geofabric_analysis

April 24, 2023

1 Analyzing TGF, HUC12, MERIT-Basins, and PFRA geofabric for the St. Mary & Milk River Basins

Here, the mentioned geofabrics for the upcoming St. Mary & Milk River Basins (hereinafter SMM) study are analyzed and their applicability is tested. Note that PFRA dataset in this Notebook corresponds to the AAFC Watershed Project - 2013 dataset.

1.1 Importing necessary libraries

[1]:

```
import geopandas as gpd # version 0.12.2
import matplotlib.pyplot as plt # version 3.7.0
import fiona # version 1.9.2
import pandas as pd # version 1.5.3
import contextily as cx # version 1.3.0

from itertools import permutations # Python 3.11 (built-in function)
from matplotlib.patches import Patch # version 3.7.0

# Also:
# * jupyterlab-markup v2.0.0 (for printing data in Markdown)
# * Python >3.11
```

1.2 Reading files

1.2.1 Source links

- TGF: https://www.sciencebase.gov/catalog/item/5d967365e4b0c4f70d113923
- HUC12: Acquired from Jamie Kolodinsky (ECCC, jamie.kolodinsky@ec.gc.ca)
- MERIT-BASINS: https://www.reachhydro.org/home/params/merit-basins (with modifications and post-processing to extract the SMM domain)
- PFRA (or Agriculture and Agri-food Canada Watersheds Project - 2013, also known as PFRA dataset): https://open.canada.ca/data/en/dataset/c20d97e7-60d8-4df8-8611-4d499a796493

1.2.2 Path defintions

[2]:
```
# defining the path to TGF downloaded from https://www.sciencebase.gov/catalog/
 ↪item/5d967365e4b0c4f70d113923
tgf_path = '/Users/kasrakeshavarz/Documents/geospatial-data/StMary-Milk/TGF/TGF.
 ↪gdb'

# define the path to HUC12 retreived from ECCC, at jamie.kolodinsky@ec.gc.ca
huc12_path = '/Users/kasrakeshavarz/Documents/geospatial-data/StMary-Milk/HUC/
 ↪HUC12/SMM_HUC12.shp'

# define the path for processed MERIT-Basins dataset. Original retreived from␣
 ↪https://www.reachhydro.org/home/params/merit-basins []MERIT-Basins␣
 ↪hydrography (based on MERIT-Hydro v0.7/v1.0, minor bug fix for coastline␣
 ↪pixels)
mrb_basin_path = '/Users/kasrakeshavarz/Documents/geospatial-data/StMary-Milk/
 ↪MERIT-Basins/SMM_updown_select/smm_catchments.shp' # sub-basin layer
mrb_river_path = '/Users/kasrakeshavarz/Documents/geospatial-data/StMary-Milk/
 ↪MERIT-Basins/SMM_updown_select/smm_rivers.shp' # river layer

# define the paths for PFRA areas retireived from https://open.canada.ca/data/
 ↪en/dataset/c20d97e7-60d8-4df8-8611-4d499a796493
pfra_gross_path = '/Users/kasrakeshavarz/Documents/geospatial-data/PFRA-2013/
 ↪fgdb/fgdb/HYD_AAFC_INCRML_GROSS_DRAIN.gdb/' # 'Incremental Gross Drainage␣
 ↪Area' sub-basin layer
pfra_nca_path   = '/Users/kasrakeshavarz/Documents/geospatial-data/PFRA-2013/
 ↪fgdb/fgdb/HYD_AAFC_INCRML_NON_CTRB_DRAIN.gdb/' # 'Non-contributing Areas'␣
 ↪within 'Incremental Gross Drainage Areas' layer

# read pfaf74 from MERIT-Basins to add the non-contributing areas manually
# retreived from https://www.reachhydro.org/home/params/merit-basins␣
 ↪[]MERIT-Basins hydrography (based on MERIT-Hydro v0.7/v1.0, minor bug fix␣
 ↪for coastline pixels)
mrb_74_cat_path = '/Users/kasrakeshavarz/Documents/geospatial-data/MERIT-Basins/
 ↪MERIT_Hydro_v07_Basins_v01_bugfix1/pfaf_level_02/
 ↪cat_pfaf_74_MERIT_Hydro_v07_Basins_v01_bugfix1.shp'
mrb_74_riv_path = '/Users/kasrakeshavarz/Documents/geospatial-data/MERIT-Basins/
 ↪MERIT_Hydro_v07_Basins_v01_bugfix1/pfaf_level_02/
 ↪riv_pfaf_74_MERIT_Hydro_v07_Basins_v01_bugfix1.shp'
```

