
Review of an Adequate Outlet

A Subcommittee Report to the Drainage Work Group

The considerations discussed in this chapter/report are intended to capture best practices and considerations for a broad swath of prospective applications and should not be considered to supersede, be a replacement for or bypass other areas of statute, rule or regulations which would otherwise govern the drainage activities.

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Introduction

The adequacy of an outlet is a significant determining factor of whether or not a drainage project can be constructed ([MN Statute 103E.261 Subd 4 \(4\)](#)). While there is guidance in the Minnesota Public Drainage Manual ([MPDM](#)) that provides direction for calculating the outlet adequacy for drainage projects, the guidance has recently been questioned about its accuracy and completeness.

A technical subcommittee of the Drainage Work Group (DWG) was convened to evaluate and provide recommendations to the full DWG regarding “outlet adequacy” as it is referenced in 103E.015 and 103E.261. The intention was to look at terms and methods used to evaluate outlets for drainage projects and to provide options and recommendations to make the evaluation of an outlet a more repeatable and defensible process. The recommendations in this report developed by the technical subcommittee are only intended for consideration by the DWG.

It is important to note that one outstanding legal question led to the most disagreement within the subcommittee, specifically whether the “adequate outlet” applies to **all** of 103E.015 Subd 1 and 103E.261 Subd 4, or specific parts within those subdivisions. Section 103E.015 uses the phrase “adequacy of the outlet” as a part of consideration in Subdivision 1 part 4. This is the only use of the words “outlet” or “adequacy” in 103E.015. Alternatively, there are other items within 103E.015 Subd 1 that must be considered by the drainage authority. Some subcommittee members felt that these items should also be considered as part of determining an adequate outlet. Since the technical subcommittee was not tasked with addressing legal questions or policy, we did not attempt to resolve this. However, this, along with lack of time and the need to include other expertise in the group, led to the subcommittee to limit their focus to the effects of flooding on the adequate outlet.

As the technical subcommittee met and discussed the approach to evaluating an adequate outlet, we quickly realized that since each situation is very unique, it is difficult to define an approach that would work for each situation. However, we did find that while many of the components in the approach discussed by the technical subcommittee were being completed by the drainage engineers, information may not be fully described in the preliminary and final engineering reports. Therefore, one overarching recommendation would be to have the drainage engineers describe fully in their reports *how* a decision was made and the extent of their evaluation.

Some subcommittee members felt this effort is not the completion of this task, but only progress on the discussion. There are several items that the subcommittee is recommending that the DWG discuss to help determine next steps. These are summarized at the end of this document.

It should also be noted that this document provides a broad suite of definitions, considerations, and best practices for determining an adequate outlet and assessing the adequacy of outlets as it relates to MN Statute 103E. Unless otherwise adopted in statute, these definitions, considerations, and best practices comprise a list of options and should not be assumed as all-inclusive of the considerations or methodologies needed to assess adequacy of an outlet for every potential drainage related action under 103E. Furthermore, they should not be considered to supersede, be a replacement for, or bypass areas of statute, rule, or regulations which would otherwise govern the drainage activities.

Summary of Consensus Items

This report contains extensive information on the approach and discussions had by the technical subcommittee. This section is intended to give the DWG a reference to where the subcommittee was able to find consensus or and when there was not consensus as we worked through this process.

Issue	Consensus	Non-consensus	Page Number(s)
Purpose Statement	Purpose Statement		6-7
Definitions	Definitions other than "Impact*" and "Adequate"	"Impact*" definition considers flood impacts only. "Adequate" does not consider all water quality impacts	7-10
Evaluating Impact*	Approaches to how flood impacts and channel stability can be evaluated.	Does not include impacts outside of flood impacts, such as water quality	8-9
Information needed for the FER/PER	Engineer should supply sufficient information in FER/PER so the full extent of engineering is understood.	Recommended Approach does not consider items outside of 103E.015 Sub 1 (4)	10-12
Natural Channel Stability	The existing outlet's stability can help inform the design considerations of a proposed project in an effort to ensure an adequate outlet.	There was not consensus if a project could be constructed upstream of an unstable outlet.	11-12
Storm Events	Evaluations should include the 5-, 10-, 25-, and 50-year, 24-hour storm events, and in some instances longer events. Bankfull or channel forming events (generally 1.5-2-year) are difficult to model reliably using the models typically used by drainage authorities, but other methods can be used to estimate these events.	Whether or not the bankfull or channel forming events (generally 1.5-2-year) need to be modeled for drainage system improvements. It is not only the engineers' and drainage authorities discretion whether it is of value and practicable to consider these lower events.	12-13
Hydrograph Duration	Approaches to how an engineer can evaluate the change in duration due to the improvement.		13-14
Calibration	Not required due to there being a comparison of conditions and different flow rates modeled.		14-15
Software used	Type and approach to models used in the drainage industry are sufficient for the current required evaluations.	Whether models used by drainage engineers must be limited to those with open source viewing availability.	15-16
Modeling Private Drain Tile	Modeling private drain tile into public systems is imprecise, however there are acceptable approaches for estimating flow from private tile.		15-16
Future Conditions	It is impractical for drainage engineers to model future conditions, but this should be considered through other efforts (e.g. 1W1P)		16
Cumulative Effects	This could be considered through other programs (e.g. statewide, CWMPs).	Not resolved and there was not consensus if the DWG should convene another committee to address this issue.	16-17
Water Quality	Water Quality is not considered outside of a scour analysis.	Not resolved and there was not consensus if the DWG should convene another committee to address this issue.	17-18

*This was somewhat resolved by defining "flood impacts" for this report, as opposed to "impacts", which can include other types of impacts.

Approach

The subcommittee met in-person on five occasions March 2023 through July 2023, with a virtual option for the July meeting. In addition to those meetings, a virtual kick-off meeting was held in March to discuss meeting logistics and dates, and several virtual meetings were held in September and October to review and finalize this report. This section discusses the approach taken by the technical subcommittee to develop this deliverable to the DWG.

SWOT Analysis

At the initial meeting, a SWOT (Strengths-Weaknesses-Opportunities-Threats) Analysis was conducted. The intent of this analysis was to 1) develop a purpose statement for the subcommittee and 2) determine where there was agreement on the current approach and where the current approach fell short or potentially needed refinement. The purpose statement was intended to be a reference that the group could use as we worked through evaluating the technical considerations of an adequate outlet. The purpose statement would also help the subcommittee not get off topic with the many aspects to drainage law.

For the SWOT analysis, each group member was given the opportunity to write down what they thought were the strengths, weaknesses, opportunities, and threats of the current approach to evaluating an adequate outlet. These were reviewed as a group and compiled into a list. Items where there were agreement were used to develop the purpose statement. Items where there were non-agreement were added to a “parking lot” for consideration later in the process.

The outcome of the SWOT analysis helped develop the purpose statement and is described further in the Purpose Statement section. A summary of the SWOT analysis is included in Appendix A.

Definition of Terms

It became evident during the first meeting there was not agreement on the definition of specific terms, such as “outlet”, “cumulative effects”, and “impact”. The second meeting was dedicated to better defining these terms. The approach to evaluating these terms included a review of how they are used in the current MPDM and if/how they are used in statute. The definitions explored and better defined by the subcommittee are included in the next section. The subcommittee requests that the DWG consider how/if these definitions be incorporated into statute or the Minnesota Public Drainage Manual (MPDM).

