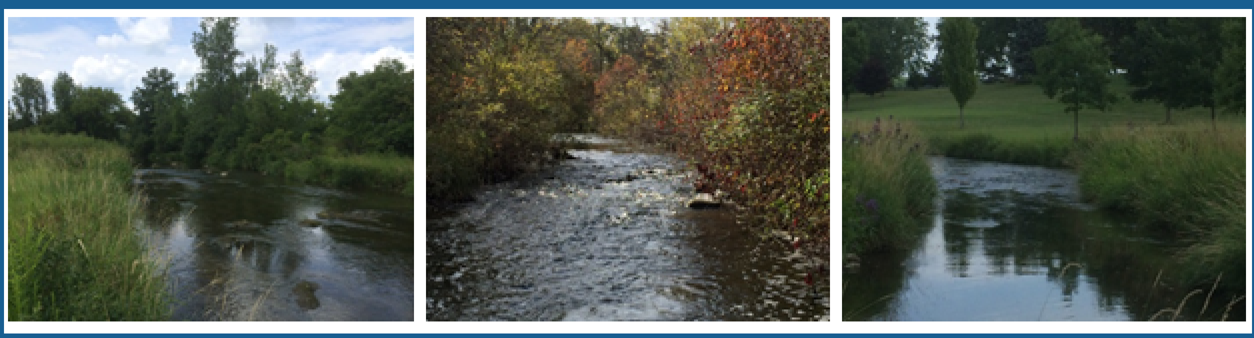
MACOMB COUNTY PUBLIC WORKS OFFICE

OPEN DRAIN DESIGN & TECHNICAL GUIDELINES

Development of Stable Open Channel Design Criteria, Sea Grant Project Number R/CCD-30



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Executive Summary

Open drains can be managed more effectively using a two-stage or multi-stage channel design approach. Rather than simplifying the channel, we must mimic the complexity of natural stream systems to provide different forms of energy dissipation. Designing stable alluvial channels that are self-sustaining improves the chances of long-term stability. Understanding the stream morphology and sediment transport characteristics can be complex, but the results would be well worth the effort.

Benefits:

- Reduced risk of failure, nuisance species,
- Improved conveyance at road/stream crossings
- Reduced flood stage and prevention of debris jams
- Erosion control (RECPs, native veg.)
- Manage (native) riparian vegetation for vertical diversity

Drainage Districts The long-term drain maintenance costs and ultimately decrease harbor dredging frequency can be reduced with better drain design

Abbreviations

FISRWG	Federal Interagency Stream Restoration Work Group
FWR	Floodplain Width Ratio
LWM	Large Woody Material
MCPWO	Macomb County Public Works Office
NEH	National Engineering Handbook
NRCS	National Resources Conservation Service
NREPA	Natural Resources and Environmental Protection Act
ODNR	Ohio Department of Natural Resources
RAP	Remedial Action Plan
RI	Recurrence Interval
RIC	Riparian Improvement Cut
ROW	Right of Way
SESC	Soil Erosion and Sediment Control
TMDL	Total Maximum Daily Loads
USACE	United States Army Corps of Engineers
USFS	United States Forest Service
WDFW	Washington Department of Fish and Wildlife
WMP	Watershed Management Plan

Glossary

1% Chance Floodplain: The floodplain area subject to a one percent chance of flooding in any given year.

Bankfull Channel: The lower stage, meander channel that corresponds to the capacity of the channel-forming (dominant) or effective discharge at the point of incipient flooding.

Bankfull Discharge: In stable alluvial streams with a fully connected floodplain, the point where the flow (of a stable channel) just begins to overtop the banks into its floodplain. It is determined in the field by surveying visual indicators along a stable, undisturbed reference reach.

Belt Width: the amplitude of a channel meander measured in the plan view.

Buffer Strip: A zone where plantings capable of filtering stormwater are established or preserved and where construction, paving and chemical applications are prohibited.

County Drain: An open or enclosed stormwater conveyance system that is under the legal jurisdiction of the Public Works Commissioner for construction, operation and maintenance.

Daylighting: Removing an existing enclosed storm sewer and restoring an open channel.

Design Storm: A rainfall event of specified size and return frequency (i.e., a storm that has the likelihood of occurring once every 10 or 100 years) that is used to calculate the runoff volume and peak discharge rate.

Discharge: The rate of flow (the volume of water passing a point in a given period of time) leaving an area usually expressed as cubic feet per second.

Drainage Area: The total tributary area of a watershed (in square miles).

Easement (also known as "Right-of-Way"): An interest in land owned by another that entitles its holder to a specific limited use and enjoyment. A legal right granted by a property owner to another entity giving that entity limited use of the property involved for a specific purpose. The Public Works Commissioner secures temporary and permanent easements adjacent to county drains for the purpose of construction and maintenance access.

Effective Discharge: The term effective discharge is the streamflow that does most of the work in transporting the maximum amount of sediment over the long term. It is determined by combining a flow duration curve and a sediment discharge rating curve.

Encroachment: Altering property so as to restrict or burden the interest holder's use of the property.

Entrenchment: The vertical containment of a channel. It is quantified by the Entrenchment Ratio which is the width of the floodprone area divided by the bankfull width. The floodprone area is the channel width at an elevation equal to two times the maximum bankfull depth.

Erosion: The wearing away of the land surface by wind, water, ice and gravity dislodging soil particles. Evidence of erosion includes gullies, rills, sediment, plumes, etc.

Fill: Added earth which changes the contour of the land.

Floodplain: For the purposes of this manual, the (hydrologic) floodplain refers to the area of land adjoining a continuous watercourse that has been covered temporarily by water at flows greater than the channel-forming or bankfull discharge.

Fluvial: Relating to a stream or river; produced by stream action.

Freeboard: The space from the top of an embankment to the highest water elevation expected for the largest design storm to be stored. The space is required as a safety margin in a pond or basin.

Geomorphology: The branch of geology that studies the nature and origin of land forms. The natural forces that shape landforms include water, ice, wind, gravity and time. Fluvial geomorphology is the study of the formation of landforms by the action of flowing water.

Meander Length: The distance equal to one wavelength along a curving stream channel (Figure 1).

Peak Discharge: The maximum instantaneous rate of flow during a storm usually in reference to a specific design storm event.

Radius of Curvature: Describes the symmetrical meander of a stream (Figure 1).

Radius of curvature $R_c = L_m K^{-1.5} / 13(K-1)^{1/2}$

Where: L_m = meander wavelength

K = sinuosity

Regime: Equilibrium or erosion and deposition in a channel over time such that the channel maintains its characteristics

Return (Recurrence) Interval: A discharge based on statistical return intervals. The bankfull discharge (measured in the field at USGS gauging stations) typically corresponds to the 1.2 to 1.8-yr (an average of a 1.5-yr) return interval on a flood frequency curve developed from long-term data at a gauge station. The actual return interval that corresponds to the bankfull discharge in a stream can vary depending on the local hydrology, geology, and hydraulic structures.

Riffle: Shallow, steeper, section of stream with fast currents at low flow.

Sediment: Soil material that is transported from its site of origin by water. May be in the form of bed load (along the bed), suspended, or dissolved.

Sinuosity: The ratio of stream length to valley length or the ratio of valley slope to stream gradient (Figure 2).

Stability: The ability of a channel to transport the water and sediment of its watershed in such a way to maintain its dimension, pattern, and profile over time without either aggrading or degrading.

Stream: By MDNR definition; "a river, creek, or surface waterway that may or may not be defined by Act 40, P.A. of 1956: has definite banks, a bed, and visible evidence of continued flow or continued occurrence of water, including the connecting water of the Great Lakes".

Stream Order: The Strahler method for classifying streams as part of a drainage network. The smallest unbranched mapped tributary is classified as first order; the stream receiving the tributary is classified as second order and so on. Streams that have no branches or tributaries are first order. Streams that receive only first order streams are second order. Streams that receive only first and second order streams are third order. The mainstem always has the highest order.

Water Surface Slope: The slope of the channel as measured at the water surface to represent the average energy grade of the channel. It is measured at two comparable points along the channel such as the upstream start (or crest) of two riffles.

Wavelength: The length of one meander along the down-valley axis. A meander is two consecutive loops pointing in opposite transverse directions.

Width-to-Depth Ratio: Determined by the ratio of bankfull surface width to mean bankfull depth.

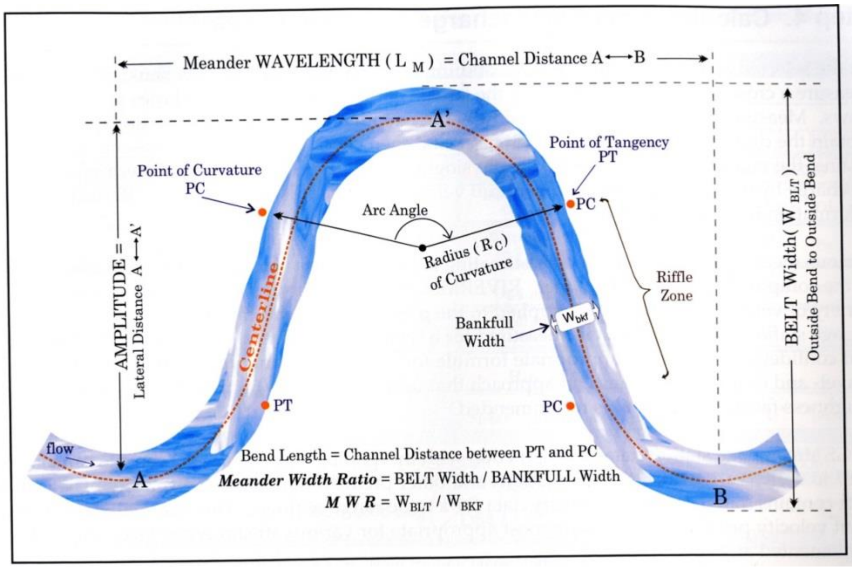

Figure 1 Meander Geometry Descriptions (Rosgen 2006, used with permission)

