IMPROVEMENT IN FLUVIAL MODELLING TO SUPPORT THE ASSESSMENT AND RESTORATION OF RIVER REACHES WITH ERODED BANKS

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DIVERSITY OF ALLUVIAL RIVER CHANNELS

STRUCTURES & FEATURES
» single/multiple threads
  cut off channels / islands
  abandoned channels
  bed forms
» spatial and temporal scales
» factors affecting planform
  soil composition
  sediment supply
  vegetation
  geological constraints
  slope

RIVER DYNAMICS
» key aspect of biodiversity
» adopt sustainable strategies
  improve restoration success
  Invest public money wisely
GAPS IN KNOWLEDGE

MEANDERING MODELS
» not well suited for real-life applications
» river complexity ignored
  lack of floodplain topography and plants
  no ephemeral/paleo/secondary channels
  regular planform and cross-section geometry
» weak physics
» unrealistic simulated patterns

KNOWLEDGE GAPS
» between local and large scales
» engineering scale
» unclear contribution of soil and plant properties

natural river 1D 2D with body-fitted coordinate system
THEORETICAL OBJECTIVES
1. determine the sensitivity of river retreat to biophysical conditions
2. verify if sensitivity varies between two reaches
3. evaluate the approach in terms of adequacy and purpose

TECHNICAL OBJECTIVES
1. verify if predictions differs between CFD models
2. establish a novel approach to simulate lateral retreat in a multi-threaded river channel
3. evaluate the developed coupled model using datasets from rivers
4. devise a statistical calibration method
## Studied River Reaches

<table>
<thead>
<tr>
<th>Site</th>
<th>Width</th>
<th>Soil</th>
<th>Vegetation</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. François River (Qc)</td>
<td>210 m</td>
<td>Sand, silt</td>
<td>Mixed</td>
<td>Mixed</td>
</tr>
<tr>
<td>Medway Creek (On)</td>
<td>20 m</td>
<td>Till, sand, gravel</td>
<td>Mixed</td>
<td>Forested</td>
</tr>
</tbody>
</table>
REACH#2 – ST. FRANÇOIS RIVER (SF)
BANK RETREAT MONITORING

2 YEARS

3 YEARS

River bed
Erosion type
- Non-monitored
- None
- Fluvial
- Geotechnical
- Combined
PURPOSE

» determine which model(s) can be used to accomplish research objectives

TELEMAC-2D V6.3

» good agreement with observations
» fixed- and mobile-bed simulations
» open source & free
A NEW MORPHODYNAMIC MODEL

PROCESSES NEEDED
» slope stability
» ground water dynamics
» vegetation growth
» physics-based

IMPLEMENTATION & TESTING
» within TELEMAC-2D v7.0
» scalar or parallel processing (MPI)
» efficient data structure
» 35,000 lines (Fortran 90)
» ~2 years of development

Integration of a geotechnical model within a morphodynamic model to investigate river meandering processes

Y. V. Rommerse & M. J. van de Wiel
Department of Geography, The University of Western Ontario, London, Canada.

Abstract: Despite significant progress made in the research conducted to understand the morphodynamics of meandering rivers using computer models, a number of challenges and limitations remain with respect to simulating both lateral and channel adjustments. In particular, some hydrological processes critical to bank erosion, e.g., bank erosion and vegetation, are often simplified or ennumerated, which renders the simulation of bank erosion processes problematic. In this context, the development of a new geotechnical model to simulate bank erosion and vegetation processes is proposed. The objectives of this project are to meet these challenges. The new model incorporates a number of innovative features that include the use of a new algorithm for simulating the interaction between vegetation growth and sediment transport, the use of a new algorithm for simulating the interaction between channel and bank erosion, and the use of a new algorithm for simulating the interaction between vegetation growth and bank erosion. The new model allows for the simulation of bank erosion processes and vegetation growth processes to be simulated in a single model. The model is validated against a number of laboratory experiments and field observations.

1. Introduction
1.1. Movement dynamics
The characteristics of the flow field and sediment transport patterns in meandering rivers are fairly well understood due to the observations made over decades in flume, field, and numerical experiments. For instance, experimental investigations by Jordan et al. (1968), Strickland et al. (1970), and Thorne et al. (1994, 1995) and numerical simulations by Holdahl et al. (2000) and Lowery et al. (2003) have demonstrated the existence of a meandering flow in meandering channels. The dynamics of these systems have been described by a number of researchers. The meandering flow patterns observed in nature are pacing (Girton & Moran, 2012) and correspond to the knowledge gaps in river meandering processes. Processes and features described here have been historically left out of the literature on studies pertaining to meandering morphodynamics, and flow patterns and processes (Proctor & Semmens, 2011, Girton & Moran, 2012).

