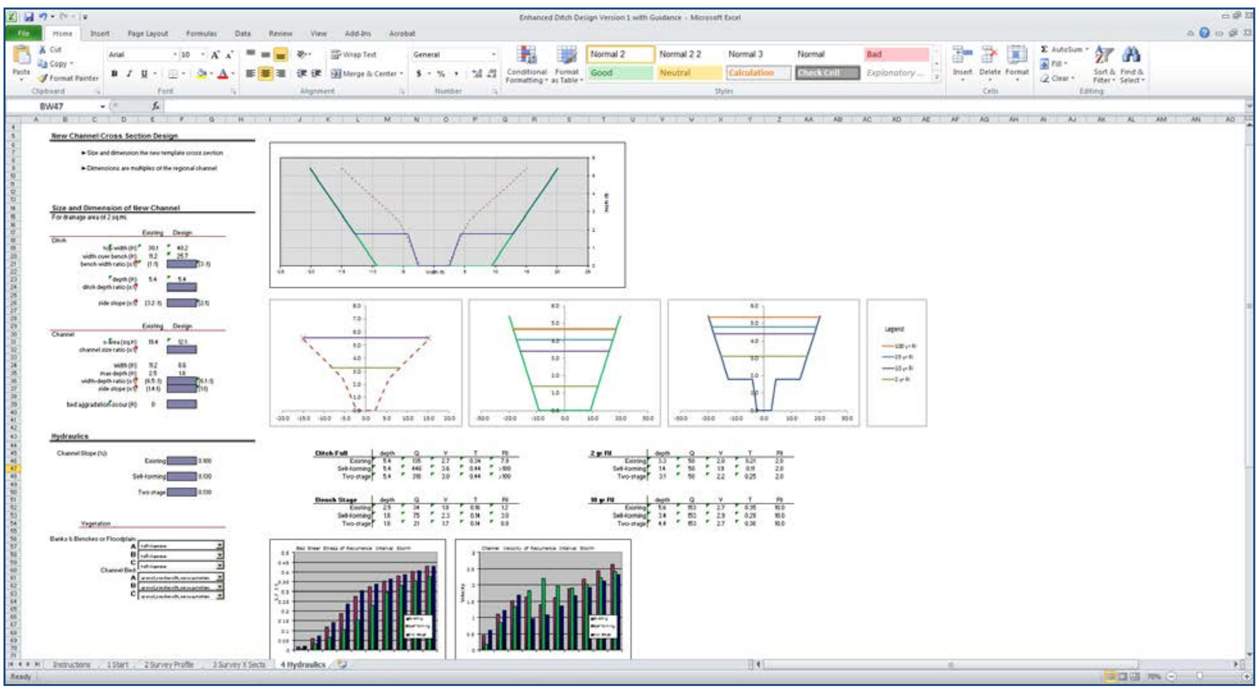
Enhanced Channel Design Version 1.0
User Guidance Manual



Jon Witter[1], Dan Mecklenburg[2], Jessica D'Ambrosio[1]

July 31, 2013

Project supported by:
Great Lakes Regional Water Program

1-Department of Food, Agricultural and Biological Engineering, The Ohio State University
2-Division of Soil and Water Resources, Ohio Department of Natural Resources

Contents

List of Figures

Introduction

The following spreadsheet tool and user guidance manual is provided as an aid to conservationists working on the design of open channels. The tool allows the user to input surveyed field data for an existing channel reach and utilizes concepts and theory from the fields of fluvial geomorphology, hydrology, and open channel hydraulics to evaluate potential alternatives to the traditional open channel design approach, which results in an incised trapezoidal geometry (Figure 1). These alternatives include the two-stage (Figure 2) and self-forming channel (Figure 3) design approaches, which attempt to reconnect the channel to an active floodplain. These designs are by no means the only options available for managing channels, but they are the focus of this spreadsheet tool and guidance. Prior to entering the design phase, an assessment of the project reach, its watershed, and the drainage network upstream and downstream of the site should be conducted to determine whether a two-stage or self-forming channel is an appropriate management approach.

Figure 1. A trapezoidal channel.

Figure 2. A two-stage ditch.

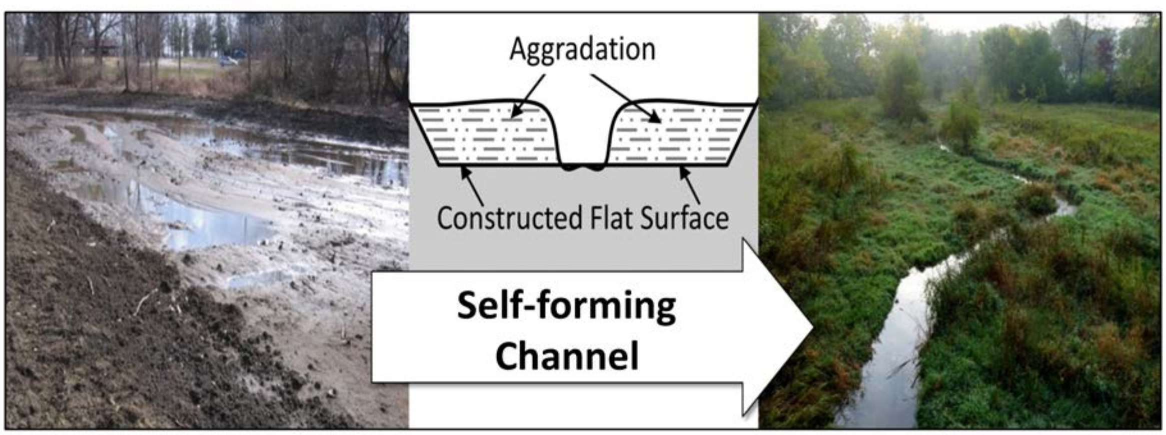


Figure 3. A self-forming channel.

The spreadsheet tool includes some common analytical methods that have been used to design two-stage and self-forming channels in low-gradient, low-energy channel systems typical of the Midwestern United States. However, the tool does not include all of the methods that might be needed to design a successful project, just some common methods that are widely used in practice. Site specific characteristics and circumstances may dictate that other methods that are beyond the capabilities of this tool are necessary and it is the responsibility of the designer to ensure that appropriate methods are employed and that risk and uncertainty are considered in the development of a design. For example, the level of design needed for a channel in a low-gradient agricultural setting in a rural area may differ from design requirements for a similar channel in a suburban setting. Many times these requirements will vary depending on local, state, and federal regulations and the requirements of authorities that administer programs that permit work in channels. Knowledge of permit needs to satisfy regulatory program requirements should be known before beginning a design.

Spreadsheet Organization

The spreadsheet, in its current version (Version 1.0), is a collection of ten worksheets including five that are visible and five that are hidden from the user. The visible worksheets provide a means to input field data and return relevant calculations back to the user. Most calculations are made on hidden worksheets to reduce the complexity of visible worksheets; however, all of the hidden worksheets can be unhidden to inspect the implementation of theory. Details regarding theory used to calculate various values are typically provided in comment boxes (red triangles in the upper right corner of cells) with references to published literature. Cells that accept user input data are filled in dark blue with white text. Calculated results are presented in white cells with black text. Many results are also graphed to provide visual aids and facilitate interpretation of data and calculated values.

The visible worksheets (Figure 4) are: *Instructions*, *1 Start*, *2 Survey Profile*, *3 Survey X Sects*, and *4 Hydraulics*. The *Instruction* worksheet simply provides basic background information on the use of the spreadsheet tool. The *1 Start* worksheet (Figure 5) allows the user to define the measurement units that will be used, input information on basic watershed characteristics (e.g. drainage area, location), and make choices that will be used in the design process (e.g. selecting an appropriate regional curve relationship, basic inputs needed to make hydrology estimates). In most cases, one or more standard methods have been coded into the spreadsheet, but additional options to provide user-defined values are included if the user determines that the included methods and/or predefined empirical relationships are not appropriate for a particular project. The *2 Survey Profile* worksheet (Figure 6) allows the user to input survey data regarding the reach profile and define how the data were collected. The *3 Survey X Sects* worksheet (Figure 7) allows the user to enter data on surveyed cross sections, calculate open channel hydraulics for the existing bankfull channel and ditchfull conditions (Figure 8), and select a proposed design approach (i.e. two-stage or self-forming channel). The *4 Hydraulics* worksheet (Figure 9) provides a side-by-side comparison of a simplified representation of the existing channel and conceptual designs for standard two-stage and self-forming channels. Additional modifications to the basic two-stage and self-forming designs can be made by changing default values provided for certain channel characteristics (e.g. bench width ratio, side slope ratios). Additionally, this worksheet provides estimates of flow velocities and shear stresses across a range of frequent and infrequent flows that can be used to assess stability of the proposed designs. Detailed descriptions for each of the visible worksheets are provided in the following sections.