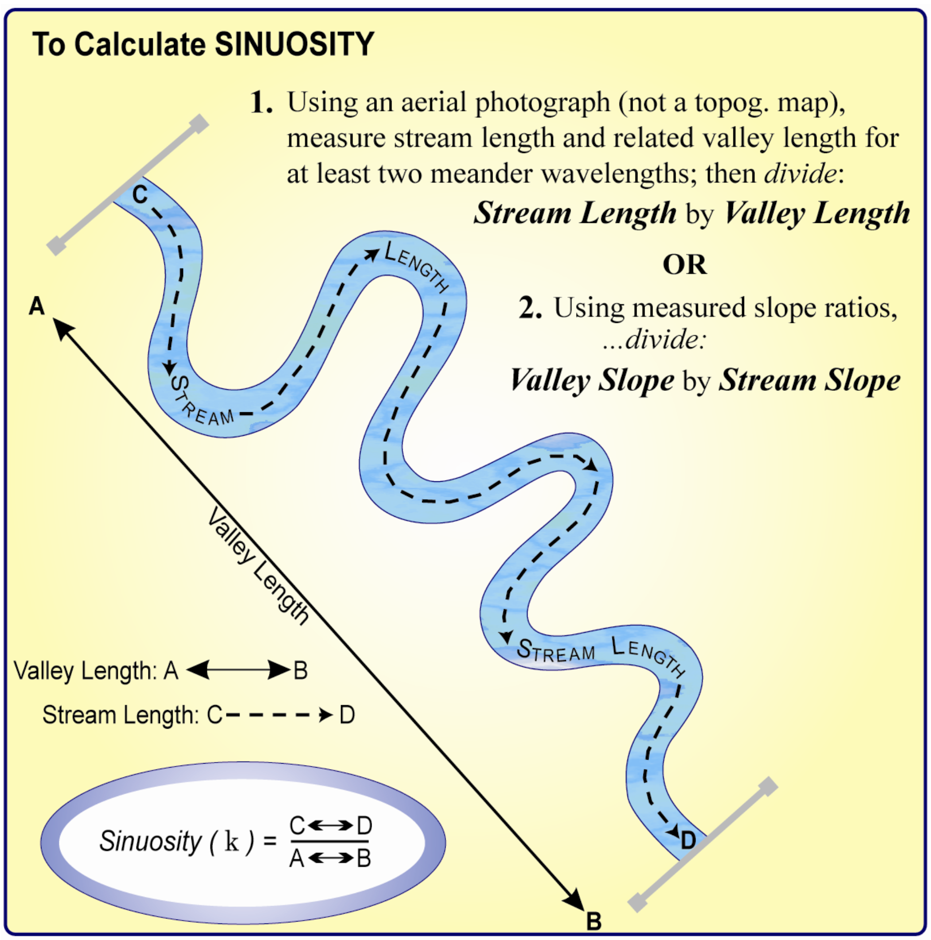

Figure 2 Determination of Sinuosity (Rosgen 2008)

1.0 INTRODUCTION

1.1 PURPOSE

Macomb County is subject to a Phase II General Stormwater Permit that requires the County to regulate both the quantity and quality of storm water runoff to state waters. Watershed Management Plans (WMPs) have been developed for most of the subwatersheds in Macomb County and outline water quality, habitat, and recreation improvement objectives. Open county drain improvement projects offer opportunities to partially or fully achieve these objectives.

The typical channel cross section for an open drain in Macomb County is a multi-stage design. The channel has at least two, but may have several, stages, including a low flow channel, an active bankfull channel, and a larger floodway that may have one or more stages (terraces). In some cases a two-stage channel is appropriate; short reaches of armored trapezoidal channels may be allowed in transitional areas with severe site constraints (such as a road crossing). However, different design approaches are allowed that may achieve even greater channel stability and meet subwatershed-specific goals and objectives related to water quality and riparian and aquatic habitat improvement. The Macomb County Public Works Office (MCPWO) encourages the use of such designs.

The purpose of this document is to provide guidelines for channel designs that will result in stable channel conditions that improve conveyance, minimize reducing long-term maintenance, and reduce water quality impacts. These designs include:

1. Multi-stage channel design,
2. Enhanced channel design, and
3. Geomorphic channel design.

Table 1.1 Comparison of Open Channel Design Approaches

	Multi-Stage Channel	Enhanced Channel	Geomorphic Channel
Objective	Restore minimum floodplain width and low flow channel, improve stability and capacity	Restore some ecological values, widen floodplain, provide habitat and canopy	Restore a stable, sustainable, self-maintaining channel with the most ecological value
Description	Floodplain bench at the bankfull elevation, low flow channel included, existing streambed features (riffles and pools) preserved,	Floodplain connectivity, aquatic habitat structures, increased sinuosity and roughness	Restored channel dimension, pattern, and profile; improved hydraulics, water quality, and habitat diversity; good/excellent water quality
Complexity of Design	Low	Moderate	High
WMP Goals	Improves water quality and stability	Improves water quality, stability, and ecological function	Improves water quality, stability, ecological function, and sediment transport
Water Quality	Good/fair	Good	Good/excellent
Stability	Better than trapezoid-shaped channel	Depends on design and construction skills	Highly stable
Sustainability and Maintenance	Better than trapezoid-shaped channel; low-to-moderate maintenance needs	Better than trapezoid-shaped channel; low maintenance needs	Self-sustaining; very low maintenance needs
Habitat/Ecology	Moderate	Better	Optimal
Long-term Maintenance Cost	Low	Low	Very low
Comments	Restores floodplain connectivity with a narrow, floodplain bench	Restores broader floodplain connectivity, addresses some aspects of stream morphology and habitat	Comprehensive approach considers hydraulics, stream morphology, sediment transport, and ecology
Requirement	Minimum county standard	Needed to meet WMP goals	Encouraged

1.2 BACKGROUND

The Problem

The conventional trapezoidal drain (drain) is highly efficient at providing drainage and moving flood flows, but has a high risk of failure. A drain is simple to build, but channel simplification does not consider negative externalities. Conventional drains have many problems including:

- drains are prone to bank erosion and channel bed sedimentation
- require ongoing dredging and maintenance
- suppress local property values rather than being a site amenity
- are susceptible to increased erosion during flood events impair aquatic habitat and provide marginal riparian habitat
- tend to warm water temperatures, increase turbidity, and lower oxygen levels
- do not have the ability of streams to naturally assimilate pollutants
- convey pollutants to receiving waters

The high cost of ongoing maintenance and indirect costs are caused by outdated design practices and these practices are widespread. Most of the headwater stream miles in Michigan's Lower Peninsula are likely county drains. Although this demonstrates the massive scope of the problem, the Drain Code also represents an existing mechanism for extensive water quality and habitat improvement throughout the state. The proposed Integrative Assessment will have a tremendous impact on the entire Great Lakes basin.

The Solution

Open drains can be managed in a cost-effective self-sustaining manner using a two-stage or multi-stage channel design approach. Rather than simplifying the channel, we need to mimic the complexity of natural stream systems. Understanding the stream morphology and sediment transport characteristics is extremely complex, but the results would be well worth the effort. Better drain design would reduce long-term drain maintenance costs and ultimately decrease harbor dredging frequency. It would also address Beneficial Use Impairments (BUIs) in the Clinton River such as:

- Eutrophication or undesirable algae
- Degradation of fish and wildlife populations
- Degradation of aesthetics
- Degradation of benthos
- Loss of fish and wildlife habitat

Designing constructed channels that mimic self-sustaining natural systems is a proven way to improve the chances of long-term stability. Macomb County has developed the first open channel design criteria in Michigan which incorporates a multi-staged design approach – a low flow channel (where appropriate), a bankfull channel, as well as flood conveyance.

Effective open channel design greatly eliminates future maintenance needs and can improve channel stability and water quality of the natural receiving waters further downstream. The adoption of sustainable drainage rules, with allowances for site-specific exceptions, could have tremendous beneficial impacts on Michigan rivers. Vegetation management guidelines that allow for vertically diverse native plant communities – trees, shrubs, and herbaceous understory would also reduce water temperatures, erosion and water quality degradation. Excessive growth of invasive shrubs can shade the banks and prevent understory growth which stabilizes the banks. Complete clearing of all woody plants can increase wind erosion, promote the growth of cattails or phragmites, and increase water temperatures.

1.3 HISTORY AND VALUE OF DRAINAGE

Drainage has not been a primarily recent issue. Drainage in the Midwest can be traced back to colonization. Prior to this, much of the Midwest was made up of vast wetlands. This land was ideal for cropland as it was extremely fertile; in order to utilize this soil, the land was drained continuously to keep it from being inundated and to prevent crop-loss from excess water. As technology furthered in the late 1800's, open-ditch drainage networks and subsurface drainage systems were put in widely (Dahl and Allord, 1997).

In addition to preventing inundation and allowing naturally wetland to be used for farming, drainage networks also allow more flexibility for farmers: a wider variety of crops can be planted, crops can be planted earlier, and crops are less susceptible to pests that thrive in marsh-like conditions, preventing the necessity for over-application of fungicides and pesticides (Blann et al. 2009). They also provide habitat for plants, invertebrates, fish, amphibians, birds, and even mammals and function as ecosystems with respect to nutrient cycling, erosion control, water purification, and even providing pollination and pest control (Herzon and Helenius 2008).

Traditional drainage

Initial drainage systems focused on straightening and expanding existing streams and connecting agricultural fields to waterways done by dredging. These are designed to transport run-off from large storm events. Many drain codes reference a trapezoidal or V-ditch design to transport run-off, as these are simple to design.

Subsurface Drainage

Subsurface drainage has also been an option for shifting inundated land to agricultural land. Although it requires a greater initial investment, subsurface drainage allows quicker drainage and requires less space than drainage ditches. Subsurface drainage can also be used to control the water table better, allowing plants to root deeper and grow larger. Despite these seeming benefits, tile drainage reduces the residence time of the water and serves as a more direct route for nutrients to reach waterways, causing higher nutrient transport rates.

1.4 IMPACTS OF TRAPEZOIDAL CHANNELS

Drains have been constructed to move water from agriculture fields as quickly as possible. During large storms, it's easy for land to get flooded. By making drainage systems that transport these large volumes of water as quickly as possible, a lot of flooding issues can be prevented. However, this traditional way of building ditches has caused issues within ditches and downstream of ditches.

As mentioned earlier, drainage practices in the Midwest initially focused on straightening and deepening the natural channels in order to facilitate the run-off water. However, this design separates the stream from the floodplain, decreases the wetted perimeter, and decreases residence time within the waterways. They also require frequent dredging to dispose of sediment buildup within the streams, which decreases the natural ecological function of the waterways. In addition, these increase the transport rates of phosphorus and nitrogen, increasing nutrient loading downstream. For example, Lake Erie is impacted by nutrient transport: hypoxic conditions and excess algae growth occur in the system and much of this is due to non-point source run-off from agriculture (Robertson and Saad 2011). Much of the research done on drainage has found that the geomorphologic features that work best are those that reconnect the floodplain to the stream (Madramootoo et al. 2007), increase the residence time within the waterways (Schottler et al. 2013), and decrease slopes and increase adsorption areas on the walls of the ditches (Shore et al. 2014); trapezoidal designs don't usually account for these objectives.

2.0 OPEN CHANNEL DESIGN APPROACHES

2.1 INTRODUCTION

The multi-stage channel design approach is Macomb County's minimum standard for open county drain design. However, state and federal agencies often have additional requirements where they have jurisdiction to review drainage improvement, channel re-location, or mitigation projects. Enhanced and geomorphic channel design methods may meet these additional requirements and can also be desirable based on the goals of a watershed management plan (WMP), site constraints, or desired ecological outcome. Macomb County encourages the use of enhanced and geomorphic channel designs, but does not specifically require them. Figure 2.1 illustrates the county's flexibility to this variety of channel design approaches.

