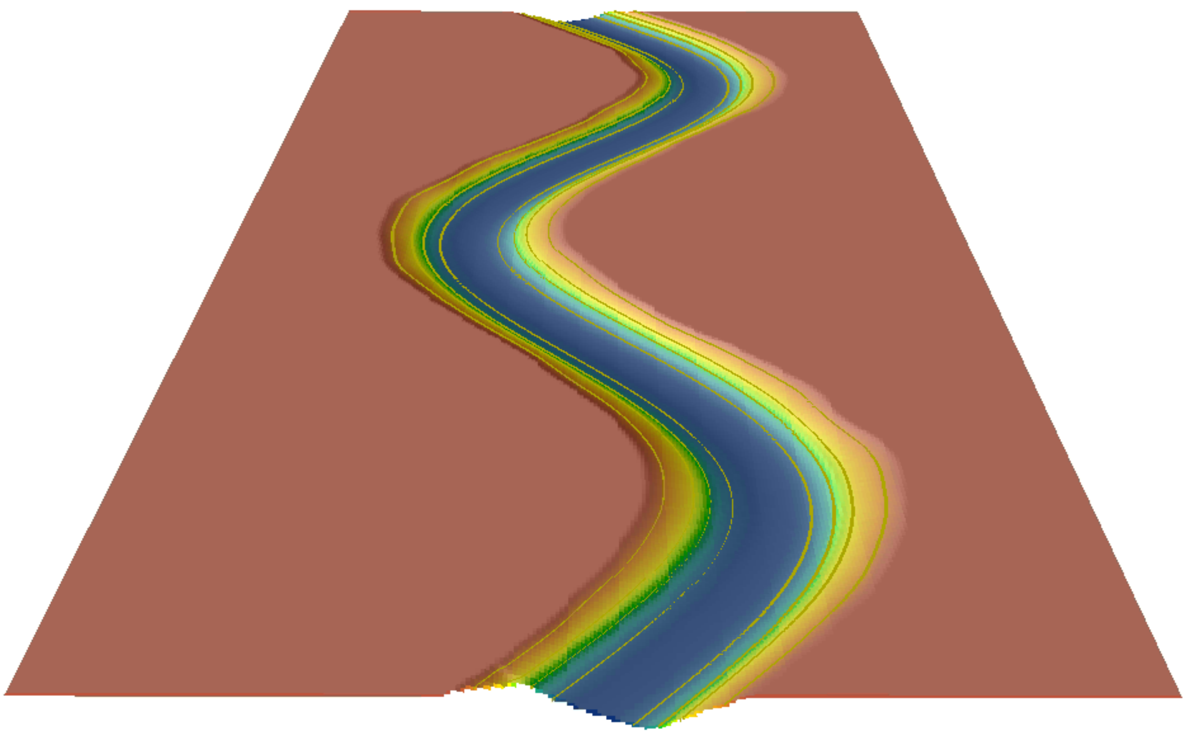
College of Agricultural & Environmental Sciences
Department of Land, Air, and Water Resources
UC Davis

River Builder User's Manual



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1 INTRODUCTION

Designing alluvial river channels that behave naturally is a central challenge facing river scientists and engineers as well as animators and video game developers in the 21st century. Though organized and responsive to driving forces, rivers exhibit complex patterns and processes from the scale of an individual grain of sediment to that of an entire continent. Despite roughly a century of research it remains highly uncertain as to which patterns and processes are most important to design explicitly versus which ones should be allowed to emerge on their own after construction. Nevertheless, our understanding of the fluvial patterns and processes as well as our ability to quantify them is increasing rapidly. We can now design much more dynamic rivers than ever before.

It is beyond the scope of this manual to explain the entire scientific foundation of this software. This introduction section simply offers a broad overview of the context of river design. The website at http://pasternack.ucdavis.edu has a lot of free educational video podcasts about rivers and related topics as well as web pages that provide more explanation of underlying concepts. Much more is available on the internet and in numerous textbooks. Most people will likely seek to just get started with the software and learn on an as-needed basis as they move along, so that is understandable.

