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Alternative Agricultural Ditch Designs, NO_3-N Treatment, Construction Costs, and Benefits—Mower County, Minnesota, USA

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Abstract: The Minnesota Nutrient Management Strategy has identified waters with the highest amounts of nutrients that could potentially enter the Mississippi River. Mower County contains the headwaters of the Cedar River Basin, a large nutrient loading basin in the upper Mississippi River Basin. Joint efforts of the UMN (University of Minnesota), the Nature Conservancy, and Mower County, MN implemented alternative agricultural ditch designs to improve water management. Designs consisted of a TSD (Two-Stage Ditch), a rock trench, a rock inlet, and two in-ditch linear treatment systems. These features were implemented to increase ditch stability and to reduce the loading of sediment and nutrients. Important costs were the possible removal of productive ag-land, construction costs, and the break-even discount (interest) rates. Benefits included lower maintenance cost, reduced sediment and phosphorus loads with more stable ditches, and enhanced removal of NO_3-N (Nitrate-Nitrogen). Results suggest costs of the TSD construction may be supplemented with subsidies to break-even with conventional ditch design costs. Subsidies based on NO_3-N removal show the TSD compares well to other NO_3-N best management practices. The break-even NO_3-N removal costs vary greatly but are lowest when the floodplain bench is inundated for longer time periods and when the discount rate, cleanout interval of the conventional design, and construction costs of the TSD are low.

Key words: Ag-drainage-best management practices, economic analysis, NO_3-N removal.

1. Introduction

Water quality in agricultural watersheds is under greater scrutiny as the landscape and hydrologic pathways are altered to increase the production of affordable food. Land use in southern Minnesota is largely row crop agricultural with the dominant crops being corn and soybean. In 2013, 3.8 million ha of corn and 3 million ha of soybeans were harvested in Minnesota [1]. Each year, large quantities of nitrogen and phosphorous are applied to these crops to optimize yields. However, a portion of these nutrients are lost and transferred to major river systems in Minnesota and beyond. “On average, 2.97 million kg of TN [total nitrogen] leaves Minnesota each year in the Mississippi River at the Minnesota-Iowa border, with just over three-fourths of this load originating in Minnesota watersheds…” [2]. The phosphorus loading to surface waters from agricultural cropland for all of Minnesota’s 10 major drainage basins is estimated to be between 821,704 and 2,657,569 kg/year, depending on whether it is a dry or wet year [3]. The Mississippi River transports significant amounts of these nutrients to the Gulf of Mexico.

Counties along the Minnesota-Iowa border have been identified in the Minnesota Nutrient Management Strategy as containing the highest amounts of nutrients with the potential to enter the Mississippi River [4]. Mower County, located in southeastern Minnesota (Fig. 1), is no exception to the nutrient loss trend.

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Mower County contains the headwaters of the Cedar River Basin, a top nutrient loading basin in the Upper Mississippi River Basin. Just east of Mower County, the geology and terrain change to karst and hydrologic pathways become interconnected between surface and subsurface flow. Mower County, however, is underlain by some of the oldest glacial till found in Minnesota [5]. As such, significant topsoil loss has occurred over the past 100 years with the plowing of the prairie. This loss of soil over a denser underlying till has reduced the vadose zone capacity to manage increasingly large storm events. Landowners and the Mower SWCD (Soil and Water Conservation District) staff have noted more headwater flooding; including standing water in fields that was characterized as "well drained" in the soil survey. Recently, landowners have sought help from the Mower County SWCD to find BMPs (best management practices) to prevent soil and nutrient loss to waterways.

Mower SWCD teamed up with scientists and engineers from the UMN (University of Minnesota) to explore better water management. Soil health has been at the top of the BMP list because infiltration and soil respiration tests across the county have shown poor soil health in intensively managed landscapes. UMN research has suggested that strategically placed treatment wetlands and saturated buffers could offer nutrient attenuation at the edge-of-field. A new edge-of-field practice, the first of its kind in Minnesota, is the alternative or TSD (Two-Stage Ditch).

This paper will focus on the alternative designs for drainage ditches studied for a private drainage ditch located in southern Minnesota (Fig. 2). Researchers at the UMN worked closely with the Nature Conservancy and Mower SWCD personnel to identify landowners willing to participate in the research activities. The Nature Conservancy provided funding for the ditch construction and modifications. Most of the research data were collected as part of the final project report [6] to the state of Minnesota.

2. Materials, Methods & Measurements

In October of 2009, approximately 2,000 m of the Mullenbach Drainage Ditch was used for the construction and analysis of alternative drainage ditch practices. This ditch was scheduled for maintenance because of bank instabilities and tile outlet failures. The landowners surrounding the ditch were supportive of the project. The main alternative ditch practice was a TSD. Other practices installed were (1) rock side inlet, (2) rock trench to reduce seepage forces and (3) active floodplain bench to treat water from tile outlets. Most of the monitoring systems were installed to study the

