Regional curves relating bankfull channel geometry and discharge to drainage area

USGS Kentucky and Pennsylvania Water Science Centers

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Introduction to Regional Curves

- Regressions relating **bankfull** channel characteristics to drainage area.

- Provide *estimates* of bankfull discharge and channel geometry at ungaged sites

- Used for validating the selection of the bankfull channel as determined in the field
What are the bankfull discharge and the bankfull channel?

“There must be some flow of intermediate size, large enough to be effective in causing change, but sufficiently frequent that the product of its frequency and effectiveness would be greater than that of any other size of flow event. (Wolman & Miller, 1960)
This system is not necessarily stationary and the inputs can be dynamic – changes to inputs will cause channel evolution as the system seeks to stabilize under the new regime (mining impacts for example).
Rosgen (1996) defined “stable” as a stream that “has the ability to maintain over time, its dimension, pattern, and profile in such a manner that it is neither aggrading nor degrading and is able to transport, without adverse consequence, the flows and detritus of its watershed”.

A stable stream is considered to be in “dynamic equilibrium” or “graded”.
In terms of stability, resource managers are generally dealing with relative rates of change and the ability of the local ecosystem to adjust without adverse effects (as noted by Rosgen and with respect to spatial scale as per Schumm and Lichty, 1965). Basically, stability goes as follows:

- Long time period = progressive loss of energy and mass (basin)
- Moderate time period = self-regulation, dynamic equilibrium (subwatershed)
- Short time period = steady state (reach)

USGS streamflow-gaging stations provide data to quantify channel stability (when coupled with basic site observations) and generally serve as the backbone of regional curves.
USGS stream gages are required to develop regional curves - they provide critical data and insight.

Gage sites become your data points, so the more the better. You can fill in with un-gaged sites, but these sites should be limited.

There are over 7,800 USGS streamflow-gaging stations nationally.
Selection of streamflow-gaging stations for PA study

For geomorphic study, many USGS gages can fall out as you filter them by selection criteria – we used only 66 out of the 350+ gages in the region.
Basic USGS stream gage – measures *stage*. To compute flow, a rating curve must be established.
Streamflow is measured over a range of stages to develop the rating curve.

Wading (in a glide)

Flood flow (at a bridge)

Note – regional curves are developed in natural riffles, so channel geometry from USGS measurements should not be used directly to create regional curves.
Stage / discharge rating curve

Notice the control shifted (scoured) at this gage and a new rating had to be established (rating #7) – ratings are good indicators of relative site “stability”
USGS also provides:

**Station Descriptions**

Tells you:

- **where the gage is located**
- **if there are any controls, diversions, or regulation**
- **where the reference marks are (to tie surveys into gage datum)**
- and much more.

**Station Description**

Station: West Branch Brandywine Creek near Honey Brook, PA
Prepared: 9/26/90 for T.A.1
Revised data: D.F.G., 10/4/91
Updated: 1/23/90

Station Number: 01480300

Location: Lat. 40° 04' 24" N, long. 75° 57' 49" W, about 100 feet upstream of right end of bridge on SR 409/1, at Brandywine, 6.4 miles downstream from Two Log Dam, 1.75 miles upstream from Lackawaxen Dam, 3.0 miles southeast of Honey Brook, 6.5 miles north of Coatesville, Chester County. (Wigington 7.5 minute quadrangle, T-25E).

Road Log:
- 0.0
  - From Honey Brook, go east on Rt. 359.
  - 0.9
    - Turn right at crossroad at Rockville Trailer Park (large brownstone building on right side of road across from intersection). (Or if you're coming from Downingtown, travel west on Rt. 359 for 10 miles until you come to the Rockville Trailer Park and then turn left.)
- 3.7
  - Cross bridge and make a right at the 2-way Intersection (T441) on Sooner Dam Road.
  - Put in at first dirt road on your left with no-bring gate across it (standard USGS 3549 key).
- 3.8
  - Walk back dirt road to gage. Invisible in dry weather.

Established: June 8, 1990 by T.A. Hackelmeier. Gage was moved upstream (same station number and datum) from the bridge to its present location in July 1990 by T.L. Duffer and K. White.

Drainage Area: 10.7 sq. mi.

Gage: Synoptics Data Collection Platform water stage recorder and Datron 8020 voice modem in vertical sheet-metal structure near a 5-foot (1.5 m) vertical concrete wall on right bank 100 ft. upstream from set concrete bridge. 3.5" floater at elevations -0.1 ft and 0.9 ft (stream level). Base gage in electric tape gages. Three outside vertical marks are located using stream stage baric. E.D. #1 reads from 0.0 ft. -3.3 ft. O.D. #2 reads from 3.3 ft -0.6 ft. O.D. #3 reads from ... A Station 8210 is equipped with modern in gage.

