

STREAM MODULES: SPREADSHEET TOOLS FOR RIVER EVALUATION, ASSESSMENT AND MONITORING^{**}

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Abstract

Stream physical condition is increasingly a priority for resource managers. Assessment, monitoring and restoration techniques continue to be developed and standardized. Toward these ends a suite of spreadsheet tools, the STREAM Modules, has been developed by the Ohio Department of Natural Resources and Ohio State University. This ongoing project began in 1998 and currently freely provides the following modules: 1) *Reference Reach Spreadsheet* for reducing channel survey data and calculating basic bankfull hydraulic characteristics, 2) *Regime Equations* for determining the dimensions of typical channel form, 3) *Meander Pattern* that dimensions a simple arc and line best fit of the sine-generated curve, 4) *Cross-section and Profile* that can be used to illustrate the difference between existing and proposed channel form, 5) *Sediment Equations* which includes expanded and condensed forms of critical dimensionless shear, boundary roughness and common bed load equations, and finally 6) *Contrasting Channels* that computes hydraulic and bed load characteristics in a side-by-side comparison of two channels of different user defined forms.

KEYWORDS. fluvial geomorphology, stream, channel, morphology, survey, monitoring, assessment

Introduction

The objective of this paper is to provide an overview of a suite of spreadsheet tools that the author's have developed to aid in the analysis of stream form and processes.

Stream geomorphology, or the forming of land by streams, occurs because of a series of complex processes that are not easily described by scientific theories. The most basic concept is that of force and resistance. Running water exerts force on the landscape and, in turn, the landscape offers resistance to this force. If the exerted force is less than the resistance, there is no change. If, the force is greater than the resistance, there is change to the slope or stream channel. We call this change geomorphic work. A poor understanding of these processes and inadequate consideration of the influence of changes that occur on the landscape and within the floodplain

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can cause a variety of adverse outcomes. Particular attention needs to be paid to the potential impact on a stream of: (a) land use changes that reduce vegetation and increase the amount of impervious area; (b) activities that modify the floodplain; (c) the construction of culverts and bridges; and (d) activities that are designed to modify the characteristics of the main stream channel. Any one of these activities might disrupt the equilibrium resulting in rapid and often undesirable adjustments. Successful stream stewardship requires combining this knowledge with sound engineering and scientific principles, together with an understanding and appreciation of the ecology of the stream and its interaction with the landscape (Ward and Trimble, 2003).

Stream channels and the landscape are shaped by erosional and depositional processes that occur across a wide range of spatial and temporal scales. Therefore, if we want to develop strategies to protect, enhance or sustain these complex systems it is important to understand the origin and evolution of a stream system. It is also important to understand the scales at which changes have or will occur. This change might occur rapidly over a few weeks, months, or years. In other cases perceived instability and channel change might simply be part of the natural cycle of channel adjustment and movement that has occurred over centuries. There is also a need to understand that different scales might apply to different aspects of the ecosystem.

Perhaps because of the complexity of stream and watershed processes, and the variability of scales that can influence these processes, there is not universal agreement on theory, evolution processes, and whether stream behavior can be predicted by morphology. Rosgen (1994, 1996) proposed a hierarchy of river morphology. He divided his classification approach into the following four levels:

- Level I: Geomorphic characterization that integrates basin topography, land form and valley morphology. At a coarse scale the dimension, pattern, and profile are used to delineate stream types.
- Level II: Morphological description that is based on field-determined reference reach information.
- Level III: Stream “state” or condition as it relates to its stability, response potential, and function.
- Level IV: Validation level at which measurements are made to verify process relationships.

Many other classification methods have been developed (Ward and Trimble, 2003) but they have seen limited application in engineering design. Insight on the uses and limitations of using geomorphological stream classification in aquatic habitat restoration is presented by Kondolf (1995). Montgomery and MacDonald (2002) propose a “*Diagnostic Approach to Stream Channel Assessment and Monitoring*” and note “*Our argument is based on the observation that a particular indicator or measurement of stream channel conditions can mean different things depending upon the local geomorphic context and history of the channel in question.*” The method requires the collection of a comprehensive set of information on a reach and a high level of expertise to be able to then use the data to make a diagnosis. The same statement applies to Level II, III, and IV Rosgen studies. We believe that regardless of the approach that might be used all stream assessments, designs, and management strategies should be based on extensive knowledge of stream processes. This will require the expertise and resources to make extensive measurements within the stream and watershed system and the ability to analyze the data to aid

in developing an appropriate self-sustaining strategy. With this view in mind we have developed a suite of spreadsheet tools to aid in the analysis of much of the data that we believe should be obtained. Typically, it will be necessary to use several of the tools and it is important to recognize that the tools do not replace the need for an interdisciplinary team of experts to make the measurements and to analyze the outputs from the tools. Also, it is probable that it will be necessary to also use other tools in developing a self-sustaining solution.

