.164	10854	52362
2	VT	04296000	USGS	Black River at Coventry VT	122	710	712	2638	1255	7.9	0.004	195906	448360
3	VT	01135300	USGS	Sleepers River (Site W-5) near St Johnsbury VT	42.9	642	640	2579	1337	8.1	0.032	46906	214108
4	VT	01133000	USGS	East Branch Passumpsic River near East Haven VT	53.8	944	945	3323	1696	9.3	0.019	54740	257940
5	VT	04282795	USGS	Laplatte River at Shelburne Falls VT	44.6	150	148	1634	515	6.4	0.008	78827	279528
6	VT	04282780	USGS	Lewis Creek at North Ferrisburg VT	77.2	118	118	2510	803	9.8	0.013	139781	397507
7	VT	04282650	USGS	Little Otter Creek at Ferrisburg VT	57.1	147	148	1325	411	5.6	0.005	92482	289370
8	VT	04288000	USGS	Mad River near Moretown VT	139	544	545	4081	1613	13.0	0.007	123434	397047
9	VT	04287000	USGS	Dog River at Northfield Falls VT	76.1	603	604	2890	1451	11.7	0.019	82458	318898
10	VT	01142500	USGS	Ayers Brook at Randolph VT	30.5	631	627	2333	1322	10.6	0.016	66164	177428
11	VT	01139800	USGS	East Orange Branch at East Orange VT	8.95	1180	1637	3356	2291	12.8	0.046	15827	65289
12	VT	NA	Temp	Waits River	3.92	1630	1175	2438	1817	14.4	0.033	30593	92782
13	VT	NA	Temp	Sucker Brook	3.48	1540	1532	3140	2138	11.4	0.049	20723	76640
14	VT	01150900	USGS	Ottauquechee River near West Bridgewater VT	23.4	1149	1152	4216	2033	14.2	0.023	41172	149934
15	VT	04280350	USGS	Mettawee River near Pawlet VT	70.2	525	528	3763	1462	13.8	0.029	100523	316864
16	VT	NA	Temp	Greendale Brook	3.65	1620	1624	2802	2104	8.8	0.053	14732	56824
17	VT	01153550	USGS	Williams River near Rockingham VT	112	304	305	2897	1265	10.8	0.017	132255	393175
18	VT	NA	Temp	West Branch Batten Kill	13.4	810	807	3353	1504	12.5	0.039	32454	103609
19	VT	NA	Temp	Deerfield River	4.72	2060	2057	3255	2393	7.7	0.028	22326	65879
20	VT	01334000	USGS	Walloomsac River near North Bennington VT	111	525	528	3750	1601	9.4	0.030	83513	386089
21	NY	04276500	USGS	Bouquet River at Willsboro NY	270	151	154	4856	1229	11.6	0.014	253362	715569
22	NY	01329490	USGS	Batten Kill Below Mill at Battenville NY	396	373	377	3839	1272	11.4	0.011	263529	824332
23	NY	01360640	USGS	Valatie Kill near Nassau NY	9.48	492	433	1355	752	6.8	0.013	45481	152208
24	NY	01333500	USGS	Little Hoosic River at Petersburg NY	56.1	587	591	2799	1425	13.5	0.021	74837	241911
25	MA	01333000	USGS	Green River at Williamstown MA	42.6	613	614	614	1558	14.2	0.024	75955	223363
26	MA	01169000	USGS	North River at Shattuckville MA	89.0	461	459	2303	1413	9.6	0.013	111175	324988
27	MA	01170100	USGS	Green River near Colrain MA	41.4	432	433	2411	1352	10.8	0.017	94170	253596
28	MA	01169900	USGS	South River near Conway MA	24.1	456	456	1841	1124	10.0	0.014	73029	192190
29	VT	04282700	USGS	Lewis Creek Tributary at Starksboro VT	5.31	640	646	2451	1408	15.0	0.017	26342	90617
30	VT	04282795	USGS	Laplatte River downstream of Shelburne Falls VT	45.8	98	98	1634	513	6.4	0.008	83950	290223

Table A-4. USGS Streamstats sourced data for each Regional Hydraulic Geometry Curve station.