Gage is equipped with AC power and a flushing system for its two strobes.

USGS with top of pipe at 132.24 ft is attached to upstream side of gage. Sick reads 5.49 ft -13.54 ft.

Index of Electric Tape: 13.076 ft, gage datum (USGS).

Channel and Control:
- Streambed is composed of sand and gravel. Channel upstream and downstream is winding and banks are overgrown with trees and brush. Dams are rather thin and will be overflowed at moderate to high stages. Controls a riffle downstream of gage.

Discharge Measurements:
- Field measurements can be made at various sections below the gage, but above the control up to stage of about 3.5 ft. At higher stages measurements should be made from downstream side of the bridge about 130 feet downstream of the gage. Bridge is marsh at 7 foot intervals for use in making stabilized measurements. The influx point is at the face of the right abutment. Bridge opening, abutment to abutment is 73 feet less center pier.

November 5, 1999
Rating Tables

Tells you:

What the flow is at any given stage - including the bankfull stage.
Peak Flow Analyses (Bulletin 17B)

Tells you:

The recurrence interval of any flow - including the bankfull discharge

Most researchers place the bankfull flow at a recurrence interval of ~1 to ~2 years

Requires 10 years (minimum) of continuous data at the gage to develop
Standard Form 9-207s

Tells you:

- Rough channel geometry (area, width, depth)
- Can help validate the roughness coefficient (Manning’s “n”) used to estimate discharge at surveyed cross-sections.
Field data for regional curves can be collected once gage data is obtained and reviewed.

The top of the bankfull channel is identified and two cross-section surveys in riffle sections then provide accurate bankfull-channel geometries and an estimate of bankfull discharge.
While surveying, commonly observed geomorphic features are: …

Common errors include mistaking a lower terrace or active-channel features for bankfull – this is why you need USGS gage data as confirmation (for example, Bulletin 17B estimates).

From Sherwood and Huitger (2005)
Commonly used bankfull indicators are ...

- changes in slope of the bank
- height of depositional features
- changes in bank vegetation
- change in the particle size of bank material
- undercuts in the bank
- stain lines
- highest elevation below which no fine debris is evident
Bankfull discharge, area, width, and mean depth are determined from the cross-sectional surveys.
Determination of bankfull stage

Longitudinal-profile survey

Relates each cross section to the gage and determines a bankfull slope.
Note how the surveyed bankfull feature is extended through the gage to validate and determine discharge and recurrence interval.
The first data point on the regional curve!

Values from the two cross sections are averaged and a mass-balance check is performed as a QA/QC check (flows estimated at the cross sections should closely match those measured at the gage).
As USGS developed curves in PA, two objectives were addressed:

- Are regional curves truly different between physiographic provinces?
- Can multiple-regression models provide better estimates of bankfull characteristics?
Different Slopes and/or intercepts = different regions (typically expected at the time)
Slopes and/or intercepts are the same =
all regions are the same
Were Regional Curves Different by Province in the Pennsylvania study?

Regional curves developed for each province had the same slope and intercept (all p-values < 0.05) - Data was therefore combined across all provinces as bankfull characteristics were similar (however, there were some outliers).
Relation between bankfull discharge and drainage area (66 gages)

Notice this does not say "karst"
Multiple Regression Models to Estimate Bankfull Characteristics

Explanatory Variables Tested:

- Drainage area
- Percent of watershed area underlain by carbonate bedrock (not karst features).
- Percent of watershed area having glacial deposition
- Other variables tested but dropped due to collinearity (% forest, etc.).

*Bold variables DID explain significant variability in the models, other variables did not.*
Results of Multiple Regression Models

- More variability was explained by this approach (using both drainage area and % carbonate rock), but the slope coefficient on the carbonate term in the multiple-regression model was negative. As a result, negative flows and areas were estimated for small basins with large amounts of carbonate bedrock.

- This was a major shortcoming of the model that made it unfeasible for use in regional curve development (especially for the person standing at the side of a stream trying to figure out why the discharge is negative).

- So… the multiple regression may not be good for estimation purposes but it still can provide insight on how to handle the carbonate watersheds.
Relation between Residuals and Percent of Basin Underlain by Carbonate Bedrock

The graph shows the relation between residuals and the percent of the basin underlain by carbonate bedrock. The residuals are measured in cubic feet per second (cfs). The data points are categorized based on the percent of the basin underlain by carbonate bedrock:

- **1 - 30% Carbonate Bedrock**: N = 14
- **30 - 100% Carbonate Bedrock**: N = 11

The graph indicates that discharge is underestimated for basins with 1 - 30% carbonate bedrock and overestimated for basins with 30 - 100% carbonate bedrock.
Regional Curves Developed for ...

