Conservation Based Approach for Assessing Public Drainage Benefits

Final Project Report

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Executive Summary

Agricultural drainage provides an essential service to farmers and producers across the Midwest. However, maintenance and improvements of the drainage system are very costly. Landowners are charged via taxation based on the amount of benefits they receive from the drainage system. Currently in Minnesota, benefits are determined by professional ditch viewers. Little guidance is provided to them by the drainage code and the process is highly laborious. Benefits are currently assigned per parcel based on discrete benefit classes. Professional judgment is an inherent component of the assessment. The main focus of this project is to investigate potential methods to improve on the current practices. The project is particularly interested in exploring the usefulness of geographic and hydrologic modeling software to automate the process, to objectively identify benefits, and to incorporate conservation practices in assessments. Alternative methods are not expected to fully replace field assessments by certified viewers. They would be used in conjunction with these assessments. Alternative methods were evaluated using a representative agricultural watershed in Martin County (JD4).

Geographic information systems (GIS) are widely used in the management of natural resources to visualize landscape attributes and processes. These tools were used extensively in the project. One of the applications utilized compared the current Minnesota method used to assess benefits with that of Ohio. The Ohio method is similar to the Minnesota method in that it does not use hydrologic models to assess benefits. To evaluate the current methodology, benefits based on the viewers' report for JD4 were digitized to match the total acreage for each benefit class by parcel. The methodology used in Ohio was replicated by selecting GIS layers that most closely represented the variables used in calculating benefits. Overall, the Ohio method does not appear to be superior to the current Minnesota method. The use of GIS to improve the Minnesota method was also investigated. This application did not use hydrologic models as part of the analysis. Of critical importance was the identification of depressions requiring the greatest amount of drainage and hilltops requiring the least amount of drainage. An algorithm was developed that used recursive portioning via classification trees to find relationships between these areas and independent variables, such as the convergence index and non-irrigated land capability subclass. This methodology was unable to identify depressional areas with sufficient accuracy. A second algorithm was developed for these areas using ArcHydro. This algorithm used the optimal stage corresponding to those digitized benefits classes in the viewer's report. Although both of the GIS algorithms show promise, additional research is needed before they can reliably be used to automatically determine parcel features.

Instead of using the current Minnesota method of discrete benefit classes, the project proposed a new method called the UM method based on drainage volume for each parcel. The UM method does not use professional judgment to assign benefit classes. The method does, however, require an estimate of the surface and subsurface drainage volume for each parcel. These volumes were obtained by

coupling GIS analyses with hydrologic models. Two models were used to explore the usefulness of the proposed method. DRAINMOD was utilized to determine the effects of contributing area and conservation drainage practices on surface runoff, drainage depth and water yield. SWAT was used to simulate surface and sub-surface flow per unit area. An important consideration in the SWAT simulations was the surface runoff from parcels without depressions flowing into adjacent parcels with depressions. To represent this process, the SWAT results were integrated with the ArcHydro depressional analysis to capture the parcel-scale redistribution of surface runoff and subsurface drainage. The total drainage volume resulting from this approach was used in an economic benefits analysis to determine the fraction of benefits for each parcel.

The UM method was also applied to the JD4 watershed. This application was done to demonstrate how benefits are shifted with the use of conservation drainage practices. If the application was done for actual assessments, then greater care is needed in modeling the hydrologic response of JD4. Two practices were evaluated: shallow placement of tiles and controlled drainage. Reductions in total drainage volume under these practices were calculated using DRAINMOD. These results were incorporated into the SWAT and the economic benefits were recomputed. Parcels with conservation drainage had a reduction in their fraction of benefits while other parcels had an increase in their fraction of benefits. A greater reduction was obtained with the controlled drainage practice. The reduction in fraction benefits decreased as more parcels implemented conservation practices. This trend was likely a consequence of the relatively simple framework used in the project.

Challenges faced in discerning benefits for depresional areas were successfully addressed through ArcHydro depressional analyses. SWAT analysis proved effective at quantifying parcel-scale distribution of flow. Utilizing the results from SWAT to assign benefits based on a continuous valuation system by drainage depth volume will help to improve accuracy of benefits assignments. Applying these alternative methodologies prior to manual, in field assessments will likely save time and money in the assessment process. DRAINMOD provided useful predictions of the effect of conservation drainage practices. Knowledge of the corresponding reductions in drainage depth volume and fraction of benefits per parcel can be utilized as part of the decision making process of applying conservation drainage practices within a watershed.

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Chapter 1
INTRODUCTION

Background

The focus of this project is to investigate potential methods for assessing benefits of agricultural drainage. The project is particularly interested in exploring a framework that could be used to incentivize landowners to reduce runoff and loading to drainage systems. Properly functioning drainage systems are important for many reasons, ranging from crop production to protection of homes and buildings. Subsurface drainage has contributed greatly to increases in agricultural production in Minnesota since the 19th century. Well-drained agricultural land generally delivers yields higher crop production, less yield variability from year to year, higher land value, and more convenient timing of field operations, resulting in increases in farm profits and property tax bases (Taff, 1998).

The Minnesota Board of Water and Soil Resources (BWSR) (2006) estimated there are at least 21,400 miles of drainage ditches in Minnesota, while Taff (1998) reported that 27,000 of the 90,000 miles of waterways in Minnesota were drainage ditches. BWSR estimated the total length of *public* drainage ditches in the state to be at least 17,300 miles (data was unavailable from two counties with known public drainage systems) (BWSR, 2006). Although these estimates vary, it is obvious that ditches play a significant role in the hydrology of Minnesota's headwater streams.

The cost of maintaining drainage systems in Minnesota is high. For example, Freeborn County (south-central Minnesota) collects $500,000 to $1,000,000 annually for drainage ditch and tile main maintenance and other expenses relating to the approximately 100 public drainage systems it oversees (Dennis Distad, Freeborn County (MN) Auditor, personal communication, July 2012). These systems comprise 344 miles of open ditches and 391 miles of public tile lines (tile mains), which is an average annual cost of $680 to $1360 per mile of open ditch or tile main, of which more is spent on open ditches than tile lines (Distad, 2012).

Project Goals

The overall goal of this study is to develop a runoff-based benefit and cost assessment framework for drainage systems that can assess benefitted lands based on use of the drainage system. Associated goals are to:

1. Create incentives for landowners to implement conservation practices that reduce runoff contribution to drainage systems;

2. Allow drainage authorities to incrementally update benefits assessments as conservation practices are adopted, and without the need for costly redeterminations of benefits; and
3. Maintain fairness and transparency in benefits determinations to ensure that assessed benefits closely match real benefits.

Ideally, a new approach would encourage water conservation in tile drained landscapes in Minnesota, while continuing to improve fairness, objectivity, and transparency in benefit and cost determinations. Although not a goal of this project, a reduction in overall drainage system repair and maintenance costs could be realized by achieving the above goals.

Overview of the Report

To work toward the project goals, it is important to first develop a broad understanding of drainage law in Minnesota, as well as the methods used to determine each landowner's share of the drainage system costs. This material is covered in Chapter 2. Alternative methods for assigning drainage benefits are evaluated and compared using a representative agricultural watershed in Martin County (JD4). Characteristics of this watershed are also given in Chapter 2. A comparison to drainage law, system functionality, and benefit assessment methods across the Midwest and in Ontario is given in Chapter 3. Parallels are also drawn between agricultural drainage systems and urban drainage (stormwater) systems in Minnesota. The current Minnesota method for assessing benefits is labor intensive. To automate the process, the use of GIS tools was explored. This work is presented and discussed in Chapter 4. The project proposed new method based on drainage depth for each parcel. This method requires an estimate of the surface and subsurface drainage depth for each parcel. These depths were obtained by coupling GIS results with hydrologic models. The method and results are given in Chapter 5.

Chapter 2

BENEFIT ASSESSMENTS IN MINNESOTA

Minnesota Drainage Law

A complex legal framework governing agricultural drainage systems in Minnesota; this framework is covered in Chapter 103E of the Minnesota Statutes (hereafter, Drainage Code). This section provides an abridged overview of relevant statutes in Drainage Code. Where applicable, specific source statutes from Drainage Code are referenced in parentheses.

Definitions

Some useful definitions from Drainage Code (103E.005) are:

- "**affected**" means benefited or damaged by a drainage system or project.
- "**ditch**" means an open channel to conduct the flow of water.
- "**drainage authority**" means the board or joint county drainage authority having jurisdiction over a drainage system or project.
- "**drainage project**" means a new drainage system, an improvement of a drainage system, an improvement of an outlet, or a lateral.
- "**drainage system**" means a system of ditch or tile, or both, to drain property, including laterals, improvements, and improvements of outlets, established and constructed by a drainage authority.
- "**lateral**" means any drainage construction by branch or extension, or a system of branches and extensions, or a drain that connects or provides an outlet to property with an established drainage system.

Drainage System Administration

Drainage systems are administered by drainage authorities; a drainage authority is usually a county board, but can be a joint county board for systems in more than one county. Authority can also be transferred to watershed districts, which may oversee areas in more than one county. Three Minnesota counties (Clay, Traverse, and Washington) have completely transferred drainage authority to watershed districts (Kean, 2012).

From Drainage Code (103E.011), "The drainage authority may make orders to:

1. construct and maintain drainage systems,
2. deepen, widen, straighten, or change the channel or bed of a natural waterway that is part of the drainage system or is located at the outlet of a drainage system,
3. extend a drainage system into or through a municipality for a suitable outlet, and

4. construct necessary dikes, dams, and control structures and power appliances, pumps, and pumping machinery as provided by law."

Drainage Code specifies that drainage authorities must consider various land use and environment factors, as well as "public utility, benefit, or welfare" before establishing a drainage project or other work affecting a public drainage system (103E.015). Drainage authorities are also required to appoint "a competent person" to serve as drainage inspector. The inspector "shall examine the drainage systems designated by the drainage authority" to assess the adequacy of systems (103E.065).

Drainage System Financing

The costs of projects and proceedings relating to public drainage systems are shared by the owners of all property affected by the drainage system. It is therefore necessary to apportion system costs amongst the landowners. Drainage Code states that drainage system costs "***must be prorated to each tract of property affected in direct proportion to the benefits***" that each tract receives (103E.601). This requires work to be done to quantify the benefits that each tract or parcel receives. In Minnesota, ditch viewers fill this role; their work is described in detail in later sections of this report.

Drainage authorities collect taxes from affected landowners to pay for all costs, including: ditch maintenance, improvements, engineering design, surveying, and system administration. Each drainage system is handled as a unique entity, and must have its own account (103E.651). Minor projects (repairs, etc.) are generally paid from the account. If the account balance is insufficient to pay the cost of a drainage project, as is common for improvements and major repairs, the drainage authority issues bonds to pay the project costs (Distad, 2012).

Types of Projects and Proceedings

The Association of Minnesota Counties (AMC) gives an excellent overview of Drainage Code and identified three main categories of drainage system projects: new systems, repairs, and improvements (AMC, 2002). There are other unique projects, some of which fall into one of the aforementioned categories to varying degrees. Some projects and proceedings require petitions by landowners. AMC (2002) reported that landowner petitions are required for the following types of project and proceedings:

1. New systems;
2. Improvements;
3. Outlet improvements;
4. Laterals;
5. Diversion or impoundment of drainage system waters;
6. Repairs that meet certain cost criteria;
7. Use of system as an outlet;
8. Transfer of a system; and
9. Abandonment of a system.

Furthermore, the following types of projects can be initiated either by landowner petition or by the drainage authority:

1. redetermination of benefits;
2. consolidation or division of a system;
3. repairs or maintenance expected to cost less than $50,000 or $1,000 per mile, in one year; and
4. transfer of a system.

All petitioning landowners must own land that is affected by the proposed project, or land over which the project would pass. The minimum number of landowners who must petition (either a *minimum fraction of landowners* or the landowners controlling a *minimum fraction of the land affected*) varies by project type (AMC, 2002; Drainage Code).

Ditch Viewing

Ditch viewing (viewing, hereafter) is the "process of determining the separable portions of a property's value attributable to a public improvement project" (Minnesota Viewers Association, 2004). The importance of the viewing process was summarized in the Minnesota Public Drainage Manual (MPDM) (Minnesota Department of Natural Resources (MNDNR), 1991): "The assignment of benefits and damages is probably the most controversial part of drainage proceedings. Viewing, as this process is called, not only determines if a drainage project is financially feasible, but also provides a formula for distributing construction costs as well as future maintenance costs of a drainage project." "Viewers need to have knowledge of agriculture, topography, residential developments, and soils found typically in the project area. They must be able to read and understand soils maps, aerial photos, and engineering and survey data. … An ideal team of viewers would have knowledge of rural/urban appraisal techniques, soil science, and drainage" (MNDNR, 1991).

Drainage Code (103E.341) states that a drainage authority may only authorize a drainage project if the "estimated benefits are greater than the total estimated cost, including damages," of the project. Furthermore, "the cost must be prorated to each tract of property affected in direct proportion to the benefits. The cost, less any damages, is the amount of liability for each tract for the drainage project" (103E.601). This forms the basis for the collection of taxes from landowners to pay for drainage system costs. Viewers are an integral part of this process, as their work establishes the extent to which each parcel is benefitted or damaged. The benefits and damages for each parcel are added to estimate the total net benefit to the drainage system. The total system benefit is compared to the proposed project cost to verify that the project costs do not exceed the benefits.

Viewers are defined in Drainage Code as "disinterested residents of the state qualified to assess benefits and damages" (103E.305). Additionally, this statute gives individual drainage authorities the power to establish qualifications for viewers. Drainage authorities must appoint three viewers to serve together to carry out viewing duties (103E.305). "The viewers, with or without the engineer, shall

determine the benefits and damages to all property affected by the proposed drainage project ***and make a viewers' report***" (103E.311).

The MPDM lists eleven projects and proceedings that require viewing by viewers:

1. New systems;
2. Improvements;
3. Improvement of outlets;
4. Laterals;
5. Redetermination of benefits;
6. Outlet fees for municipalities;
7. Resloping, leveling, erosion control;
8. Violation of grass strip provision;
9. Inclusion of additional land;
10. Removal of lands; and
11. Apportionment of liens

Descriptions of Projects Involving Viewers

This section provides more detail about the eleven ditch projects and proceedings listed above that require the involvement of viewers. This section follows the layout of the discussion presented in the Viewing/Appraising chapter of the MPDM.

New systems are relatively straightforward as benefits are determined based on the future drained condition (after establishment of the drainage system) relative to the present condition with no drainage system.

An ***improvement*** is defined as "the tiling, enlarging, extending, straightening, or deepening of an established and constructed drainage system including construction of ditches to reline or replace tile and construction of tile to replace a ditch" (103E.215). For improvement projects, viewers are only concerned with determining the benefits and damages caused by the improvement. Benefits may only apply to properties directly adjacent to the improvement; benefits may also apply to upstream properties based on an increase in drainage potential.

Damages relating to improvement projects may include taking of additional land for right of way or damages due to increased flooding or risk of flooding downstream of the improvement. As will be discussed with many types of projects, it may be prudent to conduct a redetermination of benefits for the entire system along with the improvement project. This would ensure that all land within the system is updated to reflect current land values and productivity. If a redetermination of benefits is not done on the entire system, the benefits to lands not affected by the improvement would remain at the values last determined, which could have been done several decades earlier. This inequity in benefits would result in those landowners with more recently determined benefits bearing a disproportionately high share of system costs.

The viewing process for an ***outlet improvement*** is very similar to a general improvement, as discussed above. The difference is that an outlet improvement can be done in cases where an inadequate outlet is causing ineffective drainage, flooding, or overflow onto upstream properties. The outlet improvement will allow for improved drainage of upstream properties.

The viewing process for a ***lateral*** (a new branch from an existing open channel segment) is similar to that used for a new system. If areas to be drained by the lateral are already assigned benefits within the existing drainage system, the benefits assigned to those properties in the lateral proceeding must only be the additional benefit due to improved drainage that the lateral will provide. Lands not already assessed as part of the existing system are assessed as they would be with a new system, and an outlet fee would have to be determined to assess the benefit that the new lands would get from access to the outlet (where the lateral empties into the existing ditch). As previously discussed, a redetermination of benefits may be needed to ensure that newly assessed property benefitting from the lateral is not responsible for a disproportionate amount of overall costs.

There are two key reasons for a ***redetermination of benefits*** (ROB): to update benefits and damages to reflect present land values and productivity, and to include areas that are currently receiving benefits from the system, but so far have not been assessed benefits. An ROB is treated much the same as a new system, in that all benefits assessed to lands within the system are made relative to the original pre-drainage condition. This allows for a fair evaluation of the benefits that the drainage system affords (or makes possible to landowners wishing to drain).

The addition of land not previously assessed is a major issue relating to ROBs. BWSR (2012) reported several examples, including Judicial Ditch Number 2 (JD2) in the Bois de Sioux Watershed District in western Minnesota. JD2 was assessed a benefit of $20,507 for 17,577 acres ($1.17 per acre) in about 1900, but was redetermined to have benefits of $3,927,667 for 59,690 acres ($65.80 per acre) in 1999. Thus, until 1999 the only land assessed benefits within the system was the original 17,577 acres that was deemed affected in 1900. Between 1900 and 1999, an additional 42,113 acres of land began receiving system benefits, but the landowners of the original 17,577 acres paid all system costs until 1999 when the ROB was completed. A similar case in Freeborn County saw a system increase from 394 affected acres to approximately 4,000 affected acres upon redetermination (Distad, 2012). While it may be unreasonable to conduct ROBs with regularity, there are many cases where some landowners are paying a disproportionate amount of system costs, while other benefited landowners pay nothing.

BWSR (2012) highlighted another reason to conduct an ROB: The funds in system repair accounts are limited to 20 percent of the assessed benefits of the entire system, or $100,000, whichever is greater. Section 103E.715 of Drainage Code also states that the cost of a repair may not exceed the assessed benefits of the system. Drainage Code provides no mechanism for indexing drainage benefits for inflation (BWSR, 2012). Therefore, the ability to proceed with needed repairs may be limited unless a ROB is carried out to update the assessed benefits to current day values. For many of the reasons mentioned here, several counties in Minnesota have carried out or are now conducting systematic ROBs on all of the systems that they administer (BWSR, 2012). In cases reported by BWSR (2012), the cost of ROBs ranged from approximately $2.00 to $3.75 per acre. The newly determined benefits resulting from a ROB replace the previously determined benefits and thereafter serve as the basis for all future system cost apportionments.

Outlet fees for municipalities assesses the benefits that municipality receives from the right to outlet a storm sewer or wastewater system to a drainage system. Benefits to municipalities are generally assessed differently than benefits to agricultural land (MNDNR, 1991). This topic is not addressed in this report.

From Drainage Code: "For a drainage system that is to be repaired by ***resloping ditches, leveling waste banks, installing erosion control*** measures, or removing trees, before ordering the repair, the drainage authority must appoint viewers to assess and report on damages and benefits…" (103E.715). Benefits are rarely assessed in conjunction with these projects, but damages are often paid to pay for right-of-way for placement of erosion control, grass strips, or flattening of side slopes (MPDM).

Drainage Code (103E.021) requires that ***vegetated ditch buffer strips*** (or grass strips) of 1-rod (16.5 feet) width be established between ditches and adjacent fields incrementally as project involving viewers are carried out. Violation of this rule will result in additional assessment being levied against violating landowners. "Property that is in violation of the grass requirement shall be assessed a cost of 20 percent of the repair cost per open ditch mile multiplied by the length of open ditch in miles on the property in violation." The offending landowners are assessed the appropriate fees before the remaining costs are apportioned to all landowners pro rata based on assigned benefits. (103E.728)

Inclusion of additional land is similar to the case where an ROB assigns benefits to new parcels. Drainage Code (103E.741) specifies that the engineer (in a proceeding to repair a drainage system) may notify the drainage authority if he or she "determines or is made aware that property that was not assessed for benefits for construction of the drainage system has been drained into the drainage system or has otherwise benefited from the drainage system." The engineer must submit a map (along with the repair report) showing all property affected by the drainage system. Landowners are then notified of a hearing by the drainage authority. A hearing is held to determine if there are affected lands that have not been assigned benefits. If this is the case, viewers shall be appointed to carry out a determination of benefits and damages on the affected lands, and those lands and associated benefits are included going forward.

Removal of lands from drainage systems is covered in Section 811 of Drainage Code, which deals with abandonment of a system. A petition signed by "at least 51 percent of the property owners assessed for the construction of the drainage system or by the owners of not less than 51 percent of the area of the property assessed for the drainage system" must be presented to the drainage authority to begin this proceeding (103E.811). The petitioners must show that the system is not of public benefit and utility due to abandonment of agricultural property that used the system, or because the system no longer functions and its repair is not practical.

If at least one landowner assessed benefits for the system makes a written objection to the system abandonment, the drainage authority must appoint three viewers to examine the property and report the "description and situation of the property and whether the drainage system drains or otherwise affects the property" (103E.811). Following the viewers' report, a hearing is held, at which time the drainage authority must determine whether the system serves "any useful purpose to any property or the general public." If the drainage authority determines there is any benefit to property or to the general public, the petition for abandonment must be denied. If the drainage authority determines there is no benefit to property or to the general public, the system must be ordered abandoned.

The ***apportionment of liens*** is a process divides existing assessments against a piece of property following the division of that property into two or more pieces. MPDM (MNDNR, 1991) reported that the county auditor often carries this out, but viewers can be called to do perform this function if necessary.

Viewers' Report

The viewers' work is summarized in a required viewers' report that details the extent to which each of the affected properties are benefitted and/or damaged. From Drainage Code (103E.321), "the viewers' report must include for each lot, 40-acre tract, and fraction of a lot or tract under separate ownership that is benefitted or damaged:

1. a description of the lot … that is benefited or damaged;
2. the names of the owners … and their addresses;
3. the number of acres in each tract or lot;
4. the number and value of acres added to a tract or lot by the proposed drainage of public waters;
5. the damage, if any, to riparian rights;
6. the damages paid for the permanent strip of perennial vegetation under section 103E.021;
7. the total number and value of acres added to a tract or lot by the proposed drainage of public waters, wetlands, and other areas not currently being cultivated;
8. the number of acres and amount of benefits being assessed for drainage of areas which before the drainage benefits could be realized would require a public waters work permit to work in public waters … ;
9. the number of acres and amount of benefits being assessed for drainage of areas that would be considered conversion of a wetland… if the area was placed in agricultural production;

10. the amount of right-of-way acreage required; and
11. the amount that each tract or lot will be benefited or damaged."

Drainage Code (103E.321) goes on to say "The viewers' report must include a benefits and damages statement that shows for each property owner how the benefits or damages for similar tracts or lots were determined. For similar tracts or lots the report must describe:

1. the existing land use, property value, and economic productivity;
2. the potential land use, property value, and economic productivity after the drainage project is constructed; and
3. the benefits or damages from the proposed drainage project."

Drainage Code states that "if the viewers are unable to agree, each viewer shall separately state findings on the disputed issue. A majority of the viewers may perform the required duties" of reporting (103E.321). Upon completion of the viewers' report, the report must be filed with the county auditor of each affected county, or with the watershed district secretary. The auditor then produces a report for landowners showing all benefits and damages to a landowner's property.

Benefits

Drainage Code (103E.315) provides guidance – albeit, limited – for assessing benefits and damages. Instructions are given for state land, government property, public roads, and railroads and other utilities. This Section states "viewers shall determine the amount of benefits to all property within the watershed, whether the property is benefited immediately by the construction of the proposed drainage project or the proposed drainage project can become an outlet for drainage, makes an outlet more accessible, or otherwise directly benefits the property. The benefits may be based on:

1. an increase in the current market value of property as a result of constructing the project;
2. an increase in the potential for agricultural production as a result of constructing the project; or
3. an increased value of the property as a result of a potential different land use; or

MPDM defined these benefits as *direct benefits*, or those benefits attributable to the construction of public drainage systems. MPDM provided a further analysis of benefits. The authors reported that in general, assessments for special benefits to real estate in Minnesota may only be based on an increase in market value, or "what a willing buyer would pay a willing seller for the property before, and then after, the improvement has been constructed."

Other benefits fall into the category of *indirect benefits*. Indirect benefits were defined by MPDM as "benefits from a proposed drainage project that provides an outlet." These include considerations for proposed systems that would provide an outlet for an existing system. In this case, "viewers shall equitably determine and assess:

1. the benefits of the proposed drainage project to each tract or lot drained by the existing drainage system;
2. a single amount as an outlet benefit to the existing drainage system; or
3. benefits on a watershed acre basis."

These benefits would be assigned to the existing system based on the additional benefit provided to that system by the proposed system or project. Additionally, "within the watershed that drains to the area where a project is located, the viewers may assess outlet benefits on:

1. property that is responsible for increased sedimentation in downstream areas of the watershed; and
2. property that is responsible for increased drainage system maintenance or increased drainage system capacity because the natural drainage on the property has been altered or modified to accelerate the drainage of water from the property."

This is essentially the extent of guidance given to viewers to carry out assessment of benefits.

Damages
From Drainage Code (103E.315), "damages to be paid may include:

1. the fair market value of the property required for the channel of an open ditch and the permanent strip of perennial vegetation under section 103E.021;
2. the diminished value of a farm due to severing a field by an open ditch;
3. loss of crop production during drainage project construction;
4. the diminished productivity or land value from increased overflow; and
5. costs to restore a perennial vegetative cover or structural practice existing under a federal or state conservation program adjacent to the permanent drainage system right-of-way and damaged by the drainage project."

More on Benefits and Damages
Drainage Code offers no guidance to viewers regarding the time value of money. Some benefits, such as an increase in the current market value of agricultural land or an increase in the market value based on a potential different land use, make sense as one-time benefits. However, this is not the case for an increase in the potential agricultural productivity as a result of a drainage project – in this case a farmer may realize an ongoing increase in crop yields. While there are methods for converting present-day values to annual benefits, and vice versa, there is no indication of what is expected of viewers.

As is the case for benefits, some damages – such as land permanently taken out of production for a ditch or vegetated buffer strip – seem to make sense as one-time payments, where the system is in essence purchasing affected land (or an easement) from one or more landowners for the benefit of the entire system. There are some damages that may make more sense as annual payments. An example of this is land that may be likely to suffer losses in yields due to an increased likelihood of overflow and inundation as a result of a ditch project.

Drainage Code specifies that drainage project costs may not exceed the assessed benefits of the drainage system. This seems a reasonable approach – system repair costs should not exceed the value of the system. However, because there is no further limitation on the lifetime costs of a system, a drainage project having a cost just below the assessed benefits of the drainage system could be done every year without violating Drainage Code. In as little as two years, cumulative project costs could easily exceed the system benefits.

Minnesota Viewers Association

Viewing in Practical Terms
The Minnesota Viewers Association (MVA) was founded in 1981 as the professional organization of viewers in Minnesota (MVA, 2012). MVA's mission is "…to provide an unbiased approach to the determination of benefits and damages as set forth in Minnesota Statues. This organization strives to establish a professional approach to meet the needs and requirements for the viewing process. The goals for the viewing process are results that are equitable and defendable given the limited guidance stated within the Minnesota Statue. …Through education the viewing process will meet and follow the applicable and accepted appraisal practices recognized within the Uniform Practices of Professional Appraisal Practices" (MVA, 2012).

Training Manual
The Minnesota Viewers Association Training Manual (MVATM) (MVA, 2004) was written in an effort to assist in the determination of benefits and damages. It was the first attempt to formally document and summarize the procedures generally accepted by MVA members. The following sections provide an overview of the contents of the MVATM and the standard practices developed by MVA.

<u>Introduction</u>
MVATM draws from the Standards of Professional Appraisal Practices for ethics and competency rules. MVATM also includes Standards 1 and 6 from the Uniform Standards of Professional Appraisal Practice governing Real Property Appraisal and Development, and Mass Appraisal, Development, and Reporting, respectively.

The MVATM guides viewers to begin their work by obtaining all relevant records from county auditors or watershed district offices. These records contain information pertaining to establishment of the drainage system and other useful project records. Viewers are then guided to familiarize themselves with the project at hand. This may include reviewing engineering drawings, maps, construction contracts, old viewers' reports, etc. Engineering reports, plans, and other documents may be used to determine "drainage system capacity, efficiency, and its effect upon the lands determined to be benefited."

MVATM provides a list of possible resources available to viewers when gathering further information relating to the project area: project records, county tax records, USDA soil surveys, FSA aerial photography, contour maps, zoning and land use regulation, farm management records, local grain elevators, and current photographs.

<u>Benefits Classifications</u>
Viewing is performed as a mass appraisal process, where "properties having similar characteristics are assumed to have similar values based upon the market conditions within the area of the appraisal." Furthermore "to accomplish this application of value (benefit), the viewer must determine the basis and characteristics for each of the established classifications. Adequate classifications to distinguish differences in the benefits should be established."

Viewing has historically employed a lettering system – commonly A, B, C, and D – to identify distinct benefit classes. "The description of the conditions that would exist **prior to drainage or conversion** to an agricultural or other use normally assumed for the four beginning land classes used is:

A. Standing water or cattails, wetland classification with a market value for agricultural purposes of $0.00 per acre, an economic productivity of $0.00
B. Seasonally flooded/pasture ground. Highest and best use as pasture or grass hay harvest having a market value of $______ per acre, and economic productivity of $______ based on grazing days and/or hay values.
C. Wet subsoil – Generally farmable land with moderate crop potential having a current market value of $______ per acre, an economic productivity of $______ based upon average annual yield of ______ % of optimum with $______ production costs.
D. Upland areas not specifically needing artificial drainage but irregular in shape and intermixed

This classification system helps to group different lands according to the need for artificial drainage to become "optimally productive" for crop production. This judgment is to be made according to all pertinent information available to the viewer. The use of soils manuals should be done only in conjunction with field verifications to properly determine the role of minor inclusions within the major soil classifications.

The MVATM warns viewers: "It is the responsibility of the viewer to verify that in their opinion the acres determined to be benefit the value of each class meet the characteristics describing each class and the benefit value assigned to that class is reflective of the benefit value received by that parcel."

The final determination of benefits is to be made according to the conditions anticipated upon completion of the drainage system (or project). "The classifications may be established based upon the change in characteristics of the four beginning classification descriptions, variables of the after project conditions, or for consideration of other land use, or impact to or from the project."