Map No.	State	Station	Type	Description	Drainage Area [mi^2]	NWIS Drainage Area [mi^2]	Latitude [deg]	Longitude [deg]	Upstream Water Bodies & Wetlands [%]	Mean Annual Precipitation [in]	Basin Area at or above 1200 ft Elevation [%]
1	VT	04288230	USGS	Ranch Brook at Ranch Camp near Stowe VT	3.8	3.77	44.50361	-72.78176	0	65.4	100
2	VT	04296000	USGS	Black River at Coventry VT	122	122	44.86884	-72.26991	4.75	46.6	52.9
3	VT	01135300	USGS	Sleepers River (Site W-5) near St Johnsbury VT	42.9	42.6	44.43540	-72.03860	0.71	42.9	62.3
4	VT	01133000	USGS	East Branch Passumpsic River near East Haven VT	53.8	51.6	44.63415	-71.89726	2.98	47.1	89.4
5	VT	04282795	USGS	Laplatte River at Shelburne Falls VT	44.6	44.4	44.37016	-73.21643	3.83	39.5	1.67
6	VT	04282780	USGS	Lewis Creek at North Ferrisburg VT	77.2	76.5	44.24910	-73.22817	5.93	42.2	22.4
7	VT	04282650	USGS	Little Otter Creek at Ferrisburg VT	57.1	58.4	44.19814	-73.24898	4.74	38.4	0.16
8	VT	04288000	USGS	Mad River near Moretown VT	139	139	44.27726	-72.74235	0.39	51.2	73.4
9	VT	04287000	USGS	Dog River at Northfield Falls VT	76.1	76.7	44.18250	-72.64091	0.90	45.3	74.7
10	VT	01142500	USGS	Ayers Brook at Randolph VT	30.5	30.5	43.93451	-72.65776	1.19	43.2	65.0
11	VT	01139800	USGS	East Orange Branch at East Orange VT	8.95	8.83	44.09284	-72.33555	0.18	45.4	99.9
12	VT	NA	Temp	Waits River	3.92	3.92	44.17134	-72.31087	0.10	49.5	100
13	VT	NA	Temp	Sucker Brook	3.48	3.48	43.91674	-73.01668	2.98	54.3	100
14	VT	01150900	USGS	Ottauquechee River near West Bridgewater VT	23.4	23.3	43.62239	-72.75889	3.29	55.7	97.3
15	VT	04280350	USGS	Mettawee River near Pawlet VT	70.2	70.6	43.37063	-73.21692	1.30	53.3	59.1
16	VT	NA	Temp	Greendale Brook	3.65	3.65	43.34484	-72.81333	1.63	57.3	100
17	VT	01153550	USGS	Williams River near Rockingham VT	112	112	43.19161	-72.48509	1.13	48.0	52.5
18	VT	NA	Temp	West Branch Batten Kill	13.4	13.4	43.20300	-73.05867	3.51	54.4	60.1
19	VT	NA	Temp	Deerfield River	4.72	4.72	42.99666	-72.99351	3.74	61.2	100
20	VT	01334000	USGS	Walloomsac River near North Bennington VT	111	116	42.91302	-73.25649	4.92	51.7	59.4
21	NY	04276500	USGS	Bouquet River at Willsboro NY	270	271	44.35824	-73.39670	1.13	34.2	41.9
22	NY	01329490	USGS	Batten Kill Below Mill at Battenville NY	396	396	43.10869	-73.42185	2.45	44.1	40
23	NY	01360640	USGS	Valatie Kill near Nassau NY	9.48	9.5	42.55188	-73.59153	2.02	37.1	1.33
24	NY	01333500	USGS	Little Hoosic River at Petersburg NY	56.1	55.7	42.76387	-73.33735	0.29	43.3	67.4
25	MA	01333000	USGS	Green River at Williamstown MA	42.6	42.6	42.70899	-73.19680	0.27	48.5	NA
26	MA	01169000	USGS	North River at Shattuckville MA	89.0	89.1	42.63827	-72.72511	2.17	51.7	NA
27	MA	01170100	USGS	Green River near Colrain MA	41.4	41.2	42.70335	-72.67057	1.73	51.5	NA
28	MA	01169900	USGS	South River near Conway MA	24.1	24.1	42.54195	-72.69387	2.02	51.5	NA
29	VT	04282700	USGS	Lewis Creek Tributary at Starksboro VT	5.31	5.36	44.21651	-73.05537	0.32	48.7	69.4
30	VT	04282795	USGS	Laplatte River downstream of Shelburne Falls VT	45.8	45.8	44.37898	-73.22079	3.82	39.4	1.62

Table A-5. Spearman correlations among study variables.