STREAM MODULES

The STREAM modules, are a suite of spreadsheets that as the acronym implies are **S**preadsheet **T**ools for **R**iver **E**valuation, **A**ssessment and **M**onitoring. In developing these tools the author's had the following objectives: (1) to help facilitate the activities listed in the acronym by being consistent with standard or commonly used techniques; (2) to "crunch" numbers and draw plots that at times can be laborious; (3) to present some rather challenging techniques in a more understandable way; and (4) to create educational tools. Embedded in the tools are details on the equations and theory that are used to generate the reported outputs. Therefore, in this paper we will only present an overview of the purpose of each tool. Example outputs are presented for a location on Blacklick Creek in Ohio. The Blacklick Creek flows through the eastern side of Franklin County and the western sides of Licking and Fairfield Counties Ohio. It is a tributary to the Big Walnut Creek that ultimately drains to the Scioto River. The Blacklick Creek drainage area is twenty-two square miles at the location illustrated in this paper.

The modules are grouped in two sets, the first one dealing with channel form and the second with fluvial process. Channel form (dimension, pattern, profile, and bed material) can be relatively easily seen and measured. A module is included for a reach survey, for organizing and then representing channel form from the extensive amount of data that are normally obtained during a geomorphological survey of a specific channel reach. Another approach to studying stream form is to use measured data in conjunction with relationships developed from big databases of channel form measured by others, often called the *regime approach*. Several sets of these empirical equations are organized together in a spreadsheet module. One of the more challenging tasks regarding channel form is to define and communicate not only what may exist but what are desired target or design conditions. Two modules have been developed specifically to help with this task.

The second set of modules, dealing with fluvial process, includes standard hydraulic and sediment transport equations but here too an effort has been made to illustrate and aid in communicating implications of channel process. Typically, in the United States measurements are made using English units but for applications in other countries and for research purposes the STREAM modules provide an option to use SI units.

Channel Form

Measure what is there: **The Reference Reach Spreadsheet (RRSS)**

Surveying an existing channel is perhaps the most illuminating single step toward understanding the physical aspects of a stream. *Reference Reach Spreadsheet* is for reducing channel survey

data and calculating basic bankfull hydraulic characteristics. It is generally consistent with the closest we have to a standard protocol as documented by Harrelson et al. (1994). Data may be either in the form collected with a level or a total station. In the survey the profile serves as a framework or base line. The profile, or longitudinal slope profile is measured from upstream down along the centerline of the bankfull channel. At each station, bed elevation in the thalweg, water depth, and bankfull elevation are recorded. If a point is measured at the beginning of each bed feature the spreadsheet will provide the average length and slope of the features. Also, by identifying the interception point of the profile with each of the cross-sections allows the instrument height and bankfull elevation information to link to the cross-section sheet. A profile of a reach of Blacklick Creek is presented in Figure 1.

Bed material is obtained a number of different ways for a number of reasons. The materials sheet of the RRSS is set up to accommodate pebble counts and bulk sieve samples. Pebble counts can be 1) individual such as the mobile riffle surface material or a zig-zag count of a reach or 2) weighted such as between riffles and pool each representing a portion of the reach. The spreadsheet is set up to accommodate most any combination of material data collection. The standard presentation of these data is a plot of the cumulative percent, and calculated D50 etc., and percentage of the various size classes (Figure 2). Because a semi-log scale is typically used the mathematical solution requires interpolation of the logs of the size values to get the various “percent smaller than” values.

Pattern is the dimension least well defined by a site survey. Often better information can be obtained by area photos, GIS, even topographic maps, all of which allow a greater length to be assessed. This information can be entered in the RRSS. Also, while surveying the profile with a tape and level, if an azimuth is obtained and entered with each corresponding distance then that information will be reduced and presented in plan form. In addition the water depth information is represented on the plan view allowing an interesting perspective of pool and riffle location through the meander pattern.

Cross-sections are plotted (Figure 3) and various bankfull channel dimensions are calculated including area, width, mean and maximum depth, etc. Determining bankfull location is of course necessary but is also one of the most challenging tasks in geomorphology. The RRSS facilitates the determination of bankfull a number of ways. First, using cross-sections in conjunction with the channel profile is an established standard method for this task. The spreadsheet links the profile to the cross-section. The stage at which a bankfull-trend line from the profile intersects each cross section provides a first iteration of the bankfull stage at each cross section. Refinement of the value can be based on local trends in the profile and details of the cross-section.

Another approach to determining bankfull that is utilized in the spreadsheet is based on the idea that in gravel bed channels the particle at the threshold of motion at bankfull flow is often near the measured D50. Using Shield’s parameter the spreadsheet computes the size at the threshold of motion and presents it with the D50 and D84 values for comparison.

