Sustainable stormwater management in Sogndal

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Master Thesis in Climate Change Management

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This thesis is a part of the master's program in Climate Change Management (Planlegging for klimaendringer) at the Department of Environmental Sciences, Faculty of Engineering and Science at the Western Norway University of Applied Sciences. The author(s) is responsible for the methods used, the results that are presented and the conclusions in the thesis.

Preface

This thesis paper is submitted for the master degree, of climate change management at the Western Norway University of Applied Sciences in Sogndal. The research study was conducted under the supervision of Dr.Thorben Dunse and Ms.Eli Anine Heiberg in the department of environmental sciences, faculty of engineering and science.

I would like to thank all the teachers, friends and students at the faculty of Engineering and science and the administration staff in Western Norway University of Applied Science of Sogndal, who helped me in writing this thesis.

I would like to give my special thanks to Dr.Thorben Dunse and Ms. Eli Anine Heiberg for their provision of important guidance and investing a lot of time and efforts in supervising my work. Furthermore I would like to thank for Sogndal municipality and especially for engineer Tola Bake and Markus Mohn Werner for data supply of municipal stormwater management system and planning.

I would like to thank for my friend Christian, for his helping me to use his GPS and his guiding when I am using the GIS tool.

Abstract

Stormwater management is a strategy of handling excess runoff water, which accumulate from precipitation and flow over the surface. There is a need for stormwater management in the northern side of the city of Sogndal, from the lower area of Foss up to the upper areas of Bergi and Tona. The management of stormwater using pipe systems is challenging many cities nowadays because changes in climate conditions and the modifications in land use elements, increase runoff in volume and speed. In addition, those changes affect the ecosystem elements in the sites.

The purpose of this project is to analyse the changes made in the land use elements, catchments areas, the volume of runoff discharge from them and finding potential of the site, where it is possible to open the natural streams. For that purpose, a conceptual plan design is developed, which helps minimizing the runoff and increase landscape quality in the same time.

Some of the findings of this study indicate that stormwater will be challenging in the future with increasing precipitation levels, due to the modifications that were made in land use elements and capacity of the existing pipes.

However, blue- green solution is an alternative treatment for stormwater challenges. It fit to work in cooperation with the other stormwater management solutions and it can give benefits in minimizing runoff challenges, ecosystem improvements and aesthetics.

Sammendrag på norsk

Det er behov for overvann håndtering i nordsiden av Sogndal, fra det nedre området Foss opp til de øvre områdene Bergi og Tona på stedet. Overvann håndtering er en strategi for å minimere overskytende avløpsvann, som akkumuleres fra nedbør og strømmer over overflaten. Forvaltningen av overvann som bruker rørsystemer utfordres i mange byer i dag. Fordi endringene i klimaforhold og endringene i arealbruk elementer øker avrenninga i volum og hastighet. I tillegg påvirker disse endringene økosystemelementene på nettstedene.

Formålet av dette prosjektet er å analysere enderingene i arealbruk elementene, avløpsområdene, volumet av avløps utslipp fra dere og finne potensialet på stedet der er mulig å åpne de naturlige avløpene. Videre utvikle en konsept planløsning som bidrar til å minimere overvann og kan gi bedre kvalitet av arealbruk. Noen resultat av denne Project viste at overvann vil våre utfordring i fremtiden med økende nedbørs nivå, på grunn av endringene ble gjort i arealbruk elementene og kapasitet av eksisterende rør.

Blågrønn løsning er imidlertid en alternativ løsning for å minimere overvann utfordringene. Fordi det passer til å fungere sammen med de andre overvann håndtering løsninger, og de kan gi fordeler ved å minimere avrenninga utfordring, økosystemforbedringer og arealbruk estetikk.

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1. Introduction

1.1 Stormwater management in urban area

Stormwater is the excess water that flows over the surface. It accumulates from precipitation during rain and snow melt events. Stormwater management is the effort to handle the excess runoff (Nie, Skallebakke, Campisano, & Marsalek, 2013) using different systems, such as Green infrastructure (GI) practices (Zhang & Chui, 2018), Low Impact Development (LID), and Water Sensitive Urban Design (WSUD), while also taking into consideration the future climate change (Roy et al., 2008). Stormwater is influenced and reshaped by precipitation, types of land use, density of buildings, snow melting and topography (Nie et al., 2013). Climate change, compacted urbanization, increased fraction of impermeable surface, are escalating the challenges of stormwater in most urban areas (Nie, Øyen, Groven, & Aall, 2011).

Climate change is manifested in both temperature and precipitation. The changes in precipitation will increase the rainfall level in many monsoon regions across the world (Eckstein, Paisley, Burchi, Curlier, & Stephan, 2010). The expected changes of climate variables in Norway are summarized in the report "Climate in Norway2100" (Hanssen-Bauer et al., 2015). This report shows basic information for climate adaptation in Norway. It assesses the future climate change, based on the three scenarios for emissions of greenhouse gases, "RCP 8.5" (business as usual), "RCP 4.5" (reductions after 2040) and "RCP 2.6" (drastic cuts from 2020). The time period of 1971-2000 is used as a reference to estimate the climate change up to 2100 (Hanssen-Bauer et al., 2015). The report identified changes of climate patterns for each county. Sogn og Fjordane, located in western part of Norway, will be highly influenced by runoff due to increasing precipitation (Hanssen-Bauer et al., 2015).

