A Hydrological Analysis of Sogndalselvi Watershed Using ArcGIS, Nevina and the Rational Method

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Abstract: Climate change has severely threatened global water resources, and has resulted in shifting precipitation patterns. The consequences of these changes will gravely impact communities and ecosystems, causing great socio-economic and environmental damages. While Norway's vulnerability to climate change is low compared to other countries, the country will suffer from adverse effects of climate change unless preventive and mitigative measures are taken. Under the RCP8.5 scenario adopted by the Intergovernmental Panel for Climate Change, Norway will experience an annual precipitation increase of ca.18%. In order to assist in climate adaptive measures to be taken in Norway, a hydrological analysis of the Sogndalselvi Watershed was conducted in this study. ArcGIS and Nevina were used to determine the characteristics of the watershed and sub-watersheds. The Rational Method was used to calculate the 200-year flood discharge of each sub-watershed. This study provides an overview of the characteristics, discharge and sensitivity to land use change of ten major sub-watersheds of Sogndalselvi.

1.0 Introduction:

Global water resources are facing a wide range of threats due to climate change.
As temperatures increase, precipitation patterns will shift and affect aquatic ecosystems. Increased frequency of precipitation will contribute to water quality degradation, more runoff, and increased probability of extreme weather events such as floods. As a consequence of decreased water quality and environmental degradation caused by unprecedented precipitation, communities around the world will face water scarcity and huge socio-economic losses (American Rivers, 2019). In 2015, Storm Synne, an extreme precipitation storm, caused heavy flooding in Southern Norway. This storm affected more than 100 families and caused heavy socio-economic damage (FloodList News, 2015). Additionally, in 2019, a flood triggered by heavy precipitation affected over 150 people in South Western Norway (FloodList News, 2019).

Norway was ranked 106th in the Global Climate Risk Index 2021 by Germanwatch (Germanwatch, 2021). This index analyses the extent to which countries are affected by extreme weather events, with the ranking of 1 given to the most vulnerable country (Germanwatch, 2021). Despite its low vulnerability to climate change, the country is expected to suffer consequences of this global crisis unless preventive and mitigative measures are taken. The extent to which Norwegian communities will be affected by shifting weather and precipitation patterns is majorly dependent on past and current choices made regarding the protection of natural resources and ecosystems. For instance, under the RCP8.5 scenario adopted by the Intergovernmental Panel for Climate Change (IPCC), annual precipitation in Norway will increase by ca.18%, which will cause floods induced by precipitation to increase in frequency and magnitude (Norwegian Centre for Climate Services, 2017). This will have serious implications for human life, property, infrastructure, as well as natural habitats and ecosystems.

Considering this information, a hydrological analysis of the Sogndalselvi Watershed (Figure 1) is conducted in this study. Sogndalselvi is the main river found in the Sogndal watercourse in the Sogndal municipality in Sogn og Fjordane, Western Norway. It flows from Dalavatnet To Sogndalsfjorden (NVE, 2009). The study area covered 17,400 hectares which included the ten major sub-watersheds of Sogndalselvi. This area included lakes, glaciers, forests, mires, cropland, urban areas and areas with bare rock.

The repercussions of climate change will have severe impacts on urban communities and natural ecosystems, which will not only threaten health and the quality of life, but will also lead to the grave suffering of the global economy. Therefore, it is crucial to take necessary steps to mitigate the impacts of climate change. The purpose of this study was to assist in the climate adaptive measures to be taken in Norway. This hydrological analysis will help in future urban planning and development for the study area. The research findings of this study will also provide a helping hand in the management of floods, landslides, runoff, and aquatic life. Moreover, this study can be used as a blueprint for future research studies to be conducted in other water bodies.

This study aims to answer the following research questions:

- **What are the ten major tributaries of the Sogndalselvi watershed?**
- **What are the characteristics of the watershed? (Area, topography, slope, aspect, land-use, elevation range, and drainage/stream density)**
- **What are the different discharge contributions to Sogndalselvi by the ten major tributaries?**
- **What is the sensitivity of each sub-watershed to changes in land-use?**

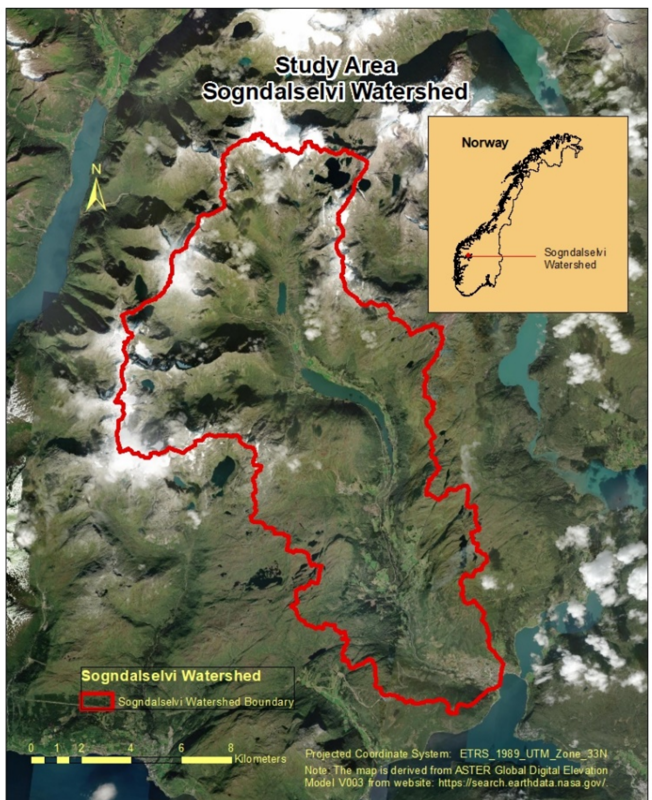


Figure 1.0 – Sogndalselvi watershed boundary

2.0 Methodology:

2.1 Spatial Analysis of Watershed and Sub-watersheds:

Stream discharge at a particular point in a watershed is affected by different factors such as slope, elevation, aspect, and stream order so the spatial analysis of these characteristics was performed in ArcGIS 10.3 with the help of Hydrology tools under Spatial Analyst tools. The ASTER Global Digital Elevation Model (DEM) V003 for the purpose of analysis was taken from the website (Figure 2.0): https://search.earthdata.nasa.gov/.

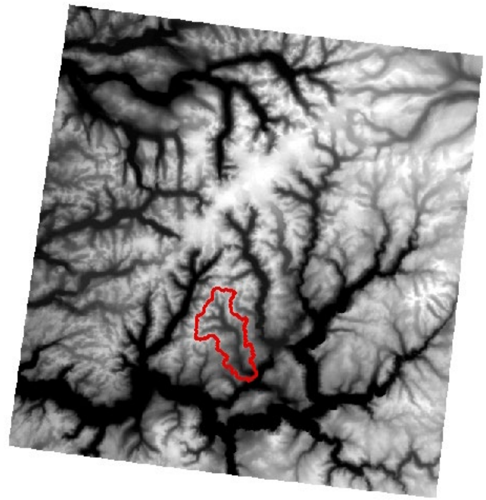


Figure 2.0 – Digital Elevation Model of the study area

At first, the study area was delineated, and it was used to crop the DEM raster to reduce the image processing time later during map production. Subsequently, the Watershed boundary was delineated which was used to clip the DEM raster afterward. The Fill tool under Hydrology tool was used to fill the sinks (depressions) in the DEM raster. The raster was then used to calculate flow direction, flow accumulation, stream order, slope, elevation, aspect, and drainage/stream density. The Flow accumulation value of more than 1000 was used to create a stream flow raster with high accumulated flow. This means that the cells that have more than 1000 cells flowing into them are used to define the stream flow network.

