Two-Stage Ditch Design

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Overview

Highly modified channels drain extensive portions of productive agricultural land in the U.S.A. In many of these areas, most natural channels have been deepened and straightened to facilitate the flow of water from agricultural subsurface drainage outlets and to maximize conveyance. Work done periodically to maintain the drainage function typically includes removal of woody vegetation and deposited sediment. Ancillary work includes stabilizing bank slope failures and toe scour. Ditch form is a result of not only construction and maintenance but also, to verifying degrees, due to fluvial (flowing water) processes.

Drainage ditch form (pattern, profile, and dimension) was measured on ditches in Northwest Ohio. Additional measurements have been made in the Wabash River and Great Miami River Watersheds. Windshield observations have been made in numerous watersheds including the Auglaize, St Mary, and Big Walnut Watersheds in Ohio and several locations in Minnesota and Illinois. Extensive measurements have also been made on natural streams throughout the state. Apparent benefits exist for incorporating fluvial process derived form into ditch construction and maintenance.

Fluvial Processes

Natural stream systems tend to include not only a main channel but also a floodplain. The floodplains of high quality streams (except those with steep gradients) are characterized by frequent, extensive over-bank flow. Channels, sized by stable fluvial processes, just convey the effective (bankfull) discharge and larger flows widen out onto the floodplain. In equilibrium, a stream system depends on both the ability of the floodplain to dissipate high flow energy, and also concentrate the energy of low flow - effectively creating a balance in sediment transport, storage and supply.

The bankfull discharge is "*considered to be the channel-forming or effective discharge*" (Leopold, 1994). The effective discharge transports the largest cumulative sediment load

(Rosgen 1996). As bed load data has improved, it has become evident that the bed load fraction of the total sediment load is most influential in the channel forming process and effective discharge (Emmett and Wolman, 2001). Typically, effective discharge may be met or exceeded several times a year and generally corresponds to 1.3 to 1.7-year recurrence intervals based on a log Pearson analysis of annual instantaneous peak flows. In wetland streams this interval may be much smaller, even nearly continuous (Jurmu and Andrle, 1997).

In flat, poorly drained areas of Ohio where subsurface drainage is widely used, the effective discharge occurs frequently and primarily consists of subsurface drainage discharges. *"The bankfull stage and its attendant discharge serve as consistent morphological indices which can be related to the formation, maintenance, and dimensions of the channel as it exists under the modern climatic regime,"* as stated by Dave Rosgen (1996). It appears that channels formed within constructed ditches might serve a similar function or are simply sized by nature to provide the most effective cross-section to convey the dominant discharge. To facilitate drainage, and reduce the frequency of over bank flows, ditches are typically constructed so flows with a 5-50 year recurrence interval are contained within the ditch. Not uncommonly, the width of the bottom of the ditch is constructed wider than the channel bottom that would be formed by fluvial processes, thus making the effective discharge relatively wide and shallow. Therefore, the constructed ditch channel is often oversized for small flows and provides no floodplain for large flows. In response to this imbalance, fluvial processes create a small main channel by building a floodplain or bench within the confines of the ditches (see Figure 1). If conditions allow, these benches can reach a stable size, and are thickly vegetated with mostly grasses. The small main channel will often meander slightly within the ditch and is sized by nature to carry the effective discharge. The channel bed will usually have steep (1:1) sides and consist of material courser than that of adjacent reaches where benches have not formed.