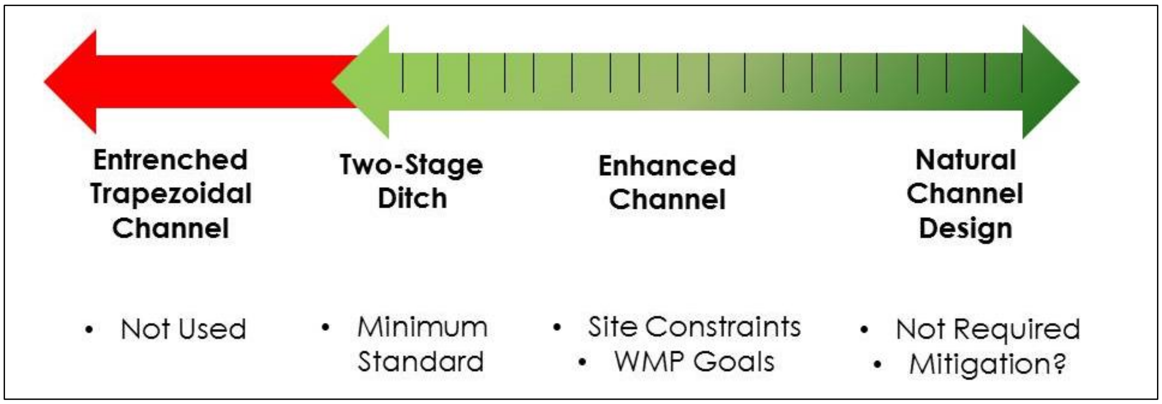

Figure 2.1 Flexibility of the Macomb County Channel Design Approach

2.2 MULTI-STAGE CHANNEL DESIGN

The typical channel cross section for an open county drain is a two-stage or multi-stage design. The channel may have several stages but, at a minimum, must consist of a smaller (bankfull) channel within a larger drain corridor or floodway (see Figure 2.2). The criteria for the multi-stage design are presented in Macomb County's Procedures and Design Standards for Stormwater Management (MCPWO, 2008). A multi-stage channel design improves the previous, trapezoidal channel design because it:

- Reduces long-term maintenance due to less erosion or bottom deposition,
- Reduces negative water quality and thermal impacts to receiving streams in compliance with local watershed plans, remedial action plans (RAPs), total maximum daily loads (TMDLs), and/or storm water permits,
- Reduces downstream flooding impacts by increasing floodplain capacity and bank storage,

- Provides a modified, but intact, riparian corridor to provide shade to prevent aquatic plant over-growth such as cattails and phragmites and for habitat connectivity, and
- Improve site aesthetics and property values.

The features of the multi-stage design are discussed in more detail below.

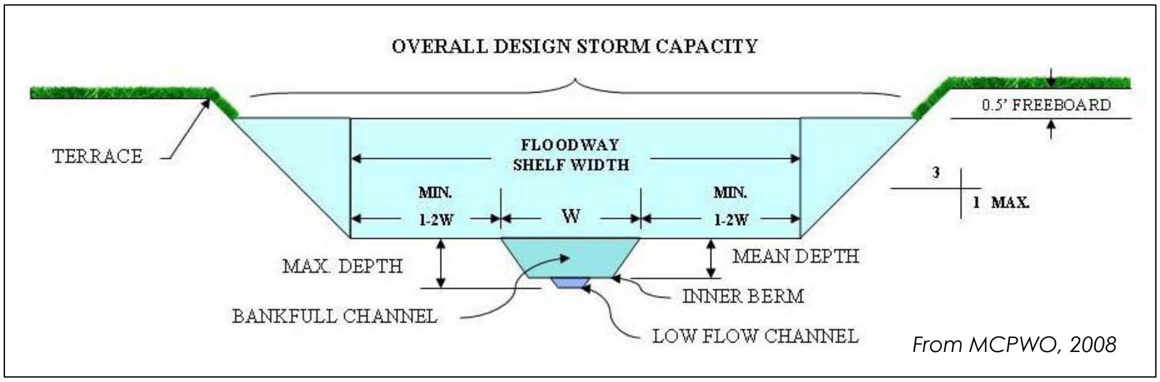

Figure 2.2 Typical Multi-stage Channel Cross Section

2.2.1 Low Flow Channel

The construction of a low-flow (or thalweg) channel is beneficial in drains that transport gravel bed material. A low flow channel maintains channel velocity and depth during periods of low discharge; this improves sediment conveyance and reduces sediment deposition. The low flow channel is constructed to create a deeper area (thalweg, flow line) within the open drain. Additional information on inner berms can be found in Chapter 11: *Stream Restoration Design* of National Resources Conservation Service's (NRCS) National Engineering Handbook (NEH) 654 *Stream Restoration Design* (NRCS 2007).

2.2.2 Bankfull Channel

The bankfull channel simulates the active channel area that conveys the channel-forming discharge. This channel is "inset" into the larger drain corridor (floodway). It may not always be centered within the floodway; rather it is allowed to meander and adjust to changing watershed conditions. However, allowing the channel to meander up against the upper side slopes of thee terrace should be avoided. The capacity of the bankfull channel corresponds to the bankfull discharge, which has been found to approximate a 1.1-1.3-yr recurrence interval (RI) discharge within the Clinton River North Branch and Middle Branch subwatersheds.

2.2.3 Drainageway

2.2.3.1 Active Floodplain

Benches are designed adjacent to the bankfull channel to serve as an active floodplain and dissipate energy during storm events that cause flow to come out of the bankfull channel. Floodplain benches help maintain a state of dynamic equilibrium within the open drain; this can reduce long-term maintenance needs. Increasing floodplain bench width generally reduces maintenance needs and improves water quality, habitat, and other stream functions. The benches along each side can vary in width, particularly if the channel meanders.

2.2.3.2 Upper Stages

The area above the active floodplain may have additional stages due to terraced side slopes, setback levees, and regulated floodplain boundaries. A freeboard depth of 0.5 ft or more must be provided between the 10-yr flood stage elevation and the top of the lowest bank (MCPWO, 2008).

2.3 ENHANCED CHANNEL DESIGN

The enhanced channel design approach is a stable channel with some restored ecological function for an intermediate cost and level of effort (Figure 2.3). In relation to open drain design, this approach may become necessary when the bankfull channel must be re-meandered to adjust slope or the channel dimensions. The need to alter channel dimensions, meander pattern, or profile is determined during the drain assessment phase and verified when the sediment transport analysis indicates excess shear stress or deposition.

Enhanced channels maintain or restore the meandering form of the channel and provide an appropriate channel gradient (or slope). The stream bed topography of enhanced channels is somewhat variable and usually includes riffles and pools where gravel is present. Existing riparian and in-stream habitat features are preserved; additional or new features are included with the design to improve energy dissipation. Enhanced channel designs often include the use of woody material in the stream, woody material management activities, vegetative buffers, and features to increase channel roughness.

The use of channel enhancement practices, in addition to the minimum multi-stage design requirements, is encouraged by the county based on the goals and objectives of the applicable WMP. Additional guidance on the design of enhanced alluvial channels is available in NEH-654, Ch. 11 (NRCS, 2007). Information on stream corridor processes is available in NRCS, NEH-653 *Stream Corridor Restoration: Principles, Processes, and Practices* (FISRWG rev. 2001).

Figure 2.3 Enhanced Channel

2.4 GEOMORPHIC CHANNEL DESIGN

Geomorphic channel design, also called natural channel design, is a comprehensive approach that incorporates natural stream processes into the restoration design to establish a self-sustaining ecosystem and maximize the stream's ecological potential. Geomorphic channel design involves restoring the dimension, pattern, and profile of a disturbed channel by emulating a natural, stable river. This approach combines analog, empirical, and analytical methods for channel assessment and design (Rosgen, 2007). Ecological restoration principals and restoration of processes such as floodplain and groundwater connectivity are considered. Water quality is also improved by restoring natural processes of pollutant assimilation.

The geomorphic channel design approach requires extensive training and an inter-disciplinary team with knowledge of hydrology, channel hydraulics, sediment transport, fluvial geomorphology, native vegetation, and aquatic and riparian ecology. Macomb County encourages geomorphic channel design where feasible. Geomorphic channel design is the current state of the practice. If Michigan state and federal agencies have jurisdiction to review drainage improvement, channel re-location, or mitigation projects, this approach may be required. Procedures for the natural channel design approach are presented in NEH-654, Ch. 11 (NRCS, 2007).

3.0 LANDSCAPE CONTEXT

3.1 INTRODUCTION

Macomb County realizes that there is not a "one size fits all" solution to designing open drains. The same channel design may not be appropriate in all parts of the County or even along the same open drain because of specific site conditions and constraints.

The county's standard multi-stage design is a minimum requirement, but may not be possible or applicable in certain situations. Valley type and channel type are fundamental design considerations; land use, encroachments, existing vegetation, topography, and other site constraints must also be considered when selecting the appropriate channel design approach. Even when the minimum design approach is used, additional site assessments, calculations, modeling, and analysis will usually be necessary to address site-specific circumstances (for example, culvert analyses and modifications may be required for roadway crossings impacted by open county drain projects). The intent of improvements to open county drains is to:

- Provide conveyance of the design flood with adequate floodplain bench width or setback levees.
- Size the channel for the channel-forming or bankfull discharge to improve stability (ex. maintain the design dimensions, slope, and pattern without excessive bed deposition or erosion (Rosgen 1996).
- Consider site constraints and beneficial land uses.
- Minimize long-term maintenance requirements.
- Demonstrate short- and long-term cost-effectiveness.
- Reduce downstream impacts (impacts to receiving waters).
- Meet the goals and objectives of applicable WMPs.

3.2 VALLEY TYPES

Valley types provide the foundation for river classification and applications. Dave Rosgen (Rosgen 2012) describes how river valleys are categorized into broad geological types that reflect specific boundary conditions and influence the movement of water and sediment. The boundary conditions are:

- Valley Materials: Valley materials determine the type of sediment available to the channel, the class of riparian vegetation, side slopes, and flow resistance.

- Valley Morphology (Shape): The width, slope, and sinuosity of the valley affect the same variables of the channel.

- Riparian Vegetation: The percentage and density of each class of vegetation (trees, shrubs, and herbaceous plants) affect channel roughness, shade, and stability.

- Large Woody Material: The availability of large wood after construction has an impact on channel roughness, energy dissipation, pool formation, and grade control.

Natural streams in southeast Michigan flow through valleys created by glacial activity; county drains flow through constructed valleys. In either case, the characteristics of the valley influence channel design. Even when local site constraints influence the valley type that can be constructed, understanding the broader watershed and landscape context is an important consideration.

In Macomb County, tributaries to the west historically flowed through Valley Type VII (wide, gently sloped valleys with well-developed floodplains adjacent to rivers and/or glacial terraces). Tributaries in the east part of Macomb County historically flowed through Valley Type X (very broad and gently sloped valleys associated with glacio- and nonglacio-lacustrine deposits). The surface geology of Macomb County is available from the Michigan Natural Features Inventory website (http://mnfi.anr.msu.edu/data/quatgeo/Macomb.pdf). Rosgen (2012) provides a detailed description of the Rosgen system of valley classifications.

3.3 CHANNEL TYPES

Understanding channel types can guide open county drain design and serves as an effective communications tool. More information on stream classification and channel types can be found in *Applied River Morphology* (Rosgen 1996) and *Technical Supplement 3E Rosgen Stream Channel Classification Technique—Supplemental Materials* in NEH-654, Ch. 11 (NRCS, 2007).