1.2.3 TGF, Transboundary Geospatial Fabric (Retreived from DOI 10.5066/P971JAGF)

[3]:
```
# Getting a list of all layers available in TGF
fiona.listlayers(tgf_path)
```

[3]:
```
['POIs', 'waterbodies', 'nhru', 'nsegment']
```

```
[4]: # reading different layers of interest
     tgf_basin = gpd.read_file(filename=tgf_path, driver='FileGDB', layer='nhru') #␣
      ↪sub-basin layer
     tgf_river = gpd.read_file(filename=tgf_path, driver='FileGDB',␣
      ↪layer='nsegment') # river network layer
```

1.2.4 HUC12 Geofabric for the SMM Area (Retrieved from ECCC, Jamie Kolodinsky)

```
[5]: # Reading the layer
     huc12_basin = gpd.read_file(filename=huc12_path) # sub-basin layer
```

Note: For the HUC12 layer, only the sub-basin layer is provided.

1.2.5 MERIT-Basins Geofabric Subset for the SMM Area (Retrieved from DOI 10.1029/2019WR025287

```
[6]: # read the layers
     mrb_basin = gpd.read_file(filename=mrb_basin_path) # sub-basin layer
     mrb_river = gpd.read_file(filename=mrb_river_path) # river network layer
```

1.2.6 PFRA Geofabric for the Canadian Prairies (Retrieved from Canada Open Data)

Based on PFRA layer's manual, the **'Incremental Gross Drainage Areas'** and **'Non-contributing Areas with Incremental Gross Drainage Areas'** are defined as following:

- The **"Incremental Gross Drainage Areas of the AAFC Watersheds Project - 2013"** dataset is a geospatial data layer containing polygon features representing the incremental gross drainage areas of the Agriculture and Agri-Food Canada (AAFC) Watersheds Project. The Project area is subdivided by hydrometric gauging station. The maximum area that could contribute runoff to each station, less that of its upstream neighbour(s) is called an 'incremental gross drainage area'. [pp. 13]

- The **"Non-contributing Portions of the Incremental Gross Drainage Areas of the AAFC Watersheds Project – 2013"** dataset is a geospatial data layer containing polygon features representing the areas within each incremental gross drainage area of the Agriculture and Agri-Food Canada (AAFC) Watersheds Project that DO NOT contribute to average runoff. The Project is subdivided by hydrometric gauging station. The maximum area that could contribute runoff to each gauging station, less that of its upstream neighbour(s) is called an "incremental gross drainage area". The "incremental gross drainage" areas can be subdivided into portions that either supply surface runoff to an average runoff, or do not. Those portions that are NOT part of the effective drainage area are called 'non-contributing'. [pp. 13]

```
[7]: # print the layers within each File GeoDataBase
     print('Gross layer includes: ', fiona.listlayers(pfra_gross_path))
     print('Non-contributing layer includes: ', fiona.listlayers(pfra_nca_path))
```

```
Gross layer includes:  ['HYD_AAFC_INCRML_GROSS_DRAIN']
Non-contributing layer includes:  ['HYD_AAFC_INCRML_NON_CTRB_DRAIN']
```

