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Two-Stage Ditch Assessment using the CONCEPTS Model

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Abstract. There are approximately 21,000 miles of drainage ditches in Minnesota. Historic and current ditch design utilizes a trapezoidal cross section. Sediment deposition in trapezoidal channels results in a smaller inset channel being formed, termed a two-stage ditch, in which: 1) an inset channel conveys the bankfull flow; 2) a floodplain-like bench above the inset channel accommodates design/flood flows. Formation of two-stage channels has been observed in Minnesota’s drainage ditches. Retrofitting existing drainage ditches by over-widening the bench area or applying the two-stage concept to new ditches is expected to reduce maintenance by decreasing cleanout frequency and improve water quality and ecology. Two-stage ditches constructed in retrofit projects in Ohio have shown through limited monitoring that channel widths have not increased and floodplain bench areas have not experienced notable deposition, which are indicators of channel stability. However, channel stability must be evaluated on a long-term basis. The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) model was used to evaluate long-term channel stability and sediment transport characteristics of a 1.9 km-long ditch segment recently retrofitted with a two-stage design. The study area is in southern Mower Co., MN, one mile north of the MN/IA border. A long-term hydrograph was generated using the SWMM model, using 29 years of 15-minute precipitation data from nearby Spring Valley, MN. Results from the CONCEPTS model show that the model appears to be capable of simulating channel morphology. Site specific soil characterization is expected to improve model results.

Keywords. Drainage ditches, sediment transport, modeling, CONCEPTS
**Introduction**

Minnesota’s economy is heavily dependent upon agricultural production. Minnesota was the 4th ranked state by commodity sales for crops in 2007 (USDA, 2009). The five crops in order of acres harvested and their rank in the United States, parenthetically, was: corn (4), soybeans (3), wheat (10), forage (15), and sugar beets (11).

Minnesota’s high level of agricultural productivity can be partly attributed to the artificial drainage network that exists in much of the state (Eidman, 1997; Zucker and Brown, 1998). The extensive artificial drainage network in MN traces its beginnings back to statehood in 1858, in which the state legislature passed its first drainage act (Wilson, 2000). Since that time, thousands of miles of tile and ditch have been constructed to provide soil conditions more suitable for production of row crops like corn and soybeans. According to the MN Department of Natural Resources (DNR), there are approximately 21,000 miles of channelized streams and ditches in the state (MN DNR, 1980). Of these 21,000 miles, about 17,000 miles are public drainage ditches, which are administered according to MN Statute 103E (MN BWSR, 2006). These estimates do not include the numerous ditches governed by private drainage agreements, tile mains in public systems, or private tile that feed public systems.

This extensive drainage network requires maintenance and is accompanied by negative unintended consequences. Maintenance of ditch systems consists of removing undesirable woody vegetation, repairing damaged sections of ditch caused by large-magnitude flows, and, more commonly, cleaning out accumulated sediment to restore the ditch to its original cross section. An informal survey of four selected drainage authorities in MN indicates that ditch repair and cleanout costs can range from about $950/mile to $22,000/mile, averaged over a 5-year period, depending on the state of the ditch, additional infrastructure required as part of the repair, and the differences in ditch system maintenance programs (Peterson, 2010).

Other consequences of artificial drainage include increased nitrate export and sediment contribution to downstream waters as well as increased water yield. Blann et al. (2009) provide a very comprehensive review of the impacts of drainage on ecosystems. These authors cite numerous studies detailing increased nitrate export from the Mississippi River Basin over the last half century. Agricultural regions with extensive subsurface drainage, growing corn and soybeans, are shown to exhibit the greatest N fluxes. In Minnesota and elsewhere, subsurface drainage systems outlet into ditches or streams. Nutrient and sediment exports have broad implications in MN and elsewhere for Total Maximum Daily Load (TMDL) allocations and addressing large-scale water quality issues like hypoxia, particularly in the Gulf of Mexico (Rabalais et al., 2001; 2010) and accelerated eutrophication in Lake Winnipeg, Canada (Pip, 2006).