Variable	by Variable	Spearman ρ	Prob>|ρ|
Altitude_ft	DA_sqmi	-0.6601	<.0001
Width_ft	**DA_sqmi**	**0.9119**	**<.0001**
Width_ft	Altitude_ft	-0.6966	<.0001
MnDepth_ft	**DA_sqmi**	**0.8313**	**<.0001**
MnDepth_ft	Altitude_ft	-0.5843	0.0007
MnDepth_ft	Width_ft	**0.7692**	<.0001
CSA_sqft	DA_sqmi	**0.9181**	<.0001
CSA_sqft	Altitude_ft	-0.6578	<.0001
CSA_sqft	**Width_ft**	**0.9488**	**<.0001**
CSA_sqft	**MnDepth_ft**	**0.9039**	**<.0001**
WtoD	DA_sqmi	0.4971	0.0052
WtoD	Altitude_ft	-0.4230	0.0199
WtoD	Width_ft	0.6890	<.0001
WtoD	CSA_sqft	0.4880	0.0062
WS_Slope	DA_sqmi	-0.6232	0.0002
WS_Slope	Altitude_ft	0.4957	0.0053
WS_Slope	Width_ft	-0.4476	0.0131
WS_Slope	MnDepth_ft	-0.6588	<.0001
WS_Slope	CSA_sqft	-0.5177	0.0034
D50_mm	WtoD	0.4475	0.0132
D50_mm	WS_Slope	0.3812	0.0377
Qbfl_cfs	**DA_sqmi**	**0.9057**	<.0001
Qbfl_cfs	Altitude_ft	-0.6676	<.0001
Qbfl_cfs	**Width_ft**	**0.9333**	<.0001
Qbfl_cfs	**MnDepth_ft**	**0.8609**	<.0001
Qbfl_cfs	**CSA_sqft**	**0.9600**	<.0001
Qbfl_cfs	WtoD	0.5085	0.0041
Qbfl_cfs	WS_Slope	-0.4618	0.0102
MinElev_ft	DA_sqmi	-0.6494	0.0001
MinElev_ft	**Altitude_ft**	**0.9903**	**<.0001**
MinElev_ft	Width_ft	-0.6843	<.0001
MinElev_ft	MnDepth_ft	-0.5661	0.0011
MinElev_ft	CSA_sqft	-0.6440	0.0001
MinElev_ft	WtoD	-0.4232	0.0198
MinElev_ft	WS_Slope	0.5143	0.0036
MinElev_ft	Qbfl_cfs	-0.6503	0.0001
MeanElev_ft	DA_sqmi	-0.4870	0.0063
MeanElev_ft	**Altitude_ft**	**0.8478**	**<.0001**
MeanElev_ft	Width_ft	-0.4024	0.0275
MeanElev_ft	MnDepth_ft	-0.4499	0.0126
MeanElev_ft	CSA_sqft	-0.4100	0.0244
MeanElev_ft	WS_Slope	0.5939	0.0005
MeanElev_ft	Qbfl_cfs	-0.4314	0.0173
MeanElev_ft	**MinElev_ft**	**0.8628**	**<.0001**
MaxElev_ft	MeanElev_ft	0.5473	0.0017

Table A-5. (Continued) Spearman correlations among study variables.

Variable	by Variable	Spearman ρ	Prob>|ρ|
Mean Basin Slope [degrees]	WS_Slope	0.4901	0.006
Mean Basin Slope [degrees]	MeanElev_ft	0.5043	0.0045
Mean Basin Slope [degrees]	MaxElev_ft	0.4334	0.0167
MainChSlope_ftperft	DA_sqmi	-0.6516	<.0001
MainChSlope_ftperft	**Altitude_ft**	**0.7348**	**<.0001**
MainChSlope_ftperft	Width_ft	-0.5373	0.0022
MainChSlope_ftperft	MnDepth_ft	-0.5785	0.0008
MainChSlope_ftperft	CSA_sqft	-0.5515	0.0016
MainChSlope_ftperft	WS_Slope	0.6090	0.0004
MainChSlope_ftperft	Qbfl_cfs	-0.5123	0.0038
MainChSlope_ftperft	**MinElev_ft**	**0.7348**	**<.0001**
MainChSlope_ftperft	**MeanElev_ft**	**0.7815**	**<.0001**
MainChSlope_ftperft	Mean Basin Slope [degrees]	0.4514	0.0123
Perim_ft	**DA_sqmi**	**0.9729**	**<.0001**
Perim_ft	**Altitude_ft**	**-0.7219**	**<.0001**
Perim_ft	**Width_ft**	**0.8830**	**<.0001**
Perim_ft	**MnDepth_ft**	**0.7922**	**<.0001**
Perim_ft	**CSA_sqft**	**0.8812**	**<.0001**
Perim_ft	WtoD	0.4840	0.0067
Perim_ft	WS_Slope	-0.6146	0.0003
Perim_ft	**Qbfl_cfs**	**0.8768**	**<.0001**
Perim_ft	**MinElev_ft**	**-0.7248**	**<.0001**
Perim_ft	MeanElev_ft	-0.5684	0.0010
Perim_ft	**MainChSlope_ftperft**	**-0.7050**	**<.0001**
MainChL_ft	**DA_sqmi**	**0.9333**	**<.0001**
MainChL_ft	**Altitude_ft**	**-0.7740**	**<.0001**
MainChL_ft	**Width_ft**	**0.8919**	**<.0001**
MainChL_ft	**MnDepth_ft**	**0.7968**	**<.0001**
MainChL_ft	**CSA_sqft**	**0.8919**	**<.0001**
MainChL_ft	WtoD	0.4724	0.0084
MainChL_ft	WS_Slope	-0.5560	0.0014
MainChL_ft	**Qbfl_cfs**	**0.8901**	**<.0001**
MainChL_ft	**MinElev_ft**	**-0.7711**	**<.0001**
MainChL_ft	MeanElev_ft	-0.6218	0.0002
MainChL_ft	**MainChSlope_ftperft**	**-0.7442**	**<.0001**
MainChL_ft	**Perim_ft**	**0.9706**	**<.0001**
Above table presents only statistically significant correlations (at α = 0.05)			
Correlations with Spearman ρ absolute value greater than 0.7 are bolded.			

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