# Are Benches in Agricultural Ditches a Benefit?


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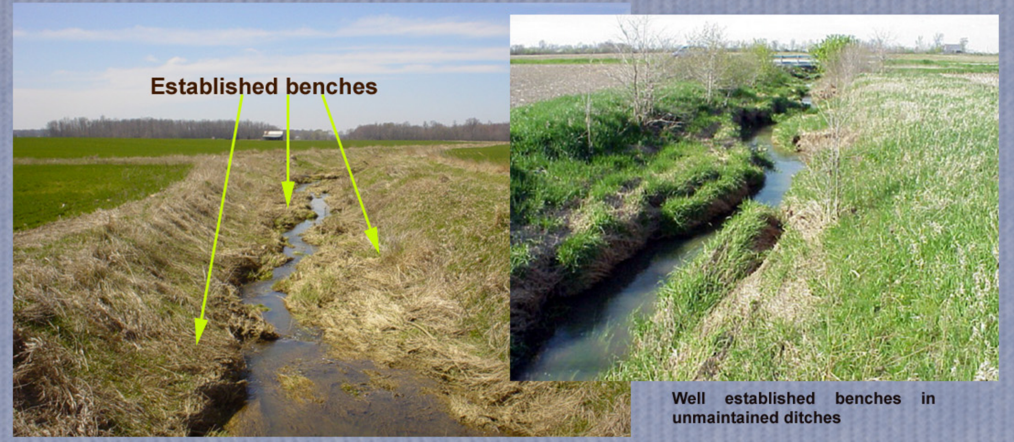
## Theory

### 1. Hypothesis

Understanding how streams seek their own stability allows us to manage and construct ditches that in the long term might require less maintenance, while providing drainage conveyance and better ecological function.

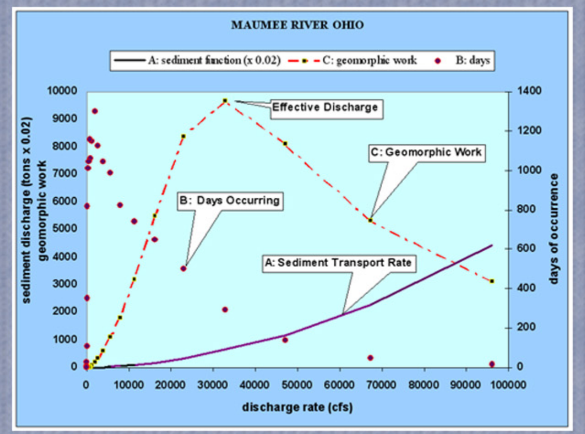
### 2. Typical Fluvial features


Benches beginning to form within recently maintained ditches




Well established benches in unmaintained ditches

### 3. Effective Discharge




The effective, dominant, and bankfull discharge are often considered as synonymous.

The bankfull discharge is "considered to be the channel-forming or effective discharge" (Leopold, 1994).

The bed load fraction of the total sediment load is most influential in channel forming processes and effective discharge (Emmett and Wolman, 2001).

The effective discharge typically occurs less than a hand full of times annually in streams and is found to occur at a much higher frequency in ditches.

Bench features are associated with high frequency subsurface (tile) flows.

Effective discharge is determined from analyzing sediment transport data, while bankfull features are determined from measuring fluvial features. In most cases the flows that are associated with these are synonymous.

### 4. Dynamic Equilibrium

Drainage ditch channels adjust to their discharge and sediment supply in predictable ways.

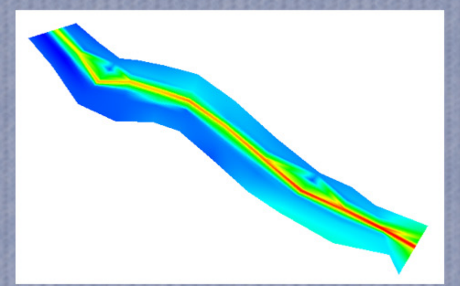
Streams seek a state of dynamic equilibrium.

Equilibrium is a function of flow and sediment.

Equilibrium is naturally associated with a main channel and a floodplain.

The dominant discharge forms the main channel.

Streams meander in a predictable manner.



The highest velocities in a channel are shown in red, with lower velocities to the sides (green/blue). These zones of low velocities correspond to depositional features.