[8]:
```
# read layers
pfra_gross = gpd.read_file(pfra_gross_path, driver='FileGDB',␣
 ↪layer='HYD_AAFC_INCRML_GROSS_DRAIN') # 'Gross' sub-basin layer
pfra_nca   = gpd.read_file(pfra_nca_path, driver='FileGDB',␣
 ↪layer='HYD_AAFC_INCRML_NON_CTRB_DRAIN') # 'Non-contributing Area' sub-basin␣
 ↪layer
```

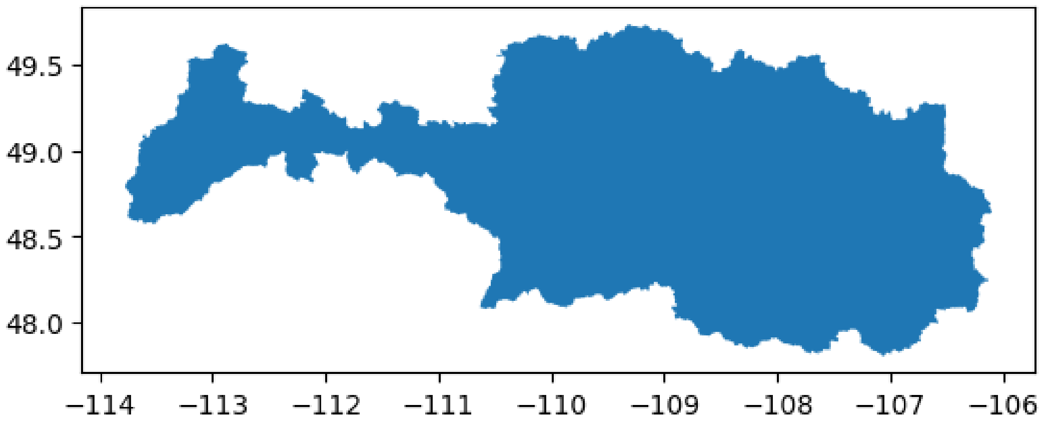
1.3 Necessary Pre-processings and Definitions

1.3.1 Boundary Layer

The `HUC12` layer is chosen to extract the boundary layer of the `SMM` system:

[9]:
```
smm_boundary = huc12_basin.dissolve()
smm_boundary.plot()
```

[9]:
```
<Axes: >
```



1.3.2 Modifying MERIT-Basins to include its non-contributing areas

The `MERIT-Basins` layer extracted for the `SMM` area, is based on the `get_all_upstream` of the EASYMORE package version 0.0.4. However, this function does not consider the non-contributing areas, as technically, these areas are not connected to the network extracted given the up-/downstream connectivity.

[10]:
```
## read pfaf 74 into GeoPandas DataFrames
mrb_74_cat = gpd.read_file(mrb_74_cat_path)
mrb_74_riv = gpd.read_file(mrb_74_riv_path)

## non-contributing (nca, or missing) COMIDs - extracted manually by looking at␣
 ↪the map on QGIS [FIXME later for automation]
```

```
nca_comids = [74000629, 74000612]
```

[11]:
```
# concatenation
mrb_basin = pd.concat([mrb_basin, mrb_74_cat.loc[mrb_74_cat.COMID.
 ↪isin(nca_comids), :]]) # adding missing nca comids to mrb_basin
mrb_river = pd.concat([mrb_river, mrb_74_riv.loc[mrb_74_riv.COMID.
 ↪isin(nca_comids), :]]) # adding missing nca comids to mrb_river
```

```
/Users/kasrakeshavarz/Documents/virtualenvs/jupyter/lib/python3.11/site-
packages/geopandas/array.py:1406: UserWarning: CRS not set for some of the
concatenation inputs. Setting output's CRS as WGS 84 (the single non-null crs
provided).
  warnings.warn(
```

[12]:
```
# resetting index
mrb_basin.reset_index(drop=True, inplace=True)
mrb_river.reset_index(drop=True, inplace=True)
```

