Analyzing hydrologic flow: the Sudd Wetlands, South Sudan

Zoe Rosenblum

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http://web.engr.oregonstate.edu/~rosenblz

Introduction

Wetland ecosystems are important for biodiversity, habitat, flood mitigation, carbon sequestration, water purification, and many other functions. They embody characteristics of both terrestrial and aquatic ecosystems. As such, they can be rather elusive in remotely-sensed data. However, field surveys are often prohibitively expensive due to the remote and difficult terrain of many wetlands. This project seeks to determine the minimum amount of information needed to reasonably delineate wetlands using remotely-sensed data.

Specifically, this project uses a digital elevation model of South Sudan as a starting point for delineating the Sudd Wetland. The Sudd Wetland is one of the largest freshwater ecosystems in the world, and the largest wetland on the continent of Africa. It is located in the Nile River Basin (figure 1). A canal has been proposed to divert water from the Sudd Wetland downstream to Egypt. I want to understand and show on a map: how much surface water flows into the wetland; how much surface water flows out of the wetland (into the river); and, if possible, how that would change with the construction of the canal (using very rough estimates of water diversion projected).

The goal of this project is to understand the hydrologic system of the Sudd Wetland in South Sudan. Future research could include similar analyses of other wetlands in the Nile River Basin and beyond.

Site Description

The Sudd Wetland is a 30,000 to 40,000 km^2 marsh located in South Sudan in northeast Africa (Mohamed & Savenije, 2014). It is a riverine wetland riparian to the Nile River Basin, and fluctuates in size based on precipitation. The rainy season is typically from April to November (Petersen and Fohrer, 2010). The area is vast, remote, and still suffers security threats from recent civil war, rendering in-situ data collection prohibitively costly and dangerous (Sosnowski et al., 2016). Thus, mapping the wetlands and its connections to other waters using remotely-sensed data is important.

The Sudd Wetland is situated between the Al-Jabal River and White Nile River sub-basins. The wetland is seen as a “waste of water” by politicians in Egypt who seek to transport more water from the river directly, bypassing the wetland with the proposed Jonglei Canal. This research project uses two stream gages to investigate flow: the Malakal flow gage at the north end of the Sudd Wetland, and the Mongalla flow gage at the south end.