1.2. Morphodynamics modeling
River meandering morphodynamics has been studied using numerical models for many years (e.g. Strickland et al. 2013). While certain features of this type of system were reproduced in certain cases, some issues remain. Firstly, the idealized mudflats developed through numerical simulations differ from those observed in nature. The latter being flat, regular, and linear. This can be partly explained by the fact that many numerical models of meandering rivers focused on the formation of channel meanders in the virtual environment, which may also indicate that the available models are not

Implementation of geotechnical and vegetation modules in TELEMAC to simulate the dynamics of vegetated alluvial floodplains

Yamani Y. Rommerse, Marco J. Van de Wiel
Department of Geography, The University of Western Ontario, London, Canada.

2. Methods
2.1. Model development
The model development is based on the implementation of a new module for simulating bank erosion and vegetation growth processes. The development of this module is based on the following steps:

(a) Development of a new algorithm for simulating the interaction between vegetation growth and sediment transport
(b) Development of a new algorithm for simulating the interaction between channel and bank erosion
(c) Development of a new algorithm for simulating the interaction between vegetation growth and bank erosion

The new algorithm incorporates a number of innovative features that include the use of a new algorithm for simulating the interaction between vegetation growth and sediment transport, the use of a new algorithm for simulating the interaction between channel and bank erosion, and the use of a new algorithm for simulating the interaction between vegetation growth and bank erosion. The new model allows for the simulation of bank erosion processes and vegetation growth processes to be simulated in a single model. The model is validated against a number of laboratory experiments and field observations.
SLOPE STABILITY

» factor of safety (Fs) to quantify slope stability

\[
F_s = \frac{\text{resisting forces}}{\text{driving forces}}
\]

If \( F_s < 1 \): slope failure
If \( F_s \geq 1 \): stable slope

METHOD OF SLICES

» based on Bishop (1955)
» solution obtained by iteration
FAILURE MODES

GENETIC ALGORITHM
» locate failure plane efficiently
» tournament selection
» optimization of genetic diversity
  cross-over with matching rules
  mutation
  immigration
  disease, mortality

PLANAR
Supported

ROTATIONAL
Supported

IRREGULAR
Supported

OVERHANG
Not supported
VECTOR-BASED SPATIAL ANALYSIS
» edge detection (water)
» direction of steepest ascent

EXTENT OF ZONE AFFECTED BY A FAILURE
» maximum erosion/deposition along transect
» affected mesh nodes within ellipse
MODEL FIT

PURPOSE
» statistically-based quantification of overall model fit
» compare observations with predictions
» identify spatial variations in fit

YOUDEN’S INDEX
» occurrence of failures along transects
» +1 (perfect fit) to -1 (bad fit)

\[
J = SN \\
J = SP - 1 \\
J = SN + SP - 1 \\
SN = \frac{TP}{TP + FN} \\
SP = \frac{TN}{TN + FP}
\]

CONFUSION MATRIX

<table>
<thead>
<tr>
<th></th>
<th>Failure NOT predicted</th>
<th>Failure predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure NOT observed</td>
<td>TN</td>
<td>FP</td>
</tr>
<tr>
<td>Failure observed</td>
<td>FN</td>
<td>TP</td>
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</table>
EXP#1 – CALIBRATION FOR A NATURAL REACH

EXPLORATION
» examine behaviour using machine learning

COUPLED MODEL
» hydraulics, transport, erosion, vegetation

ANALYSIS
» based on safety factor at transects
» quantification of fit using Youden’s $J$

RESULTS
» retreat location and extent well predicted
» over-prediction of river failures with GTC
» plants increase stability
EXP#2 – COMPARISON BETWEEN 2 NATURAL REACHES

SAME AS EXPERIENCE #1, BUT...

» vegetation module disabled
» assessment based on retreat at transects
» two experiments in parallel

CONTRASTED NATURAL RIVER REACHES

» St. François River, Quebec
» Medway Creek, Ontario
EXP#2 – PARAMETER EXPLORATION

KEY POINTS

» *bank height* \((h)\) and *angle* \((\alpha)\): key morphological parameters

» *cohesion* \((c)\) and *friction angle* \((\phi)\): key geotechnical parameters

» *flow depth* more important for SF than MC

» *bank height* more important for MC than SF

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Importance (Gini)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Morphological</strong></td>
<td></td>
</tr>
<tr>
<td>(h)</td>
<td>2807</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>1924</td>
</tr>
<tr>
<td>(h_{FS})</td>
<td>216</td>
</tr>
<tr>
<td>(h_{WT})</td>
<td>81</td>
</tr>
<tr>
<td><strong>Geotechnical</strong></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>1900</td>
</tr>
<tr>
<td>(\phi)</td>
<td>1552</td>
</tr>
<tr>
<td>(\rho)</td>
<td>182</td>
</tr>
<tr>
<td><em>compaction</em></td>
<td>84</td>
</tr>
</tbody>
</table>

\[ \rho = 1950 \, \text{kg/m}^3 \]
\[ \Phi = 9.2^\circ \]

\[ \rho = 2100 \, \text{kg/m}^3 \]
\[ \Phi = 40.0^\circ \]
EXP#2 – CALIBRATED MODELS