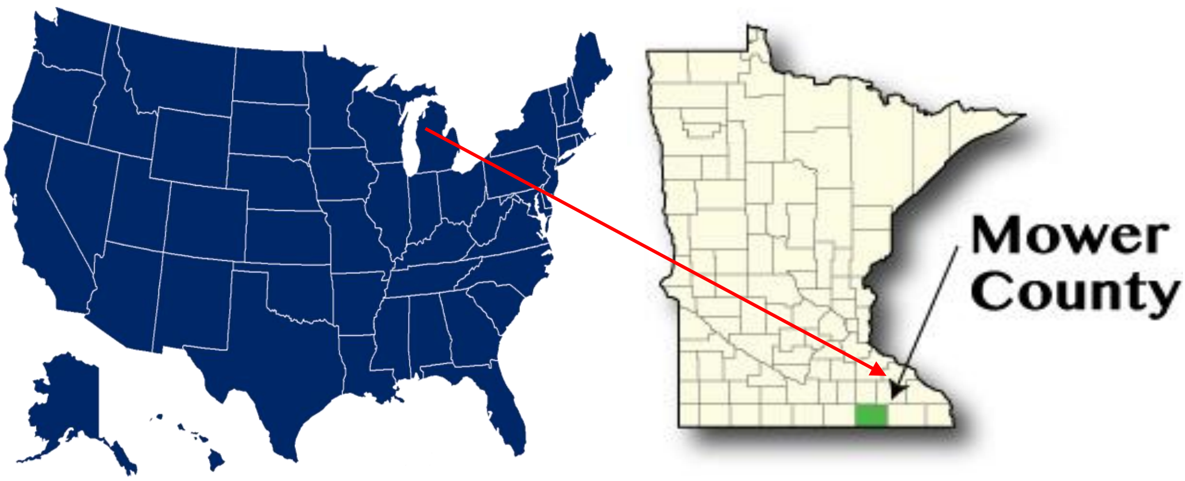

Fig. 1 Location of study site in USA and Minnesota.

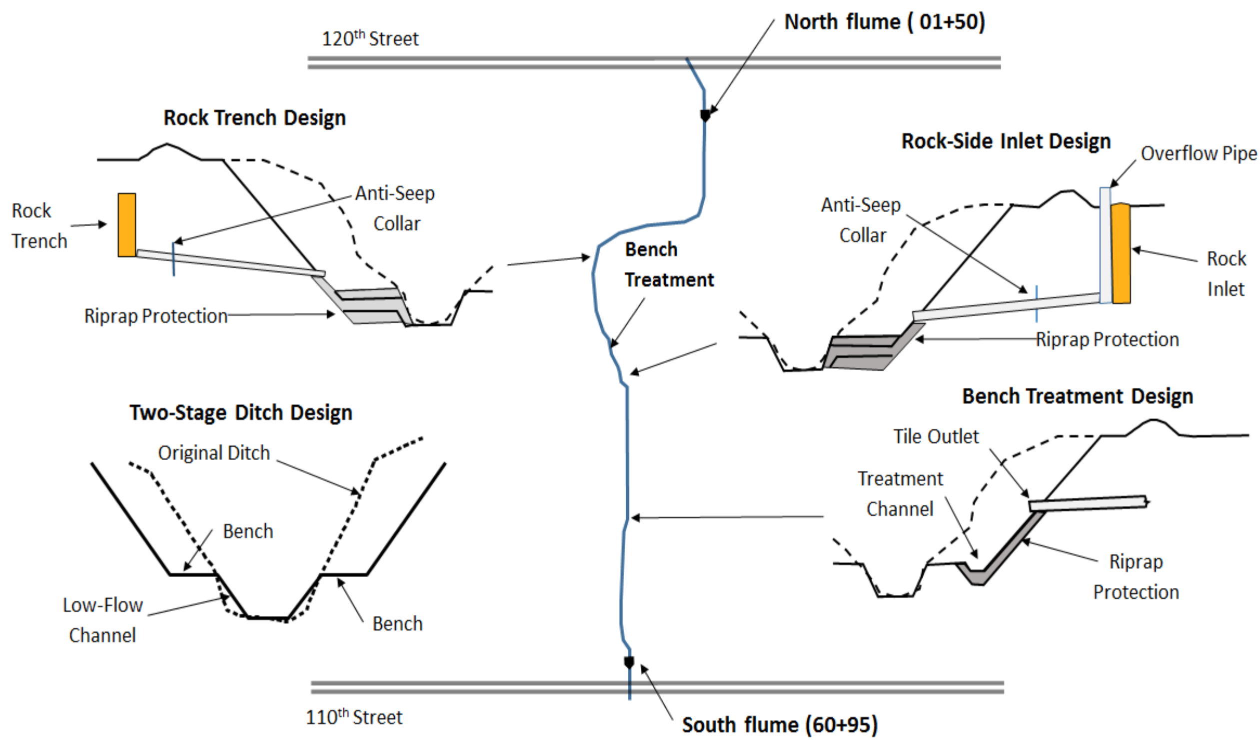

Fig. 2 Alternative drainage practices for the Mullenbach Drainage Ditch.

response of the TSD and less data were collected for these other practices. Fig. 1 shows the location of the study site in the USA, Minnesota, and Mower County. A schematic illustrating the locations and key features of the alternative ditch practices is shown in Fig. 2.