Each cross-section has calculated values for several standard dimensions and hydraulics from width-depth ratios, discharge, shear stress and unit stream power. All the equations used in the spreadsheet are explained in comments attached to each cell. To manage the information obtained from a channel survey values are typically reduced to dimensionless ratios. This also

facilitates comparisons between channels, particularly of different size. The spreadsheet provides a summary of all the sheets including an average and range of all values.

Typical values measured by others - Regime Equations

Another way to understand channel form is to consider typical values measured from many streams. Like dimensionless ratios, this information is usually presented in the form of relationships between variables. Several sources exist; perhaps the most extensive are the Williams equations (Williams, 1986). Richard Hey (Thorne et al., also developed a set of regime equations and Luna Leopold (Leopold and Langbein, 1966) defined some classic meander pattern relationships. These and others are in the Regime module. A refinement of this approach is a breakdown of typical values by channel types. This is not presently available in the STREAM Modules but is in Applied Stream Morphology (Rosgen, 1996). Table 1, illustrates some results for the Blacklick Creek reach. This sort of information can provide a reassuring check of measured values or be an indicator of a problem if measured values fall outside the range of typical values. At best regime equations must be considered coarse approximations.

Defining and communicating channel form – Pattern and Cross-section & Profile

The desired channel form must be illustrated and conveyed for construction documents, planning discussion, etc. Two modules have been developed to help with defining and communicating proposed condition.

The first, the **Meander Pattern** module, simply dimensions channel meander pattern. It is based on the sound but awkward sine-generated curve, which is a function of the continuously changing direction of flow. By first integrating the sine-generated curve then calculating a best fit of arcs and straight lines, standard dimensions are presented including amplitude, radius of curvature and meander length (Figure 4).

The second module, describing channel form, contrasts existing and desired cross-sections. In the module, **Cross-section & Profile**, the desired channel dimensions are represented by a compound cross-section, the proportions of which are adjustable values based on a regional curve. A profile may be used for tracking elevation of proposed cross-sections but is not necessary. Survey data of existing cross-sections is entered and plotted with the desired cross-section (Figure 5). The plots are especially useful for illustrating desired floodplain form. They may be adequate as construction drawings for simple restoration involving lowering high terraces down to active floodplain. They have been proven useful in two-stage ditch design projects and in discussions of channel evolution.

Channel Process

Unlike channel form which is conceptually simple, channel process is complex, particularly the process most influential in channel form, bed load sediment movement. Two modules have been developed to make some approaches to understanding channel process more accessible. The first module, **Sediment Equations**, has three different sheets with various equations pertaining to channel process one dealing with critical dimensionless shear (Figure 6), another on relative roughness and boundary resistance and the last on bed load equations (Figure 7). The

equations are presented in both an expanded format with explanations and constants shown and then in a condensed format with only input cells and answers.

The second channel process module, **Contrasting Channels**, is an application of the first. It allows a side-by-side comparison of processes given different channel forms or runoff conditions. The main strength of this module is its evaluation of an entire flow regime rather than a single surrogate stage or recurrence interval. Hydrology models developed by USGS (Koltun and Roberts, 1990; Sherwood, 1994) are built into the spreadsheet and may be used or peak discharge values from another source may be entered. Hydrographs for a series of recurrence interval storms (0.2 to 100 years) are developed. Bed load sediment is calculated by dividing the hydrographs into steps of given conditions existing for specific durations. Each runoff event is then multiplied by the number of occurrences of over a 100-year period. The calculations are performed for both channels. The results are presented by contrasting the peak flow stage of the range of runoff events as well as the calculated bed load sediment movement (Figure 8).

DISCUSSION & CONCLUSIONS

The STREAM Modules serve several needs in the area of assessing the physical quality of rivers. They provide an additional step toward standardization of methods and techniques. Also, they have application in education and in increasing the utility of methods and techniques. They can be applied to further understanding of channel form, fluvial processes and the role these play in the integrity of water resources. The existing modules are by no means a complete set of tools. The author's have developed a variety of miscellaneous tools such as a tool for determining the effective discharge (Ward and Trimble, 2003) from measured sediment data and a set of tools for evaluating different storm water management strategies. Others have developed more powerful sediment transport and bank stability models that have more extensive stream and watershed measurement requirements.

REFERENCES

- Einstein, H. A., 1950. The Bed-Load Function for Sediment Transportation in Open Channel Flow. USDA SCS, Technical Bulletin 1026, Washington D.C., pp 71.
- Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. USDA Forest Service, General Technical Report RM-245, Fort Collins, Colorado, 62 pp.
- Hey, R.D., 1976, Geometry of river meanders, *Nature*, 262, 482-484.
- Koltun, G.F. and J.W.Roberts. 1990. Techniques for Estimating Flood-Peak Discharges of Rural, Unregulated Streams in Ohio. U.S. Geological Survey, Water Resources Investigations Report 89-4126, USGS Denver, CO.
- Landwehr, K. and B. Rhoads. 2003. Depositional Response of a Headwater Stream to Channelization, East Central Illinois, USA. *River Research and Applications*, 19:77-100.