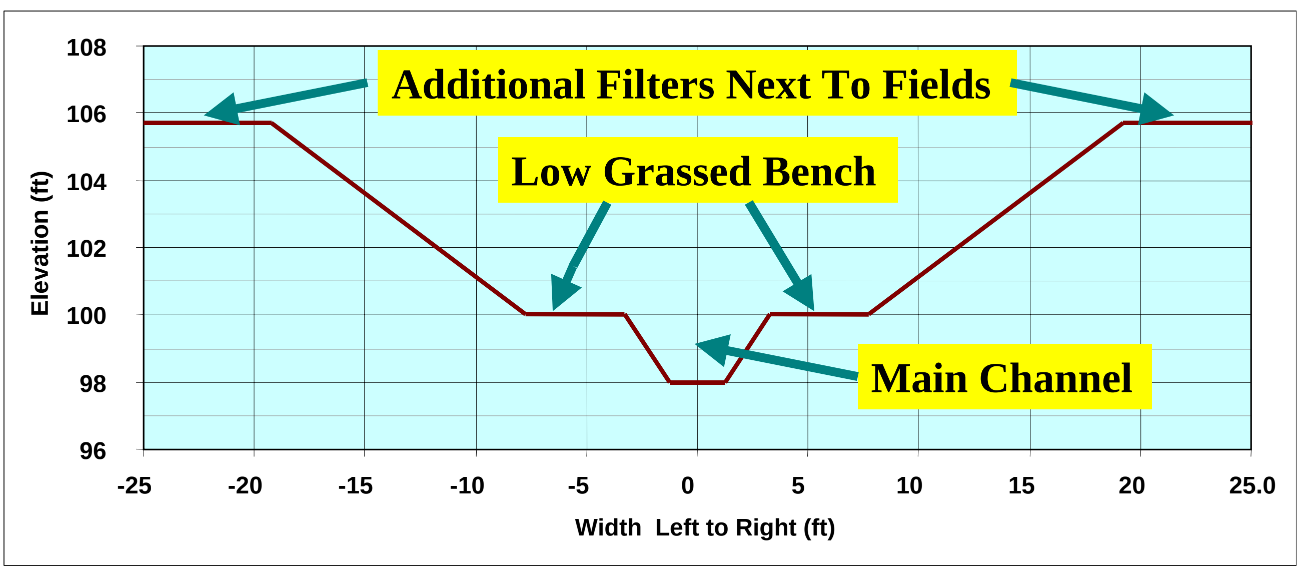

Figure 1. A two-stage ditch with a small main channel and low grassed bench.

Benefits and Costs of a Two-Stage Ditch

Benefits of a two-stage ditch over a conventional ditch include both improved drainage and ecological functions. Drainage benefits can include increased ditch stability and reduced maintenance. As already mentioned, ditches are often constructed with a wider base than a channel formed by fluvial processes would create, making the effective discharge wide and shallow and reducing the channel's ability to transport sediment. Evidence and theory both suggest ditches prone to filling with accumulated sediment may require less frequent "dipping out" if constructed in a two-stage form. Second, channel stability may be improved by a reduction in the erosive potential of larger flows as they are shallower and spread out across the bench. Stability of the ditch bank may also be improved because the toe of the ditch bank meets the bench rather than the ditch bottom. Here the bank height is effectively reduced and the shear stress (erosive force) on the toe of the bank is less. Also, this bank material will be dryer, not being in contact with low flow. However, where the main channel meanders to the toe of the ditch bank this would not be the case and bank erosion might even be induced.

The two-stage ditch has the potential to create and maintain better habitat. The narrow deep main channel provides greater water depth during periods of low flow. Grass on the benches provide quality cover and shade. The substrate in the main channel is improved since the two-stage form increases sediment conveyance and also sorting, with fines deposited on the benches and courser material forming the bed. Two-stage ditches might also improve nutrient assimilation, and therefore water quality. Work has been initiated by OSU to study the role of the main channel and benches in improving water quality and habitat.

Initial costs of two-stage ditches are higher because of increased width and more earthwork. Creating a low bench typically requires a greater top width. Assuming a two-stage ditch is approximately 10-20 feet wider than a conventional ditch, then the loss of potentially farmable land might be 1 to 3 acres per mile of ditch, depending the size of the watershed and existing ditch. The increased width however, will usually increase the capacity (amount of flow it can carry) by 25%-100%. With the loss of farmable acreage in mind, we have proposed that the establishment of the low bench be included in state and federal cost share programs, the same as establishing a grass filter adjacent to the top of the ditch. It is probable that establishment of a bench will have a greater benefit than a grass filter. However, it does not negate, nor need to replace, the benefit of also having a grass filter or maintenance strip along the top of the ditch.