Parking Lot Items

While the original intent was to discuss parking lot items in our third meeting, the subcommittee found that there were other driving factors that could help determine how important parking lot items were (e.g. – is the existing outlet stable), so discussions migrated to addressing other items first. As a result, parking lot items were handled as they arose within other conversations.

As we progressed towards agreement regarding technical considerations of an adequate outlet, it became clear we were focusing strictly on flooding considerations, as listed under 103E.015 Subd 1 (4). There was

disagreement within the subcommittee if we should be considering a wider approach to our evaluation, specifically to consider all items under [103E.015 Subd 1](#) – which were heavily called out in the parking lot and were included in our original purpose statement.

The subcommittee would like to stress to the DWG that we *did* limit our scope to 103E.015 Subd 1 (4), to be cognizant of the time commitment and the expertise of the subcommittee members, and not to ignore points that were in the parking lot. The DWG may elect to convene another subcommittee at a later date to review the Engineer’s role in evaluating the other 103E.015 considerations, but it is infeasible to further deliberate these items within the time constraints and directed scope provided by the DWG. All parking lot items are listed in Appendix B, and those that any member of the subcommittee felt were not adequately addressed during this current effort are called out with an asterisk.

Considerations for the Current Outlet

The technical subcommittee agreed that the condition of the current outlet plays an important role regarding how engineers should and do determine if there is an adequate outlet. This discussion started with a comment from the DNR representative who suggested that if we know if the current outlet is “stable”, then that is an indication that the current outlet is also adequate under the current flow regime. Meetings three and four were used to discuss an approach and evaluation to determine if the current outlet is stable as a first step in determining if there is an adequate outlet. If the current outlet is stable, that will also dictate the information that should be provided to show if the proposed Drainage Project (Project), as defined in [103E.005 Subd 11](#), will also have an adequate outlet. The approach to determine if the current outlet is adequate is included in the recommended approach section.

Considerations for Hydrologic and Hydraulic Modeling

Meeting five was intended to discuss approaches to hydrologic and hydraulic modeling, specifically what events should be modeled, appropriate modeling methodologies, and different software applications. Additional review staff from the Minnesota DNR joined the discussion since they are typically the staff that review the proposed drainage improvements and provide advisory comments to the drainage authorities.

The recommended approach for modeling, including which storm events, how to address duration changes, and if calibration is needed is provided in the Recommended Approach Section. A summary of model considerations is also included in that section.

Purpose Statement

The purpose statement developed by the subcommittee is as follows:

The purpose of the subcommittee is to reduce conflict and improve efficiencies in the proposed drainage review process by:

- a) reaching an agreement on the technical considerations (i.e. water quantity, water quality, etc.) necessary to determine whether a proposed outlet is "adequate" pursuant to Minnesota Statutes Section 103E.261, subd 4(4) and 103E.015, and*

- b) identifying technical analyses (i.e. modeling techniques, storm event, etc.) needed to support a determination whether a proposed outlet is adequate.*

This purpose statement was developed to refine the goals of the group. Since it is very easy to stray off topic when discussing 103E drainage issues, it was important that the entire technical subcommittee agree on the outcome of our effort. To develop this purpose statement ideas were taken from the SWOT analysis where there was agreement of the entire subcommittee. The remainder of this section discusses more broadly where there was agreement within the subcommittee.

The current approach to determining an adequate outlet has positive aspects, including flexibility, scalability, and regional acceptance. The current approach has science and technology-based suggestions that support current statute. This approach also includes considerations for downstream effects and a range of storm events.

However, the current approach has terms that are not well defined or are not agreed-upon, and the approach has been followed inconsistently over time. In the MPDM, the language fluctuates between what is a requirement versus a recommendation and there seems to be a lack of understanding and education regarding the approach.

As the technical subcommittee developed a suggested updated approach for determining an adequate outlet, the group aspired to incorporate the positives from the current approach, while improving the negative aspects. Specifically, we attempted to clarify definitions (e.g. downstream, impacts, etc.) and use examples and research to inform the approach. This information will help inform reviewing agencies and other interested parties on how to evaluate the PER/FER (Preliminary Engineering Report/Final Engineering Report). The subcommittee also feels early coordination could play a significant role in this process.

As we developed this suggested updated approach, the subcommittee had concerns of too strong of language in a guidance document (such as the MPDM) or requiring/recommending items that are not supported by law or statute. Another consideration that must be kept in mind is the cost of following the new approach as the burden of the cost would be placed on petitioners. It is important that the subcommittee and DWG understand that it will likely be proposing an approach that may not be perfect and may not fit all drainage systems projects, but that it is an improvement over the current approach.

Definitions

There were several terms that the subcommittee felt needed better definition to support our discussion. These included:

- Outlet and downstream limit
- Flood Impacts
- Adequate
- Cumulative
- Existing Conditions
- Project

Outlet and Downstream Limit

There was uncertainty within the subcommittee regarding what was specifically considered the “outlet”. There is no statutory definition of outlet, even though the term is used over 100 times in MN Statute 103E. The MPDM attempts to define the outlet, but that definition is ambiguous saying that it is both the “terminal point

of the drainage system under consideration” and that it “includes whatever downstream reaches that might be impacted...”.

After much discussion, the subcommittee decided that using the term “terminus” would be helpful, such that, terminus is defined as the downstream end of the legally defined project. With that in mind, the “outlet” starts at the terminus of the drainage project and extends to the furthest downstream extent of the potential project impact (Figure 1).

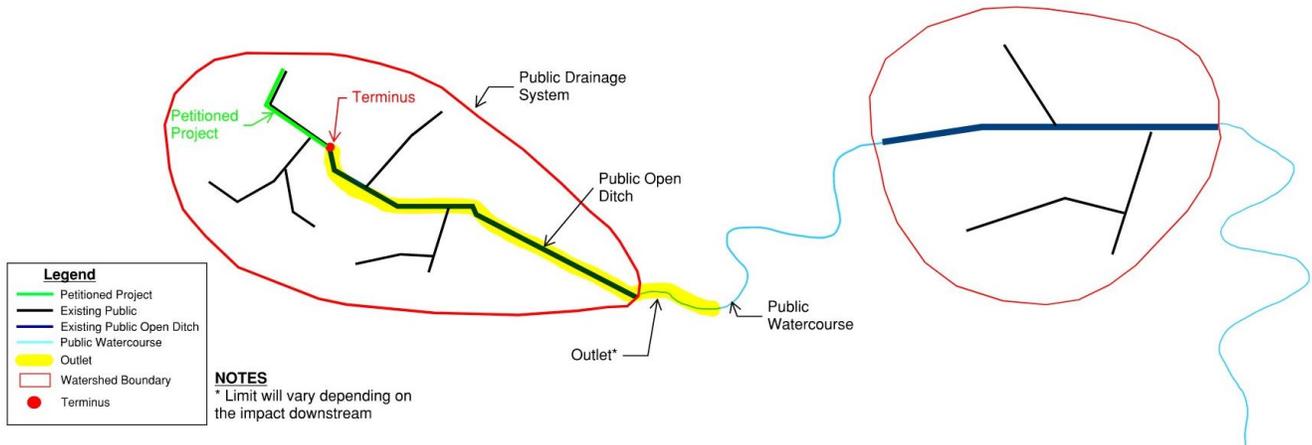


Figure 1 – Example schematic showing the extent of an outlet. In this example, the entire length of highlighted yellow would be considered the outlet. The extent of the highlighted yellow changes depending on the project impact.