1.1 Vanilla Rivers

Decades of empirical study of longitudinal and lateral transects of alluvial rivers have yielded an explanation for the central tendency of channel geometric variables averaged over a length of 100-1000 channel widths (i.e., the reach scale) to grow or decline with discharge on the basis of mutual adjustment in order to pass the typical water and sediment delivered by the catchment. Such variables include slope, bankfull width, bankfull depth, sinuosity, entrenchment ratio, and median particle size. For any river reach there can be large uncertainties in the average values of geometric variables compared to empirical regional expectations.

A synthetic river designed only according to reach-scale metrics of central tendency is called a "***Vanilla River***" (Figure 1). Although vanilla can be a delicious flavor, it is colloquially considered bland or generic, generally lacking in desirably variations and complexity. This is apropos, because in fact few river processes are driven by the central tendency of reach-scale river metrics. Instead, they are driven by local to reach scale patterns of topographic variability. Thus, few natural rivers look like synthetic Vanilla Rivers and we must turn to a more sophisticated understanding of topographic complexity to design rivers that reflect their natural patterning.

This software is capable of designing Vanilla Rivers, if that is desired. For use in real rivers, we do not recommend stopping there.

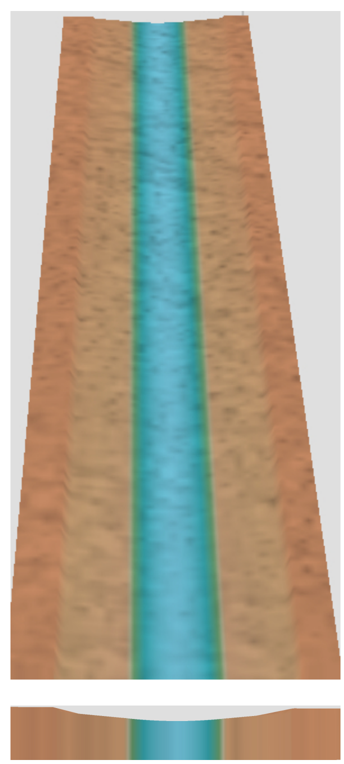


Figure 1. Vanilla River example.

1.2 Geomorphic Covariance Structures

Many measurable variables in geomorphology and allied sciences vary along a pathway, such as a river corridor. Variables could be flow-independent measures of topography, sediment attributes, flow-dependent hydraulics, topographic change, and biotic variables. Lane et al. (2017) reported that for a large region of California river variability metrics distinguished channel types better than traditional central tendency river attributes. These variations can contain some random aspects, but to a large degree they are highly organized, interlocked, and readable (Brown and Pasternack, 2014, 2017). Also, river variations can be layered on top of each other, yielding multiple spatial scales of topographic complexity.

Brown and Pasternack (2014) coined the term "Geomorphic Covariance Structure" (GCS) to mean the bivariate pattern of any two river variables along a pathway. It is not the statistical covariance, which is a single number, but instead a new concept involving the complete bivariate spatial series from which a statistical covariance could be computed if desired. The theory of Geomorphic Covariance Structures (GCSs) is not only useful for assessing the layers of topographic patterning of real rivers (Brown and Pasternack, 2014, 2017) but also for the design of synthetic rivers with more natural landforms that drive the real diversity of physical processes (Brown et al., 2014, 2015).

This software is capable of implementing GCSs to produce rivers with organized, coherent patterns of variability. This is where the real power of this software lies. However, the software does not tell you what GCSs you need to produce different outcomes. You must have in mind what you want and an understanding of what GCS metrics are required to achieve that vision. Over time we will aim to provide an increasing number of template files with different river archetypes you can use as a starting point, but that is still under development. As archetypes become available, they will be posted within the web site at the link below:
http://pasternack.ucdavis.edu/research/projects/synthetic-river-valleys/

1.3 Synthetic River Valleys

Brown et al. (2014) presented a new seven-step method of channel-floodplain design (i.e. synthetic river valley (SRV) design) involving geometric modeling in which multiple scales of continuous equations are specified in each plane (XY, XZ, and YZ) and combined in a digital elevation model (DEM). Figure 2 below combines and simplifies the steps to portray them in a general workflow.

First, you conceptualize the river corridor in terms of its essential elements and scales on the basis of ecogeomorphic goals.

Second, you specify the model domain, including coordinate systems, units, boundaries, and resolution.