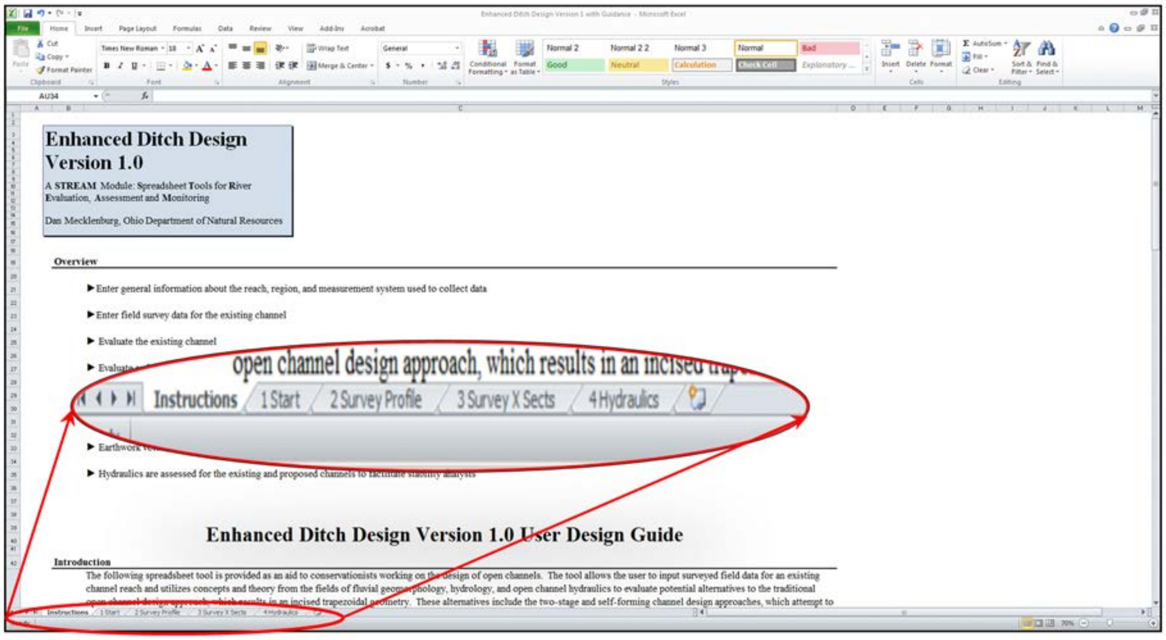


Figure 4. Design tool worksheets.

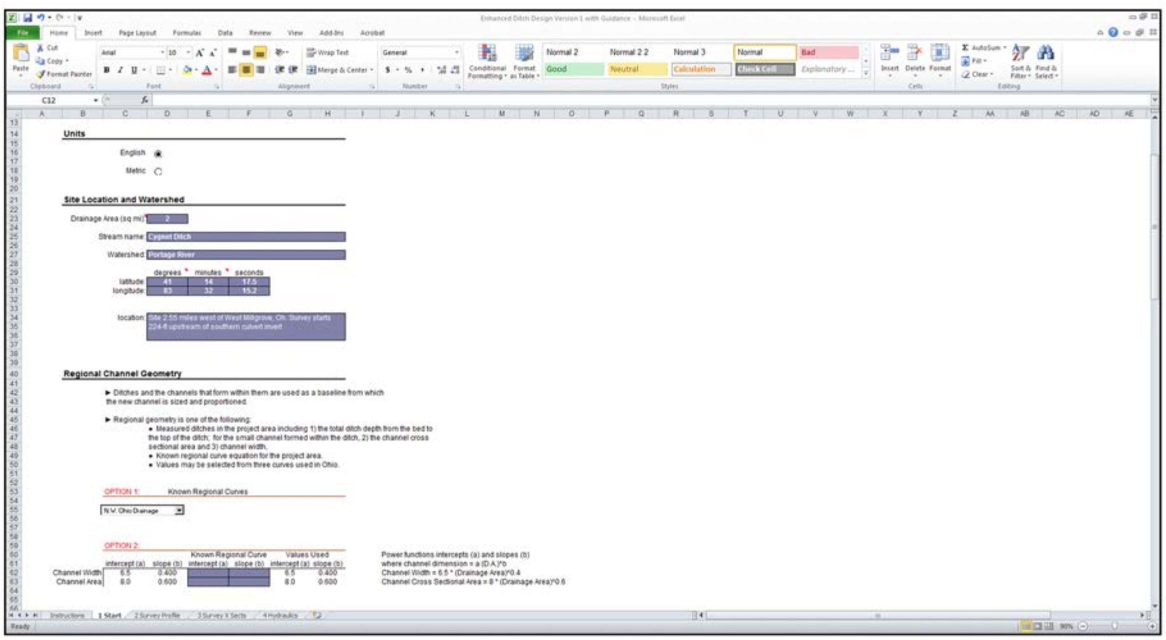


Figure 5. The 1 Start worksheet.

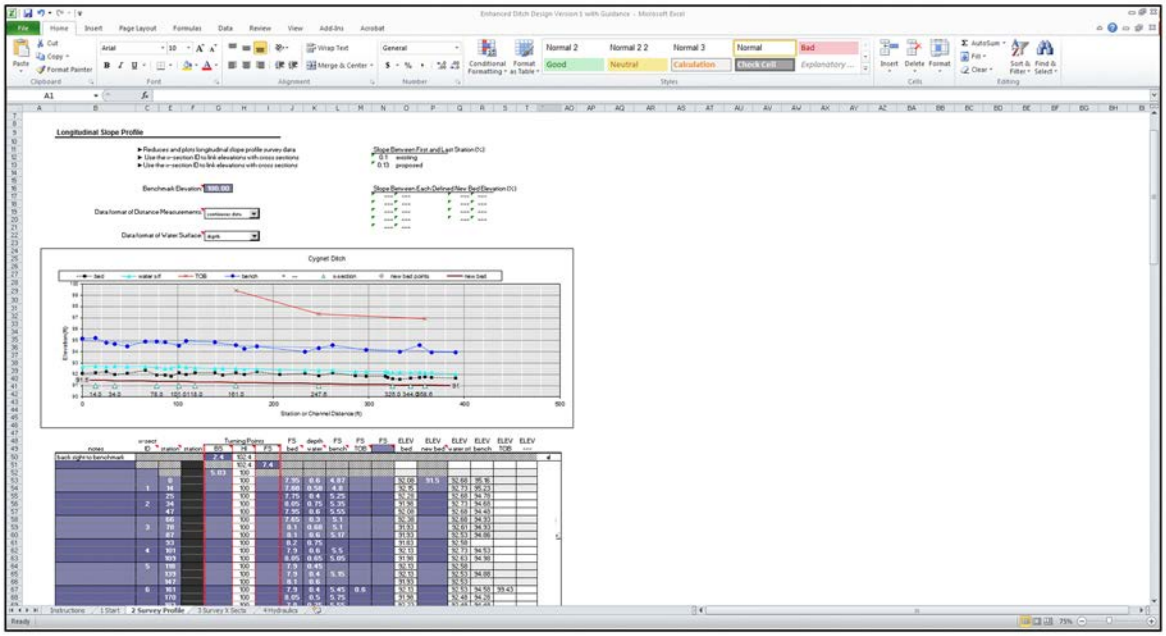


Figure 6. The 2 Survey Profile worksheet.

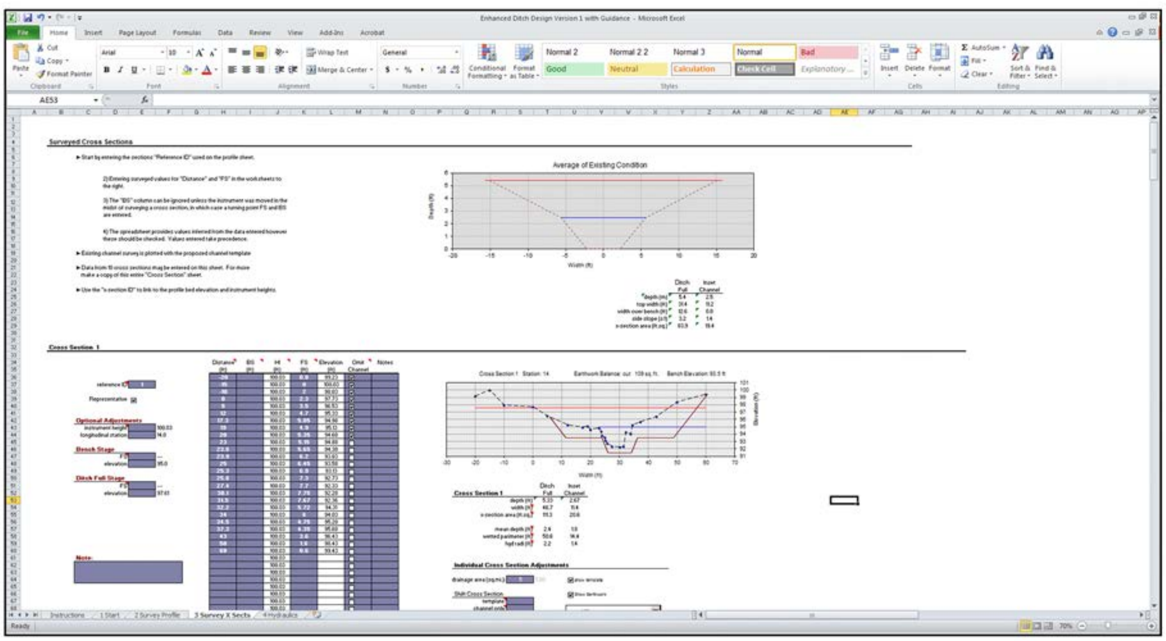


Figure 7. The 3 Survey X Sects worksheet.

