Representation of Spatial Heterogeneity in the Land-Surface Hydrologic Model MESH

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# Acknowledgements

I wish to thank the following people for their generous support in the success of this project:

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Dan Princz, Environment and Climate Change Canada, for taking time out of his busy schedule to provide training, advice, and support for the modelling portion of the project. Without his assistance, this project would not have been possible.

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My family, for their support in my completion of this Master’s program. To my husband, for taking on a larger share of our the household responsibilities, for giving me the time and space to study, and for providing encouragement and soundboarding. Also to my children, Ben and Lucy, for the joy they exude which helped me especially during the difficult times during this process. Also to my parents and in-laws for providing childcare and moral support.

# Executive Summary (10%)

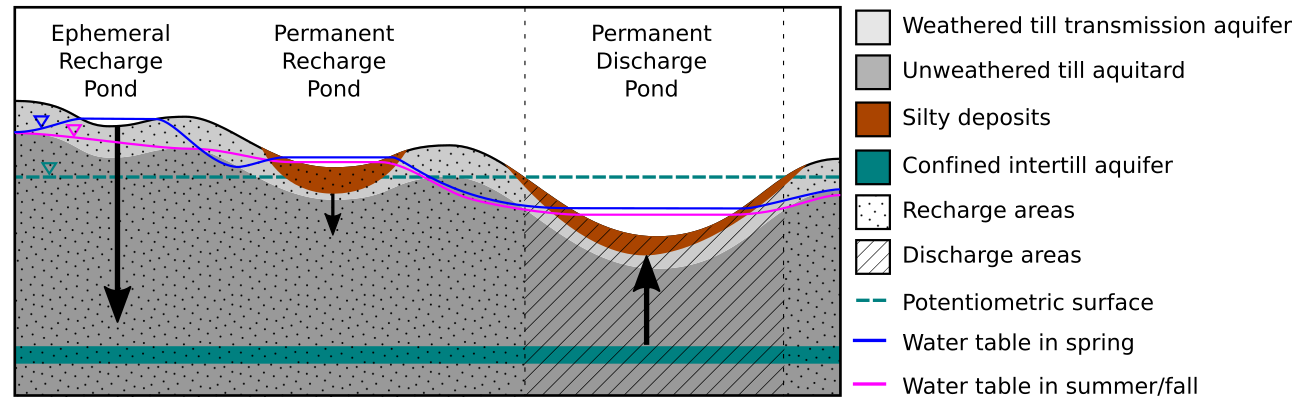
Hydrological modelling is an exercise which seeks to digitally replicate the analogue behaviour of a watershed. Hydrological models can be very useful

The purpose of this project is to examine and compare various ways of representing spatial heterogeneity in the Baker Creek Watershed (NWT) using the MESH model. MESH (Modelisation Environmentale Communautaire (MEC) - Surface and Hydrology) is a model which couples a land-surface scheme (LSS), which represents the vertical movement of water and energy between the atmosphere and earth’s surface and subsurface, and a hydrological model, which characterizes the movement of water horizontally over the land as well as through the soil (REFERENCE). MESH was developed by Environment and Climate Change Canada (ECCC) for the purposes of streamflow forecasting, building on the model WATCLASS, which coupled the CLASS and WATFLOOD models (Pietroniro et al., 2007). MESH allows the modeller to select from a number of LSSs as well as hydrological routing methods. The MESH model is continually under development by ECCC and by researchers at the Global Institute for Water Security (GIWS) at the University of Saskatchewan, with improvements to the code and additional process representations being tested and added (University of Saskatchewan, 2019). For this project, the Canadian Land Surface Scheme (CLASS) and WATROUTE options were utilized within MESH.

The project was completed in X stages: 1.

Assume that 90% of readers in future will only read this – must summarize the problem, what you did, how you did it, what you found, and what still needs to be done.