Third, you determine the geometric elements for each plane at all scales of interest that are going to be needed, including but not limited to channel centerline longitudinal profile, channel bed elevation longitudinal profile along the centerline, channel width longitudinal profile, XS channel shape (which can be uniform or vary downstream according to a function), longitudinal profile of the outer floodplain boundary on each side of the valley, and the same for optional terrace boundaries beyond the floodplain on each side. The floodplain on each side of the river is treated independently for greater freedom in design. The first three steps are aggregated into one box in Figure 2.

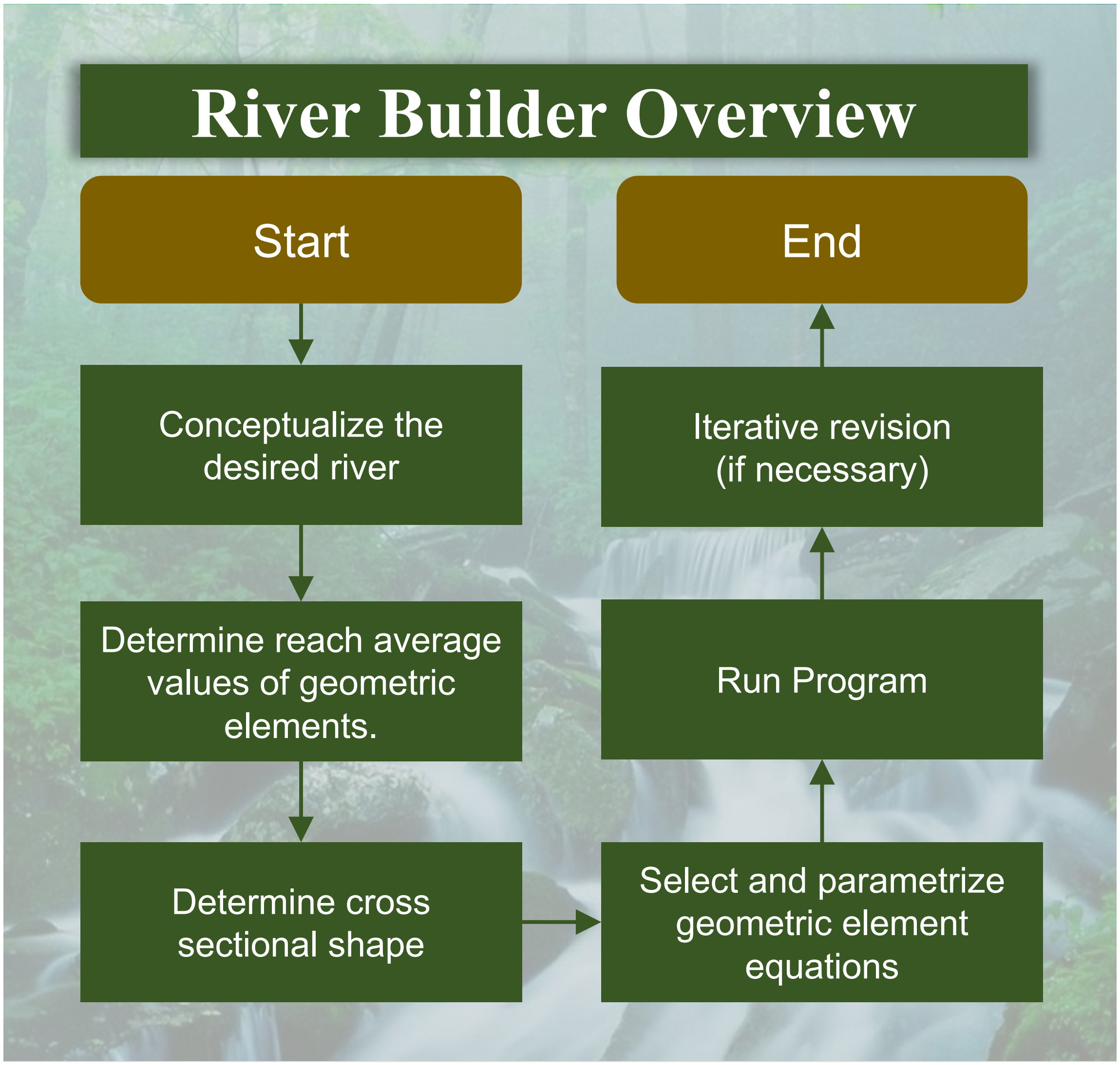


Figure 2. Simplified representation of the workflow for SRV design.