"General descriptions of after project classifications for the four beginning classes may be:

A. Drained slough area, medium agricultural productivity having a market value of $_____ per acre, an economic productivity of $_____ based upon average production of _____ % of optimum with $_____ production costs.
B. Well-drained ground, medium to high agricultural productivity having a market value of $_____ per acre, an economic productivity of $_____ based upon average production of _____ % of optimum with $_____ production costs.
C. Well-drained ground, highest agricultural productivity having a market value of $_____ per acre, an economic productivity of $_____ based upon average production of _____ % of optimum with $_____ production costs.
D. Upland area, high agricultural productivity having a market value of $_____ per acre, an economic productivity of $_____ based upon average production of _____ % of optimum with $_____ production costs.

Other benefit classifications may be described for limited or special agricultural use, residential development, municipal uses, industrial uses, recreational uses, accelerated runoff, or others deemed appropriate by the viewers to best reflect the variable characteristics established to determine a fair and accurate determination of benefit."

Benefit Valuation

MVATM interprets Drainage Code language concerning benefits to relate to an increase in market value. MVATM uses the following definition of market value:

> "the most probable price, as of a specific date, in cash, or in terms equivalent to cash, or in other precisely revealed terms for which the specified property rights should sell after reasonable exposure in a competitive market under all conditions requisite to a fair sale, with the buyer and seller each acting prudently, knowledgeably, and for self-interest, and assuming that neither is under undue duress."

The three procedures used to estimate market value under standard appraisal practices are the sales comparison approach, the cost approach, and the income capitalization approach. MVATM interprets Drainage Code to direct viewers to consider the sales comparison and income approaches. This is due to the fact that a fundamental part of any ditch project is making a determination about the cost-effectiveness of a project. The viewing process is concerned with the benefits of a drainage project (i.e. higher land values and/or higher agricultural productivity), whereas the determination of project costs falls on the drainage authority and engineers. Thus, viewers are advised to avoid the cost approach.

Sales Comparison Approach

The sales comparison approach estimates market value by comparing a property to similar recently sold properties, while "applying appropriate units of comparison, and making adjustments to the sale prices of the comparables based upon the elements of comparison." This method is based on extensive research into recent sales or similar lands in the area. Sales data must be available for parcels in both original (pre-drainage) and drained (post-project) condition.

Relevant records are kept in a city or county assessor's office, and include a certificate of real estate value (CRV). The CRV should be examined to determine the sale date, sale conditions, financing influence (if any), and parcel descriptions. For agricultural lands, the crop equivalent rating (CER) can be used to indicate the similarity of the lands being considered. Further records are available from the assessor's office relating to the valuation made by the assessor. This information may include land use, soil types, and CER.

After gathering relevant sales information, viewers begin to make appropriate adjustments. The viewers must "use their experience and knowledge to separate the various influences and segments comprising the sale value as a whole. This must be completed in a manner that will be consistent with the classification of the benefits categories established by the viewer…" (MVATM).

MVATM notes that while the sales comparison approach has historically been the dominant approach used in viewing, this approach is becoming increasingly difficult to employ. This difficulty arises from the lack of sales of lands that have not been artificially drained or affected by drainage systems to simulate the pre-drainage condition. MVATM notes that while this is a limitation of the sales comparison approach, the principle of substitution allows the viewer to set an upper limit on the benefit amount that one property is assigned. Put another way, a "buyer cannot be expected to pay more to improve a piece of property than it would cost to replace it with a property that has already been similarly improved."

Income Capitalization Approach

The income capitalization approach is used to estimate the present value of future annual benefits to property, which corresponds to an "increase in the potential for agricultural production" from Drainage Code (103E.315). This approach involves estimating the annual income for both the unimproved and fully improved condition. The difference between these two amounts is the increase in income due to the drainage system or project. This benefit can be capitalized based on rates of return and project term to calculate the present value of the future annual benefits.

For both the unimproved and drained conditions, the annual benefit is based on a wide variety of factors. Revenue depends on crop type, crop rotation, expected productivity, and crop prices. Costs to landowners include seed, fertilizer, chemicals, fuel, equipment, etc. Costs also include drain tile installation, which is converted to an annual cost from an assumed present installation cost.

Yield expectations and crop production acreages are to be based on known crop production from the project area. Generally, yield expectations (as a percentage of the optimum yield) are given for A through D land classifications.

Case Study Watershed – JD4

Overview

Judicial Ditch 4 (JD4) in Martin and Watonwan counties has been selected to illustrate how benefits are assessed with the current Minnesota method. The most recent redetermination of benefits was completed by viewers and submitted to Martin and Watonwan Counties on November 18, 2011. This case study watershed is also used to compare and contrast alternative methods for assessing benefits given later in the report.

Valuation Classifications Using the Minnesota Method

To illustrate the land valuation classifications (A through D) discussed above, a redetermination of benefits report from 2011 was obtained from MVA for the JD 4 ditch. The valuation classifications are summarized in Table 1.

Table 1. Summary of land benefit classifications: pre- and post-drainage conditions.

	Valuation prior to drainage		**Valuation with NRCS guideline drainage**	
Classification	Market Value	Economic Productivity (as a percentage of optimum yield)	Market Value	Economic Productivity (as a percentage of optimum yield)
A	$0	$0	$5500 - 6500	$701.50 (92%)
B	$1000 - $1500	$60 (grazing and hay)	$6500 - $7500	$732 (96%)
C	$5500 - $6500	$610 (80%)	$6500 - $7500	$762.60 (100%)
D	$5000 - $7000	$724.38 (95%)	$5500 - $7500	$762.60 (100%)

The production costs associated with producing agricultural commodities in this watershed was found to be, on average, $314.15 per acre. This production cost applies to all land valuation classes for the post-drainage condition, with the assumption that the drained condition is adequate to allow planting of similar crops on all lands. For the pre-drainage condition, the production cost applies only to the C and D classifications, as the B classification had value only as hay or grazing land, while the A classification had no agricultural value. An example included in the redetermination of benefits is reproduced in Table 2 to further explain this process.

From Table 3, 'B' land would be assigned a benefit of $4,560, which is due to the increase in economic productivity as a result of shifting the land from grazing and hay production to row crop agriculture. Table 3 shows the annual and present equivalent benefits of increased productivity for all four land classifications. The benefit assigned to 'D' lands is low due to the relatively high agricultural production of those lands in the pre-drainage condition. Conversely, the benefit assigned to 'A' lands is high due to the relatively high productivity in the post-drainage condition, compared to an assumed productivity of zero in the pre-drainage condition.

Table 2. Example of a benefit computation for land with a B classification.

Annual potential productivity value	$762.50
Adjustment for 96% economic efficiency (from Table 1)	$732.00
Annual production cost	- $314.15
Beginning annual productivity value (from Table 1)	- $60.00
Change in annual productivity	**$357.85**
Annual private improvements (drain tile) ($850/25 years)	- $34.00
Net annual benefit	**$323.85**
Present value (25 years @ 5%)	**$4,140**

Table 3. Example summary of benefits by land classification.

Classification	Net Annual Benefit	Present Benefit Value (25 years @ 5%)
A	$351.35	$4,950
B	$323.85	$4,560
C	$120.50	$1,700
D	$38.13	$540

It is important to note that the income capitalization and sales comparison approaches support the same benefit value. An increase in land sale value is due to increased productivity that a producer may expect going forward. This allows the estimation of a current benefit based on the income capitalization approach.

Efficiency Rate

The efficiency rate is used by viewers to account for possible loss in production due to ponded water. Ponded water may be due to extreme rainfall events, undersized tile mains, or a combination of the two. The curve number (CN) method is used in determination of the efficiency rate. Curve numbers are based on land use or cover, hydrologic soil group, and tillage practices. For a given rainfall depth, the CN method estimates the amount (depth) of rain that will become runoff. Using the CN method in this way requires the assumption that all runoff will enter the drainage system through tile drains and then pass to tile mains. This neglects any runoff that travels over the soil surface to an open ditch.

Drainage area is then used to determine the volume of water that will need to travel through the drainage system (tile main) to remove all ponded water from the surface. Known tile main sizes and slopes are used to determine the maximum discharge that the tile main affords. The time to remove all ponded water from the soil surface is then calculated as the volume of ponded water divided by the tile main maximum flow rate. Depending on the amount of time that ponded water is present on the surface, a corresponding reduction in crop yield may need to be accounted for. This process can be repeated for many storms (i.e. 2-year, 5-year, 10-year, etc. rainfall events) and estimates of crop yield reduction can be made for each storm event. The net effects of all relevant storm events (based on the project life) are summed to determine the average reduction in crop yields for a typical year. This average reflects the many years where crop yields are relatively high, while also including those relatively few years where crop yields are significantly hurt by standing water.

To calculate the net benefit to a parcel, the gross benefit (as determined from the income approach) is multiplied by the efficiency rate. Those parcels with high efficiency rates see little change between gross and net benefits, while those with low efficiency rates see a larger reduction in benefits. This shifts the burden slightly towards those parcels with properly sized tile mains, and away from those with perhaps undersized tile mains where reductions in crop yield due to ponding water will occur more frequently and with more severity.

The overall efficiency rate for each parcel is determined from three separately determined efficiency values: hydraulic efficiency, flooding efficiency, and proximity efficiency. Hydraulic efficiency depends on the hydraulic capacity of tile mains that provide drainage for each parcel. When tile mains are undersized (for the given drainage coefficient and drainage area), drainage from upstream parcels is limited by the capacity of the undersized tile main.

Flooding efficiency is the aspect of efficiency that was originally described earlier in this report. The flooding efficiency determines the negative economic impacts of ponded water as a result of large storm events. Flooding efficiency is correlated with hydraulic efficiency to the extent that the area and duration of ponding will tend to increase as hydraulic efficiency decreases. In cases where hydraulic efficiency is 100% (i.e. the tile main is adequately sized for the specified drainage coefficient), flooding efficiency may still be less than 100% due to ponded water resulting from large storm events (e.g. a 50- or 100-year rainfall).

The final efficiency term is proximity efficiency, which is related to the distance that each 40-acre tract is from the drainage system (open ditch or public tile main). Parcels along ditches and tile mains receive a proximity efficiency of 100%, while those further from the drainage system will receive lower proximity efficiencies, which may decrease by 5 to 15% for each succeeding 40-acre field. Because 40 acre fields are typically square with a side length of one quarter mile, the proximity efficiency essentially drops every quarter mile as one moves further away from the drainage system. One example provided by ditch viewers showed proximity efficiencies of 85, 70, 50 and 30 percent for parcels that were 1, 2, 4, and 6 40-acre parcels (0.25, 0.5, 1, and 1.5 miles) removed from the drainage system, respectively.

To arrive at the overall efficiency rate, viewers use professional judgment to combine the three separate efficiency rates into one final value. Little explanation of the process was available from viewers. Common sense dictates that the procedure is relatively straightforward in cases where the three efficiency values are close to each other. It is unclear how the three values are weighted when they are not in good agreement.

Benefits by Parcels

For comparison of Minnesota method to alternative methods examined in this study, it is necessary to summary the benefits by individual parcels. A sample of benefits for selected parcels of JD4 is given in Table 4. All parcels are from Township 104N, Range 32W in Martin County.

Table 4. Example of computations for selected parcel for JD 4.

Parcel ID (modified)	Section	Description	Area in tract (acres)	Non-converted or restricted wetland acres	Area by benefit class (acres)					Gross Benefit	Efficiency Rate	Net Benefit
					A	B	C	D	D-			
1	4	NENW	37.86			6	30			$71,040	85%	$60,384
	4	NWNW	18.84			3	10	5		$30,270	90%	$27,243
	4	SWNW	40	2.00		4	24	9		$57,930	100%	$57,930
	4	SENW	40		1	6	32	1		$81,585	96%	$78,322
2	4	NWNE	38.03					1		$490	80%	$392
	4	SWNE	40		4	5	24	4		$82,435	93%	$76,665
	4	SENE	40			4	26	6		$59,743	85%	$50,781
3	5	NWNW	37.25	2.00		1	12	7		$26,050	60%	$15,630
	5	SWNW	40				4	9		$10,570	60%	$6,342
4	5	NENE	13.14	2.14		1	9	1		$18,490	95%	$17,566
	5	NWNE	21			1	15	4		$29,200	85%	$24,820
	5	SWNE	40			1	30	9		$54,750	90%	$49,275
	5	SENE	37	1.00	3	4	20	4		$67,568	100%	$67,568
	5	NENW	37.35		1	3	25	6		$58,810	70%	$41,167
	5	SENW	40			2	31	7		$59,450	75%	$44,588

The parcel ID (modified in the table to save space), section, and description identify the parcels in question. The area of each tract is given in the fourth column. The number of non-converted or restricted wetland acres is given in the following column. This category includes ditches, other areas that are permanently removed from agricultural production, and wooded areas surrounding farmyards. Road acreage is removed from each parcel and the benefits that roads receive are reported in a separate area of the viewers' report. Road benefits are paid by the owner of the road. Because road benefits are a relatively minor part of the total drainage benefits, they are not discussed here. In cases where grass buffer strips have not been established in accordance with Minnesota Statute 103E.021, seeding area required for grass buffer establishment is also reported by parcel, although this is not shown in Table 4.

The remaining acreage in each tract is then divided into the appropriate benefit classes. As described earlier in this report, the benefits classes generally range from A (those lands benefitting most from the drainage system) to D (those lands benefitting the least). D- was used by viewers as an additional class in this system to categorize commercial agricultural operations (in this case, large buildings used for hog production) that benefit from the system because they generate increased runoff. It should be noted that D- is simply indicative of a fifth class, and does not necessarily indicate a connection with the D benefits class; in fact, the per acre benefit assigned to D- ($2030) falls between the values of the B and C benefit classes.

The gross benefit is calculated as the sum of the benefits for each benefit class (Figure 1). Net benefit is the product of gross benefit and efficiency rate (Figure 2). Efficiency rate is calculated as described earlier. Below are maps depicting the use of the Minnesota viewing method to assign benefits to JD4 as the fraction of net and gross watershed benefits (x 100 for ease of interpretation) by quarter-quarter parcel (parcel-qq). The creation of Figures 1 and 2 required the conversion of the viewer's report into a GIS framework. The details of this conversion are given in Chapter 4.

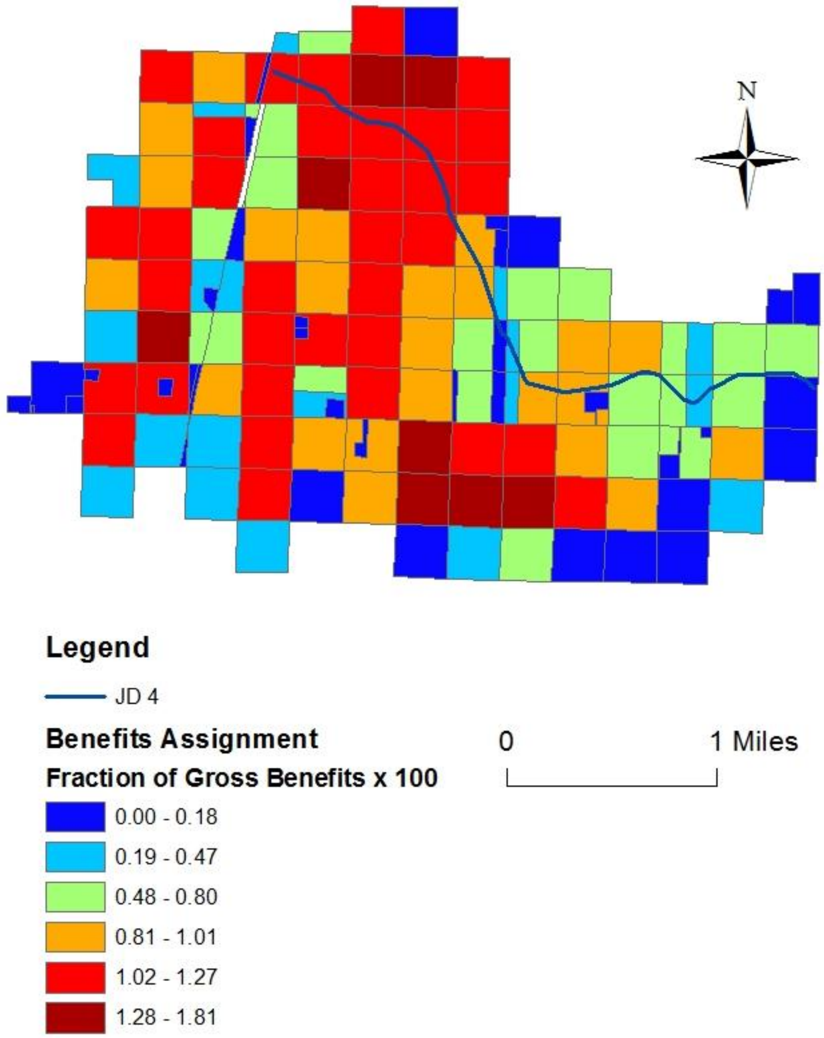

Figure 1. Map of the fraction of gross benefits x 100 by quarter-quarter parcel.

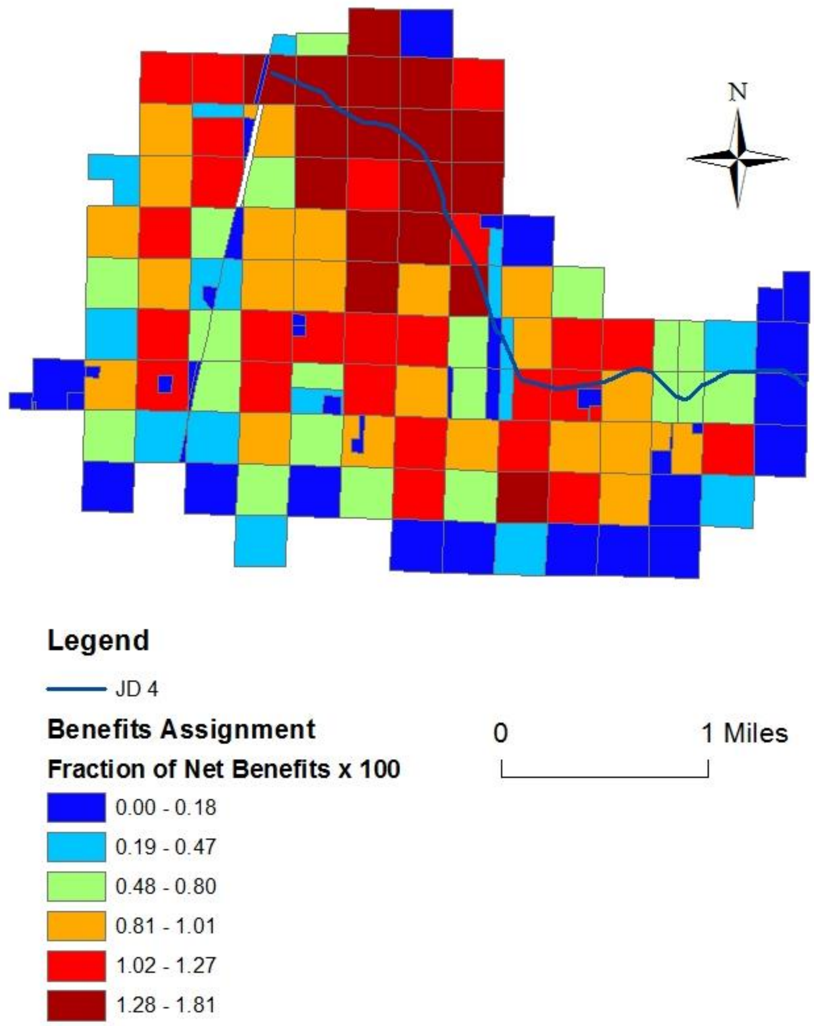

Figure 2. Map of the fraction of net benefits x 100 by quarter-quarter parcel.

Chapter 3

BENEFIT ASSESSMENT IN OTHER JURISDICTIONS

Introduction

It is useful to consider how drainage benefits are determined in other intensively drained areas. Information from Illinois, Indiana, Iowa, North Dakota, Ohio, and Ontario is summarized in the following sections. There are, inevitably, many aspects of drainage systems and corresponding legal proceedings that cannot be covered in this report. In general, a brief overview of drainage system administration and organization is presented along with relevant information pertaining to the manner in which benefits and damages are assigned. These summaries are not meant to be a comprehensive review of all aspects of drainage law in these jurisdictions.

Specifically relating to benefit and damage assessments, there are generally many levels of oversight and communication between officials (drainage boards, county auditors, county surveyors, etc.), drainage professionals (engineers, surveyors, etc.), and landowners. The power of landowners in these proceedings (petitions, appeals, etc.) will be largely overlooked here, as this report deals primarily with the manner in which benefits and damages are determined.

Illinois

In the Illinois Drainage Code (Section 1-2), a “"Ditch" means an artificially constructed open drain or a natural drain which has been artificially improved” and a “"Drain" includes ditch and means any water course or conduit, whether open, covered or enclosed, natural or artificial, or partly natural and partly artificial, by which waters coming or falling upon lands are carried away.” The Farm Drainage Act, passed in 1879, provided for the formation of drainage districts in Illinois (Uchtmann and Gehris, 1997). Courts have held that landowners cannot be forced to join a drainage district if their property has perfect natural drainage. Thus, a drainage district must show that a property has imperfect natural drainage to obtain jurisdiction over that property. Uchtmann and Gehris (1997) gave a summary of practical issues relating to court rulings, which have an influence on matters relating to drainage districts and their operation. These issues include:

1. “Assessments can be levied only against benefited land.
2. Assessments on land cannot exceed the benefits that the land will receive.
3. Assessments are not limited to land alone but may be levied against improvements, providing that there are benefits.
4. “Benefits”—the estimated value of the proposed drainage works to a particular property—are not limited to “agricultural or sanitary” benefits, but may include other kinds, such as those occurring to a railroad or manufacturing concern; therefore, assessments may be levied against such property.

5. Landowners are entitled to a court hearing on the question of benefits before they can be compelled to pay drainage assessments.
6. Drainage districts are public corporations charged with specific governmental functions and, if necessary, may acquire rights in land by instituting eminent domain proceedings and paying just compensation to the owners." (Uchtmann and Gehris, 1997)

The primary method by which a drainage district is established is by landowner petition (Uchtmann and Gehris, 1997). Upon the successful establishment of a drainage district, three temporary commissioners are appointed to the drainage district. The temporary commissioners must examine the land to determine the feasibility of the project and the associated costs and benefits. A registered professional engineer is required to assist with this activity. A report of the commissioners' findings must also be compiled and submitted to the court. A hearing is then held, after which "the court may:

1. confirm the report and enter the prescribed order declaring the district organized;
2. modify the report and confirm it;
3. order the commissioners to review and modify the report before it is confirmed; or
4. find that the district should not be organized because the benefits do not exceed the costs." (Uchtmann and Gehris, 1997)

Drainage assessments are grouped into three classifications within Illinois Drainage Code. These classifications are known as original assessments, annual maintenance assessments, or additional assessments (Illinois Drainage Code, Section 5-1). The original assessment is that "levied for the construction of the original work of the district." The annual maintenance assessments are levied to carry out annual routine maintenance within the district. Additional assessments are levied to cover all expenses not covered by the original or annual maintenance assessments.

Original assessments are determined by the commissioners after the establishment of the drainage district. The original assessments of benefits, damages, and compensation are assigned to "all lands, lots, railroads, and other property within the district other than public highways, streets and alleys, which, in their opinion, will be benefited, taken or damaged by the proposed work" (Illinois Drainage Code, Section 5-2). It appears that Illinois Drainage Code allows for annual maintenance assessments and additional assessments to be collected in proportion to the original assessment, as no other direction is provided to the commissioners. No specific direction about the nature of assessments of benefits is provided in Illinois Drainage Code, and no other information was readily available at the writing of this report. However, Illinois drainage proceedings seem to require much more involvement from the courts system than proceedings in other states (Illinois Drainage Code, Sections 1-4 and 5-19, for example).

Indiana

Indiana law allows for the combination of city and county government (as a "consolidated city"), as is the case with Indianapolis and Marion County (known officially as Unigov) (Indiana Code 36-3). There are some differences in drainage law pertaining to consolidated cities. This discussion will focus on general issues related to counties that do not contain consolidated cities.

A regulated drain is defined as "an open drain, a tiled drain, or a combination of the two." An open drain is "a natural or artificial open channel that carries surplus water and was established under or made subject to any drainage statute." A tiled drain is "a tiled channel that carries surplus water and was established under or made subject to any drainage statute." (Indiana Code 36-9-27-2).

Chapter 27, Article 9, Title 36 of Indiana Code (IC) pertains to drainage law within the state. On first adoption, Section 4 of this chapter established drainage boards in each county within Indiana. A board consists of either the county executive, or three or five persons. Appointees other than the executive must be "resident freeholders within the county who are knowledgeable in drainage matters." In addition, the county surveyor serves on the board as a nonvoting member (IC 36-9-27-5). Joint boards are created in cases where projects involve more than one county.

IC 36-9-27-29 outlines the duties and powers of county surveyors as follows: "The county surveyor is the technical authority on the construction, reconstruction, and maintenance of all regulated drains or proposed regulated drains in the county, and he shall:

1. investigate, evaluate, and survey all regulated drains or proposed regulated drains, and prepare all reports, plans, profiles, and specifications necessary or incident to any proposed construction, reconstruction, or maintenance of regulated drains;
2. prepare and make public standards of design, construction, and maintenance that will apply to all regulated drains and their appurtenances, taking into consideration … the published recommendations made by Purdue University, the American Society of Agricultural Engineers, the American Society of Civil Engineers, the United States Department of Agriculture, the department of natural resources, the United States Army Corps of Engineers, and other reliable sources of information;
3. supervise all construction, reconstruction, and maintenance work performed under this chapter;
4. catalog and maintain a record of all surveying notes, plans, profiles, and specifications of all regulated drains in the county, and of all mutual and private drains when available; and
5. perform the functions set forth in sections 67 through 69 of this chapter concerning all urban drains under his jurisdiction…"

Furthermore, the surveyor "shall classify all regulated drains in the county as drains in need of construction, drains in need of periodic maintenance, or drains that should be vacated" (IC 36-9-27-34). These classifications are performed annually. A report of drain classifications and priority is then made to the drainage board (IC 36-9-27-34). Reclassifications can also be petitioned for by at least 10 percent of the landowners affected by a drain. A reclassification is then considered at a hearing, whereupon the drainage board adopts an appropriate classification. IC 36-9-27-36 states that upon adoption of classifications by the board, "the county surveyor shall prepare a long-range plan for:

1. the reconstruction of regulated drains classified as in need of reconstruction;
2. the establishment of an annual maintenance assessment for regulated drains classified as in need of periodic maintenance; and
3. the vacating of regulated drains classified as drains that should be vacated."

The long-range plan is then subject to approval by the board, and may be amended by the board at any time. The board is required to reconsider the long-range plan for every drain annually. There are three resulting drainage proceedings to note: periodic maintenance, reconstruction, and construction of a drain.

For each of these three proceedings, the board refers the specified drain to the county surveyor, at which time the surveyor prepares a report. For periodic maintenance, the surveyor's report must include the following:

1. the estimated annual cost of periodically maintaining the drain;
2. the name and address of each owner of land that will be affected by the proposed maintenance, and the legal description of the land…
3. the nature of the maintenance work and how frequently the work should be performed. (IC 36-9-27-38)

From IC 36-9-27-39: "when the board receives a maintenance report under section 38 of this chapter, it shall prepare a schedule of assessments that includes the following items:

1. A description of each tract of land determined to be benefited, and the name and address of the owner, as listed on the county surveyor's report.
2. The percentage of the estimated cost of periodically maintaining the drain to be assessed against each tract of land…
3. The amount annually assessed against each tract of land for maintenance.

The board may consider the factors listed in section 112 of this chapter (explained below) in preparing the schedule."

From IC 36-9-27-49, for a reconstruction project, the surveyor is charged with determining the "best and cheapest method" for drain reconstruction to adequately drain all affected land. The surveyor must also make appropriate maps, profiles, plans, and specifications for the reconstruction, as well as estimate the total cost of the reconstruction. The surveyor must also make an estimate of the annual cost of periodically maintaining the proposed reconstruction. From IC 36-9-27-50, after receiving the surveyor's report for a reconstruction project, the board shall prepare a schedule of assessments and damages.

The main outcome of any Indiana drainage proceeding is that the drainage board adopts a schedule of benefits and damages to reflect the proceeding at hand. Much the like Minnesota Drainage Code, the Indiana Code provides little guidance to boards on how to determine benefits and damages. IC 36-9-27-112 provides a list of factors that boards *may consider* when determining benefits and damages:

1. the watershed affected by the drain to be constructed, reconstructed, or maintained;
2. the number of acres in each tract;
3. the total volume of water draining into or through the drain to be constructed, reconstructed, or maintained, and the amount of water contributed by each land owner;
4. the land use;
5. the increased value accruing to each tract of land from the construction, reconstruction, or maintenance;
6. whether the various tracts are adjacent, upland, upstream, or downstream in relation to the main trunk of the drain;
7. elimination or reduction of damage from floods;
8. the soil type; and
9. any other factors affecting the construction, reconstruction, or maintenance.

To obtain information about how the assessment of benefits and damages is actually performed in Indiana, a county surveyor was contacted by phone. Zach Beasley, the Surveyor of Tippecanoe County (Lafayette, IN) reported that the vast majority of counties in the northern two-thirds of Indiana (there is little need for agricultural drainage in southern Indiana) determine benefits and damages *for agricultural lands* strictly on a per acre basis (Zach Beasley, personal communication, July 30, 2012). This means that each acre affected by the drain is assessed the same benefit for maintenance or reconstruction, regardless of location or agricultural land use. There are some differences in how urban areas are handled, but those are not of particular interest here. Surveyors do, however, have the power to recommend that certain areas (such as buffer strips along the tops of ditch banks) be charged lower assessments than other areas, although this is not common (Beasley, 2012). In general, surveyors do have the authority to perform more complicated, in-depth surveys of affected lands as part of the assessment process, but this is not commonplace (Beasley, 2012).

Iowa

From the Iowa Drainage Law Manual (IDM) (2005), "any county board of supervisors is authorized to establish a drainage district whenever that action will be of public utility or conducive to public health, convenience, and welfare."

After the establishment of a drainage district, the county board appoints three commissioners to classify the lands to be improved, determine benefits, and assess costs to each property served (Iowa Drainage Law Manual, 2005). Iowa State Statute (ISS) 468.3 defines commissioners as "the persons appointed and qualified to classify lands, fix percentages of benefits, apportion and assess costs and expenses in any levee or drainage district, unless otherwise specifically indicated by law." The three commissioners must consist of a competent civil engineer and two disinterested freeholders residing in the county affected (ISS 468.38). Commissioners are to submit a detailed report of benefits and cost assessments to the board (IDM, 2005). ISS 468 offers no guidance to commissioners on how to classify benefits lands receive from drainage systems or projects.