The furthest downstream extent is expected to change for each project. It is difficult, if not impossible, to recommend an extent that will fit all scenarios. The subcommittee feels that each project should be evaluated by the drainage engineer and drainage authority to determine the extent of the potential downstream impact, therefore the length of the “outlet” itself will be defined as the project is evaluated. The hope of the subcommittee is that the recommended approach as outlined in this document will help drainage authorities, their engineers, and reviewers agree on the “outlet” for each specific project. The technical subcommittee also recognized that early coordination could be important for this discussion.

Flood Impacts

As the subcommittee discussed the term impact, we agreed that under 103E.015 Subd 1 (4), impact is limited to flood impacts, but recognized that other project impacts are possible. This is primarily due to the statute referencing specific flood events in 103E.015 Subd 1 (4). The subcommittee agreed that flood impact considerations would be as follows for our discussion:

- Quantifiable economic damages due to increases in flood stage and duration, such as crop losses due to additional areas inundated, or areas inundated for longer periods of time;
- Quantifiable channel degradation due to increases in flow rate, duration, and velocity, such as scour/erosion/deposition;

- Downstream channel capacity reduction (thereby affecting others ability to drain) that would result in a measurable adverse economic impact.

The subcommittee agreed that there could be other project impacts outside of 103E.015 Subd 1 (4). These were mentioned during the SWOT analysis as concerns and they include changes in ecosystem services, wildlife habitat, cultural resources, and nutrients. These items are also required considerations specified under 103E.015 Subd. 1 which the Engineer is required to address within the Preliminary Survey Report (a.k.a. "Preliminary Engineers Report" or "PER").

Adequate

Through our work a definition of adequate was discussed. There was not consensus on the overall definition, however the subcommittee agreed that for the purposes of this report, adequate refers to the ability of the outlet to sustain the change in hydraulics resulting from the project flood impacts. Some members of the subcommittee felt that water quality impacts needed to be included within the statement of adequate, which is why the definition does not have consensus outside this report.

Cumulative

The term cumulative could relate to different aspects of a drainage system, but for the purposes of the subcommittee's discussion and this report, cumulative was defined as minor increases in peak flow rate from more than one individual project that can lead to a potential larger impact.

The subcommittee agreed that this was more of a concern in the MN River Basin and southern MN than in the Red River Basin. The Red River Basin uses the [BTSAC Briefing Paper #3](#) and distributed storage to address cumulative impacts. The subcommittee agreed that the approach in the Red River Basin could be considered for the MN River Basin. However, the subcommittee also agreed that this term is not found within the 103E statute or the MPDM and further recommendation from the DWG could clarify if this term warrants further discussion.

Existing Conditions

The existing or current condition is generally understood as an as-constructed subsequently improved condition (ACSIC) condition, with no deterioration of the system, when evaluating proposed designs. The subcommittee decided that this description was adequate. However, this helped support the idea that it would be helpful to have a better approach to determining if the existing outlet and system is adequate.

It should be noted that an assessment of the current condition is completed as drainage engineers begin their work to evaluate a system, and as a matter of practice assessments of current conditions are on-going. This includes: periodic inspections by staff or drone video, repairs, drive-by assessments by petitioners, and when infrastructure improvements occur. Repairs have addressed deterioration, or the current state of the system may have deteriorated. Vegetative buffers have been required upon appointment of viewers within 103E for some time and have been more broadly required on all 103E open ditch systems since 2016 under 103F.48. With all of these changes happening within a specific drainage system, the ACSIC condition is a realistic existing conditions scenario to use for modeling purposes.

Project

Within this report, the term Project refers to a Drainage Project., as defined in 103E.005 Subd 11, meaning “a new drainage system, an improvement of a drainage system, an improvement of an outlet, or lateral.”

Recommended Approach

The DWG should note that the recommended approach did not address all the concerns that were identified by members of the subcommittee. The subcommittee could agree however, that this is a good step towards our goal of clarifying the evaluation of an adequate outlet, and by following this approach we make progress towards fulfilling our purpose statement.

The recommended approach considers flood impacts, channel stability, and geomorphology. The subcommittee suggests that this approach be considered to help define if the current outlet is stable and can inform if the proposed project will have an adequate outlet. The subcommittee agreed that this addressed the need for an adequate outlet evaluation for 103E.015 Subd 1 (4), but there was disagreement that this approach covered all the aspects of an adequate outlet (see Other Items section).

Flood Analysis

As the subcommittee looked at the components of flooding, we focused our discussion on stage and duration (peak flow rate and velocity are considered below under stability). It is important that ditch authority and agency staff that review these projects understand how changes in stage or duration may result in potential negative impacts downstream. The subcommittee felt that summarizing the potential negative impacts would help both entities make good decisions about whether or not the project is feasible.

The subcommittee agreed that the extent of the engineer’s hydrologic and hydraulic (H&H) model(s) should at a minimum be to the next downstream crossing or outlet (for a lake or other storage area), unless there are other factors that would warrant the engineering stopping short of that distance (for instance, the receiving water having a flow and volume multiple magnitudes greater than the system discharge). The report should include some kind of evaluation of *why* the analysis did not go further downstream. For example, the report could state that the hydraulic model ended because the peak flow rate had diminished or that there was a confluence with a larger area where there would not be coincident peaks. The most important part would be to show that the engineer had evaluated the need to go further downstream and made an educated decision regarding the model extent.

The subcommittee decided that another important item for the engineering report would be a summary of infrastructure (including roads, buildings, parks and golf courses, or another other man-made facilities) currently affected by the modeled storm events and how changes in elevation or duration of the flood would affect that infrastructure.

To further understand the effects of duration, the subcommittee suggested that the engineer consider the size of the improvement’s drainage area compared to the size of the drainage area of the receiving water, and also the type of water body downstream. Since these factors mean there is no one-size-fits-all solution for

considering duration, an evaluation of the proposed duration against the existing duration would also help drainage authorities and state agencies understand any potential impacts from the project due to changes in duration.

Stability Analysis

Stability was considered as a component of flooding because flow alterations may impact channel stability with an improved system. While stability isn't a flooding characteristic as called out in 103E.015 Subd 1 (4), the stability analysis accounts for changes in peak flow, duration, and velocity during a flood, whereas the flood analysis only evaluates stage and duration of flooding. In addition, frequent floods such as the 1.5- to 2-yr reoccurrence intervals are also not flooding characteristic called out in 103E.015 Subd 1 (4), however these are "channel forming flows" and the stability analysis can be used to consider the potential for sediment transport during these events depending on sediment size and available sediment load.