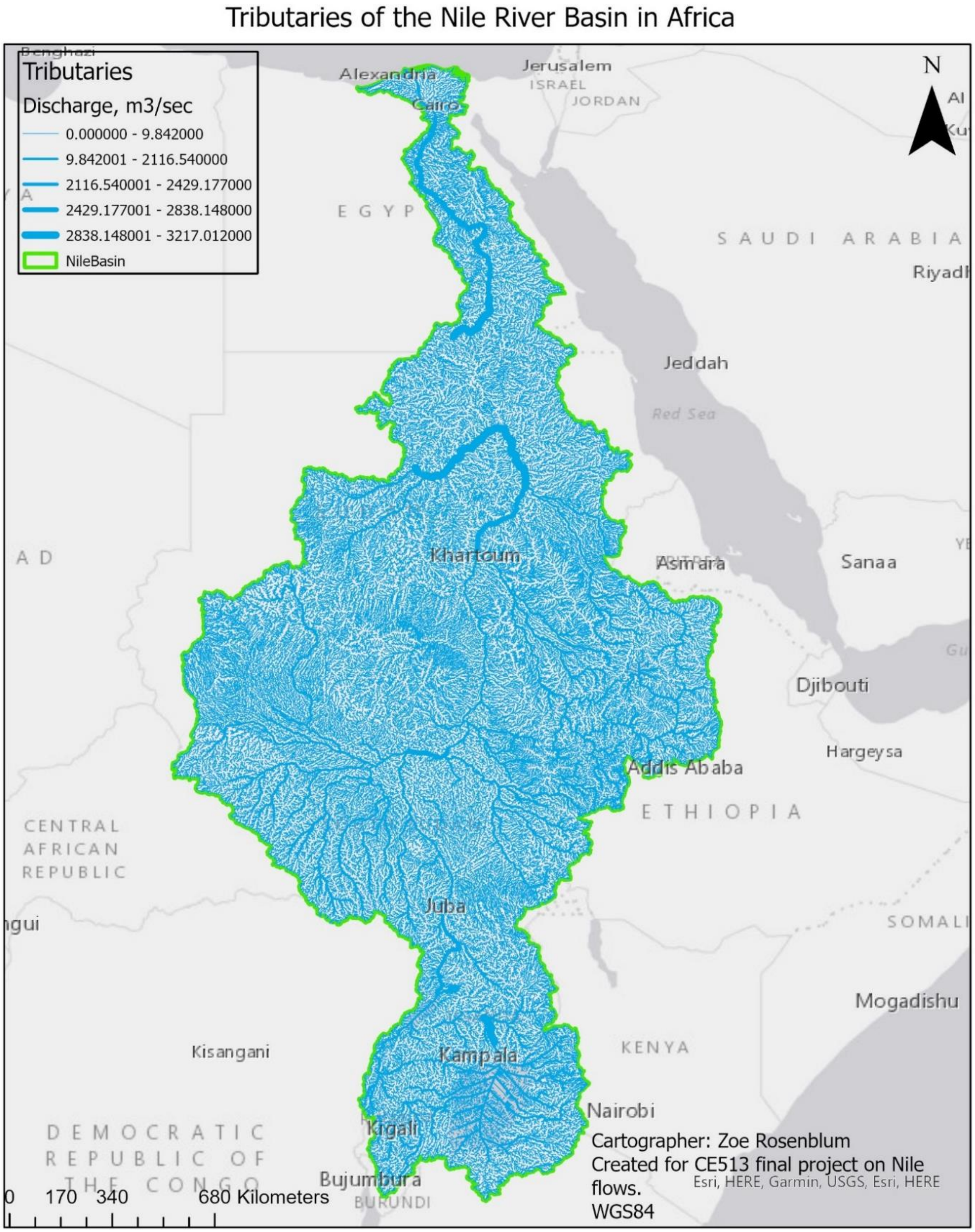

Figure 1. Map of the Nile River Basin with tributaries symbolized based on discharge in cubic meters per second.

Data

For this project, I used a variety of sources for hydrologic and land surface data (table 1).

Title	Projection	Units	Type	Source	Notes/Attributes used in project
Africa HydroBASINS	WGS 84	degrees	vector	https://www.hydrosheds.org/products/hydrobasins	Sub-basin area, distance from upstream headwaters
Africa HydroRIVERS	WGS 84	degrees	vector	https://www.hydrosheds.org/products/hydrorivers	Tributary length, Average discharge
NileRiverBasin	WGS 84	degrees	vector	https://transboundarywaters.science.oregonstate.edu/content/transboundary-freshwater-spatial-database	Shapefile for Nile Basin
GMTED2010 DEM	WGS 84	30 arcsec	raster	https://earthexplorer.usgs.gov/	Slope, aspect
Gaging Stat		Decimal degrees	x,y coordinates	https://www.compositerunoff.sr.unh.edu/html/Polygons/P1673600.html	x,y-coords, mean discharge (m3/sec)
Tropical Wetlands	WGS 84	degrees	raster	https://www2.cifor.org/global-wetlands/	Global wetland cover

Table 1. Description of data used in project.

Land Surface Data

I obtained the digital elevation model of the region through the USGS Earth Explorer application. I had to download two DEMs to cover my region of interest.

Hydrologic Data

To understand the hydrology of the region, I searched for information that would be comparable to the flowlines and HUC watersheds we used in class. I used the HydroBASINS and HydroRIVERS files from the HydroSHEDS project of the World Wildlife Fund. I downloaded files at the continent level (Africa) and then focused in first on the Nile River Basin, based on the Transboundary Freshwater Diplomacy Database spatial dataset, and then further honed in on the Sudd Wetland area in South Sudan. I used the basin area and length attributes, as well as the river length and discharge attributes.

I also wanted to explore in-field monitoring data, and found stream gage data available from the Global Runoff Data Centre supported by the University of New Hampshire. From their global dataset, I used gages located within the Nile River Basin (figure 2 and separate full-page attachment) and then further narrowed down to two gages within close proximity of the Sudd Wetlands.