Reclassification can be initiated by the board (or by landowner petition), either in conjunction with a project or as a stand-alone procedure (ISS 468.65). The board can decide to conduct a reclassification if it determines that the current classification is inequitable. Benefits determined as a result of a reclassification replace the original (or most prior) benefits for all purposes going forward.

For proposed improvements or new open ditches, the county auditor "shall appoint three appraisers…to assess the value of the right of way required for open ditches or other improvements" (ISS 468.24). The three appraisers shall consist of one engineer and two resident freeholders of the county with no interest in the proposed improvement. ISS 468.3 defines appraisers as "appointed and qualified to ascertain the value of all land taken and the amount of damage arising from the construction of levee or drainage improvements." As is the case for the work of the commissioners, ISS gives no guidance to how the work of the appraisers should be carried out.

The Iowa State Association of County Auditors (2012) states that the "assessment or classification of land in a drainage district is based on the benefit that land is seen to receive from being in the district." At the time of this writing, there were no other readily available sources that explained the practical nature of determining benefits and damages in Iowa.

North Dakota

Chapter 61-21 of the North Dakota Century Code (NDCC) deals with drainage projects in the state. Projects are generally initiated as a result of a petition by landowners in the project area. Petitions are submitted to the board of managers of a water resource district and, if the board deems further investigation is called for, a competent surveyor or engineer is designated to assist the board. The surveyor or engineer is responsible for making plans and specifications for the proposed drain. The surveyor or engineer is also responsible for estimating the cost of the drainage project, and for determining the lands affected by the drain or project. Chapter 61-21-12 states that "the estimate of costs prepared by the surveyor or engineer shall be in sufficient detail to allow the board to determine the probable share of the total costs that will be assessed against each of the affected landowners in the proposed drainage district."

NDCC gives no indication of how benefits are to be assigned. However, further investigation with the North Dakota Water Commission suggests that these benefits are based only on contributing, or affected, area (Aaron Carranza, North Dakota State Water Commission, personal communication, July 31, 2012). Costs for future repairs and maintenance are apportioned to the affected lands based on the last determination of benefits. Redeterminations of benefits may be conducted, and the resulting benefits replace the prior determined benefits for future proceedings.

Ohio

There are four procedures that are used in Ohio to initiate drainage projects: Mutual Agreement, County Petition, Conservation Works of Improvement (Senate Bill 160), and Ohio Conservancy District Law (Atherton, Brown, Fausey, and Hitzhusen, 2004).

Atherton, Brown, Fausey, and Hitzhusen (1999) provided a thorough overview of various methods used in Ohio to determine benefits from public drainage systems. The authors identified seventeen distinct methods in use by county engineers and soil and water conservation districts across the state. The methods were categorized into three groups: simple multiplicative index, complex multiplicative index, and methods which use derived financial benefits. The methods are summarized in Table 5; a thorough review of each of the assessment methods is given following the table. A brief explanation of all the model parameters described in Table 5 is given here:

A – benefitted area
D – drainage class factor
E – elevation factor, relating the elevation of the parcel to the project area
F – flood factor, related to a reduction in flooding
G – ring factor, usually expressed as a percentage
H – hydrologic soil group factor
I – increase in productivity factor
L – length factor, e.g. length of a project used or % of a project used
M – degree of problem correction factor
N – need for problem correction factor
R – remoteness factor, usually a function of the distance to the ditch project
S – subsurface drainage adjustment factor
T – topography factor or slope factor
U – land use factor
V – runoff volume factor

Table 5. Summary of methods and associated variables used to determine benefits in Ohio (adapted from Atherton et al., 1999).

↓ Increasing Complexity ↓

	Variables Used in Method														
Assessment Method	**A**	**U**	**L**	**R**	**D**	**E**	**H**	**S**	**G**	**T**	**N**	**M**	**I**	**V**	**F**
Methods which use a simple multiplicative index															
Acre Equal	X*	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benefit Units	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--
Putnam County	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--
Benefit Acres	X	X	X	X	--	--	--	--	--	--	--	--	--	--	--
Sandusky County	X	--	X	X	X	--	--	--	--	--	--	--	--	--	--
Fairfield County	X	X	X	X	--	--	X	--	--	--	--	--	--	--	--
Preble SWCD	X	X	--	--	--	X	X	--	--	--	--	--	--	--	--
Defiance County	X	X	--	--	--	X	X	X	--	--	--	--	--	--	--
Methods which use a more complex multiplicative index															
Target	X	--	--	--	--	--	--	--	X	--	--	--	--	--	--
Varied	X	--	X	X	--	--	--	--	--	--	--	--	--	--	--
Parcel Benefit Factor	X	X	X	X	--	--	--	--	--	--	--	--	--	--	--
Paulding County	X	X	X	X	--	--	--	X	--	--	--	--	--	--	--
Benefit Adjustment Formula	X	X	X	--	--	--	X	--	--	X	X	X	X	--	--
Montgomery County	X	--	X	X	--	X	--	X	--	--	--	--	X	X	X
Methods which use financial benefits															
Moran	Obligation benefit based on accelerated runoff (curve number method) and equal to assessable cost; drainage benefit based on increased productivity and locating within drainage system (factors E, R, I)														
Sectionalized	Obligation benefit based on accelerated runoff (curve number method); drainage benefit based on increased productivity, location, soils (factors E, R, freeboard of outlet, I, S)														
Miami County	Most complex benefit method; based on increase in productivity (crop yields, crop prices, production costs, drainage class), location (E, R), and drainage factor (S)														

*An X indicates that a variable is included in the model.

Methods Employing a Simple Multiplicative Index

The simplest of these methods is the **Acre Equal** method (Eq. 1)

$$B = A \qquad (1)$$

where B is the benefits ($). This method assigns an equal benefit to each affected acre within the project area (A), regardless of land use or other factors. The **Benefit Units** method (Eq. 2)

$$B \ = \ A * U \qquad (2)$$

adds a land use factor (U) to the Acre Equal method, which shifts a larger portion of maintenance costs to those land use activities that tend to contribute more runoff per acre. For example, the Putnam County Engineer and Putnam County SWCD (Soil and Water Conservation District) use U values of 0.1, 1.0, and 2.0 for woods and pasture, cropland, and residential and commercial properties, respectively. The Van Wert County Engineer uses values of 1.0 for agricultural cropland and 1.5 for residential and commercial; no value was reported for woods and pasture. Many of the following assessment methods also employ a land use factor. Many of the U values used in the methods below are not specified here, although a thorough overview of values was given by Atherton et al. (1999).

The **Putnam County** method (Eq. 3)

$$B = A * U * L \tag{3}$$

adds a factor (L) to account for the portion of the project length that the runoff from each parcel travels. This factor apportions higher relative benefits to those lands that are more upstream in the project watershed because runoff from more upstream parcels will travel through a greater portion of the project to the outlet. L was defined by Atherton et al. (1999) as "the ratio of the length between the project outlet and point when the water from the *n*th parcel enters the project, to the length of the entire project." L approaches one for the most upstream parcels and zero for the most downstream parcels.

The **Benefit Acres** method (Eq. 4)

$$B = A * U * L * R \tag{4}$$

adds a remoteness factor (R), which is based on the location of each parcel relative to the main project location. This assumes that the benefit a parcel derives from a project is also inversely related to its distance from the project. The Henry County SWCD calculates R as one minus the ratio of "the distance along the flowpath from the main project to the parcel" to "the length of entire flowpath in that reach." When used in conjunction, R and L values for a particular parcel will generally be inversely related.

The **Sandusky County** method (Eq. 5)

$$B = A * L * R * D \tag{5}$$

is similar to the Benefit Acres method, but replaces the land use term (U) with a drainage class factor (D). Where the previous variables (A, U, L, R) presented here are unitless, the drainage class factor has units of drainage benefit per acre ($). The D values reported by Atherton et al. (1999) ($0 to $160 per acre), suggest that this is an annual benefit, not an increase in land value. The Sandusky County engineer uses seven drainage classifications, ranging from the maximum benefit for lands with subsurface and surface drainage flowing into the project, and no drainage benefit for land which "has no natural or subsurface drainage, for which drainage is not practical or feasible, and land which has not been removed from its natural state." Other classifications include: surface drainage only, subsurface drainage only, and lands for which subsurface drainage is impractical. The Sandusky County method also uses a different remoteness factor (R) which ranges from 1.0 to 0.15 for lands located 0 to 1 miles and 6 or more miles from the main channel, respectively. These tabulated R values are less subjective than some R values used elsewhere in Ohio.

The **Fairfield County** method (Eq. 6)

$$B = A * U * L * R * H \tag{6}$$

introduces a hydrologic soil group factor (H). H is based on the four hydrologic soil groups (A, B, C, D) used by the NRCS (Natural Resources Conservation Service). H values are 0.25, 0.50, 0.75, and 1.00 for A, B, C, and D soils, respectively. This reflects the increased need for subsurface drainage as one moves from an A soil to a D soil.

The **Preble SWCD** method (Eq. 7)

$$B = A * U * L * H * E \tag{7}$$

adds an elevation factor (E), with the assumption that land at higher elevations has less need for artificial drainage and therefore receives less benefit from drainage projects. Areas falling within elevation bands are identified and assigned E values based on elevation relative to the project outlet. Total E values for each parcel are calculated as the area-weighted average E value. For example, Logan County SWCD uses E values ranging from 1.0 for 0 to 10 feet above the project outlet to 0.01 for 51 or more feet above the project outlet.

The **Defiance County** method (Eq. 8)

$$B = A * U * L * H * E * S \tag{8}$$

is similar to the Preble SWCD method, but introduces a subsurface drainage factor (S). S values used by the Defiance County Engineer are given in Table 6. S ranges from 0.8 to 1.0 for those with subsurface drainage draining *away* from the project, and from 1.0 to 1.2 for those with subsurface drainage draining *into* the project. Parcels with no subsurface drainage are assigned an S value of 1.00. This approach is interesting in that parcels with subsurface drainage draining away from the project actually receive a lower S value than parcels with no subsurface drainage. This means a landowner with a tile system draining away from the project receives less drainage benefit (lower S value) than a landowner with no subsurface drainage system installed. This may be due to the potential for tile-drained parcels to reduce *surface* runoff entering the drainage system.

Table 6. Summary of S values assigned by the Defiance County Engineer (adapted from Atherton et al., 1999).

	Subsurface drainage drains…	
Hydrologic Soil Group	…to the project	…away from the project
A	1.20	0.80
B	1.13	0.87
C	1.07	0.93
D	1.01	0.99
No subsurface drainage	1.00	

Also surprising is the fact that for parcels with subsurface drainage draining into the project, S values increase from the D to A soil groups. This is counter to the hydrologic soil group factor (H) introduced in the Fairfield County method, where soils with an increasing need for subsurface drainage receive higher H values. Perhaps the opposite approach is taken with the S factor is to penalize landowners who may be over-draining (i.e. draining A lands that don't need subsurface drainage to be highly productive) and adding excess runoff and stress to the drainage system.

Methods Employing a More Complicated Multiplicative Index

Those methods described by Atherton et al. (1999) and using more complex multiplicative indices than those discussed above are covered in this section.

The **Target Method** (Eq. 9)

$$B = A * G \tag{9}$$

also known as the ring method, uses concentric rings centered on the main project outlet to partition the project area into segments that are assumed to have equal benefits. The ring factor (G) is the relative benefit received by land within a given ring. Using this method, lands adjacent to the main project outlet are assumed to have the greatest benefits, and are assigned a G value of 1.0. Moving outward from the project outlet, successive rings are generally assigned G values of 0.1 less than the previous ring.

The **Varied Method** (Eq. 10)

$$B = A * f(L, R) \tag{10}$$

also known as the 100% Acres Method, is similar to methods described previously. However, the factors L and R are combined into a single term, *f(L, R)*, which is assigned to parcels based on location within the drainage system, and generally varies between 0.4 and 1.0. Atherton et al. (1999) reported that "a *f(L, R)* value of 1.0 is assigned to parcels at the upper end and 0.4 to 0.5 assigned to parcels at the lower end of the project." This explanation suggests that the *f(L, R)* term is actually similar to a modified L term, and perhaps has little to do with the remoteness term, R, as values of *f(L, R)* will tend to increase as parcels become more remote and higher in elevation relative to the outlet.

The **Parcel Benefit Factor Method** (Eq. 11)

$$B = A * U * \ f(L, R) \tag{11}$$

is similar to the Benefit Acres method, but differs in that the L and R terms are combined as in the Varied Method. The calculation of the *f(L, R)* factor in the Parcel Benefit Factor Method is different from the Varied Method in that the L term is first determined and then adjusted downward based on the distance between the center of the parcel and the main channel of the project. This approach seems to depend more on the remoteness factor than the Varied Method.

The **Paulding County Method** (Eq. 12)

$$B = A * U * (L - R) * S \tag{12}$$

adds the subsurface drainage factor (S) to the Parcel Benefit Factor Method. The S term is generally taken to be 0.5 when the subsurface water drains away from the project and 1.0 in most other cases. The L-R term is similar to the way that the *f(L, R)* term is handled in the Parcel Benefit Factor Method described above.

The **Benefit Adjustment Formula** (Eq. 13)

$$B = A * U * L * (H + T) * (N + M + I) \tag{13}$$

was developed to simplify the explanation of benefits calculations to property owners, yet is one of the most complicated methods of benefits assessments discussed by Atherton et al. (1999). The factors A, U, L, and H have been previously discussed; T is a surface drainage factor; N is a factor based on the need for correction of a drainage problem for a parcel; M is assigned as the degree of problem correction that the project affords a parcel; and I is “based on the degree of productivity and value enhancement of the parcel by the project.”

Four counties employ the Benefit Adjustment Formula. For the surface drainage factor, T, the minimum value of 1 is given for high slopes (25 to 35%), while the maximum value of 10 is given for depressional areas. N, the need for correction of a drainage problem, varies from 0.1 for no new drainage benefits to 10 for areas with severe problems threatening property and/or health.

The degree of problem correction afforded to each parcel (M) varies from 0 to 10, based on an estimation of the extent to which current drainage needs will be addressed by the project. Only two of the four counties using this method include the improvement factor I, which is an estimation of the level of productivity and value added to a parcel. I values vary from 0 to 10, where 10 corresponds to a 100% increase in productivity or land value. The I value is capped at a 100% increase, while increases beyond 100% may be possible. The values of the other factors (U, L,

H) used in the Benefit Adjustment Formula may differ slightly, but are similar to the values used in other methods.

The **Montgomery County Procedure** (Eq. 14)

$$B = A * L * f(E, R) * S * I * V * F \tag{14}$$

introduces the factors V (runoff volume factor) and F (flood factor, related to a reduction in flooding). The elevation (E) and remoteness (R) factors are combined into a single term, *f(E, R)*. E is defined as the elevation difference between the parcel and the hydraulic grade line, while R is defined as the distance from each parcel to the point at which its runoff enters the main channel of the project. *f(E, R)* is determined from a table using E and R values; *f(E, R)* varies from 1 to 10 and decreases as both E and R increase.

The variable S, the subsurface drainage factor, is equal to 0.8 for parcels with subsurface drainage draining away from the project; 1.0 is used for all other cases. The increase in productivity factor, I, is calculated differently in the Montgomery County Procedure than it was in the Benefit Adjustment Formula (Eq. 15)

$$I = 10 * (CAUV_n / CAUV_{max}) \tag{15}$$

where CAUV is current agricultural use valuation, used in Ohio to measure land values based on agricultural productivity. $CAUV_n$ is the value assigned to the parcel in question, while $CAUV_{max}$ is the maximum CAUV value "in the area." According to Atherton et al. (1999), the idea is that "the project will provide a parcel with increased production in proportion to the ratio of the parcel's CAUV to the highest CAUV… in that area." This seems to suggest that all parcels will have a fixed percentage increase in their CAUV values as a result of a project.

The volume runoff factor, V, is calculated as Eq. 16

$$V = 10 * (ROV_n / ROV_{CN=100}) \tag{16}$$

where ROV is runoff volume (depth) from a design storm, ROV_n is the runoff depth from the parcel in question, and $ROV_{(CN=100)}$ is the runoff depth from a land use with a curve number of 100 (all precipitation becomes runoff for CN = 100). The curve number is used to estimate runoff depth for each parcel based on the parcel's land use, hydrologic soil group, and management (i.e. tillage practices). Thus, V is proportional to the surface runoff generated by the design storm event. F, the flood reduction factor, is similar to N (the need for drainage problem correction) used in the Benefit Adjustment Formula. High F values correspond to parcels with severe flooding problems that cause low property values or hazards to health and safety; low F values are assigned to properties that have little need for improved drainage.

Methods Employing Derived Financial Benefits
Atherton et al. (1999) reported three additional methods which use derived financial benefits as a basis for apportioning system benefits. These three methods are the Moran Method, the Sectionalized Method, and the Miami County Method.

The **Moran Method** partitions benefits into two categories: obligation benefits and drainage benefits. Obligation benefits are related to the "legal obligation a parcel has for the increased or accelerated runoff brought on by development of the parcel from its natural state." Drainage benefits are defined as "the result of providing or improving outlets for surface and subsurface drainage systems, such as the increase or potential increase in crop production."

Obligation benefits are first calculated as Eq. 17:

$$B_{o,1} = A * L * (V_c - V_o) \tag{17}$$

where V_c is the runoff depth from a parcel under current conditions and V_o is the runoff depth from a parcel assuming its natural condition. The sum of obligation benefits for the entire drainage system is defined as equal to the assessable cost of the project. Therefore, the obligation benefit assigned to a parcel is given as Eq. 18:

$$B_{o,2} = C_a * (B_{o,1}/\Sigma B_{o,1}) \tag{18}$$

where $B_{o,2}$ is the scaled obligation benefit based on the project's assessable cost, C_a. Because the sum of obligation benefits is set equal to the assessable cost, any further benefits assigned to any parcels in the project area will result in project benefits exceeding project costs.

Drainage benefits are calculated as Eq. 19

$$B_d = A * f(E, R) * I \tag{19}$$

The *f(E, R)* term is used much the same as in the Montgomery County Procedure, where a matrix is used to determine the *f(E, R)* term based on E and R values. While the Montgomery County Procedure uses *f(E, R)* values that range from 1 to 10, the Moran Method instead allows *f(E, R)* to vary from 0 to 1. This allows for certain tracts – those high above the hydraulic grade line or very far from the main channel – to receive a drainage benefit assessment of zero. There are five classifications for I, the increased productivity factor, varying from $0 for land that is not drained or cannot be drained to $115 per acre for land that is drained or needs to be drained.

Like the Moran Method, the **Sectionalized Method** uses obligation and drainage benefits, but divides the drainage project into reaches to more accurately account for the differing costs associated with unique project areas. Costs (and benefits) are determined for each of the reaches and partitioned amongst the benefitting parcels. A parcel's total benefit is the sum of its benefits from each of the project's reaches. A similar approach is used in Ontario benefits assessments, which are discussed below.

The Sectionalized Method differs fundamentally from the Moran Method in the way it calculates obligation benefits. Where the Moran Method sets total obligation benefits equal to the project's assessable cost, the Sectionalized Method sets the obligation benefit equal to a portion of the assessable cost. Specifically, the obligation benefit is the assessable cost multiplied by the ratio of accelerated runoff to total runoff from the project area. This means that if 25 percent of a project's runoff is accelerated (due to change in land use from its natural state), the obligation benefit will be 25 percent of the assessable cost. The ratio of accelerated runoff to total runoff must be less than 1 if the assumption is made that all land will produce runoff in its natural state. The obligation benefit will always be less than the assessable cost and thus require some drainage benefit for benefits to exceed costs.

Drainage benefits are calculated as Eq. 20

$$B = A * f(E, R, S_f) * I * S \tag{20}$$

where S_f is the freeboard of the parcel's subsurface drainage outlet. Freeboard is the elevation difference between a drain pipe outlet and the bottom of the channel, or above the channel water level during low flow conditions. There are two differences between the drainage benefits calculation in the Sectionalized Method and the Moran Method. First, The freeboard is added to the elevation and remoteness factors to create a new variable *f(E, R, S_f)*. This term is the same as the *f(E, R)* term in the Moran Method, but further reduces the term as freeboard increases.

Second, a subsurface drainage adjustment factor (S) is added to account for the amount of project length that a parcel needs to use to achieve effective drainage. To calculate S, three new variables are defined: L_d, L_r, L_s. L_d is the length of project that must be improved to obtain full drainage benefit for the parcel in question, L_r is the length that water leaving the parcel in question travels to reach the project section under consideration, and L_s is the length of channel in the section under consideration. S depends on L_d, L_r, L_s as Eq. 21 (set):

$$\begin{aligned}
&\text{for} \quad L_d < L_r \quad S = 0 \\
&\text{for} \quad L_d > L_r \\
&\text{if} \quad L_d - L_r < L_s \;\text{ then }\; S = \frac{(L_d - L_r)}{L_s} \\
&\text{if} \quad L_d - L_r > L_s \;\text{ then }\; S = 1
\end{aligned} \tag{21}$$

so that S varies from zero to one. If the project reach in question is too far downstream to provide drainage benefits to a parcel, the parcel's drainage benefit is zero. Furthermore, any drainage benefits assigned are based only on the portion of the project reach that is needed by a parcel to achieve full drainage benefits. As in the Moran method, the total benefits for a parcel are the sum of obligation and drainage benefits, which in the Sectionalized Method are summed for each of the project reaches in question to achieve the total benefit for each parcel.

The **Miami County Method** calculates drainage benefits based on drainage classes. Although it is unclear from Atherton et al. (1999) what these drainage classes correspond to, it seems likely they are based on the aforementioned USDA drainage classes (A, B, C and D). Benefits are calculated as (Eq. 22):

$$B = \Sigma(A_j * Z_j) \tag{22}$$

where A_j is the area corresponding to the *j^th^* drainage class and Z_j is the adjusted agricultural benefit for the j^{th} drainage class.

The variable Z_j is given as Eq. 23:

$$Z_j = (I_j * f(E, R)) - (C_s * (1 - S_j)) \tag{23}$$

where I_j is the increase in productivity factor, C_s is the annualized per acre drainage installation cost, and S_j is a subsurface drainage factor. The *f(E, R)* term is used in a manner similar to other methods, and varies from 0.1 to 1.0. S_j values are taken from a table and vary from 0 for well-drained soil to 0.75 to very poorly drained soil. The overall effect of the Miami County Method is to adjust the increase in productivity term by the familiar term incorporating elevation and remoteness terms. The resulting value is then adjusted downward based on the cost of drainage installation and a factor to account for the need for artificial subsurface drainage.

The increase in productivity term, I, is calculated as Eq. 24:

$$I_j = \Sigma\left(N_i * Y_i * X_i * Yr_{i,j}\right) \tag{24}$$

where N_i is the estimated net return per bushel for the i^{th} crop, Y_i is the county average yield for the i^{th} crop, X_i is the percentage of the watershed planted in the *ith* crop, and $Yr_{i,j}$ is the yield reduction factor for the i^{th} crop and the j^{th} drainage class. I is calculated for each drainage class; $Yr_{i,j}$ depends on the drainage class, while N_i, Y_i, and X_i do not. The values for N_i, Y_i, X_i, and $Yr_{i,j}$ are based on data from various federal, state, and local sources.

Ontario

The Ontario Drainage Act (ODA) defines “drainage works” as “including a drain constructed by any means, including the improving of a natural watercourse, and includes works necessary to regulate the water table or water level within or on any lands or to regulate the level of the waters of a drain, reservoir, lake or pond, and includes a dam, embankment, wall, protective works or any combination thereof” (Section 1). Furthermore, benefits are defined as “advantages to any lands, roads, buildings or other structures from the construction, improvement, repair or maintenance of a drainage works such as will result in a higher market value or increased crop production or improved appearance or better control of surface or subsurface water, or any other advantages relating to the betterment of lands, roads, buildings or other structures” (Section 1). This is perhaps the broadest definition of benefits in any jurisdiction discussed in this report.

There are two types of ditches in Ontario: mutual agreement ditches and petition ditches. A petition is submitted by a landowner to the clerk of the municipality in which the project is located to initiate the process for a drainage works project. If the council of the municipality decides to proceed with the project, an engineer is appointed. The engineer is then required to "make an examination of the area requiring drainage as described in the petition and to prepare a report which shall include,

1. plans, profiles and specifications of the drainage works, including a description of the area requiring drainage;
2. an estimate of the total cost thereof;
3. an assessment of the amount or proportion of the cost of the works to be assessed against every parcel of land and road for benefit, outlet liability and injuring liability;
4. allowances, if any, to be paid to the owners of land affected by the drainage works; and
5. such other matters as are provided for under this Act."

ODA (Section 21) states the engineer "shall assess for benefit, outlet liability and injuring liability…for each parcel of land and road liable therefor." ODA (Section 22) states that benefits may be assigned to "lands, roads, buildings, utilities or other structures that are increased in value or are more easily maintained as a result of the construction, improvement, maintenance or repair of a drainage works." According to ODA (Section 23), outlet liability can be applied to lands that "use a drainage works as an outlet, or for which, when the drainage works is constructed or improved, an improved outlet is provided either directly or indirectly through the medium of any other drainage works." When "water is artificially caused by any means to flow upon and injure any other land or road, the land or road from which the water is caused to flow" may be assigned an injuring liability, which is to be based upon "the volume and rate of flow of the water artificially caused to flow upon the injured land or road" (Section 23).

Assessment of allowances and compensation, approximately the same as damages as discussed in Minnesota Drainage Code, relating to drainage works are covered in Sections 29 through 46 of ODA. Allowances may be made for right-of-way access as it pertains to drainage works (Section 29); damage to trees, fences, lawns, crops, etc. (Section 30); existing drains (Section 31); damage due to an insufficient outlet (Section 32); and permanent loss of access (Section 33). The engineer is responsible for determining all allowances and compensation, and there is no specific guidance given for how to determine the amounts of allowances or compensation.

Benefit assessments form the basis for cost apportionment for future maintenance and repair to drainage works; updated assessments replace previous assessments for future maintenance and repair (Section 76). Benefits assessments are given as percentages of the overall project cost. It is interesting to note that this approach does not measure the cost-effectiveness of a project, but simply apportions costs to each tract based on the relative benefits that each tract receives. Objections to project cost could be raised by either landowner petition, the council, or by the engineer at various stages of the project process (Sections 40, 42, 47, and 48).

Example of Benefits Assignment

Dries and Todgham (1988) provided an excellent summary of the practicalities of assigning benefits in Ontario. This section deals entirely with their summary and an example case they presented.

The authors reported two methods of distributing the costs of a drainage works: a pro rata assessment and a new assessment. A pro rata assessment uses the benefit percentages assigned to lands in the previous assessment to calculate the costs assigned to each parcel in the current project (a parcel which was charged 10% of the previous project cost would again pay 10% of the current project cost). This requires no new assessment, but the authors reported that a pro rata assessment is usually only done when the following five conditions are met:

1. The work is strictly the repair of an existing municipal drain,
2. The work covers the same length of the drain as the last previous report and bylaw,
3. The work to be done is similar in all respects to the work under the previous report - for instance, there are no bridges or culverts not covered in the last report nor are there any new areas to be rip-rapped or any new surface water inlets,
4. The conditions and land use in the watershed have not changed since the last report, and
5. The Engineer who made the previous report and assessment was knowledgeable and experienced.

When these conditions are not met, a new assessment should be carried out.

The authors discussed an example case of assigning benefit, outlet liability, and allowances within a drainage works. The authors summarized many rules guiding the assignment process; some key rules are:

1. You cannot assess a property for any part of the cost of work that is done upstream from it (unless this happens to be some type of cutoff or diversion, but this is a special case),
2. You cannot assess a property for benefit for work done some distance downstream although you can assess it for outlet liability on this work,
3. You cannot assess for benefit lands that are not reasonably close to the drain (Usually those assessed for Benefit are abutting the drain or, perhaps, one farm removed),
4. You would not normally make Benefit assessments on an area or acreage basis but, rather, on the basis of "Benefit to be Derived" by each property. While the frontage of a property along the drain may have some bearing on its assessment, the area of the property seldom has,

5. You cannot assess those lands in the watershed which have a natural drainage of their own. (These are usually the highlands toward the outer edge of the watershed), and
6. You cannot assess those lands that are too low to make any use of the work such as gravel pits, marl beds, etc.

Generally, rules 1 and 2 show that property cannot be assessed for work done either upstream or downstream of that property, except in the case of assigning outlet liability. For these reasons, the authors began their example case by recommending that the project length be split into appropriately sized reach segments on the order of 300 to 1000 meters (about 1000 to 3200 feet). Applicable project costs are then assigned to each project reach. For each project reach, the affected lands can be assigned relative benefits to cover project costs relating to that reach.

For each project reach, relevant costs are partitioned into benefits, outlet liability, and special benefits. Special benefits are installations such as culverts, road crossings, rail crossings, etc. The example discussed below will deal only with the most downstream reach of the example presented by the authors. The costs of special benefits are split up most easily before handling benefits and outlet liabilities. A farm culvert was presented as a special benefit; in their example 80 percent of the cost of the culvert was assigned to one landowner (presumably this landowner owned all of the land around the culvert), while the other 20 percent of the culvert cost is apportioned equally to all acres upstream of the culvert. This cost apportionment must be made by the engineer using professional judgment.

Following the apportionment of the costs associated with the special benefit, the remaining costs are then split between the adjoining (within the first project reach) and upstream land parcels. This is another portion of benefits assignment where the engineer must make a well-informed, professional decision. In this case, the authors assigned 65 percent of the remaining liability to upstream lands, and 35 percent to those lands within the first project reach. The 65 percent that is assigned to upstream reaches is entirely outlet liability, as only outlet liability can be assigned to reaches upstream of the project reach (following rule 2 above). This 65 percent is applied to each acre upstream from the first project reach on a per-acre basis, with each acre being charged the same outlet liability (these same parcels will be charged an additional outlet liability when the next upstream section is considered; the $5.13 is a flat rate because all water draining from the upstream reach has its water pass into the first reach at the most upstream point). In the example, the authors arrived at an outlet liability of $5.13 per acre for the each acre in the upstream project reach. This value is used as a starting point to determine the outlet liability for each parcel within the first project reach.