Drainage ditches also convey sediment to receiving waters, through in-stream processes and sediment originating from field sources. Kelley and Nater (2000) reported a 12-fold increase in sediment load from the MN river basin, a highly agricultural region with extensive subsurface drainage, over historic levels. Surface inlets to tile systems, used to drain depressional topography, provide a direct pathway for sediment and nutrients in surface runoff to enter drainage ditches (Burt Oolman and Wilson, 2003).
In-stream and bank geotechnical processes also convey sediment to downstream water resources. In stable channel systems, temporal average channel parameters (channel width, depth, slope, sediment input and output) are stationary over a long time period (approximately 10 years or more; Shields et al., 2003). Changes in channel planform and periods of net erosion and deposition are expected in what is referred to as dynamic equilibrium. Channel characteristics (width, depth) at the bankfull flow are used to describe this stable channel condition. The bankfull flow, sometimes referred to as the “channel forming” or “dominant” discharge under stable channel conditions is the representative flow from a hydrographic record that results in a stable channel’s geometry (Shields et al., 2003). The bankfull discharge is also defined as the maximum discharge before the flow overflows onto the floodplain (Copeland et al., 2001).

Agricultural ditch systems have not been designed to be stable fluvial systems; they have been designed to remove runoff from a drainage area, generally within 24 hours (NRCS, 2001). However, NRCS (1971) states that ditches must be designed such that neither degradation nor aggradation occurs. Adhering to this guidance means designing the ditch to achieve a velocity within some designated range for the maximum design discharge (NRCS, 1971). Design guidance for agricultural ditches recommends a trapezoidal cross section with side slopes ranging from 1:1 to 2:1 (H:V) under most circumstances (NRCS, 2001). Natural channels were often straightened for drainage purposes (Jayakaran and Ward, 2007). Instability in drainage ditches has been documented by numerous researchers (Christner et al., 2004; Hansen et al., 2006; Jayakaran and Ward, 2007). This instability usually takes the form of aggradation on ditch bottoms, forming small floodplain benches within the channel, with a small low-flow or pilot channel between the benches (Hansen et al., 2006; Jayakaran and Ward, 2007), resulting in what is termed a two-stage channel or ditch (Jayakaran and Ward, 2007).

Powell et al. (2006), Christner et al. (2004), and Hansen et al. (2006), and Jayakaran and Ward (2007) discuss formation of two-stage ditches through channel fluvial processes. Generally, over-widening of an agricultural ditch during construction or maintenance results in a trapezoidal channel cross section with a bottom width wide enough to create conditions conducive to channel aggradation during low-flow periods (Landwehr and Rhoads, 2003). Jayakaran et al. (2005) found that contributing drainage area was also a key factor in bench development, and that bench elevation is correlated with the bankfull flow. The recurrence interval of bankfull flow in natural streams is typically one to two years (Shields et al., 2003). Powell et al. (2006) found that recurrence intervals for bankfull flows for low-gradient rivers in Ohio ranged from 0.3 to 1.4 years. Jayakaran and Ward (2007) reported recurrence intervals of 0.2 to 0.5 years for Ohio ditches. Recognition that a two-stage ditch design may result in a self-sustaining ditch (i.e., little or no maintenance) and provide additional water quality and in-stream biota has led to design guidance and construction of two-stage ditch systems (Powell et al., 2007a and 2007b).

Powell et al. (2007b) present several case studies of two-stage ditch systems constructed in Indiana, Ohio, and Michigan. Limited data were available when published, but the authors collected three years of post-construction survey information and found little change in bench elevation and a narrowing in bankfull channel width. The narrowing of bankfull width is attributed to the originally over-wide system approaching its bankfull width. There is little literature documenting performance of two-stage agricultural ditch systems. There is continued and ongoing interest in using a two-stage ditch design to reduce maintenance costs and to improve water quality, yet very little information exists regarding long-term efficacy and design guidance is based on knowledge gained from natural streams and instances where a two-stage channel has evolved in existing agricultural ditches. The objective of this study is to evaluate the long-term sediment transport characteristics of a recently constructed two-stage ditch system in
Mower County, MN, using the CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) model (Langendoen and Alonso, 2008; Langendoen and Simon, 2008).