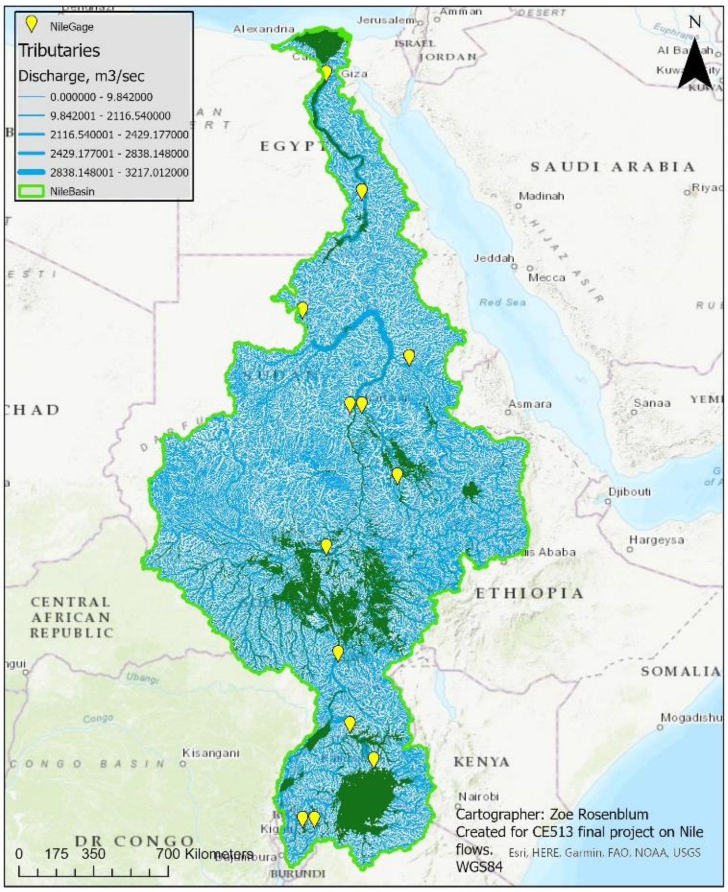

Figure 2. Snippet of tributaries, gages, and wetlands in the Nile River Basin.

Lastly, I needed a shapefile of the wetlands to locate the Sudd Wetlands. I was unable to find a shapefile specifically for the Sudd Wetlands, so I used the Sustainable Wetlands Adaptation and Mitigation Program global wetland raster, which covers the tropics and subtropics. I then used a mask of the Nile Basin to display only the wetlands in the Nile, and then further extracted the raster by the mask of the Sudd Wetlands boundary I created.

Methods

For this project, I pieced together many different datasets. Perhaps the most time-consuming steps were downloading and re-projecting the data, defining the study area boundary, and then extracting the many layers to the defined region of interest. Aside from the processing steps, I generally followed the steps we used in exercise 4 to delineate the watersheds and convert from the DEM to vector features (figure 3).

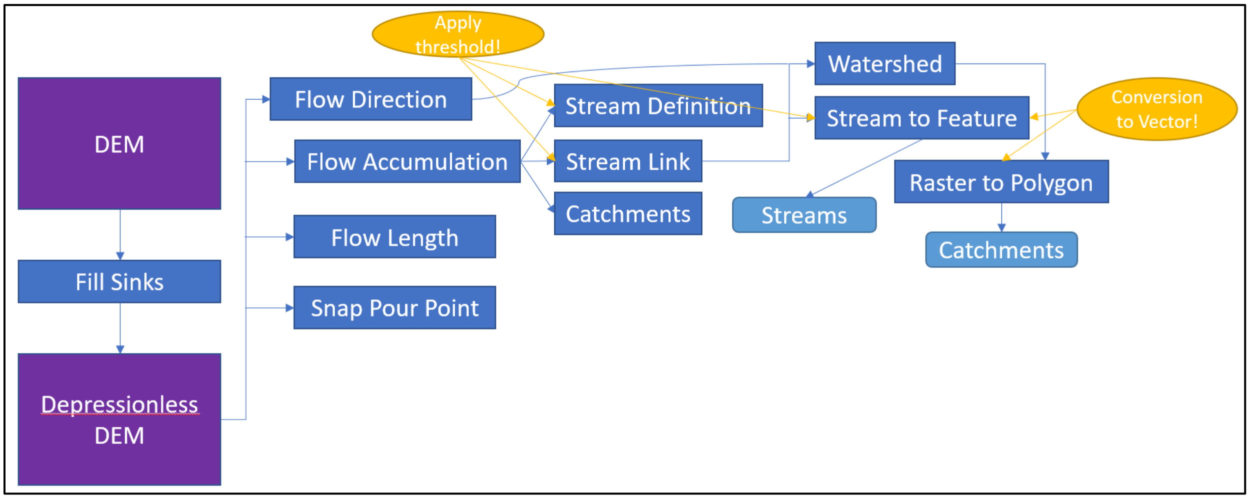

Figure 3. Flowchart of processing steps to go from a DEM to vector features.

Results

1. Watershed Tool
   I used the Watershed tool, as described in Exercise 4, to identify the catchment for the Malakal Stream Gage. To my surprise, the catchment delineated is quite small (Figure 4). The attribute table for the output watershed indicates an area of 1.48 km^2. Due to the small size of this delineated watershed, I decided to broaden the area of interest to include the entirety of the Sudd Wetlands.

