Magpie Workflow Walkthrough

Welcome to the Magpie Workflow Walkthrough #1, where we will develop a semi-distributed model for the Petawawa River catchment, ($4,122km^2$), located on the outskirts of Ottawa, Ontario.

In this comprehensive exercise, we begin by generating a shapefile for our study area. Following this, we downloading and format essential layers, including DEM, elevation band, landcover, and soil cover. These layers are then integrated into Basin Maker to discretize the catchment.

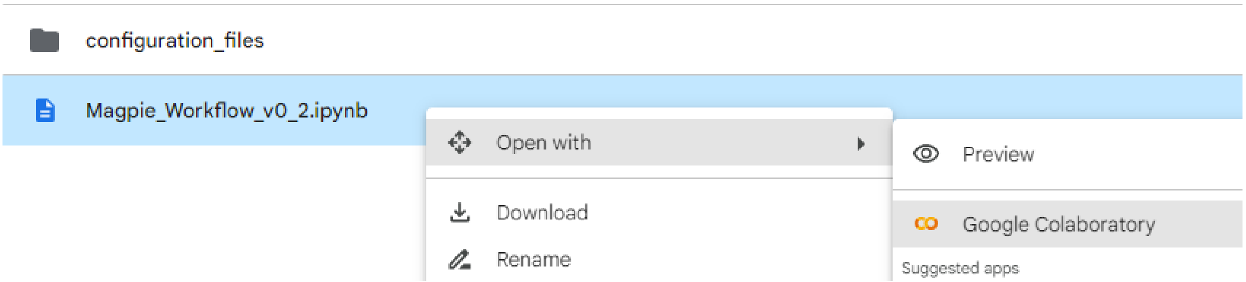
Once the basin is discretized, our focus shifts towards obtaining forcing data and generating the remaining input files (RVI, RVH, RVP, RVT, and RVC) necessary for executing a Raven simulation.

As you navigate through each section of the Magpie Workflow, you'll find accompanying short videos that provide demonstrations on how to effectively utilize each section. In the spirit of fostering a deeper understanding, you are encouraged in this walkthrough to deviate from the script, play around, and learn all you can about each section.

Set up

Once the Magpie Workflow is downloaded, unzip the file locally on your computer and drag and drop the unzipped Magpie Workflow folder into your Google Drive. Ensure the path of the folder is “My Drive” → “Magpie_Workflow”.

Once the upload is complete, right click on “Magpie_Workflow_v0_2.ipynb”, select “Open with”, and “Google Colaboratory” to open the workflow. For additional guidance, check out the provided short video to assist you in navigating the Magpie Workflow setup.



If this marks your first encounter with the Magpie Workflow, take a moment to acquaint yourself with the "Overview" section for more information.

Execute the "Python Library Installation" section. This section only need to be run once, as it downloads Python packages necessary for the Magpie Workflow into your Google Drive to prevent long installation times each time you use Magpie. After the Python libraries have been successfully installed, please restart your notebook.

> To restart the notebook, select "Runtime" → "Restart Runtime"

> Please note both "Python Library Installation" section will take a while to run, an estimated runtime is available in the workflow description

Execute the "R Library Installation" section. This section only need to be run once, as it downloads R packages necessary for the Magpie Workflow into your Google Drive to prevent long installation times each time you use Magpie. After the R libraries have been successfully installed, please restart your notebook.

After both sections have been run and the notebook has been restarted, proceed to the `Workflow Set up (Mandatory)` section. Execute `Run to Set up Workflow`. This step is crucial to establish connections between the Workflow and your Google Drive, load essential libraries, and define working and output directories. Keep in mind that every time the notebook is disconnected or restarted, the `Run to Set up Workflow` will need to be rerun. Verify that the displayed main directory matches the actual location where the Magpie folder has been stored. You can verify this by checking the folder directory.

For this tutorial, we can uncheck and ignore the `Write Model Decisions to Configuration File` at the end of each section. For improved model reproducibility, users have the option to document the model decisions within the Magpie interface by saving them to a configuration file. This configuration file can then be executed in Magpie Developer, enabling the recreation of an identical model with consistent results. For more information about this, please check out section `7.0 Magpie Configuration File`.