Fourth, you determine reach-average values of geometric elements using standard geomorphic methods. Key values include reach-average bed slope, channel width, floodplain width, median grain size, and either hydraulic radius or bankfull depth. Some variables may be computed from theory and other variables to insure adherence with process concepts, such as computing mean bankfull depth from the Shields equation. Cross-sectional shape is usually often at the reach-scale, but it can be made to vary down a reach. In Figure 2, cross-sectional shape is given its own box, because River Builder software allows you to use a variety of methods for specifying the shape and varying it downstream, so it is not just dependent on reach-average values.

Fifth, you select equations for the longitudinal variations of each geometric element. Although Brown et al. (2014) focused on sinusoids, by now the available functions have expanded to include lines, curves, sinusoidal oscillations, and Perlin noise profiles. Hopefully in the future there will be cnoidal oscillations, autoregressive meanders, and manually generated polylines and splines (e.g., imported river reach's centerline profile). The decision of which equation to use rests on a firm geomorphic understanding of the local reach, its river, and the region. You can use multiple functions for any one geometric element to obtain complex patterns, especially if the parameters are set to obtain different spatial scaling for each function. For example, one might use a cnoidal function for floodplain sinuosity in a confined valley to represent the river impinging on a bedrock wall and then nest within that a higher frequency sinusoidal function for inset channel sinuosity.

Sixth, you construct the geometric model using some form of software platform. Brown et al. (2014) described how to program an implementation of the theory and provided a Microsoft Excel® version for simplified cases. Past and ongoing software implementations are described in the next section. The River Builder software that this manual describes provides what you need to have a geometric model for many river types and with many features. It does this for you using code programmed in R.

Finally, you parameterize the equations to obtain the locally sized and positioned attributes of the synthetic river. Although parameters for each equation may be specified independently, self-maintenance processes in rivers often produce coherent patterns among multiple geometric elements, including mutual longitudinal variations identified through spectral or wavelet analysis of spatial series or the covariance function between them. Thus, the key decision for parameterization is to decide which two or more variables will be linked to vary coherently. For that to happen the variables have to be described by the same equation, and then parameters governing frequency, amplitude, and phase are specified to yield oscillations that produce the desired landform structure. This is where GCSs come into play. Beyond creating landforms, the deeper goal is to obtain topographically steered, stage-dependent hydraulics that drive a variety of channel maintenance mechanisms when operated on by a natural flow regime. At the same time, there is another goal of providing spatially organized yet heterogeneous aquatic and riparian habitats to serve different species needs in their various life stages.

Once all of this is done, you run the program containing the geometric model to render the synthetic river and get the associated output files. Based on analysis of those outputs, you may then choose to iterate the design to refine and improve it until you have the desired outcome.

1.4 Past SRV Implementations

The underlying equations needed to make synthetic river valleys are already known, published, and non-proprietary. How those equations are organized into software is what is at issue here. Prior to the development of this R software, SRV algorithms were produced at UC Davis in two different software platforms for different purposes. First, there was the "RiverSynth" approach using Microsoft Excel®. This approach reproduces the examples in Brown et al. (2014) and has received some subsequent development with a few other features.

Second, using an unrestricted donation, my group at UC Davis sponsored World Machine, LLC to incorporate SRVs into the World Machine platform on the hopes that this would make this methodology more accessible. World Machine (http://www.world-machine.com) is a native geometric modeling platform for digital terrain development that allows for precise specification of parameters to design diverse landscapes through dialogue boxes and flowcharting. Implementations of World Machine with river design capabilities may not be available for free and may still be developmental, with little to no technical support. Be sure to touch base with World Machine, LLC to find out the current status of SRV tools in that platform as well as what support they offer to users to help learn their implementation of SRV tools and to address any bugs or problems that come up with your projects.

1.5 User's Manual Purpose

The purpose of this manual is to provide you with an explanation of River Builder software that has the capability to design rivers that meet regional, reach-scale geomorphic expectations, but go far beyond that to have multiple scales and layers of organized sub-reach variability. Certainly, there are still many river archetypes the software cannot yet produce and we welcome future developments that expand the software's functionality more through time.