The purpose of the stability evaluation is to determine if the existing outlet is unstable and if additional analysis should be required to evaluate if the project would contribute to the channel instability. Considering whether an outlet is stable can also help the county, watershed district, or other entities prioritize channel restoration. Examples of stability analyses are provided in Appendix C and D. It is important to also consider the potential causes of an outlet's instability. If the area to be improved seems to be the cause of the instability, it may be necessary for the system improvement to modify the design to minimize the instabilities of the outlet or potentially fix the downstream instability as part of the project. Alternatively, if the area to be improved is an insignificant contributor to the outlet and likely did not contribute to the outlet's instability, the improvement may not be responsible to fix downstream issues. However, any improvement project must demonstrate how the project will change the peak discharge, duration, or velocity from the as-built condition. Most importantly, the drainage engineer should note in their reports observations and conclusions regarding outlet instabilities so the drainage authority can make informed decisions regarding fixing instabilities in the system.

While the technical subcommittee had several good discussions regarding approach to evaluating stability and how it should be addressed, there was not consensus on this item. Some subcommittee members felt that a proposed project could not move forward if it was "inadequate for stability". Other subcommittee members felt that the term "inadequate for stability" was inconsistent with the measurement of an outlet's existing condition, and a project could not be dismissed on this basis (based on in the terms of 103E.261 Subd 4).

However, the following criteria was discussed by the subcommittee as a way to evaluate and address channel stability as part of adequate outlet determination, but the technical subcommittee did not quite come to full agreement on this approach. It is still presented here to provide some an idea on a suggested approach, and it may be worth future consideration.

1. The channel stability protocol for natural and engineered channels provided in Appendix C and D are example of tools that can be used by drainage project engineers, where appropriate. This protocol could identify whether the current outlet is adequate considering existing and future drainage to the system and stability of the outlet. The approach also considers projected changes to precipitation patterns affecting drainage discharge. All approaches should be defined, substantiated, and reviewed by the appointed Professional Engineer, who is qualified, responsible, and legally liable for

performance. Additional information may be required if there is the potential for significant impacts to public waters, as DNR permitting may be required.

2. If storage is considered for an improvement project, the project engineer could verify that the discharge associated with the extended duration is less than the channel forming discharge (approximately 1.5 to 2-year flood event using USGS Regression analysis or DNR Regional Curve).

Natural Channels

The stability evaluation includes current physical features and the state of channel evolution (in the case of natural channels) to determine if the channel is evolving to a more stable form or a less stable form based on observed morphological evidence. A channel evolving to a less stable form will erode faster and perhaps over a larger area and there must be additional consideration when evaluating if there is an adequate outlet.

Several methods were introduced to the group to evaluate the stability of the outlet. These ranged from compiling inputs for a BEHI evaluation along with WRSSS or the modified Pfankuch Stability Rating analysis as presented by the DNR. The subcommittee agreed, for example, a modified Pfankuch Stability Rating analysis could be a simple, effective, and repeatable approach for evaluating the stability of natural channels. However, this approach was developed for mountainous regions of the United States and the DNR and the University of Minnesota are working on completing the metrics and standards for this methodology in the Midwest. Since this approach is not finalized at the time this paper is written, the subcommittee recommends that this be one of many options for stability analysis, along with other methodologies provided in Appendix C. The subcommittee further recommends that the engineer continue to work with reviewers to decide the best approach for evaluating outlet stability based on their specific project. As with other evaluations, the engineer should provide details in the reports to explain how stability was evaluated for their project outlet.

Engineered Channels

There was a suggestion that a geotechnical analysis may be necessary to better understand the potential for failure in engineered channels. A potential approach is included in Appendix D, but it is not intended that this be the only approach for evaluating the stability of engineered channels. The feedback from the drainage engineers was that geotechnical analyses are highly dependent on the characteristics of the project. The drainage engineers typically evaluate early in the project if a geotechnical analysis is needed.

As suggested with other evaluations, the engineer's report should include a discussion of why or why-not geotechnical evaluation is needed for a project and the basis for how the drainage engineer evaluated if the outlet is adequate or not adequate regarding stability.

Hydrologic and Hydraulic Modeling Considerations

Storm Events

The subcommittee acknowledged that the 5-, 10-, 25-, and 50-year, 24-hour storms must be evaluated, as specified in statute. In addition, the subcommittee discussed, and agreed, that in some rare occurrences the engineer may need to evaluate a longer duration event (i.e. 48-hour event or 10-day snowmelt event) if it is

known that the unique composition of the watershed suggests that the critical flood events are longer duration than 24-hours and that the project has a likelihood of impacting these events.

In current project design and evaluation of agricultural benefits, the 10-year event is often deemed the critical design event when considering flooding on agricultural lands. If a project can reduce flooding and inundation on agricultural lands to less than 48 hours in the 10-year event that typically maximizes benefits and crop production goals.

There was much discussion, and no subcommittee agreement, on the modeling and evaluation of storm events greater than a 5-year occurrence (e.g. – the 1.5- and 2-yr rainfall events). The biggest concern regarding requiring the modeling of these events is that as the storm events get smaller, the reliability and accuracy of current hydrology modeling methods is reduced. Meaning the modeling results of the 2-year event may be less predictive of hydraulic changes resulting from the project than larger events. To accurately simulate these smaller events, different models could be used, but they would need to have a better way to estimate antecedent conditions, soil water holding capacity, interaction with groundwater, and the existence of tile.

However, the bankfull or channel forming events (generally 1.5-2-year low-flow events) are an important aspect to bank stability as they can drive near-channel erosion and channel degradation. Estimating the low-flow discharge can be important, especially when the project has a storage component. The additional storage could reduce peak flows, but exacerbate downstream conditions because of channel degradation. Although engineered channels can be designed to address the higher base flows, and the natural watercourse could be damaged by changes in the low-flow regime. Some subcommittee members felt these considerations are fundamental to determining whether an outlet is adequate because they evaluate whether the volume and duration of the project design flows will alter the hydraulic performance of the outlet including increases to the scour of the channel bed or banks downstream of the project outlet.

The subcommittee did brainstorm ways to potentially model and understand the bankfull event for each system. An approach may be to use the hydraulic geometry curves or regression equations to figure out the bankfull flow for the outlet. This information can then be used with stage hydrographs for the larger events to determine how much longer the system may be at bankfull (see Duration below for additional details). But ideally, a basin wide, continuous model could inform the system on how a project may affect bankfull flows. The subcommittee did agree that this would be outside the scope for drainage projects, but they would encourage additional discussion on the topic to find the best ways to calculate and evaluate bankfull flows through other efforts.

In summary, there was consensus amounts the subcommittee regarding modeling events larger than the 5-year event, and non-consensus that smaller events should be modeled. More information on these lower flow events is included in the Future Considerations section.

Duration

It is important to note that anytime there is a decrease in peak flows, especially with the addition of storage within the contributing watershed, there will be an increase in duration of some flows/velocities in the hydrograph. The only way to not have an increase in duration is to have a volume reduction somewhere in the

watershed, through additional infiltration or evaporation/evapotranspiration. While those efforts will continue in Minnesota through soil health practices, they can't be accomplished via public drainage projects.

The subcommittee brainstormed ways to evaluate the effects of increased duration to determine if they could result in excessive scour that may need mitigation for the outlet to be considered adequate. The subcommittee identified three ways that the drainage engineers may consider and present to help reviewers and the drainage authorities understand the effects duration changes. Note that none of these considerations are required in a PER or FER.