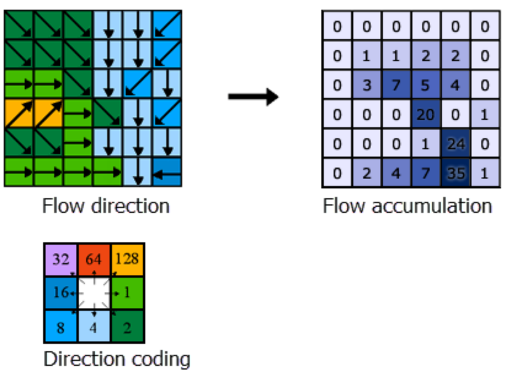


Figure 3.0 – Flow accumulation map process visualization

2.2 Strahler Stream Order:

Strahler method uses the rule of streams intersection to determine and assign orders to certain streams in a stream network. According to the rule, the stream without any tributaries is assigned an order of 1 and the stream is named “first order”. The order number increases as the streams with the same order join together. In case two streams with different order join together, the resulting stream order will be the same as that of the stream with higher order. The highest stream order will be the stream at the outlet. The discharge increases as the streams combine on its way

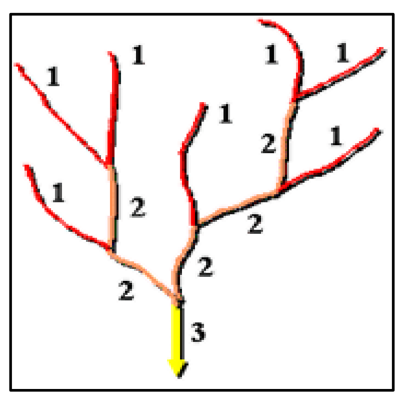


Figure 4.0 – Strahler Stream order processes visualization

to the outlet, so it is essential to determine the stream order (Esri, n.d.-b).

2.3 Drainage/Stream Density Map:

Density tool under the Spatial Analyst tool, was used to calculate the density of certain input features within an area around each output raster cell. In this project, the streamlines with orders were our input feature. The density map hence generated shows where the points or lines are concentrated. Mathematically, it is the ratio of the sum of length of lines to the area of the circle enclosing the lines (Esri, n.d.-a).

Density = ((L1 * V1) + (L2 * V2)) / (area_of_circle)

Where,

L1 and L2 are the length of portion of lines falling within the circle

V1 and V2 are the corresponding population field values (Stream order)

The area of the circle can be adjusted manually, but it was kept default for this project.

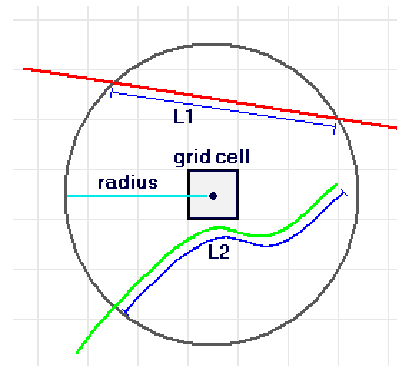


Figure 5.0 – Visualization of stream density calculation process

There are basically two types of Density we can compute in ArcGIS for Line features. They are Line Density and Kernel Density. The Line Density tool calculates the length per unit area from the polyline features that fall within a fixed radius around each cell, but the Kernel Density tool calculates the length per unit area of the polyline features using a kernel function to fit a smoothly shaped surface to each polyline feature (Esri, n.d.-a).

It is important to compute drainage/stream density because a high density represents:

- A "matured", well-developed channel system
- Surface runoff moves rapidly from hillslopes (overland flow) to channels
- Thin/deforested vegetation cover
- Basin rocks/soils/surface has generally low infiltration rate
- It also describes the texture of a stream network.

Slope and Aspect are calculated with the help of slope tool and aspect tool under the Spatial Analyst tool. The slope was classified into 3 classes namely, low (0-15)º, medium (15-30)º, and high (30 and above)º

Elevation map was generated by classifying the elevation range (in meters) into 5 different classes namely, very low (0-315)m, low (315-630)m, medium (630-945)m, high (945-1260)m, and very high (1260-1582)m from the mean sea level.

2.4 Rational Method for 200-Year Discharge Calculation:

The Rational Method for determining Peak Discharge in response to a given rainfall intensity and watershed characteristics is suitable for small watersheds with no significant flood storage. It provides us with a peak discharge value for a certain year extreme flood event to design flood (Thomason, 2019).

2.5 Assumptions and limitations (Thomason, 2019):

- The method is useful if time of concentration (tc) is less than duration of peak rainfall intensity.
- Rainfall intensity is assumed uniform throughout the duration of the storm.
- The frequency of occurrence for the peak discharge should match the frequency of the rainfall producing that event.
- Rainfall is uniform over the drainage area.
- The duration used for computing rainfall intensity should be less than 10 minutes. In case it is less than 10 minutes, the 10 minutes should be used to compute rainfall intensity.
- The method does not account for storage in the watershed. All storage is assumed to be filled.
- The method does not compute a time series of flow nor flow volume, but only provides a peak discharge value.

Mathematically, the Peak Discharge (Q) is given by the following formula.

$Q = C * i * A * Sf$

where,

Q = Peak discharge (l/s)

C = Average runoff coefficient (0 to 1)

i = Rainfall intensity (l/s*ha)

A = Area of watershed (ha)

Sf = Safety factor = Climate factor (for Norway Sf is 1.4)

2.6 Runoff coefficient (c):

It is a dimensionless coefficient which relates the amount of runoff to the amount of precipitation received in a particular area. Its value depends on the type of land uses. Higher value corresponds to the area with low infiltration and high runoff and lower value corresponds to permeable land surfaces such as well vegetated areas, forest and flat land surface. Therefore, it is determined with the help of soil type, gradient, permeability, and land use but due to lack of data, only gradient and land use was used to determine runoff coefficient in this Project. Higher value was assigned for land use classes with steeper slopes and vice-versa (The California Water Boards, 2011).

Surface category (Land use classes)	Runoff coefficient (c)
Concrete, asphalt, bare rock	0.6 - 0.9
Gravel roads	0.3 - 0.7
Agricultural land, parks, and other green areas	0.2 - 0.4
Forest	0.2 - 0.5
Glacier and Lake	0.5

Table 1.0: Runoff coefficient and surface category (Dunse, 2020)

Area of each sub-watershed was obtained from reports generated in Nevina tool and the area-weighted mean coefficient was calculated for sub-watersheds with multiple land-use classes:

$$C = \frac{(C_1 * A_1 + \ \dots + C_n * A_n)}{A} = \frac{1}{A}\sum_{i=1}^{n} C_i * A_i$$

Where,
C_i is runoff coefficient for land use class i
A_i is area of land use class i

2.7 Rainfall Intensity (i):

Rainfall Intensity is average rainfall rate per ha. It is derived against Time of concentration (Tc) from IVF (Intensity-duration-frequency) curve for 200-years flood event (Dunse, 2020).

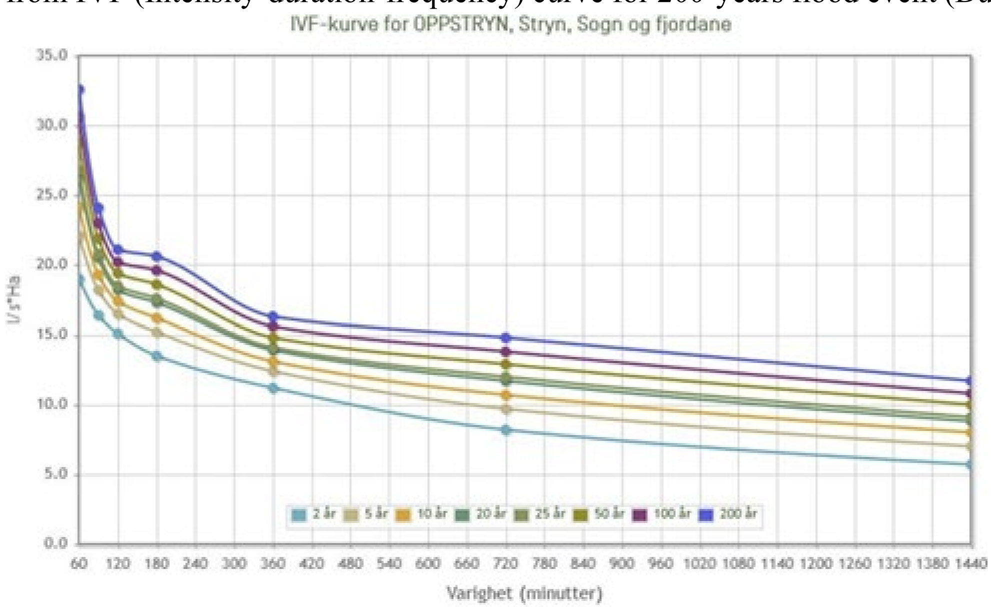


Figure 6.0 – Intensity Duration Frequency (IDF) curve obtained from klimaservicesenter.no

2.8 Time of concentration (Tc):

It is the time taken for the entire watershed to contribute to the runoff to its outlet.
Tc = 0.6 * L * H -½ + 3000 * Pl
Where,
Tc is time of concentration (minutes)
L is watershed length (meters),
H is height difference (meters), and
Pl is effective lake area (in percentage)

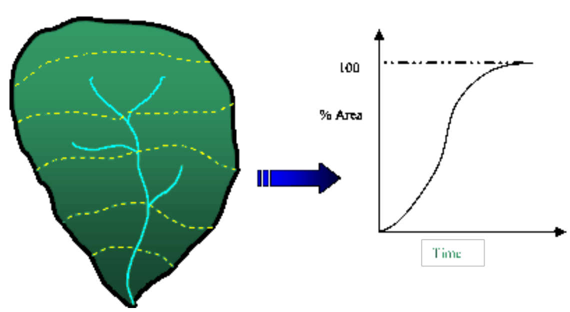


Figure 7.0 – Time of concentration (Tc) visualization

Note: Length and height difference of each sub-watersheds are obtained from reports generated in Nevina

2.9 Effective Lake Area (Pl):

It is the area of the watershed contributing to the discharge at the outlet of the lake. It is obtained from Nevina.

$$P_l := 100 * \frac{1}{A^2} \sum_{i=1}^{n} A_i * a_i$$

Where, A is watershed area, *Ai* is the contributing area to the lake and *ai* the lake area.