The Rosgen stream classification system (see Figure 3.1) is based on quantitative measurements of channel morphology (shape). Rosgen (1996) lists the following objectives of stream classification:

- To predict a stream's behavior from its appearance.

- To develop specific hydraulic and sediment relationships for a given stream type.

- To provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics.

- To provide a consistent framework of reference for communicating stream morphology and condition among a variety of disciplines and interested parties.

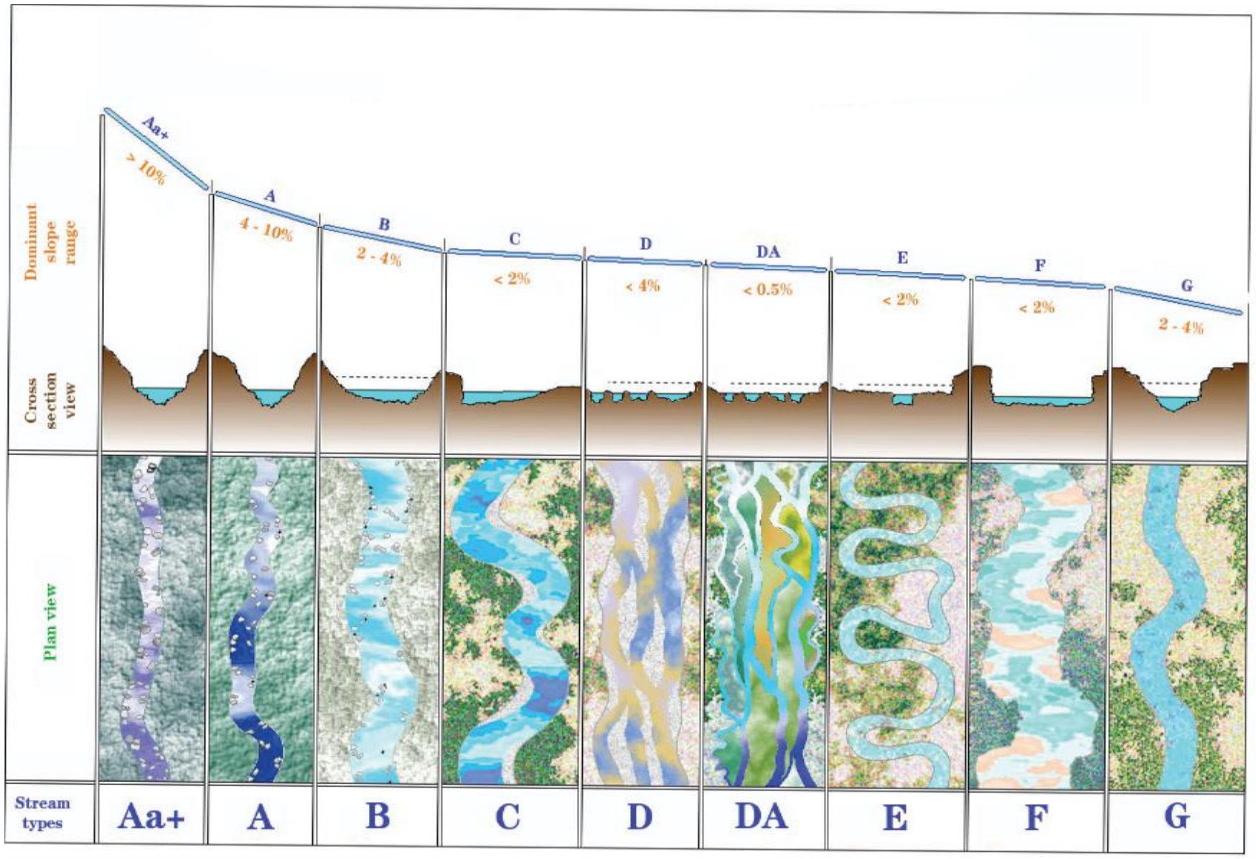

Figure 3.1 Rosgen Stream Classification System

The open county drain design concept plan should consider the appropriate type of channel to design based on the site conditions, potential, and constraints. Natural streams in Macomb County were historically Rosgen C and E stream types. In general, smaller streams (with a drainage area of <5 square miles) were usually Rosgen E stream types and larger tributaries were Rosgen C stream types. Most open county drains were constructed as wide, deep, Rosgen F stream types. Many have become G (gully) stream types if down-cutting (incision) has occurred. Channels designed using the county multi-stage design approach will typically mimic laterally confined C channels or E channels with limited meandering.

4.0 OPEN CHANNEL DESIGN CONSIDERATIONS

4.1 INTRODUCTION

Most drain projects are unique, with different watershed conditions and site constraints. After considering the landscape context, the designer should complete a channel assessment, determine the site conditions, causes of channel instability (if present), and the most appropriate design approach. Sections 4.2 to 4.9 describe several planning-level design considerations.

4.2 ALLUVIAL VS. THRESHOLD DESIGN

4.2.1 Alluvial Channel Design

In an **alluvial channel,** the bed and banks are made up of mobile sediment and/or soil. An alluvial drain mimics a stream that is self-formed, meaning that the channel is shaped by the water and sediment produced by the drainage district and the ability of these flow to erode, deposit, and transport sediment (alluvium). Most riffles should be constructed with alluvial materials are not heavily armored unless grade control is required at infrastructure (see Section 4.2.2 Threshold Design).

The sediment loading in most open drains in Macomb County is high; these drains should be designed as alluvial channels. Alluvial channels have active beds and are capable of adjusting their boundaries. Low to moderate amounts of channel adjustment and bank erosion may occur over time, but the same stream type is maintained and the overall bed elevation of the channel does not change (i.e. it does not aggrade nor degrade). The bankfull channel is designed to promote a state of dynamic equilibrium. Dynamic in that it is constantly changing at a slow rate and at a state of equilibrium or balance with the incoming sediment load.

It is important to dissipate energy in alluvial channels, particularly in urban watersheds, by maintaining a moderate amount of channel complexity. As water flows downstream, it must expend the energy impart to it by gravity to reduce acceleration. A flat, uniform, flat bed channel with a smooth surface armoring or a monoculture of vegetation is easy to model, but it transfers its kinetic energy downstream. Conversely, a channel naturally meandering within its floodplain tends to dissipate the effects of high magnitude flow events and subsequently reduces the flooding hazard further downstream (Soar and Thorne, 2001). Flowing water uses 2-5% of its potential energy doing work such as moving the sediment produced by its watershed (Gordon et al., 2004).

The stream power generated during overbank events can be moderated by mimicking the complexity of natural systems:

- Allowing the channel to meander within the drain corridor dissipates energy and allows for low rate adjustments in slope over time due to changes in watershed conditions,

- Maintaining or constructing channel boundary roughness components,
- Maintaining or constructing riffle/pool or similar stream bed formations with localized changes in gradient and flow rate variability, and
- Providing access between the channel and floodplain to spread water out when out-of-bank flows occur. Floodplain connectivity is created by constructing benches along the channel at the bankfull elevation. The bank heights can even be reduced to a few inches below the bankfull elevation if there is a high sediment load from upstream.

Sediment transport is a critical design consideration for alluvial channels (see Section 5.2.5). For more information on alluvial channel design, see NEH-654, Ch. 9 (NRCS, 2007).

4.2.2 Threshold Channel Design

In a **threshold channel**, movement of the channel boundary is minimal or nonexistent for stresses at or below the design flow condition. Therefore, it is a rigid boundary system meaning that the bed and banks are designed to not move during the design life of the project.

A threshold channel design approach should only be used in localized areas. This approach involves sizing the materials that form the channel boundary to be immobile (not move) when subjected to the design discharge. In addition, the channel must have sufficient capacity to transport the sediment load from upstream and the surrounding surface water runoff (usually sand and silt) to avoid aggradation. Threshold channels are expensive to construct and maintain and cannot adjust to changes in watershed conditions, therefore, use of this approach should be limited to:

- Sizing stone grade controls where there is high shear stress and the channel can move a larger size particle than what is present at the site or in the watershed.
- The bed is composed of erosion resistant materials.
- The sediment load from upstream has been significantly reduced, such as below dams and in-line weirs.
- Areas where channel movement during the design flow is unacceptable such as under bridges or critical infrastructure that cannot be relocated.

Imported bed material should be natural round rock with no fractured rock or broken concrete to prevent the formation of mid-channel bars that can cause bank erosion.

For more information on threshold channel design, see NEH-654, Ch. 8 (NRCS, 2007).

4.3 DEPENDENT VS INDEPENDENT VARIABLES

Independent variables such as watershed hydrology, sediment regime, channel materials, and valley slope are factors that cannot typically be changed during open county drain design. For example, the upstream and downstream culvert elevations can determine the valley slope. The dependent variables of channel dimension, pattern, and profile must be selected to accommodate the independent variables and then evaluated for stability. For example, if the channel gradient (slope, profile) is reduced, then the channel may need to be narrower and deeper to move the sediment. Leopold (1994) listed eight inter-related channel variables: width, depth, velocity, slope, sediment load, size of sediment, hydraulic roughness, and discharge that should be considered, at a minimum. The NEH-654, Ch. 11 (NRCS, 2007) lists over 60 design variables that can be used in natural channel design, some or all of which may be included in open county drain design.

4.4 REFERENCE REACHES

The typical values provided in Section 5.0 (County Drain Design Guidelines) provide initial design guidance. Where possible, final design parameters should be determined by examining field measurements of a stable "reference" reach. A reference reach is a portion of a river segment that represents a stable channel within a particular valley morphology (Rosgen 1998). For example, bankfull discharge can be determined using Manning's equation after surveying the reference reach's channel slope and cross-sectional area at a riffle (a channel reach that is straight, narrow, and vegetated and unarmored and thus free to move its boundaries). Bankfull discharge for the project site can then be extrapolated by comparing the drainage area of the reference reach to that of the project site.

Designing for natural channel complexity provides better energy dissipation, but simple models assume a straight, uniform channel with clear water discharge. Reference reach data can be collected and used to design for greater channel variability and can also be used to in the design of enhanced channels or geomorphic channels. Measuring characteristics and features in stable channels in areas with similar watershed characteristics can reduce the uncertainty with allowing some channel variability.

A reference reach does not need to be pristine, but it should characterize the stable form of the proposed stream type. The number of quality reference reach site locations is limited in Macomb County, but site selection is important. The following site locations are listed in relation to the project drain site in order of priority (Rosgen, 2011):

1. Immediately upstream
2. Immediately downstream
3. Same channel but not immediately upstream or downstream

4. Within the same watershed

5. Outside of watershed, similar size and scale, and similar landscape and materials

6. Outside of watershed, different size and scale, and similar landscape and materials

An introduction to surveying reference reaches is provided in *Stream Channel Reference Sites: An Illustrated Guide to Field Technique* (USFS 1994). Additional guidance on the reference reach approach is provided in NRCS - NEH654 (NRCS 2007).