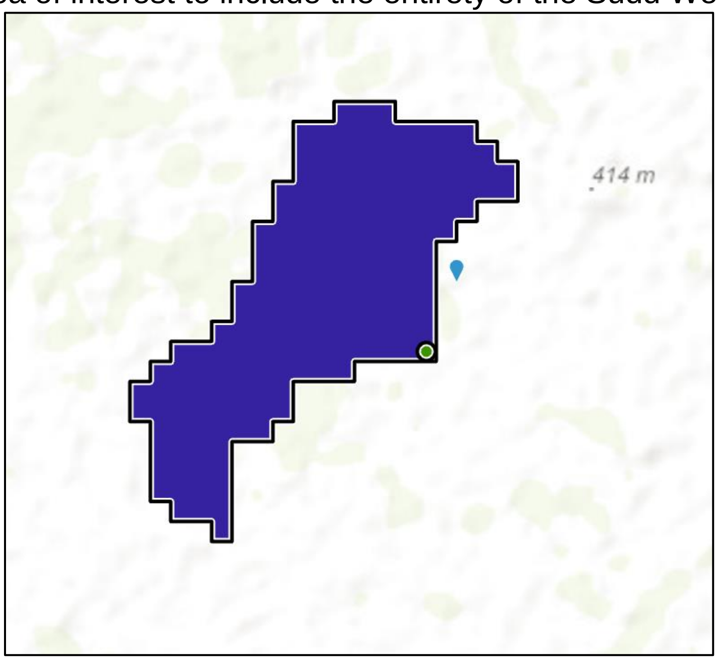

Figure 4. Snippet of the catchment delineated by the Watershed tool for the XY coordinates of Malakal Gage.