- Drainage engineers could evaluate how long the duration will be at bankfull flow or higher, and how that might change with the improvement. One concern is that increasing the duration of bankfull flow can result in additional erosion along the ditches or streams. So the length of time, along with the change in water surface elevation, can be an important indication of how the improvement could potentially change the system.
- Drainage engineers can check the velocity in areas where there is a change in duration for a critical flow. If there is an increase in duration at a critical flow/flood elevation, but velocities remain low, it can indicate that there will be no additional erosion even though the overall duration may be longer.
- Drainage engineers can also take a closer look at potential downstream issues due to a longer duration (for instance, the flooding of agricultural lands for greater than a 48-hour duration). If there are already flooding or erosion concerns downstream, an evaluation of the increase in duration against when and where the flooding or erosion concerns take place can provide valuable information regarding whether the project will exasperate those issues. For example, there may be an increase in duration, but it may be lower in elevation than the current flooding or erosion issues.

It is important to note that the Engineer is required to evaluate only a narrow selection of rainfall events (5-, 10-, 25-, and 50-year) and that not all public drainage projects require a detailed hydrologic and hydraulic analysis. In particular, drain tile improvements on a branch that has a small drainage area with respect to its receiving water have a lower likelihood of resulting in significant velocity and flow changes in the receiving water. In such cases, duration evaluation will not be possible as peak flows would be generated via regression equations, manning's equation, and/or StreamStats.

Overall, the subcommittee suggests that the drainage engineers include a statement or narrative in their report indicating whether a significant change in duration of flooding or flows in the outlet are likely to result from the project to better inform drainage authorities and reviewers.

Calibration

Calibration or model validation is very difficult for these systems. There is seldom a steam gage within the system that can be used for calibration, and verification methods can be imprecise (e.g. – use of StreamStats). The calibration or validation effort is often not worth the results, or worse, may prompt the modeler to make adjustments that decrease the accuracy of the model. However, a drainage engineer may attempt to verify a model using survey data or drone footage taken during/following a major storm event, when this information is available and particularly if the engineer's conclusions are being challenged.

The subcommittee agreed that comparing ACSIC conditions to a proposed improvement does not necessarily require a calibration or verification since the relative change between the two conditions is more important than the accuracy of a modeled flow event. The modeling of multiple storm events (as required under the statute) also helps broaden the considered hydrologic conditions and decreases the value of calibration. For example, if the model was reporting 10% or even 20% low or high flow rates, the next higher or lower event still represents an overall change to the system for different flow rates.

Software

Analyzing the modeling results is an important part of understanding how the system is changing due to the proposed Project. The subcommittee agreed that in most cases an unsteady model will be most helpful to understand the effect of an improvement across the entire hydrograph, though not all projects require an unsteady model to evaluate the likelihood of project impacts. In a perfect world, the hydrologic/hydraulics model would be able to accurately simulate rainfall-runoff, different infiltration and abstraction volumes based on available pore space, shallow groundwater recharge, and inflow from private draitile systems into the public system. However, it is important to note that current modeling methodologies and corresponding site-specific input data do not exist for ALL of these within one model. The subcommittee did agree that it is necessary for the drainage engineer to evaluate a compromise of overall effort and enough output to understand the effects of the improvement.

Some subcommittee members expressed concern that the models be reviewable by state staff or other entities. These subcommittee members felt that if the model is proprietary, it is important that the software have some type of “viewer” capabilities, meaning that the model can still be opened and inputs/outputs reviewed by an entity that does not own the software. This is of specific concern with ICM, which is the software that is replacing XP-SWMM and does not currently have a viewer. In lieu of a viewer, reviewers could request specific outputs.

Other subcommittee members indicated that it is impracticable to require drainage engineers to limit their modeling tools to those that potential reviewers have access to or expertise with. Other stormwater management reviews on public infrastructure projects infrequently require submittal of model data files and review within the utilizing modeling software.

Examples of information requested by reviewers, that could take the place of a full model review, could include:

- hydrologic inputs such as curve numbers, times of concentration, and drainage areas,
- hydraulic inputs such as pipe sizes and roughness coefficients, minor losses, cross-sections of ditches
- computed hydrographs for all events under both ACSIC (as-constructed subsequently improved condition) and proposed conditions
- mapped flooding extents for all events under both ACSIC and proposed conditions

The subcommittee agreed that modeling draitile flow from private systems into the public system is inherently imprecise, as the size and location of private tiling is infrequently known and is subject to change in the future.

Drain tile flow becomes more important as drain tile size increases, if the engineering analysis includes duration of flow, and if there is develop of more water storage projects. Current modeling methods don't have an good way to return private drain tile flow into a hydrograph. However, it can be conservatively assumed that between the private tile connections and open intakes, the public drainage system tile will be flowing full under all modeled rainfall events (5-year recurrence and greater). There are multiple ways to surcharge the tile within the model, including modeling of open intakes in surface depressional areas or adding constant flows. The engineer should indicate the approach utilized for considering private draintile in their description of the modeling methods.

It should be noted that if a public waters permit is needed, there might be additional considerations requested by DNR staff for approval of the public waters permit. The subcommittee suggests that drainage engineers work closely with the DNR area hydrologist or other DNR staff early in the process to understand current conditions and concerns of any affected public waters.

Items without Final Recommendation

This section summarizes other topics that were discussed thoroughly by the subcommittee, but were not included in the final recommendations. These items the subcommittee would like to defer to the DWG to determine next steps. High level discussion of each topic is include help the DWG understand the concerns and thoughts of the subcommittee.

Future Conditions

The concern about future conditions is that hydrologic changes in the watershed may contribute additional flow in the future that wasn't being accounted for in the project engineering analysis. These changes include private tiling, modified cropping practices, or rainfall patterns. The subcommittee noted that it is impossible to precisely predict these changes, all of which the drainage authorities do not have control over. Additionally, legally the drainage authority cannot utilize system funds to pay for studies that do not reasonably provide benefit to the drainage system and its benefitting landowners. Therefore, watershed-wide studies, including those that consider future conditions, were removed from consideration as a suggested submittal item for drainage improvements.

Nevertheless, future conditions could be addressed through watershed-wide studies being completed by an outside entity, such as the 1W1P efforts, a statewide effort, or specific legislative funding. The results of these studies could be used by water management authorities for planning and conservation efforts.

Cumulative Effects

Cumulative effect is a concern that if one drainage system or part of the drainage system is improved and there is a slight increase in peak flow and the outlet is considered adequate for the improvement, then the next adjacent drainage system or part of the system is improved, there could be another slight increase in peak flow, and over time all of the slight increases in flow would result in a significant increase in flow.

MN Statute 103E does not address cumulative effects, and drainage authorities to date have evaluated the utility and impact of projects independently. However, drainage authorities in their management of open channels that collect drainage from multiple tile lines do consider maximum likely level of service (i.e. drainage coefficient) from upstream flows when sizing culverts.

There were multiple ways suggested by individual subcommittee members for addressing this issue. One suggestion was that each improvement must go through the recommended approach in this document for an adequate outlet. This would provide more assurance that each project will have an adequate outlet on its own merit, so additionality of projects would not matter as much. This would also be consistent with other programs, such as the FEMA floodplain program, where if the allowable increase is used up, then future projects are required to change their design so that there is no more increase in flood elevation. In this scenario, if the next project may be too much of an increase for the system, that project may need to be redesigned so that it will not have a negative impact.