1.0 Data Collection

In the absence of any data or Raven input files, users can use Section 1.0 Data Collection to acquire and format the necessary data for running the HRU discretization tool in BasinMaker. Each section within this module is optional, offering users the flexibility to select and execute only those components that align with their model objectives. Additionally, users can choose to upload data directly within each section or use Google Earth Engine resources available within Magpie.

1a) Study Area

1. **Access the "Generate Study Area" Subsection**: In the 1.0 Data Collection section, locate and expand the "1a) Study Area" → "Generate Study Area". Here, you will find options to download a shapefile of the Petawawa River catchment.
2. **Load Necessary Functions**: Execute the "Load Functions" cell to load the required Magpie functions. This step is crucial for the subsequent processes to work correctly.
3. **Choose Download Method**: You have two options to download the product:
   - **By Coordinates**: (Not used in this exercise)
   - **By Gauge Name**: For this exercise, select this option. Run the first two cells without any modifications since we are not defining coordinates. An interactive map for visualizing potential gauges is not required as we specifically target gauge number 02KB001.
4. **Define the Product Name**:
   - Go to the "Define the product name" section.
   - Use the drop-down menu to select the product type **NALRP**.
   - Enter the `gauge_name` as **02KB001**.
   - Execute this cell.
5. **Copy Subbasin ID**: The cell will output a Subbasin ID, like `Subbasin Id of the interested gauge is: 3048815`. Copy this ID.
6. **Enter the Subbasin ID**: Paste the copied Subbasin ID **3048815** into the `most_down_stream_subbasin_ids` field. Leave `most_up_stream_subbasin_ids` as **-1**.

7. **Run Additional Cells**:

    - Run the `Visualize shapefile of study area` cell. This will generate an interactive plot of the subbasin's outline.

8. **Save the Shapefile**: The final shapefile will be automatically saved to Google Drive, completing the study area section.

9. **Optimize Disk Space**:

    - Run "Remove temporary" data the corresponding cell to delete any temporary data that is no longer needed.

10. **Configuration File Settings**:

    - Leave the "Write Model Decisions to Configuration File" option unchecked.
    - Execute this cell.

1b) DEM

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1. **Initiate the DEM Section**: Navigate to the "1.0 Data Collection" section, then proceed to "1b) DEM" and finally to the "Generate DEM" subsection.

2. **Load Necessary Functions**: Execute the "Load Functions" cell to ensure that all the required Magpie functions are loaded and available. This is a crucial step for the functionality of the upcoming processes.

3. **Download DEM Data**:

    - Leave the pre-set values unchanged in the "Download DEM data" cell.

Download DEM data

By default, Magpie is set up to download the MERIT DEM. However, by changing the data source, band name, and scale (information available in Earth Engine Data Catalog) users can download other DEM datasets available on Google Earth Engine

Please refer to the [Earth Engine Data Catalog] to view other data source options

If Earth Engine cannot download the extent of your study area, increase size of scale

for example, adjust scale to "90"

`data_source:` " MERIT/DEM/v1_0_3 "

`band_name:` " dem "

`scale:` 90

Show code

- Run this cell.
- Optionally, you can click on the provided link to explore additional data available in the Earth Engine Data Catalog. However, for this exercise, we will use the default MERIT dataset.

4. **Clip DEM Layer to Study Area**: Execute the Clip DEM layer to study area cell. This process will tailor the DEM layer to your specific study area.
5. **Visualization Options**:
   - In the Check the box to visualize clipped DEM layer section, select the following options for visualization: `DEM_visualize`, `Slope_visualize`, and `Aspect_visualize`.
   - These selections will allow you to view the DEM, slope, and aspect layers of the study area.
   - Note: There is no need to save a shapefile of the aspect to your drive.
6. **Save the Final DEM Layer**: The final DEM layer will be automatically saved to your Google Drive, marking the completion of the DEM section.
7. **Optimize Disk Space**:
   - Run "Remove temporary data" the corresponding cell to delete any temporary data that is no longer needed.
8. **Configuration File Settings**:
   - Leave the "Write Model Decisions to Configuration File" option unchecked.
   - Execute this cell.