You are encouraged to create and include here a graphical abstract - that is a diagram that summarized what you did in your project. Create the image in powerpoint, inkscape or the software of your choice, save as a png file with 300 dpi, and include the figure with the following command:

 Pictures to add: - Photo of the watershed, graphical abstract

# Introduction

Scientific research in the field of hydrology is continually seeking to better understand, predict, and model the movement of water throughout the earth. This research is important in a plethora of applications with great importance to society. For instance: better prediction of floods and droughts opens the doors for better management of watersheds with respect to impacts to water supplies, agricultural land, critical infrastructure, etc. A better understanding of the fundamentals of the various aspects of the water cycle can help us predict the possible impacts of a variety of changes - namely direct human impacts, and a changing climate. The fundamental purpose behind all of this is to improve the well-being of humankind, both now and into the future, as it relates to our interaction with water - which touches every aspect of our daily lives.

What is spatial heterogeneity? In the context of hydrology and, more specifically, hydrological modelling, it is the small- and large-scale variations in the characteristics of the watershed that affect the storage and movement of water and energy. Spatial heterogeneity is the variation in the characteristics of the soil type, soil structure, land slope and aspect, surface conditions, vegetation characteristics, properties of streams, lakes, rivers, and aquifers. There is also an incredible amount of spatial variabilty within the meteorological conditions (i.e. precipitation, wind, solar radiation, humidity, temperature, and air pressure).

## Problem background

There is an ongoing debate in the field of hydrology related to the best method of representing a waterhsed in the model and the required level of complexity. With limited input and validation data, time, computational resources, watershed characteristic information. The degree to which watershed characteristics are represented individually, or lumped into “effective” parameters, and the resulting effect on mondel performance. How complex is “good enough”?

In 2017, a Master’s of Water Security student at the University of Saskatchewan completed a project which explored the affect of different representations of spatial heterogeneity in the White Gull Creek watershed in Saskatchewan using the MESH model (Mkandla, 2017). The purpose of this project was to replicate that methodology in the Baker Creek, NWT, watershed to see if the same conclusions would results, and then to take the work further. What follows is a summary of the Mkandla report.

The purpose of the Mkandla project was to compare the model performance under a number of different representations of sub-grid spatial variability in the MESH model. The model configurations ranged from relatively simple - considering areal-averaged forcing data and model parameters - to more complex setups which considered distributed forcing data and parameters. The results of the experiment showed that the performance of the model improved with increasing spatial heterogeneity in the model setup, and more distributed configurations resulted in less spread among the calibrated runs and better validation results. However, increasing the model complexity also increased the model run time.

* Profile of partner organization and the specific problem Environment and Climate Change Canada

## Objectives

The objectives of this project are as follows:

1. In the Baker Creek Watershed (NWT), replicate the work of past MWS student Herbert Mkandla in the Whitegull Creek Watershed (SK) evaluating the effect of complexity in the representation of spatial heterogeneity in the MESH model on model performance
2. Take the work further and explore additional model configuration options to expolre the effect of model performance.

Include references as appropriate and write down all reference information in the file references.md

# Site Description

The Baker Creek watershed is located in the Taiga Shield Ecozone, the Tazin Lake Upland Ecoregion, and the Beaulieu River Ecodistrict (number 260) ( (Agriculture and Agrifood Canada (AAFC), 2019).

<see also Phillips 2011 for a further description of ecozones/regions> This area is characterized by …

## Climate

## Land use

## Vegetation

## Hydrology

## Geology and Soils

Include Maps, Photos and Figures, using the command:



Include references as appropriate and write down all reference information in the file references.md

# Literature Review

The literature review was conducted with the following purposes: 1. Review the current state of the science regarding

i) hydrological model calibration  
  
 ii) spatial discretization  
  
 iii) and ...

1. Assess the work completed by H. Mklanda in order to replicate the methodology
2. Gather site characteristics

## Summary of the Mkandla experiment

Provide a summary of the methods and results of the modelling that Herbert completed

### Purpose

### Methods

### Results

## Scientific Literature Review

Provide a discussion of the current state of the literature

Given that a literature review was recently completed by H. Mkandla, this literature reveiw focuses on literature published since (2011??)

## Watershed Characterization

A literature review was also completed to characterize the hydrolocial characteristcs of the Baker Creek Watershed with respect to climate, geology, soils, vegetation, and land use. This information was used to parameterize the model and evaluate the results. Details of the site characteristics are presented in the [Site](site.html) section.

## Results

Results. Include Photos and Figures, using the command:



## References

Please refer to the [Reference List](references.html)

# Model

**OPTIONAL**

Describe the objective of the modelling exercise, describe the model used and any relevant methods, provide results and a conclusion. You must be concise. If additional details are generated which will be useful to future workers, these can be included in an appendix.