Side inlets are at the edge-of-field and the drainage ditch and are used to discharge ponded water created by the ditch berms. A traditional open pipe side inlet design was used for twelve of the inlets located in the study reach. However, at station 35+25, a rock inlet design was installed that ponded water in the field for temporary storage and sediment deposition. Additional sediment has the potential to be trapped as the sediment-laden flow moves through the rock filter. The rock side inlet was evaluated after two storms near the end of the project in 2014; for these two storms, the rock filter performed well. For example, a 77 mm rainfall depth resulted in a ponded depth of 0.3 m for only 2 h. Sediment deposition within the rock filter itself was small. More details of the rock side inlet design and the experimental procedures are given by Krider et al. [6].

Seepage forces can contribute to bank sloughing, given bank slope, into fields with high water tables. Visual inspection of the ditch prior to construction suggested that this process was a problem for this site. To reduce seepage forces, a 30.5 m long seepage trench was designed and installed within the study reach. This trench intercepts groundwater flow and safely discharges it into the ditch. Groundwater wells were installed to evaluate the effectiveness of the trench, however the well data suggested that the trench was not needed at this specific location. Selecting the locations for interception trenches in the field is not easy, and additional work is needed before the use of rock seepage trenches can be recommended. More information on the rock trench design can be obtained in Krider et al. [6].

For TSDs, water from tile outlets can be directed to treatment systems located on the benches that flow parallel with the ditch. These treatment systems have the potential to remove nutrients. Two experimental bench treatment systems of 61 m length were constructed to enhance nutrient reduction in tile outlet water by increasing residence time and water-plant contact. The performance was evaluated by diverting tile water from the tile outlet into the treatment systems and measuring the influent and effluent concentrations. Overall, the reduction in NO_3-N (Nitrate-Nitrogen) concentration was typically less than 10%. Additional contact time was likely needed to improve the NO_3-N removal rates. More careful consideration of the soil and plants in the treatment system might also improve the NO_3-N removal rates.

A TSD has a low-flow channel (1st Stage) to convey base flow below the channel forming discharge and benches (2nd Stage) that serve as active floodplains for frequent flood flows to aid in sustaining dynamic equilibrium in the system [7]. Estimates for the dimensions of the low-flow channel were calculated according to regional curves previously developed for south-central Minnesota [8]. These curves resulted in a design depth of 0.57 m and a top width of 3.28 m. Approximately 80 percent of the existing channel prior to constructions was within these design specifications. To reduce the amount of sediment disturbed during the construction process and preserve the growing vegetation, the low-flow channel for this portion of the ditch was obtained by leaving the existing ditch intact [7]. The constructed depth therefore varied with location but was roughly 0.61 m. The constructed widths varied between 2.74 m and 3.35 m. The benches were sized using the minimum ratio of 3:1 of flooded to low-flow-channel widths [9-11]. Each side of the low-flow channel had a bench width approximately equal to the top width of the channel. The side slope ratio of the ditch bank was designed at 2:1 [6].

The stability of the TSD was assessed using longitudinal and cross-sectional surveys as well as visual inspections. The longitudinal and cross-sectional data were analyzed using RiverMorph Version 4.3 and the Reference Reach Spreadsheet [6, 10]. The TSD had a substantial improvement in the number of pool-riffle formations. Prior to construction, only five pool-riffle sequences were identified within the pre-existing ditch [12]. In 2013, a longitudinal survey of the TSD identified 68 pool-riffle sequences. The low-flow channel dimensions were relatively stable during the study period. Cross-sections surveys were conducted at the same 6 locations in 2010, 2012 and 2013. Four of the locations had no net change in depth, and 3 of the locations had minor changes in top width. The average depth increased from 0.4 m to 0.49 m, and the average top width increased from 3.47 m to 3.87 m [6, 12].

Vegetation surveys and fish population data were collected to assess the impact of the TSD on the biological characteristics. Riparian vegetation was largely left intact during construction. A standard seed mix was applied after construction and covered with erosion control blankets. A seeding with rye grass was also applied in November of 2009. Some areas of the ditch required more than 2 years to establish thick cover. Although the species composition changed, the number of non-native or invasive species remained a significant component of the vegetation throughout the study period. FIBIs (Fish indices of biological integrity) were used to assess changes in the ecological health with the TSD [13]. Two locations were sampled for fish on the Mullenbach Ditch in 2009 (pre-construction) and again in 2011 and 2013 (post-construction). Fish communities were sampled using a backpack shocker walking downstream to upstream, and FIBIs were computed using standard methods [13]. The post-construction FIBI scores increased for both locations indicating improved ecological health. The downstream location increased by 11 and 18 points for 2011 and 2013, respectively. The upstream location increased by 6 and 3 points for these sampling periods [6, 13].

NO_3-N removal for the TSD design was investigated using monitoring systems at the upstream and downstream sites. Groundwater and tile flows were also measured. At different times during the study period, nearly continuous water quality data were also collected using a YSI 6800 Sonde and a Hach Nitratax nitrate probe. Approximately 8,000 readings of pH and specific conductance and 2,500 temperature values were measured with the Sonde probe. Approximately 60,000 readings of NO_3-N concentrations were obtained with nitrate probes. NO_3-N removal was estimated using mass balance relationships based on field data for in-channel denitrification and using N_2O-N emission for soil denitrification in a laboratory setting.