4.5 INCISED CHANNELS

Most existing open county drains in Michigan were constructed as moderately-to-deeply incised channels, i.e. the bank height is much greater than the bankfull depth. Rosgen (1997) identified four prioritized approaches for restoring incised channels. These methods are detailed in (Doll, et al., 2003): http://www.fws.gov/northeast/virginiafield/pdf/partners/priority_restoration_defintions.pdf.

These four priorities are useful conceptual designs for planning improvements of channels. Most two-stage ditches are constructed using the Priority 2 approach.

4.5.1 Priority 1

A Priority 1 design includes a bankfull channel and setback levees. If a stable bankfull channel exists, the design may only need to include construction of the setback levees. Each levee should be located at least two times the bankfull channel top width away from the edge of the bankfull channel. This design typically applies only to newly established drains with a drainage area of less than 2 square miles. Priority 1 designs are mostly C or E stream types.

4.5.2 Priority 2

A Priority 2 design includes a two-stage channel (C or E stream type) constructed by excavating a floodplain on one or both sides and grading back and/or terracing the side slopes. The base elevation of the channel bed may be raised, but not up to the historic elevation. Priority 2 designs typically require more excavation than Priority 1 designs. On-site disposal of the excavated material and the reuse of on-site materials such as wood, gravel, and topsoil can reduce costs. Protection of existing woody vegetation from the excavation may be important.

4.5.3 Priority 3

Existing site constraints may not allow for the width of floodplain excavation necessary to create a Rosgen C or E stream type. In this case, a Rosgen B stream type is designed to accommodate the constraints. Narrow floodplain benches are retained or constructed as lateral constraints allow. This Priority 3 approach results in a stream that is narrower, with a series of riffle-pools or step-pools in the stream bed to dissipate energy in lieu of a broad floodplain. These channel use energy dissipation structures such as steps constructed of logs or rock or armored riffles. The use of this approach may be necessary in localized areas, but should be minimized due to the cost of structures.

4.5.4 Priority 4

The Priority 4 approach consists of armoring a conventional trapezoidal channel in place. Localized channel armoring may be necessary at some bridge crossings and around critical infrastructure that cannot be relocated, but its use should be limited.

4.6 ROAD STREAM CROSSINGS

It is important to consider bridge and culvert constrictions along an open county drain whether or not they are involved in the design for several reasons:

- Culvert inverts often control the channel gradient.
- Floodplain benches may need to be gradually tapered back into or out of a constriction at the road crossing.
- Vegetation management and instream structures should not promote debris accumulation or scour at the road.
- In open bottom culvert or bridge crossings, the channel bed should be designed as a riffle to prevent scour and blockages.

Stream morphology, sediment transport, and hydraulic analysis should be considered when sizing and replacing stream culverts. Overly-wide culverts lead to excessive deposition which will cause either a chronic maintenance problem or reduced capacity. A transition must be created that: 1) conveys flood flows up to the design flow for the bridge/culvert, 2) conveys sediment flow without causing additional scour, and 3) does not produce aggradation beneath the crossing (Johnson, et al. 2002). The final sizing of all proposed bridges and culverts should be verified with appropriate hydraulic and sediment transport modeling and analysis of stream morphology and alignment.

The Stream Simulation approach (USFS 2008) provides a detailed description of the latest road crossing design methods. Most of the concepts of the MESBOAC approach to sizing and replacement of stream culverts (Verry, 2005) should be considered as a minimum guideline to improve channel stability and reduce maintenance.

4.7 EXISTING VEGETATION

It is important to minimize the disturbance of existing desirable woody vegetation. Construction can be completed by excavating a floodplain bench at the bankfull elevation with one-sided excavation, preferably along the north side of wooded drains (Figure 4.1). This reduces costs and maintains the vegetative canopy along the south bank where growing conditions are slightly harsher, and vegetation recovery slower following disturbance. However, the construction of floodplain benches may be required along the base of the undisturbed side slope to provide a minimum width that will reduce shear stress along the side slope.

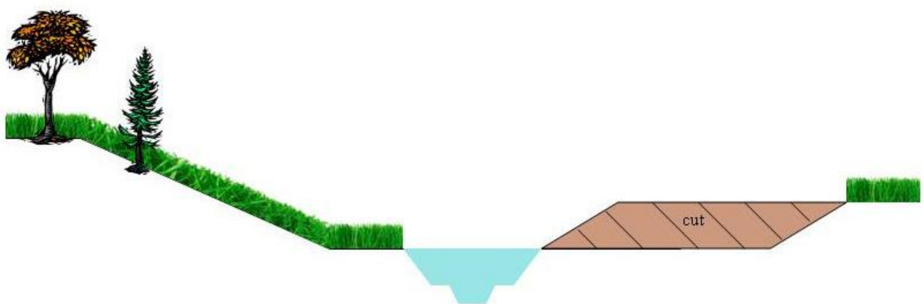

Figure 4.1 Example of One-Sided Excavation

4.8 BANK STABILIZATION

The bankfull channel and upper banks of open county drains should be vegetated and unarmored. Because drain projects tend to be linear, the floodplain benches and upper side slopes of larger projects may be cost-effectively stabilized with wood fiber based hydraulic mulches or blown straw with tackifier or crimping. Channel banks and slopes steeper than 2:1 (H:V) should be stabilized with appropriate rolled erosion control products and native vegetation or soil bioengineering stabilization using native vegetation. Macomb County's *Procedures and Design Standards for Stormwater Management* (MCPWO 2008) provides guidelines for erosion control blankets and other rolled erosion control products in Appendix H. Information about stream bank protection measures is *Integrated Streambank Protection Guidelines* (WDFW, 2003). NRCS, NEH654, Ch. 11 (NRCS 2007) has guidelines on flow redirection techniques to reduce near-bank shear stress such as J-hook vanes.

Rock revetments or deflectors should be localized measures used only where necessary such as to protect infrastructure. The use of extensive boulder structures, cross-vanes, and J-hook vanes is typically not necessary along the low energy channels in Macomb County.

4.9 SOIL EROSION AND SEDIMENT CONTROL

Macomb County's Soil Erosion Control Ordinance requires a Soil Erosion and Sediment Control Permit for most open county drain projects. The timing, sequencing, and phasing of projects should be planned to minimize the area and duration of disturbance. Disturbed areas must be stabilized within 5 days of final grading which may involve stabilizing constructed reaches in phases rather than having miles of disturbed open drain at the same time. The use of temporary in-stream sediment traps may be required, but their effectiveness is limited in clay soils.

5.0 COUNTY DRAIN DESIGN GUIDELINES

The following guidelines are provided to assist the engineer with a more efficient plan development and review process. Once site assessments and existing data are compiled, the project manager should meet with the County Engineer to review the general approach and conceptual plan prior to completing and submitting a final detailed design. As previously stated, each site is different and the designer should use professional judgment to determine to most appropriate channel characteristics based on site conditions.

The multi-stage channel is a minimalist approach and more extensive analysis is typically required based on professional diligence. The use of enhanced channel practices or natural channel design should be considered along at least part of the drain based on project goals and/or State requirements. These guidelines will continue to evolve over time as new data is compiled. Check the County's website for periodic updates or addendums.

5.1 INTRODUCTION

During the planning stages, several general guidelines should be considered:

- The minimum Macomb County drain design standard requires the use of a channel with at least two stages for sand bed and a multi-stage channel for gravel bed systems. Exemptions to allow the limited use of an armored trapezoid or constrained channel design may be provided based on existing site constraints that cannot be modified.

- Do not add new and/or remove existing dams, weirs, and in-line detention that can cause maintenance problems and nuisance species. Provide longitudinal connectivity of the channel profile from upstream to downstream and avoid significant changes in gradient, if possible.

- Avoid lowering the base level of the drain bottom to prevent headcutting of tributaries, bank instability, and lowering of the groundwater table. Lower channel bed elevations also require additional width at the top of bank to provide stable side slopes. Grade controls may be necessary, particularly downstream of road culverts.

- Protect existing mature hardwood trees to provide shade and stability. Consider one-sided channel excavation along the channel (ex. north bank) to maintain trees, reduce clearing costs, and minimize the area of disturbance. However, floodplain bench construction may be required along the toe of the undisturbed bank.

- Avoid creating stagnant water conditions at outfalls, weirs, and culverts to reduce sediment deposition and mosquito breeding.

5.2 TWO-STAGE OR MULTI-STAGE CHANNEL DESIGN

County drain design involves the following minimum steps:

- Perform channel stability assessment.
- Estimate bankfull discharge and channel dimensions.
- Survey the project reach.
- Perform preliminary calculations.
- Conduct stability checks and adjust the design accordingly.
- Complete the final channel design.
- Implement post-construction monitoring and maintenance.

Additional steps will often be required depending on the project goals and site constraints. Some of the concepts for alluvial channel design and geomorphic channel design provided in NRCS, NEH654, Ch. 11(NRCS, 2007) may be a useful reference for drain design.

5.2.1 Existing Channel Characterization

- Compile existing information on the open drain, the right-of-way, and the watershed.
- A stability assessment of the channel is highly recommended. At a minimum, a visual and qualitative assessment of channel conditions should be conducted by someone trained in stream geomorphology. Sites with high levels of instability or altered hydrology and sediment regime should consider a more detailed assessment methodology such as the Watershed Assessment of River Stability and Sediment Supply (WARSSS): http://water.epa.gov/scitech/datait/tools/warsss/
- Determine the valley slope, channel slope, and sinuosity (see Glossary). The upstream and downstream bed elevations selected should consist of natural riffle crests, road culverts, weirs, and other grade controls. The valley slope is often an independent variable that will not be changed (Section 4.3).
- Determine the critical grain size diameter. It is important to determine the size of the largest sediment that will be transported into the project reach during the channel-forming discharge (the critical grain size diameter) if more than 16% of the bed material upstream of the project reach is gravel (2 - 64 mm diameter). The critical grain size is represented by the size of the largest bar material or D84 of riffle material. Gravel bed material can usually be characterized by a simple pebble count of riffle areas and/or a sieve of bar material. Note that over-wide reaches of channel may be depositional and not representative of the largest material available to the channel. Professional judgment should be used. Sediment sampling is addressed in Bunte and Abt (2001), NRCS NEH654 Ch.11 and NEH654. TS13A (NRCS, 2007), and Ashmore et al., 1988.
    - ***Sand bed channels:*** Assume that sand and finer material (up to 1-2 mm in diameter) must be conveyed through the project reach.
    - ***Gravel bed channels:*** Determine the D84 of the riffle material (or D100 of the bar material) if more that 16% of the bed material is gravel (i.e. 2-64 mm in diameter).

5.2.2 Design Discharges

The overall capacity of the drain must convey the 10-yr, 24-hr storm plus 0.5 feet of freeboard based on the proposed fully vegetated condition. See MCPWO (2008) for guidance on the 10-yr flood flow for the overall drain capacity. If the project is located within a FEMA-mapped area, then a hydraulic model may be necessary to determine possible changes in 1% annual chance (100-year recurrence interval) flood elevations.