The authors use a methodology that assigns a weighted outlet liability to each parcel in the first project reach based on its position (more upstream or more downstream) in the project reach. By this logic, the upstream parcels use more of the reach as an outlet, and the downstream parcels use less of the reach as an outlet. The practice employed by the authors is to vary the outlet liability from $0.00 per acre at the downstream end of the first project reach to $5.13 per acre at the upstream end. The first project reach is then split into appropriate land parcels and each parcel is given an outlet liability (on a per-acre basis) based on the position within the first project reach at which its drainage water outlets to the drain. After the total outlet liability for all parcels within the first project reach is determined, the remaining cost must be apportioned to parcels within the first project reach based on each parcel's benefit. Thus, the relative benefits of all parcels within the first project reach are to be determined next. This determination is done based on the professional judgment of the engineer, and completes the engineer's assessment of the first project reach. Benefits, outlet benefits, and special benefits can then be computed iteratively for each of the upstream project reaches, beginning with the next section upstream.

Scientific Approach to Benefits Assessments

With the aim of creating an objective benefit assessment procedure, Bengtson, Drablos, and Jones (1969) created an approach to benefits assessments based on relevant physical features. The study had three goals:

1. to identify the physical features that influence drainage benefits,
2. to determine the relative degree of influence of each of those features on drainage benefits, and
3. to formulate an assessment procedure based on the correlation between the significant physical features and drainage benefits

Based on previous work, the authors identified six factors that they believed best correlated to drainage benefits:

1. horizontal distance to the main drain
2. horizontal distance to the main drain outlet
3. change in elevation to the main drain
4. change in elevation to the main drain outlet
5. soil permeability
6. soil productivity rating

The authors proposed the following for benefits (Eq. 25):

$$\frac{A_n}{A^*} = C_1 \frac{X_n Y^*}{X^* Y_n} + C_2 \frac{L_n}{L^*} + C_3 \frac{P_n}{P^*} + C_4 \frac{D_n}{D^*} + C_5 \frac{K_n}{K^*} \qquad (25)$$

where A is a tract's drainage benefit, X is the depth of the main drain corresponding to the tract, Y is the relative elevation between the mean plain of the tract and the main drain outlet, L is the shortest horizontal distance from the centroid of the tract to the main drain, P is the productivity rating of soil in the tract, D is the shortest horizontal distance from the centroid of the tract to the main drain outlet, and K is the coefficient of permeability relating to the tract. *n* subscripts correspond to the *nth* parcel, and '*' terms correspond to the maximum values for any parcel found in the drainage system. For example, D* is the maximum horizontal distance from any tract in the system to the main drain outlet, while K* is the maximum soil permeability in the system. Each of the '*' terms may correspond to a different tract. The A* term is the maximum overall benefit to any one parcel, thus A_n will vary from zero to one. The C terms are coefficients used to equate the two sides of the equation.

A multiple regression approach was used to determine the appropriate coefficients for the equation based on two drainage systems in Illinois. The benefits to each plot were taken to be equal to increases in crop yields that were due to tile drainage. To determine crop yield increases, crop yield records were examined for the two years before and after drainage installation; adjustments were made for weather variation. The relevant physical features discussed above were estimated for each parcel in the drainage systems. The initial multiple regression revealed that the factors L_n/L^*, D_n/D^*, and K_n/K^* were more than twice as important as the variables X_n/X^*, Y_n/Y^*, and P_n/P^*. Further work, including the analysis of more land parcels, resulted in the final equation (Eq. 26):

$$A_n = 1.4845 - 0.3476 * (\frac{L_n}{L^*}) - 0.4680 * (\frac{D_n}{D^*}) - 0.4434 * (\frac{K_n}{K^*}) \qquad (26)$$

Increasing values of L_n, D_n, and K_n result in lower benefits; this corresponds to parcels further from the drain and drain outlet, and those with higher soil permeability. This supports the theory that those parcels which are lower in the landscape (closer to the drain and the drain outlet) and those with lower soil permeability have a greater need for drainage, and thus are assigned higher relative benefits. The minimum value for A_n is approximately 0.23 (as all fractions approach one), while the theoretical maximum value is 1.4845 (as all fractions approach zero). The predicted benefits were compared to assigned benefits (those determined independently by the drainage district) in two Illinois drainage systems and showed good agreement between predicted and actual benefits.

Comparison to Urban Stormwater Systems in Minnesota

Background

Urban stormwater systems in the United States are regulated as Municipal Separate Storm Sewer Systems (MS4s) according to the National Pollution Discharge Elimination System (NPDES), which is part of the Clean Water Act (CWA). The United States Environmental Protection Agency (USEPA) was given the responsibility of creating water quality standards and administering permits required under CWA and NPDES. In Minnesota, this responsibility has been taken over by Minnesota Pollution Control Agency (MPCA). A municipal separate storm sewer system is a conveyance or system of conveyances (roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains, etc.) that are:

- owned or operated by a state, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State law) having jurisdiction over disposal of sewage, industrial wastes, stormwater, or other wastes…;

- designed or used for collecting or conveying stormwater;
- not a combined sewer; and
- not part of a publicly owned treatment works.

There are three types of MS4s: mandatory, designated, and petition. Storm sewer systems either fully or partially within urbanized areas (areas with a total population of at least 50,000 and a population density of at least 1,000 people per square mile) are categorized as mandatory MS4s. Cities or townships with a population of at least 10,000 are categorized as designated MS4s. Cities or townships with a population of at least 5,000 are also categorized as designated MS4s when their systems discharge (or have the potential to discharge) to 'valuable or polluted waters'. Petition MS4s are established after a successful public petition to MPCA. There are 192 mandatory MS4s (as of 2007) and 43 designated MS4s (19 of which have populations of 10,000 or less) in Minnesota (MPCA, 2012).

The MS4 operator/owner collects tax assessments to in order to meet the requirements specified by MPCA, as well as to maintain adequate drainage of stormwater. MS4 maintenance and improvements (as needed) help to reduce the risk of property damage and injury resulting from heavy rainfall and runoff events and is thus an important service for taxpayers.

To combat MS4 network expansion and improvement costs, MS4 owners and other special purpose governmental entities have found innovative solutions that help reduce overall system cost (and thereby the tax burden of landowners), while reducing stress on the current infrastructure and also potentially improving water quality.

Capitol Region Watershed District

The Capitol Region Watershed District (CRWD) is a watershed district comprising parts of five cities in Ramsey County, Minnesota. The CRWD area is urban, with a population of approximately 245,000 and an area of 40.6 square miles (CRWD, 2010). CRWD does not own or operate an MS4, but offers reimbursement and grant programs to help pay for rain barrels, rain gardens, pervious pavement, green roofs, and other projects (CRWD, 2012)

These grants are limited to $2,000 for single-family homes, and $10,000 for other properties (schools, homeowners' associations, etc.). The grants help support CRWD's mission of reducing runoff volume and improving runoff water quality. Projects such as rain gardens rain barrels will certainly reduce the amount of runoff entering an MS4, but because these systems are owned by municipalities and not the watershed district, CRWD does not offer reductions in tax assessments to homeowners who adopt these practices. This highlights the difference between incentives that reduce homeowners' ongoing tax assessments and cost sharing measures that help pay for installation of best management practices (BMPs).

City of Minneapolis

The City of Minneapolis charges a stormwater utility fee, which is based on equivalent stormwater units (ESU) (City of Minneapolis, 2011). ESU is a measure of the amount of impervious surface within a property. One ESU is equivalent to 1,530 square feet of impervious area; the stormwater utility fee is $11.34 per month per ESU (current as of 2011). For simplification, single-family homes are grouped into three ESU categories for assessment of the stormwater utility fee. Group 1 (less than 1,485 square feet of impervious surface) is charged at 0.75 ESU ($8.57 per month); Group 2 (1,486 to 1,585 square feet of impervious area) is charged at 1.00 ESU ($11.34 per month); and Group 3 (1,586 square feet or more of impervious area) is charged at 1.25 ESU ($14.27 per month) (City of Minneapolis, 2011). For all other properties, the stormwater utility fee is based on the actual ESUs the property contains. For example, a commercial lot having 4,590 square feet of impervious surface would contain 3 ESU, and would therefore be assessed a monthly stormwater utility fee of $34.02.

In an effort to reduce loading to the city's MS4, encourage infiltration, and promote water quality improvements, the City of Minneapolis has two programs through which property owners are able to reduce (or even complete remove) their monthly stormwater utility fee. These programs are the Stormwater Quality Credit Program and Stormwater Quantity Credit Program. The Stormwater Quality Credit Program provides a credit (or reduction) of up to 50 percent of a landowner's stormwater utility fee for installing BMPs that address water quality (rain gardens, infiltration trenches, etc.) (City of Minneapolis, 2011). The Stormwater Quantity Credit Program provides a credit ranging from 50 to 100 percent of a property owner's stormwater utility fee for installing BMPs that address water quantity (City of Minneapolis, 2012a). Credits are cumulative, and may not exceed 100 percent (City of Minneapolis, 2012b). A single-family home in Group 2 could save more than $68 every year by achieving a 50 percent credit.

For the Stormwater Quality Credit Program, property owners must submit an application that details the impervious area on the property, the property's current stormwater utility fee, and the installed BMPs with their corresponding treatment areas. The impervious area treated by the BMP(s) is used to compute the percentage of the property's impervious area that is treated. The stormwater utility fee reduction is then computed as one half of the percentage of impervious area that is treated on the property. For example, if a house having an impervious surface area of 1000 square feet installs a rain garden to treat runoff from 400 square feet of impervious surface, the percentage of impervious area treated would be 40 percent, and the reduction in the stormwater utility fee would be 20 percent (or half of 40 percent). The credit is limited to 50% of the stormwater utility fee due to the fact that the fee reduction is equal to half of the impervious area treated (City of Minneapolis, 2011).

Application for the Stormwater Quantity Credit Program is similar to that discussed above, but slightly more rigorous. To receive a fee reduction under this program, a state-licensed engineer or landscape architect must certify the application. Furthermore, the homeowner must demonstrate that the installed BMPs have the ability to handle at least a 10- or 100-year storm event (of SCS Type II). Properties demonstrating the ability to handle a 10-year storm event are eligible for a fee reduction of 50 percent, while those able to handle a 100-year storm event are eligible for a 100 percent reduction in the stormwater utility fee (City of Minneapolis, 2012a). This program is unique in that it may be feasible to install BMPs to meet these criteria on properties of any size. This is due to the fact that the ESU scheme used by the City of Minneapolis is scaled to the lot size – larger properties have more to gain by reducing their stormwater utility fee, but they will also likely need to install a larger and more expensive BMP structure to handle the runoff from a lot with an increased impervious area.

Cities of Burnsville, Mankato, Roseville, Saint Cloud, and Saint Paul
No stormwater utility fee credits similar to the programs in place in Minneapolis were found with a brief review of several cities ranging in population from approximately 30,000 to 300,000. All five of the cities reviewed had SWPPPs (stormwater pollution prevention plans), but no grant, cost sharing or fee reduction schemes (City of Burnsville, City of Mankato, City of Roseville, City of Saint Cloud, City of Saint Paul).

Summary of Current Benefit Assessments

SWCDs and similar agencies encourage adoption of BMPs through grants and cost-sharing programs to offset BMP installation cost, but offer no ongoing cost savings. Programs enacted by the City of Minneapolis differ in that they do not reduce the costs of installing BMPs, but instead promise a reduction in stormwater utility fees. This is based on the idea that reduced runoff will alleviate stress on the MS4, and thereby reduce system costs. Like the City of Minneapolis MS4, funding for a public drainage system comes from landowners who benefit from the system. Funds collected by both an MS4 and a drainage authority are spent on system repair, improvement, and administration. Because the users are paying directly for the system, any reduction in system costs will be passed on to benefitted landowners. In a perfect world, any savings realized should be passed on to those landowners whose actions directly caused the savings. This project is a step in that direction. While some changes will inevitably need to be made for the agricultural lands within drainage systems, the general principle that the City of Minneapolis uses incentives for landowners to reduce runoff can be applied to public drainage systems in Minnesota.

There are a variety of methods employed across several states and in Ontario to assign benefits and damages to affected lands within drainage systems. These methods apply varying levels of rigor to accomplish the goal of apportioning system benefits amongst affected landowners. A few methods explored in this report take land use into consideration when determining benefits; three additional methods used in Ohio consider runoff depth generated by a parcel in benefits determination. The thorough understanding of benefit and cost determination methods in other jurisdictions developed in this report will inform the process of suggesting changes to benefit and cost assessments in Minnesota.

Chapter 4

APPLICATION OF GIS METHODS

Introduction

GIS (geographic information system) is a powerful tool for manipulating spatial data and therefore has the potential to reduce the cost of ditch viewing and reporting. There are many possible options for using GIS in assessing the benefits of drainage to parcels of land. For example, data layers could be created using the current classification system. Changes in benefits based on land value or the price of commodities could then be easily computed. GIS could also be used to assist in the identification of benefit classes. Although field inspection would still be required, the time required to perform this inspection could be reduced. As a final example, GIS methods can be coupled with hydrologic models to provide quantitative estimate of the flow rates and volume being discharged to the drainage system.

This chapter will focus on GIS methods used in this project that are not linked to hydrologic models. Project activities to incorporate Minnesota method within a GIS framework are presented first. These activities focused on algorithms to automatically estimate the spatial extents of the benefit classes within each parcel. The JD 4 drainage ditch discussed in Chapter 3 was used to test these algorithms. GIS methods were also developed for applying the Ohio method. This activity allowed an easy comparison of the Ohio and Minnesota methods for the JD 4 drainage ditch.

JD 4 Viewer's Report Within GIS Framework

Conversion Process

To allow for easy comparison of different methods to assess drainage benefits, it was necessary to convert the values of the viewer's report into GIS framework. GIS representation is a convenient format to elaborate on features of the Minnesota method given in Chapter 2. The conversion of the viewer's report required the use of GIS tools to create benefit layers. The layers were created using elevation (LiDAR DEM of 1-m resolution), soils (SSURGO databases), aerial photographs, and land-parcel boundary data sets.

Total acreage for each benefit class by parcel was taken from the viewers' report and mapped so that good agreement was achieved between the assessed acreage and the mapped acreage for each parcel. In general, A and D benefit classes were most easily mapped and were performed first. Relatively few parcels contained land assigned to the A benefit class; this land is fairly easy to identify from both DEM and soils layers. An iterative approach was used to achieve the correct amount of land in the A benefit class. Land in the D benefit class was similarly identified as the land generally highest in elevation in the parcel and mapped as a soil with a high land capability class with little or no excess water issues (perhaps a 1 or 2, generally without a ‘w’). Approximately one quarter of all acres within the JD4 sub-watershed were A or D. The C benefit class predominated amongst the remaining acres. Lands in the B benefit class were identified as those remaining acres most in need of drainage based on elevation and soils information. All remaining acreage was mapped as C.

The level of detail in the viewers’ report helped to limit the errors made in mapping the benefits, as no line contains more than 40 acres. A summary of the acreage reported by the viewers and determined through GIS mapping is given in Table 7. There are small differences in each benefit class, but the two methods showed good agreement for the total benefitted acres. Overall, the GIS exercise identified about 10 acres more benefitted land than the viewers’ report.

Table 7. Summary of JD4 acreage reported by viewers and mapped at UMN by benefit class.

	Acreage by Benefit Class						
	A	B	C	D	D-	Non-benefitted	**Total**
Viewers’ report	42	364	2256.5	884	5	83.45	**3635**
GIS mapping	41.8	364.5	2260.8	891.6	5.2	80.8	**3644.7**
Error	0.57%	0.14%	0.19%	0.86%	4.10%	3.16%	**0.27%**

Mapping Results

The mapping results of the fraction of the net and gross benefits have been previously shown by Figures 1 and 2. A GIS map of the net drainage benefits in JD4 are shown in Figure 3. Figure 4 shows the overall efficiency assigned to each of the parcels within JD4. The net benefits are defined as the product of the gross benefit and the overall efficiency. The line showing the extents of the drainage district is approximate and does not align perfectly with the extent of benefitted acres determined by the viewers. Many of the ‘holes’ of white areas included within the drainage system are due to missing data in the viewers’ report.

While the net benefits shown on the map are represented using a continuous scale, the lands within JD4 can be loosely categorized visually for the four benefit classes based on the darkness of color. The darkest color corresponds to the A benefit class with a gross benefit of $4950 per acre, while the lightest color corresponds to the D benefit class, with a gross benefit of $540. Within each group of benefit class, there are slight differences in the net benefit due to differences in overall efficiency.

There are many other areas that are dark in color, which correspond to field scale depressions. Growing crops in these areas would have been difficult, if not impossible, without drainage. Many of the dark areas have a relatively high efficiency due to the fact that they tend to be close to the drainage system.

The second darkest areas on the map correspond to the B benefit class. Many of these areas are seen abutting the A benefit class areas around the ditch system. Of the remaining areas, the vast majority are grouped into the C benefit class. There are some discernible differences between different lands within the C benefit class as the parcels become more remote from the drainage system. The lightest colored areas tend to correspond to the D benefit class, or lands within the C benefit class with low efficiency values.

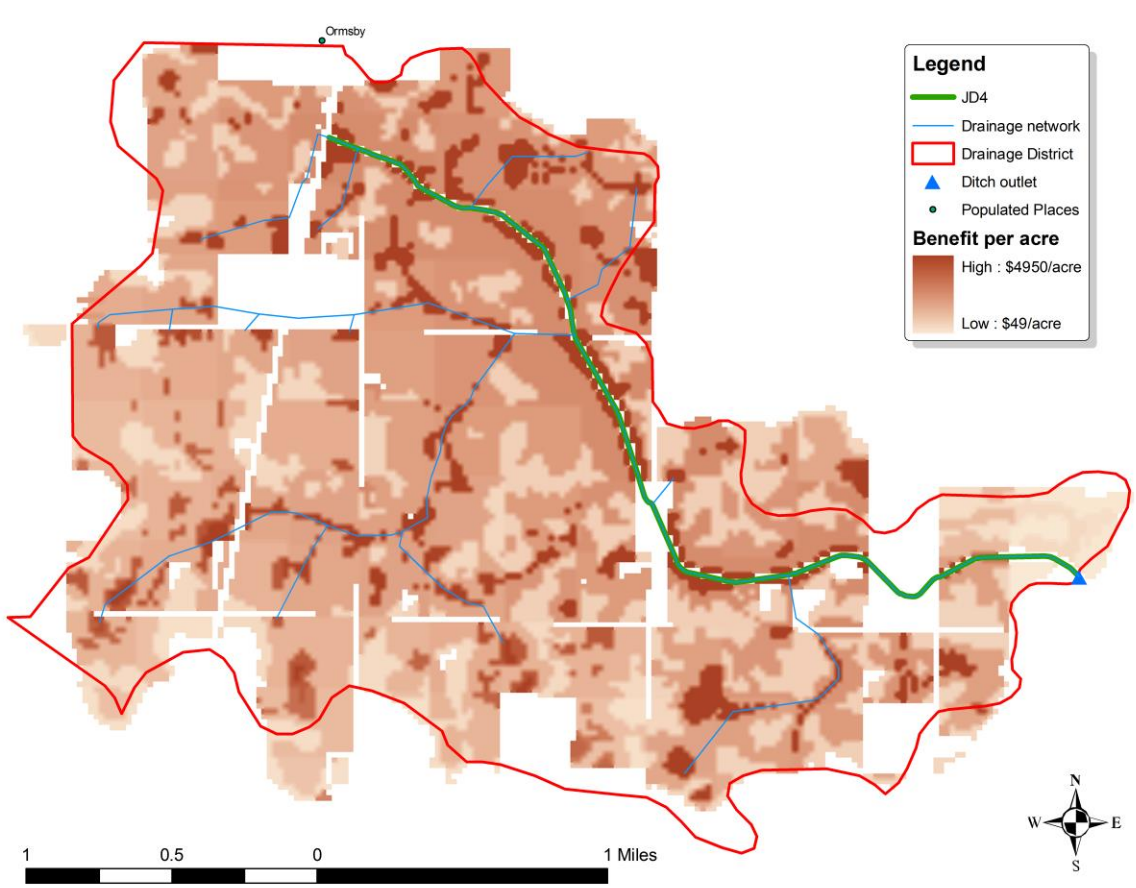

Figure 3. Mapped net drainage benefits within JD4.

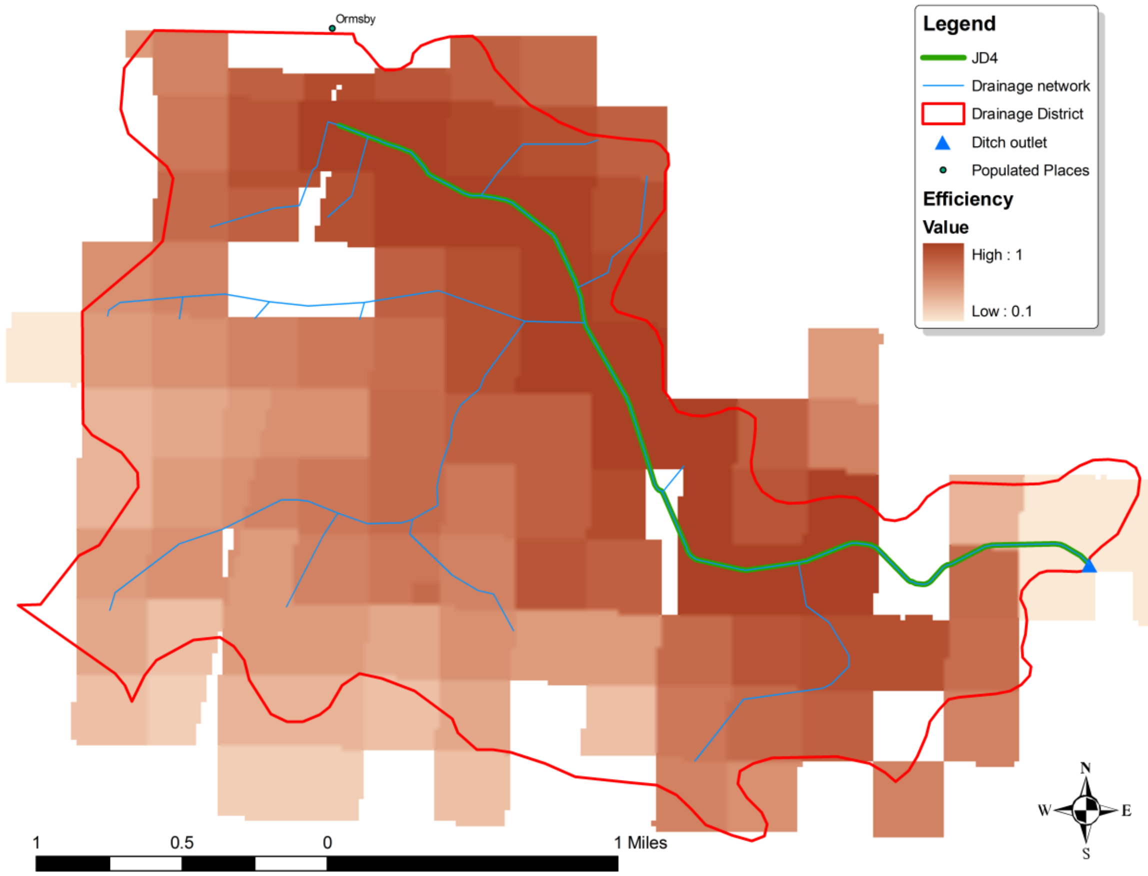

Figure 4. Overall efficiency by parcel within JD4.

Most of the dark red areas (those with the highest determined net drainage benefits in Figure 3) closely follow both the open ditch and public tile mains. The drainage system is generally constructed to follow the lowest areas where water tends to collect and flow toward the drainage system (both through surface and subsurface pathways). Those areas along the naturally low-lying areas were historically wet areas where drainage is necessary to achieve high agricultural productivity. In some cases, drainage may have been necessary just to allow machinery to enter fields to plant crops.

While the viewers' report assigned benefits on a parcel-by-parcel basis, they often assess each parcel on a soil-by-soil basis. This means that they partition each parcel into distinct areas where the soil has been mapped as a single area. This is a further level of detail that is not reported to drainage authorities or landowners, but helps to compartmentalize viewers' work into smaller subsets of land areas as they carry out their work. It also simplifies viewers' work in that each soil group will generally fall largely within two benefit classes. For example, when mapped correctly, a sandy soil that is common on hill tops will likely never be assigned a benefit class of A or B. Errors in soil mapping may create exceptions, but this is largely not the case.

Comparison of Ohio and Minnesota Methods

Methodology

The methods used in Ohio showed the most promise as an alternative to the Minnesota Methods. To allow for comparison between the two approaches, the Ohio method was applied to the JD 4 watershed. Because many Ohio methods are mathematical formulas where benefits are products of multiple factors, it was necessary to create GIS layers for each factor affecting benefit determination.

A summary of the Ohio methods has previously been given by Table 5. There are 17 benefit determination methods. GIS layers for land use (U), length (L), remoteness (R), and hydrologic soil group (H) factors were computed based on information from several sources. The four layers created were used because of the relative ease in determining those factors by using databases (for U and H) or GIS techniques to compute the factors for JD4 (L and R). The layers were computed in a way that was consistent with the descriptions given by Atherton et al. (1999). Development of additional layers was hindered by time constraints, data availability, and, in some cases, a lack of understanding or experience with how the factors should or would be computed.

The land use GIS layer was computed from the National Land Cover Database (NLCD). Length and remoteness layers were computed based on the drainage system network. The length factor is directly related to the percentage of the drainage system through which its water flows. The remoteness factor is a measure of the distance from a parcel to the drainage system, effectively the shortest distance that a parcel's drainage water will travel to enter the public drainage system. Parcels abutting the system are assigned remoteness values close to one and the value decreases (to zero, presumably) as one moves away from the drainage system.

Figure 5 shows the interpretation of the ***Remoteness Factor, R***, as applied to JD4. Remoteness from the Ohio methods is similar to the overall efficiency used by viewers in Minnesota. The description of various Ohio methods suggested that public tile mains should be included as part of the drainage system for the purposes of determining R, while it can be seen in Figure 4 that the overall efficiency used in Minnesota is only relative to the section of the drainage system that is an open ditch.

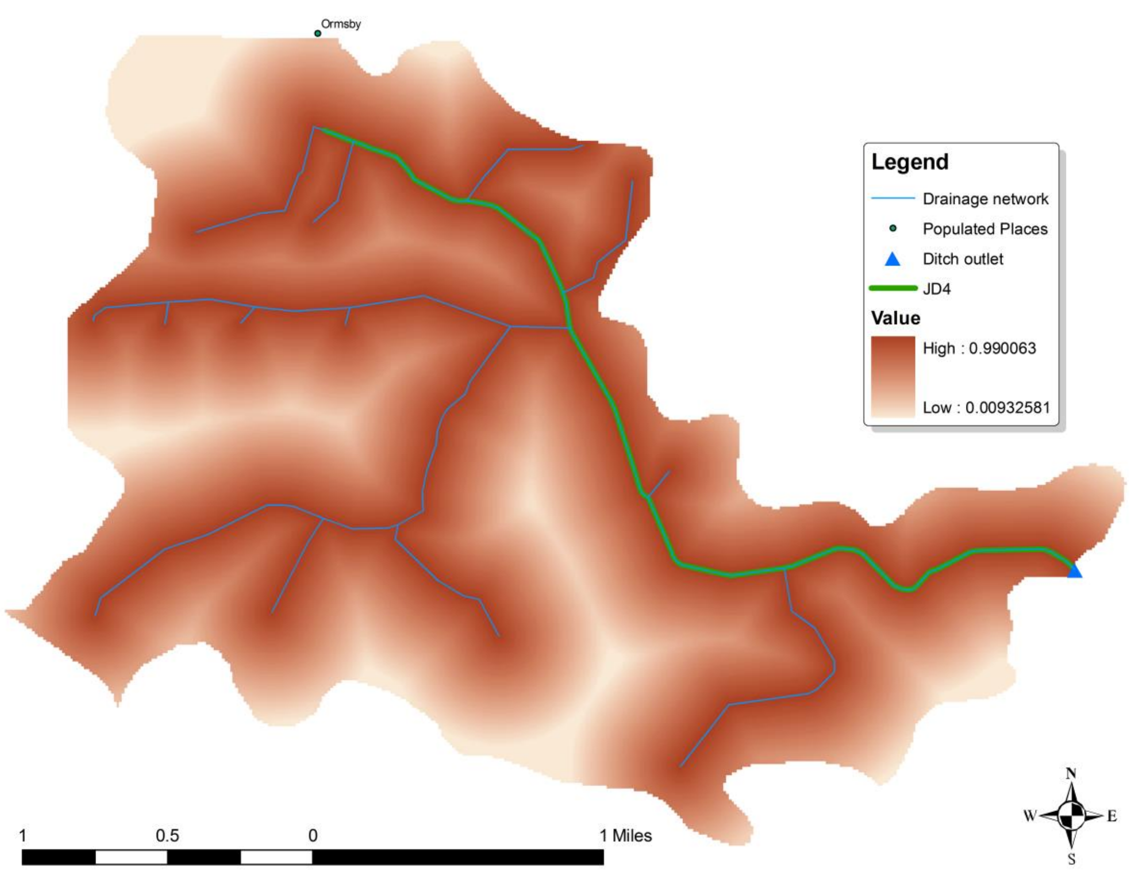

Figure 5. The Remoteness factor, R, as applied to JD4.

There is a slight difference between the graduated decreases in overall efficiency seen in the Minnesota method and the continuous decrease in R seen in the Ohio method. There was some uncertainty about the minimum R value that is used in Ohio, but a value of zero was used here. The remoteness factor, R, does not consider productivity losses due to standing water, or reductions in efficiency due to undersized tile mains. Even so, it is expected that the remoteness factor, R, could easily produce results very similar to the overall efficiency if the differences in the extent of the drainage system considered and the ranges of values (i.e. zero to one) were reconciled.

The ***length factor, L***, is shown in Figure 6. While the length factor stands in stark contrast to the remoteness factor, it does have its merits. Landowners in the upper reaches are further from the watershed outlet, and thus their water must travel through more of the drainage system (both public tile mains and open ditch) than water from parcels near the outlet. Parcels near the outlet have little use or need for the upper reaches of the drainage ditch, only the sections that their drainage water travels through. There is no apparent correlation between the length factor and the methodology currently used in Minnesota.