Leopold, L. B. and Langbein, W. B., 1966, River meanders; Scientific American, June, pp. 60-69.

Rosgen, D., 1994. A Classification of natural Rivers. *Catena* 22: 169-199.

Rosgen, D., 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado.

Sherwood, J.M. 1994. Estimation of Volume-Duration-Frequency Relations of Ungaged Small Urban Streams in Ohio. *AWRA Water Resources Bulletin* 30(2):261-269.

Thorne, C. R., R. Hey, M. Newson. 1997. Applied Fluvial Geomorphology for River Engineering and Management. John Wiley & Sons.

Ward, A. and S. Trimble. 2003. Environmental Hydrology 2nd Edition. CRC Press.

Williams, G. P., 1986. River Meanders and Channel Size. *Journal of Hydrology*, 88:147-164.

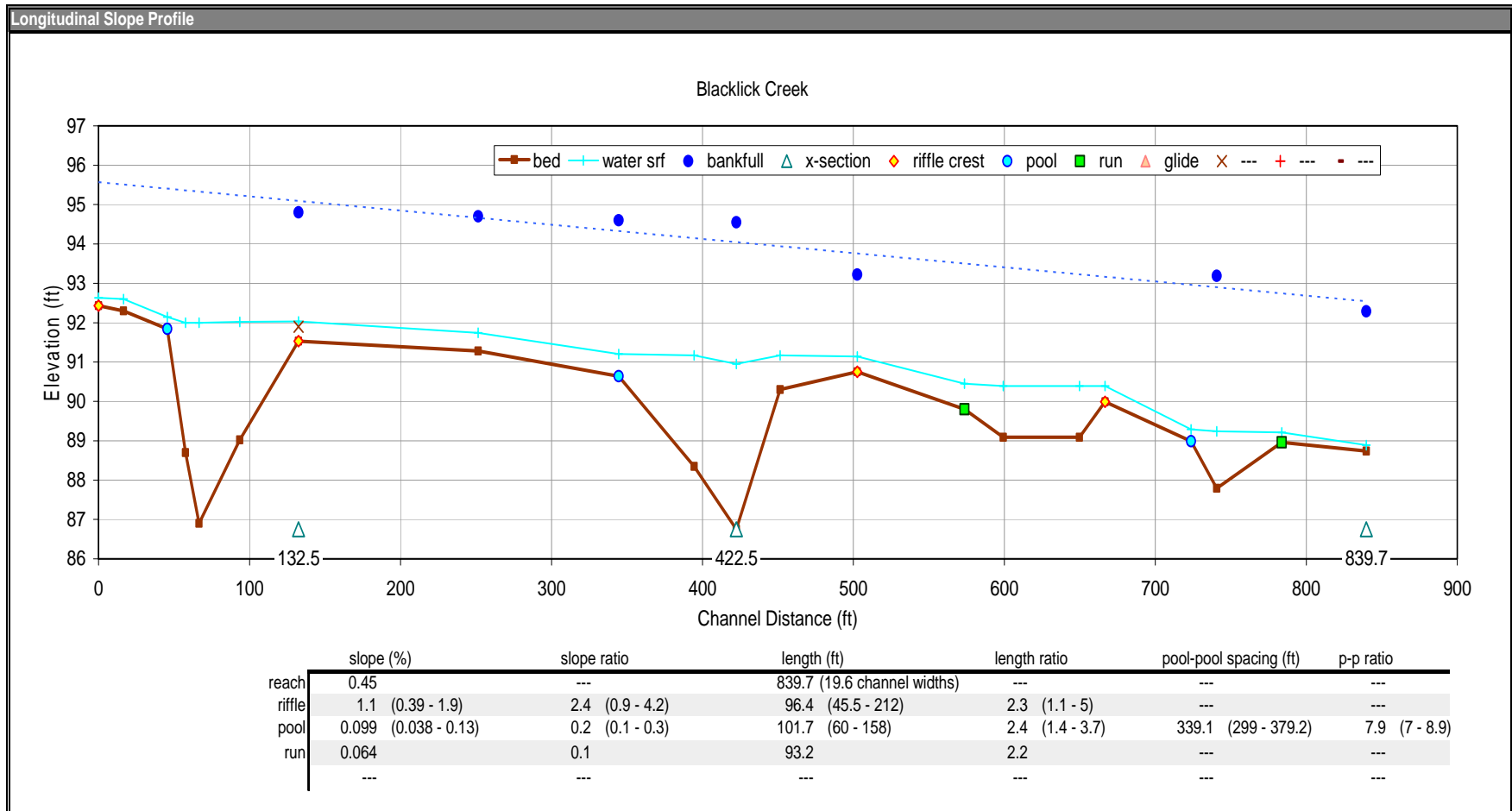


Figure1. Example profile output from the *Reference Reach Spreadsheet*.