1.3.3 Intersection/Overlap Extraction for TGF and PFRA

[13]:
```
# tgf overlapping with SMM boundary
tgf_overlapping_smm = gpd.sjoin(left_df=tgf_basin.to_crs(epsg=4326),
                                right_df=smm_boundary.to_crs(epsg=4326),
                                how='inner',
                                lsuffix='TGF',
                                rsuffix='HUC12')
```

[14]:
```
# extract `clipped` polygons
pfra_nca_clip_smm = pfra_nca.to_crs(epsg=4326).clip(smm_boundary.
 ↪to_crs(epsg=4326))
pfra_nca_clip_smm = pfra_nca_clip_smm[~pfra_nca_clip_smm.is_empty]
```

1.4 Analysis

1.4.1 Non-contributing Areas of each Geofabric Dataset

The `smm_boundary` is used as defined in 1.3. as the boundary layer:

For `HUC12`, the `tohuc` column contains values as `CLOSED BASIN` where it indicates the basin does not contribute to the overall flow of the system. Furthermore, the `areasqkm` columns shows the area of each sub-basin in km^2.

[15]:
```
# HUC12's non-contributing areas in km2
huc12_nca_smm = huc12_basin.loc[huc12_basin.tohuc == 'CLOSED BASIN', :]
```

For `MERIT-Basins`, the non-contributing areas are those that have a non-valid value assigned to their corresponding `NextDownID` in the `mrb_river` GeoDataFrame. Furthermore, the `unitarea` column of the `mrb_basin` GeoDataFrame (or `uparea` of `mrb_river`) shows the area of each non-contributing sub-basin in km^2.

[16]:

```
# MERIT-Basins's non-contributing areas in km2
mrb_nca_smm = mrb_basin.loc[mrb_river.NextDownID == 0, :]
```

For `TGF`, first, the layer is checked to see which polygons overlaps with the `SMM` area. Second, the overlaped areas are taken into account to calculate the non-contributing areas. The non-contributing areas are those sub-basin features with `Type_NCA` column values of `1` based on the metadata of the dataset. Moreover, the area of each sub-basin is printed under `Shape_Area` column of the `tgf_basin` GeoDataFrame in the unit of m^2.

[17]:

```
# TGF's non-contributing areas in km2
tgf_nca_smm = tgf_overlapping_smm.loc[tgf_overlapping_smm.Type_NCA==1, :]
```

For `PFRA`'s non-contributing areas, first the 'Non-contributing Areas within Incremental Gross Drainage Areas' layer is checked to see which polygons intersect with the `SMM` area. Second, the area of the **clipped** polygons are calculated after transforming their Coordinate Reference System (CRS) to EPSG value of `6931` based on Brodzik et al. (2023). The CRS transformation is done to get the best estimate of the areas (see the reference for more details.)

[18]:

```
# calculate areasqkm column
## transform to EPSG=6931 and calculate area. Then convert the unit to sqkm
pfra_nca_clip_smm['areasqkm'] = pfra_nca_clip_smm.to_crs(epsg=6931).area/1e6
## reorder columns
cols = pfra_nca_clip_smm.columns.tolist() # make a list of columns
cols = cols[:-2] + list(reversed(cols[-2:])) # reorder columns
pfra_nca_clip_smm = pfra_nca_clip_smm[cols] # assign new columns
pfra_nca_clip_smm.columns = pfra_nca_clip_smm.columns.tolist()[:-2] +␣
 ↪['areasqkm'] + [pfra_nca_clip_smm.columns.tolist()[-1]] # rename area column
```

1.4.2 Summary of Non-Contributing Areas of each Geofabric Dataset

[19]:

```
# Summary of the 4 geofabric layers
huc12_nca_area = huc12_nca_smm.loc[:, 'areasqkm'].sum() # in sqkm
tgf_nca_area = tgf_nca_smm.loc[:, 'Shape_Area'].sum()/1e6 # in sqkm
mrb_nca_area = mrb_nca_smm.loc[:, 'unitarea'].sum() # in sqkm
pfra_nca_area = pfra_nca_clip_smm.loc[:, 'areasqkm'].sum() # in sqkm
```