- Watersheds underlain by less than or equal to 30% carbonate bedrock (noncarbonate).
- Watersheds underlain by greater than 30% carbonate bedrock (carbonate).
Noncarbonate Regional Curves

- Piedmont: N = 12
- Ridge and Valley: N = 18
- Appalachian Plateaus: N = 24
- Central Lowland: N = 1

$R^2 = 0.92$

95-percent confidence interval
Noncarbonate Regional Curves

- Piedmont: N = 12
- Ridge and Valley: N = 18
- Appalachian Plateaus: N = 24
- Central Lowland: N = 1

95-Percent Confidence Interval

R² = 0.72
Carbonate Regional Curves

These are definitely unique regional curves, but these are statistically weak!!!
Carbonate Regional Curves

\[ R^2 = 0.76 \]

- 95-Percent Confidence Interval

- Piedmont: \( N = 2 \)
- Ridge and Valley: \( N = 9 \)

DRAINAGE AREA, IN SQUARE MILES

BANKFULL CROSS-SECTIONAL MEAN DEPTH, IN FEET

DRAFT
Three Regression Pathologies

All graphs below have the same $R^2$

Figure 9.18  Four key pathologies in regression (after Anscombe, 1973).

## Diagnostic Stats for Regional Curves

<table>
<thead>
<tr>
<th>Bankfull Response Variable</th>
<th>N</th>
<th>R²</th>
<th>Cook’s Distance (Max)¹</th>
<th>Residual Stnd. Error (log units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log₁₀(bf area)</td>
<td>55</td>
<td>11²</td>
<td>0.92</td>
<td>0.20</td>
</tr>
<tr>
<td>Log₁₀(bf Q)</td>
<td>55</td>
<td>11</td>
<td>0.92</td>
<td>0.27</td>
</tr>
<tr>
<td>Log₁₀(bf width)</td>
<td>55</td>
<td>11</td>
<td>0.81</td>
<td>0.25</td>
</tr>
<tr>
<td>Log₁₀(bf depth)</td>
<td>55</td>
<td>11</td>
<td>0.72</td>
<td>0.28</td>
</tr>
</tbody>
</table>

¹Critical value of Cook’s Distance is approximately 2.2
²Blue = statistic for carbonate setting
Curves for the Carbonate Setting are Weaker than the NonCarbonate Curves Because…

- Drainage area alone can’t explain variability due to karst development.

- Nonuniformity of karst in regional carbonate bedrock.

- There are fewer streamflow-gaging stations.
Karst Features are not Uniformly Distributed

*Karst* overlaps physiographic provinces and does not occur in all *carbonate* areas.

Map adapted from Kochanov and Reese, PADCNR (2003)
Iron Run - shale
Iron Run – carbonate (karst)
Spring Creek
(Iron Run as it emerges at a geologic contact with a resistant carbonate formation)
Limitations and Application of Regional Curves

- Regional Curves generally apply only to the study area unless validation occurs to support the contrary.

- Regional Curves only apply to watersheds with characteristics (land use, etc.) that are consistent with station-selection criteria.

- Application of Regional curves for carbonate settings should be accompanied by rigorous site-specific field data collection.

- Regional Curves should not be used as the sole tool for computation of bankfull channel dimensions. A REFERENCE REACH is required for this process.
The reference reach is ...

- A stable reach of stream that meets the criteria described earlier (Rosgen, 1996).

- Reference reaches serve as “templates” for bankfull pattern, profile, and dimension that are then “transferred” to a disturbed project reach located in a similar hydrologic setting.

- Regional curves are used to help identify and validate the bankfull characteristics on reference reaches.
Designers of restoration projects assume that a stream reach modeled after a stable reference reach of the same stream type will convey streamflow and sediment as effectively as the reference reach.

The reference reach must then equate to the probable stable form of the project reach’s stream type under the present hydrology and sediment regime (as described in Rosgen, 1996) (establish a post-mining reference reach?).

Reference reaches must also be chosen carefully as variability can exist even within the reference reach itself.
Bermudian Creek reference reach (PA) downstream
Bermudian Creek reference reach (PA) upstream
Bermudian Creek reference reach
Dedicated streamflow-gaging station

Intensive annual surveys (for several years) to confirm stability
Where can I find regional curves?
Many places - you need to do a bit of homework!

- NRCS -
- Private industry -
- EPA -
  [http://water.epa.gov/lawsregs/guidance/wetlands/wetlands.mitigation_index.cfm#training](http://water.epa.gov/lawsregs/guidance/wetlands/wetlands.mitigation_index.cfm#training)
- USGS (search for “regional curve”) -
- Also check with local universities and state agencies -
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