One difficulty with tracking these cumulative effects is that there is no “starting point” from when cumulative effects would be tracked. With no good baseline for these areas, tracking cumulative effects across the state would not be consistent. Also, without watershed-wide models, it is impossible to evaluate the cumulative effects from different drainage improvement projects as the peak flows are unlikely to be directly additive.

There was group consensus that cumulative effects could be addressed by more broadly implementing programs and projects that address hydrologic effects from land use, infrastructure, and climactic changes, namely; 1) Comprehensive Watershed Management Plans (CWMP) and implementation efforts; 2) water storage programs; and 3) local rules (for example some entities have adopted a maximum drainage coefficient). An advantage of this approach is that the local nuances of the region are captured within the planning and projects to best address the changing landscape. A disadvantage of this approach is that it relies on the buy-in of local water management entities which may be inconsistent across the state.

There was not consensus within the subcommittee that this is an adequate response to this concern, and some subcommittee members would like further discussion on this topic.

Water Quality

The subcommittee’s purpose statement provides, in part, that it will work to “reach agreement on the technical considerations (i.e. water quantity and water quality, etc.) necessary to determine whether an outlet is ‘adequate’ pursuant to Minnesota Statutes Section 103E.261, Subd. 4 (4) and 103E.015. While some aspects of water quality are addressed by 103E.015 Subd 1 (4), they are only in terms of how the hydrology and hydraulics changes from the project affect scour and stability of the outlet (which in turn affects TSS and TP). There has also been only limited discussion of nutrient impairments, mostly focused on nitrogen. Nitrogen is of special concern if there is a decrease in contact with the soil and a decrease in the potential for N-treatment. Phosphorous needs to be addressed as well. This is complex because these nutrients need to be evaluated in different ways because of how they are transported through the system.

Some subcommittee members did not agree that this level of water quality evaluation should fall under 103E.015 Subd 1 (4), and noted that water quality already is considered under Subd. 1(6) and the FER and PER must address both conditions. More specifically, subcommittee members disagree about how the

considerations enumerated in MN Statutes 103E.015 are to be further included in outlet adequacy determination under 103E.261 4 (4). Because this is a legal/policy question and not a scientific or technical question, its resolution requires discussion within the DWG.

There was not consensus within the subcommittee that this is an adequate response to this concern, and some subcommittee members would like further discussion on this topic.

Storage

Another important consideration of duration is the effect of adding storage to the system. Storage, unless designed to create a non-contributing area within the watershed, will increase duration of portions of the hydrograph as it decreases overall peak flows. While the subcommittee agrees that storage is generally helpful for addressing altered hydrology within a watershed, it is important to consider where and how much storage is added to evaluate the impacts of storage on the downstream system. To help understand if the storage has a positive impact downstream, flow duration curves may be helpful under some circumstances to evaluate the effectiveness of a storage project in achieving the implementers' goals. This would not be an expectation of an evaluation of adequacy of a drainage project, but is a tool for implementors of any storage project in the state.

While the above information is true with any storage that is added to a hydrologic system, it can be especially important for drainage systems because of the change in the hydrograph's duration and the specific flow rate of the hydrograph throughout that extended duration will effect the stability and adequacy of the outlet.

Future Considerations

The subcommittee realized that there were issues that should potentially be discussed, but they either 1) were not directly applicable to the adequate outlet discussion (therefore outside of the duties of the subcommittee, or 2) were more related to statute changes than a suggested technological approach. This section is meant to summarize items that the subcommittee would like to suggest for further discussion by either the DWG or other subcommittees of the DWG.

Research, Education, and Messaging

Entities such as Discovery Farms and Michigan State University are doing extensive research on conservation drainage. Their work, and other research work, can lead to improved ways of evaluating, modeling, and addressing drainage water. Two practices, conservation drainage and drainage water recycling, may change the need or design for drainage system improvements and help with water quantity and quality concerns.

In addition, drainage engineers are already considering structural storage practices in many drainage systems as part of the system improvement. Field tours and conference presentations have showcased how these designs can help reduce peak runoff from our agricultural sites.

The technical subcommittee felt that more education and messaging regarding research and new approaches, along with frank and honest two-way dialogue could reduce miscommunication and build trust will all stakeholders and create understanding around issues with instability in our streams. Better communication can

simplify or reduce the number of times there are concerns with an adequate outlet. The subcommittee recommends the DWG consider supporting the education and messaging component of our work.

The subcommittee also recognized the need for agency staff training opportunities for reviewing drainage projects and on-the-ground decision making between drainage engineers and contractors. The intricacies of modeling a drainage system are very different than typical watershed systems that focus on surface runoff. When there is staff turnover, this can be an additional challenge to help new staff understand the complexity of these projects. An approach to address this was outside of the scope of this technical subcommittee, but it was discussed as a need that would help improve the review process for these projects. The subcommittee would also like to urge the DWG to encourage agencies to develop some type of internal agency training to help onboard new staff dealing with drainage projects.

Any training developed could also include our partners such as SWCDs or the NRCS. Their understanding of the need for, and impacts from agricultural drainage is critical for planning, adoption, and implementation.

Policy

Throughout this process, the subcommittee often deviated from our purpose statement and would discuss drainage policy. It was very difficult to separate technical considerations from what may end up effecting policy.

The most significant policy item discussed by the subcommittee, which we suggest that the DWG consider, is if an “adequate outlet” is applicable outside of 103.015 Subd 1 (4) and 103E.261 Subd 4 (4). Outlet adequacy is specifically listed in these items, so some subcommittee members felt it was tied only to these statements. There is no history of adequacy of outlet being applied outside of flood, drainage, scour damage, in any public drainage hearing. Other subcommittee members felt outlet adequacy had a further reach and is tied to the other parts within 103E.015 Subd 1 and 103E.261 Subd 4.

Evaluation of Bank Full events (approximately 1.5-2yr recurrence intervals on natural channels)

Competing interests between managing for peak flows and minimizing duration of bank full events can result in activities with positive intentions cumulatively leading to adverse and unintended downstream consequences. In several areas of this report there is discussion about the potential effects of peak flow and duration of bank flow on channel stability, scour and sedimentation, and non-sediment related water quality issues. The Storage section specifically speaks to the challenges of managing for peak flow potentially adversely effecting bank flow duration and velocities in respect to water quality and channel stability. These competing interests lead to uncertainty and challenge when designing a drainage project, storage projects and even planning for general water quality improvement projects which are dependent on hydraulic change as the mechanism to provide for water quality treatment (water quality ponding for example). While some of this seems focused on the MN River basin, it may not be exclusively of concern there.

To inform the decision-making process and help guide implementation of these potentially beneficial activities the technical subcommittee encourages the DWG to consider a recommendation for funding of a pilot assessment of the MN River basin to prioritize areas of the basin which should be managed for peak flows versus bank flow. This prioritization and basin wide assessment would be best completed by a disinterested third party, so that all appropriate Minnesota stakeholders could participate, through a facilitated process. This

discussion should result in a technical assessment and modeling of geological, land use, hydraulic, and other factors which are influenced and affected by changes to hydrology resulting from these or other potentially beneficial activities.