A low flow event that is probably more frequent than the effective discharge and well below the bench features.

A high flow event that in this case corresponds to the 2 year flood event.

A ditch at bankfull flow. The person is standing on a bench feature.

Somewhere between the frequent low flow events and the infrequent flood events, there exists a dynamic equilibrium where the amount of sediment imported is equal to that exported by the ditch system. Typically following construction or cleanout, benches will form within a few years and quickly reach a stable (neither aggrading nor degrading) cross-section.

## Design

### 1. Identify the Problem

Numerous problems with ditches exist and some examples are bank instability (above), cut banks (right), sediment deposition (far right), restricted outlets, inadequate subsurface drainage, and insufficient capacity.

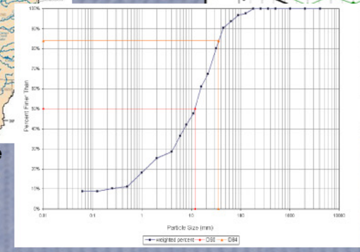
### 2. Conduct Reconnaissance

Identify site specific conditions, learn about the watershed, and collect information.

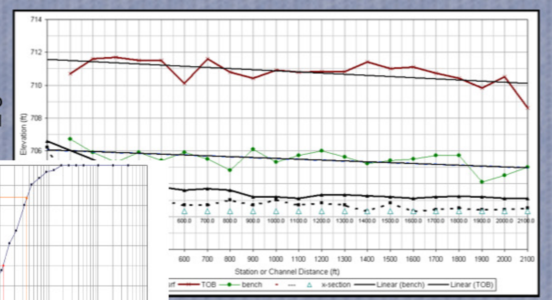
Conduct a ditch survey (above), rapid regional measurements (left), and pebble count (far left).

### 3. Data Analysis

(Above) Calculate the drainage areas for all regional measurements to generate a regional curve.



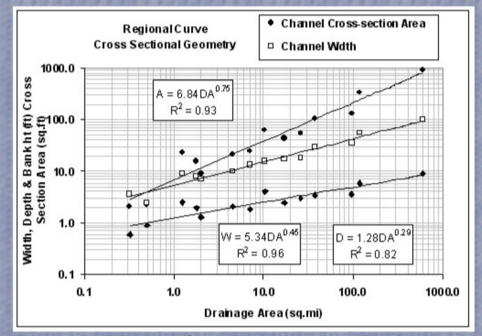
(Below) Plot the pebble count data to determine mean bed material size



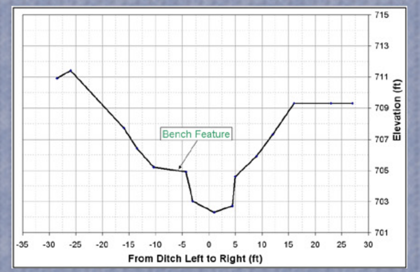
(Above) Analyze data collected during detailed survey to generalize the bed slopes, water slope, location of existing benches and top of bank.

### 4. Determine Bankfull Features

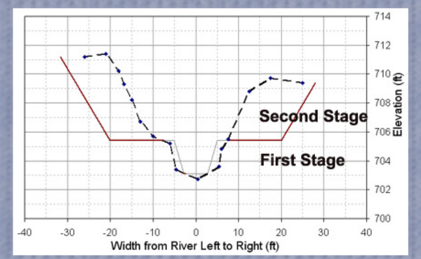
(Below) The bankfull feature (below) can be seen visually by inspection on site. Significant grade breaks typically identify the bench elevation. Resistance equations can be used to determine flow. The regional curve can be used to size the effective discharge elevation on a ditch with poorly defined bench features.




(Above) An example of a generated rapid regional curve using quick measurements of bankfull width, depth and drainage areas.