The CONCEPTS model simulates open channel hydraulics, sediment transport, channel morphology, and geotechnical processes of bank failure by tracking bed changes and channel widening. Bank erosion accounts for basal scour and mass wasting of cohesive banks. CONCEPTS simulates transport of cohesive and cohesionless sediments, both in suspension and on the bed, and selectively by size classes. It can predict the dynamic response of flow and sediment transport to in-stream structures.

CONCEPTS uses the Saint Venant equations, also called the dynamic wave model, and the diffusion wave model for unsteady, gradually-varying, one-dimensional, open-channel flow.

CONCEPTS recognizes that sediment transport rates are a function of flow hydraulics, bed composition, and upstream sediment supply. The rate of erosion or deposition is based upon the difference between sediment being transported and sediment transport capacity, with the relationship dependent upon whether the material is cohesive or cohesionless. Sediment transport capacity is calculated for 13 different size classes of particle.

Streambank erosion occurs in a wide variety of geomorphic contexts and is usually accompanied by changes in other morphological parameters such as channel depth, roughness, bed material composition, riparian vegetation, and energy slope. To predict the detachment of soils from the streambank, CONCEPTS uses an excess shear stress relationship developed and tested by Hanson and Simon (2001). Bank stability is analyzed based on equilibrium of forces.

**METHODS**

*Project Description*

The project site is located in Mower County, MN (Figure 1), located in the Western Lake section of the Central Lowland physiographic province. The topography is nearly level. Soils in the area comprise mainly poorly drained silty sediment over glacial till and outwash, deposited most likely prior to the Illinoian glaciation (Meyer and Knaeble, 1998). Total annual average precipitation in this region is 80 cm (31.5 in). The watershed area is 12.6 km² (3,102 acres). Land use is predominantly row crop agriculture, the main crops being corn and soybeans.

Construction of the two-stage channel occurred in the fall of 2009. The existing, privately managed, drainage ditch was in need of maintenance because of the following ditch instability issues: 1) seepage induced bank instability; 2) planar failure of ditch side slopes; 3) toe erosion; and 4) tile outlet failures. The original ditch was constructed in the historic drainage way. The dominant soil type in the ditch is a Clyde silty clay loam (Fine-loamy, mixed, mesic Typic Hapludolls). The Clyde series developed in shallow depressions and drainageways and is poorly drained with moderate permeability (NRCS, 1989). As indicated in the soil survey and evidenced in the field, this soil is typified by bands of pebbles and other course material. These bands of coarse material act as conduits, conveying water to the ditch.
The two-stage channel was designed using the spreadsheets developed by Mecklenburg and Ward (2004). Regional hydrologic curves developed by Magner and Brooks (2005) were used to estimate channel geometry. A comparison of the pre-construction cross section to the design cross section is shown in Figure 2 at four selected cross sections. The pre-construction channel bottom width generally increased from upstream to downstream, reflecting the increase in drainage area. The design cross section was not varied from upstream to downstream. The low flow design pilot channel aligns fairly well with the pre-construction channel. Moving downstream, the existing channel appears to be wider than the design cross section. As stated earlier, the channel system was fairly unstable prior to construction, exhibiting several failure points and large sand and gravel deposits. Also, a road overtopping the previous year at the upstream end of the project site had eroded a massive volume of soil, which was deposited in the lower half to one-third of the project site and downstream. Figure 2c shows evidence that a floodplain bench was being developed.
A key input to the CONCEPTS model is a user-supplied hydrograph for the upstream boundary condition. The Storm Water Management Model (SWMM; Rossman, 2008) model was selected to simulate the input hydrograph for the CONCEPTS model. As noted by Baker et al. (2004), as watersheds become smaller the use of mean daily flows masks short-term flow oscillations, which are important to capture in order to model sediment transport. Moreover, watersheds with high length to width ratios combined with row crop agriculture and low-permeability soils (Baker et al., 2004) are more prone to ‘flashy’ hydrographs. For these reasons, a model with a sophisticated hydraulic routing component operating at a sub-daily time step that was also capable of modeling rainfall/runoff was desired.