With an assessment of this nature the third party could develop and provide recommendations of landscape specific areas throughout the MN River Basin which should be managed for peak flows, high frequency flows, or other hydrological recommendations. Such recommendations can help inform thoughtful and intentional drainage, storage, and water quality design. This will improve the likelihood of more sustainable agricultural production and environmental and societal outcomes with fewer unintended downstream consequences.

DWG Considerations

The subcommittee has presented this document to the Drainage Work Group for consideration. There are a few specific items that the technical subcommittee would suggest the DWG consider:

- How and if the definitions of Outlet and Downstream Limit, Flood Impacts, Adequate, and Cumulative will be added to the drainage manual or statute.
- How and if the recommended approach should be incorporated into the drainage manual or statute. In addition, if example submittals should be included in this document or in the drainage manual to help guide future submittals.
- If “adequate outlet” should be considered with all parts of 103E.015 Subd 1 and 103E.261 Subd 4 or be limited to the parts addressed in our technical review.
- If the DWG will support additional research and education with regards to conservation drainage and to help with messaging on best approaches for conservation drainage and conservation practices.
- If the DWG will support the proposal of a MN River Basin wide effort to assess the impacts of managing for channel forming and flood events to minimize unintended downstream impacts in this dynamic system.
- How and if we can continue to collaborate with all entities with an interest in the technical aspects of drainage projects.
- If the DWG will support agency training of staff for consistent review standards.
- Next steps in addressing the non-consensus items as listed in Table 1.

While the work of this technical subcommittee is complete upon completion of this report, members of the subcommittee will ask that the DWG direct action on several of these steps, especially how to address any outstanding non-consensus items.

Appendices

Appendix A – Summary of SWOT analysis

Appendix B – Parking Lot

Appendix C – Natural Channel Stability Analysis

Appendix D – Additional Geotechnical Analysis for Engineered Channels

Appendix A: Strengths-Weaknesses-Opportunities-Threats Analysis Results

This is a shortened list of items discussed during the SWOT analysis and includes only those that had consensus from the subcommittee. Items that did not have consensus were moved to the Parking Lot (Appendix B).

Strengths of the current approach:

- Flexible, scalable, regionally acceptable.
- Considers a lot of factors, such as downstream effects.
- Reflects what is in the statute .
- Science and technology based.

Weaknesses of the current approach:

- Definitions are not clear or there is disagreement on definitions.
- Inconsistent approaches because there is not agreement on best methodologies.
- Lack of clarity on requirements vs. recommendations in 103E and the MPDM.
- Lack of understanding on best approach for determining outlet adequacy for agency, staff, DA's, landowners, etc.

Opportunities for this subcommittee:

- Use research and examples to inform approach for determining outlet adequacy.
- Clarify definitions to help inform submittal, evaluation, and review of outlet adequacy.
- Come to agreement on how to address impacts downstream.
- Better define benefits and outcomes of early coordination with respect to adequacy of an outlet.

Threats of a new approach:

- Too strong of language – using “require” or “must” when it is not law/statute
- Staying within the spirit and intent of the law or statute, (i.e. - don't introduce new ideas that conflict with statute)
- Additional costs (to agencies, petitioners, etc.)
- Definitions remain unclear and end product does not improve the process or outcomes
- Letting perfect get in the way of good enough

Appendix B: Parking Lot

These items arose during the SWOT analysis, but there was not consensus amongst the subcommittee that they were strengths/weaknesses/opportunities/threats. The intent was to make sure to consider these items as the subcommittee worked through their discussions on an adequate outlet.

Strengths of the current approach:

- Decisions are left up to the PE and DA's discretion.
- Modeling can be used to educate landowners for other practices.
- Modeling software is advanced and can be used to be more accurate. Under-modeling can cause over-design.

Weaknesses of the current approach:

- Outlet does not include provisions for full development of watershed with evaluation of project and potential future projects.
- Assumes an existing system had an adequate outlet. No consideration if the current outlet is inadequate (i.e. - excessive sediment, property at outlet is currently flooded).
- Pre-project conditions should be included in damages – if existing streams/lakes are impaired these are existing damages and should be included in the damage assessment.
- 1-2yr return period is not fully addressed.
- No basic fluvial transport/deposition analysis or geological materials analysis.
- Considers sediment, but WQ is not specifically defined.
- No limit on stage increases for proposed projects.
- No consideration of duration.

Opportunities for the subcommittee:

- Figure out a way to consider cumulative impacts.
- Better describe how we consider downstream impacts.
- Approach can include designs of structures, water storage, and treatment at one time during improvements of an adequate outlet.
- A new approach may provide opportunity to increase storage and decrease sedimentation/erosion.
- Considering water quality and environmental protections could incentivize, provide grant opportunities – including water storage projects.

Threats of a new approach:

- Concern that impacts to receiving waters will be limited if “consideration” is not further refined/defined.
- We could lose water quality gains.
- Landowners may lose management options.

Other items that surfaced outside the SWOT Analysis

- Systems are in place and are failing, they need to be maintained.
- The word “improvement” is not always bad and benefits the system and drainage is not always bad.
- Look at 1W1P for projects that will be part of Drainage Projects.
- How can we consider larger watershed-wide studies to support or check drainage system.

Appendix C: Natural Channel Stability Analysis

The following natural channel stability analysis was developed and provided by Dr. Joe Magner as an option for evaluating stability on natural channels within or downstream of drainage systems. This is not intended to be a required approach for improvement projects but is provided as a suggestion to drainage authorities and their engineers.

An Initial Adequate Outlet Stability Analysis Protocol

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The purpose of this protocol is to provide guidance to the drainage authority and drainage engineer on how to estimate the relative channel stability at a proposed drainage improvement outlet and beyond the proposed drainage outlet. This work was inspired by conversations with representatives of the Drainage Work Group (DWG) subcommittee on defining the meaning of an Adequate Outlet in Minnesota. This document was reviewed by three MN Department of Natural Resources (DNR) technical experts and their comments were incorporated into the document. Having published extensively on drainage systems in Minnesota¹ the ideas presented in this document have been time tested in Minnesota and provide a baseline understanding of information for the drainage engineer to consider.

Proposed steps:

Step 1 – examine historical records including as-built plans and aerial photos. Compare past and present channel and riparian corridor features (Davies et al., 2018). Does the comparison show similar features? If the most recent aerial photos show an enlarged downstream channel or other evidence of instability, then contact the appropriate DNR staff and request a joint field visit. Natural channel restoration may be required before a drainage project could be considered for improvement. But the DNR will make the decision.

Step 1a- If outlet is a basin: examine aerial photos, lake gauge records, or water level monitoring history of the wetland or lake downstream of the outlet or as the direct project outlet. What is the lake or wetland flooding frequently, what infrastructure or property is at risk, is the outlet of the dam or shoreline eroding, is the lake or wetland managed or designated for DNR or US Fish & Wildlife Service management, is the management of the basin possible, are unique or rare resources in on or around these basins, what flow, stage, duration or total volume increases will the drainage project add to the basin.