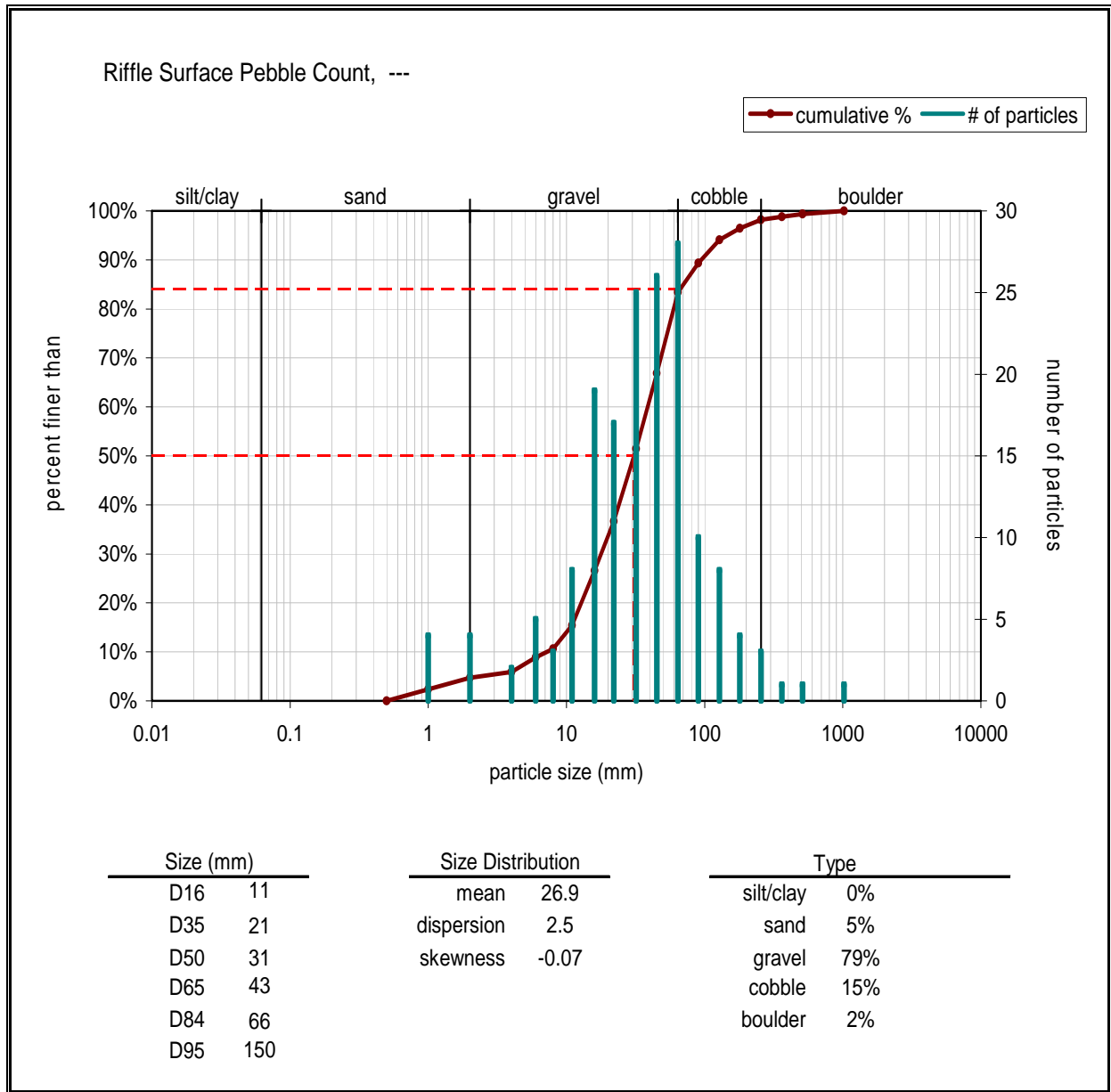


Figure 2. Example channel materials output from the *Reference Reach Spreadsheet*.