In most cases we expect people will use this software to design examples of real rivers to yield improved natural outcomes, but in fact the underlying geometric modeling is capable of allowing you to let your imagination run wild and design rivers for other purposes, such as testing dysfunctional river archetypes and creating unnatural, imaginary rivers for fictional purposes (e.g., video games, movies, animations, etc.). Whether you need a digital river design to fix a degraded real river or to save yourself millions of dollars in manual artistic effort for your next 4K resolution open-world fantasy game, this software can be very useful to meet your needs.

2 INSTALLATION AND SET-UP

Refer to the following links depending on your operating system to install R and RStudio:

- Linux: http://www.jason-french.com/blog/2013/03/11/installing-r-in-linux/
- Windows/OS X: https://www.andrewheiss.com/blog/2012/04/17/install-r-rstudio-r-commander-windows-osx/

Note: RStudio is not necessary, but it is highly recommended. It is compatible for Linux, Windows, and OS X and provides an easy-to-use graphical interface for the user to more easily examine program variables, plots, tables, and access other useful features that are not available on a terminal.

To access the R package, ArcGIS Python script, and example river archetypes, refer to download links on Gregory Pasternack's website: http://pasternack.ucdavis.edu/

3 RIVER BUILDER WORKFLOW

Figure 3 below shows a more complete workflow for this software. It does not show everything in the software, but it gives a much more complete representation of the steps and decision points.

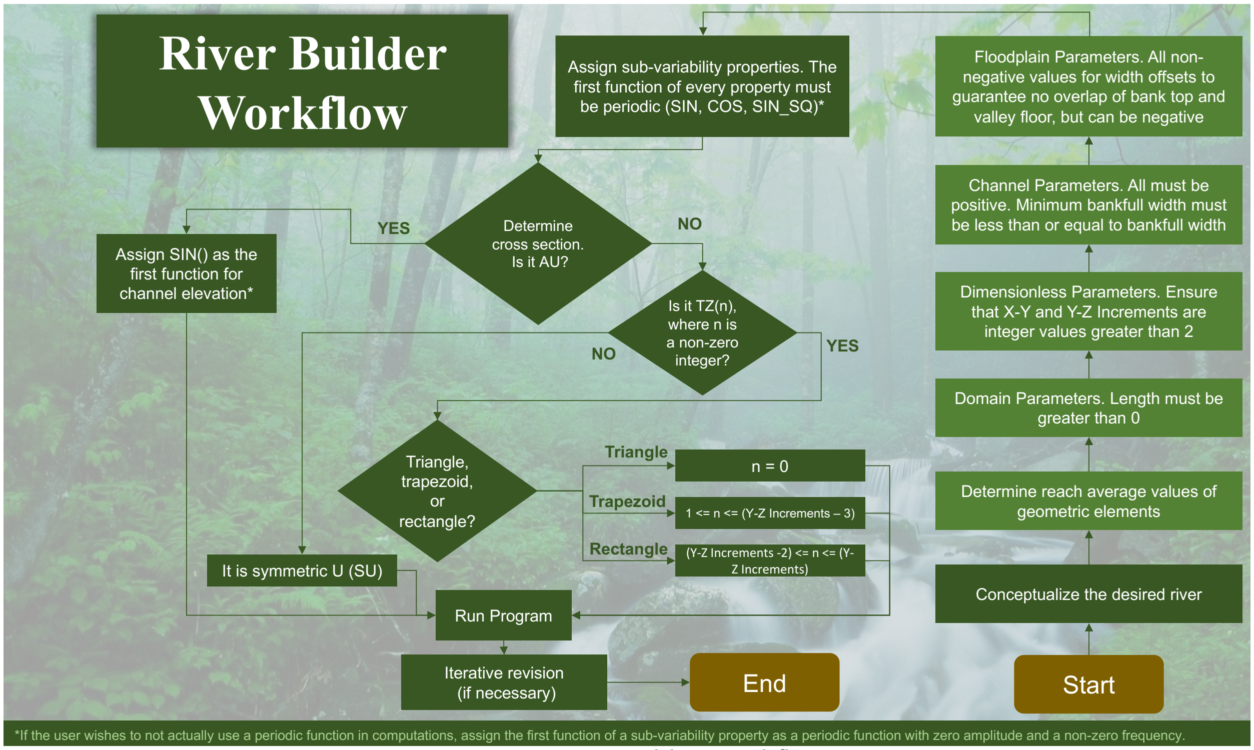


Figure 3. River Builder Workflow.