Step 2 – If the aerial photo analysis or drone fly over does not reveal any egregious instability of the natural downstream channel, lake or wetland then obtain the appropriate regional hydraulic geometry (RHG) curve from DNR for streams or hydrology history for lakes and wetlands. For river and streams, estimate the approximate channel forming or bankfull geometry and flow for the current drainage system. This would be defined as the *contributing drainage area*². For lakes and wetlands, hydraulically model water level stage and duration increases. If the contributing drainage area will be changed as part of the drainage improvement project, the RHG curves can be used to estimate the change in channel geometry necessary for the proposed hydrology. For lakes and wetland reflect those changes in the modeling fields.

Step 3 – For Streams only, arrange a field visit with the appropriate DNR staff or *approved technical services provider*³. The field visit is designed to validate and synchronize the RHG curves with survey data and documentation of fluvial features (e.g., bankfull indicators, if applicable). Conduct a Bank-Height Ratio (BHR) analysis:

$$\text{BHR} = \text{LBH}/d_{bmx}$$

Where LBH = to the lowest bank height and d_{bmx} is the bankfull maximum depth at a representative riffle cross section (Brooks et al., 2013). If the field visit indicates the outlet channel is showing signs of instability, then go back to step 1 and seek grant funds for channel protection/restoration. If the field results indicate no major channel downcutting or widening, but a channel with an active flood prone area for energy dissipation and frequent flood storage advance to the next step.

Step 4 – Using the principles described in Chapter 10, *Fluvial Processes and Implications for Stream Management* (Brooks et al., 2013), use Figures 10.4 and Figure 10.10 to determine the direction of natural channel evolution. Knowing the current stage of channel evolution will determine if the outlet is adequate and the drainage project can proceed or if more detailed measurements must be made in consultation with the DNR. If the outlet occurs in a trapezoidal constructed channel, then use MADRAS as described in (Abraham et al., 2015) to estimate the geotechnical stability of the channel bed and banks. At the end of Step 4, if the drainage engineer must collect more data, then the appropriate DNR staff must be contacted to conduct a *modified*⁴ Pfankuch Stream Reach Inventory and Channel Stability Classification (1975). The Pfankuch stability ranking (PSR) is designed to qualitatively estimate the dynamic of boundary shear and critical shear strength of the channel bed, lower bank and upper bank of natural channels. If the field modeling results yield low ranking, then the proposed project has an adequate outlet. Lakes/Wetlands- Provide hydraulic modeling to DNR for internal review.

Footnotes:

¹*Nine peer-reviewed papers published in seven different journals and Chapters 8, 9, and 10 in a Wiley-Blackwell published hydrology textbook.*

²*contributing drainage area.* The watershed may have wetlands that are isolated and do not contribute discharge to the watershed outlet except during extreme events and then excess water overflows from the wetland. Improved drainage coefficient in wetland soil and depressional landscapes will increase the contributing drainage area and volume of water delivered to the outlet.

³*approved technical services provide. TBD by the Drainage Management Team*

⁴*modified = A 2019 MN State version of the original 1975 publication.*

https://mrbdc.mnsu.edu/sites/mrbdc.mnsu.edu/files/public/event/warsss_121108/15_SOP_Pfankuch_No_v19.pdf

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Abraham Joel, Ingrid Wesström & Ingmar Messing (2015) A tool for assessing the status of drainage ditches and the need for remedial measures, *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, 65:sup1, 100-109, DOI: 10.1080/09064710.2014.996589

Brooks, K.N., Ffolliott, P.F. and Magner, J.A.: (2013). *HYDROLOGY AND THE MANAGEMENT OF WATERSHEDS*, 4th edition, Wiley-Blackwell, Hoboken, NJ: 533 pp.

Stephen N.G. Davies, Lawrence W.C. Lai, Mark Hansley Chua, (2018)

Seen from above: The theoretical future of aerial photos in land use, environmental and planning study, *Land Use Policy*, 78: 19-28. doi.org/10.1016/j.

Appendix D:

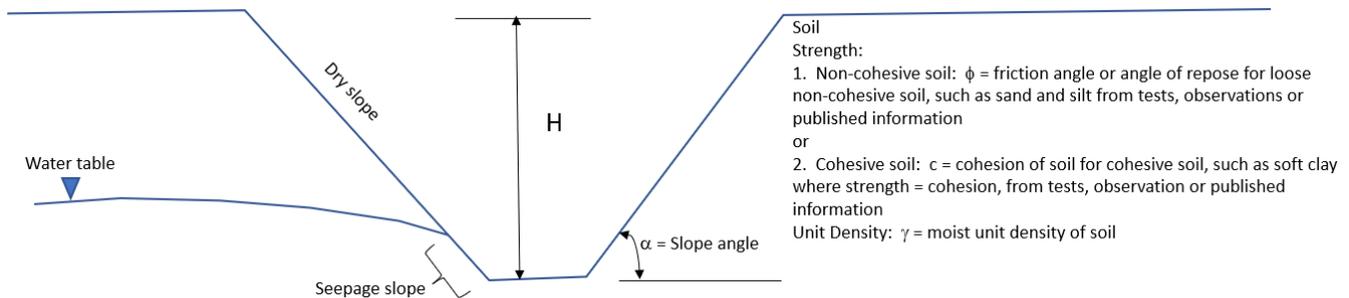
The following geotechnical approach was provided by Phil Solseng as an option for evaluating stability on engineered channels within or downstream of drainage systems. This is not intended to be a required approach for improvement projects but is provided as a suggestion to drainage authorities and their engineers.

First Approximation for Bank Stability of Engineered Channels

The first approximation for stability of outlet provides an approximate factor of safety for evaluating shallow sloughing of bank slopes. The factor of safety is calculated using soil strength and soil mechanics, and the first approximation of safety is based on soil classification and approximate soil strength values for relevant soils from grain size test data and published information, observations, and available information. (see example)

If the below calculations indicate unstable or questionable factors of safety ($FS < 1.2$), more detailed data and analyses for bank stabilization may be required, or redesign should be considered (such as flatter bank slopes).

Example:



v

Soil classified as non-cohesive: (infinite slope analysis)

Dry slope: Factor of safety, $FS = \tan \phi / \tan \alpha$ (**pp 193)

Seepage slope: Factor of Safety, $FS = \frac{1}{2} \times (\tan \phi / \tan \alpha)$

Soil classified as cohesive: (shallow failure in homogeneous clay)

Factor of safety, $FS = c/mH\gamma$ (* pp 512)

Where m = stability number for face failure and varies from:

$m = \sim 0.16$ for slope angle, α , $\sim 1H:1V$

$m = \sim 0.13$ for slope angle, α , of $\sim 2H:1V$,

interpolate/extrapolate "m" for other slope angles, α

Calculated Factor of Safety indicates the following:

- Factor of safety < 1.0 is unstable*
- Factor of safety 1.0 to 1.2 is questionable*
- Factor of Safety of 1.3 is satisfactory for cuts and fills
- Factor of Safety of 1.5 is acceptable for dams
- Existing slopes showing signs of sloughing, cracking or instability are assumed to have a factor of safety of < 1.0

Other factors may need to be considered, and some conditions may require a more thorough analysis regardless of Factor of Safety, such as existing scour or long term saturation of channel bank slopes and sudden drawdown within the channel.

*Introductory Soil Mechanics and Foundations, Sowers and Sowers

**Soil Mechanics, Lambe and Whitman