## Objective

Here’s my objective

## Methods/Model description

Methods. You are encouraged to include here a conceptual model/diagram of your model, if appropriate

* Parameterization of the scenarios; general methodology and sources of the ranges (see table in Davison et al)
  + Of note is the difference between the parameterization of the soil layers; Should discuss this in detail and consider recommending something different for the future??

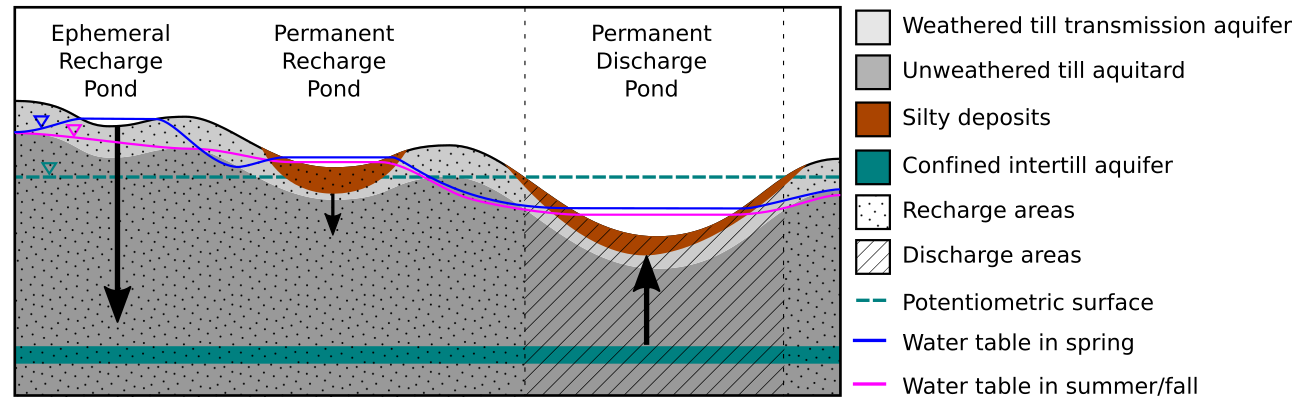
You can (and should!) include equations like this:

For the initial setup of Scenario 2, the watershed was divided up into 6 GRUs - each characterized by one of the six land cover types: conifers, deciduous, wetland, peatland, water, and bedrock. The CLASS and hydrological parameters were selected to reflect the on-site conditions as closely as possible. However, when running the model, errors and instabilities were encountered. Upon further assessment, it was determined that this method would not work when running the MESH model in point mode (i.e. no routing of water through the basin). Essentially, the model calculates the water and energy balance for each GRU and then transmits runoff directly to the outlet. In reality, runoff from the upland areas is stored in downstream wetlands, peatlands, and lakes. The large water bodies have the capacity to store large amounts of water, depending on the antecedent conditions, and slowly release the water downstream. Therefore, Scenario 2 was re-configured to allow the model to account for this storage and slow release in an alternative manner.

The alternate setup of Scenario 2 consisted of the same GRU configuration, but the parameterization was adjusted so that each GRU represented the vertical water and energy balance of that landcover type, as well as the storage capacity of the runoff that would otherwise be stored in downstream waterbodies. The maximum value of the ranges for calibrated parameters related to storage (i.e. soil properties and ponding) were expanded to represent the runoff water that would be stored downstream prior to being transmitted to the basin outlet.

## Results

Results. Include Figures using the command:



* Very poor model performance based on evaulation using the Nash-Sutcliffe. Possibly due to the limitations of the model in representing bedrock, the prevalence of large water bodies in the basin which attenuate the streamflows and can even create backwater conditions (see Chris’ hydrology paper)
* Also, lnNSE should have been used as an evaluation metric due to the prevalence of low flows in the basin
* Try running Scenario 2 with logNSE as the calibration parameter? Just to see the results if it makes any difference. Also ask Dan if there may be some reason why the NSE results are rarely above zero.
* Which parameters could have used wider ranges in order to see better results?