The SWMM model simulates rainfall-runoff, hydraulic routing, and water quality on either an event or continuous basis. The user can prescribe the computation time step for routing while the time step for runoff is based on the user-supplied precipitation file. The user has the option of simulating excess rainfall using the Horton, Green and Ampt, or SCS Curve Number method. Either the Kinematic or Dynamic Wave routing methods may be selected. In this case, the Dynamic Wave method was selected.

The contributing watershed was delineated into nine subwatersheds, based on hydraulic control points (i.e., culverts at road crossings) and tributary inflows (Figure 1). The SCS Curve Number methodology was selected to model excess rainfall. Curve numbers for each of the nine
subbasins were assigned an initial value of 78 for straight row crops on hydrologic soil group B in good condition (NRCS, 2004). The curve number was subsequently used as a calibration parameter. Twenty-nine years of 15-minute precipitation data from the National Climatic Data Center (NCDC) for the Spring Valley, MN site were used as input to the SWMM model.

Because there were no measured flow data to calibrate the model to, different benchmark values were prescribed based on literature and other guidance to determine whether the modeled hydrograph was a reasonable representation of that system (Table 1). The key water balance characteristics of annual surface runoff volume, water yield, and evapotranspiration were used to calibrate modeled water balance. Because there are scarce data documenting measured water yield from tile drainage, simulated water balance characteristics from Luo et al. (2010) were used as an additional check, particularly on drainage water yield. Luo et al. used a calibrated DRAINMOD (Skaggs, 1978) model with a 90-year climate record to model different artificial subsurface drainage scenarios. Their study site was located in Waseca, MN, which is approximately 95 km from the project site, making hydrologic comparisons between the two areas apt. Results from their ‘conventional drainage’ scenario are used for comparison purposes.

Modeled flow rates from SWMM were calibrated to represent typical peak flow rates from a watershed of this size and characteristics by calibrating to estimated peak discharges (Lorenz et al., 1997) and by using knowledge of tile inlets to the system to estimate tile discharge capacity. The size of each tile inlet in the study area was noted. Assuming a grade of 0.5%, which approximates the land surface grade, the capacity of each tile in the study area was estimated. Peak flow rates from groundwater discharge (i.e., tile flow) over the 29-year simulation period were then compared to the tile capacity. Contribution of tile flow to peak flow rate was determined two ways: 1) by summing the capacity of individual tile lines entering the system; and 2) determining the maximum contribution based on drainage coefficient.

**CONCEPTS Model**

The CONCEPTS model requires data describing the physical layout of the channel network, soil characteristics, boundary conditions, and user-defined options. As mentioned previously, the dimensions of the two-stage channel were determined based on the regional hydrologic curves developed by Magner (2005). This cross section shape and its design profile were used as input to the model. Forty four cross sections were used to represent the 1,896-meter channel. Channel roughness, represented by Manning’s ‘n’ values were set to 0.035 for floodplain and 0.025 for the channel section.

Soil particle size distribution information was derived from the Mower County Soil Survey (NRCS, 1989). The soil survey provides representative values for percent of material passing the 4, 10, 40 and No. 200 sieves (4.75, 2.0, 0.425, and 0.075 mm, respectively). Also provided are representative values of percent clay and percent of fragments in the 76 – 254 mm range. These data were plotted to develop a percent finer versus particle size relationship. The CONCEPTS model requires the percent finer at 17 different particle classes. The percent finer for each of these particle sizes was determined using the curves developed based on the soil survey information. Particle density was assumed to be 2.6 g cm$^{-3}$. Porosity was estimated based on the representative values for bulk density provided in the soil survey.