[20]:

```
# set precision number for pandas
pd.set_option("display.precision", 2)

# Temporary pandas DataFrame - only to show the numbers
print('Non-Contributing Areas of each Geofabric Datasets (in sqkm): ')
pd.DataFrame([
              ['HUC12', 'TGF', 'MERIT-Basins', 'PFRA'],
              [huc12_nca_area, tgf_nca_area, mrb_nca_area, pfra_nca_area]
             ],
              columns=range(1,5), index=['Geofabric', 'Non-Contributing Areas␣
 ↪(km2)']
).T
```

```
Non-Contributing Areas of each Geofabric Datasets (in sqkm):
```

[20]:

```
      Geofabric Non-Contributing Areas (km2)
1        HUC12                        2496.44
2          TGF                        4706.36
3  MERIT-Basins                        110.19
4         PFRA                        6743.34
```

NOTE: Since there is hole in the MERIT-Basins sub-basin polygons that was not delineated, an area of ±20 km^2 should be considered for the `MERIT-Basins` Non-contributing Areas.

1.4.3 Shared Non-Contributing Areas between Pairs of Geofabric Datasets

[21]:

```
# `common_area` intersects two layers and calculates total area (km2) in␣
 ↪EPSG=6931 projection
common_area = lambda gdf1, gdf2 : gpd.overlay(gdf1.to_crs(epsg=4326), gdf2.
 ↪to_crs(epsg=4326), how='intersection').to_crs(epsg=6931).area.sum()/1e6

# dictionary of geofabrics for SMM
nca_geo_dict = {'HUC12':huc12_nca_smm,
                'TGF':tgf_nca_smm,
                'MERIT-Basins':mrb_nca_smm,
                'PFRA':pfra_nca_clip_smm,
               }

# Pre-allocating a Pandas DataFrame to store the common NCAs between pairs of␣
 ↪datasets
common_nca = pd.DataFrame([], index=nca_geo_dict.keys(), columns=nca_geo_dict.
 ↪keys())

# Calculating common NCAs between datasets
for perm in permutations(nca_geo_dict, 2):
    common_nca.loc[perm] = common_area(nca_geo_dict[perm[0]],␣
 ↪nca_geo_dict[perm[1]])
```

[22]:

```
# set precision number for pandas
pd.set_option("display.precision", 2)

# only to show the numbers
print('Shared Non-Contributing Areas between Pairs of Geofabric Datasets (in␣
 ↪sqkm): ')
common_nca
```

```
Shared Non-Contributing Areas between Pairs of Geofabric Datasets (in sqkm):
```

[22]:

```
                HUC12      TGF MERIT-Basins     PFRA
HUC12             NaN  2244.07          0.0  1227.98
TGF           2244.07      NaN         0.73  2129.43
```

```
MERIT-Basins       0.0      0.73           NaN    109.01
PFRA           1227.98   2129.43        109.01       NaN
```

1.4.4 Visual Overview of Non-Contributing Areas of each Geofabric Dataset

[23]:

```python
def plot_nca(ax: plt.Axes,
             boundary: gpd.GeoDataFrame,
             nca_polys: gpd.GeoDataFrame,
             fig_size: tuple,
             title: str = None,
             nca_color: str = 'red',
             boundary_color: str = 'black',
             kwargs: dict = {},
):
    # plot boundary layer
    boundary.to_crs(epsg=3857).plot(figsize=fig_size, alpha=0.5,␣
 ↪facecolor=boundary_color, edgecolor='black', ax=ax, **kwargs)
    # plot NCA polygons
    nca_polys.to_crs(epsg=3857).plot(alpha=0.5, facecolor=nca_color,␣
 ↪edgecolor='black', ax=ax)
    # plot a basemap
    cx.add_basemap(ax, source=cx.providers.Stamen.Terrain, attribution_size=5)
    # setting the title
    if title:
        ax.set_title(title)
    # remove margins
    ax.margins(0)
    # adjust basemap
    basemap_pos = ax.get_position()
    ax.set_position([basemap_pos.x0, basemap_pos.y0, basemap_pos.width, 0.425])


    return ax
```