Sizing a Two-Stage Ditch

The probable dimensions of the low-flow channel can be empirically determined based on regional studies similar to those that are conducted for natural streams. Similarly, measurements at Ohio study sites suggest that a broad ditch with a total bench width approaching or exceeding that channel width might result in stable benches. However, the work by Rhoades and Herricks (1995) indicates that there might be a threshold width at which the low-flow channel will induce meander changes in the ditch itself.

The Ohio State University and ODNR are in the process of developing a two-stage ditch design procedure. This work is being conducted in collaboration with several county, state and federal agencies, faculty at other institutions in Ohio, Illinois and Minnesota, and watershed groups.

The goal of this work will be to develop a rapid, practical procedure that can be used throughout Ohio to correctly size the main channel, to provide a minimum bench width to ensure stability, and to size the cross-sectional capacity of the second stage (above the bench) to carry a design discharge to prevent over-bank flow based on a recurrence interval that satisfies local, county, watershed, or state requirements. An example of a regional curve for the main channel that was developed based on one day of measurements is presented in Figure 2.

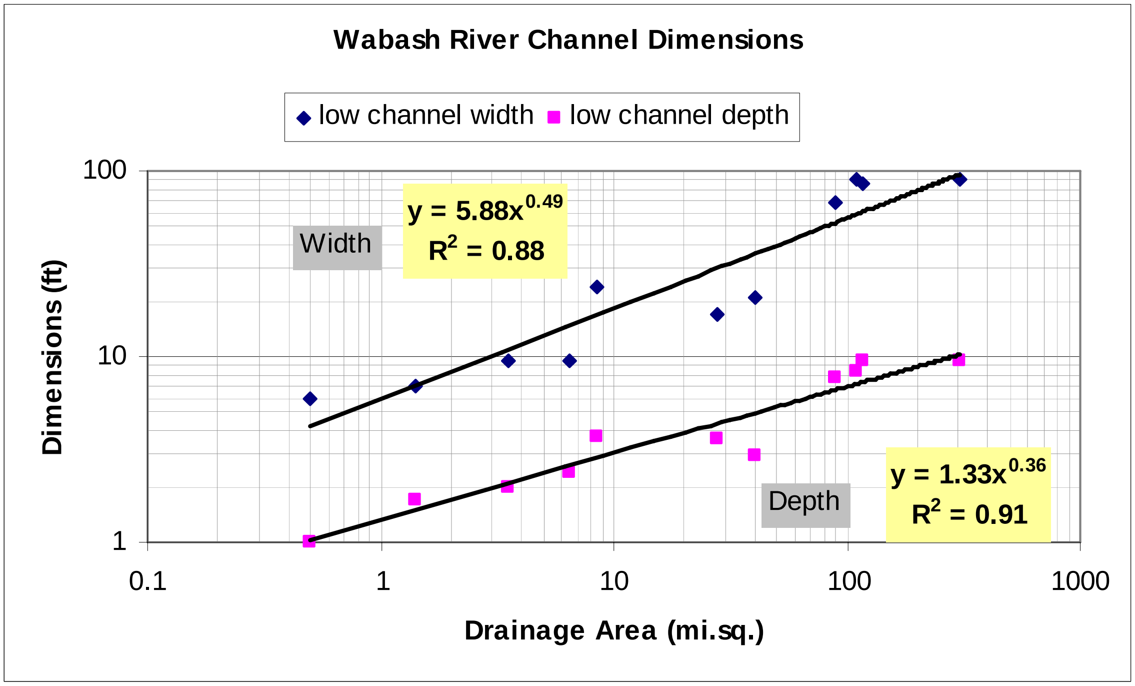

Figure 2. Effective discharge channel dimensions for the Wabash River (based on rapid measurement techniques).

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