3. Results

3.1 Nitrate Removal Results

From the field data, percent removal of NO_3-N was estimated to be between 14% and 16% for the 2013 data, 34% for the 2011 data, and between 15% and 25% for the 2010 data. Denitrification rates estimated using N_2O-N emissions varied greatly with habitat zones. The estimated denitrification rate using the habitat-weighted areal rates is supportive of the values obtained with the mass balance approach. Estimates of NO_3-N removal from field data are largely limited to flows in the low-flow channel. Potential removal by utilizing the entire bench width was computed using the denitrification rates from the laboratory data. For the inflow load for the 2011 data, the potential removal efficiencies were estimated to be between 42% and 75% [6].

3.2 Economic Analysis Results

Economic analysis is an important component in assessing the feasibility of alternative ditch designs. The economic viability of a TSD project was computed by comparing the expected costs of an existing conventional ditch with the replacement cost of a TSD. The cost was calculated for a specified project length based on pre-2022 inflation. Based on the input parameters for a given site, the NPV (Net Present Value) is defined as, net value of all future costs expected over the project life was obtained for both the current conventional ditch system and a potential constructed TSD. The ditch system with the lower NPV is, thereby, determined economically preferable.

The following costs associated with the construction of ditches were used:

- Earthwork required to widen the ditch system
- Erosion control and prevention measures
- Land lost to widening of the ditch system
- Side inlet and tile outlet modifications and reinforcements

Potential economic benefits considered in the economic model are:

- Reduced ditch maintenance and cleanout frequency
- Water quality benefits—NO_3-N removal
- Improved habitat for both aquatic and terrestrial organisms
- A more natural and aesthetically pleasing landscape

Ditch cleanouts are generally the greatest cost of maintaining an existing conventional drainage ditch. For this reason, cleanout costs are the main determining factor of the cost effectiveness of a TSD. Drainage ditches that require relatively frequent cleanouts tend to be the best candidates for TSD replacement.

A detailed list of construction costs associated with the Mullenbach TSD can be found in Krider et al. [6]. Total excavation costs account for only $28/linear m. Miscellaneous costs included $2,500 for mobilization/demobilization of equipment and $3,500 for permitting, inspections and associated paperwork.

Replacement of tile outlets, side inlets, and work related to riprap and geotextile armoring at outlet structures onto the ditch benches accounted for $35/linear m. Erosion control blankets to cover the ditch benches and outside ditch banks were $37/linear m, the most expensive single project component. Controlling erosion using straw mulch crimped into the soil would have been one order of magnitude less expensive. However, in this study it was critical to provide a higher level of protection for demonstration purposes.

Powell et al. [14] reported a range of construction costs from $33 to $218/linear m for 4 constructed two-stage channels in northwestern Ohio and southeastern Michigan [14]. The cost to construct the Mullenbach Ditch system (neglecting design and data collection costs) was approximately $105/linear m, which falls within the range of reported costs [14].

The TSD upfront construction and land purchase costs were expected to be large but less frequent relative to the cleanout costs of a conventional ditch. The conventional ditch cleanout interval varied from 5 to 12 years in the analysis [6]. A project life of 100 years was assumed for the TSD to reflect enough cleanouts to cover upfront TSD costs in present value terms. The TSD tends to become unprofitable with a relatively short project life. However, when a monetary value was assigned to the NO_3-N removed by a TSD, Spier et al. [15] showed large scale NO_3-N reduction and the TSD becoming a competitive NO_3-N reduction BMP.

The Watershed Nitrogen Reduction Planning Tool (NBMP.xlsm) developed at the UMN shows estimated costs ranging from a $8 kg/N to $216 kg/N for 12 BMPs that would reduce the NO_3-N leaving Minnesota cropland [1].Given that we do not know which BMPs will ultimately be adopted, we arbitrarily chose a value of $10 kg/N reduced to calculate a break-even project life under various discount rates, cleanout intervals, and TSD construction cost scenarios (Table 1).

A ditch cleanout cost of $9.84/linear m for a conventional ditch in Ohio (before conversion to a two-stage channel) was reported by Powell et al. [14]. Few other estimates are available that specify the cost of maintenance activities per cleanout event, as most literature reviewed cites annual average ditch maintenance costs for counties or states [16]. Peterson et al. [17] reported cleanout and maintenance costs of $590 to $13,600/km.

[1] The NBMP model and documentation are available at z.umn.edu/nbmpdoc.

3.2.1 Economic Analysis Results without Subsidies

Economic analyses were first given without any direct financial subsidies for the TSD. These results are reported using a break-even discount (interest) rate. A discount rate in an NPV model has the effect of reducing the present value of costs or benefits in the future compared to upfront costs or benefits. When comparing two alternatives that have similar total costs, but where one alternative has a higher upfront cost while the costs of a second option occur further in the future, a higher discount rate would reduce the present value of the second alternative's future costs and make the second option appear more profitable (it would have a higher NPV). Conversely, a lower discount rate raises the present value of those future costs and would make the first option appear relatively more profitable. The break-even discount rate shown in the Figs. 3-5 is the interest rate at which the NPVs of the existing conventional ditch and the proposed TSD are equal. The TSD involves larger upfront construction costs while the conventional ditch involves more cleanout costs in the future. Therefore, if a discount rate lower than that of the break-even rate can be obtained for two-stage construction, the NPV of the conventional ditch will be lower than that of the TSD over the project life because the future cleanout costs are weighted more heavily in the NPV.

