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Selecting and Sizing a Two-stage Channel System in an Agricultural Landscape

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An approach to drainage construction has been developed that results in a stable ditch system working in harmony with natural fluvial processes so that sediment transport is in balance (Figure 1). This two-stage channel system has an inset channel, (1st Stage) to convey the bankfull discharge, and attached upper stages on each side, often called benches, (2nd Stage) that provide a floodplain to aid in sustaining dynamic equilibrium in the 1st Stage (Figure 2). Agricultural fields, woods, pastures, roads, and areas associated with human activities adjacent to the ditch can be considered as a 3rd Stage in the system and are important because:

Figure 1. A two-stage channel system 6 years after construction.

- runoff from these areas might cause erosion problems;
- they are the upper boundary of the system that influences bank stability;
- excavated material is often placed in these areas; and
- in agricultural settings, this is where Best Management Practices (BMP) are located.

The main objectives in modifying a trapezoidal channel to two-stage geometry are to provide a connected active floodplain to provide stability, reduce bank erosion, reduce the frequency of flooding in the 3rd Stage, improve water quality, and improve the ecology of the system.

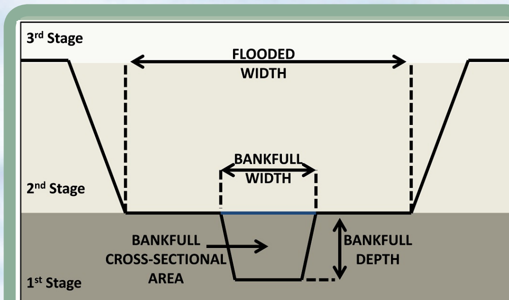

Figure 2. Characteristics of a two-stage channel cross section.

The two-stage system is best suited for drainage areas of 1 to 10 square miles where natural drainage patterns have been altered, in channels with bed slopes that are less than 0.5%, and in settings where existing land use on the 3rd Stage must be preserved. Two-stage channel sizing, construction, and assessment procedures include nine steps: (1) project/problem identification; (2) data collection; (3) data analysis; (4) hydrologic evaluation; (5) conceptual sizing; (6) project assessment/validation; (7) final sizing and design; (8) construction; and (9) monitoring and performance evaluation.[1,2,3] Selecting and implementing a two-stage channel modification should be based on a weight-of-evidence approach considering each of the steps. The remainder of this fact sheet provides a summary of each step.

Step 1: Problem Identification

The initial step for any channel modification project is to evaluate site conditions to identify problems and potential solutions. Identifying channel problems involves evaluating physical, hydrological, ecological, and chemical aspects of both the channel and watershed. Determination of system failure, recovery and/or dynamic equilibrium is critical. System failure might include: down-cutting, widening, bank instability (Figure 3), sediment deposition on the bed, restricted or drowned drainage outlets, inadequate subsurface drainage, and insufficient conveyance capacity. System recovery is usually associated with the formation of an inset channel (the 1st Stage) and fluvial processes building point bars and benches (Figure 4). Consideration also must be given to land use changes in the watershed such as they often increase peak discharges, the frequency of discharges, and the volume of runoff.

Figure 3.Bank instability in a ditch.

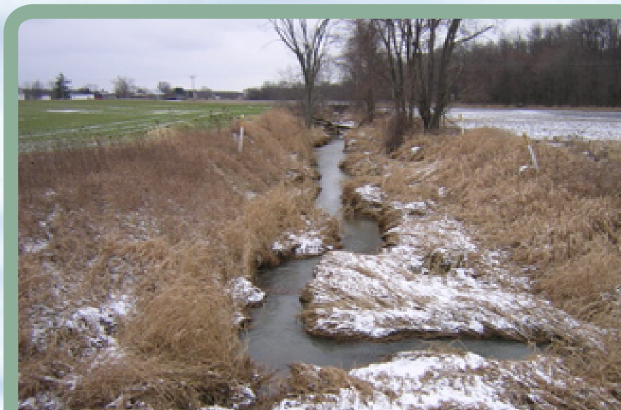

Figure 4. Recovery occurring in a ditch.

Step 2: Data Collection

A detailed geomorphic survey of the project site always is required. Geomorphic data should be collected at a reference site, if possible, and throughout the watershed where the project will take place. Drainage areas are required for the project site, reference reach, and all locations where measurements were made to construct a regional curve (Figure 5).[4] Site-specific data needed to size a channel system are:

1) drainage area; 2) channel slope; 3) inset channel dimensions; 4) regional curve; 5) bed material; and 6) an estimate of bankfull discharge and 7) an index of the frequency of out-of-bank discharges. Photographs also should be obtained of identified problems and at several surveyed cross-sections. It is recommended that channel geomorphology measurements are consistent with published procedures.[5] Video tutorials on how to make measurements are provided at *http://streams.osu.edu/modules/module1/mod1.html.*