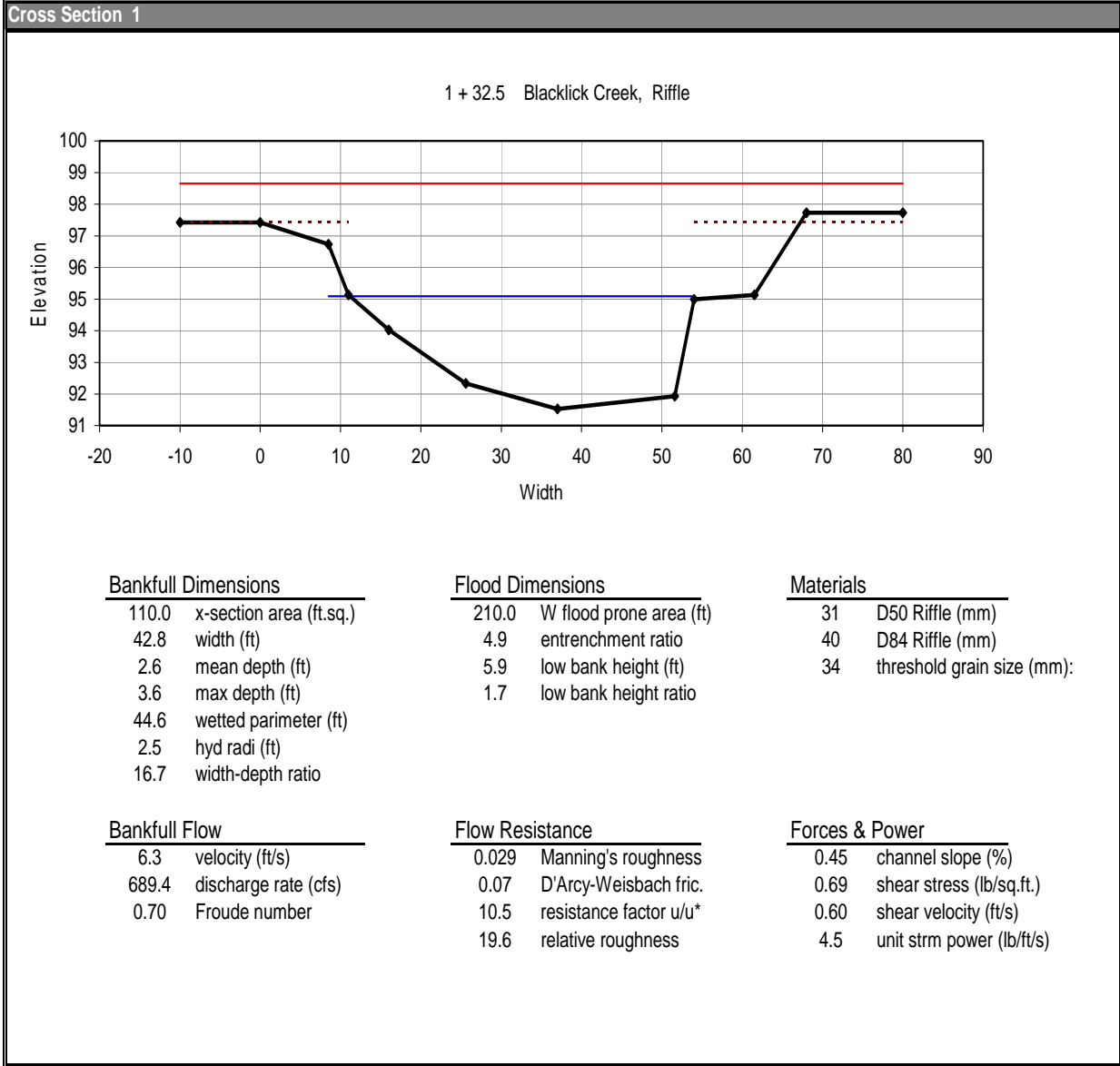


Figure 3. Example cross section output of the Reference Reach Spreadsheet module.

William's "River Meanders and Channel Size"

Mid values are from equations fit to 41 to 191 data points. Low and high values are from the standard deviation of residuals not the extremes.

Source: Williams, G.P., 1986. River meanders and channel size. Journal of Hydrology, 88 pp.147-164

Meander Pattern from Bankfull Dimension	Input	meander length			belt width			radius of curvature			length bend		
cross-section area	150	344	545	867	209	327	510	61	106	187	228	400	708
width	50	317	520	858	172	296	515	68	104	161	215	352	580
mean depth	3	281	685	1658	200	425	914	46	122	324	201	457	104
													1
Depth from Width or from Width and Sinuosity		meander depth											
	width	50	1.3	2.5	4.9								
	sinuosity (and entered width)	1.3	1.3	2.2	3.8								
Width from Depth or from Depth and Sinuosity		width											
	mean depth	3	23	62	160								
	sinuosity (and entered mean depth)	1.3	68	152	336								
Bankfull Dimension from Meander Pattern		area			width			mean depth					
	meander length	500	62.1	126.6	257.1	30.7	48.0	74.8	1.3	2.4	4.3		
	beltwidth	300	66.0	129.5	255.1	30.3	49.7	80.9	1.4	2.4	3.9		
	radius of curvature	100	56.4	134.3	319.7	33.2	48.8	72.2	1.4	2.6	5.0		
	length bend	400	59.9	142.7	342.4	34.4	53.8	83.9	1.6	2.8	4.8		
Meander Pattern Relations		meander length			belt width			radius of curvature			length bend		
	meander length	500			232	305	400	91	110	133	304	400	528
	beltwidth	300	372	489	640			74	105	149	294	387	507
	radius of curvature	100	376	453	548	20	288	409			279	377	509
	length bend	400	380	500	660	237	312	408	77	104	140		

Table 1. Example output from the Regime Equations module for Blacklick Creek Ohio.