1c) Elevation Bands

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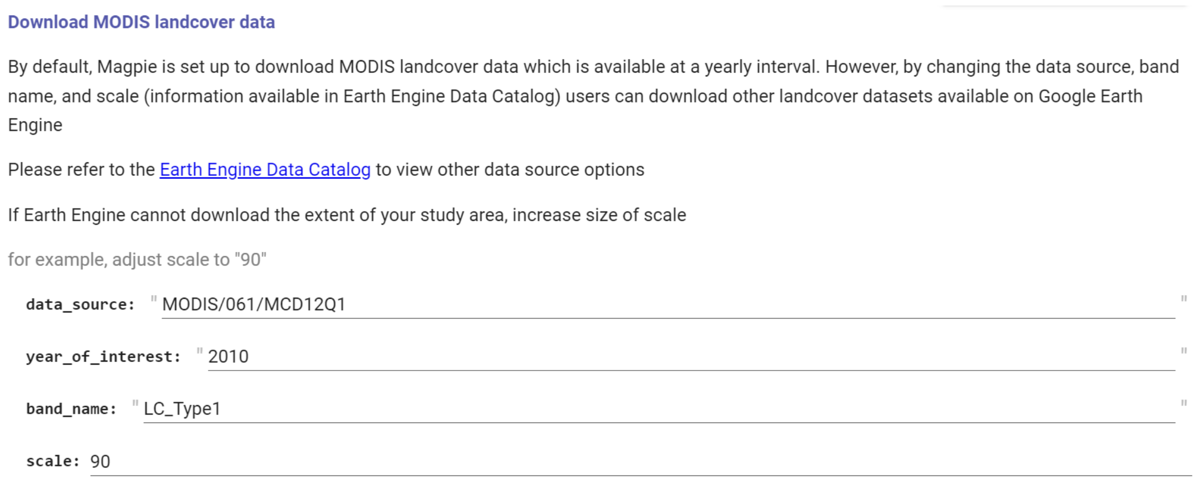
1. **Access the Elevation Bands Section**: Go to the "1.0 Data Collection", then to "1c) Elevation Bands", and finally to the "Generate Elevation Bands subsection".
2. **Load Necessary Functions**: Execute the "Load Functions" cell to load all necessary Magpie functions. This ensures that you have all the required tools for the subsequent steps.
3. **Determine Elevation Range**:

- Run the first cell in this section to calculate the minimum and maximum elevation of the subbasin.
- This information is vital for accurately defining your elevation bands.

4. **Define Elevation Bands**:
    - Based on the provided minimum and maximum elevations (136 and 562), set the `min_elev` value at 100 and the `increment_val` at 100.
    - Run this cell to apply these settings.
5. **Visualize Elevation Bands**:
    - Run cell to visualize the final elevation band shapefile.
6. **Save the Final Elevation Band Shapefile**: The final elevation band shapefile will be automatically saved to your Google Drive, completing this section.
7. **Optimize Disk Space**:
    - Run "Remove temporary data" the corresponding cell to delete any temporary data that is no longer needed.
8. **Configuration File Settings**:
    - Keep the "Write Model Decisions to Configuration File" option unchecked.
    - Execute this cell to complete the settings.

1d) Landcover

1. **Navigate to the Landcover Section**: Proceed to the "1.0 Data Collection" section, then to "1d) Landcover", and finally to the "Generate Landcover" subsection.
2. **Load Essential Functions**: Run the "Load Functions" cell to ensure that all necessary Magpie functions are loaded. This step is critical to enable the functionality of the upcoming processes.
3. **Download MODIS Landcover Data**:
    - In the "Download MODIS landcover data" section, leave the default values as they are and run the cell.



- Optionally, you can explore additional data available in the Earth Engine Data Catalog through the provided link. For this exercise, however, we will use the MODIS landcover data available via Google Earth Engine.