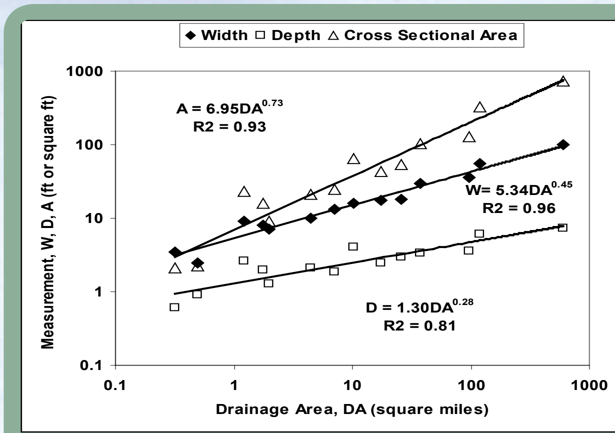

Figure 5. Example of regional curves obtained using field measurements.

Step 3: Data Analysis

Analyzing data from the project site and watershed helps build a weight-of-evidence approach for selecting sites for two-stage modification. A suite of freely-available spreadsheet tools have been developed to aid in the analysis for Steps 3, 4, and 5.[6] In modified ditch systems, dimensions of the inset channel usually vary throughout the project reach, there are often several grade breaks on the banks, dominant benches are not always evident, and maintenance activities and bank slumping make it difficult to identify fluvial features (Figure 6). These factors make it useful to compare measured representative bankfull widths, depths, and cross-sectional areas to estimates from the regional curve. If there is poor agreement, or the project site currently does not exhibit benches and an inset channel, further investigation might be needed before a decision is made on whether to construct a two-stage system. A pebble count provides information on the particle size distribution of the bed material. Channel systems in dynamic equilibrium often have mean bed-shear stresses associated with the bankfull discharge that move particle sizes similar to the measured median bed particle size.[4] A channel already in equilibrium may not be a good candidate for two-stage construction.

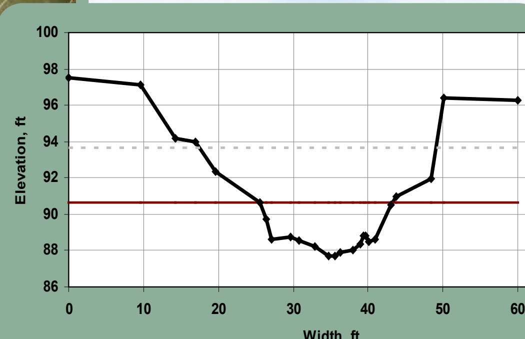

Figure 6. Deeply incised ditch with extensive scour and slumping on outer bends but some point bar (bench) formation on the inner bends (above); the representation of this measured cross-section in the Reference Reach spreadsheet tool (right).

Step 4: Hydrologic Evaluation

Included in the spreadsheet tools, are a variety of methods for predicting peak discharges in urban and rural ungaged watersheds in Ohio.[7,8] The USGS internet tool StreamStats provides an excellent approach to determining discharge versus recurrence interval relationships. StreamStats also delineates watershed boundaries and determines drainage areas. We recommend calibrating the selected hydrology method with data from the nearest USGS gage.[9]

Sizing fluvial channels should never be based solely on a discharge associated with a specific recurrence interval. In ditch systems dominated by herbaceous vegetation and having low stream power, the bank-full discharge for the inset channel is often much smaller than a 2-year recurrence interval discharge[10] and, typically, is less than a 1-year recurrence interval; the benches are located in the lower third of the ditch. Benches should be constructed low enough to flood frequently (10-60 days annually) to have useful nitrate-nitrogen reduction benefits.[11]

In addition to providing adequate bench width, the 2nd Stage of the channel system should be able to transport a design flow that will prevent frequent flooding of adjacent areas. The maximum design flow is typically based on economic criteria including loss of crops, flooding, or maintaining capacity flow. Modification of a channel system to two-stage geometry will provide a greater increase in conveyance capacity than conventional maintenance activities that remove sediment deposits on the bed and benches. In agricultural settings, we recommend the recurrence interval of the ditchfull discharge (1st Stage plus 2nd Stage) to be at least 5 years.

Step 5: Conceptual Channel Sizing

Sizing a two-stage channel involves 1) determining the inset channel geometry, which defines the bench height, 2) sizing the flooded width at the bankfull elevation of the inset channel, and 3) determining the channel side slope for the second stage. The flooded width includes the width of the fluvial benches and the channel width.

The project drainage area is applied to the regional curves developed in Step 3 to provide estimates for bankfull width, depth, and cross-sectional area. Estimates from the regional curve need to be compared with actual measured fluvial features at the project site, the reference reach, hydrologic estimates, shear stress depth, and estimated bankfull/effective discharge depth. If there is good agreement between all of these factors then the likelihood of success is high and the project should proceed.