Figure 8. Diagram of ditchfull and bankfull locations on a two-stage ditch.

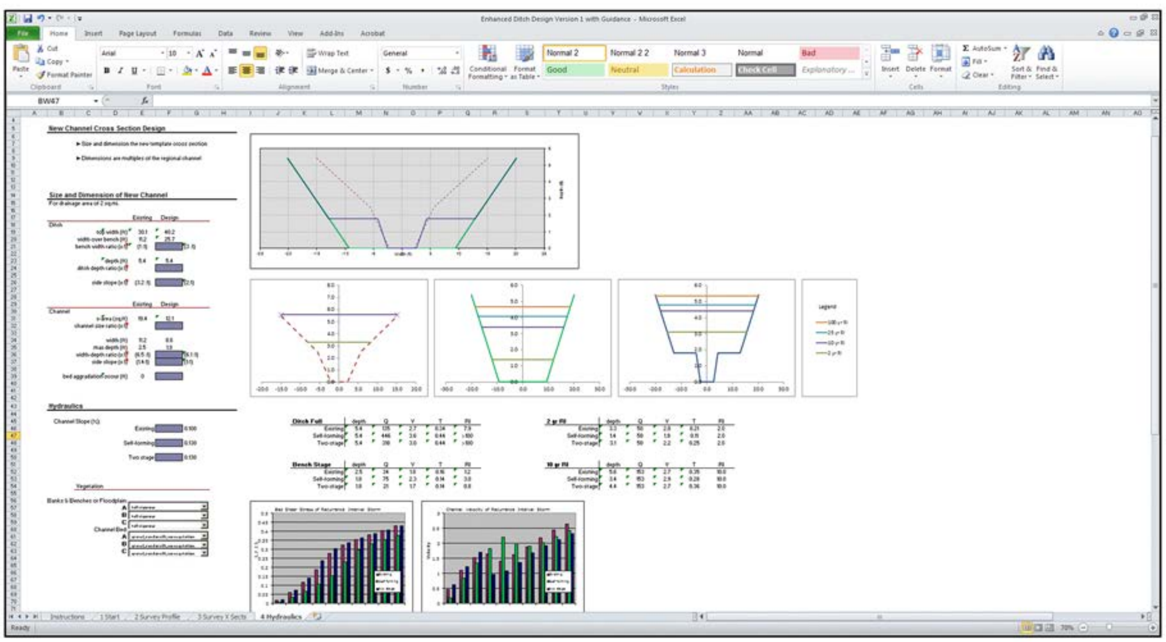


Figure 9. The 4 Hydraulics worksheet.

1 Start Worksheet

In this worksheet, the user can define some basic characteristics about the project reach, region, and the measurement system used to collect data. In the Units section, radio buttons are provided to identify the type of units (i.e. English or metric) that were used in data collection and also the units that will be used to define calculated output values (Figure 10). Unfortunately, at this time the spreadsheet does not automatically convert input data and calculated outputs from one system to the other. Here, the user can also enter information on the watershed size (Drainage Area; cell D23), stream and watershed name (cells D25 and D27), and location information including GPS coordinates (cells D30:F31 and D34:H36), if available (Figure 10). Drainage area is a required input as it is the basis for the initial sizing of a two-stage or self-forming channel. Drainage area can be determined by numerous methods including manual delineation of topographic maps, planimeter, or GIS tools (e.g. USGS Streamstats).

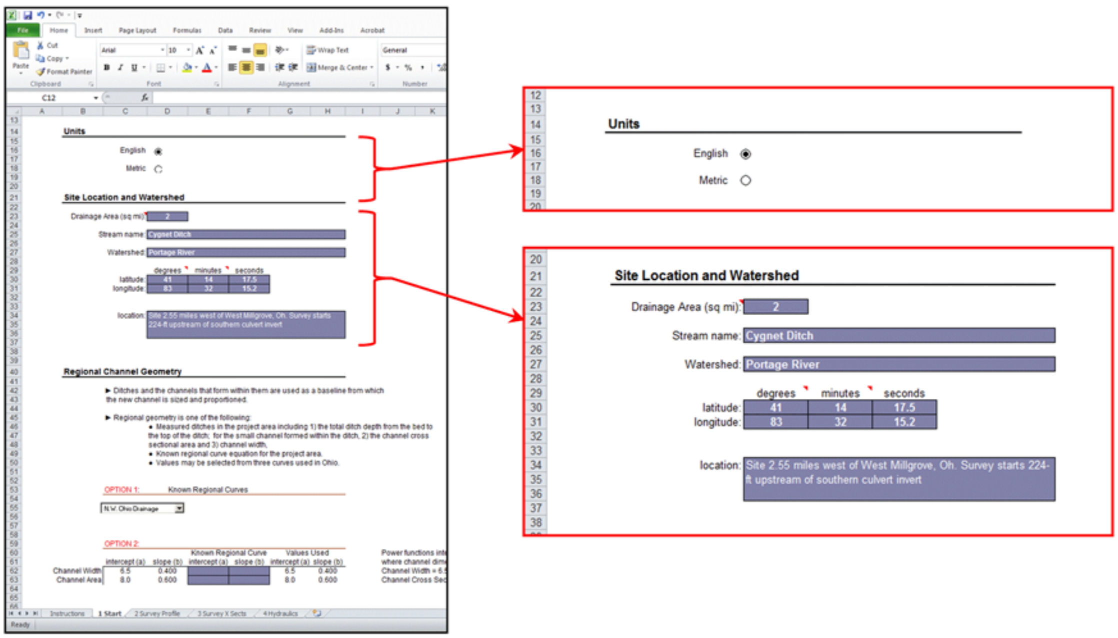


Figure 10. Locations to specify measurement units and site and watershed information.

The user also has the option to select a regional curve relationship that will be used as a starting point in the design process (Figure 11). The initial geometry of a proposed design is defined by a set of regional curves, which describe the relationship between drainage area and bankfull channel dimensions (i.e. width, depth, and cross sectional area). They provide a general estimate of the size of channel that nature is likely to create and sustain at a particular site. As the name indicates, regional curves vary by region and the relationships are a function of land use conditions, soils properties, topography, geology, management, hydrology, and riparian vegetation characteristics. It is up to the designer to select an appropriate regional curve to serve as the starting point for design. Here the user has the option of selecting from a series of predefined regional curves from a pull-down menu or to provide user-defined input values (i.e. coefficients and exponents of the regional curve equation typically expressed in the form of a power function equation), which relate drainage area to bankfull channel width, depth, and cross sectional area.

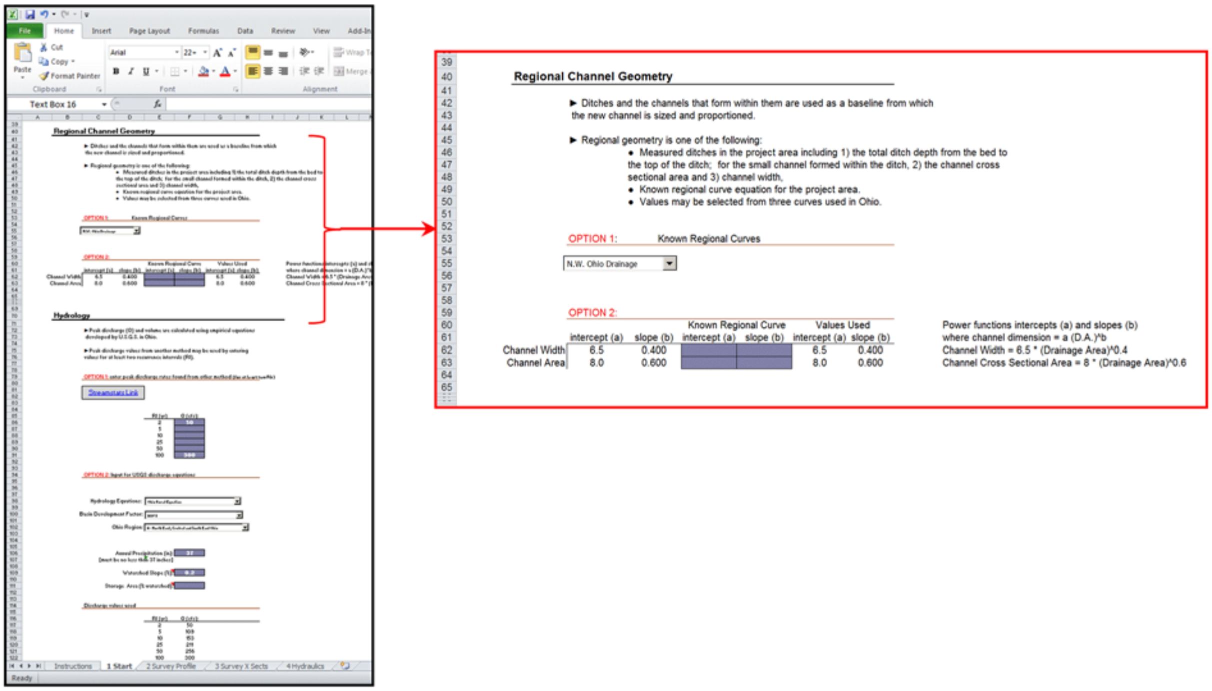


Figure 11. Input cells for regional channel geometry.