### 5. Size the Dimensions, Pattern, and Profile

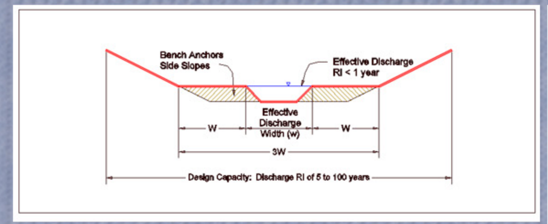
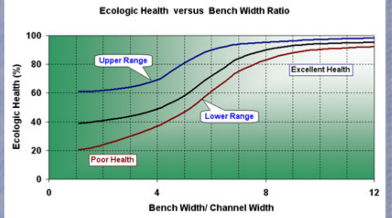
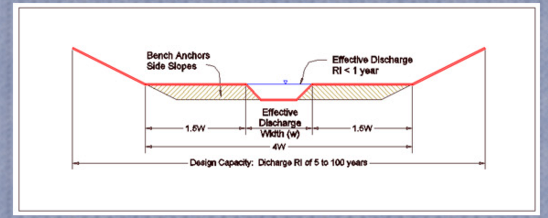



Once the bench feature is determined, the remaining design features of the channel can be designed. The pattern of the ditch is usually confined to the sinuosity of the ditch banks. Small meanders can occur within a ditch, however the perception exists that a "dog legged" stream will not functioning properly. Sinuosity is not part of a two stage design, however it is believed that the ditch will determine its own sinuosity given adequate flood plain width.

The Channel profile is the slope of the stream. The channel bed must join existing structures such as culverts and allow drainage pipes to discharge.

The main channel dimensions will not be altered during the construction phase. The bench will be excavated at the elevation that corresponds to the effective discharge elevation determined in step 4.

### 6. Design Bench

The width of the two-stage ditch is determined by the ratio between the effective discharge channel and the total width of the proposed benches. Evidence suggests that the wider the benches are the more healthy the water course will remain (ODNR, 2003). If the bench width ratio is greater than 5, fluvial processes will dictate ditch geometry making for a healthier ditch. In ditches, the width of a constructed bench is also a function of the capital investment to excavate earth and the loss of productive farm land.

## Introduction


The study addresses regional and national concerns regarding high nitrogen loading to the Great Lakes and Gulf of Mexico. Our goal is to quantify the extent that agricultural drainage ditches can reduce nitrogen loading, and to identify management practices that increase nitrogen removal while maintaining economic viability. To achieve our goal, we will study: (1) the geomorphic evolution of ditches in response to their hydrologic regimes; (2) their ecological function and how it can be improved; and (3) the quantity, quality, and temporal distribution of discharges to agricultural ditches. This poster addresses goal 1: the design of two-stage channels. For nutrient study see *Potential for nitrogen removal in agricultural headwater streams.* The fluvial channel design dimensions are determined by measuring the bankfull features at the project site and making regional curve measurements. Benches are the natural result of fluvial processes in most ditches. The bench acts as a floodplain within the ditch to dissipate energy, thereby reducing the erosive potential of high flow volumes, and mitigate shear stresses on the bank toe. It is anticipated that two-stage ditches will have improved conveyance capacity, will be more self-sustaining, will create and maintain better habitat, and will improve water quality.

## Outline



## Conclusion

In establishing a two-stage geometry, the ditch is widened at the elevation that corresponds to existing bench features or the elevation at which these benches are predicted to form from fluvial processes. Vegetation is left along the fringe of the existing channel and no work is done to reshape or narrow the current channel if there has been no degradation of the low flow channel. The benches will vegetate quickly and it is anticipated that the channel will adjust its shape as a function of fluvial processes. In establishing a two-stage geometry it is often not cost-effective or practical to form a floodplain as wide as fluvial processes would like. Large deep agricultural ditches have often already been constructed to facilitate discharges from subsurface drainage systems. Making these large ditches even wider would result in extensive earth moving, high cost, and substantial losses in agricultural land. Also, the side slopes and depths of the ditch above the benches must satisfy geotechnical engineering requirements to provide bank stability. In many locations a "do nothing" approach might be considered. Removing benches will only provide a temporary increase in the conveyance capacity of the ditch. Often maintenance is carried out without any real understanding of what the problem is or what the maintenance is designed to solve. The rapid regional curve approach has been used by the authors on several watersheds in Ohio and typically provides relationships between the fluvial channel and drainage area with $r^2$ values greater than 0.8. Naturally formed two-stage ditch geometries exist in ditches located throughout the Midwest region of the United States. In addition, two-stage geometries have been constructed on short reaches, typically less than 0.5 miles in length, at several locations in Ohio and Michigan. These ditches exhibit a range of bench to channel width ratios and will be monitored to evaluate if they are self-sustaining, provide water quality benefits and improve ecological conditions.