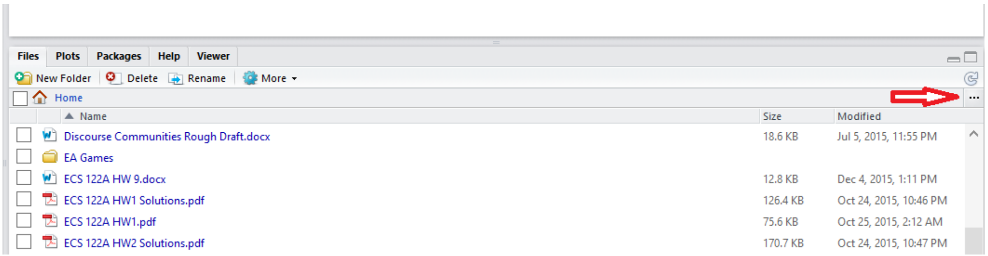
4 RUNNING THE PROGRAM

Have the file "riverbuilder.r" and the input text file in the same directory. There are two ways to run the program:

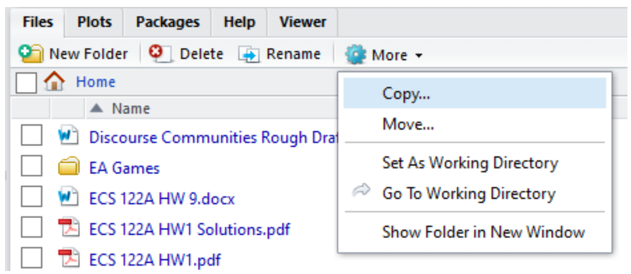
4.1 *Assuming the most recent version of R is already installed, simply go to the project directory via terminal then execute the following commands:*

```
R
source("riverbuilder.r")
riverbuilder(<file name>)
```

4.2 *On RStudio, first establish the working directory. This can be done by clicking the "…" button on the far right of the interface, as shown in the next page.*



A window will pop up in which the user must browse for and select a working directory. Choose the project directory, then click “OK”. Next, click the “More” tab on the interface, then the “Set As Working Directory” option. The project directory is now established as the working directory. Execute the commands ‘source(“riverbuilder.r”)’ then ‘riverbuilder(<file name>)’ on RStudio’s command line, and the program will run.



5 HOW TO USE IT

Define reach-average variables with numerical values and sub-variability parameters with functions. The default input text file has pre-defined, acceptable minimum values for the program to function correctly. For full assurance, the user must follow the guidelines specified at the top of the text file. Once the program is run, a prompt appears that tells the user to specify the name of the text file in the current directory to be processed. Several messages will appear on the terminal to indicate the status of the program as well as what CSV and PNG files are generated in the current directory.

6 PROGRAM OUTPUTS

BoundaryPoints.csv
Contains keys that map to specific points in CartesianCoordinates.csv that comprise the boundary around a river’s floodplain. This is an essential input file for ArcGIS.

CartesianCoordinates.csv
Contains comma-separated XYZ coordinates for the synthetic river valley. This is an essential input file for ArcGIS.

Data.csv
Contains coefficients of variation, averages, standard deviations, channel slope, and other important information.

ChannelElevation.png

Displays the elevation of the river's channel meander.

CrossSection.png
Displays the river's cross section at its midway point. The cross section is bounded above by the river's bank top and below by the thalweg.

GCS.png
Displays the geometric covariance structures of: bankfull width and thalweg elevation; thalweg elevation and the channel meander.

LongitudinalProfile.png
Displays the side view of the river which consists of valley top, valley floor, bank top, and thalweg elevation.

Planform.png
Displays the bird's eye view of the river which consists of the channel meander, channel bank, valley floor, and valley top.