Estimates of peak discharge rates for a number of frequent and infrequent storm events provide a means to assess channel performance over a range of flow conditions (Figure 12). Low flows are typically more influential in the development and maintenance of the bankfull channel whereas less frequent flows are more likely to impact flooding and channel stability. A link is provided to the USGS Streamstats webpage under Option 1, which is a useful tool for estimating peak discharge rates in many states. A second option is available to estimate peak discharges from USGS empirical peak discharge equations based on watershed characteristics. Currently, empirical relationships are only provided for the State of Ohio, but this method will be expanded to include other states in future software releases. If either of the included approaches is determined not to be appropriate, the user has the option to select another method to estimate flow rates and manually enter the results for any or all of the 2, 5, 10, 25, 50, and 100-yr recurrence interval events (cells F86:F91).

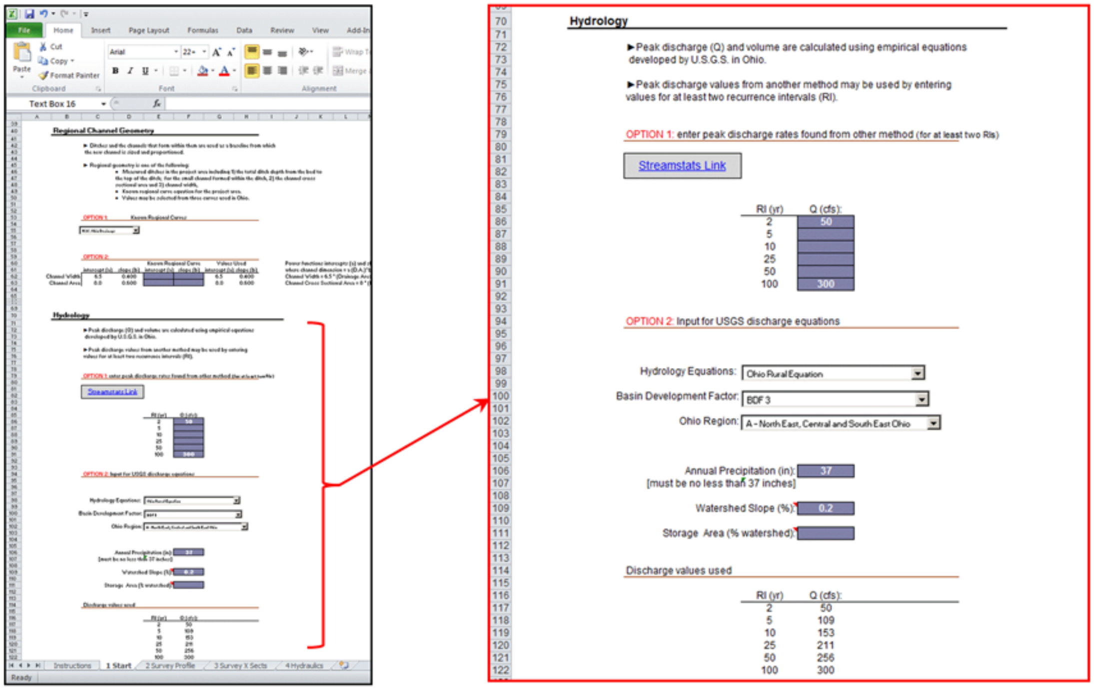


Figure 12. Input cells for hydrology information.

2 Survey Profile Worksheet

The *2 Survey Profile* worksheet allows for the input and reduction of field survey data to define the longitudinal profile of the reach. Currently, the spreadsheet is only set up for data collected using laser level survey techniques. To begin, the user defines characteristics of the survey starting point (i.e. the benchmark elevation) and identifies how the survey data were collected (Figure 13). Often, the benchmark elevation may simply be assigned an arbitrary elevation (e.g. 1000.0-ft) and referenced to a stable benchmark (e.g. point on a bridge abutment) that is not likely to change during the course of a project. In some projects, it may be desirable to establish true vertical elevations and a survey must be conducted to bring vertical control to the site. Either way, once an elevation benchmark is set the user can define the starting benchmark elevation (cell G16).

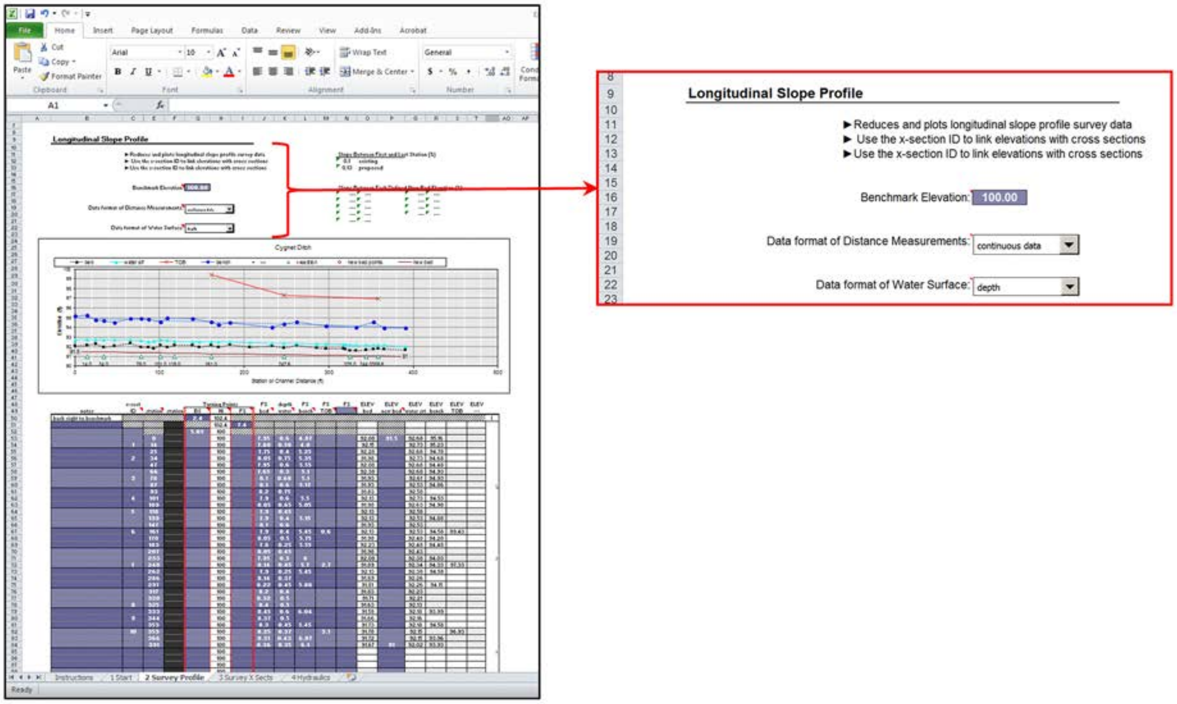


Figure 13. Input cells to identify the survey vertical datum and survey data collection methods.

Next the user will identify how the survey data were collected. Distance measurements can either be collected incrementally or continuously. Incremental measurements describe the distance between successive profile measurements whereas continuous measurement describes the distance along the reach relative to the survey starting point. During the survey, information is also typically collected on the depth of water in the channel, which is used to calculate a water surface slope. To establish the water surface elevation the user may collect data on the depth of water in the channel at the thalweg (i.e. deepest part of the channel) or simply use the rod and receiver to make an elevation measurement at the water surface. The latter method will establish the water surface elevation directly, whereas the depth method requires adding the measured depth to the thalweg elevation to calculate the water surface elevation.

After defining how the data were collected, the user can start entering field survey data (Figure 14; cells B50:P:222). Descriptions of individual points can be included in the Notes column (cells B50:B222). Each point of measurement along the reach should be assigned a unique identifier (x-sect id; cells C50:C222). The unique identifier is required as it ties measured cross sections (see *3 Survey X Sects* worksheet) to their position along the profile. Often, survey stationing (e.g. 1+00) is used to name cross sections. The positions of the cross sections are also plotted on the graph (i.e. white triangles with blue outlines). Distance measurements along the profile are entered to the Distance column (cells E50:E222). If incremental data are entered, the continuous measurement along the reach is calculated in the Station column (cells F50:F222). If continuous data are entered, no additional data manipulation is needed and conditional formatting blocks out the Station column calculation.