## Construction

### 1. Site Locations

The location of eight different two-stage ditches are shown on the map to the left. Four of these ditches have been constructed with excavated benches. Two sites, Hancock County Site 11 and Pone Creek, have naturally formed benches and are presented as examples. Most agricultural ditches exhibit grade breaks caused by fluvial processes and have intermittent stable benches.

The Bokes Creek Water Quality Enhancement Project was funded primarily through an OhioEPA Section 319 grant to promote Natural Channel Design concepts, improve water quality and conveyance capacity. The primary distinction between the design employed in Bokes Creek and other two-stage agricultural ditches is that with Bokes Creek a meander pattern was re-established for the main channel with a variety of vegetation, at the cost of a large tract of adjacent land. This while ideal for stream restoration, is unfeasible for agricultural ditches where adjoining lands are a premium and main channels tend to be incised and disconnected from their floodplain.

### 2. Construction Images


(Far left) Naturally formed benches on Pone Creek, Fayette County, Ohio.

(Left) Construction photo of Wabash Creek Ditch project, Mercer County, Ohio.


(Far left) Naturally formed benches on Loramie Ditch.

(Left) Constructed benches in Hillsdale County, Michigan.

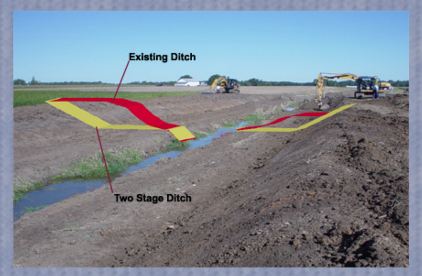

(Far left) Post construction photos of the Fast Road ditch, Wood County, Ohio.

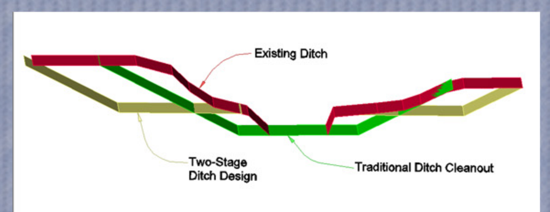
(Left) Construction of two-stage ditch on Needles Creek, Ohio. Increased bench width constructed only on one side.

### 3. Two-Stage Ditch Case Study

The ditch shown was cleaned out six years previously and had significant sediment accumulation on the bed. A two-stage ditch was constructed with a grant obtained by the Nature Conservancy and can be seen below.


(Below) A mock overlay of the Michigan Ditch project, showing the existing ditch location and the constructed two-stage ditch. The image below shows the same cross section with the existing ditch data, the constructed two-stage ditch and the traditional ditch excavation. Notice the channel vegetation in the construction photo, the two-stage construction does not interfere with the channel or the vegetative growth.



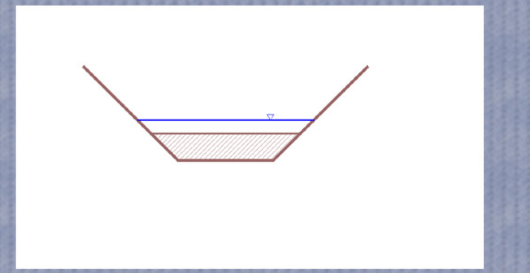

### 4. Bench Width/Channel Width Ratios

| Site Name | Natural/Constructed | Date | Bench/Channel Width |
|---|---|---|---|
| Traditional | Constructed | NA | 1 |
| Pone Creek | Natural | NA | 2 - 3 |
| Hancock Site 11 | Natural | NA | 2 - 3 |
| Loramie Ditch | Natural | NA | 2.4 |
| Wabash Ditch | Constructed | March 2003 | 2.5 |
| Fast Road Ditch | Constructed | July 2002 | 2.5 - 3 |
| Needles Creek | Constructed | October 2003 | 3 |
| Michigan Ditch | Constructed | September 2003 | 3.5 |
| Bokes Creek | Constructed | March 2003 | 4 |