2.10 Climate factor:

It is a safety factor used in the rational method for determining peak discharge assuming that uncertainties might happen in future with changes in climate (Koutsoyiannis & Xanthopoulos, 2014). It is recommended to apply a safety factor of 1.4 for the projects in Norway (Dunse, 2020). Such factors increase the reliability of the flood design (Koutsoyiannis & Xanthopoulos, 2014).

2.11 Sensitivity to discharge with changes in land use:

The changes in land use impacts the runoff coefficient and the effective runoff area which in turn impacts the peak discharge at the outlet (Dunse, 2020). Therefore, in order to observe sensitivity of discharge with changes in land use, the forest area of 30 ha (0.3 sq.km.), which is the largest covering land use class in all sub-watershed, was converted to urban area in the analysis.

3.0 Results and Discussion:

The results of this study fall into two categories. The first are the characteristics of the full watershed and sub-watersheds which were determined using both ArcGIS and Nevina. These tools determined the stream order, size, slope, aspect, land use, and other key watershed defining characteristics. The second category of results are those concerning 200-year flood discharge and they were determined using the Rational Method. These focus on the discharge of each sub-watershed, how they compare to one another, the entire watershed, and how they might be impacted by changes in land use.

3.1 Characteristics

3.1.1 Stream Order and Stream Length

A Strahler Stream Order analysis was done to determine the streams with the most contributing tributaries that feed Sogndalselvi. 8 streams were identified to have stream orders of 2 or higher and were selected as significant contributors to Sogndalselvi (Figure 8.0). To determine the remaining 2 significant contributing streams, the length of the streams and the size of their contributing watersheds were measured using ArcGIS and Nevina. Through this method Sub-watershed 8 and Sub-watershed 10 were added to our list of significant streams.

The watersheds of these 10 streams are somewhat evenly divided with 5 sub-watersheds east of the river and 5 sub-watersheds west of the river.

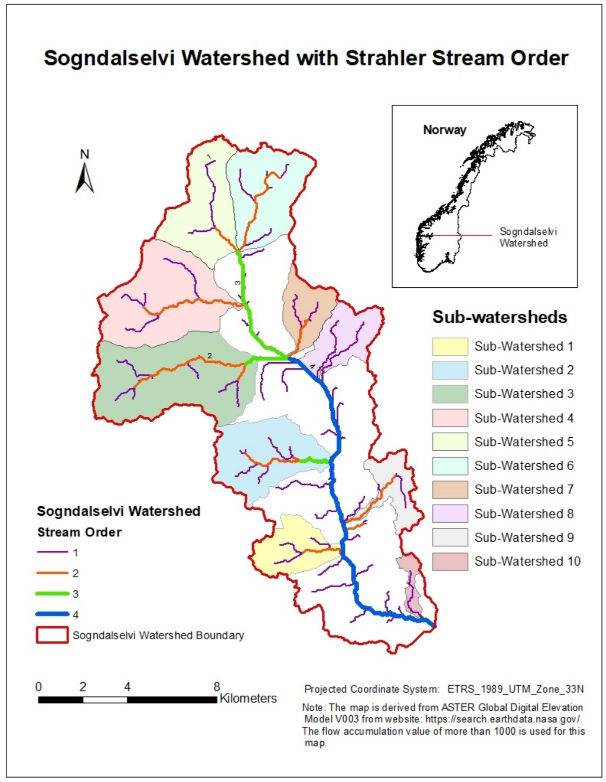


Figure 8.0: Strahler Stream Order analysis map depicting the streams that form the basis of the sub-watersheds the two additional significant streams and sub-watersheds (SW 8 and SW10).

3.1.2 Area

The average sub-watershed area is 10.50 km^2 but the range in size is wide with a standard deviation of 6.77 km^2. The smallest sub-watershed is 1.57 km^2 (SW 10) and the largest is 23.22 km^2 (SW 3). The combined area of the sub-watersheds is 105 km^2, only accounting for 60% of the total 174 km^2 of the Sogndalselvi watershed.

Sub-Watershed	Sub-watershed Area (km^2)	Percent of total Watershed
SW1	6.9728	4.01%
SW2	13.0459	7.50%
SW3	**23.2243**	**13.35%**
SW4	18.5493	10.66%
SW5	12.5571	7.22%
SW6	12.7653	7.34%
SW7	5.5808	3.21%
SW8	6.1146	3.51%
SW9	4.6139	2.65%
SW10	**1.5707**	**0.90%**
All Sub-Watersheds	104.9947	60.34%
Average Sub-watershed	10.49947	6.03%
Standard Deviation	6.772443042	3.89%
Total Songdalselvi Watershed	174	100.00%

Table 2.0 - Watershed and sub-watershed areas in km2 and as a percentage of the entire Sogndalselvi watershed. The largest and smallest watersheds are in bold

3.1.3 Elevation and Slope

Sub-watershed elevation differences and slopes are similar to areas in that they have a wide range of values. The average elevation was 907 meters above sea level and the standard deviation was 330 meters. Generally speaking, the highest elevation differences were located in the northwest area (Annex 1.0 and 2.0) in the Sogndalselvi watershed, these include SW 3, SW 4, SW 5, SW 6 and SW 7, all of which had over a 1,100 m change in elevation (Table 3.0). The average of all the average sub-watershed slopes was 190 with a standard deviation of 6.56. Geographic dispersion of steep slopes generally followed that of large elevation differences, with the steepest slopes being located in the north and northwest areas of the watershed.

Sub-Watershed	Elevation Difference (m)	Average Slope (degrees)
SW1	**162**	13.1
SW2	1014	13
SW3	**1196**	26
SW4	1162	27.7
SW5	1134	**28.4**
SW6	1124	23
SW7	1110	17.3
SW8	833	15.1
SW9	656	**12**
SW10	665	14.5
Average	905.6	19.01
Standard Deviation	330.30	6.56
Songdalselvi Watershed	1600	20.5

Table 3.0 - Elevation Difference and Average Slope. Maximum and minimum values are in bold.

3.1.4 Aspect and Flow Accumulation

Aspect and flow accumulation were both mapped across the entire watershed using ArcGIS (Annex 3.0 and 4.0). The results gave a better understanding of the Sogndalselvi watershed and the 10 significant sub-watershed. The aspect map revealed that the east side of Sogndalselvi was dominated by west facing slopes whereas the east side had more north and south facing slopes.

3.1.5 Line and Kernel Density

Line and Kernel Density maps were also produced on a full watershed scale (Annex 5.0 and 6.0). These maps, like the aspect and flow maps, also helped better understand the characteristics of the full watershed and were used as a reference when doing further evaluation. The maps reveal that the top of the watershed has a lower density of contributing streams and the river increases in line and Kernel density as it approaches the outlet.

3.2 Discharge Analysis

3.2.1 Current 200-year Flood Discharge

Using the Rational Method, the precipitation intensity, runoff coefficients, and 200-year flood discharge was determined for all 10 sub-watersheds and for the Sogndalselvi watershed (Table 4.0). The discharges were calculated with and without a climate (i.e. safety) factor of 1.4. Discharge was also calculated with a land-use transformation from forest to urban in 0.30 km^2 of each sub-watershed where possible.