The bankfull channel should be sized to the channel-forming or dominant discharge (Qcf) which is a general term defined as a theoretical discharge that, if maintained indefinitely, would produce the same channel geometry as the natural long-term hydrograph (USACE, 2000). The Qcf is considered to be the same as the bankfull discharge for the purposes of these guidelines. The Qcf has not been calibrated to a specific storm event in Macomb County. There are several ways to determine the Qcf and the use of more than one approach is recommended.

a. ***Bankfull Discharge:*** The bankfull discharge (Qbkf) is the point where the flow just begins to overtop the banks into its floodplain in stable alluvial stream systems with a fully connected floodplain. Bankfull stage is determined in the field by surveying visual indicators along a stable, undisturbed reference reach and then estimating the discharge at bankfull stage using Manning's equation. Bankfull determination requires someone with training in applied fluvial geomorphology.

b. ***Effective Discharge:*** The term effective discharge is the streamflow that does most of the work in transporting sediment over the long term. It is determined by combining a flow duration curve and a sediment discharge rating curve.

c. ***Recurrence Interval (R.I.):*** A discharge based on statistical analysis of annual peak flood data at a USGS gage station with 10 years of record or more. The bankfull discharge in areas of the North Branch and Middle Branch subwatersheds of the Clinton River corresponds to the 1.1 to 1.3-yr R.I. Flood frequency data for USGS gage stations is provided in Table 5.1.

d. ***Localized Regional Curves:*** The bankfull discharge within the Clinton River North Branch and Middle Branch subwatersheds can be estimated with the East Regional Curve for the Southern Lower Michigan Ecoregion (E-SLME) power function:

$$Qbkf = 17.63 \times DA^{0.70}$$

Regional curve relationships can be used to confirm other estimates of channel-forming discharge. The bankfull discharge in other parts of the County may vary depending on the local hydrology, geology, and hydraulic control structures.

Table 5.1 Macomb County Flood Frequency Data

Subwatershed	USGS Site	Description	Road Crossing	Lat/Long (NAD 27)	Drainage Area (mi^2)	$Q_{1.1\text{-}yr}$	$Q_{1.3\text{-}yr}$	$Q_{1.5\text{-}yr}$	$Q_{1.3}$ / DA (cfs per mi^2)
North Branch	4164450	McBride Drain at 24 Mile Road near Macomb, MI	24 Mile Road	Latitude 42°41'14", Longitude 82°55'14"	5.79	77	99	110	17.10
North Branch	4164250	Tupper Brook at Ray Center, MI	29 Mile Road	Latitude 42°45'42", Longitude 82°54'04"	8.62	86	105	114	12.18
North Branch	4164010	North Branch Clinton River at Almont, MI	M-53	Latitude 42°54'59", Longitude 83°02'42"	9.56	117	167	167	17.47
North Branch	4164200	Coon Creek at North Avenue near Armada, MI	North Avenue	Latitude 42°47'41", Longitude 82°52'58"	10.00	91	138	158	13.80
North Branch	4164400	Deer Creek at 25 1/2 Mile Rd near Meade, MI	Hagen Road	Latitude 42°42'39", Longitude 82°51'32"	12.70	257	306	339	24.09
North Branch	4164300	East Branch Coon Creek at Armada, MI	Prospect Ave.	Latitude 42°50'45", Longitude 82°53'06"	13.00	160	255	318	19.62
North Branch	4164350	Highbank Creek at 32 Mile Road near Armada, MI	32 Mile Road	Latitude 42°48'24", Longitude 82°51'08"	14.90	217	350	422	23.49
Middle Branch	4165200	Gloede Ditch near Waldenburg, MI	M-59 (Hall Road)	Latitude 42°37'39", Longitude 82°57'10"	16.00	149	211	241	13.19
Red Run	4163400	Plumbrook at Utica, MI	Ryan Road	Latitude 42°36'05", Longitude 83°04'17"	16.50	193	314	369	19.03
North Branch	4164100	East Pond Creek at Romeo, MI	N Main Street	Latitude 42°49'21", Longitude 83°01'13"	21.80	52	83	105	3.81
Middle Branch	4164600	Middle Branch Clinton River at Schoenherr Road near Macomb, MI	Schoenherr Road	Latitude 42°42'03", Longitude 82°59'44"	22.20	271	448	500	20.18
Red Run	4163500	Plumbrook near Utica, MI	Van Dyke Ave.	Latitude 42°35'01", Longitude 83°01'50"	22.90	114	248	285	10.83
Red Run	4162900	Big Beaver Creek near Warren. MI	Mound Road	Latitude 42°32'31", Longitude 83°02'52"	23.50	200	273	318	11.62
Stony/Paint	4161580	Stony Creek near Romeo, MI	32 Mile Road	Latitude 42°48'03", Longitude 83°05'25"	25.60	69	88	97	3.44
North Branch	4164360	East Branch Coon Creek at 29 Mile near New Haven, MI	29 Mile Road	Latitude 42°45'46", Longitude 82°50'57"	36.10	417	573	680	15.87
Middle Branch	4164800	Middle Branch Clinton River at Macomb, MI	Romeo Plank Road	Latitude 42°42'23", Longitude 82°57'33"	41.00	360	665	843	16.22
North Branch	4164050	North Branch Clinton River at 33 Mile Rd near Romeo, MI	33 Mile Road	Latitude 42°49'11", Longitude 82°58'35"	49.70	291	549	646	11.05
Red Run	4162010	Red Run at Ryan Road near Warren, MI	Ryan Road	Latitude 42°31'46", Longitude 83°04'07"	61.00	1,400	1,744	1,872	28.59
Stony/Paint	4161800	Stony Creek near Washington, MI	26 Mile Road	Latitude 42°42'55", Longitude 83°05'31"	68.20	140	187	227	2.74
North Branch	4164150	North Branch Clinton River at 27 Mile near Meade, MI	27 Mile Road	Latitude 42°43'50", Longitude 82°54'23"	89.60	570	840	1,005	9.38
North Branch	4164500	North Branch near Mt. Clemens, MI	M-59 (Hall Road)	Latitude 42°37'45", Longitude 82°53'20"	199.00	1,120	1,630	2,020	8.19

Velocity: The velocity of the proposed channel can be calculated using Manning's equation and the proposed channel slope and roughness based on the fully-vegetated condition. Check the discharge and confirm that it corresponds to the channel-forming discharge. If not, adjust the channel sinuosity or cross-sectional area accordingly. This may require several iterations.

Verify that the velocity is appropriate by dividing the discharge by the area. The bankfull velocity is typically 2.5-5 ft/s. However, using a minimum velocity approach alone is not recommended for determining channel stability.

The Manning's equation can be used to determine the velocity of the channel with uniform flow:

Velocity (υ) = (1.486 / n) $R^{2/3} S^{1/2}$ (English units)
Where: n = Manning's roughness coefficient
R = Hydraulic radius
S = Channel slope (ft/ft)

The continuity equation (Q = υA) can then be used to determine the discharge.

There are several methods of estimating channel and floodplain roughness:

- Calibrate roughness at a USGS gage station with measured velocity data.
  $n = 1.486 / Q\ (A)(R^{2/3})(S^{1/2})$

- A friction factor approach (υ/υ*) can be used to estimate Manning's n (Table 11-7 in NRCS NEH654, Ch. 11 (NRCS, 2007)). It is based on the channel hydraulic radius and the diameter of bed material of the 84th percentile of riffles.

Descriptive and pictorial guides are also available for estimating channel and floodplain roughness:

- USGS Water-Supply Paper 2339. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains (Arcement and Schneider, 1989)
  http://pubs.usgs.gov/wsp/2339/report.pdf

- Flow Resistance Estimation in High Gradient Streams(Yochum and Bledsoe, 2010)
  http://acwi.gov/sos/pubs/2ndJFIC/Contents/5E_Yochum_01_04_10_2_.pdf

5.2.3 Channel Dimensions

The channel cross-sectional area (A) is a related to the proposed velocity by the continuity equation. The bankfull width and depth refer to the dimensions at cross sections at riffles or shallow cross-over areas between meander bends. Riffles control the channel gradient and sediment transport. Therefore, the design channel dimensions will be a function of its sediment transport capabilities.

A preliminary estimate of the bankfull channel can be determined based on local reference reach surveys. The measured values can be compared to the E-SLME power function (NOTE: this relationship was developed from streams with velocities from 1.7 to 3.4 ft/s and is only applicable within that range.):

$A = 8.26 \times DA^{0.67}$

The width-to-depth ratio is a simple dimensionless measure of shape of the channel cross section that indicates if a stream is wide and shallow or narrow and deep. In general, the width-to-depth ratio tends to be lower in headwater areas, Rosgen E channels, more cohesive soils, and in dense rhizomatous grass/sedge vegetation.

Calculate the bankfull width using $W = (W/d \text{ ratio} \times A)^{1/2}$.
Calculate the mean depth (d) by $d = A / W$.

The riffle and pool features and bed topography of an existing, stable bankfull channel should be preserved. If this is not possible those features should be re-constructed to provide energy dissipation. Pools are typically wider and deeper than riffles with a larger cross sectional area and lower water surface slope.

A bankfull channel riffle cross section with a low flow (thalweg) channel and inner berms is preferred over a trapezoidal channel if the bed material has a high supply of gravel bed material. Inner berm features are used along riffles in Rosgen C and B channels with gravel or cobble beds and a drainage area >2 square miles. E channels have a flat or parabolic bottom. This creates a low flow channel that improves summer flow depth and sediment transport. The East Regional Curve for the Southern Lower Michigan Ecoregion (E-SLME) indicates a cross-sectional area for the low flow channel to be 50% of the bankfull channel. The mean riffle depth is a calculated value. The ratio of maximum depth-to-mean depth is typically 1.2-1.4 for C stream types. However, the preliminary dimensions of low flow channels should be field verified with local reference reach measurements. It may take several iterations to determine the final channel shape once the sediment transport has been evaluated.

5.2.4 Meander Pattern and Slope

Channel sinuosity should be maintained or restored to achieve a uniform rate of energy loss. It may not be necessary to design a detailed channel planform (i.e. meanders, riffles/pools, bend curvature, etc. for a stable multi-stage channel. See Glossary for definitions.

If a change to the channel meander pattern is proposed as part of the open county drain design, then a professional with experience in applied fluvial geomorphology should be consulted. Once a channel layout is developed, it must be checked against the permissible shear stress of the bankfull channel and sediment transport capabilities and then the dimensions or slope adjusted accordingly.

a. ***Belt Width:*** Belt width is limited by the available floodplain width. If more sinuosity is required to reduce the channel slope, then that should be considered when selecting the proposed floodplain width. A floodplain bench of at least 2-6 ft wide should be maintained between outer bends and the upper side slopes.

b. ***Riffle-to-Riffle Spacing Ratio:*** Riffles should typically be 4.5 to 7 times bankfull width apart. For example, if the width of the bankfull channel is 10 feet, then riffles should typically be

45-70 feet apart. Riffles should be located along the cross-over areas in channels that meander (Figure 1). The area under road crossings should typically be designed as riffles and the spacing should be designed accordingly. In general, the riffle spacing should increase with drainage area and decrease in lower gradient channels. Riffle lengths are often about 1-2 times the bankfull width.

c. ***Radius of Curvature-to-Width Ratio:*** Although some sinuosity may be desirable, channel bends should not be too sharp. The radius of curvature (Rc) of bends in the channel will vary with sinuosity and meander length. The radius of curvature-to-width ratio of a bend is typically 2.5-4 or greater.