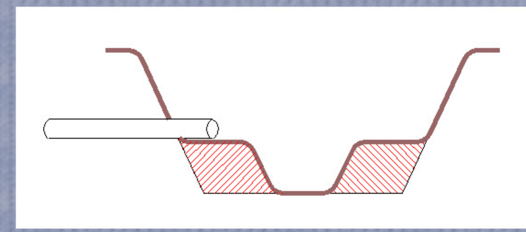
Compare the table above with the graph shown in Design Step 6. The graph shown in Design Step 6 was created to compare stream systems. These constructed ditches are not being reclaimed into natural streams, the effort is to allow them to function by natural fluvial processes with little maintenance. However, the formation of benches will not only increase the effectiveness of conveying large floods, but also improve the ecological health. The overall benefit to the ditches will be stability requiring little or no maintenance, increased capacity, reduced flow rates during high flows, and reduced sediment load from the system. There are indications of improved habitat conditions and nutrient cycling which are currently under investigation.

## Benefits & Tradeoffs

### 1. Self Maintaining

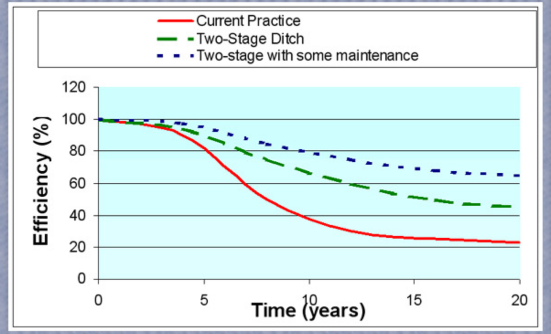



The primary cause for ditch maintenance is the accumulation of sediment in the ditch channel, which reduces the conveyance capacity at low flows. Sediment is deposited when the water velocity is reduced and loses the energy to keep the sediment in suspension. Traditional ditch designs (above left), result in the spreading of channel flows at low flow rates. The shallow depth magnifies sediment deposition causing a wetland like environment in the ditch (above right) further encouraging sediment deposition.




The two stage design (above left) concentrates low flows within a smaller cross sectional area, keeping sediments in suspensions and enabling a cleaner substrate (above right) within the low flow channel.

Current ditch clean out practices if not carried out frequently result in poor conveyance in a ditch. It is hypothesized that a two stage system functions at a higher efficiency over a longer period of time (right). With some additional maintenance, it may be self maintaining, proving in the long run to be a cheaper alternative .




### 2. Improved habitat

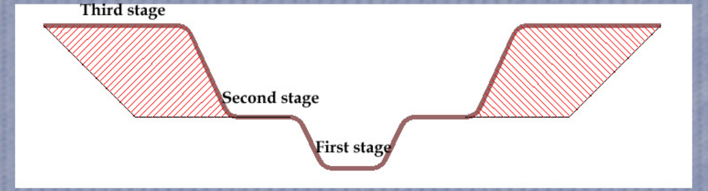
The two photos above contrast the amount of vegetation on a traditional ditch versus a naturally formed two-stage ditch. These photos were taken in Hancock County, Ohio. The photo on the left shows a traditional ditch with a wide channel and relatively straight sides. The photo on the right shows a ditch channel with existing benches on either side, covered with grass and other vegetation. The NRCS in Michigan allowed this additional width on the bench to count toward the required grass buffer strip for the ditch built in Hillsdale County. The channel on the left also produces more shade, which acts as protection for biota.

### 3. Tradeoffs

*Economics: $5 to $25 per linear foot for earth moving depending on the depth of excavation required.*

*Loss of land: Found to be approximately 2 acres per linear mile of ditch system for a bench width ratio of 3.*

The constraints of land loss and economics imply that there is a maximum width to which benches can be constructed. Extreme flood events such as the 1 in 100 year flow are unlikely to be contained on the second stage of the ditch. In these extreme cases the benefit of a third stage becomes critical, where the third stage (below) is the agricultural field itself. A risk factor is inherent to all two-stage ditch designs, dictated by the need to keep flows within the ditch while keeping within economic and land loss limits. In many cases the ditches are so incised that building a bench to accommodate moderate flows itself is an expensive operation. This is almost better to leave the ditch cross section alone.





**Funding:** Project Title *Fluvial geomorphology and nutrient processing in low-order streams in Midwestern tile-drained agricultural landscapes.* USDA-CSREES and the EPA-NCER Nutrient Science for Improved Watershed Management Program. Contact: Michael O'Neill, National Program Leader for Water Quality USDA-CSREES, email: moneill@reeusda.gov



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