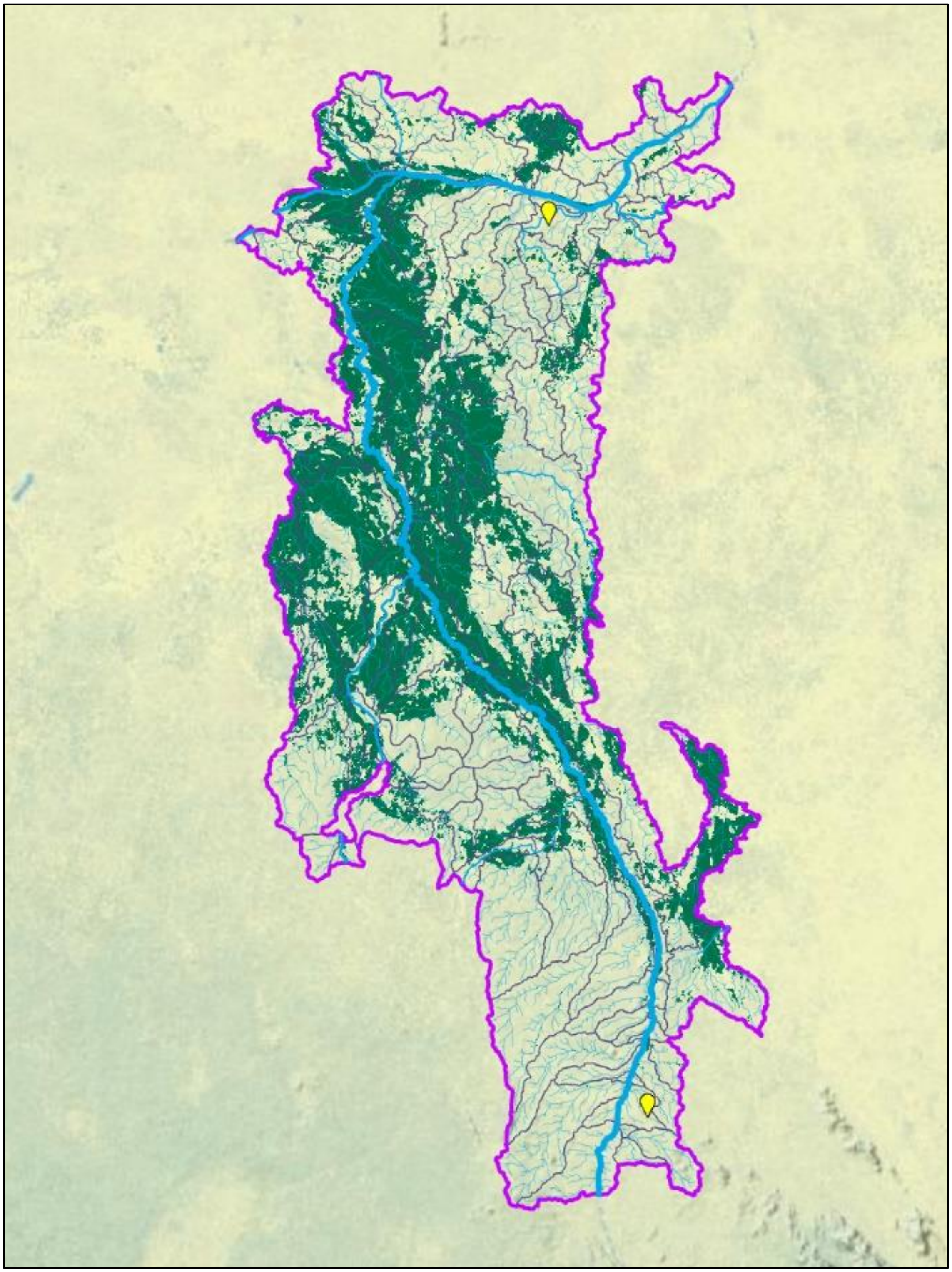

Figure 5. Snippet of the region interest: the Sudd Wetlands, tributaries, HUC8 watersheds, and stream gages.

2. Wetland Boundary Delineation
   To make my study area more manageable (smaller than the Nile River Basin) and more relevant (larger than the Malakal Gage delineated Watershed), I delineated a watershed based on the HUC8 attribute “Main Basin.” In this way, I selected all of the HUC8 basins in the Nile River Basin that had a common main basin that was the same as the Sudd Wetland, and exported those as a new feature dataset to my geodatabase. I then used the “Pairwise Dissolve” tool to create a watershed boundary (pink line in snippet, figure 5).
   I then used the watershed boundary as a mask by which to extract the raster layers (wetlands and DEM). I used the “Raster to Polygon” tool to convert the wetlands into a polygon. I used the watershed boundary to “Select” the gaging stations and tributaries (HydroRIVERS) with their center in the boundary, and then exported each of those as new feature classes to the geodatabase.
   The defined study area includes 126 HUC8 watersheds.

3. DEM
   I explored the raster statistics (figure 6), filled the sinks, and used the raster calculator to investigate the topography. The area is rather flat, and I am concerned that wetlands were filled in, so I decided to ditch the idea of further investigating raster statistics for my analysis.

Statistics

Build Parameters: skipped columns: 1, rows:

Band Name	Minimum	Maximum
Band_1	387	1109

Raster Information

Columns	15725
Rows	32366
Number of Bands	1
Cell Size X	20
Cell Size Y	20

Figure 6. Snippets of raster statistics for DEM after projection to UTM Zone 34N.

4. Hydrology
   At the north end (outflow) of the Sudd Wetlands, the Malakal Gage drainage area is 1080000 km^2 with a mean discharge of 938.57 m^3 per second. At the south end (inflow), the Mongalla Gage drainage area is 450,000 km^2 with a mean discharge of 1050.25 m^3 per second.
   The proposed Jonglei Canal project would divert approximately 140 m^3 per second mean annual discharge from Mongalla to Malakal (Allam et al., 2018).
   I used the attribute table for the HUC8 layer and calculated the summary statistics for the sub_area field, which is the area (in km^2) of each HUC8 polygon). The total watershed area is 100310.8 km^2. I also calculated the total

tributary length like this; the total tributary length in the Sudd Wetland “basin” is 22,014 km. I used excel to calculate the drainage density of each HUC8 and the whole basin (drainage density is equal to the length of all tributaries in the basin divided by the area of the basin). The drainage density is 0.219 km/km^2.

Challenges and Limitations

The two biggest challenges during this project were accessing data and working with large files. In class, we focused on the United States, for which data is abundant and fairly easy to access. In order to access datasets for the Nile Basin, I had to do a lot searching and comparing files. I also had to read research papers and reports to determine the rough location of the Sudd Wetlands. Furthermore, the files I worked with were enormous compared to the files we used in class. I crashed ArcGIS countless times, and ran out of storage space on multiple thumb drives and OSU file drives. In the future, I will make sure to work in a location with plenty of space from the start!

Future Research

This research project relies on existing datasets and extrapolation to get a sense of how much water is “lost” to the Sudd Wetlands. In future studies, I would recommend comparing wetland datasets to ensure the ecosystem is fully represented and accounted for. This could also include using remote sensing to locate the wetland of interest, rather than extrapolating from comparing datasets. Furthermore, a more comprehensive study of the Sudd Wetlands requires more in situ data collection. To understand wetland hydrology, a field-based experiment with piezometers and water level loggers should be installed. This will allow for more precise understanding of how much surface water enters and exits the wetland.

References:

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