## Conclusion

Conclusion

Include references as appropriate and write down all reference information in the file references.md

# Data analysis

**OPTIONAL**

If a substantial component of the work involves statistical analysis of existing data, which could include environmental, economic or social data, and could be time series data or spatial (GIS) data, this should be written up here. Include the objectives of the analysis, the data available (including the source of the data), quality assurance and quality control activities that were performed on the data by you, methods of analysis, results, including figures, interpretation and conclusions. Often appropriate plots of data are preferable to formal statistical analyses. You must be concise. If additional details are generated which will be useful to future workers, these can be included in an appendix.

## Analysis objectives

The objectives of the data analysis portion of this project were to prepare the driving data and streamflow data for the model, and process the model calibration and validation results.

## Data summary

Meta-data describing the available datasets, where they are from, how they can be obtained, etc.

Driving data for the model was obtained from 4 sources: 1) Environment and Climate Change Canada’s historical records for the Yellowknife A station (REFERENCE) 2) Hydrometeorological and hydrological data collected within the Baker Creek Watershed during research activitys betwen 2003 and 2016 (Spence & Hedstrom, 2018) 3) Environment and Climate Change Canada’s GEM model (REFERENCE) 4) CAPA

PROVIDE A MORE DETAILED DESCRIPTION OF THE GEM AND CAPA DATA HERE

Streamflow measurement were obtained from the Water Survey of Canada for station 07SB013 “Baker Creek at the Outlet of Lower Martin Lake”(Water Survey of Canada, 2019).

## Quality assurance and quality control

The If appropriate, provide details of any data processing that was undertaken.

## Methods

All data processing and plotting was done using the R programming language via RStudio (Studio Team, 2018). The general methodology was to inspect the data for duration and completeness, load into R, plot the data, perform unit conversions, scale the meteorological observations up to the measurement height required for the model. The datasets from each source were prepared separately and converted into a consistent format. Then, the forcing variable from each source was compared, and compiled into one complete set. contains the R scripts used in the driving data preparation.

Streamflow measurements obtained from the Water Survey of Canada at station 07SB013 were loaded into R, and then processed for use in the model. MESH does not read negative flow values, so missing values were replaced with an arbitrary negative number (i.e. -9999), and subsets for the calibration and validation periods were created by converting flows outside the period of interest to negative values.

Methods - e.g. statistical methods applied and assumptions.

## Results

Results. Include Photos and Figures, using the command:



## Conclusions

Intrepretation of results and conclusions

Include references as appropriate and write down all reference information in the file references.md

# Summary of findings

1 page of writing, with additional figures (i.e. you are encouraged to include figures, in particular conceptual diagrams, if these support your findings, and these don’t count towards the page limit). In this section, the conclusions from the individual components are brought together, showing how these are related to one another and how they support, or contradict one another. The overall findings are summarized, concisely. Do not repeat the results from earlier sections, but emphasize take home messages and conclusions. **The primary audience for this section is your faculty advisor and the academic community**.

# Towards a solution

1 page of writing, with additional figures or tables. In this section, you have the opportunity to either present a prototype solution to the partner organization, or provide a number of future recommendations for further research towards a solution. For the prototype solution, you might provide a detailed method or policy, which could be expressed as a conceptual diagram, a flow chart, a table, or as a single page of text. For the further research, you should outline the outstanding problems that need to be overcome or understood to solve this problem, and you should try to make concrete recommendations for what the partner organization should do next to move towards a solution. **The primary audience for this section is your external advisor and partner organization**.

Future recommendations for further research

* Explore the effect that calibrating to logNSE would have on the results
* Expand the parameter ranges to see if better results could be obtained
* Consider adding a reservoir to represent the behavior of the large lakes in the basin
* Consider using the PDMROF and/or LATFLOW to represent the fill-spill behavior of the basin
* Since streamflow is minimal from this basin - especially during dry years - consider calibrating to a differnt metric, such as evaporation.

# Reference List

Include a reference list here if appropriate, in APA style. Consider using a reference manager such as *Zotero*

# Appendix

**OPTIONAL**

Note, Appendix A and B in the syllabus should not be included in your report. You may add appendicies if you wish to, in particular if this would help future students and researchers to reproduce your work.

## List of Appendicies

Appendix A - Monthly Progress Reports

Appendix B - R Code

Appendix C -