Parameter values for soil cohesion, friction angle, and suction angle were assigned based on recommended values for different textural classes contained in the model documentation.

The CONCEPTS model allows one to simulate soil detachment using on excess shear or Shield’s approach by prescribing the percent fines below which the soil is considered to be
eroded based on its gravimetric resistance to flows. Above this value erosion is modeled using an excess shear approach.

There are numerous methods to estimate critical shear stress and erodibility. Clark and Wynn (2007) compared some of these methods to measured critical shear and erodibility and discussed implications for erosion rate predictions. They found that the $\tau_c$ values were greater than estimated values, with the exception of the Julian and Torres (2006) method. Clark and Wynn did not evaluate the method of Temple et al. (1997). Estimates of $\tau_c$ were developed for the predominant soil type, Clyde, at the lowest soil layer, since material from this layer likely forms the substrate of the channel bottom, using the $I_w$ and $D_{50}$ methods of Smerdon and Beasley (1961), the SC method of Julian and Torres, and method of Temple et al. (1997). These methods yielded estimates ranging from 1.98 to 13.91 Pa. The Temple et al. (1997) method, which uses plasticity index and void ratio for different ASTM soil classifications, provided values ranging from 3.35 to 5.08 Pa, using the mid and high value plasticity index values from the soil survey. Based on the authors’ experience, this range appeared to be reasonable based on the site conditions.

RESULTS AND DISCUSSION

SWMM Hydrograph Development

Table 1 shows key benchmark hydrologic water balance characteristics and results from the current study. The greater average precipitation in this study reflects a wetter period in 1971–1999 than 1940-1969 in the case of Farrell et al. and Baker et al. and a slightly different geographic setting than Luo et al. The average annual modeled water yield was 162 mm, or 20 percent of average annual precipitation, which is in agreement with the measured values of Farrell et al. and Baker et al. and the modeled results from Luo et al. (Table 1). The ET estimate from Farrell et al. is simply the balance of precipitation minus water yield.

Table 1. Average hydrologic characteristics for southern Minnesota based on measured and modeling studies.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Mag (mm)</td>
<td>% Precip</td>
<td>Mag (mm)</td>
<td>% Precip</td>
</tr>
<tr>
<td>Precipitation</td>
<td>770</td>
<td>780</td>
<td>779</td>
<td>829</td>
</tr>
<tr>
<td>Infiltration (mm)</td>
<td>756</td>
<td>97</td>
<td>715</td>
<td>86</td>
</tr>
<tr>
<td>Water Yield (mm)</td>
<td>150</td>
<td>19</td>
<td>155</td>
<td>20</td>
</tr>
<tr>
<td>Drainage</td>
<td>129</td>
<td>17</td>
<td>135</td>
<td>16</td>
</tr>
<tr>
<td>Surface Runoff</td>
<td>26</td>
<td>3</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>620</td>
<td>81</td>
<td>625</td>
<td>80</td>
</tr>
<tr>
<td>Other Losses (mm)</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Water yield + ET total more than 100% because ET estimates were independently estimated

Table 2 and Table 3 show tile drainage system capacity estimated based on summing individual inlet pipes and drainage coefficient, respectively. These estimates involve several assumptions but serve as a realistic guide for the amount of tile drainage entering the system. Table 2 indicates the drainage system has a capacity of greater than a 25.4 mm (1 in) drainage coefficient. Most installers in this area of Minnesota use a 9.5 mm (3/8 in) drainage coefficient.
(Morrison, 2010, personal communication). Farmers outletting to this ditch likely opted for a slightly higher drainage coefficient, necessitating higher capacity outlets. The modeled peak annual groundwater discharge ranged from 0 to 0.37 m$^3$s$^{-1}$ with a mean of 0.19 m$^3$s$^{-1}$. These results seem to be consistent with our knowledge of the system. The preceding results are from subwatershed 3, which contains the two-stage ditch reach. The parameters in SWMM controlling groundwater flow were modified similarly for the other subwatersheds upstream, which have similar extents of artificial subsurface drainage (Morrison, 2010, personal communication).