4. **Clip and Visualize Landcover Layer**:
    - Execute the remaining cells in this section to clip the landcover layer to the extent of your shapefile.
    - These steps will also enable you to visualize the final landcover layer.
5. **Generate Landcover Breakdown**: As part of this process, a percentage breakdown of each landcover type found within the study area is generated. This gives you a detailed understanding of the landcover composition.
6. **Save the Final Landcover Shapefile**: The completed landcover shapefile will be automatically saved to your Google Drive, marking the end of the landcover section.
7. **Manage Disk Space**:
    - Run “Remove temporary data” the corresponding cell to delete any temporary data that is no longer needed.
8. **Configuration File Adjustments**:
    - Leave the “Write Model Decisions to Configuration File” unchecked.
    - Execute this cell to finalize your settings.

1e) Soil

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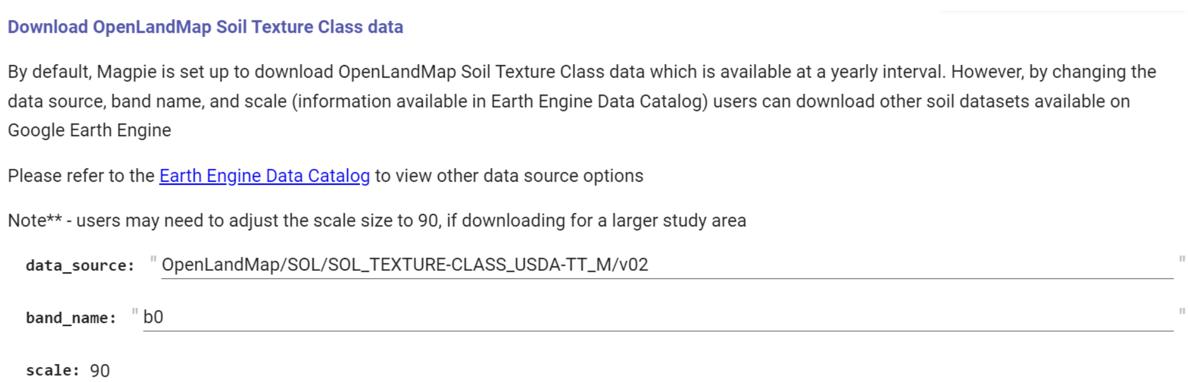
1. **Access the Soil Section**: Navigate to the “1.0 Data Collection” section, then to “1e) Soil”, and finally to the “Generate Soil” subsection.
2. **Load Required Functions**: Begin by running the “Load Functions” cell to ensure that all necessary Magpie functions are loaded. This is a crucial step for enabling the functionality of the subsequent processes.
3. **Download Soil Texture Class Data**:
    - In the “Download OpenLandMap Soil Texture Class data” section, keep the default values and run the cell.



    - You have the option to explore additional data in the Earth Engine Data Catalog via the provided link. However, for this exercise, it's recommended to use the predefined values.
4. **Clip and Visualize Soil Layer**:
    - Proceed to run the remaining cells in this section. These steps are designed to clip the soil layer to match the extent of your shapefile.
    - This will also allow you to visualize the final soil layer.
5. **Generate Soil Composition Breakdown**: As part of this process, a percentage breakdown of each soil type present within the study area is generated. This provides valuable insights into the soil composition of the area.
6. **Save the Final Soil Shapefile**: The completed soil shapefile will be automatically saved to your Google Drive, indicating the completion of the soil section.
7. **Optimize Disk Space Usage**:

- Run “Remove temporary data” the corresponding cell to delete any temporary data that is no longer needed.

8. **Finalize Configuration File Settings**:
    - Leave the “Write Model Decisions to Configuration File” option unchecked.
    - Run this cell to complete the settings.

1f) Classification

1. **Navigate to the Classification Section**: Go to the “1.0 Data Collection” section and then proceed to “1f) Classification”.
2. **Load Required Functions**: Start by running the Load Functions cell. This is essential to load all the necessary Magpie functions, ensuring that the classification processes work correctly.
3. **Execute Classification Cells**:
    - Run the following sections without any modifications:
        - “Landcover Classification”
        - “Vegetation Classification”
        - “Soil Classification”
    - These classifications are important for the RVH (basin definition file) and RVP (class parameters file) in the Raven model files.
4. **Adjusting Classifications (If Needed)**:
    - If you did need to customize the classifications, you can modify the values in each section.
    - When altering values, remember to separate each value with commas.
    - Ensure there are no spaces between the values to maintain proper formatting.