Break-even project life and break-even NO_3-N removal costs are also used in our analyses. For break-even project life, we used discount rates of 3%, 5%, and 7%. The values of NO_3-N removal ($10 kg/N) were set, and the project life was determined so that the NPVs were equal for the 2 types of ditches. Again, for break-even NO_3-N removal costs, we used a discount rate of 3%, 5%, and 7%, assuming a project life of 100 years, and where the value of NO_3-N removal was determined to obtain equal NPVs.

Fig. 3 shows the break-even discount rates for a TSD construction cost of $33/m for 3 different agricultural land prices and for different cleanout intervals. For land value adjacent to the ditch of $14,820/ha, and an

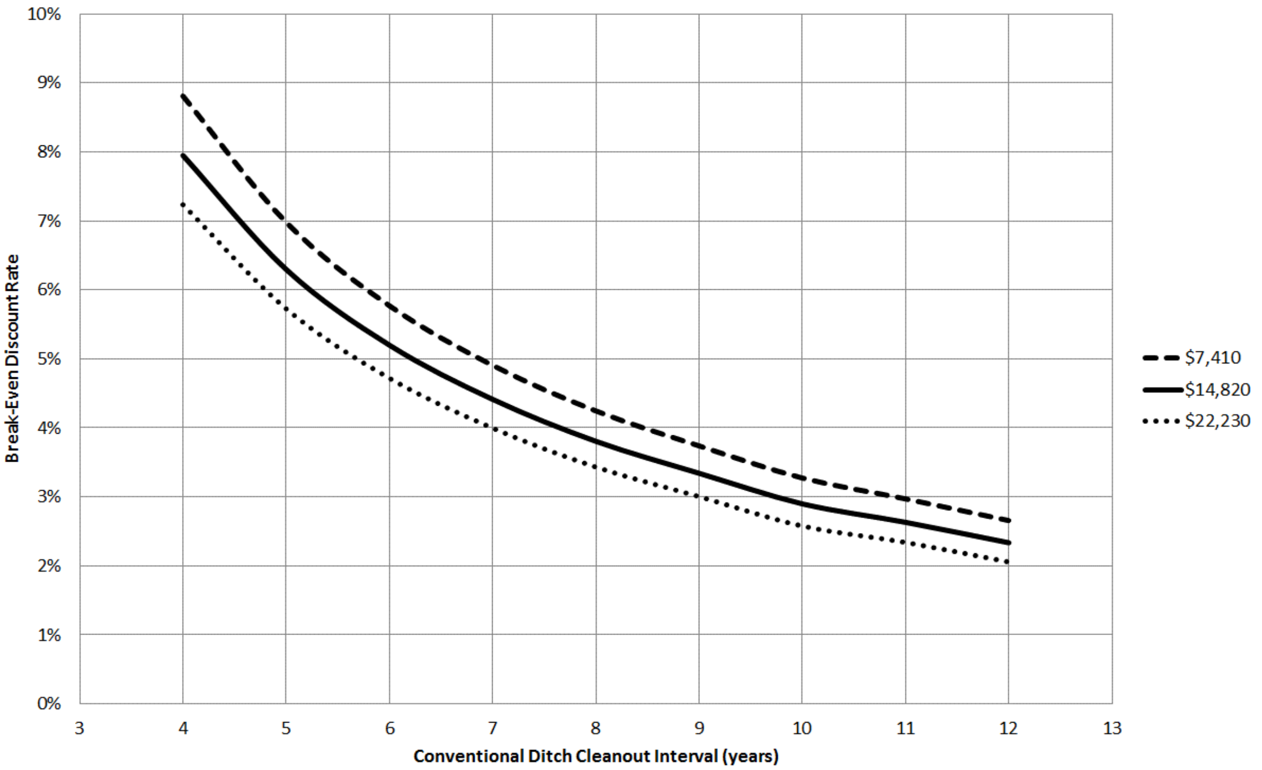

Fig. 3 Break-even discount rate vs. cleanout interval for 3 adjacent land prices ($7,410/ha, $14,820/ha and $22,230/ha) and a TSD construction cost of $33/linear m.