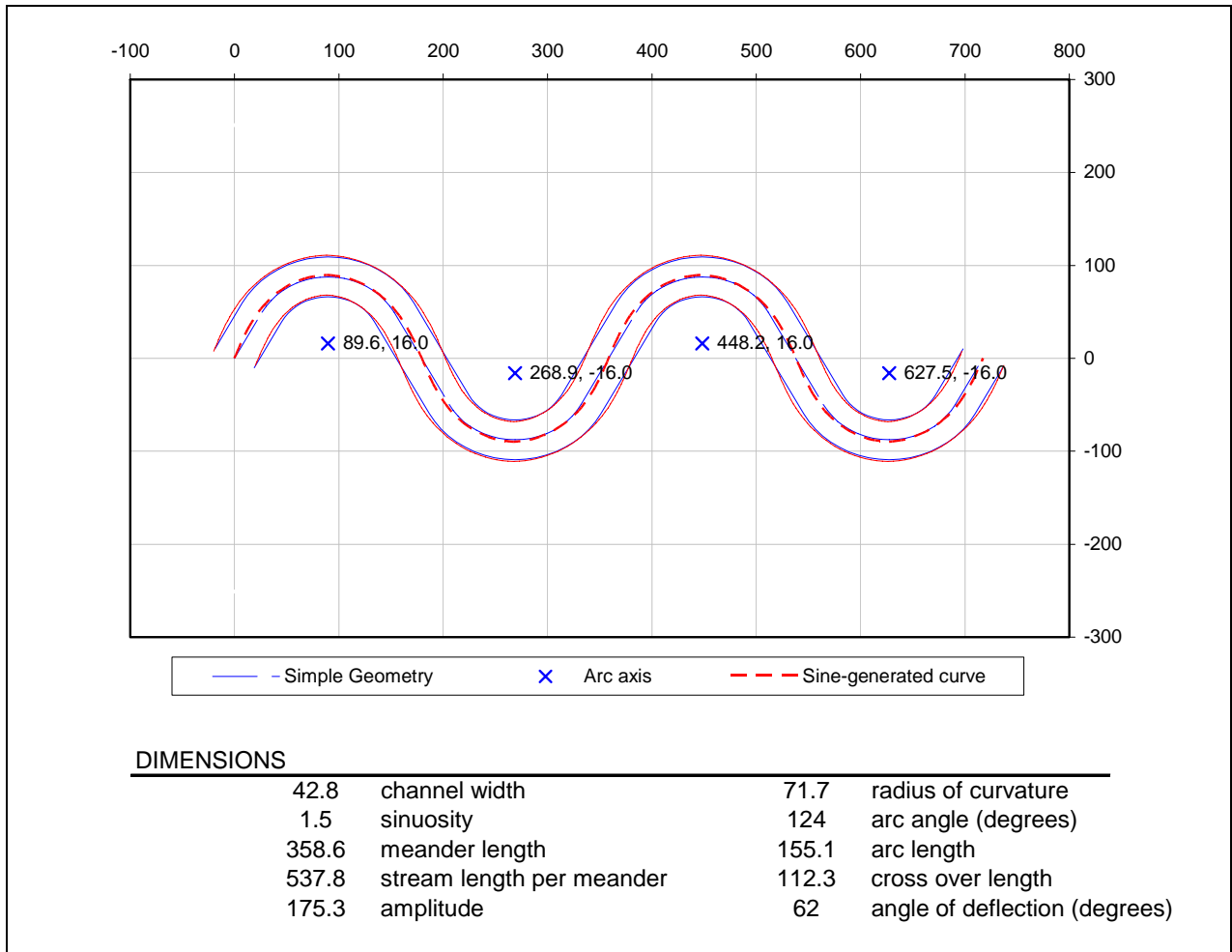


Figure 4. Example output from the *Meander Pattern* module.