Additional Information

- **Relevance of Classifications**: These classifications are integral to defining various aspects within the Raven model RVH (basin definition file) and RVP (class parameters file) files.

2.0 Discretize Basin

Magpie utilizes the light version of BasinMaker, developed by Han et al. (2021), to generate HRUs. For this exercise we will be using the layers we generated in section 1.0 Data Collection to discretize the subbasin.

Before running this section be sure to restart the workflow, go to “Runtime”→”Restart session”. Reminder to run “Run to Set up Workflow” to reload libraries and paths.

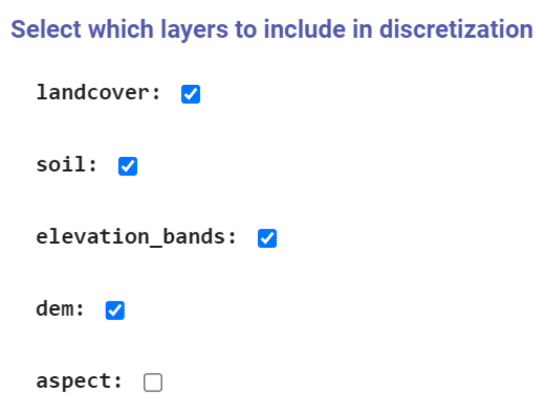
2a) Subbasins

1. **Access the Subbasin Section**: Go to “2.0 Discretize Basin” → “2a) Subbasins” → “Derive Subbasin with Light BasinMaker”.
2. **Load Required Functions**: Ensure to run the Load Functions cell for loading necessary Magpie functions.
3. **Define Study Area**:
    - Use the drop-down menu to select the product type **NALRP**.
    - Choose Option 1 to define the `gauge_name` as **02KB001** and run the cell.
    - Leave `define_lat`, and `define_lon` as “NA”.
4. **Extract Drainage Area**:
    - Copy the subbasin ID (e.g., **3048815**) from the previous output.
    - Paste it into `subid_of_interested_gauges`.
    - Set `most_up_stream_subbasin_ids` to **-1** for BasinMaker to collect HRUs upstream of the provided subbasin ID.
5. **Simplify Drainage Product**:
    - Set `lake_size` to **5** to exclude lakes smaller than 5km².
    - Run the cell for simplification.
6. **Adjust Subbasin Size**:
    - Change `minimum_subbasin_drainage_area` to **50.0** for a minimum drainage area of 50km².
    - Execute the cell.

7. **Save Routing Product**: Run the “Save Routing Product to Drive” cell to back up the simplified routing product.
    - Leave “Write Model Decisions to Configuration File” unchecked and run the cell.
8. **Remove Temporary Data**: Execute the cell to save disk space.
9. **Skip Configuration File**: Leave “Write Model Decisions to Configuration File” unchecked and run the cell.

2b) Hydrologic Response Units (HRUs)

1. **Navigate to HRUs Section**: Proceed to “2.0 Discretize Basin” → “2b) Hydrologic Response Units (HRUs) - BasinMaker” → “Derive HRUs with Light BasinMaker”.
2. **Load Functions**: Again, run the “Load Functions” cell.
3. **Select Input Layers**: Check the boxes for landcover, soil, elevation bands, and DEM.



1. **Set Area Ratio Thresholds**: Define `area_ratio_thresholds` as **[0.1, 0.2, 0.2]** for default HRU mapping. Adjust these values later for finer discretization. Keep `pixel_size` set to **30** and `product name` as **NALRP**.
2. **Skip Configuration File**: Leave “Write Model Decisions to Configuration File” unchecked and run the cell.

2c) RVH and RVP Files

1. **Access RVH and RVP File Section**: Go to “2.0 Discretize Basin” → “2c) RVH and RVP Files” → “Generate RVH and/or RVP File(s)”.

2. **Generate RVH and RVP Files**: Execute the "Use BasinMaker to Generate RVH File and RVP Template" cell.
3. **Finalize Settings**: Leave "Write Model Decisions to Configuration File" unchecked and run the cell.