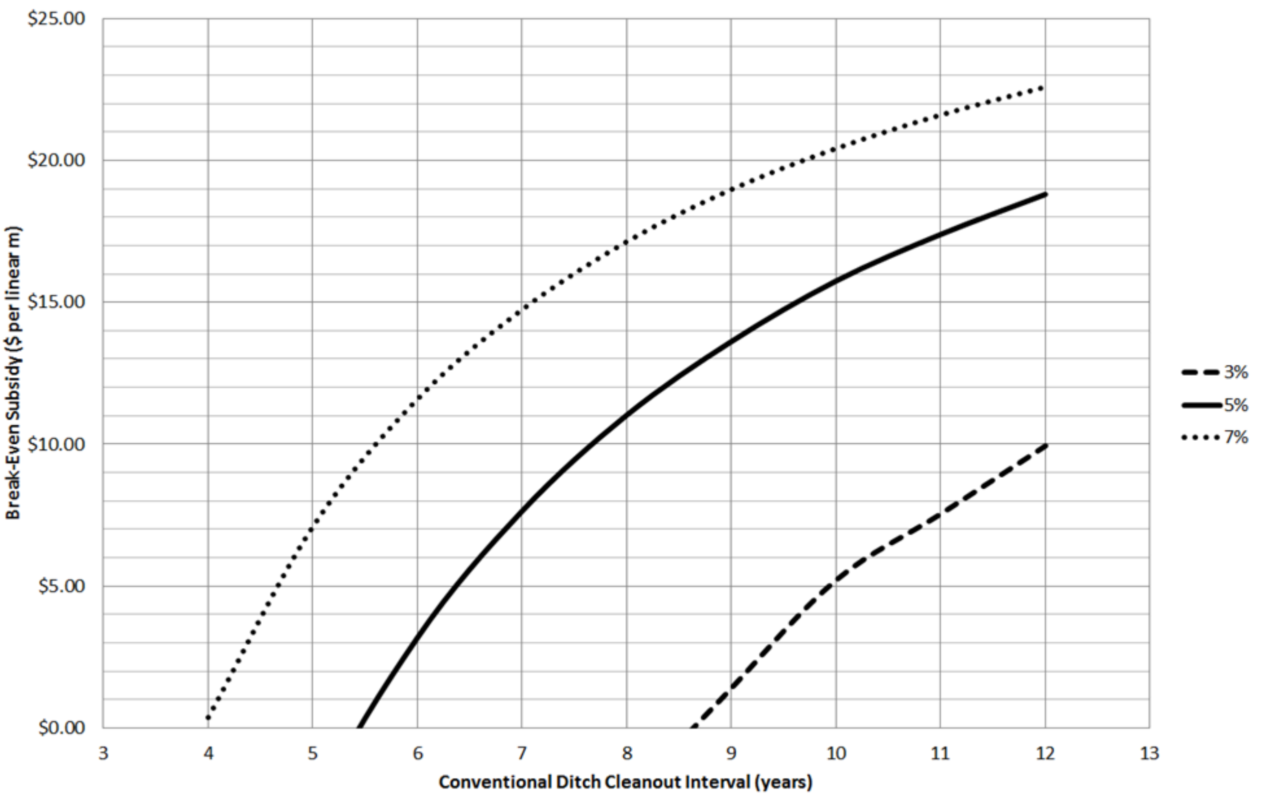

Fig. 4 Break-even subsidy as a function of conventional ditch cleanout interval for various discount rates at a TSD construction cost of $33/linear m and an adjacent land price of $14,820/ha.

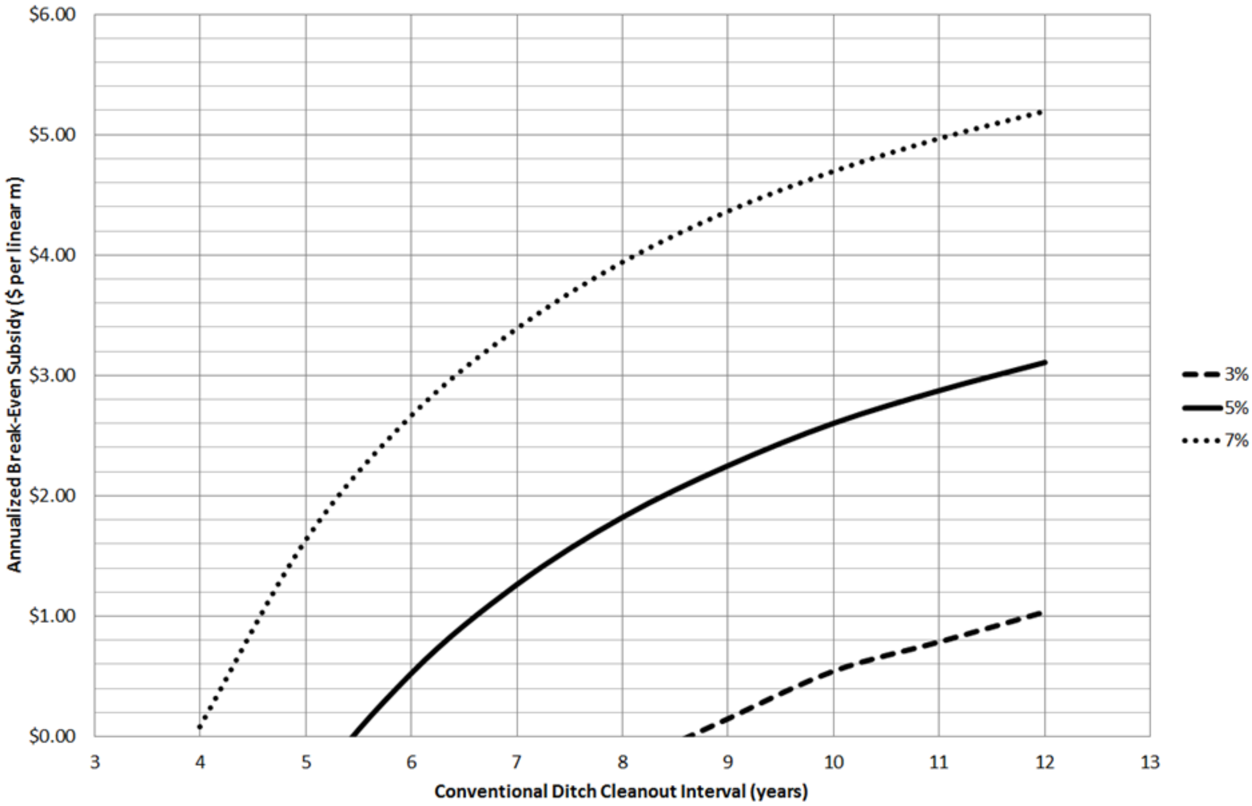

Fig. 5 Annualized break-even subsidy as a function of conventional ditch cleanout interval for various discount rates at a TSD construction cost of $33/linear m and an adjacent land price of $14,820/ha.