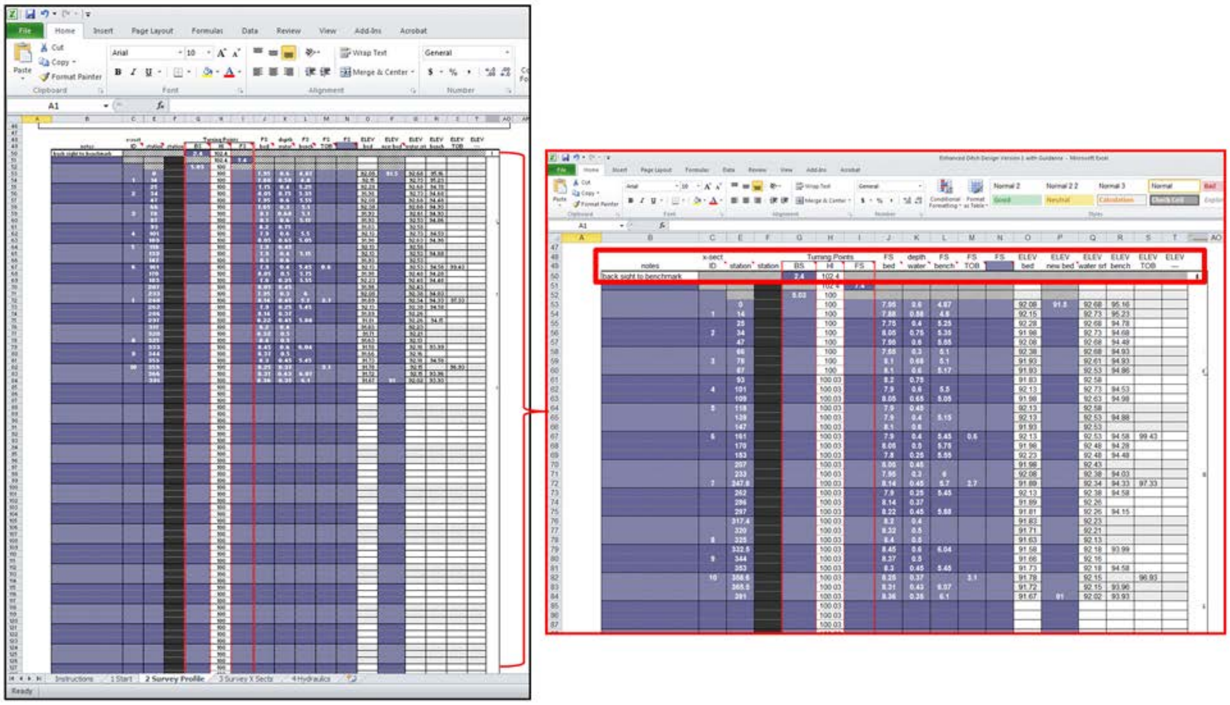


Figure 14. Input cells for survey data for the longitudinal profile.

Many field surveys also require that the survey instrument, in this case the laser level, be moved as the survey progresses downstream. The spreadsheet accounts for the movement of the instrument through the inclusion of turning points, which transfers vertical control of the elevation datum as the instrument location changes elevations between successive set ups. When the instrument is moved the surveyor takes a foresight reading to a stable point (cells I50:I222), moves the instrument to a new location, and makes a backsight reading (cells G50:G222) to the same stable point. The difference in elevation between the backsight and foresight readings is then added to the HI column (i.e. Height of the Instrument; cells H50:H222) to adjust the vertical datum and provide continuity between survey measurements. No distance measurements are entered for turning points and conditional formatting (cross-hatching signifies cells that should remain blank) is provided to guide the user through the data entry process.

To determine the slope of a reach the elevation of the thalweg is measured at points along the reach and entered into the FS Bed column (cells J50:J222). The calculation of reach slope (Figure 15; cell N12) is then determined from the change in elevation from the beginning of the survey to the end divided by the length of the reach. Alternative calculations of slope for user defined sections of the survey reach can also be made (Figure 15; cells N17:R21).

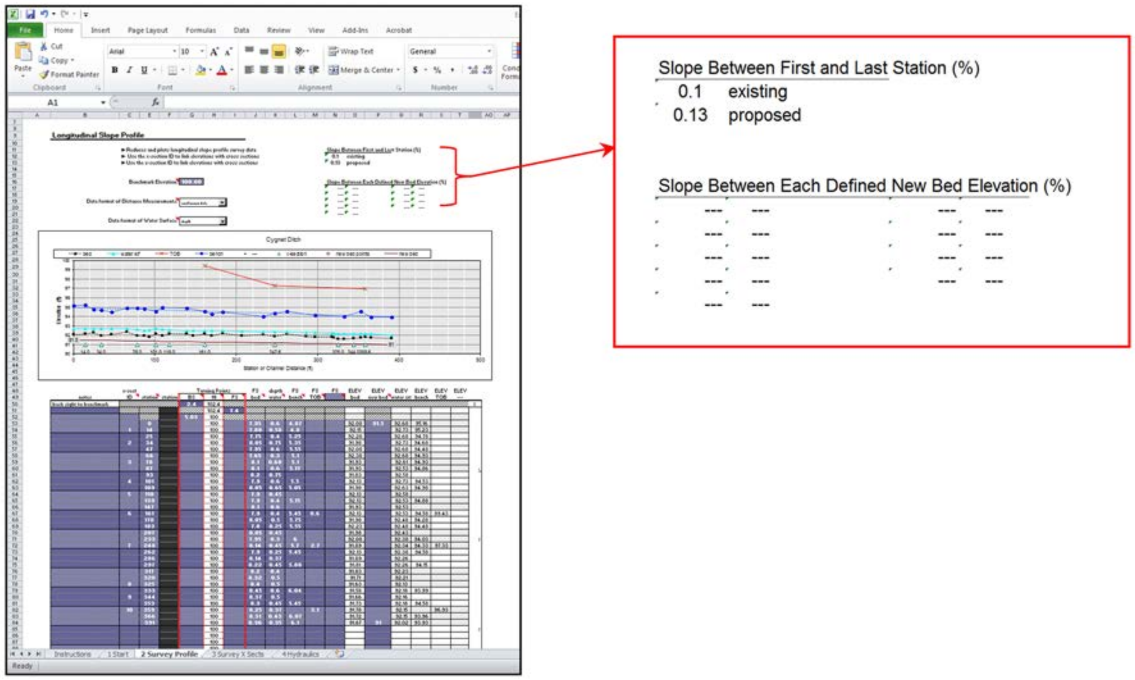


Figure 15. Calculations of the existing channel slope and any proposed designs for the entire reach or user specified sections of the reach.

As described previously, the surface of the water can be determined by measuring the water surface elevation directly or by measuring the depth of the water in the channel at the thalweg. If the Depth option is chosen the depth of water is read directly off the front of the surveying rod and entered into the Depth Water column (cells K50:K222). If the Surface option is selected the title of the column changes to FS Water and elevation measurements are entered into the same column (cells K50:K222). Additionally, as the survey progresses, if any distinct bankfull features (e.g. small floodplain benches) are identified the elevation readings of the features should be surveyed and entered in the FS Bench column (cells L50:L222). Similarly, the surveyor may wish to identify the elevation of the top of bank and enter that information into the FS TOB column (cells M50:M222). Any other features of note may also be recorded using the FS column (cells N50:N222), which can be titled by the user (see cell K49). The bed elevation at all points along the survey is then determined by subtracting the elevation (i.e. the rod reading in the survey) from the vertical elevation of the instrument (i.e. HI). This value is reported in the Elev Bed column (cells O50:O222). If the user wishes to establish new bed elevations along the reach for the designed channel the proposed elevations can be entered into the Elev New Bed column (cells P50:P222) and the slope of the proposed channel bed is calculated (cell N13). Additional calculations are made to determine the elevation of the water surface, elevation of any bench features, and the top of bank in the ELEV Water SRL (cells K50:K222), ELEV Bench (cells K50:K222), and ELEV TOB(cells K50:K222) columns, respectively.

3 Survey X Sects Worksheet

On this worksheet (Figure 16), cross section survey data is entered and a number of design choices are specified. To begin, each cross section requires a unique identifier in the Reference ID column (e.g. cell E37) that corresponds to a value in the X-Sect ID column on the *2 Survey Profile* worksheet. Next, the user typically enters distance (e.g.cells H36:H80) and elevation data (e.g. cells K36:K80) from the survey. Similar to the profile survey the user can enter a turning point if the instrument was moved during the course of a cross section survey. The FS turning point is simply entered into the cross section survey at the point that it occurred and is followed by a backsight reading in the row immediately below. No distance values are entered in association with the turning point values and conditional formatting appears to guides the user. Inclusion of a turning point will be indicated by a change of vertical datum in the HI column (e.g. cells J36:J80). All cross section elevations are calculated in the Elevation column (e.g. L36:L80). Depending on the geometry of the cross section, some points may need to be omitted for accurate calculation of channel morphology values (e.g. cells Q52:U59) by clicking on the checkboxes in the Omit Channel column (e.g. cells M36:M80). Additionally, any notes related to a particular point in the survey can be entered into the Notes column (e.g. cells N36:N80).