3.0 Forcing Data

With the study area discretized, the next step is to obtain forcing data and generate the RVT file for Raven. The Magpie Workflow provides several forcing options, including the ability to upload your own forcing data in CSV format, which can be formatted into an RVT file. Note that not all forcing sections need to be run; select those that suit your model's needs.

Before running this section be sure to restart the workflow, go to "Runtime"→"Restart session". Reminder to run "Run to Set up Workflow" to reload libraries and paths.

3d) Environment Canada Climate data

1. **Utilize Gauged Data**:
   - Skip to the section "3d) Environment Canada Climate data".
   - Run the "Load Functions" cell to ensure necessary Magpie functions are loaded.
2. **Visualization (Optional)**:
   - Check `map_visualize` in the "Visualization of Potential Climate Stations in Study Area" for an interactive plot. This allows identification of potential station names, latitudes, and longitudes within the study area shapefile.
3. **Station Look-up**:
   - Run the "Station Look-up by Province" cell, downloading a station lookup CSV.
   - Change `province` to **ON**, and set `start_year` to **2010**.
   - After running, navigate to "temporary_data" → "station_lookup_dir" → "station_lookup_ON.csv". Once the CSV file is open, select 'Filter', enter "**Petawawa**" in 'Name'.
4. **Generate Daily Climatic Variables**:

- In “Generate Daily Climatic Variables for Selected Station”, set `stations_of_interest` as “**47527, 6900**” (use a comma to separate values without spaces).
- Define `start_year` as **2010**, `end_year` as **2015**, and use the dropdown to set `time_step` to **daily**.

5. **Preview Station Data**:
   - After downloading, go to “temporary_data” → “weather_data” → “47527” to view the CSV files.
6. **Define Variables**:
   - Copy the relevant variables' column names (e.g., **['Total Precip (mm)’, ‘Max Temp (°C)’, ‘Min Temp (°C)']**) and paste them into `col_name_lst`
   - In `params_list`, type **‘PRECIP, TEMP_MAX, TEMP_MIN’**.
   - For `units_lst`, enter **‘mm/d, C, C’**, matching the order of `var_lst`.
7. **Create RVT Files**:
   - Run “Generate Raven RVT Input containing Station Information” to create RVT files for each station.
8. **Manage Disk Space**:
   - Run the ‘Remove temporary files’ to remove unnecessary files in the folder directory.
9. **Finalize Settings**:
   - Leave “Write Model Decisions to Configuration File” unchecked and run the cell.

3f) Hydrometric Data (HYDAT)

1. **Initial Setup**:
   - Run the “Install and Load Related R Packages”.
   - Download HYDAT Data through the “Download HYDAT Data” cell. This process may take a few minutes and requires inputting **1** and pressing enter.
2. **Setting Up Your Environment**:
   - Adjust the `main_dir` variable in the R script to match the path to your Magpie folder. Example:

```
main_dir <- "/content/google_drive/MyDrive/Magpie_Workflow"
```

- Define your stations of interest in the `stations_lst` variable, separating multiple stations with commas. For example:

```
stations_lst <- c("02KB001")
```

- Set the `start_date` and `end_date` for the data you wish to analyze:

```
start_date <- "2010-01-01"
end_date <- "2015-12-31"
```

3. **Data Download and Visualization**:
    - Execute the “Download available HYDAT data” cell after defining the variables.
    - Stations with flow data available within the defined time period will be downloaded.
    - To visualize the data, run the “Plot Station HYDAT Data” cell.
    - For an interactive plot of potential flow gauges in the study area, check “interactive_map_response” in the “Visualization of Potential Flow Gauges in Study Area”. This will produce a plot where you can click on points to identify potential station names, latitudes, and longitudes.
4. **Generating and Adjusting RVT Files**:
    - Run “Generate RVT files for each of the available stations”.
    - Follow with “Add station RVT information to existing RVT file or generate a new RVT file”.
    - **EXTRA STEP**: Adjust the station RVT file to define the subbasin ID. First, set the `flow_gauge_ID` to **02KB001** and run the cell. Navigate to the `st_02KB001.rvt` file within your Google Drive Magpie Workflow Exercise path, and modify it as follows:
        - Double-click on “st_02KB001.rvt”.