[24]:

```python
fig, axes = plt.subplots(2, 2, figsize=(15,10))

for a in axes.flatten():
    a.axis('off')
    a.margins(y=0)

# HUC12 dataset
plot_nca(ax=axes[0,0],
         boundary=smm_boundary,
         nca_polys=huc12_nca_smm,
         fig_size=(15,10),
         title='a) HUC12 Geofabric')
```

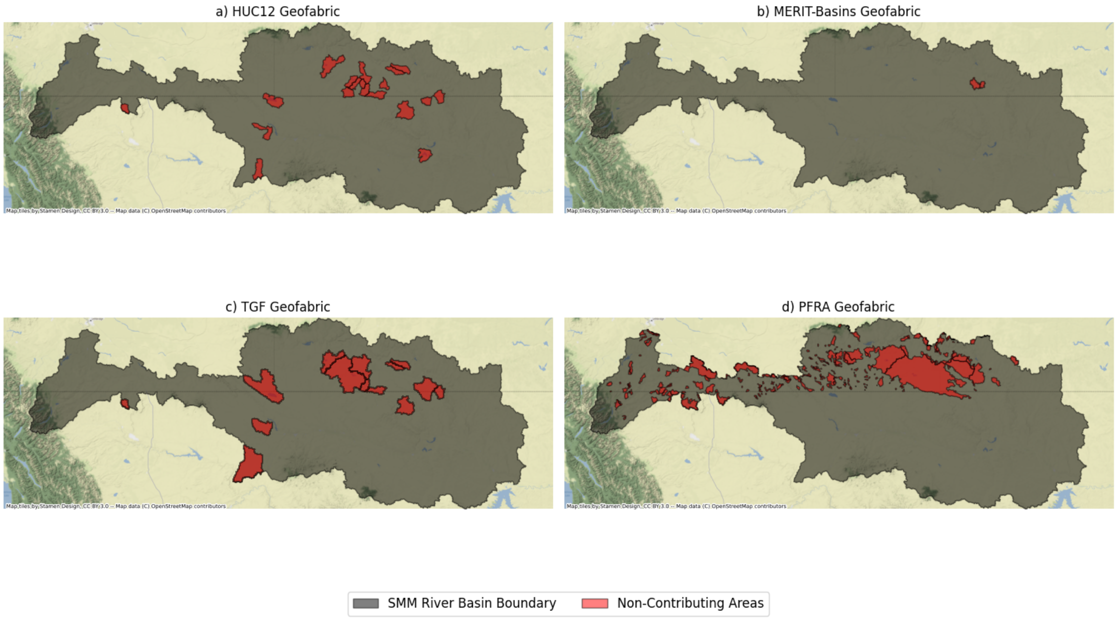
```python
# MERIT-Basins dataset
plot_nca(ax=axes[0,1],
         boundary=smm_boundary,
         nca_polys=mrb_nca_smm,
         fig_size=(15,10),
         title='b) MERIT-Basins Geofabric')

# TGF dataset
plot_nca(ax=axes[1,0],
         boundary=smm_boundary,
         nca_polys=tgf_nca_smm,
         fig_size=(15,10),
         title='c) TGF Geofabric')

# PFRA dataset
plot_nca(ax=axes[1,1],
         boundary=smm_boundary,
         nca_polys=pfra_nca_clip_smm,
         fig_size=(15,10),
         title='d) PFRA Geofabric')

# set legend items (common for all geofabric datasets)
legend_elements = [Patch(facecolor='black', edgecolor='black', alpha=0.5,␣
 ↪label='SMM River Basin Boundary'),
                   Patch(facecolor='red', edgecolor='black', alpha=0.5,␣
 ↪label='Non-Contributing Areas'),]

# set legend for the figure
fig.legend(handles=legend_elements, loc='lower center', fontsize=12,␣
 ↪frameon=True, ncols=2)
fig.tight_layout()
# plt.savefig("/Users/kasrakeshavarz/Desktop/test.png", bbox_inches='tight')
```


a) HUC12 Geofabric
b) MERIT-Basins Geofabric
c) TGF Geofabric
d) PFRA Geofabric
Map tiles by Stamen Design, CC BY 3.0 -- Map data (C) OpenStreetMap contributors
SMM River Basin Boundary
Non-Contributing Areas