7 PARAMETERS AND INPUTS

7.1 Domain Parameters (in meters)

- Datum – a fixed starting point of operation to measure changes of a specific property. Used for thalweg elevation. Input must be a real number.
- Length – the x-axis of the river. Input must be a positive real number.

7.2 Dimensionless Parameters

- Valley Slope – the slope along the X-Z plane used to calculate the overall channel slope with a given sinuosity and govern the incline/decline of the surrounding valley. Input must be a real number.
- Slope – the slope along the X-Z plane used for thalweg elevations. Input must be a real number.
- Critical Shields stress – amount of force necessary to move a particle of the river bed. Input must be a positive real number.
- X-Y Increments – the number of data points along the X-Y plane for the channel. Input must be a positive integer greater than 1.
- Y-Z Increments – the number of data points along the Y-Z plane for the cross section. Input must be a positive integer greater than 1.

7.3 Channel Parameters (in meters)

- Bankfull Width – the value around which the distance between the bank tops on the X-Y plane is based. Input must be a positive real number.
- Bankfull Width Minimum – the minimum distance between the bank tops on the X-Y plane. Input must be a positive real number.
- Bankfull Depth – the value around which the distance between the bank top and thalweg on the X-Z plane is based. Input must be a positive real number.
- Median Sediment Size – the particle size of the material comprising the river bed. Input must be a positive real number.

7.4 *Floodplain Parameters (in meters)*

- Top Height – the elevation distance between the valley floors and valley tops. Input must be a real number.
- Bottom Width Offset – the distance between the channel banks and valley floors on the X-Y plane. Input must be a real number.
- Top Width Offset – the distance between the valley floors and valley tops on the X-Y plane. Input must be a real number.
- Bottom Height – the elevation distance between the bank tops and valley floors. Input must be a real number.
- Boundary Width – an offset to produce an extra boundary beyond the valley top for Cartesian coordinates. Input must be a non-negative real number.
-

7.5 *Cross-Sectional Shape*

- The shape of the cross section on the Y-Z plane. Input must be AU, SU, or TZ(n), where n is the number of edges that defines the length of the trapezoidal base such that $0 \leq n \leq$ (Y-Z Increments).
-

7.6 *Sub-Variability Parameters – all inputs must be user-defined functions.*

- Meandering Centerline – governs the shape of the river bend on the X-Y plane.
- Channel Elevation – governs the shape of the river bend on the X-Z plane.
- Bankfull Width – distance between the channel meander and bank tops on the X-Y plane.
- Thalweg Elevation – elevations of the river bed on the X-Z plane.
- Left/Right Floodplains – valley floors and tops that surround the river.

8 How the Text File is Processed

The program parses the text file line by line. In each line, every parameter has a value associated with it by the usage of '='. As stated in the guidelines at the top of the text file, to ensure the program functions, no parameter should be left blank. It is important to note that anything after the symbol '#' on a given line will not be read in by the program, so the user can make use of this to add any desirable notes/comments anywhere on the text file.

8.1 *Domain, Dimensionless, Channel, Floodplain Parameters*

These are read in by the program in a specific order, so the order of these sections and parameters must not be modified in the text file.

8.2 *Sub-Variability Parameters*

These are read in by the program not according to a specific order of parameters, but to the parameter names themselves, which serve as keys to specific river properties. Users can define their own functions each with specified values and assign however many functions they want to any sub-variability parameter. For example, if the user wants to add another function to the meandering centerline, he/she must simply add the line "Meandering Centerline Function=<some function>" below the current list of functions for the meandering centerline.

The only restrictions for the sub-variability parameters are:

- The first channel elevation function for just the asymmetric U-shape *must* be a sine function. The reason for this is that the channel elevation is computed by taking the first and second derivative values of the sine function at a given amplitude, frequency, and phase shift for the asymmetric U-shape only.

- The first function of every sub-variability property must be periodic (sine, cosine, sine^2) (this applies to channel elevation as well if the cross-sectional shape is *not* an asymmetric U). This is because some parameters for Data.csv rely on amplitudes and frequencies to be specified. If the user wishes to not actually use a periodic function for a given property while ensuring Data.csv is produced, he/she can simply define the first periodic function with zero amplitude and a non-zero frequency. The default text file “Input.txt” already does this.