The design of the new flooded width in the channel is a function of the top width of the inset channel. In systems with cohesive bank materials that can readily be planted with grasses the ratio of the flooded width to the inset channel width should be at least 3 and not more than 10 feet. The bench elevation corresponds to the height above the channel bed as estimated by the inset channel depth; the existing bank will be excavated at the bench elevation (Figure 7). In cohesive soils, the inset channel side slopes typically form at one-to-one slopes. In the 2nd Stage of the channel, side slopes are typically formed at two-to-one slopes. The side slopes need to be stable and not allow slump failures during high flow events. A geotechnical engineering analysis should be conducted to ensure that the bank stability has a factor of safety of at least 1.5.[12] The 2nd Stage can be sized to accommodate the maximum design flow rate used for the existing trapezoidal channel.

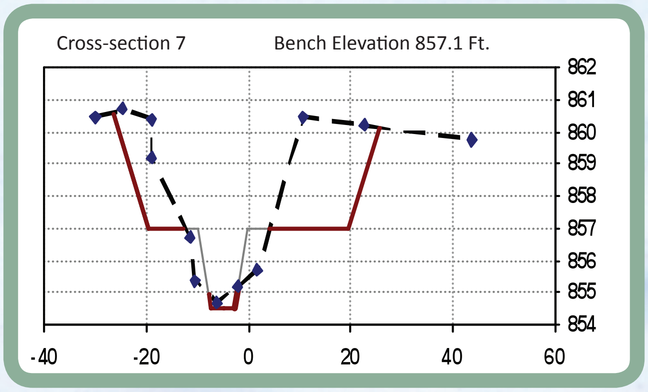

Figure 7. A graphical representation of a surveyed cross-section of a ditch showing the original geometry (dashed lines) and proposed location of the constructed benches and banks (solid lines).

Step 6: Project Assessment/Validation

Results from the previous five steps need to provide sufficient detail to obtain a cost-benefit estimate of the project. The Ohio State University has developed a spreadsheet tool to aid in conducting a cost analysis for constructing a two-stage ditch (http://agdrainage.osu.edu). A final project assessment and design presentation should occur with all stakeholders participating and should include, but not be limited to, outlining all previous steps, costs, pre-construction monitoring, and post-construction management plans. The two-stage channel concept involves widening the existing ditch to accommodate adequately-sized benches. Landowners must be willing to have some amount of land permanently excavated or agree to compensation for the loss of this land.

An integral part of project assessment is the establishment of a post-construction management plan that should address landowner, engineering, and environmental concerns. In some cases no modification or maintenance activities will be needed. In other cases, for example where the subsurface drainage outlets are well below the proposed floodplain elevation, a conventional removal of deposited sediment might be warranted. Ditches that exhibit rapid building of extensive benches are good candidates for either no channel maintenance to allow system recovery or a two-stage channel approach. A two-stage channel design should be considered where improving conveyance capacity, ecological function, water quality, and self-sustainability are desirable.

Step 7: Final Sizing and Design

If the decision in Step 6 is to move forward with the two-stage approach, then the conceptual design will need to be finalized. Depending on the client and legal requirements, this might require the preparation of engineering drawings that are approved by a licensed professional engineer. The stability of two-stage systems is highly dependent on the quality and extent of vegetation on the benches. Grasses provide excellent protection for the two-stage channel, especially immediately after construction. As constructed benches evolve to develop structure, vegetative cover, and ecology they have the potential to function similar to grassed buffers[13] or, in some cases, linear wetlands. Woody vegetation as the dominant vegetation type on benches is not recommended because it often shades portions of the benches and limits the growth of necessary stabilizing grass cover.

Figure 8. Construction of a two-stage ditch. The benches were made wide enough for vehicle access (top) and are located just below subsurface drainage outlets (above). Discharge from the outlets flows across vegetated benches.

Step 8: Construction

Construction of two-stage systems uses similar equipment to other types of ditch projects. It is recommended that a professional engineer provide supervision of the construction work. It is particularly important that the benches be constructed at the correct elevation and with the correct dimensions. The low bank and channel bed should be left undisturbed (Figure 8). Existing vegetation along the inset channel bank can provide stability and facilitate the narrowing process. In many cases, it is desirable to construct the floodplain width so it is at least wide enough to allow vehicle access.

Step 9: Monitoring and Performance Evaluation

Few Best Management Practices (BMPs), storm water management projects, and stream projects are evaluated following construction and, therefore, we have very little knowledge of how well or poorly any practice performs. Much more knowledge is needed on all conservation practices and BMPs, including two-stage channels, to maintain and improve drainage ditch systems. Ideally, pre- and post-construction monitoring would consider ecology, geomorphology, and water quality. In Ohio, water quality is related to aquatic life use attainment and assessed using the Index of Biotic Integrity (IBI)[14], the Invertebrate Community Index (ICI)[15] and the Qualitative Habitat Evaluation Index (QHEI).[16] It is recommended that, in addition to data needed to size a two-stage system, pre-construction monitoring includes making IBI, ICI, and QHEI assessments to determine how well the system is functioning and how well it evolves over time.

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