Table 2. Inlet drainage tile flow capacity determined based on the assumption of 0.5% grade and Manning’s ‘n’ of 0.017.

<table>
<thead>
<tr>
<th>Tile Size (cm)</th>
<th>Tile Flow Capacity (m$^3$s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.06</td>
</tr>
<tr>
<td>30</td>
<td>0.06</td>
</tr>
<tr>
<td>20</td>
<td>0.02</td>
</tr>
<tr>
<td>15</td>
<td>0.01</td>
</tr>
<tr>
<td>30</td>
<td>0.06</td>
</tr>
<tr>
<td>15</td>
<td>0.01</td>
</tr>
<tr>
<td>20</td>
<td>0.02</td>
</tr>
<tr>
<td>15</td>
<td>0.01</td>
</tr>
<tr>
<td>25</td>
<td>0.03</td>
</tr>
<tr>
<td>20</td>
<td>0.02</td>
</tr>
<tr>
<td>30</td>
<td>0.06</td>
</tr>
<tr>
<td>15</td>
<td>0.01</td>
</tr>
<tr>
<td>61</td>
<td>0.29</td>
</tr>
<tr>
<td>20</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.67</strong></td>
</tr>
</tbody>
</table>

Table 3. Tile capacity based on drainage coefficient.

<table>
<thead>
<tr>
<th>Drainage Coefficient (mm)</th>
<th>Flow Rate (m$^3$s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4 1/4</td>
<td>0.14</td>
</tr>
<tr>
<td>9.5 3/8</td>
<td>0.21</td>
</tr>
<tr>
<td>12.7 1/2</td>
<td>0.28</td>
</tr>
<tr>
<td>15.9 5/8</td>
<td>0.35</td>
</tr>
<tr>
<td>19.1 3/4</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>25.4</strong></td>
<td><strong>0.55</strong></td>
</tr>
</tbody>
</table>

Lorenz et al. (1997) provide guidance for estimating peak flows on small streams in Minnesota. Estimates of peak flow for 2-, 5-, 10-, 25-, 50-, and 100-year return periods were developed using regression equations developed by Lorenz et al. (1997) given drainage area and slope of main channel length. Those estimates are plotted in Figure 2 with SWMM-modeled annual peak flows and associated return periods. The modeled estimates of peak flow generally appear to agree with the estimates using the methods of Lorenz et al. for return periods of 10 years and less. Because there are only 29 years of simulated data, estimates of peak flow for less frequent...
events should be viewed with some skepticism (Haan et al., 1994). Thus, it appears that the SWMM-modeled flows are representative of annual peak flows for a watershed with this given set of characteristics.

Figure 2. A comparison of SWMM-modeled annual peak flows to estimated peak flows based on regional regression equations of Lorenz et al. (1997).

Two-Stage Channel Assessment using CONCEPTS

There were no measured sediment yield data with which to calibrate the model. The Minnesota Department of Natural Resources has been monitoring flow and total suspended solids (TSS) as part of a paired watershed study nearby. The two watersheds being monitored for that study are approximately 20-km away and have very similar land use and management to the watershed in this study. Preliminary monitoring results for 2009 from the paired watershed study show the average TSS exiting the 2,412-ha watershed to be 226 kg ha\(^{-1}\). The CONCEPTS-modeled portion of sediment < 0.025 mm exiting the watershed was estimated to be 76 kg ha\(^{-1}\) yr\(^{-1}\). The comparison between TSS and suspended sediment concentration (SSC) becomes less meaningful as SSC concentration increases (Gray et al., 2000).