5.2.5 Sediment Transport

Sediment load needs to be considered in addition to sediment competence or size of sediment moved, particularly in watersheds with an altered sediment regime; for example, channels with excess incoming sediment supply or a lack or bedload due to in-line detention or urban runoff. This will reduce long-term maintenance problems with channel erosion or the need to dredge. See NRCS-NEH654 (NRCS, 2007) for details on determining sediment transport capabilities. HEC-6 or other models may also be used.

Sediment Competence or Entrainment: The ability of the channel to move the largest particle made available from the immediate upstream sediment supply (Rosgen, 2008).

Sediment Transport Capacity: The ability of a channel over a wide range of flows, including floods, to transport the sediment load produced by its watershed (Rosgen, 2008).

Shear Stress: The initiation of particle movement is often related to a shear stress empirically correlated with the corresponding movement of various grain sizes (Rosgen, 2008).

Shear Stress (τ) = 62.4 lb/ft^3 x mean depth x slope

Stream power: Power is the rate at which work is done or energy is expended. Stream power is defined as the rate of energy supply for overcoming friction and sediment transport (Brookes and Shields, 1996). Brookes recommends a gross stream power (specific stream power per unit bed area of bed) of 5 to 35 W/m^2. This guideline is for sand and gravel bed channels only and has not been calibrated on local channels. Channel instability from erosion occurs at higher stream power and instability due to excessive deposition occurs at lower stream power.

Specific Stream Power (W/m^2) = (P)(g)(Q)(s)/W

5.2.6 Floodplain Width

Determine the floodplain width ratio (FWR) as the total floodplain width divided by the channel width. Review the existing woody vegetation, aspect of the drain, site constraints, infrastructure, and right-of-way widths. The floodplain width will likely vary along the length of a drain due to site constraints. Then determine the overall drainage channel capacity and compare it to the 10-yr flow.

The floodway shelf width should be maximized to the widest area available based on the site constraints. The FWR may be based on the watershed goals/objectives (ODNR):

- 3-5 x W for channel stability (minimum requirement as existing site constraints allow),
- 5-10 x W for water quality,
- >10 x W for habitat,
  Where W = the top width of the bankfull channel

A FWR of 3 to 5 should be used for most County drains. Where a FWR of 3 or more is not possible due to existing site constraints, a Rosgen B stream type should be constructed (See Section 5.4). Floodplain width transitions should be gradual to avoid excessive hydraulic head or energy loss.

Exceptions: A minimum FWR of 5 is required on the following County drains:

- All County drains that are tributaries to East Branch Coon Creek upstream of New Haven Road including, but not limited to, Hill Drain, Ray-Lenox Drain, Stark Drain, and Woodbeck Drain. These county drains have a total maximum daily load (TMDL) limitation.
- All County drains that are tributaries to North Branch Clinton River upstream from the confluence of East Pond Creek near 32 Mile Road. These county drains have a trout stream designation.

5.2.7 Final Construction Plans, Monitoring and Maintenance

The location, dimensions, and materials for erosion control, grade control, and tile drain or outfall stabilization measures should be clearly noted. Describe project scheduling, sequencing, and phasing, as necessary. Provide adequate width for an access road along the top of bank, if required, and stabilize. See Section 6 for information on the seeding and planting plan.

A monitoring and maintenance plan must be developed to address localized erosion, manage invasive plants, and over-seed vegetation for a period of at least one year following construction completion. The monitoring plan must include:

- ***Dimensions:*** Insure that there are no areas of over-widening, excessive pool deposition, or mid-channel bar formation. If so, corrective measures may be necessary.
- ***Pattern:*** Monitor for abrupt changes in channel pattern, tight bend radius (low Rc/W Ratio), or chute cutoffs of outer bends. Have changes to pattern altered the channel slope? Is it the proposed stream type?
- ***Profile:*** slope reversals, headcutting, downcutting, excessive deposition.
- ***Materials:*** change in D50 of riffle or bed material.

5.3 CONFINED CHANNEL DESIGN

Rosgen type "B" streams are single thread streams that are moderately confined (entrenched) without a well-developed flood plain, i.e. they have narrow floodplain benches. The B type tends to be dominated with step-pool or riffle-pool sequences, a moderately high width/depth ratios (>12), and moderate sinuosity when they are naturally occurring in a stable condition. Even though they are moderately entrenched (vertically contained), they provide roughness elements that dissipate energy. It is not necessary to fully construct a B channel, but some of the features of this stream type should be used to provide energy dissipation. County drains with a narrow floodplain width do not have much sinuosity or floodplain connectivity, so other mechanisms must be used to prevent transferring energy downstream.

- Managing for a moderate amount of woody vegetation with a dense herbaceous understory will improve bank stability during floods and floodplain roughness.
- Allow a low to moderate amount of large woody material to remain anchored in the channel bed to provide roughness and grade control. Managing for moderate amounts of wood is beneficial (MCPWO, 2011). Any wood proposed during drain stabilization should be firmly anchored or buried with adequate ballast. See Section 6 for further guidance on the management of large woody material.
- Maintaining or establishing a variable bed topography (riffles or steps and pools) will provide flow variability. Grade controls are often necessary and pools can be strategically excavated at appropriate locations – such as near outer bends and where temporary sediment traps are proposed. However, grade controls should be transitioned gradually so that they do not pose sediment transport or aquatic organism passage issues in the future.
- Structures such as vanes, deflectors, and roughened toe protection can add localized roughness conditions that dissipate energy. Designed plunge pools below storm sewer outfalls can mimic natural channel pools.
- Narrow floodplain benches should still be constructed (or maintained) at or just below the bankfull elevation and at least a small amount of sinuosity should be provided.

6.0 VEGETATION PLANTING, CONTROL, AND MAINTENANCE

6.1 PURPOSE

The lateral stability of open county drains depends on well-established vegetation. Proper landscaping practices, soil amendments, irrigation, and appropriate selection of the types and species of vegetation are necessary to establish vegetative cover. Short-term maintenance is often necessary because it may take a few years for native riparian vegetation to become established. Once the drain is stabilized and functioning, only periodic maintenance should be necessary to insure proper functioning.

6.2 MANAGING EXISTING VEGETATION

Part of the conceptual design process involves determining the best approaches to 1) protect, 2) manage, or 3) remove existing vegetation along the drain.

6.2.1 Vegetation Protection

Protect existing healthy native trees and shrubs that are providing stream bank stability. Leave vegetation on stable floodplain benches. Full-scale clearing of wooded drain corridors can often be avoided by single-sided floodplain excavation.

6.2.2 Vegetation Management

Manage desirable vegetation by selective clearing and thinning within the drain right-of way (R.O.W.). Riparian Improvement Cut (RIC) is a forestry term for selective thinning practice that leads to stand improvement. The RIC practice manages vegetation for bank stability and a low to moderate amount of channel roughness. The riparian canopy should be managed for approximately 50-70% shade coverage with the assumption that some additional growth will occur over the following 5 years.

The optimal channel canopy is about 65-75% with a vertically-diverse mixture of trees, shrubs, and herbaceous vegetation (see Figure 6.1). Stream banks are typically bare in areas with 90-100% canopy due to a lack of grass and forb understory vegetation. Conversely, streams with less than 50% canopy lose drainage capacity (cross-sectional area) due to excessive growth of aquatic and emergent vegetation such as cattails and phragmites that increase roughness and cause sediment deposition.

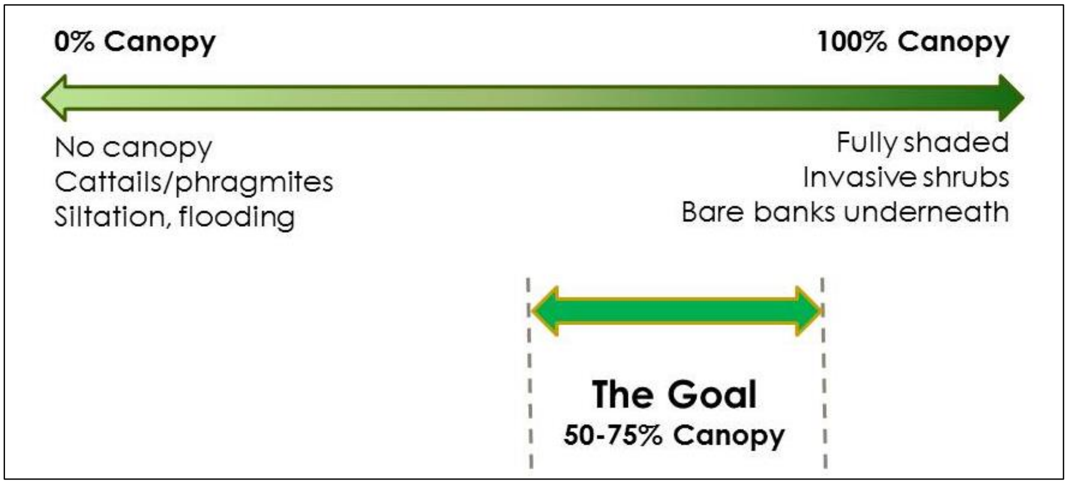

Figure 6.1 Optimal Canopy Density

The RIC practice involves the following:

- Thin trees to a density of approximately one tree every ten feet. Emphasize the removal of dead, diseased, disease-susceptible species, multiple trunks, and less desirable softwood species. Cut stumps to within 6 inches of the ground. Clear branches 6 feet from the ground of trees that are to remain. All pruning and removal must be done in accordance with ANSI A300 and ANSI Z133.1 standards.

- Clear and treat all invasive shrub and vine species within the R.O.W.

- Logs and sale-able timber may be offered to the landowner. Branches and undesirable woody material may be buried, burned, or chipped for upland erosion control mulch.

- Logs, brush (without thorns), tops, and branches may also be used for toe wood structures or bundled with a biodegradable twine or rope and used for bank stabilization. As deposition occurs along toe wood, these areas can be seeded with a wild rye mix following snow melt/spring rains.

6.2.3 Invasive Vegetation Removal

Cut and spray herbicide on existing invasive plant species to remove them from the future project site. It is important to know the timing and treatment methods for the species of concern. Woody species such as buckthorn and honeysuckle require different treatment methods than phragmites and narrowleaf cattail. Prescribed burns may also be used depending on local bylaws. Only approved herbicides should be used, particularly in agricultural areas. Effective treatment of most invasive species may take a few seasons. A list of common species that should be prohibited and should be removed from riparian areas is provided in *Macomb County's Procedures and Design Standards for Stormwater Management*, Table M-6 (MCPWO, 2008). For additional information on common Michigan invasive plants and treatment methods, see http://mnfi.anr.msu.edu/invasive-species.

6.3 LANDSCAPE DESIGN

The design of open county drains should include a landscaping plan. Incorporating regionally native plants into the design is recommended because these plants are better adapted to local climate and soil conditions and tend to need less long-term maintenance. The county may consider waivers from specific landscaping guidelines on a site-by-site basis.