Table 1 Break-even NO_3-N removal costs and break-even project life for TSD constructed in various settings.

Discount rate	Cleanout interval (year)	Two-stage construction cost ($/linear m)	Annual overbank flow (days)	Break-even N removal cost ($/kg N removed at 100-year project life)	Break-even project life at N removal value of $10/kg N removed (year)
3%	7	49.21	30	$5.52	71
3%	11	32.81	30	$5.30	66
3%	12	16.40	30	$0.60	25
3%	12	32.81	100	$2.42	26
5%	6	49.21	30	$29.73	> 100
5%	7	32.81	30	$8.92	71
5%	11	49.21	10	$168.78	> 100
5%	12	16.40	100	$0.18	13
7%	5	32.81	100	$3.39	21
7%	10	16.40	100	$1.81	11
7%	12	16.40	30	$11.72	> 100

approximate conventional ditch cleanout interval of 10 years, the break-even discount rate is slightly less than 3%. This means that if a discount rate of less than this value can be achieved, the TSD will be economically feasible.

Achievable discount rates will have a large bearing on project feasibility (perhaps more so than cleanout frequency or land price), and small reductions in the discount rate may tip the economic analysis in favor of a TSD in some cases. Nevertheless, because there is considerable uncertainty surrounding the discount rate that is expected for TSD construction practices, presenting the break-even discount rate based on other factors may be especially useful for considering the feasibility of TSD projects in the future.

Based on the economic analysis, there were conditions, such as frequent ditch cleanouts, where a TSD was economically preferable to the existing conventional ditch using our initial economic model. However, TSDs have other benefits tied to reduced sediment load for stable ditches, improved water quality, and enhanced biotic habitat. The economic model was expanded to allow for the payment of subsidies for these benefits. These subsidies could offset two-stage construction costs enough to reduce the NPV of a TSD to a level below that of the existing conventional ditch.

3.2.2 Economic Analysis Results of Subsidies

Instead of assigning a value to the benefit directly, the analysis was done using a break-even subsidy. The break-even subsidy (given in $/linear m of constructed TSD) was defined as cash payment at the time of construction necessary to reduce the TSD NPV to that of the current ditch over the project life. If subsidies meeting or exceeding the break-even subsidy amount are available, the TSD will be economically preferable. To simplify the presentation of results, this analysis assumes an adjacent land value of $14,820/ha. Other costs to consider can be found in Krider et al. [6].

The break-even subsidy values for various scenarios were given in Fig. 4. For example, the break-even subsidy for a ditch with a conventional ditch cleanout frequency of 10 years is approximately $5.20/m, $15.75/m, and $20.40/m for discount rates of 3%, 5% and 7%, respectively. For a discount rate of 5%, this corresponds to a subsidy of $15,750/km.

Measurable water quality benefits may provide justification for subsidies in some cases. To demonstrate this point, the potential for water quality improvements, specifically increased NO_3-N removal [15], was estimated and used as a basis for these subsidies. To simplify the analysis, justification for subsidies is only based on NO_3-N removal. Other possible benefits tied to habitat enhancement or other water quality improvements were not considered, but clearly important to the State of Minnesota for meeting the biotic water quality goals. The analysis of the previous section was expanded here to include increased NO_3-N removal to compute the break-even NO_3-N removal cost ($/kg N removed) and break-even project life (years). This framework was particularly useful for comparing the costs of NO_3-N removal in TSDs to the costs of NO_3-N removal with other BMPs [4]. If NO_3-N removal can be achieved less expensively (i.e., more NO_3-N removed per dollar of subsidy) with a TSD than with other BMPs, a TSD will likely be economically feasible if subsidies are available.

The break-even subsidies for NO_3-N removal are essentially equivalent to the NPV of all subsidies required over the project life. However, here the cost of NO_3-N removal on an annual basis is more useful. The analysis of the previous section has been modified to determine the *annualized* break-even subsidy. Results using the alternative format are given in Fig. 5. A break-even example of the previous mentioned scenario (i = 5%, cleanout frequency of 10 years, construction cost of $33/linear m, and adjacent land value of $14,820/ha requires an annual subsidy of approximately $2.60/linear m, compared to the cash payment at construction of approximately $15.75/m.

The results of Fig. 4 allow for the calculation of NO_3-N removal costs on an annual basis. The break-even NO_3-N removal cost is determined as follows:

$$C_{NR} = \frac{S_{ABE}}{\Delta r_{NO3}} \quad (1)$$

where C_{NR} is the break-even NO_3-N removal cost ($/kg of additional NO_3-N removed in the TSD, compared to a conventional ditch), S_{ABE} is the annualized break-even subsidy as determined by Fig. 5 ($/linear m of TSD constructed), and Δr_{NO_3} is the marginal NO_3-N removal (kg N removed/linear m of two-stage channel constructed) obtained by construction of a TSD defined as

$$\Delta r_{NO3} = r_{NO3,2st} - r_{NO3,c} \quad (2)$$

where $r_{NO3,2st}$ and $r_{NO3,c}$ are the annual NO_3-N removal rates (kg NO_3-N removed/linear m) achieved with TSD and conventional ditches, respectively.