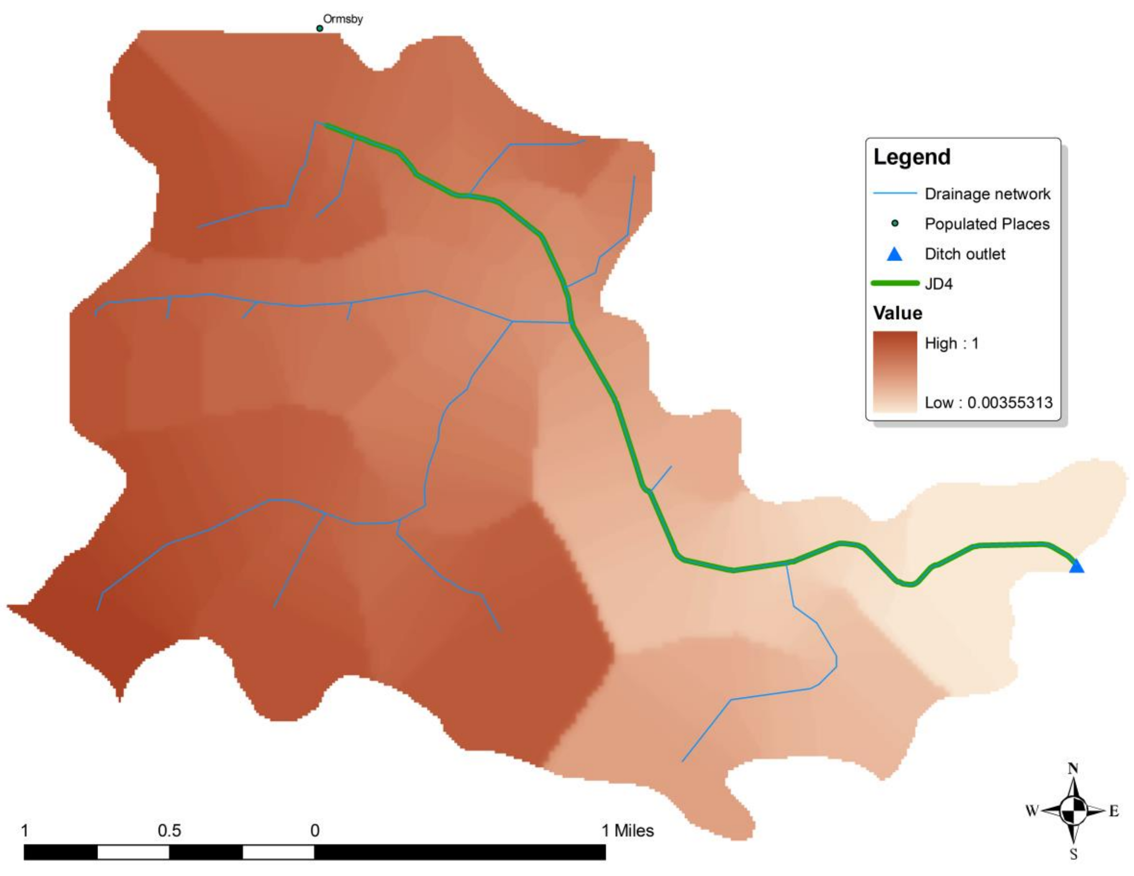

Figure 6. The Length factor, L, as applied to JD4.

The ***land use factor, U***, as applied to JD4 is shown in Figure 7. Land use within JD4 is almost entirely agricultural, although forested and natural areas exist within the watershed. Agricultural areas are assigned a land use factor of 1, roads a value of 2, while undeveloped areas are assigned a land use factor of 0.1. This is similar to the way in which undeveloped lands (or lands permanently removed from agricultural production) are given a gross benefit of zero in the current Minnesota method. Including land use in the benefits calculation is only useful in distinguishing agricultural lands from commercial, road, or undeveloped land uses, and will provide little help in distinguishing the benefits that should be assigned to different agricultural lands.

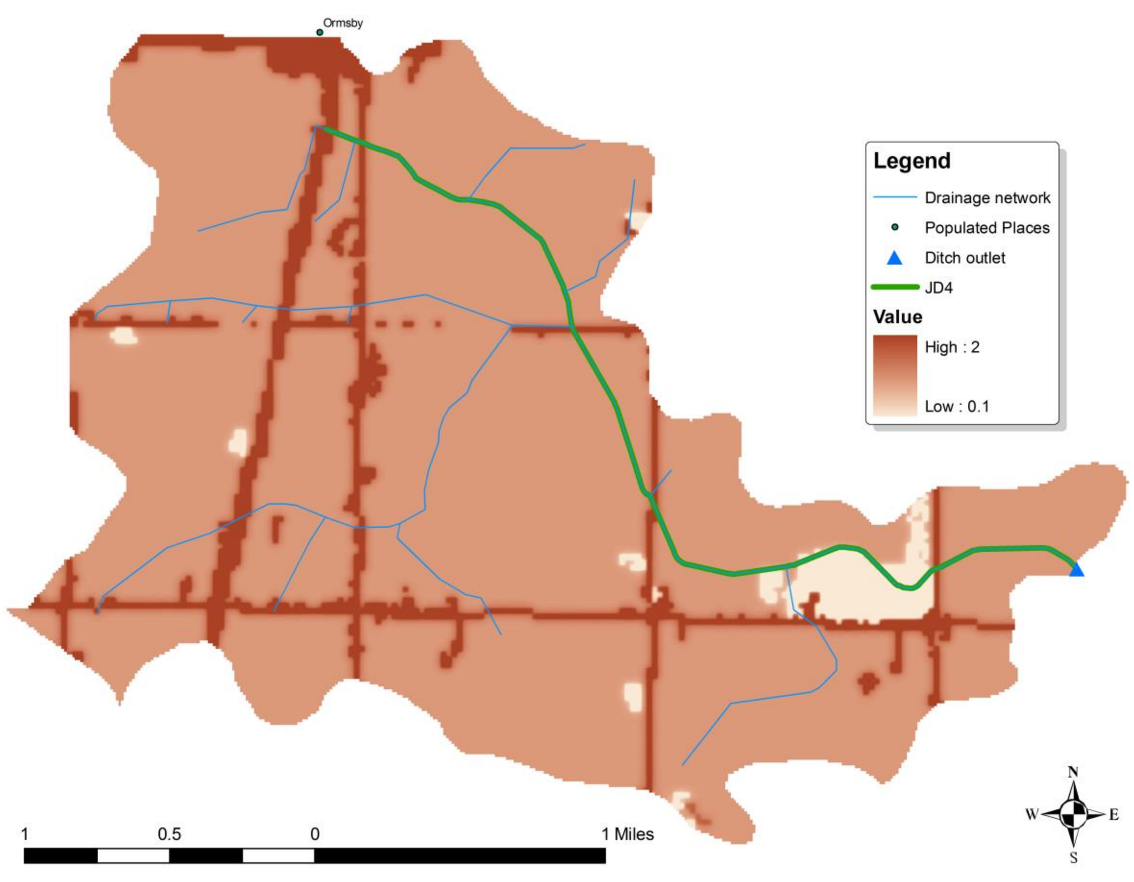

Figure 7. The Land Use factor, U, as applied to JD4.

Figure 8 shows the distribution of ***hydrologic soil groups*** within JD4, while Figure 9 shows the hydrologic soil groups translated into the ***factor H***. H equals 0.25, 0.5, 0.75 and 0.1 for A, B, C, and D hydrologic soil groups, respectively. B/D (a hydrologic soil group D in the undrained condition and group B in the drained condition) is the dominant hydrologic soil group within JD4. Hydrologic soil group D is the group most needing drainage, while A is the group that needs drainage the least. This is the exact opposite of the benefits classes used by viewers (where A is the land most in need of drainage, while D areas where drainage provides only slight benefits).

For the purposes of mapping H, the value for the undrained condition (D) was used instead of the drained condition (B) for the B/D soil. This is consistent with the general approach of viewers in Minnesota to assess benefits based on the need for drainage given the original condition of the land or on the degree to which drainage improves the productivity of a given area. A more reasonable approach for use in Minnesota might be to base the H factor on the degree to which drainage improves the situation on the field. This would perhaps assign a value of 0.5 to a B/D soil (0.5 = 1 – 0.5) or a value of 0.25 to a C/D soil (0.25 = 1 – 0.75).

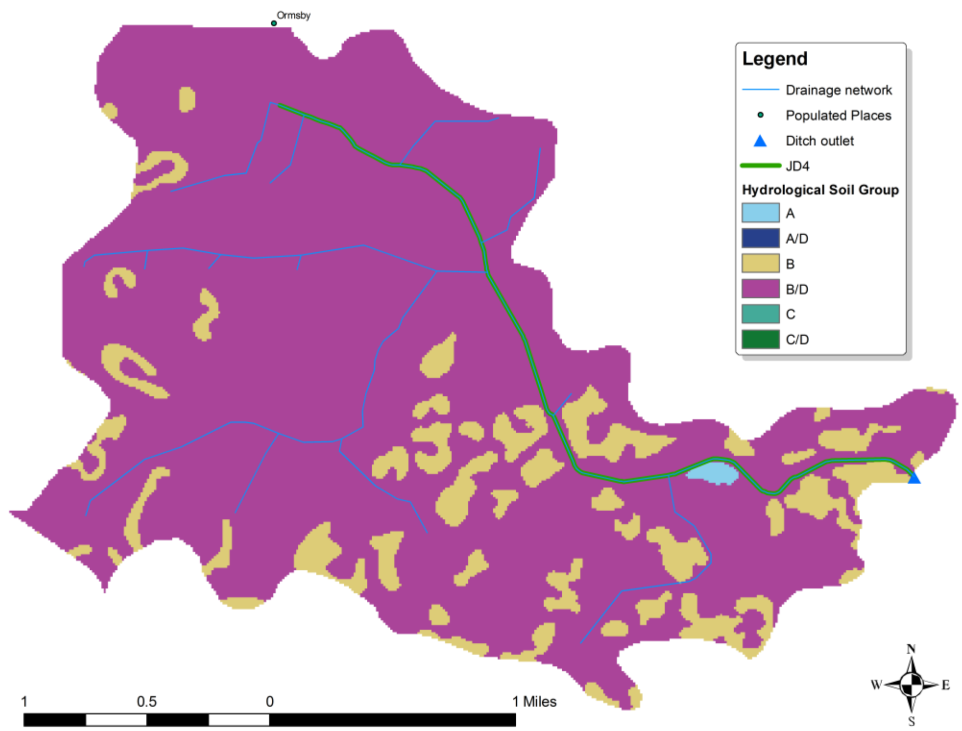

Figure 8. Hydrologic soil groups within JD4.

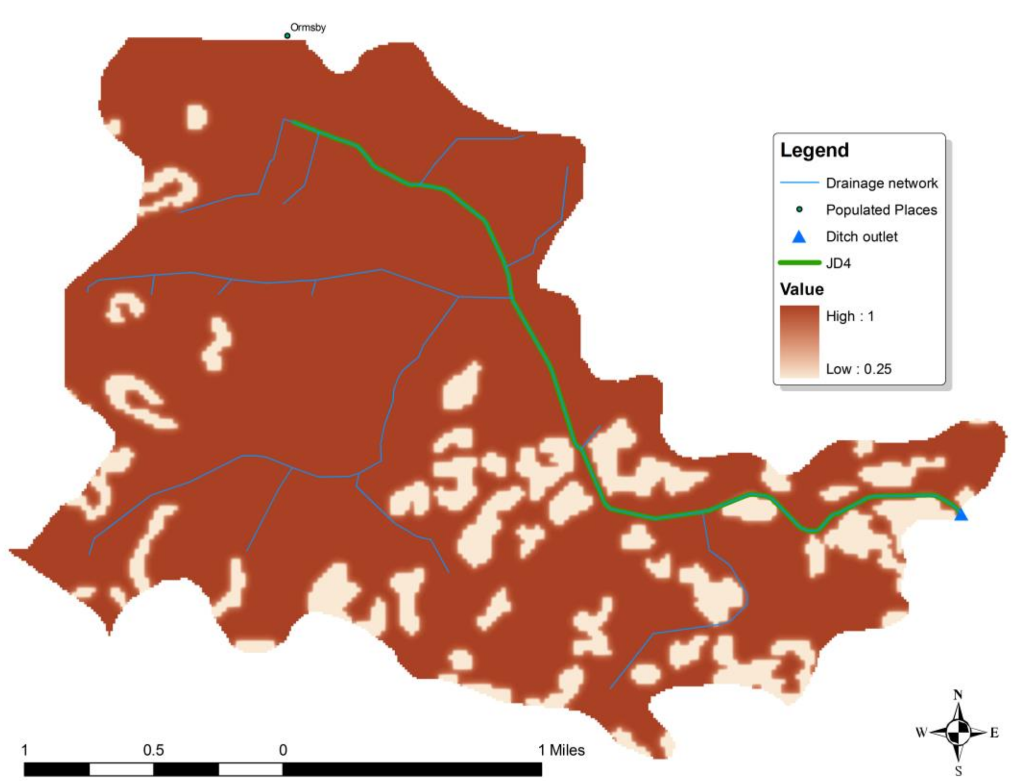

Figure 9. The hydrologic soil group factor, H, as applied to JD4.

Figure 10 shows the combination of the L, R, U and H factors to assess the ***relative benefits*** for JD4 using the Ohio Method.

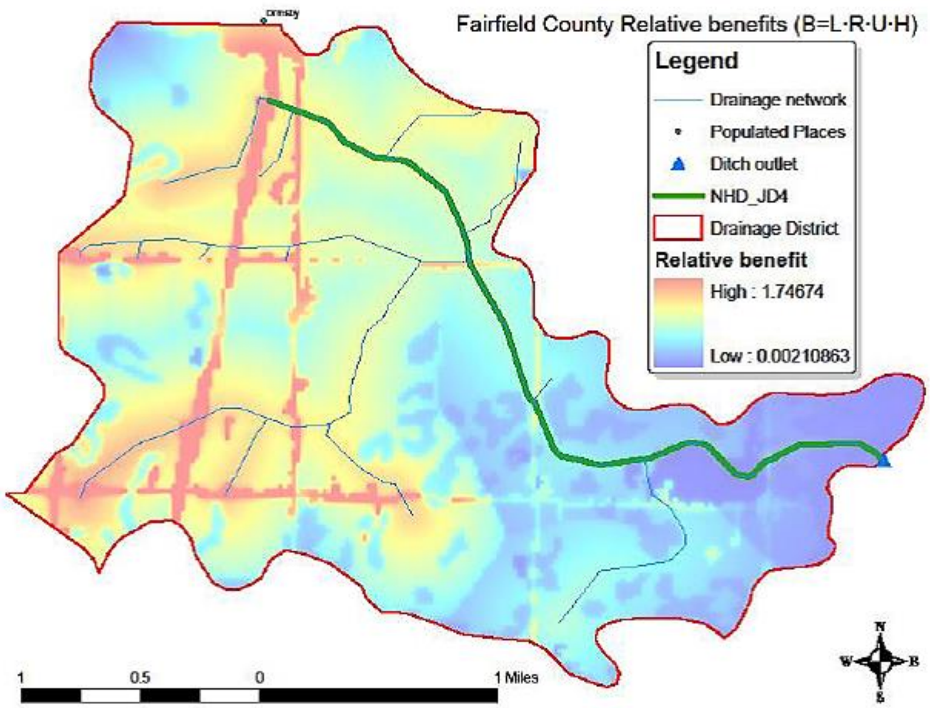

Figure 10. Relative benefits, as applied to JD4.

Discussion

The analysis of Ohio methods was limited by the number of GIS layers that could be easily produced to replicate relevant drainage factors. The Fairfield County method that uses the factors R, L, U, and H was therefore for selected for comparison to the Minnesota Method. A comparison of the two methods is shown in Figure 11. There are significant differences between the two methods. The Ohio method show larger benefits for drainage areas located farther from the outlet. Roads are also highlighted as having greater benefits from the drainage system. The Minnesota method identified depressional areas as having larger benefits. These areas were not identified in the Ohio method. In general, areas located next to drainage channels were assigned larger benefits than other parcels. There is insufficient evidence to recommend replacing the current Minnesota method with the Ohio method.

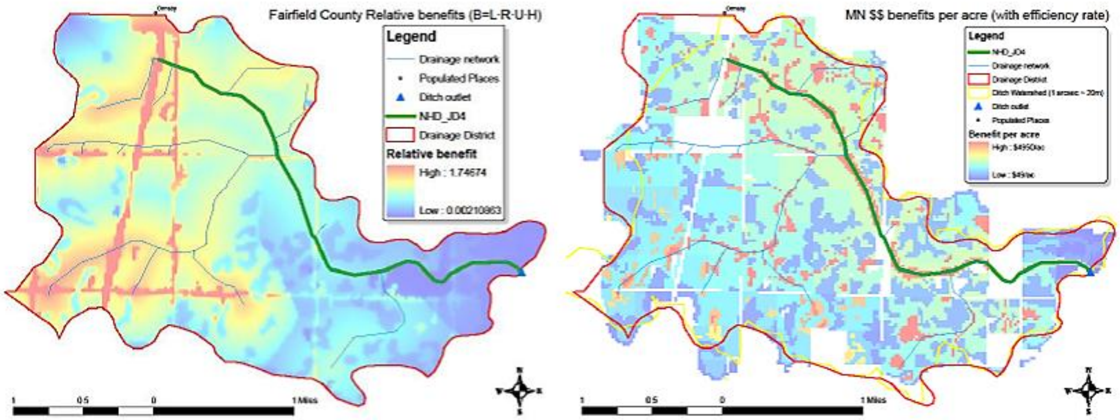

Figure 11. Relative benefits per the Ohio method, as applied to JD4 (left) and the results of the Minnesota method (right; benefits per acre with efficiency rate).

There are 17 different Ohio methods. Factors in some of these methods were not easy to determine within our GIS framework. A general discussion of their role is given below. It is recommended that further investigation of the Ohio methods compute them for comparison with the Minnesota method.

The *elevation factor, E*, makes physical sense because land at higher elevations will need less drainage than identical land that is situated at a lower elevation. This is also due to the fact that land situated at a high elevation (relative to the other lands within its drainage system) will tend to have a smaller drainage area and thus receive less runoff from upstream parcels, which results in less need for drainage.

The *flooding factor, F,* is used to represent the decrease in flooding that a parcel will see as a result of a drainage system. This is already embedded within the Minnesota methodology in that A and B benefit classes receive higher benefits because they will suffer less frequent and less damaging flooding as a result of a drainage system.

The *increase in productivity factor, I,* is used to assess the extent to which a farmer will realize financial benefits as the result of a drainage system. This is similar to the income approach that is a central component of the viewing process in Minnesota.

The *runoff volume factor, V,* is used to determine the amount of runoff a parcel generates, usually expressed as an increase in runoff from the natural condition of the parcel. The additional runoff (beyond the natural condition) that is generated by a parcel is referred to as the accelerated runoff. This approach is not used within the current Minnesota method. It is, however, consistent with the proposed method given in Chapter 5.

Minnesota Method using GIS

Overview

Earlier in the chapter the GIS results from the viewer's report was given within a GIS framework. This work is invaluable in comparing different methods, but it relied heavily on the manual collection of data given in the viewer's report. This type of assessment is time consuming. The accuracy is dependent on the professional judgment of the viewer using multiple factors such as soil classification and terrain characteristics. In this section, possible approaches to automate the process of assigning benefit drainage classes A, B, C, and D are discussed. The proposed methods require desktop GIS software and the analysis will be limited to the JD4 watershed.

We envision a three step process with our proposed method. First, rasterized benefits are assigned in an automated way. Second, field work would be conducted to correct possible errors obtained from the GIS layers. After these corrections are entered into the layers, the third step would be to summarize raster grid data per parcel or per parcel fragments within quarter-quarter sections, as it is currently done. Our work here focused on the first step of this process.

Currently, rounding of acreage takes place during field surveys. It is common to round to whole acre or, in rare cases, to the first decimal point. Therefore, we suggest adopting a raster-based practice of benefit assignment where raster cell size can be chosen to achieve an acceptable accuracy, e.g., 15 m × 15 m for a cell size of approximately 0.06 acres. Roads, seeding area, and non-benefited areas are minimal and are not considered in our method. They can, however, be easily incorporated in the workflow by rasterizing these features.

In the next section, automated ways to derive benefits are discussed in detail. Raster editing is a fairly common task and existing software can be used for it. They include *ARIS GRID Editor for ArcMap* or *d.rast.edit* tool from *GRASS GIS*. Little discussion is given on how to aggregate raster grid data. There are many tools available to derive zoned statistics, e.g., *Zonal Statistics* from the *Spatial Analyst* extension of *ArcGIS* or using a database like *PostGIS* to aggregate summarized data within polygons.

Sample Data Overview

As previously discussed, there are several factors that determine how to assign drainage benefit classes A, *B*, *C*, and *D* in the Minnesota method. The main driving factors are topography and soils. For the JD 4 watershed, most of the area is classified as C's, while hill tops are D's. There is some ambiguity whether bowl-shaped lowlands can hold enough water to be classified as A's or shall be classified as B's.

Elevation on its own is not a suitable factor as any trends need to be removed to classify local terrain features like ridges and depressions as these can be found at various elevations (Figure 2).

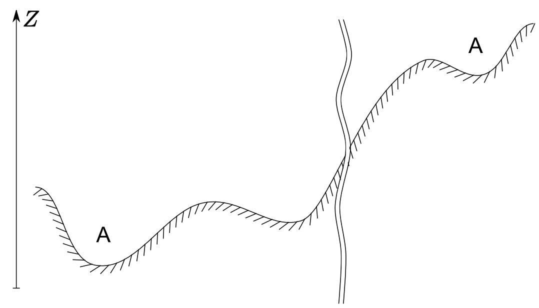

Figure 12. Hypothetical landscape. Absolute elevation going up along the overall slope is irrelevant for classification. It is local terrain features that matter.

Several transformation methods were used with the elevation data, including log transformed flow accumulation and related indices like stream power index (SPI), Topographic Wetness Index (TWI), and *SAGA GIS* wetness index (Böhner & Selige, 2006), multi-resolution index of valley bottom flatness (Gallant & Dowling, 2003), and convergence index (regarding overland flow using the aspect of surrounding cells). Among these methods, the convergence index shows good correlation with manually recreated drainage benefit classification, as shown in Figure 13. Box plots for the multi-resolution index of valley bottom flatness and the SAGA wetness index are given for reference in Figures 14 and15. While some indices demonstrate median separation, they are not sufficient by themselves as there are numerous outliers.

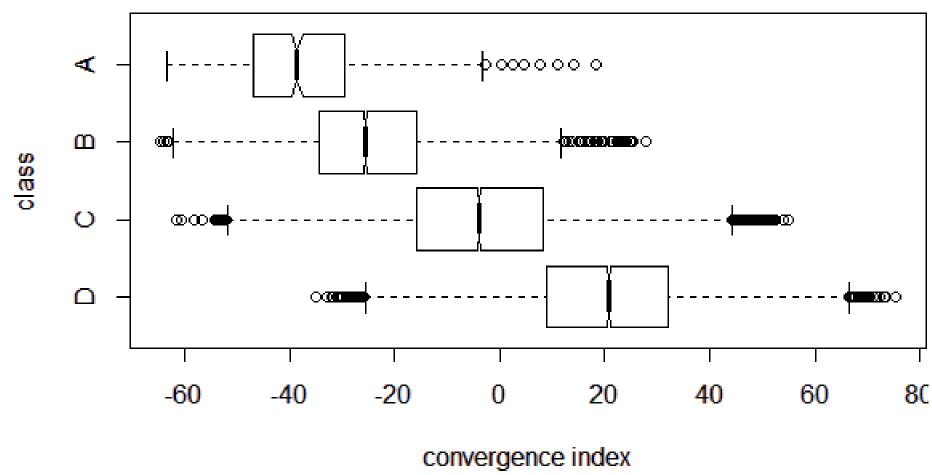

Figure 13. Box plot of convergence index for raster grid cells classified as A, B, C, or D. -100 corresponds to a bowl-shaped surrounding, +100 corresponds to a hill top with divergent flow. There is almost no overlapping between boxes.

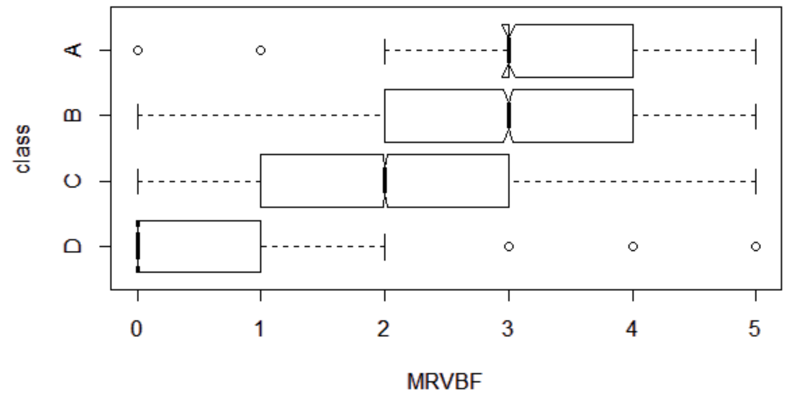

Figure 14. Multi-resolution index of valley bottom flatness. Initial threshold for slope in the algorithm was set to 3% instead of 17.7% for a 15 m DEM. Otherwise, there would be a worse box separation.

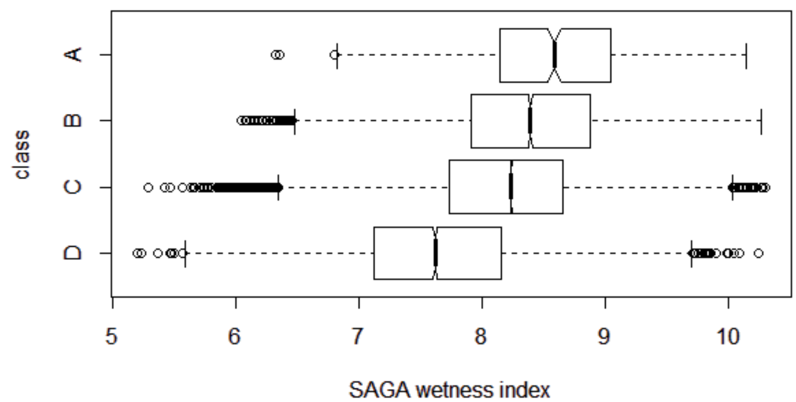

Figure 15. Topographic wetness index from a recursively smoothed flow accumulation raster. Original flow accumulation may vary drastically in low relief areas, therefore, it does not accurately represent wetness in proximity.

Recursive binary partitioning by conditional inference (Hothorn, Hornik, & Zeileis, 2006) and, separately, multinomial logistic regression (Venables, 2002) were used to match drainage benefit class with soil characteristics and aforementioned indices. The following soil characteristics from SSURGO were used in the analysis: soil hydrologic group, non-irrigated land capability class and subclass (NIRRCAPSCL). Hydrologic soil groups represented in the study area are **A**, **B**, and **B/D**. Land capability classes for soils in the area are ***1***, ***2***, and ***3***, i.e. those suitable for agricultural activity.

Recursive Partitioning

Recursive partitioning used in this work is based on the work of Strasser and Weber (1999). At each step of a recursion, the algorithm finds an independent variable that has the greatest effect on the dependent variable. If such statistically significant relationship is found, the data set is split into two pieces based on a threshold value for that variable. The process is then repeated until no more statistically significant independent variables can be found or until maximum level of splitting is reached.

Figure 16 suggests that non-irrigated land capability subclass and convergence index (CI) have great impacts on the distribution of drainage benefit classes in selected areas. For example, soils with non-irrigated land capability subclass ***w*** are rarely assigned to drainage benefit class D.

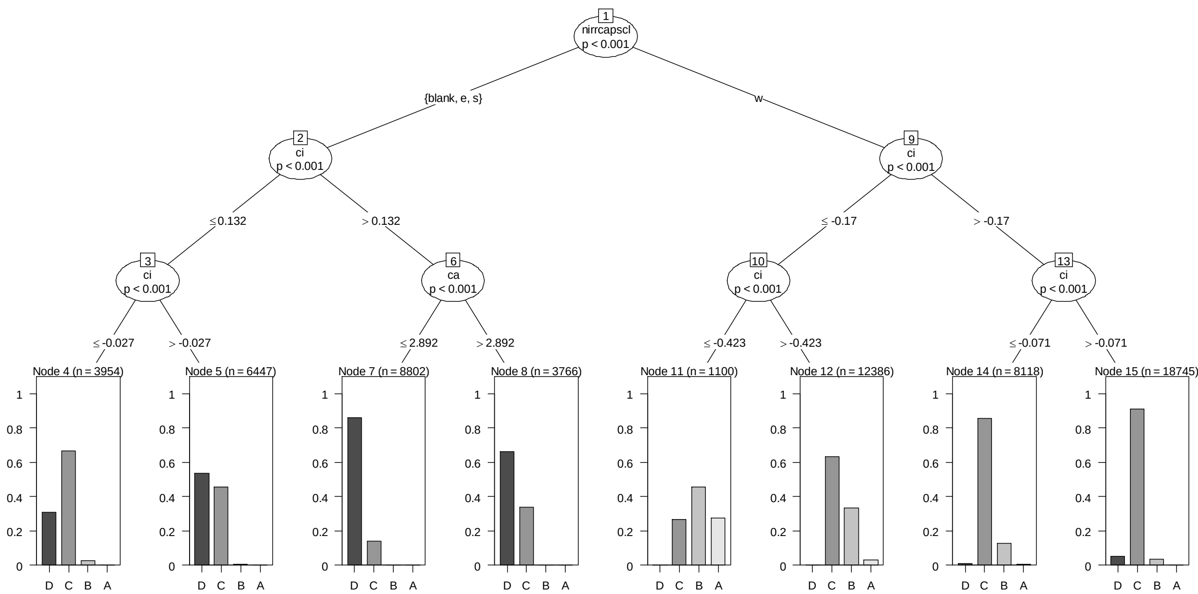

Figure 16. Classification tree indicating strong influence of non-irrigated capability subclass, convergence index, and contributing area on the distribution of drainage benefit classes.

Figure 16 was used to demonstrate the influence of CI and NIRRCAPSCL. While contributing area does affect the distribution of benefit classes C and D, we will exclude all indices except the convergence index as a surrogate for topography in subsequent analyses. Keeping only one topography related index simplifies calculations. A classification tree based on CI, soil hydrologic group, non-irrigated land capability class and subclass is shown in Figure 17.