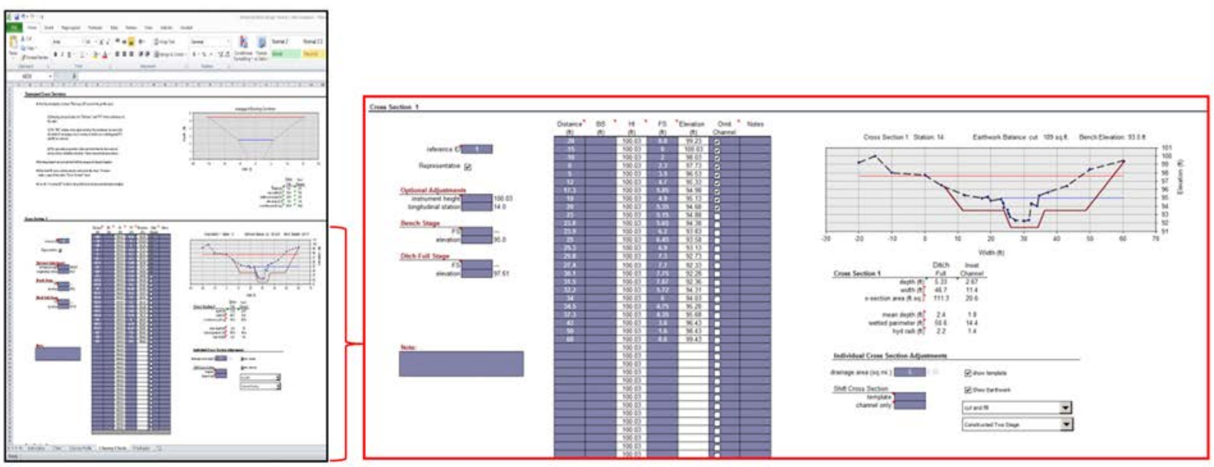


Figure 16. Input cells for cross section survey data.

Next, the user can specify whether the entered cross section is representative of the overall reach by clicking the Representative checkbox. All cross sections that are representative of the reach are being used to develop a simplified cross section (Figure 17; cells O8:AB24) that is later used in the *4 Hydraulics* worksheet to analyze open channel hydraulics for a “representative” existing cross section. The user also has the option to make a number of adjustments to survey data including manipulation of the instrument height (e.g. cell E43) and to the corresponding longitudinal stationing (cell e.g. E44) values. The user can identify the bankfull channel or “bench stage” by entering a value in the FS column (i.e. foresight rod reading; e.g. cell E47) or a direct elevation reading (e.g. cell E48). The elevation of the bench stage is identified in each corresponding cross section graph as a horizontal blue line. Similarly, the user can identify the ditchfull stage by entering a value in the FS column (i.e. foresight rod reading; e.g. cell E51) or a direct elevation reading (e.g. cell E52) that identifies the elevation where the channel intersects with the adjacent upland landscape. The elevation of the ditchfull stage is identified in each cross section graph as a horizontal red line. Calculations of important bankfull and ditchfull channel geometry values are reported (e.g. cells Q52:U59) under each graphed cross section. Descriptive information on the surveyed cross section can be entered in the Note column (cells C62:F64) as needed.

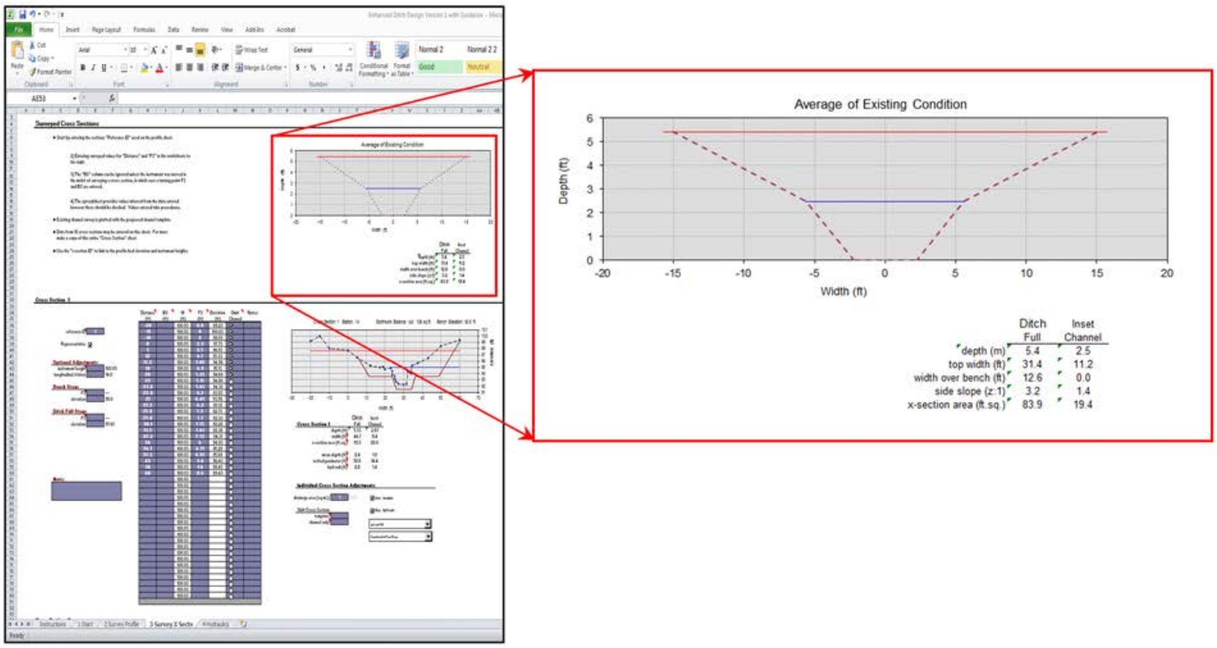


Figure 17. The spreadsheet generates a representative cross section from the survey data. The representative cross section has a simplified geometry to facilitate efficient calculation of open channel hydraulics.

At this point the user can select the proposed design approach (i.e. two-stage or self-forming channel) and specify how the construction will be completed (e.g. “cut and fill”, “cut bench only, no channel work”, or “cut bench and lower bed, no fill”) by making selections from pull-down menus under the Individual Cross Section Adjustments section . The user also has the option to overlay the proposed design on the graphed existing cross section by clicking the Show Template checkbox. The calculated earthwork volume can also be included in the graph title line by clicking the Show Earthwork checkbox. Both checkboxes are located in the Individual Cross Section Adjustments section. Additional adjustments to manipulate the size and location of the proposed channel can be made by entering values into Drainage Area (e.g. cell S64) and the Shift Cross Section cells (e.g. cells S67 and S68). The drainage area input cell is particularly useful when a tributary enters along a project reach and the design cross section changes due to a change in the contributing watershed area. The location and configuration of the proposed channel can also be manipulated by entering values in the Template cell (e.g. cell S67), which shifts the entire cross section laterally, or the Channel Only cell (e.g. cell S68), which shifts the position of the inset channel within the design ditch cross section. Other specific manipulations to the proposed channel are made on the *4 Hydraulics* worksheet.

4 Hydraulics Worksheet

The *4 Hydraulics* worksheet provides the results of an analysis of open channel hydraulics for three channel configurations: 1) the representative cross section derived from the existing channel survey (see *3 Survey X Sects*), 2) a two-stage ditch, and 3 a self-forming channel. This analysis not only allows for comparison of hydraulics amongst approaches, but also facilitates an analysis of stability (e.g. allowable velocity, permissible shear stress), which is often used by engineers in channel design. It is important to note that the tool does not conduct a geotechnical bank stability analysis, which could be undertaken with other tools such as the Bank Stability and Toe Erosion Model (BSTEM; Simon et al., 2000), for example.

On this worksheet, the user can also manipulate various design parameters (e.g. side slopes, bench width ratio). Input design parameters include those specific to the ditch and those specific to the inset bankfull channel (Figure 18). Calculated values for the ditch include the Top Width (cells E19:F19), ditch width at the bench stage (cells E20:F20), and the overall ditch depth (cells E23:F23). Parameters for the ditch that can be manipulated include the Bench Width Ratio (i.e. the width of the inset bankfull channel relative to the ditch at the bench elevation; cell F21), the ditch depth ratio (cell F24), and the ditch side slope ratio (Horizontal:Vertical; cell F26). Variables calculated for the inset bankfull channel include the bankfull cross sectional area (x-area column; cell F31), width (cell F34), and maximum depth (cell F35). Variables that can be manipulated in the design include the channel size ratio (i.e. ratio of the proposed channel to predicted regional channel dimensions; cell F32), the width-depth ratio (cell F36), and the inset channel side slope ratio (Horizontal:Vertical; cell F37).