9 User-Defined Functions

9.1 List of Available Functions

- Sine – amplitude, frequency, and phase shift must be defined in the form:
    - SIN#=SIN(a, f, ps).
- Cosine – amplitude, frequency, and phase shift must be defined in the form:
    - COS=COS#(a, f, ps).
- Sine^2 – amplitude, frequency, and phase shift must be defined in the form:
    - SIN_SQ#=SIN_SQ(a, f, ps)
- Linear – slope and y-intercept must be defined in the form:
    - LINE=LINE#(s, y).
- Perlin noise – amplitude and wavelength must be defined in the form:
    - PERL=PERL#(a, w).
    -

9.2 How to Assign Functions

In general, amplitude controls the amount displaced from the horizontal axis, while both frequency and wavelength govern the frequency of oscillations present in a wave.
The ‘#’ is a placeholder for a positive integer for assigning a unique set of parameter values to a function variable (ex: SIN1, COS3, LINE2, etc). There are two ways to assign a function to a sub-variability parameter:

1) Define a function variable with a specific function and parameter values, then assign it to a sub-variability parameter. Suppose SIN5=SIN(20, 4, PI/2). To use this function for, say, the meandering centerline, the user must make the following assignment:

   Meandering Centerline Function=SIN5

2) Assign a function directly without the need to define his/her own function variable beforehand, like so:

   Meandering Centerline Function=SIN(20, 4, PI/2)

Note: **Do not modify the names of the following parameter names in the input text files** (doing so will result in failure to use the functions or values correctly):

Cross-Sectional Shape
Meandering Centerline Function
Channel Elevation Function
Bankfull Width Function
Thalweg Elevation Function
Left Floodplain Function
Right Floodplain Function

10 Generating 3D Renderings in ArcGIS® (ArcMap®)

Below are the steps necessary to generate a 3D rendering of a river using ArcGIS® and the provided Python script:

1. Open ArcMap®. Look for the "Catalog" tab on the far right of the interface. If it does not show, go to Windows -> Catalog from the top menu to have it opened.
2. In Catalog, locate the directory in which the River Builder toolbox is stored. If the directory is not visible, select "Connect to Folder" from the Catalog toolbar, and select the desired directory.
3. Once the desired directory is visible in Catalog, expand the toolbox it contains, right-click the "River Builder" tool, and go to Properties. Under the Source tab, enter the location of where the Python script "RiverBuilder.py" is stored in your local machine. Click OK.
4. The River Builder tool is now available for use on ArcMap. Select it, and a window will appear. Enter values for the following four inputs:

- Name: The label applied to each output file, i.e. <Name>_Layer.shp, <Name>_Boundary.shp, etc.
- Output Folder: The location in which an output folder named <Name> will be produced. That folder will contain all the output files generated by the script.
- XYZ File: The Cartesian coordinates file produced by the R program.
- Boundary Points: The boundary points file produced by the R program.

5. When all the inputs are filled, click OK, and the script will run. After it is finished running, go to the <Name> folder in the output folder that you specified to access the newly generated shape and raster files.

11 Acknowledgements

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12 References

Brown, R. A., Pasternack, G. B. 2014. Hydrologic and topographic variability modulate channel change in mountain rivers. Journal of Hydrology 510: 551-564.

Brown, R. A., Pasternack, G. B. 2017. Bed and width oscillations form coherent patterns in a partially confined, regulated gravel–cobble-bedded river adjusting to anthropogenic disturbances, Earth Surface Dynamics, 5, 1-20, doi:10.5194/esurf-5-1-2017.

Brown, R. A., Pasternack, G. B., Lin, T. 2015. The topographic design of river channels for form-process linkages for river restoration. Environmental Management, 57 (4): 929-942. doi: 10.1007/s00267-015-0648-0

Brown, R. A., Pasternack, G. B., Wallender, W. W. 2014. Synthetic river valleys: creating prescribed topography for form-process inquiry and river rehabilitation design. Geomorphology 214: 40-55. 10.1016/j.geomorph.2014.02.025.

Lane, B.A., Pasternack, G.B., Dahlke, H.E., Sandoval-Solis, S. 2017. The role of topographic variability in river channel classification. Physical Progress in Geography. 18 doi:10.1177/0309133317718133.