- Copy the “Subbasin ID: **3048815**“.
- Paste this ID into the RVT file, as shown in the example.

```
:ObservationData HYDROGRAPH 3 m3/s
  2010-01-01 00:00:00 1 2191
 38.2
 38
 36.5
 36
 35.9
 35.6
 35
 34.4
```

```
:ObservationData HYDROGRAPH 3048815 m3/s
  2010-01-01 00:00:00 1 2191
 38.2
 38
 36.5
 36
 35.9
 35.6
 35
 34.4
 33.9
```

- Save the changes by pressing “Ctrl+S” and then close the file.

5. **Accessing Hydrometric Data**:
    - For users specifically interested in hydrometric data, skip to section “3f) Hydrometric data (HYDAT)” to download flow data.
    - Ensure you run the “Load Functions” cell to load the necessary Magpie functions.

By following these steps, users can efficiently navigate the process of downloading, visualizing, and managing flow data using the Magpie system in R.

4.0 Raven Input Files

This subsection focuses on generating the remaining Raven inputs (rvi, rvh, and rvc files) through RavenR, developed by Chlumsky et al. (2022)

Before running this section be sure to restart the workflow, go to “Runtime”→”Restart session”. Reminder to run “Run to Set up Workflow” to reload libraries and paths.

Initial Setup

1. **Load Necessary Functions**:
    - Run the “Load Functions” cell to load the necessary Magpie functions.
2. **Install and Setup Raven**:

- Execute the “Install and Setup Raven Executable”. This process might take a couple of minutes.

3. **Define Model Name**:

   - In the R script, set the `model_name` variable. Ensure it's in string format:

     ```
     model_name = "model_name"   # Replace with your desired model name
     main_dir <- "/content/google_drive/MyDrive/Magpie_Workflow"
     ```

4. **Install Related R Packages**:

   - Run the “Install and Load Related R Packages” cell.

Generate RVI File

1. **Selecting a Template**:

   - For more information on available templates, refer to the Raven Manual or set `view_rvn_rvi_write_template` to “yes” and run the cell.

2. **Setting Up the Template**:

   - Use the Canadian Shield Configuration (“CdnShield”) for this exercise:

     ```
     define_template_name <- "CdnShield"
     author_name <- "Magpie"
     user_description <- "RVI file for Raven model created by RavenR"

     rvn_rvi_write_template(template_name=define_template_name,
        filename=file.path(getwd(), paste(model_name,"rvi", sep=".")),
        author=author_name,
        description=user_description)
     ```

Generate RVP File

1. **Creating the Template**:

    - Navigate to the `model_name.rvi` file in your Google Drive Magpie Workflow path. Add "**:CreateRVPTemplate**" to the RVI file, save with "Ctrl+S".

2. **Running the RVP Cell**:

    - Run 'Run Raven' to generate the RVP file.
    - After running, you should see a message indicating a successful creation of the RVP file.

```
Bash Command Output:
============================================================
                        RAVEN
 a robust semi-distributed hydrological modelling framework
    Copyright 2008-2024, the Raven Development Team
                    Version 3.8.0
                BuildDate Jan 24 2024
============================================================
Generating Master Parameter List...


============== Exiting Gracefully ==========================
Exiting Gracefully: Template RVP File Created.
============================================================
============================================================
```

    - Reopen the `model_name.rvi` file, remove "**:CreateRVPTemplate**", and save again.
    - Run the remaining cells in the "Generate RVP File" subsection as they are.

Generate RVC File

1. **Create an Empty RVC**:

    - Run the cell in the "Generate RVC File" section to produce an empty RVC file.
    - For this exercise, leave the RVC file as is. Users can modify initial conditions in the RVC file at a later date.
    - Leave "Write Model Decisions to Configuration File" unchecked and run the cell.

5.0 Run Raven

Pre-Run Setup

1. **Restart Workflow**:
    - It's recommended to restart the workflow and run the mandatory workflow set-up to ensure a clean start.
2. **Configure the RVI File**:
    - Open the `model_name.rvi` file.
    - Adjust the `:StartDate` to `2010-01-01 00:00:00`.
    - Change the `:Duration` to `1095` (for a 3-year model duration).
    - Add custom output commands for daily average precipitation and snow for each HRU at the end of the RVI file:

    ```
    :CustomOutput DAILY AVERAGE PRECIP BY_HRU
    :CustomOutput DAILY AVERAGE SNOW BY_HRU
    ```

    - Save the changes with “Ctrl+S”.