4. Discussion

This study did not determine the removal rate of NO_3-N for a conventional ditch, but used data presented in [18] to estimate Δr_{NO3}. Floodplain denitrification rates of 142 g/d and 708 g/d were reported for the 366 m ditch section in trapezoidal ditch and TSD forms, respectively. This resulted in denitrification rates of 0.39 g/d/m and 1.94 g/d/m for the trapezoidal ditch and TSD, respectively—a difference of 1.55 g/d/m. The annual number of days of overbank flow plays a major role in the estimation of annual floodplain NO_3-N removal rates [19]. Roley et al. [19] reported 29 and 132 annual days of overbank flow in 2008 and 2009, respectively, at their study site in Indiana. These data show a wide variation in the number of days of overbank flow each year. The analysis given here will focus on three scenarios: 10 days, 30 days, and 100 days (annually) of overbank flow, and the associated NO_3-N removal costs that reflect those values.

To provide useful and realistic results, sample ditch dimensions were combined with the data discussed previously to present a hypothetical ditch for calculation of NO_3-N removal costs. The *hypothetical* ditch dimensions and characteristics illustrate potential economic benefits of NO_3-N removal in TSD systems. Characteristics are purely intended as a demonstration of how accounting for additional NO_3-N removal in a TSD may positively impact the economic analysis presented previously [6].

Break-even NO_3-N removal cost obtained from Eq. (1) can be computed for a number of different scenarios (Table 1) [20]. Discount rate/TSD construction cost combinations that are economically feasible without subsidies are not included in Table 1. For low discount rates, a large number of days with overbank flow, and low TSD construction costs, the break-even NO_3-N removal costs become low, approximately ($3/kg to $4/kg of additional NO_3-N removed). Conversely, there are many situations where the break-even price of NO_3-N removal may be very high. These cases correspond to situations with high TSD construction costs, fewer annual days of overbank flow, and generally high discount rates.

Also shown in Table 1, are the calculations for break-even project life. The values for NO_3-N reduction (kg/year) were based on the annual days of overbank flow. At 100 days of overbank flow, the value for annual NO_3-N removed was $0.95/m. At 30 days, this value became $0.29/m. Scenarios with 100 days of overbank flow and $16.40/linear m of TSD construction costs produce a break-even project life of 11 and 13 years, under discount rates of 7% and 5%, respectively (Table 1). Scenarios with break-even project lives greater than 100 years have a wider range of variable attributes, including discount rates of 5% and 7%, overbank flow of 10 and 30 days, as well as $16.40/linear m and $49.21/linear m of TSD construction costs. The trend among these scenarios was the higher end discount rates and shorter span of overbank flow.

The National Science and Technology Council CENR (Committee on Environment and Natural Resources) [21] has summarized previously reported NO_3-N removal costs. Edge-of-field NO_3-N loss reduction costs were as low as $0.88/kg NO_3-N removed and show an exponential increase in removal cost as load reduction targets increase. CENR [21] also showed that a 20% reduction in NO_3-N loads could be achieved at a cost of just $0.69/kg NO_3-N removed through reduced fertilizer use alone. NO_3-N removal costs associated with wetland restoration in the Mississippi River Basin are estimated as $6.06/kg NO_3-N removed for the first half million ha restored.

5. Conclusion

The results presented here, although approximations, suggest that some TSD projects may compete with other BMPs and large-scale practices. Discount rates play a large part in determining the economic feasibility of a two-stage drainage system. Nevertheless, even at higher discount rates there are likely ditches (such as those with short cleanout intervals or low adjacent land values) that may provide the right economic conditions for cost savings and nutrient reductions through the implementation of a TSD.

UMN worked closely with the Mower County SWCD to explore better water management for Mower County. Alternative agricultural ditch designs were installed and analyzed as part of this joint effort. Alternative designs discussed included: two-stage channel, a rock trench, a rock inlet, and two bench treatment systems. The rock inlet performed well during the study period. The rock trench was ineffective largely because it was not properly located where there was substantial seepage to the ditch. The bench treatment systems were not long enough to effectively remove NO_3-N. Additional retention time was needed for all designs discussed based on results discussed in Speir et al. [15], and the selection of organic rich soil and vegetation [6]. The TSD design was very effective at this Mower County location (Fig. 2). The design was stable [12], enhanced fish habitat [13], and showed the potential for substantial NO_3-N removal based on the results reported above.

Costs and benefits for the TSD design compared to a conventional ditch were explored using assumptions developed by Kramer [20]. The construction costs of TSDs were variable but, in general, were only slightly more than the costs of the conventional ditch design. However, under certain circumstances, this TSD design could provide the benefits of a low cost per mass of NO_3-N removed similar to other low costs of NO_3-N BMPs. The ideal TSD provides the most benefits at the lowest costs. This occurs when the floodplains are inundated for long periods of time, the discount rate is low, the cleanout interval of the conventional design is short, and the two-stage channel construction costs are low. Break-even project life could be achieved for some scenarios in less than 15 years. Financial subsidies could also be used to incentivize the TSD design and encourage drainage authorities to take a closer look at the TSD option.

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