Landscaping plans should be developed to achieve a vertically-diverse mix of vegetation in Drain Right-of-Way areas. Following channel improvements, seeding and plantings in conjunction with soil amendments are used to stabilize bare or disturbed areas. Native shrub plantings are often used as part of soil bioengineering practices to stabilize channel banks and fill slopes. In agricultural areas, the conventional vegetative buffer along the top of bank may be planted with perennial crops by property owners upon MCPWO approval. A mix of nut trees, hay, firewood, berry bushes, or other perennial crops may be grown (with County approval) rather than having the area "taken out of production".

The following general landscaping guidelines apply to county drains.

6.3.1 Erosion Control

Disturbed areas must be stabilized within 5 days of final grading per Part 91, Soil Erosion and Sedimentation (SESC), of the Michigan Natural Resources and Environmental Protection Act (NREPA),1994 PA 451, as Amended. Vegetative stabilization of all disturbed areas with slopes steeper than 4:1 (H:V) should be completed with appropriate erosion control blankets and seed and mulch. Disturbed areas on flatter slopes may be stabilized with appropriate mulching or blankets. Areas exposed to channelized flow may require the use of erosion control blankets, turf reinforcement mats, stone revetment, or other measures to provide stabilization. Guidelines on the application of Rolled Erosion Control Products for permanent erosion control are provided in Macomb County's *Procedures and Design Standards for Stormwater Management (2008)*, Appendix H.

6.3.2 Soil Amendments

In order to promote the establishment of vegetation, topsoil and/or soil amendments may be necessary to establish vegetation in subsoil areas such as newly excavated floodplain benches. A minimum 4" thick layer of planting medium, such as compost or topsoil should be tilled into compacted sub-soils to a minimum depth of 8"-10" and graded. Apply an additional 2" or more of planting medium on the graded surface prior to seeding. Additional soil amendments may be necessary as determined by soil testing. It is the designer's responsibility to consider specific site conditions and standard horticultural practices in the recommendation of soil amendments.

6.3.3 Irrigation

Water newly seeded areas. Maintain adequate soil moisture for at least 14 days or until new grass becomes established.

6.3.4 Mulch

See Table 6.1 for mulching materials for temporary stabilization of areas flatter than 4:1 (H:V).

Table 6.1 Mulch

Material	Amount	Season
Weed free small grain straw	2 tons/ac (normal) 2.5 to 3 tons/ac (critical areas)	All Year
Seasoned hardwood mulch or shredded bark	10 ton (50 CY)/ac	All Year
50:50 Hydraulic mulch (paper/wood fiber)	2,000-4,000 lb/ac	Spring-Summer

6.3.5 Planting Recommendations

The following guidelines apply to restoring, establishing, or supplementing vegetation along open county drains. Specific requirements may vary based on the bankfull channel width, stream type, and site-specific goals and objectives. Riparian vegetative buffers should be established for the entire width of the open drain Right-of-Way. See Section 6.4 for maintenance guidelines.

6.3.5.1 Riparian Vegetative Buffers

The riparian buffer should include 6-10 feet wide no till/no mow/no turf grass zone along the top of bank. Plantings of native hardwood shade trees and shrubs in this upper area and along the side slope terraces provide shade and help lower water temperatures (Figure 6.2). The existing native trees and woody shrubs should be retained to the extent practicable during open drain construction. The priority is to preserve trees and/or shrubs on the east side of north-south flowing channels and on the south side of east-west flowing channels, although large trees on the north side should also be retained. Supplemental plantings of tree and shrub coverage should be established along the channel easement such shading of the bankfull channel is provided.

Consider specifying specific plantings based on the frequency of inundation along the channel banks, floodplain benches, upper side slopes, and top of bank areas.

Figure 6.2 Typical County Drain Riparian Buffers

6.3.5.2 Native Trees

Trees to be planted shall be bare-root and a minimum 1-1.5" caliper. A diverse mix of tree species should be selected that are appropriate to the site conditions. NRCS (2002) recommends the general list of Michigan riparian tree species (see Table 6.2). Other appropriate native trees may be added based on local soils, hydrology, and site characteristics.

Table 6.2 Typical Michigan Riparian Trees

Species	Flood Tolerance	Large Debris	Soil Drainage	Shade Value	Wildlife Value	Height (ft)
Basswood	L	H	WD	H	H	75
Yellow Birch	M	H	W, WD	M	M	70
Silver Maple	H	H	W, WD	H	M	80
Sugar Maple	L	H	WD	H	H	80
Red Maple	H	H	W, WD	H	M	70
Bur Oak	H	M	A	H	H	70
Red Oak	L	M	W, WD	H	H	80
Swamp White Oak	M	M	W, WD	H	H	70
White Oak	L	H	WD, D	H	H	70
White Spruce	M	M	W, WD	M	M	75
Black Spruce	M	L	W, WD	L	M	60
Sycamore	H	H	W, WD	M	H	90
Tuliptree	L	M	WD	M	M	90

Key	
A = All	M = Medium
D = Dry	VH = Very High
H = High	W = Wet
L = Low	WD = Well Drained

6.3.5.3 Native Shrubs

Native shrubs are often used in soil bioengineering practices during fill slope construction or bank stabilization. Shrubs provide much greater soil stability than herbaceous cover without the potential that trees have for windthrow. Low to moderate amounts of shrub plantings are often appropriate for sand and gravel channels with higher width-to depth ratios (>10-12). Hydraulic calculations should consider the presence of mature shrubs in estimates of floodplain roughness.

NEH-654, Technical Supplement 14I – Streambank Soil Bioengineering (NRCS, 2007) provides guidelines on the use and selection of native shrub plantings in bank stabilization.

6.3.5.4 Herbaceous Plants

The native herbaceous understory seed mix may be a commercially-available mix or custom mix depending on soils, hydrology, shade, aspect, and land use. Preferred seeding dates are:

- April 1 – May 20
- August 10 – October 1

Areas should be prepared and final graded prior to seeding to allow good seed-to-soil contact. Planting surfaces shall not be too soft or rain compacted. Seed should be drilled or uniformly broadcast on prepared areas prior to installing mulch, hydraulic mulch, or erosion control blankets.

Acceptable commercial seed mixes for County drains include:

- Genesis Nursery's Urban Wetland/Floodplain Seed Mix or Streambank Stabilization Mix
- Cardno/JF New's Stormwater Seed Mix,
- Native Connections' Stormwater Seed Mix,
- Or custom-made, comparable mix of native seed and cover crop mix.

6.3.6 Vegetation Maintenance

6.3.6.1 Short-Term Vegetation Maintenance

The first year after planting is critical to providing open county drain stability. The following maintenance is recommended:

- Maintenance access routes or travel-ways should be provided on at least one side of open drains as part of drain construction. The travel-ways and access points must blend into the topography, the landscape, and adjacent land uses.

- The drain corridor and surrounding areas should be continuously kept clean during construction and maintenance. The work and staging areas should be cleaned at the end of each day of work.

- Watering during the first year is important; however no watering will be necessary once native plantings are established. Extensive watering may promote disease and lodging (breaking of stalks).

- Limit access to newly seeded areas with fencing, signage, or other appropriate methods.

- Appropriate signage may be necessary to insure preservation, prevent mowing, reduce feeding of waterfowl, or to address safety issues.

- Inspect stabilized areas periodically and following storm events. Stabilize areas of erosion and repair any rills or gullies.
- Over-seed or install supplemental plantings as necessary after the first growing season. Wait several weeks before seeding following any herbicide application.
- Excessive algae and ecologically invasive aquatic plant growth should be removed to prevent competition with native plants, decomposition, nutrient cycling, and associated nuisances.
- The persons responsible for long-term site maintenance should be trained and/or riparian residents should be educated regarding appropriate mowing and maintenance practices. Borders (edging), temporary fencing, or other methods may be necessary to prevent mowing. Permanent boundary markers and signage should be installed to delineate the easement and identify "No Mow" or "Grow Zones". Upland areas above the drain corridor may be maintained annually by mowing or electrical trimming to a minimum height of 6 to 8 inches in late fall or early spring to remove dead plant materials. More frequent trimming and mowing of riparian areas is not recommended.
- Spot treat invasive plants in late spring following construction. Seeded areas with no (or few) woody plantings may be mowed in early May to a height of 6 inches to control weeds.
- Natural vegetation should be allowed to grow along open drains and tributaries to control erosion and provide shading. Shading is a preferred management alternative to cutting and spraying where phragmites and excessive aquatic vegetation are a concern.

6.4 LONG-TERM GENERAL DRAIN MAINTENANCE

A satisfactory agreement that assures long-term maintenance of all drainage improvements should be in place before submission of the final plat. Periodic drain inspections are recommended and the following maintenance guidelines should be applied:

- Excessive algae and ecologically-invasive aquatic plant growth (ex. curly-leaf pondweed) should be removed to prevent decomposition, nutrient cycling, and associated nuisances.
- Woody shrubs may be trimmed to the ground every 5 to 7 years, if necessary, and then allowed to re-grow along open channels.
- Man-made litter and debris should be removed from the drain.
- Inspect outfalls and hydraulic structures for erosion or structural damages.

- Stagnant water conditions should be avoided to reduce mosquito breeding.

6.4.1 Management of Large Woody Material

The *Field Manual on Maintenance of Large Woody Debris for Municipal Operation and Maintenance Crews* (MCPWO, 2011) defines large woody material (LWM) as branches, rootwads, and trees >4 inches in diameter and >6 feet long. The removal of excessive accumulations of LWM from the drain may be required to prevent erosion, debris accumulation, structural problems, and drainage impairment. However, the manual also describes the benefits of moderate amounts of wood. Wood provides structure that can moderate flow, maintain pools, control grade, and trap sediment. The impacts of wood on localized flooding have historically been over-stated. With the two-stage channel approach, the drain usually exceeds the 10-yr storm capacity even if the bankfull channel is completely blocked. The Field Manual can be accessed online: http://www.hrwc.org/wp-content/uploads/2013/03/LWD%20Manual%20Final.pdf

The presence of wood only may begin to become a problem when it exceeds 50-75% of the bankfull cross-sectional area, in which case the central third of the channel should be opened and embedded wood left in place. All beaver dams and large wood within about 100 yards from a road culvert should be removed. Selective thinning and clearing in the floodplain may be required when the Manning's roughness coefficient exceeds 0.15. The materials should be removed and disposed of so they do not re-enter the channel.

The following guidelines are recommended for LWM removal activities:

- Access materials from inside bend (point bar).
- Minimize clearing and disturbance.
- Use the smallest equipment possible.
- Avoid compaction.
- Stabilize disturbed areas (seed and mulch, use erosion control blankets if necessary).
- Burn, bury or pile material depending on land use; locate piles far enough away to prevent them from washing back into the channel.
- Decide whether to protect or cut leaning trees; leave secure rootwads.
- If localized dredging is conducted, locate spoils from removal operations away from the channel. Do not pile soil around the base of trees. Stabilize spoils with seed and mulch or erosion control blankets, if necessary.

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