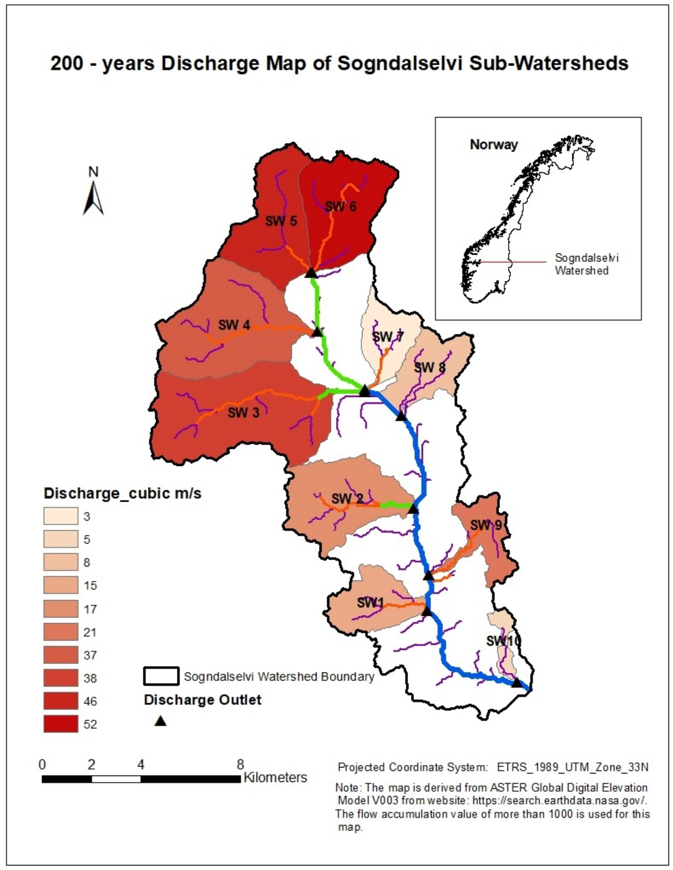


Figure 8.0 – 200-year Discharge Map

The combined total discharge of all 10 sub-watersheds is 87.58% of the discharge calculated for the entire Sogndalselvi watershed. The majority of discharge is contributed from the sub watersheds west of the river (SW1 - SW5). Area seems to be a major determining factor as the sub-watersheds with the largest and smallest area (SW 3 and SW 10) were also the sub-watersheds with the largest and smallest discharges.

Sub-Watershed	Sub-watershed Area (km^2)	Runoff Coefficient [0-1]	Rainfall intensity (cm/s*m^3)	200-yr Flood Discharge (m^3/s)
SW1	6.97	**0.30**	**200**	4.13
SW2	13.05	0.46	250	15.13
SW3	**23.22**	0.76	210	**36.91**
SW4	18.55	0.77	230	32.78
SW5	12.56	0.79	270	26.68
SW6	12.77	**0.81**	260	26.95
SW7	5.58	0.72	310	12.38
SW8	6.11	0.68	260	10.85
SW9	4.61	0.59	210	5.71
SW10	**1.57**	0.34	**330**	**1.79**
All Sub-Watersheds	104.99	N/A	N/A	173.31
Sub-Watershed Average	10.50	0.62	253	17.33
Standard Deviation	6.77	0.19	43	12.58
Songdalselvi Watershed	174	0.71	160	197.89

Table 4.0 - Calculated areas, runoff coefficients, rainfall intensities, and 200-year flood discharges for all 10 sub-watersheds and the entire Sogndalselvi watershed. Minimum and maximum values are in bold.

3.2.2 Climate Factor

Adding a climate factor of 1.4 demonstrated that on average, the 10 sub-watersheds could contribute an excess of over 69 cubic meters per second to the river compared to the present day. SW3's discharge was raised to 51.67 m^3/s and SW 10 was 2.50 m^3/s (Chart 1.0).

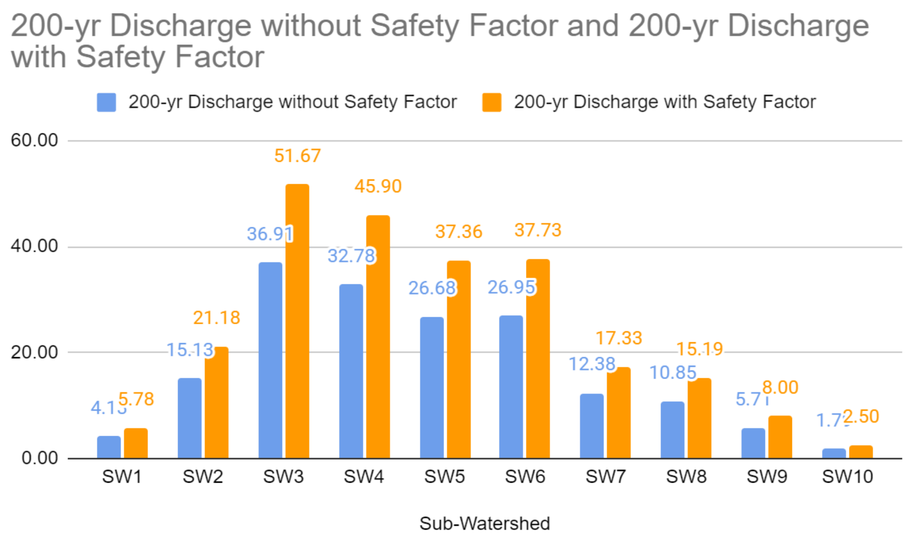
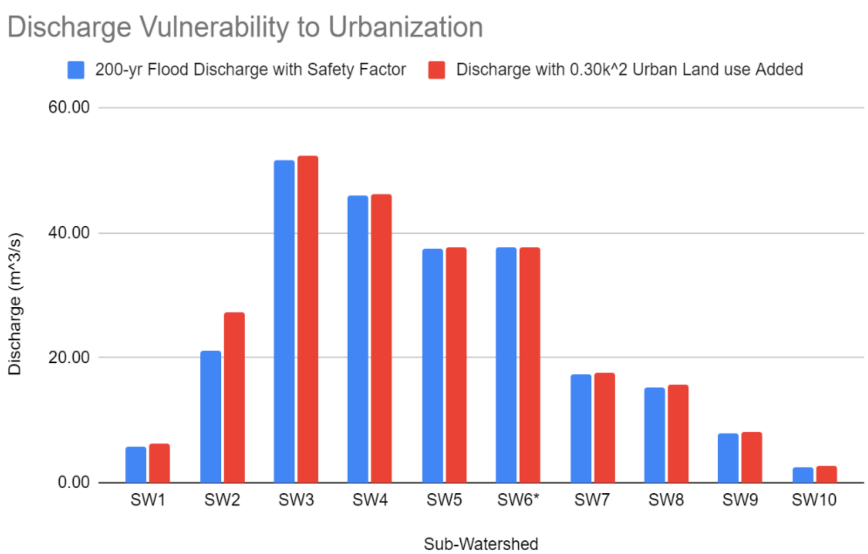


Chart 1.0 - 200-year Discharge for Sub-Watersheds both with and without a climate factor of 1.4.

3.2.3 Land Use Transformation

The land use transformation exercise demonstrated the reaction each sub-watershed had to urbanization. All but one sub-watershed (SW 6) had 0.30km^2 of forested land which was converted to urban land use by switching the corresponding runoff coefficients. SW 6 consisted mostly of bare rock, lake, and glacier land uses thus it was determined to leave the sub-watershed out of the



Graph 2.0 - Change in discharge when 0.30 km2 of forest is changed to urban land use. SW2 shows the most vulnerability to urbanization.

**SW6 did not have sufficient land needed for urbanization (e.g. forest, mire, cropland) thus it's land use coefficients were kept the same.*

urbanization analysis. The transformation revealed that SW2 was most vulnerable to this land use transformation (Figure X), resulting in an extra 6.10 m^3/s being added to its discharge if 0.30 km^2 of its forested land were transformed to urbanized land use.

4.0 Conclusion:

This study demonstrated several methods for a broad analyis of the spatial characteristics, and discharge, for the Sogndalselvi watershed. ArcGIS, Nevina, and the Rational Method proved to be effective tools in analyzing the hydrology of Sogndalselvi and provided some key insights that can be expanded on in the future. While this was a partial analysis only concerned with the 10 most significant sub-watersheds, it nevertheless gives a deeper understand of the hydrology of the study area.

Some noteworthy findings of the study are Sogndalselvi's contributing sub-watersheds are dynamic across several characteristics, however sub-watershed area seems to have the most impact on the discharge of the sub-watershed. Additionally, some sub-watersheds are more sensitive to land transformation, specifically from forest to urban land use, as demonstrated by Sub-watershed 2. This finding is particularly noteworthy as Sub-watershed 2 contains a ski area that has potential to expand, and thus increase its urbanized area.