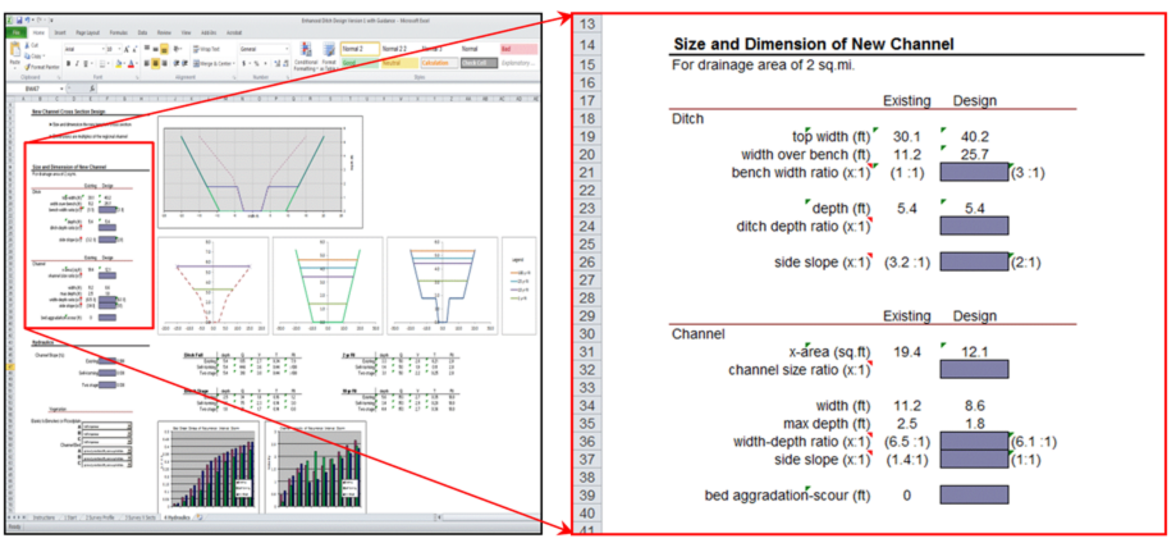


Figure 18. Input cells to manipulate characteristics of the designed two-stage and self-forming channels.

In order to calculate open channel hydraulics variables, it is necessary to have a measurement of channel slope. In the Hydraulics section of the worksheet, the existing and/or proposed slopes from the *2 Survey Profile* worksheet are used as default values (Figure 19; cells G46, G48, and G 50); however, the user has the option to overwrite the default values, when appropriate, using the blue input cells (cells F46, F48, and F50) immediately to the left of the default values. The user also needs to specify the vegetation of the ditch banks and floodplain separately from the inset channel bed using the pull down menus in the Hydraulics section of the worksheet (Figure 20) to aid in the selection of roughness values for hydraulics calculations.

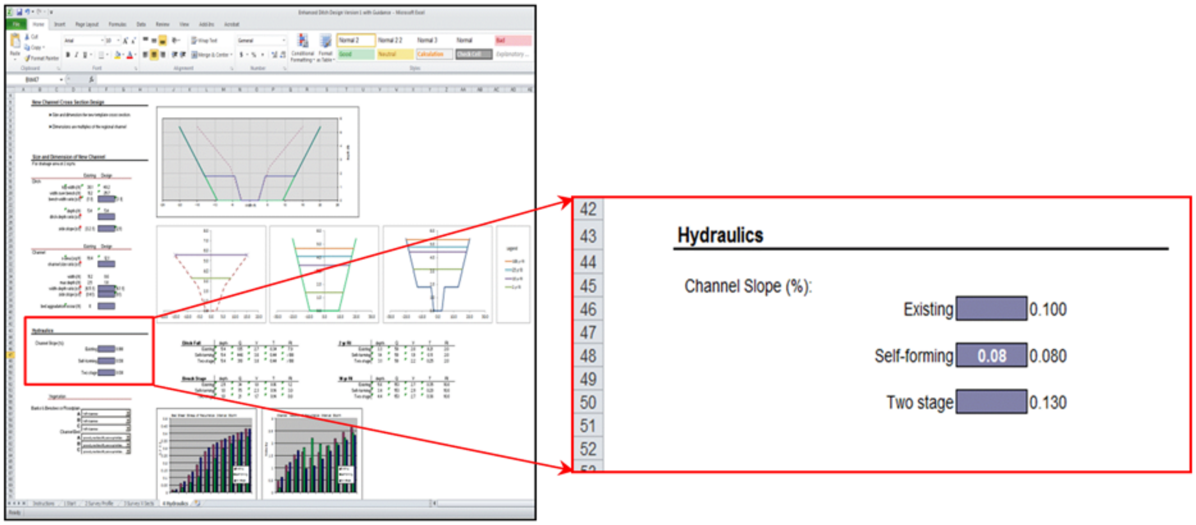


Figure 19. Input cells to specify channel slope for hydraulics estimates.

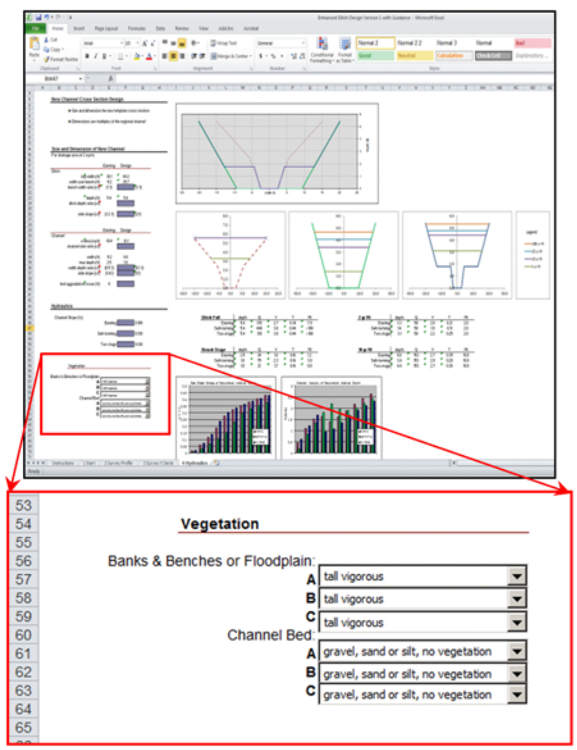


Figure 20. Pull-down menus used to specify vegetation in the channel, floodplain, and side slopes. Vegetation is used to identify channel roughness values for hydraulics calculations.

Outputs from the hydraulics analysis consist of a series of graphs and tables including: 1) a graphical overlay of channel geometries for the simplified representation of the existing channel and the proposed two-stage and self-forming channels (Figure 21), 2) a series of three individual graphs representing each channel geometry showing the estimated water surface elevations for the 2-, 10-, 25-, and 100-year recurrence interval storm events (Figure 22), 3) four tables with estimates of hydraulics for the ditchfull and inset channel bankfull conditions and the 2-year and 10-year recurrence interval storm events (Figure 23), and 4) a pair of bar graphs (Figure 24) that show bed shear stresses and channel velocities for all three channel configurations over a range of storm events (i.e. 0.2-, 0.4-, 0.8-, 1.6-, 3.1-, 6.3-, 12.5-, 25-, 50-, and 100-year recurrence interval events).

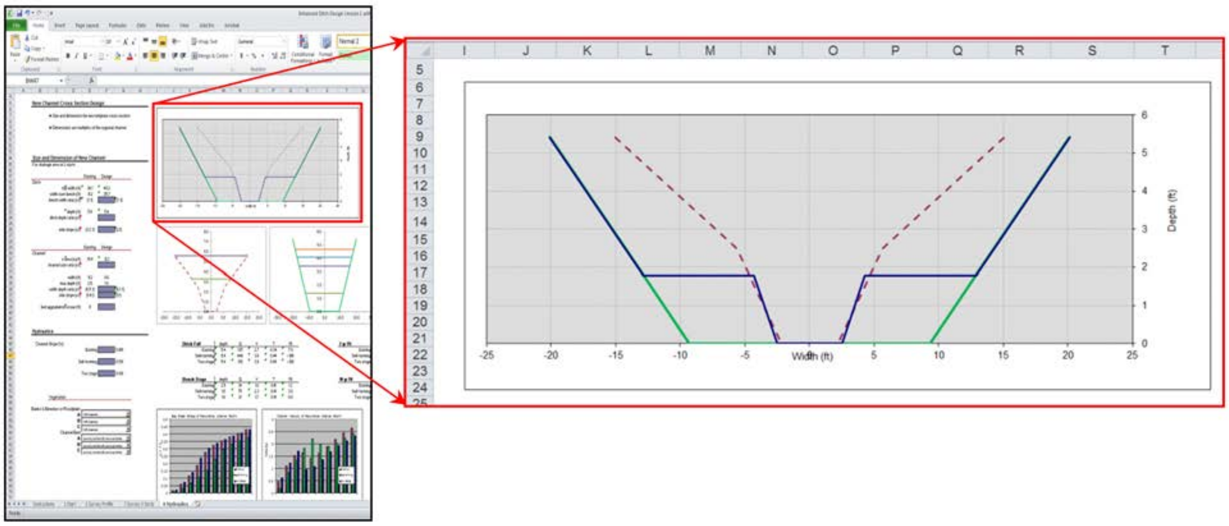


Figure 21. Overlay of channel geometries for the representative existing channel and the proposed two-stage and self-forming channels.