[25]:
```
fig.savefig("./NCA.png", bbox_inches='tight')
```

2 Saving Produced Shapefiles

[26]:
```
import os
```

[27]:
```
# General folder to save outputs
try:
    os.mkdir('./Shapefiles')
except:
    pass # not a big deal if the directories already exist


# Creating folders for each dataset
try:
    for gdf_name in nca_geo_dict.keys():
        os.mkdir('./Shapefiles/'+gdf_name)
        os.mkdir('./Shapefiles/'+gdf_name+'/NCA_shapefiles')
        os.mkdir('./Shapefiles/'+gdf_name+'/Original_shapefiles')
except:
    pass # not a big deal if the directories already exist
```

[28]:
```
# save non-contributing shapefiles
for gdf_name, gdf in nca_geo_dict.items():
    # print NCA shapefiles
    gdf.to_file('./Shapefiles/'+gdf_name+'/NCA_shapefiles/'+gdf_name+'_NCA.shp')
```

```
/var/folders/rw/ngg2x10x2s139yr4lchhykz40000gn/T/ipykernel_8029/2306969324.py:4:
UserWarning: Column names longer than 10 characters will be truncated when saved
to ESRI Shapefile.
  gdf.to_file('./Shapefiles/'+gdf_name+'/NCA_shapefiles/'+gdf_name+'_NCA.shp')
/var/folders/rw/ngg2x10x2s139yr4lchhykz40000gn/T/ipykernel_8029/2306969324.py:4:
UserWarning: Column names longer than 10 characters will be truncated when saved
to ESRI Shapefile.
  gdf.to_file('./Shapefiles/'+gdf_name+'/NCA_shapefiles/'+gdf_name+'_NCA.shp')
```

[29]:

```
# save original shapefiles
## Making a dictionary of them
orignal_geo_dict = {'HUC12':huc12_basin,
                    'PFRA':pfra_gross,
                    'TGF':tgf_overlapping_smm,
                    'MERIT-Basins':mrb_basin,
}
## Saving them
for gdf_name, gdf in orignal_geo_dict.items():
    gdf.to_file('./Shapefiles/'+gdf_name+'/Original_shapefiles/
 ↪'+gdf_name+'_subbasins_original.shp')

## Saving mrb_rivers as well as it has non-contributing area information
mrb_river.to_file('./Shapefiles/MERIT-Basins/Original_shapefiles/
 ↪MERIT-Basins_rivers_original.shp')
```

```
/var/folders/rw/ngg2x10x2s139yr4lchhykz40000gn/T/ipykernel_8029/3954465540.py:10
: UserWarning: Column names longer than 10 characters will be truncated when
saved to ESRI Shapefile.
  gdf.to_file('./Shapefiles/'+gdf_name+'/Original_shapefiles/'+gdf_name+'_subbas
ins_original.shp')
/var/folders/rw/ngg2x10x2s139yr4lchhykz40000gn/T/ipykernel_8029/3954465540.py:10
: UserWarning: Column names longer than 10 characters will be truncated when
saved to ESRI Shapefile.
  gdf.to_file('./Shapefiles/'+gdf_name+'/Original_shapefiles/'+gdf_name+'_subbas
ins_original.shp')
```

3 Detailed Maps of Geospatial Fabrics for SMM

Since the higher quality maps are not material to reproducibility, they were created using QGIS, and produced Shapefiles saved above, and are printed under the `Maps` directory.

Please contact kasra.keshavarz1@ucalgary.ca in case of any questions.