By determine the 10 major sub-watersheds, a wide variety of their characteristics, their contributing discharge, and vulnerability to urbanization, the study has answered the research question stated in the introduction.

The main limitation of the study is it only looks at 10 sub-watersheds within the Sogndalselvi watershed. Other limitations of this study include those involved with the Rational Method (e.g. assumptions of uniform rainfall distribution throughout sub-watersheds), and a variety of assumptions made due to unavailable data (e.g. land-use maps and storage capacity of lakes).

Future research can delve deeper into the different characteristics of the sub-watersheds and their effect on the discharge into Sogndalselvi. This study can provide a good jumping off point, these future studies and give a broad introduction to the Sogndalselvi hydrological system

References:

American Rivers. (2019). The Impacts of Climate Change on Rivers | American Rivers. American Rivers. Retrieved 26 April 2021, from https://www.americanrivers.org/threats-solutions/clean-water/impacts-rivers/#:~:text=More%20frequent%20droughts%20and%20shifting,do%20significant%20harm%20to%20ecosystems.

FloodList News. (2015). Norway – Record Rain Causes Flooding in South. FloodList. Retrieved 25 April 2021, from http://floodlist.com/europe/norway-record-rain-causes-flooding-in-south.

FloodList News. (2019). Norway – 1 Missing After Floods and Landslides in South West. FloodList. Retrieved 25 April 2021, from http://floodlist.com/europe/norway-floods-landslides-jolster-forde-july-2019.

Germanwatch. (2021). Global Climate Risk Index. Retrieved 25 April 2021, from https://germanwatch.org/en/cri

Germanwatch. (2021). Who suffers Most from Extreme Weather Events? Weather-related Loss Events in 2019 and 2000 to 2019 (p. 40). Germanwatch. Retrieved from https://germanwatch.org/en/19777

Norwegian Centre for Climate Services. (2017). *Climate in Norway – a knowledge base for climate adaptation* (p. 7). Bergen: Norwegian Centre for Climate Services. Retrieved from https://www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf

NVE. (2009). 077/1 Sogndalselvi - NVE. Nve. Retrieved 25 April 2021, from https://www.nve.no/vann-vassdrag-og-miljo/verneplan-for-vassdrag/vestland/077-1-sogndalselvi/.

Dunse, T. (2020). *Design floods and hydrological response of small catchments*.

Esri. (n.d.-a). An overview of the Density toolset—Help | ArcGIS for Desktop. Retrieved April 26, 2021, from https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/an-overview-of-the-density-tools.htm

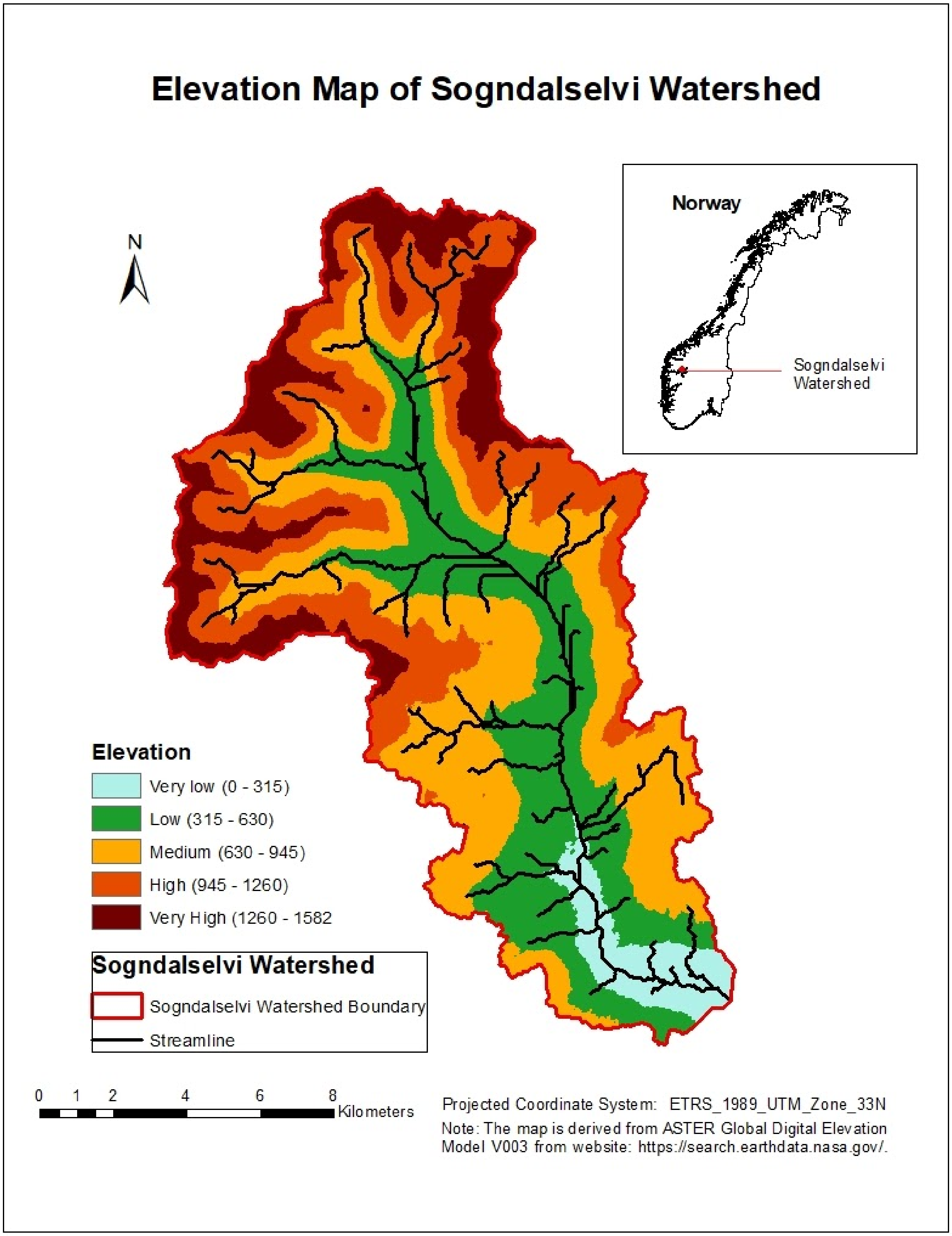
Esri. (n.d.-b). How Stream Order works—ArcGIS Pro | Documentation. Retrieved April 26, 2021, from https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-stream-order-works.htm

Koutsoyiannis, D., & Xanthopoulos, T. (2014). *Floods*.

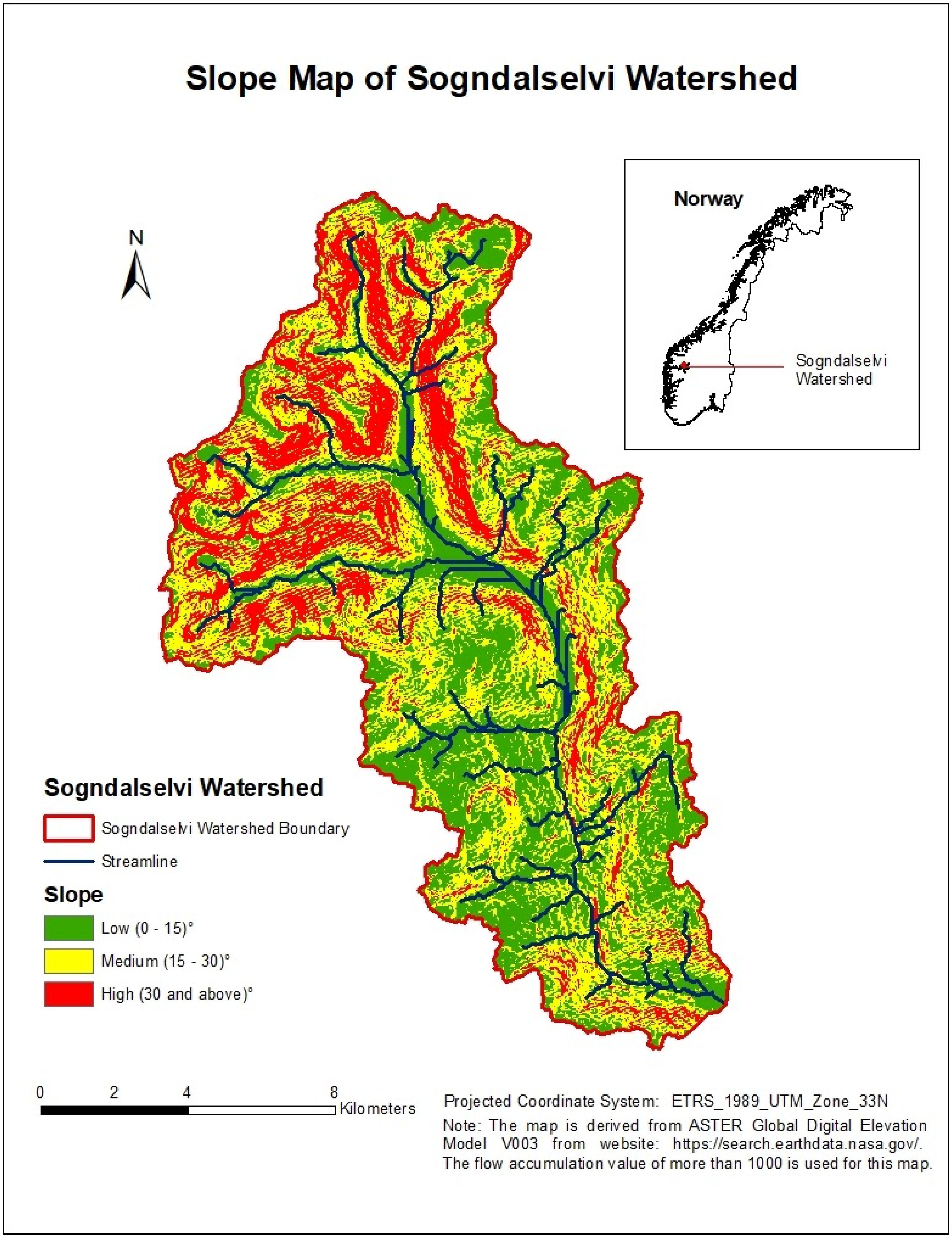
The California Water Boards. (2011). Runoff Coefficient (C) Fact Sheet. In *The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment State Water Resources Control Board 5.1.3 FS-(RC)*. Retrieved from http://water.me.vccs.edu/courses/CIV246/table2b.htm