50.2%

58.7%

25.0%
EXP#2
FIT
ST. FRANÇOIS RIVER

PARAMETERS SETS

<table>
<thead>
<tr>
<th>Cohesion (c, kPa)</th>
<th>0.125</th>
<th>0.250</th>
<th>0.375</th>
<th>0.500</th>
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</thead>
<tbody>
<tr>
<td>Friction angle (ϕ, °)</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Parameter set</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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EXP#2
FIT
MEDWAY CREEK

<table>
<thead>
<tr>
<th>Cohesion (c, kPa)</th>
<th>0.125</th>
<th>0.250</th>
<th>0.375</th>
<th>0.500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction angle (ϕ, °)</td>
<td>30 35 40</td>
<td>30 35 40</td>
<td>30 35 40</td>
<td>30 35 40</td>
</tr>
<tr>
<td>Parameter set</td>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
<td>10 11 12</td>
</tr>
</tbody>
</table>
EXP#2 –
HETEROGENEITY
VS. FIT

much higher river bank
non cohesive (top) and glacial till (bottom)
abandoned channel and pond nearby
well sorted material
# EXP#2 – MACHINE LEARNING VS. COUPLED MODEL

## MACHINE LEARNING

<table>
<thead>
<tr>
<th>Sub-reach</th>
<th>c</th>
<th>ϕ</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td>0.5 – 1</td>
<td>10</td>
<td>23.3</td>
</tr>
<tr>
<td>MC&lt;sub&gt;A&lt;/sub&gt;</td>
<td>0.1 – 5</td>
<td>10 – 40</td>
<td>0.0</td>
</tr>
<tr>
<td>MC&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.1</td>
<td>30</td>
<td>47.0</td>
</tr>
<tr>
<td>MC&lt;sub&gt;C&lt;/sub&gt;</td>
<td>0.5</td>
<td>10</td>
<td>8.3</td>
</tr>
<tr>
<td>MC&lt;sub&gt;D&lt;/sub&gt;</td>
<td>0.1</td>
<td>40</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>30</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>20</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>10</td>
<td>0.0</td>
</tr>
</tbody>
</table>

## COUPLED MODEL

<table>
<thead>
<tr>
<th>Sub-reach</th>
<th>c</th>
<th>ϕ</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td>0.125</td>
<td>20</td>
<td>50.2</td>
</tr>
<tr>
<td>MC&lt;sub&gt;A&lt;/sub&gt;</td>
<td>0.500</td>
<td>30</td>
<td>25.0</td>
</tr>
<tr>
<td>MC&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.250</td>
<td>35</td>
<td>58.7</td>
</tr>
<tr>
<td>MC&lt;sub&gt;C&lt;/sub&gt;</td>
<td>0.500</td>
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<td>0.0</td>
</tr>
<tr>
<td>MC&lt;sub&gt;D&lt;/sub&gt;</td>
<td>1.000</td>
<td>40</td>
<td>0.0</td>
</tr>
</tbody>
</table>

## KEY POINTS

» better fit with the coupled model for SF, MC<sub>A</sub> and MC<sub>B</sub>

» the coupled model accounts for the interaction between processes
REAL-LIFE ISSUES

» examine fluvial and geotechnical processes simultaneously
» compatibility with natural rivers
  single and multi-threaded channels
  lateral retreat and vegetation
  cohesive soil or not
» pre- and post-processing techniques
  calibration using machine learning
  statistical assessment of fit

RESEARCH-WISE

» a new framework to examine channel evolution
» behaviour of various river channels
CHALLENGES OF THE APPROACH

» large data requirement for calibration
  parameters related to flow, sediment, soil material, plants
  long temporal scale

» complexity of the concepts involved

IMPROVEMENTS TO THE MODEL

» more user-friendly (model, calibration, analysis, documentation)
» integration of machine learning into the model
» adaptive mesh
» automatically calculate retreat

SOLVED AUTOMATICALLY

» increase computation power
» data availability
  LiDAR
  airborne imagery
FIELD WORK PLANNING AND EXECUTION

Dr. Nathaniel Bergman  Renee Lazor
Dr. Eric Desjardins (UWO)  Dr. Francisco Flores-de-Santiago
Dr. Mohammad Reza Jelokhani Niaraki

DATA

Dr. Claudine Boyer  Michèle Tremblay

SUPPORT

Dr. Pauline Leduc  Mélanie Langlois
Dr. Roberta Bgeginski  Dr. Micha Pazner
Lisette Girard, Jean-Paul and Marie-France Rousseau