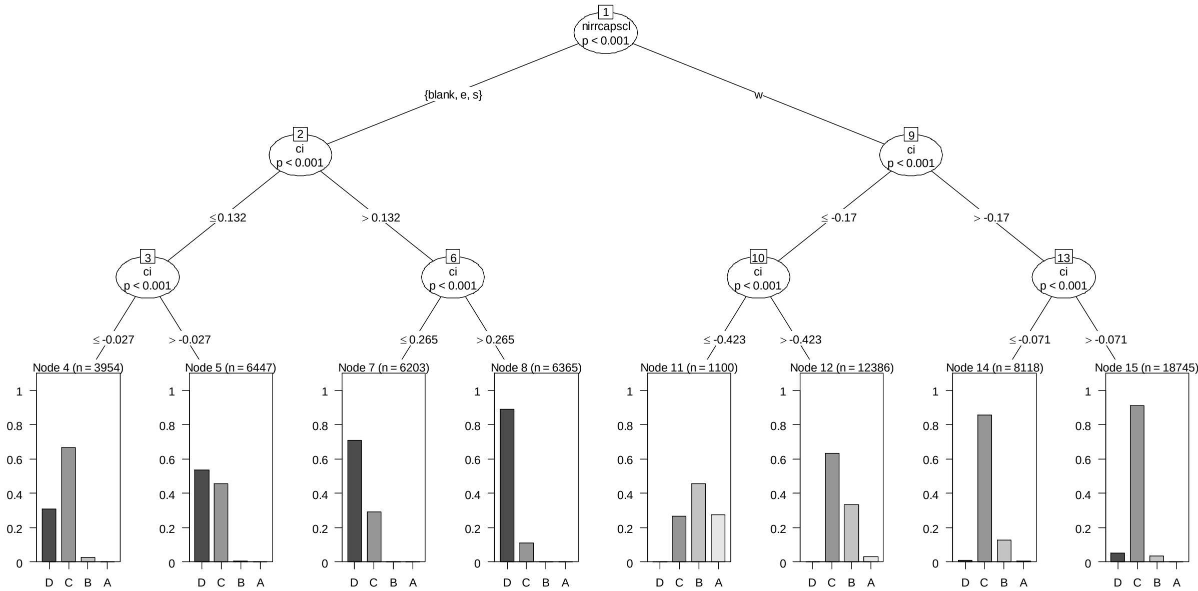

Figure 17. Classification tree based on convergence index, soil hydrologic group, non-irrigated land capability class and subclass. Tree is pruned after 3 splits.

Since we excluded all special drainage benefit classes and left A, B, C, and D only, we can use the fact that these levels of dependent variables are ordered, i.e. depending on how we look at it, we can say that D < C < B < A in that the drainage benefit for class B is between those for A and C. Ordering of factor levels affects the classification algorithm used, thus more accurate predictions can be made. The resulting tree is shown below in Figure 18. Note that there is less influence of NIRRCAPSCL on the distribution of drainage benefit classes on a given level of splitting compared to CI.

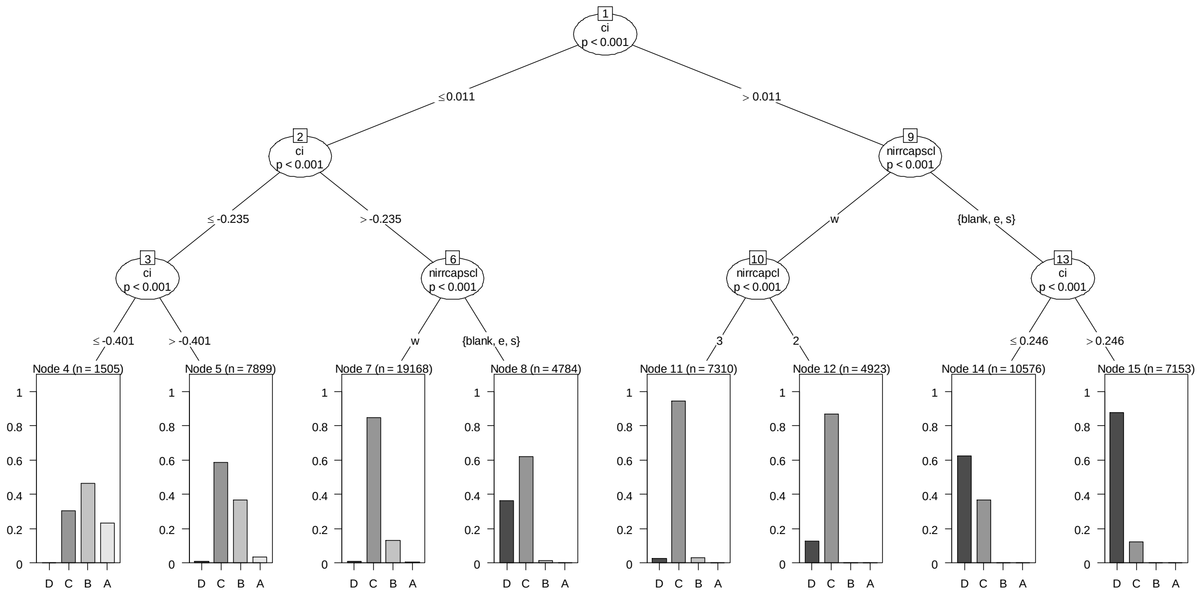

Figure 18. Classification tree based on CI and soil characteristics. Analysis assumes ordered factor levels of dependent variable.

While it is generally possible to discern A from D, variables used are not sufficient to discern, e.g., A from B. Therefore, we will use an additional two step analysis based on depression detection in *ArcMap* with *ArcHydro* followed by an analysis of those depressions and matching depression area below a certain water stage to manually delineate benefit class A.

Before we move to benefit class A and B separation, we will discuss another alternative for predicting drainage benefit classes. As demonstrated below, this approach yields similar results to recursive partitioning described above. Multinomial logistic regression used in this work employs a single-hidden-layer neural network with possible skip-layer connections. The same variables as mentioned above were used, namely CI, hydrologic soil group, non-irrigated land capability class and subclass. Regression coefficients are reported below in Table 8. Contrasts for treatments have been used for hydrologic soil groups, non-irrigated land capability class and subclass, i.e. indicator variables (regressors) have been introduced, e.g., nirrcapcl.2 in the table is 1 when non-irrigated capability class is 2, and 0 otherwise.

Table 8. Regression coefficients as returned by the model to predict log ratio of the probability of a certain benefit class to the probability of benefit class D using indicator variable coding (treatments contrast).

	Intercept	ci	nirrcapcl.2	nirrcapcl.3	nirrcapscl.e	nirrcapscl.s	nirrcapscl.w	hydgrp.B	hydgrp.B/D
C	-0.443	-5.666	-0.127	1.484	0.066	-1.332	2.624	0.066	0.823
B	-3.182	-13.285	-0.520	2.266	-0.398	-1.709	3.853	-0.398	-1.075
A	-158.118	-20.886	-103.835	2.553	72.335	-278.533	104.916	72.335	48.080

For example:

$$log\frac{P(A)}{P(D)}$$
$$= \beta_{0,A} + \beta_{ci,A}CI + \beta_{nirrcapcl=2,A}(NIRRCAPCL = 2) + \cdots$$
$$+ \beta_{soil_{group}=B/D,A}(Soil = B/D)$$
$$= -158.118 - 20.886CI - 103.835(NIRRCAPCL = 2) + \cdots + 48.08(Soil = B/D)$$

Note that there are no coefficients for a reference category used in analysis, i.e., drainage benefit class D as an outcome probability $P(D)$ can be reconstructed from Eq. 27:

$$\log\frac{P(A)}{P(D)} + \log\frac{P(B)}{P(D)} + \log\frac{P(C)}{P(D)} = 1 \quad (27)$$

We also explored an approach to detect depressional areas assigned an A class based on depressions delineated with *ArcHydro* and delineated class A benefit polygons. *ArcHydro* is a powerful *ArcGIS* extension for hydrological analysis. *Depressional Analysis* tool in *ArcHydro* allows the characterization of depressions and delineation of their boundaries along with the drainage area corresponding to these depressions. This tool is applied on hydrologically corrected DEM with known culverts and waterways burned into the LiDAR derived DEM. The output of this tool, however, includes numerous isolated sink areas with a substantial drainage area. A threshold for drainage area needs to be set before running the tool.

To reduce the number of depressions by removing those below a particular size, one may utilize histograms for drainage area, depression volume to drainage area ratio, maximum fill depth, etc. Small depressions were removed by filling and then analysis was repeated to obtain proper drainage area for larger depressions. The extent of the resulting depressional areas can be, potentially, larger than *the area for* benefit class A (Figure 19). Therefore, a subsequent analysis of depressions is necessary.

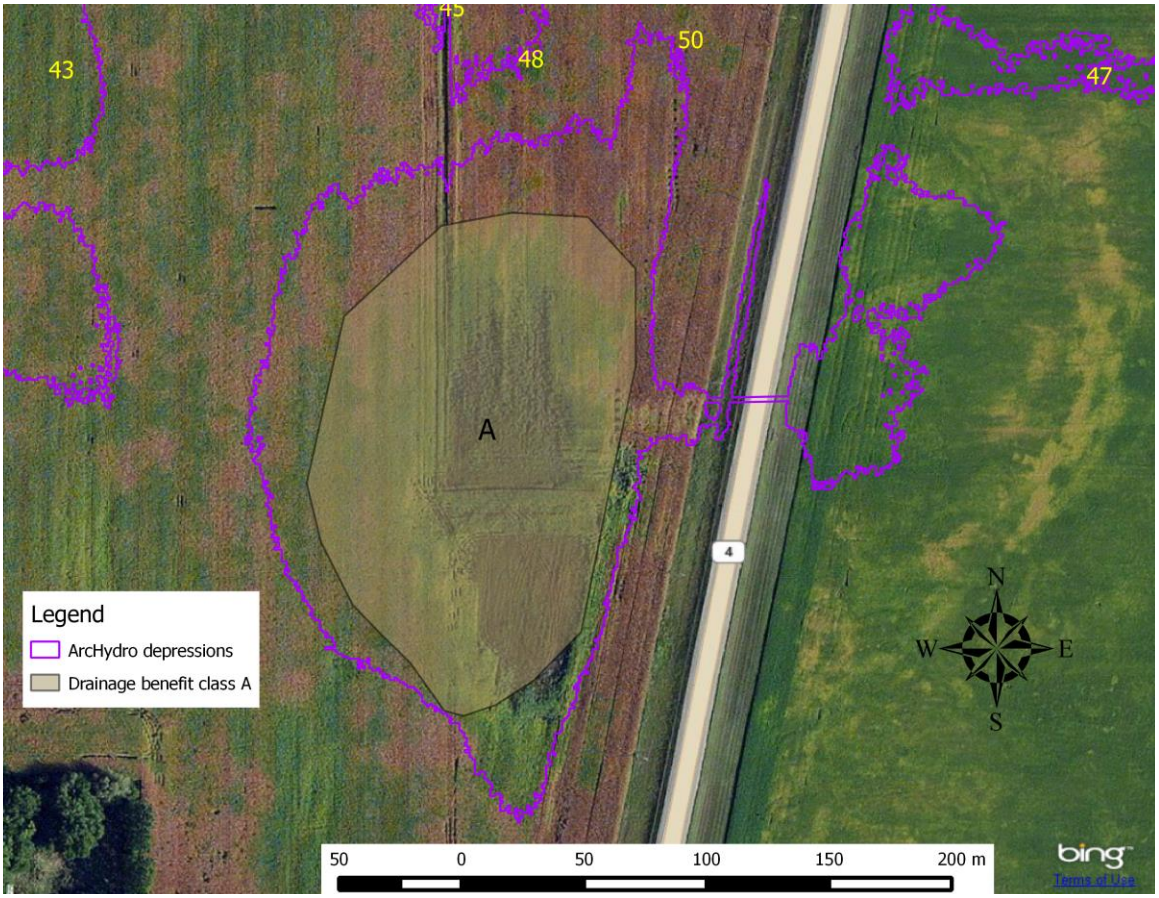

Figure 19. Class A drainage benefit area occupies a fraction of the ArcHydro delineated depression.

The subsequent analysis of a depression begins by slicing the DEM of the depression from the bottom up to the top and comparing the area that is below a certain elevation with the extent of the area classified as benefit class A. To assess the match between class A benefit polygon area and polygon P representing the area of the DEM below a certain elevation that contains the depression bottom, we define objective function within each depression by Eq. 28:

$$F(P) \stackrel{\text{def}}{=} F_A(P) = \frac{|P \cap A|}{|P|+|A \setminus P|} \quad (28)$$

where $P \stackrel{\text{def}}{=} P(h)$ is a polygon representing land (containing depression bottom) below a certain elevation (or stage above the depression bottom), $|A|$ is the area of class A benefit polygon, $A \setminus P$ is land classified as A that is not covered by P, and $P \cap A$ is the intersection of P and A (Figure 20).

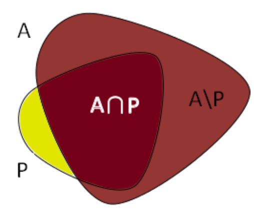

Figure 20. Venn diagram for slice P at some stage and area classified as A.

This objective function has the following properties:

- $F = 0$, when there is no overlap between the sliced area and the benefit class A polygon
- $F = 1$, when polygons perfectly coincide
- $\lim_{n\to\infty} F(P_n) = 0$ for $P_1 \subset P_2 \subset \cdots$, i.e. $F \to 0$ when polygon P grows larger as we progress above the depression bottom
- $F(P_1) > F(P_2)$ if $A \supset P_1 \supset P_2$, i.e. if A contains both P_1 and P_2, a higher value of objective function is reached on a larger polygon P_1 since all slices are nested as we go up from the depression bottom

The rest of the depression above the threshold shall be considered as benefit class B.

By solving the optimization problem, we can detect the optimal slice *P* that matches closely to the delineated polygon of the benefit class A. We can see on Figure 21 that the maximum corresponds roughly to 1 ft stage above the bottom of *ArcHydro* delineated depression, with some slight variation between depressions. There is no distinct maximum for #3 and #42 as those depressions are almost coincident with the class A polygon and the next elevation slice results in an exceedance of the depression boundary (Figure 22). Figure 23 shows that there is no apparent reason why #50 would have a maximum closer to 2 ft. as the drainage area and volume are not outliers. Therefore, in place of finding individual maximums and performing regression analyses, we simply calculate the drainage area weighted curve shown in Figure 24. The maximum on the curve is at 1.12 ft. stage height above the depression bottom.

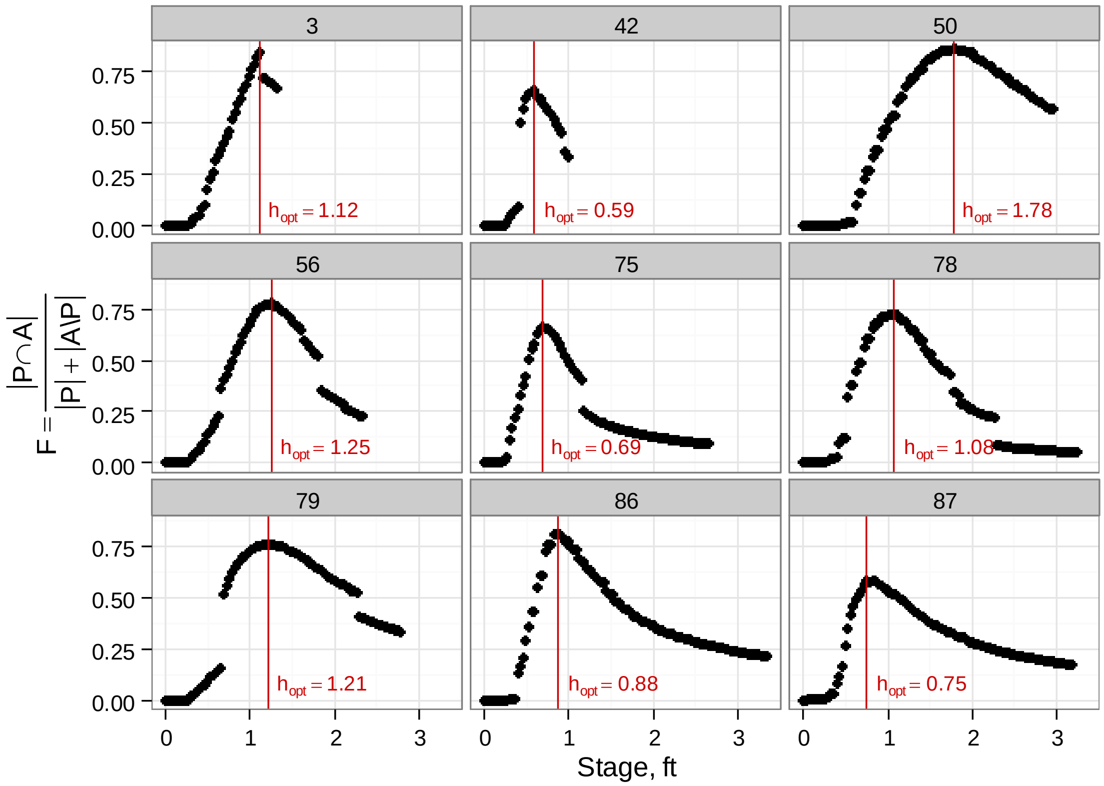

Figure 21. Objective functions for nine depressions containing benefit class A polygons.

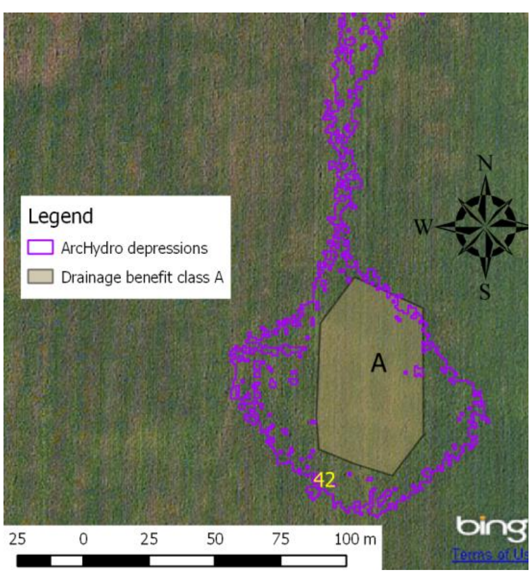

Figure 22. Manually mapped benefit class A polygon overlaps ArcHydro delineated depression boundary.

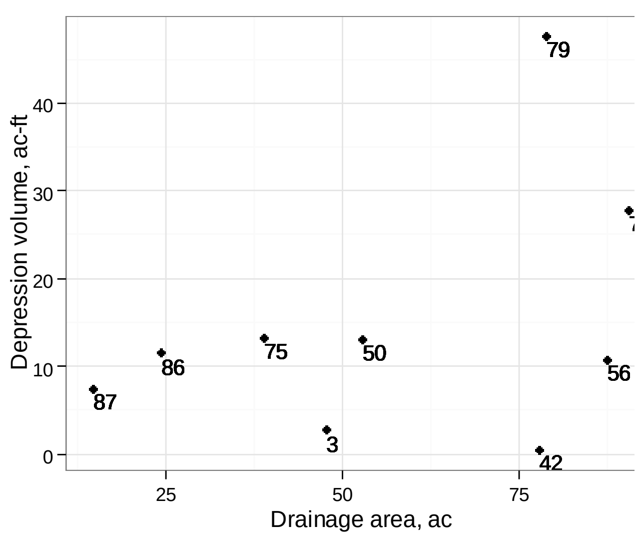

Figure 23. Volume and drainage area for depressions containing benefit class A polygons.

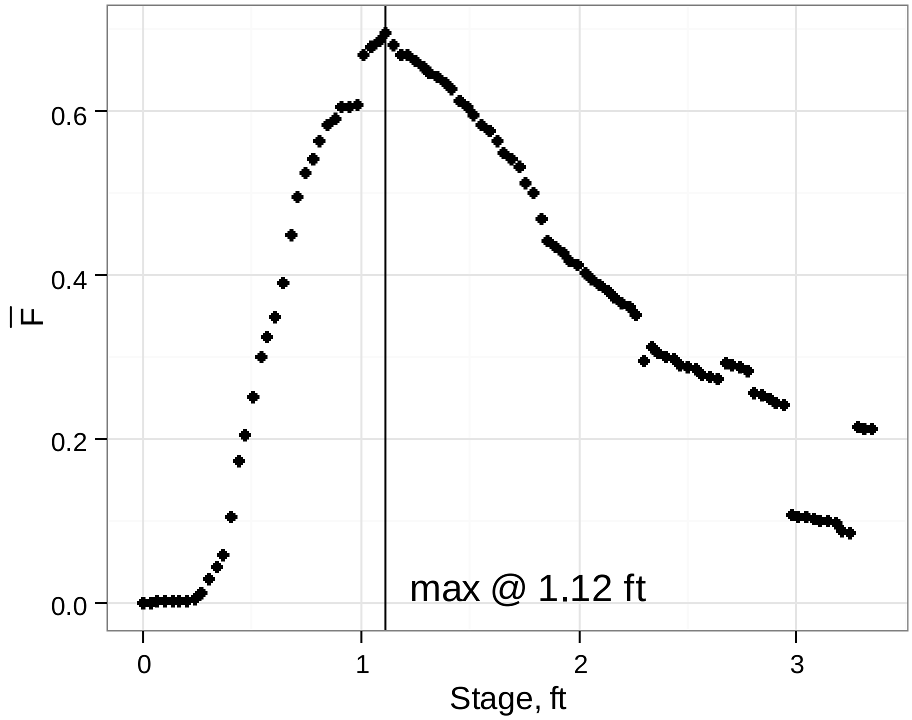

Figure 24. Drainage area weighted objective function piecewise linearly interpolated from individual data points for 9 depressions containing class A benefit.

For the sake of completeness, we include scatter plots (Figure 25) of individual optimal stages for each relevant depression versus its characteristics.

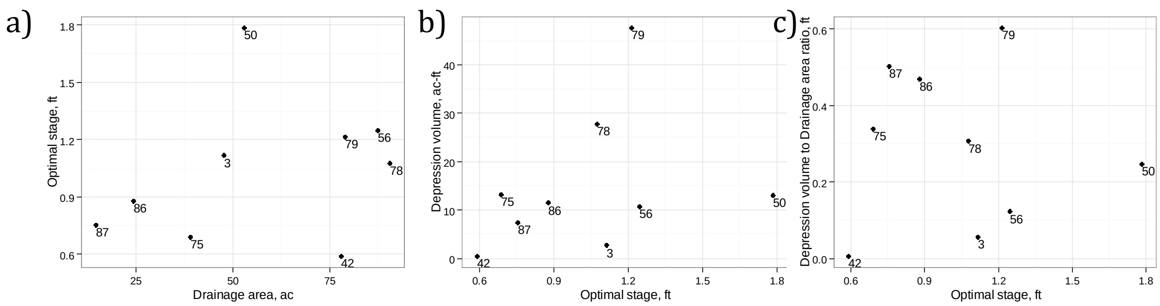

Figure 25. Scatter plots of optimal stage corresponding to manually delineated drainage benefit class A polygon vs depression characteristics: a) drainage area, b) volume of depression, and c) volume to drainage area ratio.

Discussion of a Polygon Detection Method

The independence of critical stage from depression characteristics seems counterintuitive. One may expect to have a somewhat larger optimal stage corresponding to the drainage benefit class A polygon for small volume depressions with larger drainage areas, such as #56 in Figure 23. However, it is not the case according to Figure 19. This result is likely tied to the limitation of the tool currently used for analysis.

There are two major limitations: 1) the depression bottom has to reside within a benefit class A polygon, 2) one class A polygon can be analyzed within a depression delineated with *ArcHydro*. A case where the lowest point falls outside of a class A polygon is shown in Figure 26.

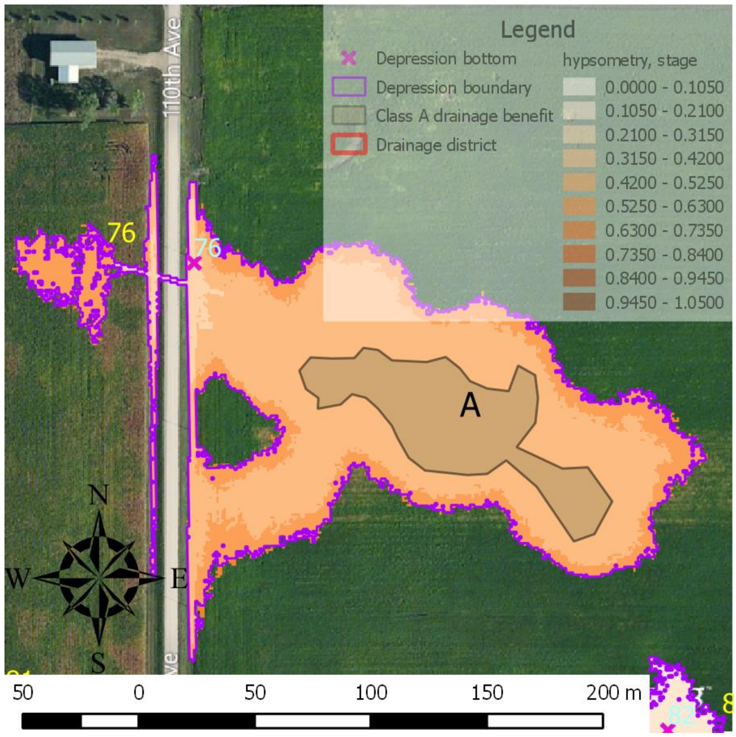

Figure 26. Depression #76 with the lowest point outside of the benefit A polygon.

As one may see in Figure 27, two disjointed polygons may reside within the depression, while only the one containing the lowest point was used in the analysis. It is necessary to account for the presence of other "sub-depressions". However, with the existing *Depressional Analysis* tool from *ArcHydro*, it would require a series of iterations to establish drainage area for each nested depression unless an alternative tool is developed.

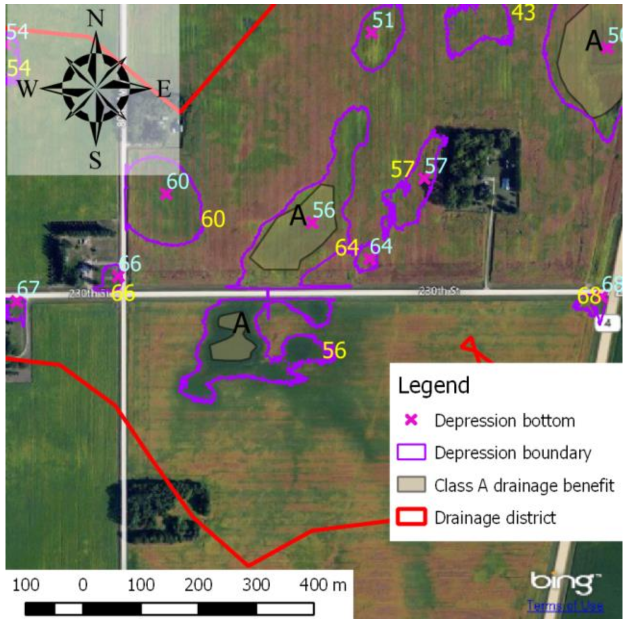

Figure 27. ArcHydro delineated depressions in a hydrologically corrected DEM with a road culvert burned-in and two polygons representing benefit class A within depression #56.

The current tool implementation cannot be applied in cases such as those shown in Figures 26 and 27.

Manually mapped polygons do not support the idea that the area of every depression that is at least 1.12 ft. deep shall be classified as benefit A. These polygons may be inaccurate due to the nature of existing valuation practice and subsequent mapping effort. For example, *ArcHydro* depressions ## 1, 2, 43, 47, 51, 60, 66, 67, 69, 71, 88 are deeper than 1.12 ft. as can be seen from Figure 28. However they do not contain areas classified as A's but are classified mostly as B's. It is unclear whether it was a valuation error. Characteristics of these depressions (Figure 29) are similar to those in Figure 23.

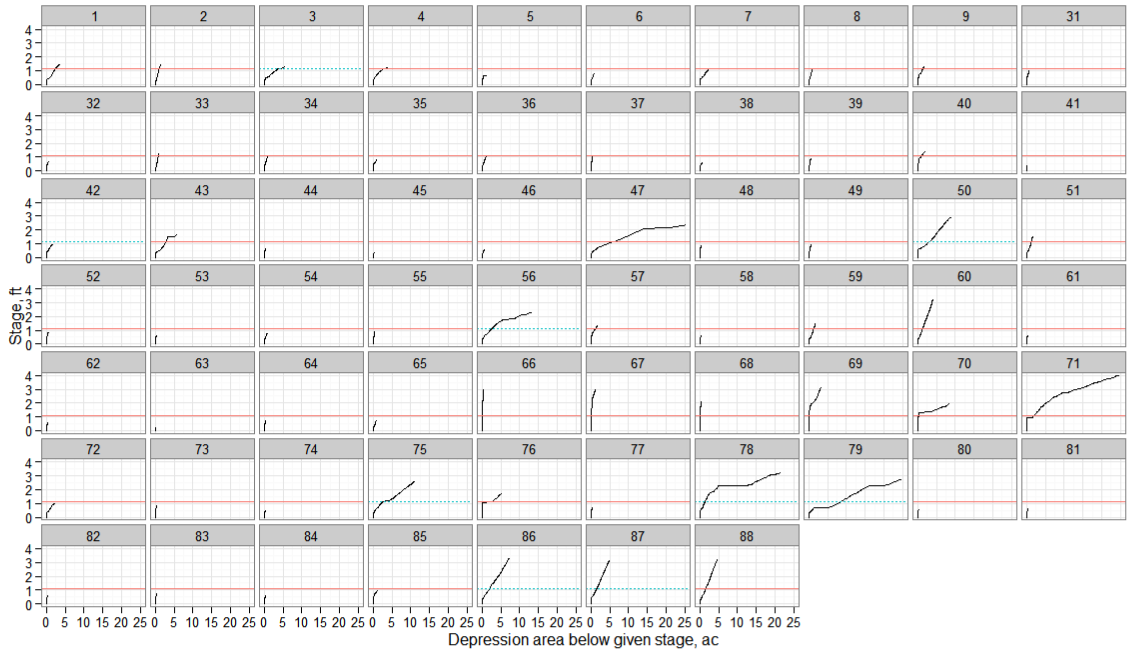

Figure 28. Stage-area curves for all ArcHydro delineated depressions. Horizontal lines correspond to the previously established threshold of 1.12 ft. Blue dotted lines correspond to previously analyzed depressions and the solid red lines correspond to other depressions.