Thomason, C. (2019). *Hydraulic Design Manual: Rational Method*. Retrieved from http://onlinemanuals.txdot.gov/txdotmanuals/hyd/rational_method.htm

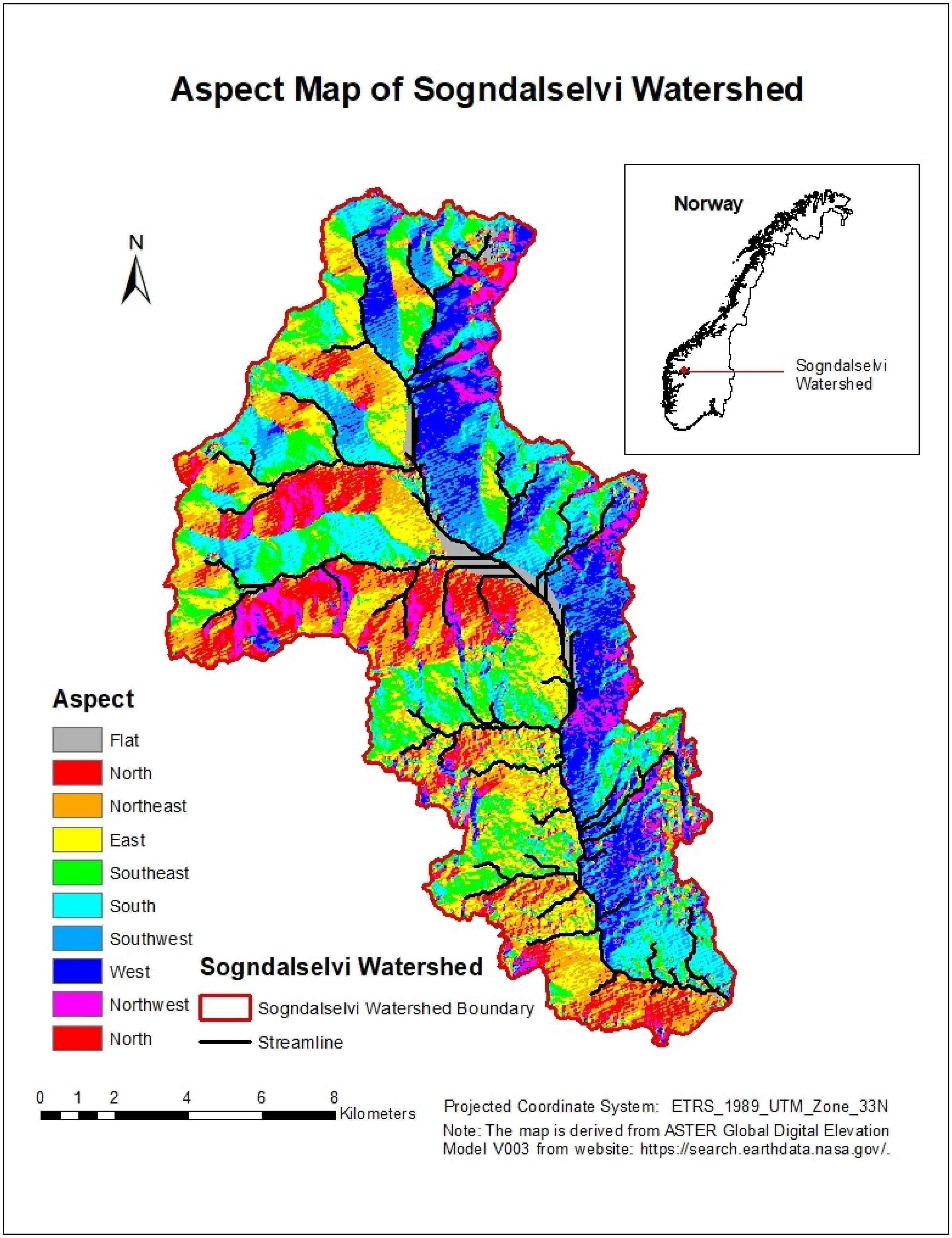
Annex:



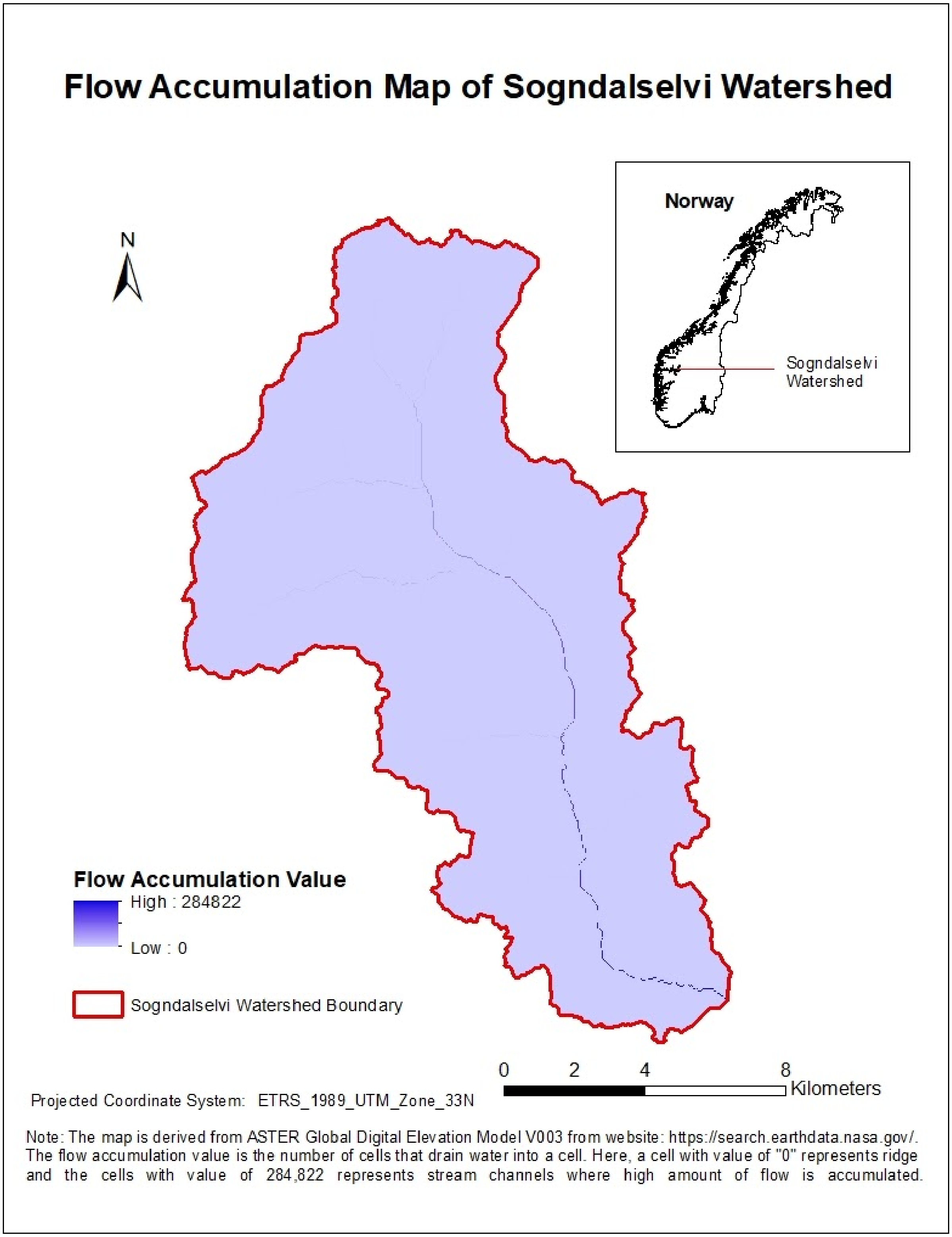
Annex 1.0 – Elevation Map



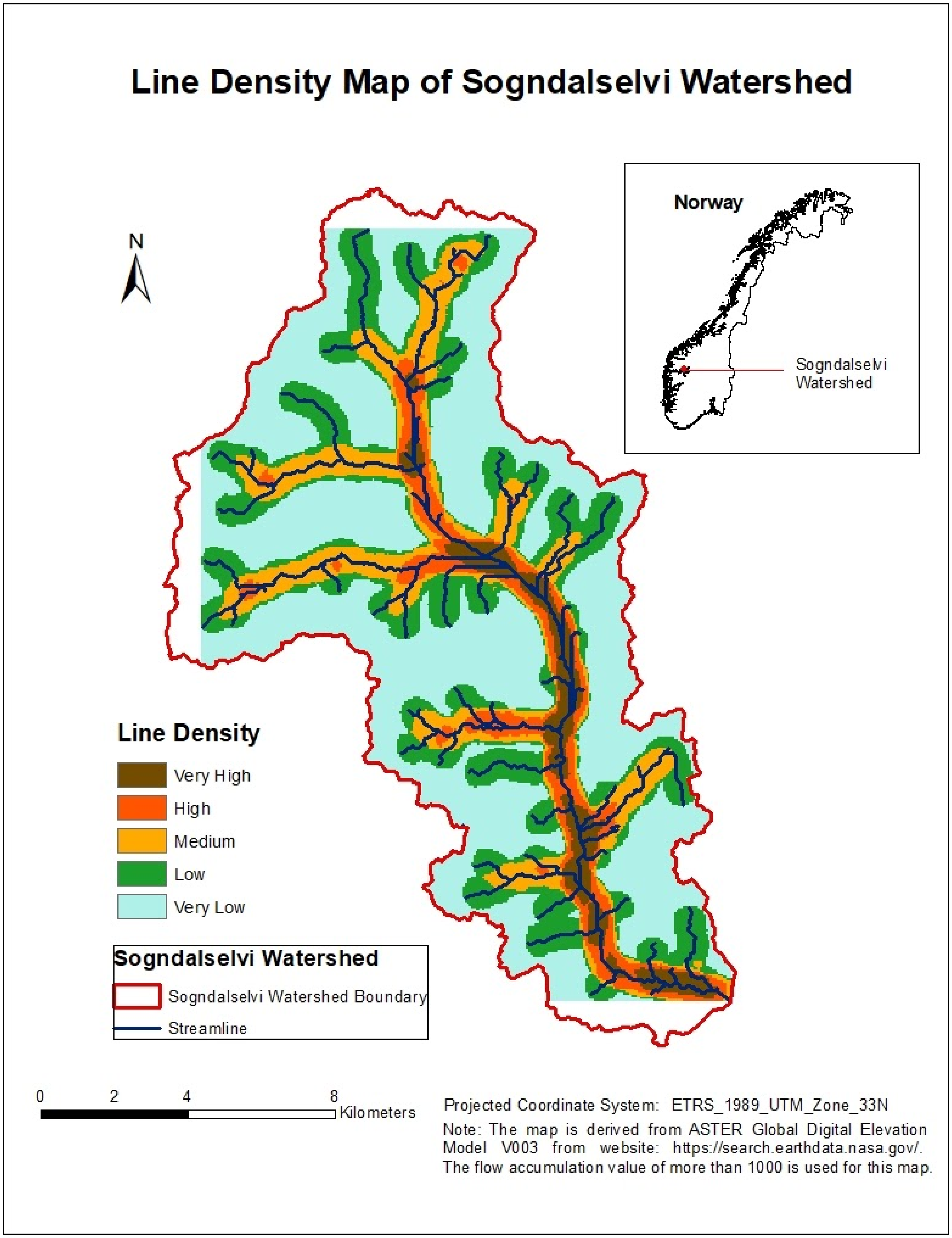
Annex 2.0 – Slope Map



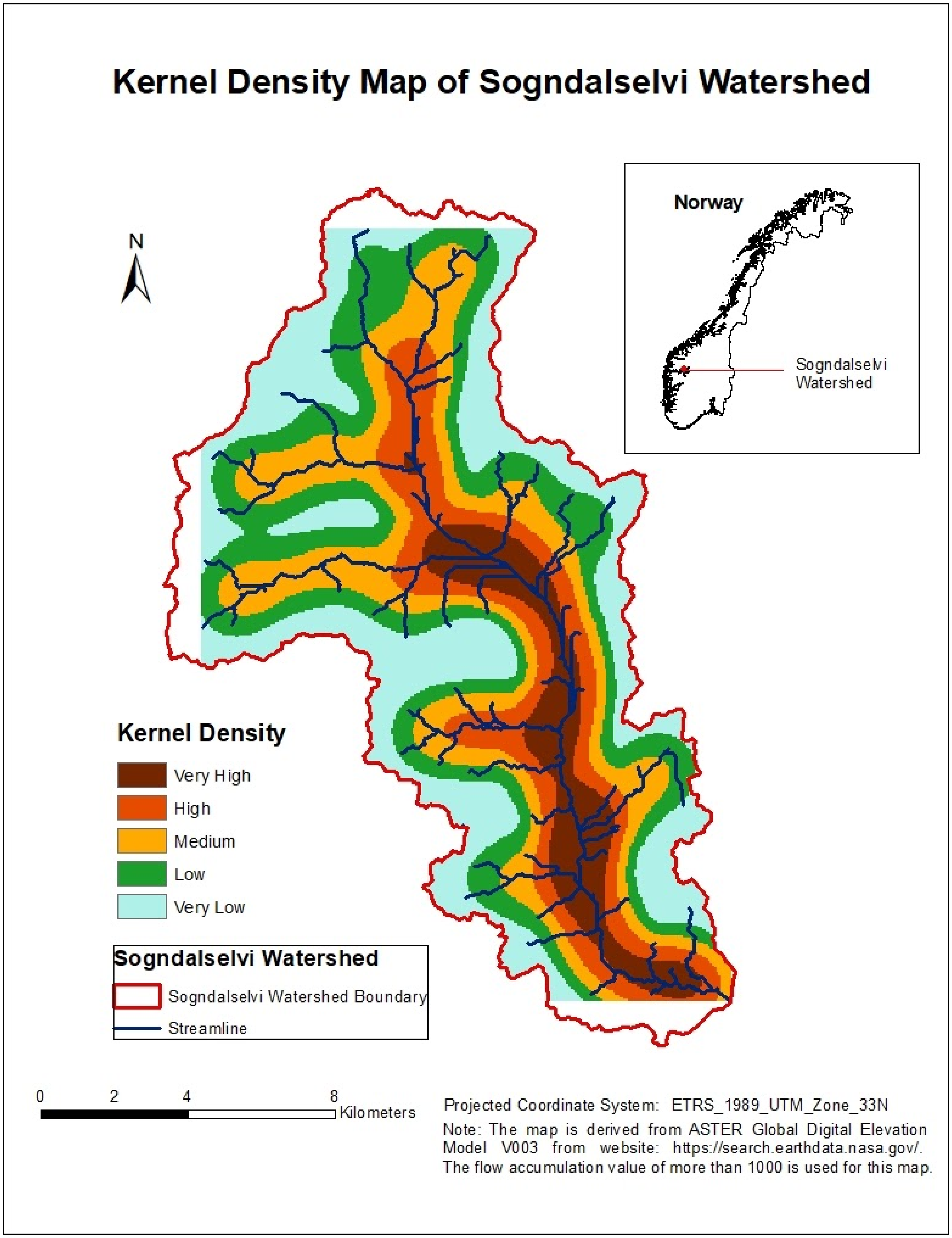
Annex 3.0 – Aspect Map



Annex 4.0 – Flow Accumulation



Annex 5.0 – Line Density Map



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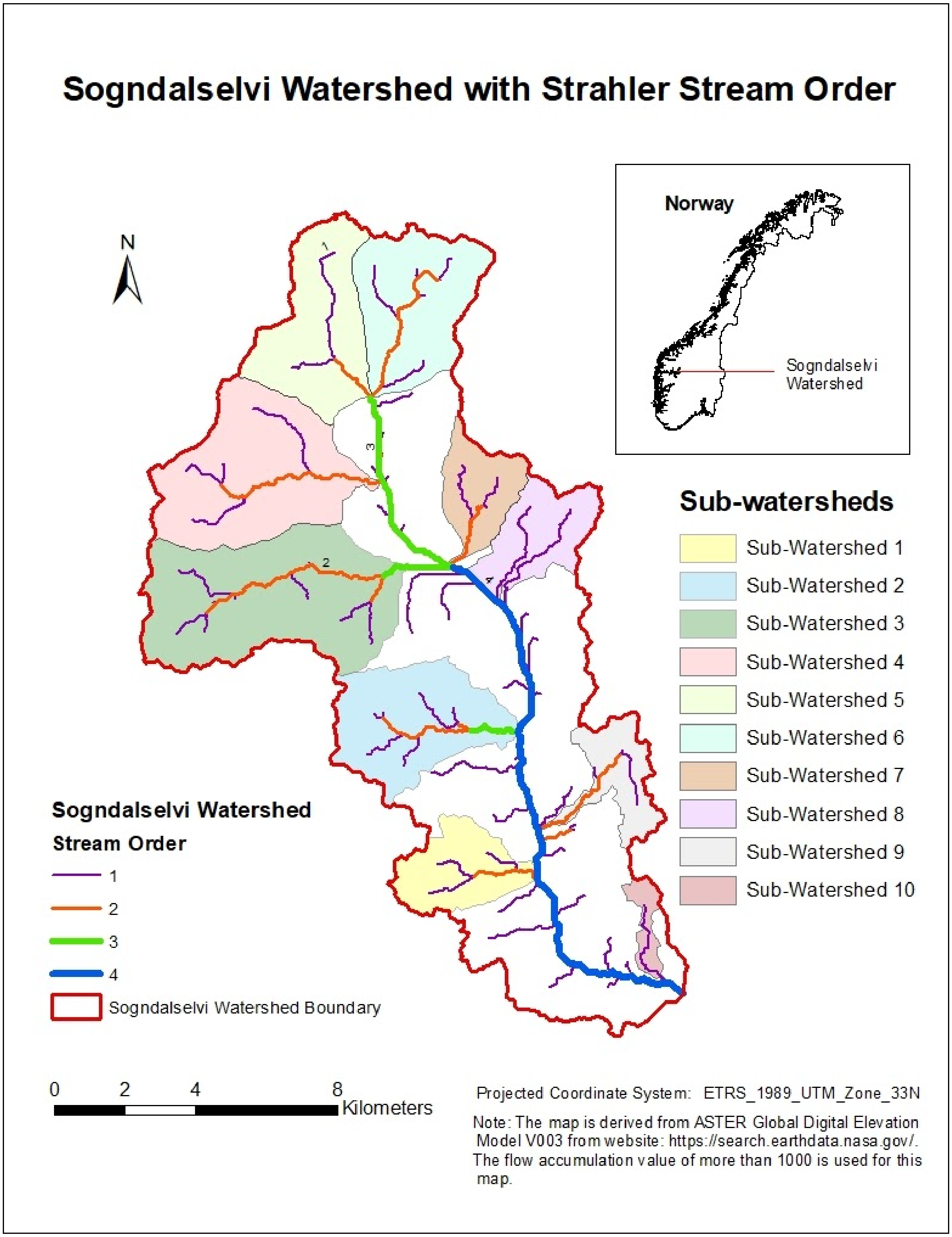
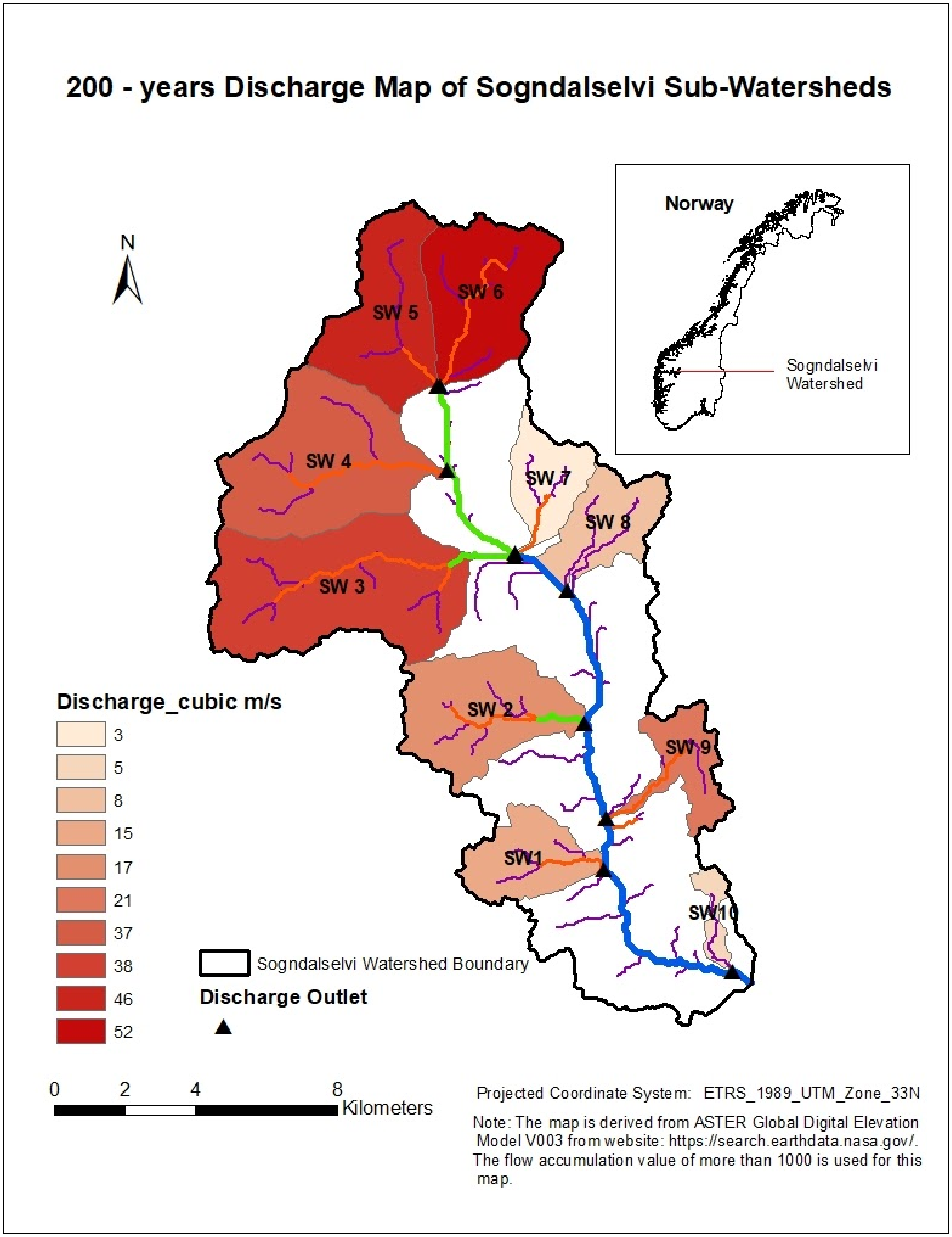


Annex 7.0 – Strahler Stream Order Map



Annex 8.0 – 200-year Discharge Map

Author Contributions:

Manoj performed the hydrological analysis using GIS and produced the maps. Melake used Nevina to gather data for the hydrological analysis and worked on the Rational Method. Shehroze did background research and the helped with calculating discharge using the Rational Method. Supa determined the limitations and conclusions of the study and helped with GIS mapping. All students contributed equally to the discussion of results, the presentation, and the writing of the report.