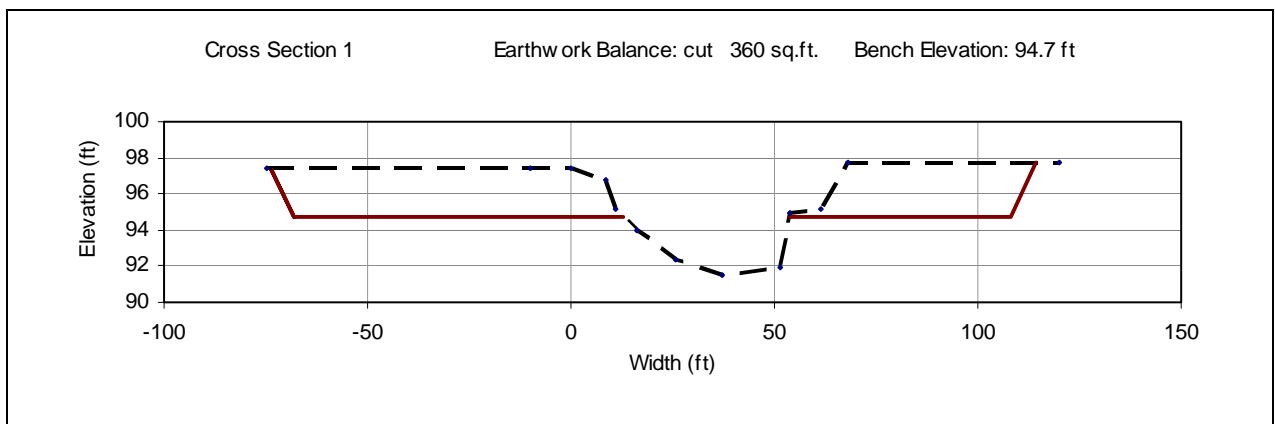


Figure 5. Example output from the *Cross Section Module* showing existing and proposed condition.

Solutions for Shield's Equation (English)				
Solve for:	Shields parameter	slope (ft/ft)	depth (ft)	particle size (mm)
Shield's Parameter	0.070	0.0045	2.6	31
slope (ft/ft)	0.06	0.0039	2.6	31
depth (ft)	0.06	0.0045	2.246	31
particle size (mm)	0.06	0.0045	2.6	36

Figure 6. Example of Shield's Eq from the *Sediment Equations* Module.

Ackers and White	Meyer-Peter	Einstein ₅₀
depth 2.6 ft	depth 2.6 ft	depth 2.6 ft
slope 0.0045 ft/ft	slope 0.45 %	slope 0.0045 ft/ft
D ₃₅ 21 mm	D ₅₀ 31 mm	D ₅₀ 31 mm
n 0.034	Φ 0.019	Φ 0.019
q _b 0.00067 ft ³ /s per foot width	q _s 0.0064 ft ³ /s per foot width	q _s 0.00439 ft ³ /s per foot width

Figure 7. Example of bedload equations from the *Sediment Equations* Module.

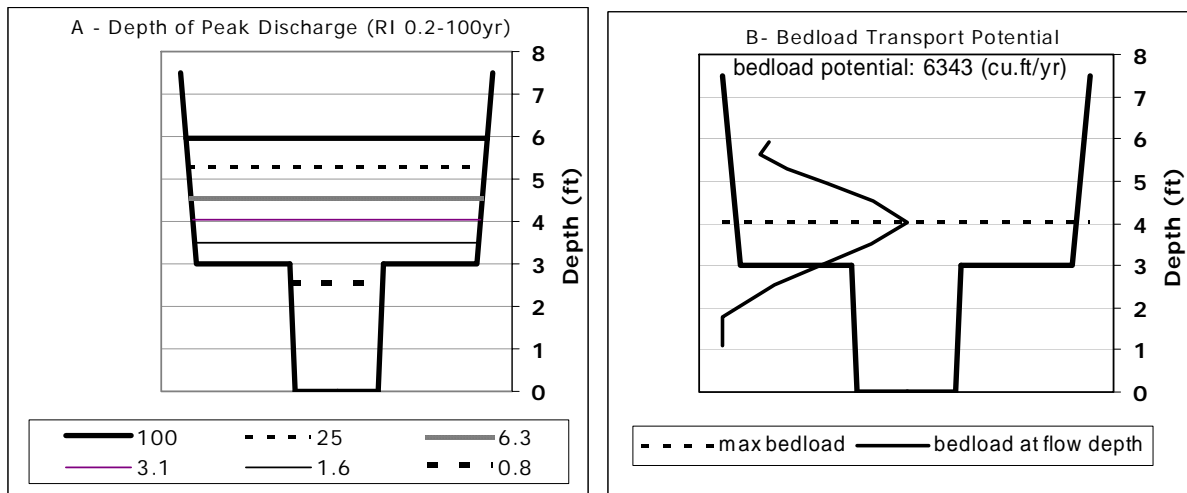


Figure 8. A. Depth of flow for different recurrence interval peak discharges suggest that the main channel can convey a discharge associated with a recurrence interval of 0.8 to 1.6 years. B. Potential bedload transport suggests the greatest bedload transport occurs at a flow greater than bankfull.