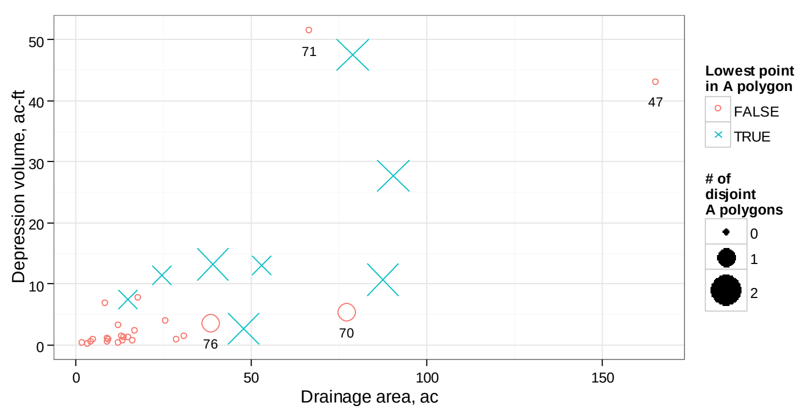

Figure 29. All depressions delineated with ArcHydro that are at least 1.12 ft deep. Blue crosses represent depressions that have been previously analyzed. Large red circles are those that were not analysed since the lowest point in the depression resides outside of class A polygon. Small red circles represent depressions that have no class A polygons inside.

Overall Summary

Table 9 shows a match between the predicted drainage benefit classes and the ones mapped as a ratio of correct prediction over the total number of reference raster grid cells having A, B, C, or D classifications. Regression and tree based predictions were augmented by A and B polygons, as suggested by the depressional analysis. Note that a depth threshold of 1.12 ft. was used to classify depressional area as benefit class A. As it follows from the table, augmentation does increase prediction accuracy for A & B classes. However, this results in a slightly decreased overall match, likely due to the fact that some C and D classes were erroneously overridden by A and/or B.

Table 9. Overall prediction accuracy.

Measure	Tree	Augmented tree	Regression	Augmented regression	Total # of non-null cells
A, B, C, and D match	78.0%	75.8%	77.4%	75.7%	64,237
A & B only match	10.1%	44.9%	20.0%	49.7%	7,327

Regression based prediction augmented with A and B class prediction based on depressional analysis gives slightly better results compared to those of the classification tree. Figure 30 shows the original and predicted drainage benefit classes. Prediction can help with the initial assessment of a study area.

a) b)

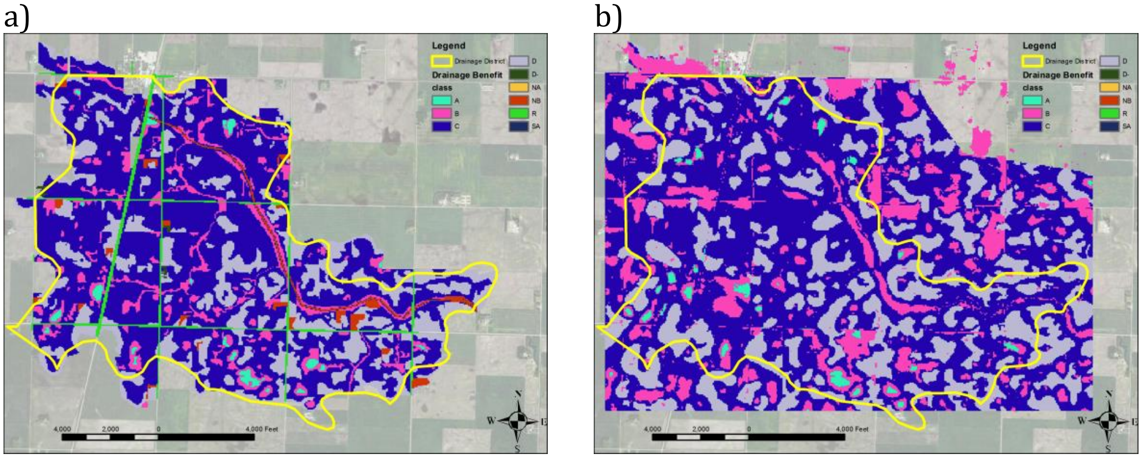

Figure 30. Original (a) and predicted (b) drainage benefit classes. Original also includes classes other than A, B, C, and D. Orphaned class B areas on the predicted figure stems from slightly different cropping of DEMs used for the depressional analysis.

Chapter 5

THE UNIVERSITY OF MINNESOTA METHOD

Introduction

None of the methods for assessing drainage benefits discussed thus far allows for the direct consideration of conservation practices. An alternative method is therefore needed to incorporate the use of these practices. Such a method, called the UM (University of Minnesota) method, is developed and evaluated in this chapter. This method is based on the drainage volume for each parcel. It does not rely on discrete benefit classes. The UM method does, however, require an estimate of the surface and subsurface drainage depth for each parcel. These depths can be obtained by coupling GIS analyses with hydrologic models.

The theoretical framework for the UM method is first presented. The method is then applied to the JD 4 watershed. Two models are used in this application. The DRAINMOD model is used to determine the effects of contributing area and conservation drainage practices on surface runoff, drainage depth and water yield. The SWAT model is used to simulate surface and sub-surface flows. A separate section is used for each of these models. An important consideration in the SWAT simulations is the surface runoff from parcels without depressions flowing into adjacent parcels with depressions. To represent this process, the SWAT results are integrated with the ArcHydro depressional analysis to capture the parcel-scale redistribution of surface runoff and subsurface drainage. The final section is used to summarize the calculations of the fraction of benefits for each parcel.

Theoretical Framework

The UM method is based on the drainage volume from each parcel. A parcel that contributes the greatest volume to the drainage system has the largest drainage benefit. The contrast between the Minnesota and UM methods is shown in Figure 31. For the Minnesota Method, the drainage benefits are assigned for discrete drainage classes (as traditionally used), that is, each parcel has to be lumped into either A, B, C or D classes. For the UM approach, the drainage benefits are determined by the conventional drainage volume for the parcel. Conventional drainage is the drainage without conservation practices. Since a unique drainage volume can be obtained for each parcel of land, drainage benefits are no longer limited by an arbitrary division of four groups. It varies continuously with drainage volume.

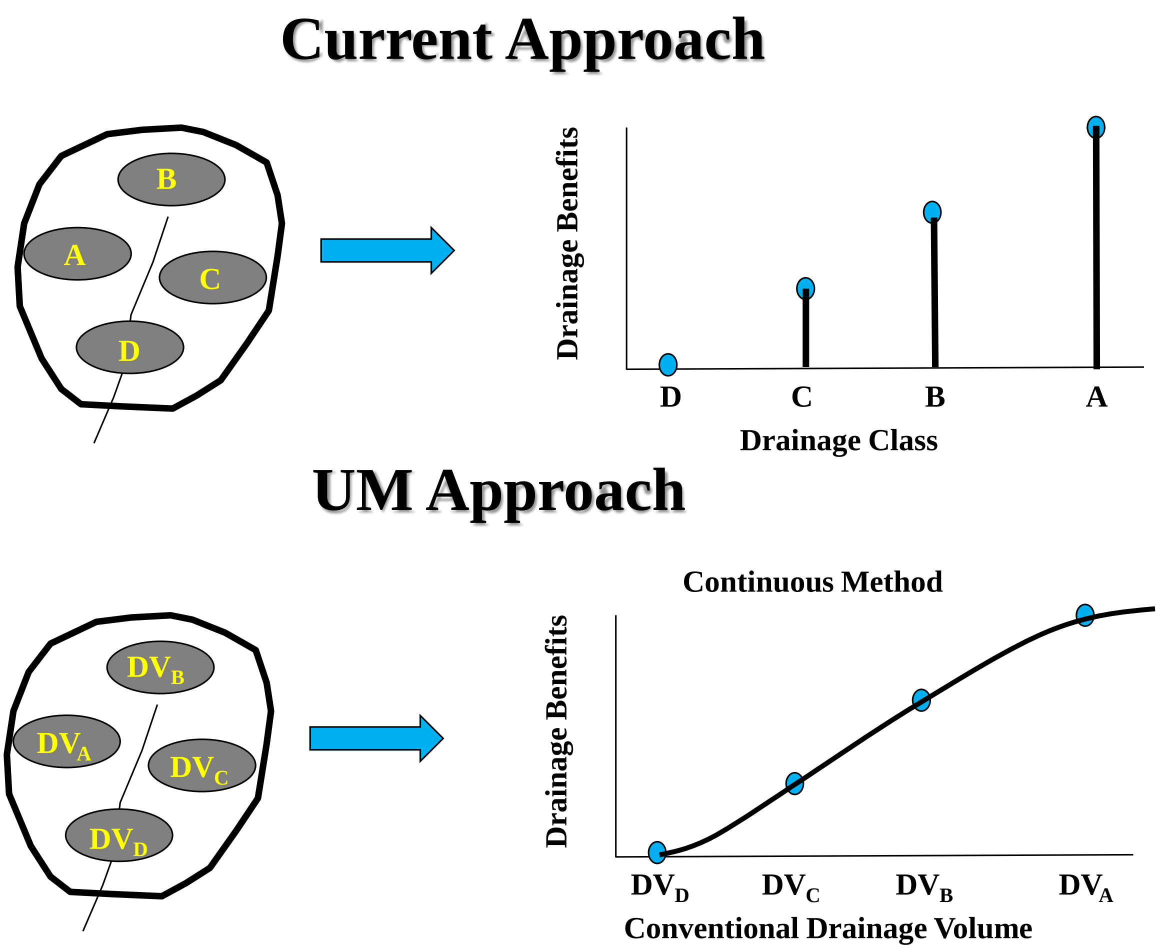

Figure 31. Illustrations of Minnesota and UM Methods.

The development of the theoretical framework starts with the definition of parcel assessment fee as

$$F_i = D_{bi} + C_i \tag{29}$$

where the subscript i refers to the i^{th} parcel of land, F_i is the parcel assessment fee (in dollars), D_{bi} is the drainage benefit (in dollars), and C_i is the cost. The cost could be tied to maintenance issue or possibly environmental costs in some areas of the world. For our analysis, costs will be taken as zero.

By defining the drainage benefits directly tied to drainage volume, and for $C_i = 0$, Equation 29 can be solved as

$$F_i = D_{bi} = R_{bi}(DV_i) \qquad (30)$$

where DV_i is the drainage volume to the drainage system and includes both surface and subsurface (especially tile line) flows and R_{bi} is the drainage-benefit ratio. The drainage-benefit ratio is defined as

$$R_{bi} = \frac{\Delta Y_i}{DV_{ci}} \qquad (31)$$

where ΔY_i is the increased value of the land (because of increased crop yields) and DV_{ci} is the conventional drainage volume necessary to obtained the increased crop yields. The total conventional drainage volume (DV_{cT}) is defined as

$$DV_{cT} = \int_{DV_{ci,min}}^{DV_{ci,max}} dDV_c \qquad (32)$$

For JD 4 watershed, the total benefit (D_{bT}) is known from the viewer's report. We will use this total benefit to estimate R_{bi}. The total benefit is defined mathematically as

$$D_{bT} = \int_{DV_{ci,min}}^{DV_{ci,max}} R_{bi}\, dDV_c \qquad (33)$$

For the special case where the drainage-benefit ratio is constant, this ratio is defined readily as

$$R_{bi} = \frac{D_{bT}}{DV_{cT}} \qquad (34)$$

It is not necessary to assume a constant drainage-benefit ratio. If, for example, the drainage-benefit ratio varies linearly with drainage volume, that is,

$$R_{bi} = \alpha DV_c \qquad (35)$$

The coefficient α is defined by substituting Equation 35 into Equation 33. After integration, α is obtained by

$$\alpha = \frac{2D_{bT}}{DV_{ci,max}^2 - DV_{ci,min}^2} \qquad (36)$$

The role of conservation practices becomes clearer by rewriting our parcel assessment fee (i.e., Equation 30) as

$$F_i = \left(\frac{\Delta Y_i}{DV_{ci}}\right) DV_i \qquad (37)$$

where DV_i is the actual drainage volume. For parcels that don't use conservation practices, $DV_i = DV_{ci}$, that is, the parcel assessment fee is equal to the increased value of the land resulting from the drainage system. For parcels that use conservation practices, $DV_i < DV_{ci}$, and, therefore, the parcel assessment fee is less than increased value of the land. Under conservation practices, a smaller drainage volume is needed and therefore it uses less of the drainage system to obtain the crop yield. The parcel assessment fee is then reduced.

The apportion of maintenance and other costs for the drainage system to individual parcel is computed using

$$f_i = \frac{F_i}{F_T} \tag{38}$$

where f_i is the fraction of the assessment for the i^{th} parcel and F_T is the total assessment defined as

$$F_T = \sum_{i=1}^{n} F_i \tag{39}$$

If all of the parcels uses equivalent conservation practices, then the assessment fees is reduced equally for each parcel. The maintenance costs are then distributed based on increased land value for parcels, that is, parcels no longer have reduction in f_i because of conservation practices. The landowners would, however, still likely benefit from the conservation practices because of reduced maintenance costs.

The implementation of the UM method requires estimates of the (1) surface and subsurface flows to the drainage system for each parcel under conventional drainage (DV_{ci}), (2) the surface and subsurface flows for each parcel with conservation practices (DV_i), (3) the total conventional drainage volume for the drainage system (DV_{cT}), and (4) the total drainage benefit (D_{bT}). The total drainage benefit will be taken for JD 4 from the viewer's report. The impact of conservation practices is determined using the DRAINMOD simulation model. DRAINMOD is also used to explore interdependence of surface and subsurface flow processes. The other sets of information are obtained from the SWAT model. The DRAINMOD results will be discussed first. This information will then be integrated into the SWAT model as it is applied to the JD 4 watershed.

DRAINMOD Investigation

Introduction

DRAINMOD is a computer simulation model developed by Dr.Wayne Skaggs at North Carolina State University (Skaggs, 1980). It simulates the hydrology of poorly drained, high water table soils on an hourly or daily basis, for long periods of climate records. The model has been successfully tested and applied in wide variety of geographical and soil conditions. In the last 20 years, the model's capability has been extended to predict the effects of drainage water management practices on the hydrology and water quality of agricultural and forested lands, both on field and watershed scales.

In this project, DRAINMOD was used to investigate the effect of surface storage, contributing area, and drainage practices on the water yield (surface runoff and subsurface drainage) in the JD4 sub-watershed.

Effect of Surface Storage

Surface storage is one important parameter to be selected in the design of a subsurface drainage system. Low values of surface storage will increase surface runoff prediction, while high values will increase infiltration and subsurface drainage, as shown in Figure 32. To illustrate the effect of surface storage, values were varied from 0.5 cm (0.2 in) to 15 cm (6.0 in) (the upper limit of the surface storage value taken from an initial estimate of the SWAT model for the average depth of depressions in Benefit Class A of the study area). Other design parameters commonly used in southern Minnesota (Luo et al., 2010) were drain depth (120 cm or 4ft) and drainage spacing (3450 cm or 113 ft) for a drainage coefficient of 0.5 in/day under conventional drainage. In addition, simulations used a continuous corn crop, a Webster soil, and the climate inputs for Waseca, MN (1915-2005).

As shown in Fig. 32, surface runoff decreases and subsurface drainage increases rapidly for low and medium values of surface storage. For high values of surface storage, however, values of surface runoff and subsurface drainage tend to stay constant. Water yield (surface runoff + subsurface drainage) and crop yield does not change substantially. Of particular importance in this study is the observation that the drainage depth does not change dramatically with surface storage.

Effect of Contributing Area

DRAINMOD performs a comprehensive water balance between two parallel subsurface drains placed at specific configurations of drain spacing and drain depth. DRAINMOD also has the capability of simulating the effects of surface runoff/run-on from adjacent areas to the field of interest. To quantify the contributing area effect, the ratio between the sizes of the contributing area (Benefit Class D) and the receiving area (Benefit Class A) was varied from 1 to 100. Several dimensionless relations were used to test the hypothesis that as contributing area increased, the primary effect would be an increase in surface runoff. Figure 33 displays the relative changes in subsurface drainage and surface runoff for increases in contributing area under conventional drainage. Surface runoff depth is defined as the runoff volume of the contributing area divided by the surface area of the depression. A fixed surface storage depth of 20 cm (8 in) was used for these simulations. Results indicate an increase in surface runoff in the receiving area as the size of the contributing area increases, particularly after the maximum surface storage depth is exceeded.

If the contributing area runoff volume is less than the storage capacity of the depression, this volume is largely discharged from the depression by subsurface drainage discharge. This trend is shown in Figure 33 by the increase in drainage depth and by the negligible change in surface runoff for $RO_d/h < 1$. The contributing area runoff volume is greater than the storage capacity for $RO_d/h > 1$. For this condition, most of the difference between contributing area volume and storage capacity is discharged from the depression by surface runoff. Consequently, as shown in Figure 33, the drainage depth does not appreciably increase for $RO_d/h > 1$ and the change in runoff increases nearly linearly with the contributing area runoff depth.

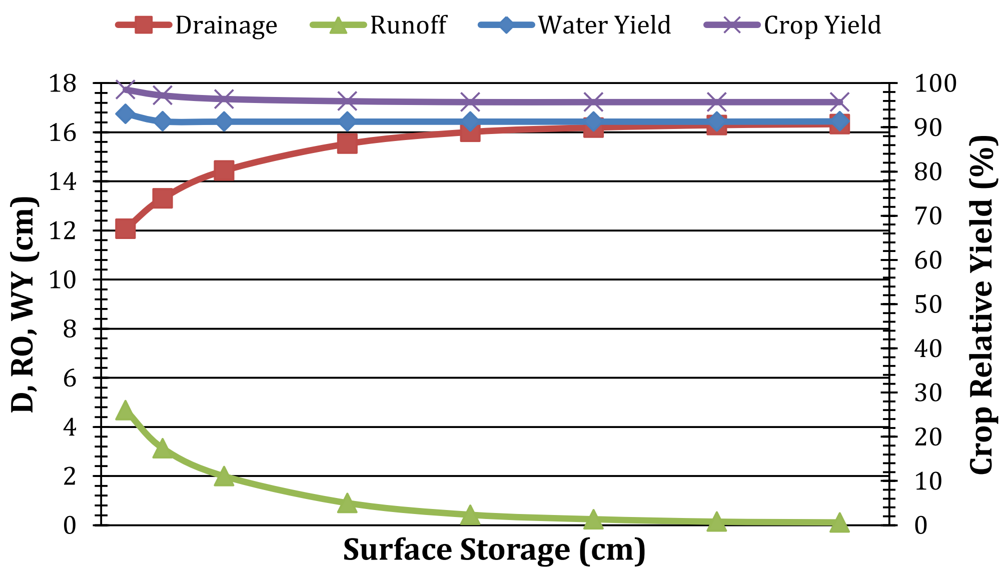

Figure 32. Effect of surface storage on drainage depth, surface runoff, water yield, and crop yield.

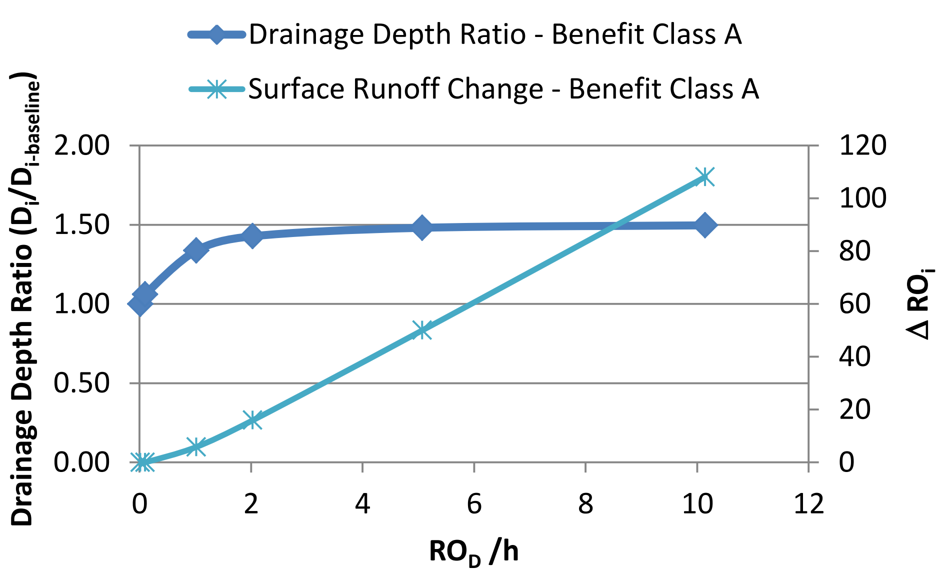

Figure 33. Effect of contributing area on surface runoff under conventional drainage for various drainage depth ratios.

Effect of Conservation Drainage

DRAINMOD was used to investigate the change in surface and subsurface runoff depths and in ET depth for conservation drainage practices of shallow drainage and controlled drainage systems. Details of the controlled drainage practices are shown in Table 11. Shallow drainage corresponds to a depth of 90 cm (compared to 120 cm for conventional drainage). The other drainage variables are the same as used for the conventional drainage.

As shown in Table 10, values of evapotranspiration and surface runoff increase from conventional to controlled drainage, while values of drainage depth and water yield decrease (under the weir settings shown in Table 11). Controlled drainage is more effective at keeping the water within the soil profile and, therefore, reducing potential loss of nutrients by subsurface drainage.

Table 10. Evapotranspiration (ET), subsurface drainage depth (D), surface runoff (RO), and water yield (WY) for three drainage practices in benefit class A (values in parenthesis indicate the percentage change compared to conventional drainage).

	Conventional Drainage	**Shallow Drainage**	**Controlled Drainage**
ET (in)	24.9	25.8 (+3.6)	26.3 (+5.6)
D (in)	5.3	4.1 (-22.6)	3.2 (-39.6)
RO (in)	1.0	1.5 (+50.0)	1.8 (+80.0)
WY (in)	6.3	5.6 (-11.1)	5.0 (-20.6)

Table 11. Weir settings for the controlled drainage simulations.

Crop	**Schedule**	**Weir Depth (in)**
Corn	November 10th - March 31st April 1st - April 30th May 1st - November 9th	6 48 24
Soybean	November 10th - April 24th April 25th - May 31st June 1st - November 9th	6 48 24

SWAT and Depressional Analysis Approach

Introduction

Many agricultural watersheds in southern Minnesota contain parcels with depressions. A main concern is when surface runoff from parcels without depressions flows to adjacent parcels with depressions. Thus, a parcel may be responsible for the draining runoff not generated within its boundaries. To account for parcel-scale re-distribution of flow for drainage benefits allocation, an approach using a combination of the SWAT hydrologic model and depressional terrain analysis was developed. The SWAT model was used to simulate surface and subsurface flow per unit area and the depressional analysis was used to redistribute these predictions to areas with significant depressions. The methodology used for the SWAT model and simulated results are given here. The incorporation of the depressional analysis is given in the next section.

SWAT Methodology

SWAT (Arnold et al., 2012) is a semi-spatially distributed model (i.e., "lumped") which simulates hydrologic response according to the spatial intersections of soil and landuse type within a given sub-watershed. SWAT aggregates flow from all soil-landuse intersections within a sub-watershed regardless of landscape position and routes them through the sub-watershed's designated channel reach. SWAT, therefore, does not explicitly account for the influence of local terrain features such as depressions. Models such as GSSHA (Downer and Ogden, 2004) are spatially-explicit grid based models that simulate hydrology at a very fine scale, thereby capturing the influence of local terrain features on overland flow. However, because these models are relatively cumbersome to parameterize and computationally intensive to run, they are not generally seen as viable options across larger areas of focus.

SWAT 2012 was employed to simulate estimates of surface and sub-surface drainage in the JD4 sub-watershed assuming continuous corn rotations and subsurface pattern tiling. An advantage of SWAT version 2012 is the integration of the DRAINMOD algorithm (Youssef et al., 2005) for tile drainage. SWAT 2012 (hereafter referred to as SWAT) simulates total water yield (consisting of surface runoff, tile drainage, interflow and groundwater baseflow components) at the intersection of three landscape attributes: soil type, landuse and slope class. Each intersection is referred to as a hydrologic response unit (HRU).

Generally, many HRUs exist as modeled watersheds are commonly large and have large variability of soils, landuses and topography. However, the JD4 subwatershed is relatively small (3,200 acres), predominantly cropland (85%) and generally possesses slopes less than 2%. In addition, drainage benefits apply to cropland only, and landuse in JD4 was fixed as continuous corn for purposes of evaluating relative change. As a result, the JD4 SWAT model was only a function of soil type (as per SSURGO), greatly simplifying model parameterization and interpretation of results.

Modeling

SWAT simulations were done at a daily timestep using the curve number method for runoff and the Penman-Monteith method for evapotranspiration. Since JD4 is an ungauged watershed, no observed flow data was available for calibration. However, two constraints were imposed on the model to ensure uncalibrated simulations were reasonable for JD4's soils, landuse and climate:

(1) Simulated water balance from 2003-2012, expressed as Q/P (i.e., total yield/precipitation), had to conform to the Q/P for the same period at the outlet of the gauged Watonwan HUC8 that JD4 lies within (this assumed negligible deep groundwater recharge).

(2) Simulated surface runoff to sub-surface tile drainage ratios had to match results from a tile drainage study conducted at the University of Minnesota Waseca Experiment Station (located 60 miles ENE; Luo et al., 2009).

Water balance Q/P is principally a function of precipitation and evapotranspiration. Daily precipitation was calculated to be the mean of the three NWS COOP stations JD4 was located nearly central and equidistant to (St. James Filt Plant, Fairmont and Windom). Evapotranspiration was simulated using the 3-station daily mean temperature, dew point equal to the 3-station mean daily minimum temperature, daily average wind speed at the St. James Airport AWOS station and daily solar radiation from the U of M Waseca Experiment Station. Water balance calibration was achieved by adjustment of the SWAT ESCO soil evaporation parameter until the simulated average annual Q/P was within +/- 10% of the observed value of approximately 0.25.

Tile parameters were set based on Luo et al. (2009) where soils and slopes matched closely with those in the JD4 watershed:

1. Re = 25 mm
2. Depth to Impervious Layer = 3 m
3. Depth to tile = 1.2 m
4. Tile Spacing = 25 m
5. Drainage Coefficient = 0.5 in/day
6. Surface storage = 5 mm (for calibration; 0 mm thereafter)

Surface to sub-surface tile drainage ratios were calibrated by adjusting the curve number. By, default, SWAT was over-estimating surface runoff and under-estimating tile drainage; thus, curve numbers were reduced (by 20%) to increase infiltration until surface to sub-surface ratios equaled approximately 1:7, as reported in Luo et al. (2009). Surface storage is a very sensitive parameter in DRAINMOD as it determines how much runoff is ponded, and therefore drained by the tile system or evaporated, which otherwise would have flowed directly into nearby channels. Some surface storage is implicit in the curve number's initial abstraction parameter but to match a surface storage depth of 5 mm as reported in Luo et al., SWAT pothole features were implemented (depth = 5 mm).

Once the SWAT model was calibrated as per the two constraints discussed above, the potholes were removed to simulate tile drainage without surface ponding. This was necessary for SWAT integration with the depressional analysis, where depressional storages were being considered separately and explicitly; simulations with SWAT potholes would have resulted in redundant counting of depressional storage.

Results

SWAT results were summarized by calculating the average annual surface and tile flows for each soil type from 2003-2012 for the months March-June (Figure 33). This four-month period was selected for the depressional component of the modeling approach because SWAT predicted that March-June accounted for 75% of the average annual tile drainage. Most soil types yielded similar results because the SWAT curve numbers are assigned according to hydrologic soil group and all soils within JD4 are hydrologic soil group 'B' or 'B/D'. Therefore, simulated flow variations were solely the result of the variation in the physical parameters (mainly available water capacity) and stratigraphy of each soil.

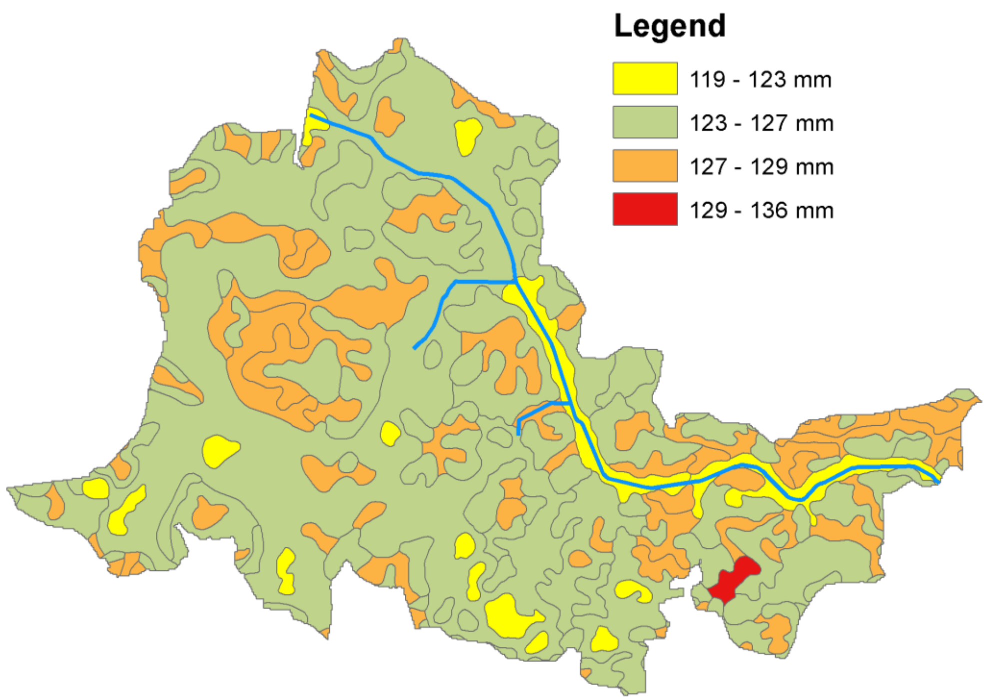

Figure 33. Average annual SWAT simulated total water yield (March-June; 2003-2012) across SSURGO soil polygons in the JD4 sub-watershed.

SWAT and Depressional Analysis Approach

Depressional Analyses

It is observed from aerial photographs that a significant number of depressions are present in the JD4 watershed. ArcGIS ArcHydro terrain analysis using available LiDAR show depressions and their associated drainage areas comprise a significant portion of the watershed and potential depressional storage is substantial is some areas (Figure 34). The important effect of these depressions from a drainage benefits perspective is when surface runoff from parcels without depressions is re-distributed to adjacent parcels with depressions. A given depression's volume as well as the size and runoff potential of its drainage area will dictate how much re-distributed water is stored in its depressional volume (and thereby discharged through the parcel's sub-surface drainage system) and how much overtops the depression and flows to down slope areas. Thus, a parcel may be responsible for the draining runoff not generated within its boundaries and vice-versa in the case of adjacent parcels lying within its depressional drainage area(s).