Running the Raven Model

Downloading Raven Input Files (Optional):

- Users have the option to download the Raven input files.
- Check the box “Download Raven Input Files”.
- This action zips all Raven input files and forcing data generated within the Magpie Workflow.
- Right-click on the generated zipped file to download it for local use or running on an alternative server.

For this exercise we will run Raven within the Magpie Workflow.

1. **Load Necessary Functions**:
    - Run the “Load Functions” cell to ensure all necessary Magpie functions are loaded.

2. **Load Raven Executable**:
    - Execute the "Load Raven Executable" cell.
3. **Execute Raven Model**:
    - Ensure the output name is set as `outputA`.
    - Run the "Run Raven" cell and just like that have successfully run our Raven Model!
    - After running, check the `Raven_errors.txt` file for any warnings or errors that may have occurred.

Post-Run Considerations

- Please be aware that this setup produces a basic model. Further documentation with recommendations to enhance the model's performance will be provided.
- For more detailed guidance, refer to the Raven Manual, which is linked throughout the Magpie Workflow.

By following these steps, users can successfully run the Raven model within the Magpie Workflow, adjust the model parameters as needed, and optionally download the input files for use outside the workflow environment.

6.0 Raven Visualization

Basic Visualizations within the Workflow

1. **Visualize Hydrographs**:
    - Go to the "Visualize Hydrographs with Magpie" section.
    - Keep the `output_name` as `outputA`.
    - Check both "visualize_precip" and "visualize_hydrographs".
    - Run the cell to generate interactive plots of precipitation and hydrographs.
2. **Visualize Custom Outputs by HRU**:
    - Expand the "Visualize Custom Outputs by HRU" section.
    - Run the first cell to set up the output directories. Ensure `output_name` remains as `outputA`.

- Execute the “Format data” cell.
- Choose the CSV file for visualization. For example, copy “PRECIP_Daily_Average_ByHRU.csv” and paste it into the `select_var` field.
- Define the range of HRUs to visualize, noting that the selection is based on the data frame's index, not the HRU ID. For this example, use `hru_min` as 0 and `hru_max` as 10.
- Run the cell to produce an interactive plot for the selected HRUs.

Using RavenView for Advanced Visualization

1. **Prepare Files for RavenView**:
    - In the “Raven Visualization” section, navigate to the “RavenView” subsection.
    - Ensure `output_name` is set to `outputA`.
    - Run both cells to generate a zipped folder containing Raven input and output files compatible with RavenView.
2. **Downloading and Using RavenView**:
    - In Google Colab's files directory, right-click and download the generated zipped folder to your local machine.
    - Click on the “RavenView” link provided in the workflow to access the visualization tool.
    - Unzip the downloaded folder locally.
    - Import `subbasin_map.geojson`, `river_map.geojson`, and `hru_map.geojson` into RavenView.
    - Drag and drop additional Raven input and output files, such as custom outputs, into RavenView for spatial and temporal visualization.

By following these steps, users can effectively visualize Raven model outputs using both the basic visualization tools within the Magpie Workflow and through the more advanced features available in RavenView.

References

Chlumsky, R., Craig, J. R., Lin, S. G., Grass, S., Scantlebury, L., Brown, G., & Arabzadeh, R. (2022). RavenR v2. 1.4: an open-source R package to support flexible hydrologic modelling. Geoscientific Model Development, 15(18), 7017-7030.

Craig, J. R., Brown, G., Chlumsky, R., Jenkinson, R. W., Jost, G., Lee, K., ... & Tolson, B. A. (2020). Flexible watershed simulation with the Raven hydrological modelling framework. Environmental Modelling & Software, 129, 104728.

Han, M., H. Shen, B. A. Tolson, J. R. Craig, J. Mai, S. Lin, N. B. Basu, F. Awol. (2021). BasinMaker 3.0: a GIS toolbox for distributed watershed delineation of complex lake-river routing networks. Environmental Modelling and Software.