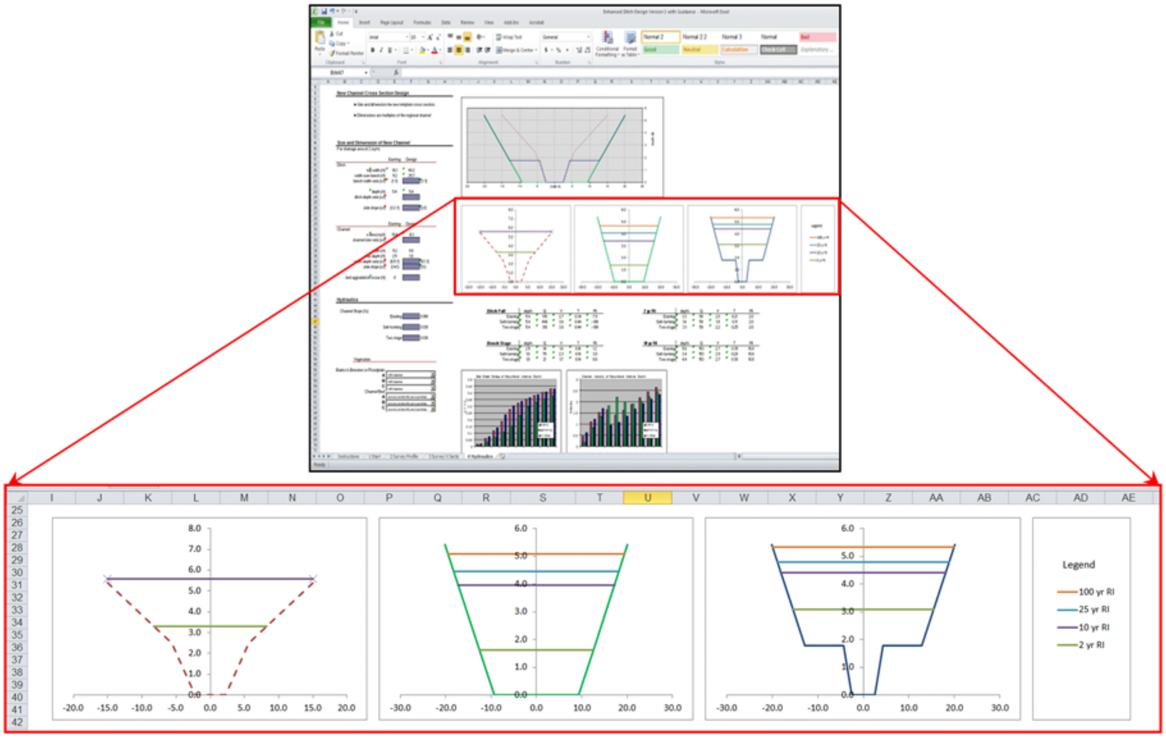
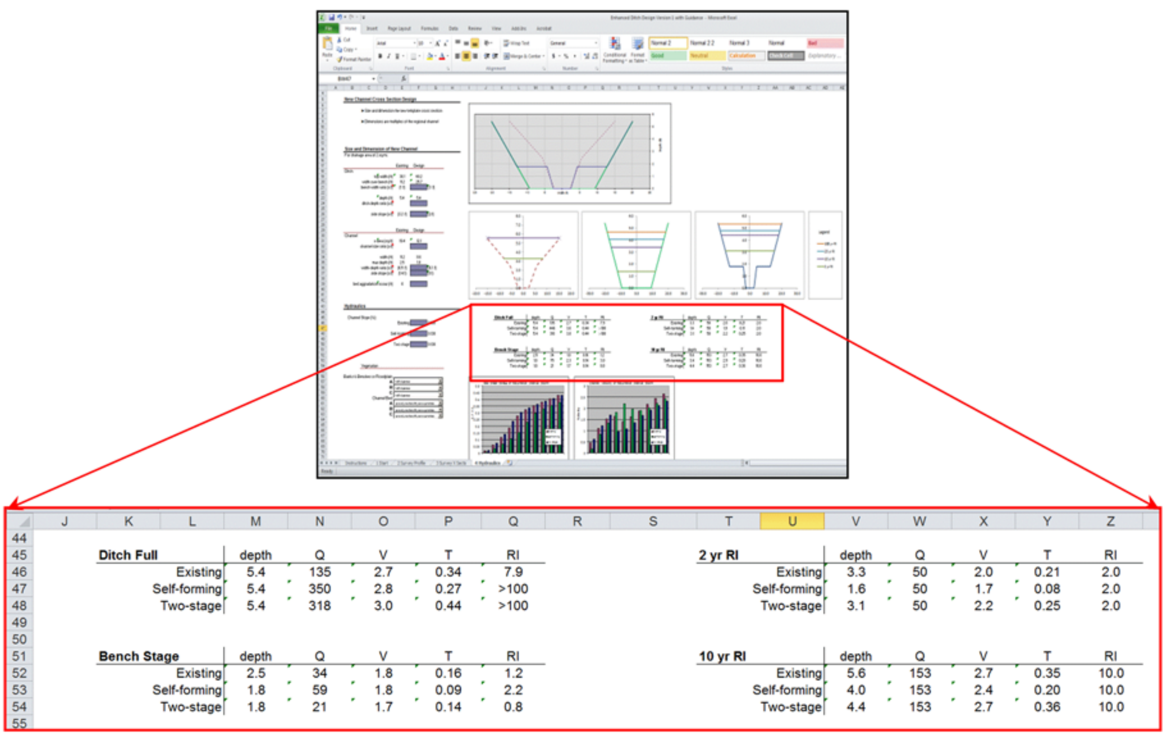


Figure 22. Estimated elevations of the water surface for the 2-, 10-, 25-, and 100-year storm events.



Ditch Full	depth	Q	V	T	RI
Existing	5.4	135	2.7	0.34	7.9
Self-forming	5.4	350	2.8	0.27	>100
Two-stage	5.4	318	3.0	0.44	>100

2 yr RI	depth	Q	V	T	RI
Existing	3.3	50	2.0	0.21	2.0
Self-forming	1.6	50	1.7	0.08	2.0
Two-stage	3.1	50	2.2	0.25	2.0

Bench Stage	depth	Q	V	T	RI
Existing	2.5	34	1.8	0.16	1.2
Self-forming	1.8	59	1.8	0.09	2.2
Two-stage	1.8	21	1.7	0.14	0.8

10 yr RI	depth	Q	V	T	RI
Existing	5.6	153	2.7	0.35	10.0
Self-forming	4.0	153	2.4	0.20	10.0
Two-stage	4.4	153	2.7	0.36	10.0

Figure 23. Hydraulics estimates for the bankfull and ditchfull stages and the 2- and 10-year storm events.

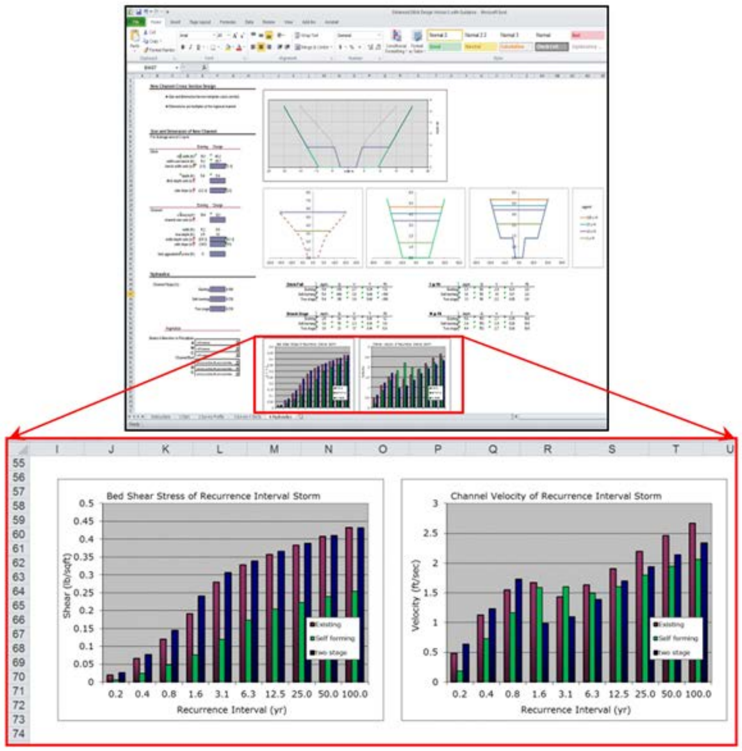


Figure 24. A comparison of channel velocities and bed shear stresses for the existing channel and the proposed two-stage and self-forming channels. Values are provided for a number of frequent and infrequent flow events.

References

Simon, A., Curini, A., Darby, S.E., Langendoen, E.J., 2000. Bank and near-bank processes in an incised channel. Geomorphology 35: 183-217.