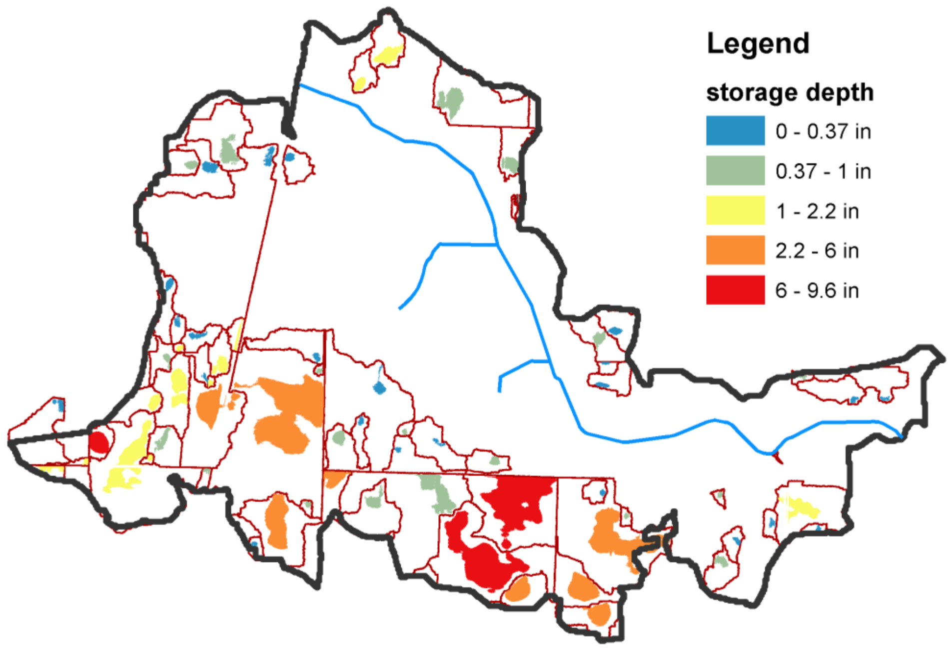

Figure 34. The storage depth (depressional volume/depressional drainage area) of significant depressions and their associated drainage areas (red outline) in the JD4 sub-watershed.

Depressional analyses were used to identify significant depressions (Figure 33). ArcHydro (AH) uses the function *Depression Evaluation* to identify depressions as well as their geometric attributes and drainage areas (DA's). Some iteration of this function was necessary to create an accurate depressional layer. Running *Depression Evaluation* on the raw LiDAR DEM yielded a multitude of small depressional errors arising from DEM sink errors. Thus, the DEM was first "pre-filled" using the AH *Sink Prescreening* function using a minimum drainage area of 5000 m^2. *Depression Evaluation* was re-run and resulting depressions were compared to aerial photographs and omitted if deemed spurious. Common examples of spurious depressions were caused by culverts that had not been "burned" into the DEM resulting in inaccurately identified roadway impoundments (culverts observed or inferred from aerial photographs were "burned" into the LiDAR DEM). The following criteria were also used during this iteration to select significant depressions:

1. Depressional surface area greater than 1000 m^2
2. Depressional DA greater than 5000 m^2
3. Depressional storage (depressional volume/depressional DA) greater than 0.05 cm

Once a representative depressional map had been created, the AH *Fill Sinks* function was run to fill all non-representative depressions. Last, *Depression Evaluation* was run again to ensure depressional DA's were also representative because omission of depressions leaves "orphaned" depressional DA's that need to be aggregated into the DA's of representative depressions (Figure 34). It is important to keep in mind that some parcels have more than one depression present, that a depression may be shared between parcels and that some parcels have no depressions but have a substantial portion of their area within another parcel's depressional DA.

Linkage of SWAT and Depressional Analysis

March-June SWAT results were integrated with the depressional analyses to more accurately represent the parcel-scale re-distribution of surface runoff expected to occur in depressional areas of JD4. For simplification, it was assumed that SWAT surface runoff originating within each depressional drainage area could be conceived as a single runoff volume input to its associated depression and that depressional evaporation could be neglected. Results of the approach are calculations of total drainage volume benefit per parcel (total surface + subsurface flow volume). The following rules applied to allocating drainage benefits:

A. Any tile drainage originating with a particular parcel, before accounting for depressional tile drainage, is counted as a benefit to that parcel.

B. Any surface runoff that originates within a particular parcel but outside a depressional DA is counted as a benefit to that parcel.

C. Any surface runoff that accumulates in a depression is counted as a benefit to the parcel(s) that contain the depression regardless of where surface runoff originated and whether it subsequently ponds or overtops. Stored depressional volume is assumed to flow through the parcel's tile drainage system while runoff that overtops the depression is assumed to flow directly to the ditch regardless of what parcels or depressions exist downslope. These assumptions are supported by the DRAINMOD simulations previously summarized in Figure 33.

Thus, for a given parcel, cumulative flow considered as drainage benefit would be calculated by the Eq. 40:

$$\Sigma DDV_i = A + B + C \quad (40)$$

Where ΣDDV_i is the total drainage depth volume per parcel, A = tile drainage before accounting for additional depressional tile drainage, B = surface runoff not originating in a depressional drainage area, and C = total surface runoff flowing to depression(s) within the parcel (if applicable).

The approach is divided into the following generalized GIS and computational steps:

1. Convert SWAT surface and tile output soil polygons to raster grid cells.
2. Calculate non-depressional tile volume for each parcel by zonal mean of parcel polygons and SWAT tile output raster X parcel polygon area (Variable A from Eq. 28).
3. Determine what fraction of each parcel area is and is not located within a depressional DA by (a) intersecting parcel and depressional DA polygons and (b) using resultant layer to eliminate depressional DA's from parcel polygons.
4. Calculate non-depressional surface runoff volume for each parcel by zonal mean of non-depressional DA parcel polygons and SWAT surface output raster multiplied by the non-depressional DA parcel polygon area (Variable B from Eq. 28).
5. Calculate total surface runoff volume to each depression by zonal mean of depressional DA polygons and SWAT runoff output raster multiplied by the depressional DA polygon area.
6. Determine which depressions and what storage volume fractions are contained within each parcel by intersecting parcel and depression polygons.
7. Multiply each depressional fraction contained within each parcel by each depression's surface runoff volume inflow; sum all depressional runoff volumes for each parcel (Variable C from Eq. 28).
8. Sum results of steps 2, 4 and 7 for each parcel (Eq. 40)

Results of this approach are shown in Figure 35. The variation in the parcel volumes shown are mainly a function of parcel size (due to SWAT flow predictions being similar across soil types per unit area) and re-distribution of surface runoff to depressional areas. Therefore, after parcel size has been factored out, parcels with high total drainage are those that contain depressions that receive significant runoff from outside the parcel boundary (see red parcels). Likewise, parcels with relatively low total drainage are those with a significant portion of their area comprised of depression DA associated with a depression located outside the parcel boundary (see light orange and yellow parcels adjacent to red parcels).

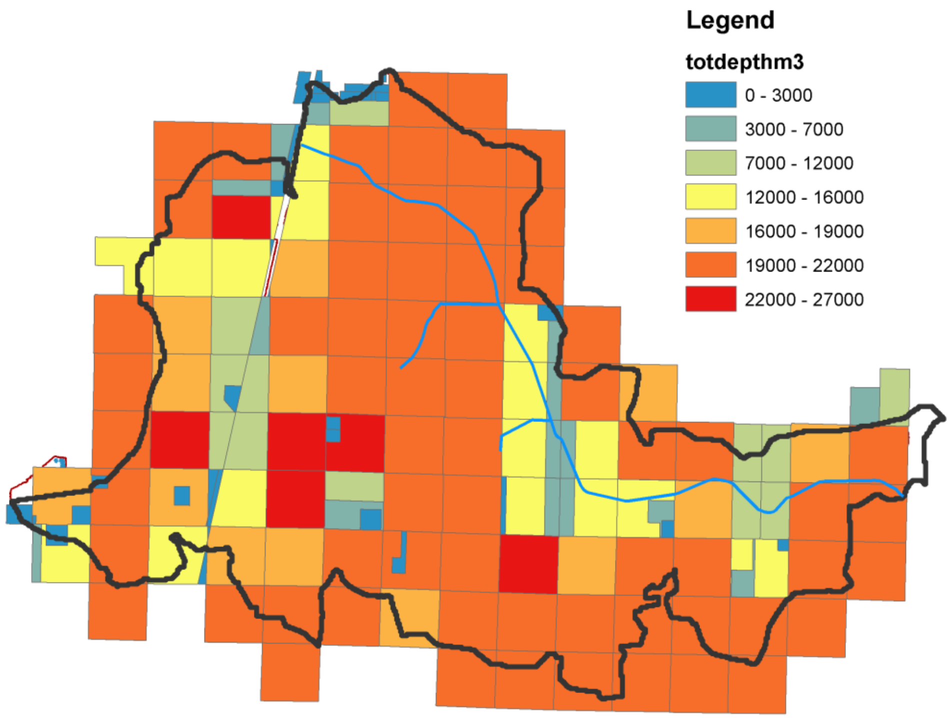

Figure 35. Total drainage volume (surface + sub-surface; m^3) by parcel in the JD4 sub-watershed resulting from SWAT and depressional analysis approach.

Conservation Drainage Scenarios

Methodology

Two conservation drainage scenarios were run in DRAINMOD to simulate the surface, tile and total volume changes from shallow and controlled drainage. Both scenarios resulted in increased surface volume, decreased tile volume and decreased total volume, i.e., a resultant decrease in total drainage benefit. These results were applied to the SWAT and depressional approach on parcels comprising the top 10% and 25% of the total JD4 drainage volume but not influenced by depressions (either containing them or draining to them). This condition ensured the increases in surface volume were not re-distributed to parcels containing depressions thereby *increasing* their drainage benefit.

Results

The total volume reductions from the DRAINMOD shallow and controlled drainage scenarios were 11% and 21%, respectively. Therefore, applying these reductions to JD4 parcels resulted in total JD4 reductions of 1.1% and 2.8% for shallow drainage in the top 10% and top 25% of parcels by total drainage volume, respectively (i.e., 11% * 10% and 11% * 25%) and reductions in 2.2% and 5.3% for controlled drainage (i.e., 21% * 10% and 21% * 25%). Figure 36 shows the distribution of parcel volumes resulting from the controlled drainage on the top 25% of parcels; each applicable parcel's total volume was reduced by 21%.

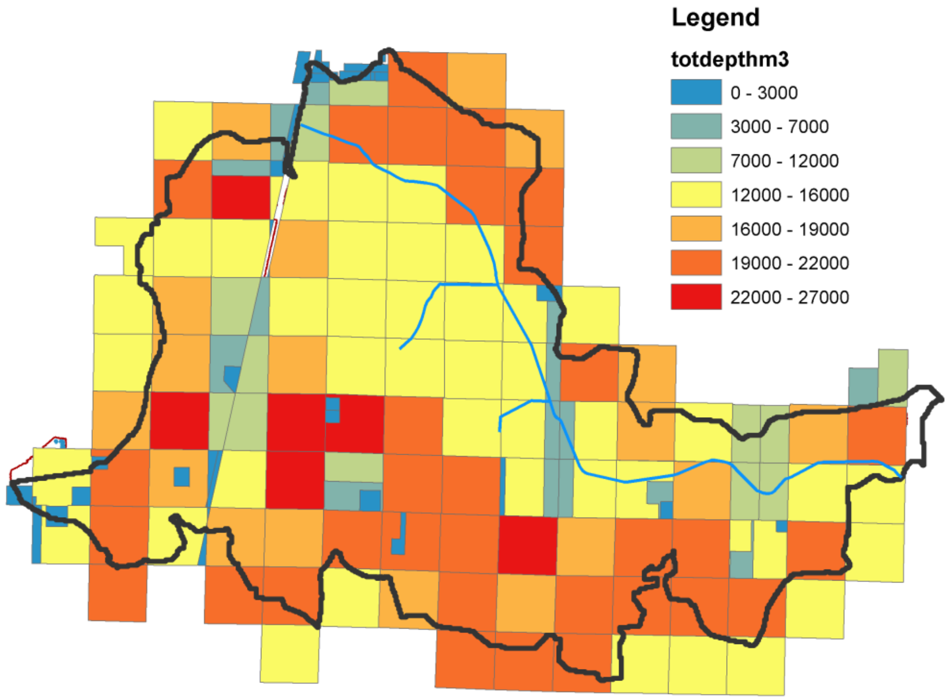

Figure 36. Controlled drainage scenario in parcels representing top 25% of total drainage volume in the JD4 sub-watershed. Total drainage volume (surface + sub-surface; m^3) by parcel resulting from SWAT and depressional analysis approach.

Benefits per Parcel Using Drainage Volume Fractions

Methodology

As a possible improvement in the current Minnesota method, the UM method has been developed to assess benefits using drainage-volume for land parcels. This method would shift the viewing process from discrete benefit classes (A, B, C and D) to a continuous scale of benefit valuations. It also allows conservation practices to be included in the analysis. The UM method is applied to the JD 4 watershed by (1) the drainage depth values from the preceding SWAT analysis, (2) the total and gross benefits values from the viewer's report, and (3) the reduction in drainage volume obtained from the DRAINMOD simulations. In this section of the report, this information is combined to calculate the benefits per drainage depth volume and the fraction of benefits per parcel-qq.

The drainage benefit for parcel has been previously given by Equation 40. For our analysis, a constant drainage-benefit ratio (as defined by Equation 41) is used. The drainage benefit for parcels can then be written as

$$D_{bi} = R_{bi}(DV_i) = (\frac{D_{bT}}{DV_{cT}})DV_i \tag{41}$$

Based on the simulation results of SWAT, the average drainage volume under conventional practices for the JD 4 watershed has been estimated as 2.11 million m^3. The benefits (gross) from the viewer's report is $4.4 million. The constant drainage-benefit ratio is then defined as

$$R_{bi} = \frac{D_{bT}}{DV_{cT}} = \frac{\$4.42x10^6}{2.11x10^6\ m^3} = \$2.09\ per\ m^3 \tag{42}$$

An alternative computation form of Equation 41 can be written as

$$D_{bi} = D_{bT}\left(\frac{DV_{ci}}{DV_{cT}}\right)\left(\frac{DV_i}{DV_{ci}}\right) = D_{bT}FV_cFV_r \tag{43}$$

Where FV_c is the fraction of the total drainage volume for the i^{th} parcel using conventional drainage and FV_r is the fractional ratio of the drainage volume for that parcel using conservation practices. Based on the analysis of DRAINMOD (see Table 10), $FV_r = 0.89$ for shallow drainage (SD) and $FV_r = 0.79$ for controlled drainage (CD).

As previously discussed, two different scenarios are used to investigate the impact of conservation. For the first scenario, half of the parcels (42 parcel-qq's) were chosen for a conservation practice. For one application, the conservation practices were applied to the 25% largest drainage parcels. For the next application, the 50% largest drainage parcels were selected and further refined down to 25% by randomly selecting half of the parcels in the top 50%. For the second scenario, the conservation practices were only applied to the 10% largest drainage parcels (17 parcel-qq's).

Results and Discussion

The drainage depth volume per parcel-qq (resulting from the SWAT analysis detailed in the previous section) expressed as the fraction of benefits results in the map depicted in Figure 37 below.

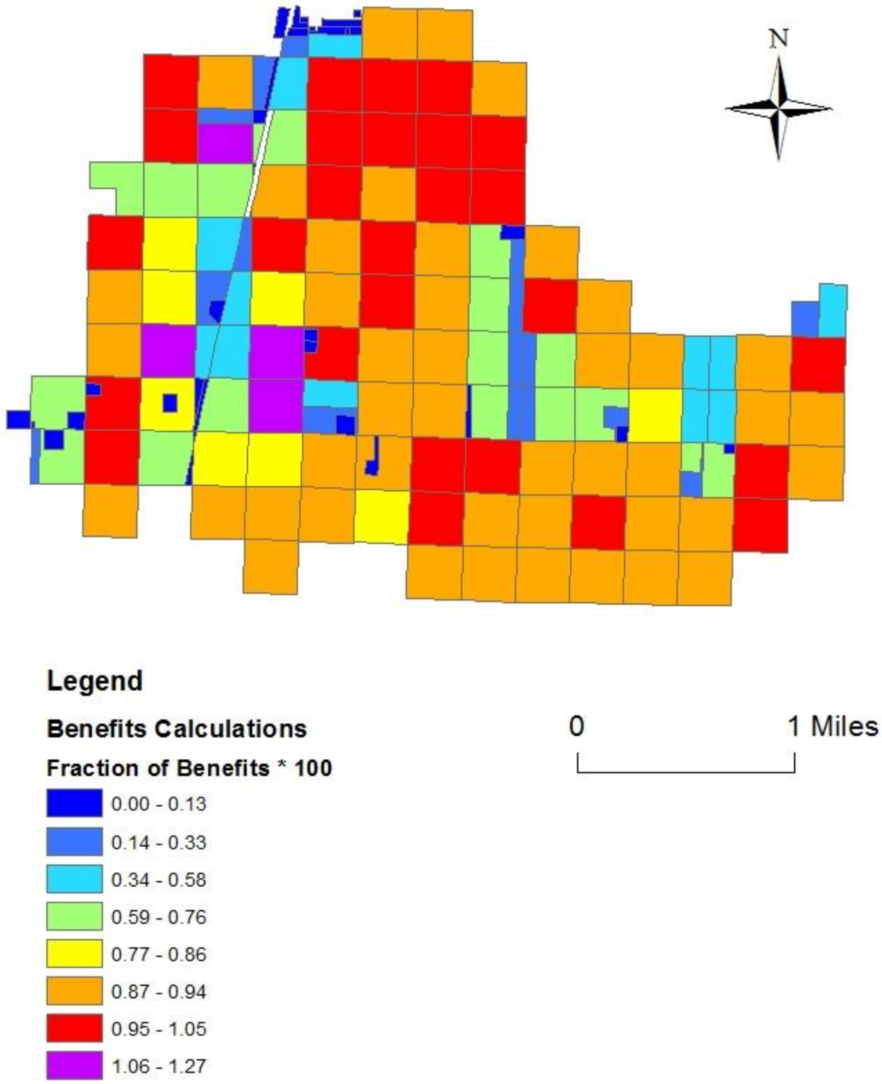

Figure 37. Fraction of benefits * 100 per parcel-qq.

The drainage depth volume as a fraction of benefits per parcel-qq under shallow and controlled conservation drainage practices applied to a random half of the top 50%, the top 10% and the top 25% of drainage depth volume results in the maps depicted in Figures 38 - 43 below.

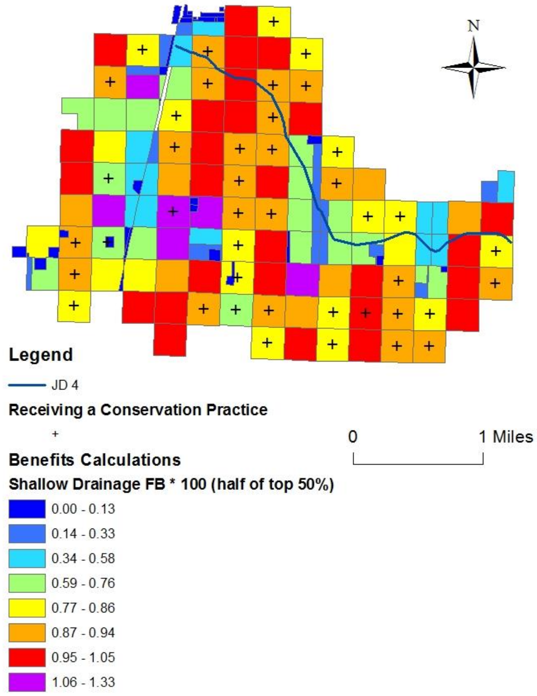

Figure 38. Fraction of benefits * 100 per parcel-qq with 42 parcels (half of top 50%) under a shallow drainage practice.

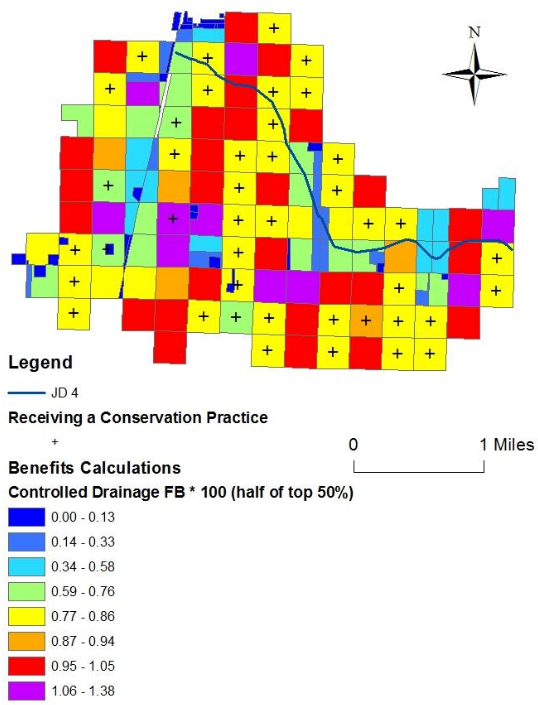

Figure 39. Fraction of benefits * 100 per parcel-qq with 42 parcels (half of top 50%) under a controlled drainage practice.

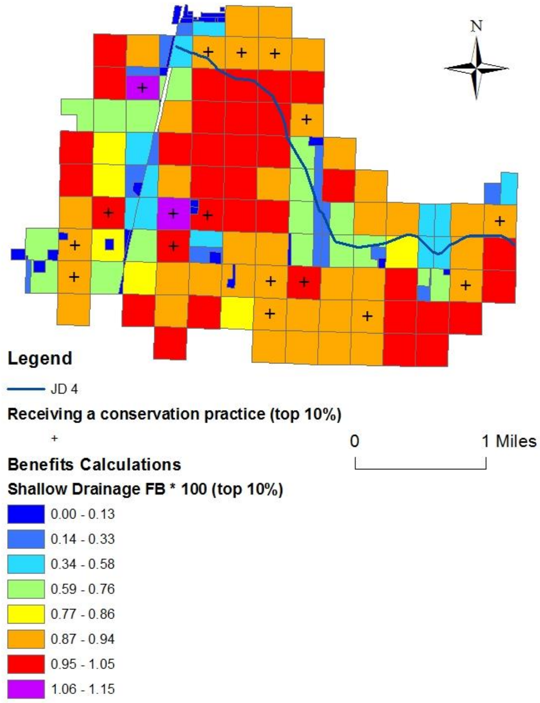

Figure 40. Fraction of benefits * 100 per parcel-qq with 17 parcels (top 10%) under a shallow drainage practice.

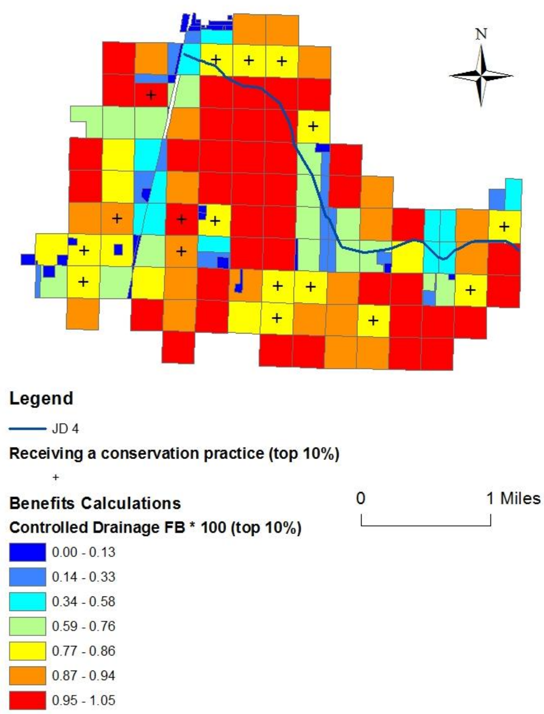

Figure 41. Fraction of benefits * 100 per parcel-qq with 17 parcels (top 10%) under a controlled drainage practice.

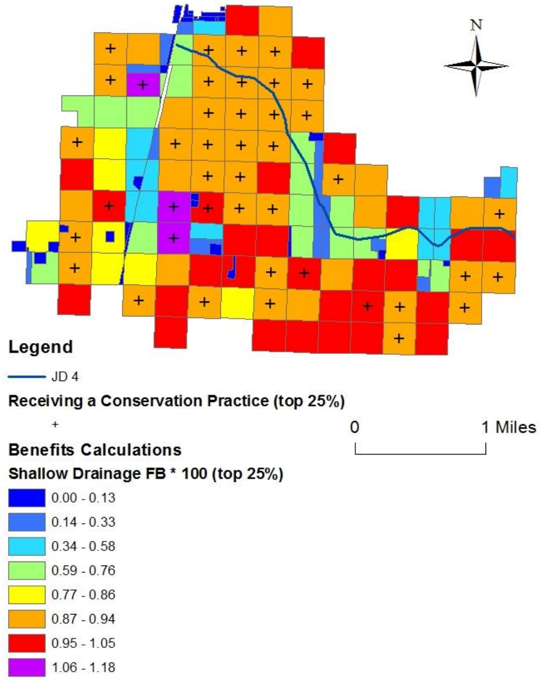

Figure 42. Fraction of benefits * 100 per parcel-qq with 42 parcels (top 25%) under a shallow drainage practice.

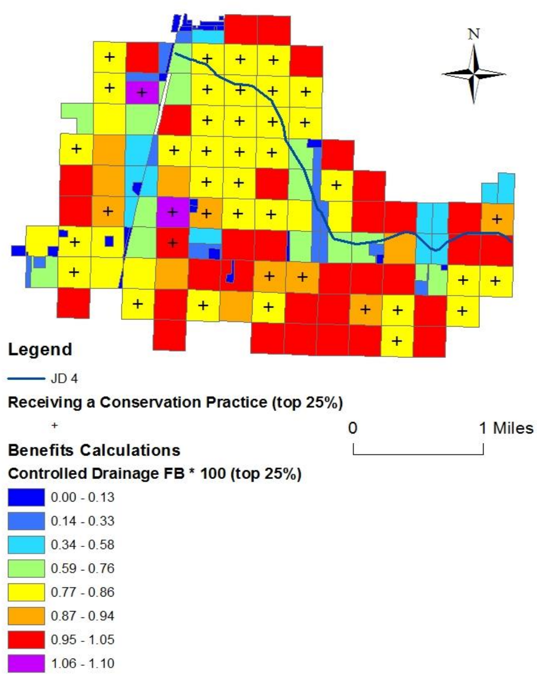

Figure 43. Fraction of benefits * 100 per parcel-qq with 42 parcels (top 25%) under a controlled drainage practice.

Table 12. Summary of the change in fraction of benefits per parcel-qq under three selection scenarios (half of the top 50%, top 25% and top 10%) of shallow and controlled CDPs.

	Change in Fraction of Benefits	
Practice	**Receiving a CDP**	**Not Receiving a CDP**
SD FB * 100 (1/2 of top 50%)	-0.09 to -0.06	Up to 0.06
CD FB * 100 (1/2 of top 50%)	-0.17 to -0.11	Up to 0.11
SD FB * 100 (top 25%)	-0.09 to -0.06	Up to 0.04
CD FB * 100 (top 25%)	-0.17 to -0.12	Up to 0.09
SD FB * 100 (top 10%)	-0.12 to -0.09	Up to 0.02
CD FB * 100 (top 10%)	-0.22 to -0.17	Up to 0.04

Of both practices (shallow and controlled), parcel-qq's that received the controlled conservation drainage practices (CDP) had the greatest reductions to their fraction of benefits compare to those using shallow CDP. Applying a CDP randomly vs. to a top percentage of parcel-qq's (regarding drainage volume) resulted in minimal changes to the fraction of benefits for parcel-qq's with a CDP. However, for parcel-qq's without a CDP, the random selection approach resulted in a larger increase of the fraction of benefits. Applying a shallow CDP to 10% of parcel-qq's resulted in moderate decreases to their fraction of benefits while providing the least amount of increase to the parcels not receiving the CDP. Applying a controlled CDP to 10% of parcel-qq's resulted in the largest decreases to the fraction of benefits while providing a minimal amount of increase to the parcels not receiving the CDP.

Without the application of conservation practices, the majority of parcel-qq's fall within the 0.87 – 1.05 range of fraction of benefits (Figure 37). Since the benefits calculations are based on drainage volume, most of the smaller parcel-qq's have a smaller fraction of benefits. The majority of the parcel-qq's has similar (if not identical) agricultural practices. Consequently, they have similar fraction of benefits for the same parcel size.

Choosing to selected 42 random parcel-qq's within the top 50% of those with the highest drainage volumes resulted in the selection of parcel-qq's with drainage volumes that were relatively low in comparison to the highest values (hence the selection of yellow colored parcel-qq's in Figure 37). This also resulted in the parcel-qq with the highest fraction of benefits (1.27 under no CDPs, upper left purple parcel-qq in Figure 37) not being selected for a CDP.

Applying conservation practices not only reduced the assessed benefits on those parcels, but also increased the assessed benefits on the other parcels. The largest decrease in the fraction of benefits was obtained using controlled drainage. It was beyond the scope of this project to determine whether this practice was feasible for all of the parcels.

Summary and Conclusions

Benefits determinations based on drainage volume provides a rational and parcel-specific methodology for assessing drainage benefits. Parcels are assessed based on the volume of drainage water received by the drainage system. Since drainage volume is continuous, the errors inherent in categorical benefits assessment no longer apply. The UM method also incorporates landscape characteristics for each parcel that are readily available as GIS layers.

The UM method requires greater communication among landowners in the watershed. Implementation by some farmers will ultimately affect others in the watershed. Greater communication has the potential to develop strategic plans to manage the water in their drainage system.

The UM method was applied to the JD 4 watershed to demonstrate how it could be implemented. It was done solely for demonstration proposes. The analysis needs to be done more carefully for actual implementation of the method. For example, the location of culvert would need to be more rigorous included in the method. The application also had all of the surface and subsurface flows as part of the benefits of the drainage system. Some of these flows would be discharged from the watershed before the installation of the drainage system. Consideration of this situation was outside the scope of the project and was not needed to demonstrate the proposed methodology.

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