CONCEPTS-simulated changes in channel profile and top of bank over the 29-year simulation period are shown in Figure 3. The model has the option of setting the downstream cross section as unerodible, meaning that the downstream-most cross section cannot be eroded. This option was selected because the grade at the downstream end is controlled by twin 3.05 by 3.05 meter box culverts. No such control was present at the upstream end, though there is a grade control at the upstream end provided by a 2.1 meter wide by 2 meter high arch culvert. The model can still provide information on channel morphological changes, however. As shown in Figure 3, the design channel profile consists of 4 different channel grades, with the most downstream consisting of a relatively steep segment (0.22% compared to overall grade of 0.187%). This relatively steep segment reflects the fact that the design profile was superimposed over the surveyed profile. The last segment exhibited rock riffle structure immediately upstream of the
culvert, in keeping with a steeper, higher velocity channel section. However, the channel was
modeled by assuming a homogeneous channel substrate of a sandy clay loam soil. This last
segment was eroded in the model simulation, with a trend towards flattening the last segment.
Also of interest is the change in the top of bank relative to the channel thalweg. The model
simulates continued deposition on the floodplain bench over the course of the simulation, with
generally greater deposition depths with downstream distance. Average deposition over the
length over the channel is approximately 1.8 meters on the upstream end over the 29-yr
simulation and tapers towards about 1 meter of deposition on the downstream end. The
simulated deposition on the floodplain bench is greater than is expected intuitively. The
upstream sediment boundary condition was set such that the incoming flow transported 10% of
transport capacity for each of the different particle size classes. This assumption may have
introduced an excessive amount of sediment to the system.

![Figure 3](image)

Figure 3. Channel and average top of bank profile over time.

As stated previously, the assumption of a homogeneous stream bed and floodplain was made.
The CONCEPTS model tracks particle size distribution at each modeled cross section. Figure 4
shows how the median particle diameter, $D_{50}$, changes over the length of the channel profile at
selected points in time. The bed material generally coarsens with distance, reaching a maximum
median diameter at 13+00, which is immediately upstream of the flattest segment of the
channel. When the actual drainage channel was constructed in 1975 it was designed at a
uniform grade of 0.16%. From that time until the recently-completed construction, channel has
slightly degraded, to a average slope of 0.187%. The twin box culverts at the downstream end
were installed within the last year, before that a bridge was in place, allowing the channel
bottom to degrade. As noted earlier, the channel immediately upstream of the downstream
section exhibited a riffle section, which is what the CONCEPTS model is predicting.
Changes in channel cross section at selected stations over the course of the model simulation are shown in Figure 5. These cross sections confirm what was shown in Figure 3; channel incision is greatest in the upstream portion of the channel and becomes progressively less downstream. Coarser material is deposited as the channel becomes flatter near STA 15+00. This coarser material also helps to armor the bed, reducing the amount of incision further downstream. The cross sections in Figure 5 indicate that no modeled bank failures occurred, though the model was set to simulate this process. Further investigation to determine the why the model is not properly simulating bank failure will be conducted.
SUMMARY AND CONCLUSIONS

The CONCEPTS model, coupled with the SWMM model, was used to evaluate the long-term sediment transport dynamics, and associated channel morphology, on a recently constructed two-stage agricultural ditch in southern Minnesota.

Twenty-nine years of 15-minute precipitation data were used to drive the SWMM model. Long-term simulated water balance components were in good agreement with regional estimates and other modeling studies. Peak flows and associated return intervals for the modeled flows were in agreement with estimates of peak flows using regionally developed regression equations for small streams.

Soil and sediment properties used by the CONCEPTS model were estimated using county soil survey information. While these data are entirely reasonable, it is obvious that within-reach variability is not accurately represented.

Part of our ongoing project work will aimed at better characterization of project site soils and sediments, specifically particle size distribution, shear stress and erodibility. A better understanding of upstream sediment contribution to the project reach will also help to improve modeling results.
Acknowledgements

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