Intense rise of precipitation will generate heavier loads on the existing stormwater systems (Nie, Lindholm, Lindholm, & Syversen, 2009). By connecting the urban catchments to the sewer systems, and due to the changes in land-use, the stormwater volume that is accumulated by the pipes increased. Most of the impervious surfaces in urban catchments are connecting to the pipe system, which means most of the stormwater is routed into the pipes. (Burns, Fletcher, Walsh, Ladson, & Hatt, 2012). Modification of land cover and intense precipitation increase are affecting the reliability of the design and management of stormwater pipes. To determine the capacity of the pipe system to accommodate stormwater, available runoff data, land cover pattern and the Intensity Duration Frequency (IDF) are required (Hailegeorgis & Alfredsen, 2017).

This project aims to re-open some of the natural streams as part of the modern and sustainable stormwater management, minimizing the possibilities of risk for existing infrastructures and buildings and integrating the re-opened water ways with ecological and aesthetic benefits on the site of Fosshaugane and Foss in Sogndal. Where are the natural stream networks? Which amount of runoff discharge into the study site in northern side of Sogndal city? Which streams are replaced by pipe system management and where is it possible to re-open them? Why? How much water would discharge?

1.2Effects of climate change

As the report "Climate in Norway 2100" indicates, the climate variables precipitation and temperature will have significant effect in all regions of Norway. The mean annual runoff of stormwater in Norway is approximately 1100mm and precipitation is estimated 1600mm during the period of 1971-2000 (Hanssen-Bauer et al., 2015) (Figure1). Precipitation and temperature are expected to increase by 18% and 4.5^0c respectively up to the year 2100 as comparing the time period of 1971-2000 (Figure 2). The highest level of warming will be seen in wintertime and lowest in summertime. The frequency and intensity of an extreme precipitation events are expected to increase by 30% and the heavy precipitation days will double (Hanssen-Bauer et al., 2015).

There will be a large variation of climate patterns in different counties of Norway. The level of precipitation in Sogn og Fjordane varies drastically over the years. Today's annual precipitation varies from 500 to3500 mm in the county. By the year of 2100, the temperature and precipitation are expected to increase by 4°C and 15% in comparison to the period of 1971-2000. The temperature will rise most in winter and autumn. The short period intensity for the extreme precipitation will rise by 40%. The increase in temperature will cause change in seasonal precipitation type and snowmelt. Snow will melt earlier in the year and more precipitation will fall as rain in the wintertime. The short period rainfall which happens in less than 3 hours will have the highest increase, both in intensity and frequency, resulting in higher flood risk (Hanssen-Bauer et al., 2015).

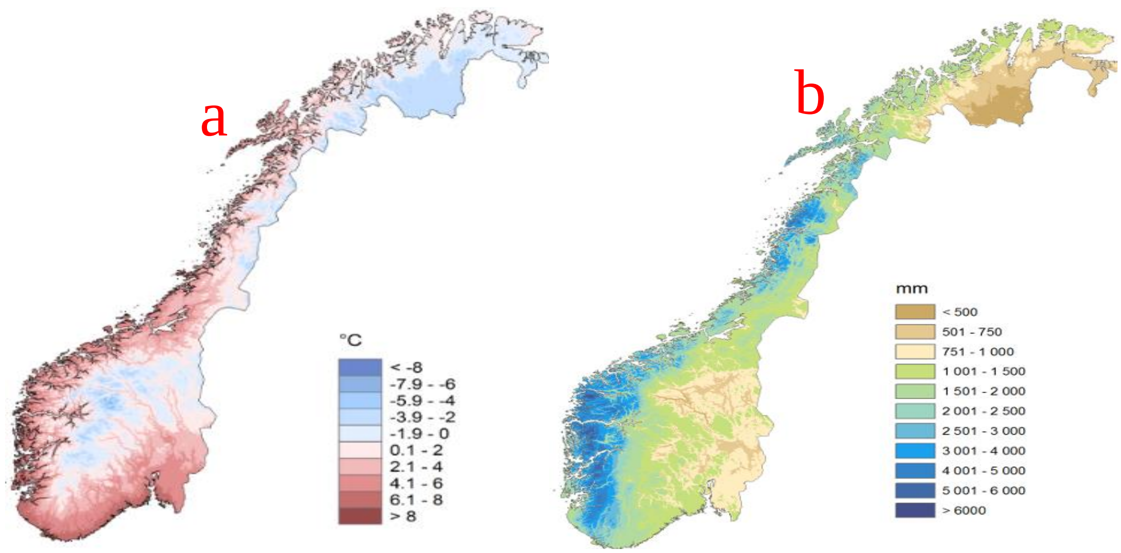


Figure 1: Mean annual temperature and precipitation in the time period of 1971-2000. Illustration is taken from (Hanssen-Bauer et al., 2015).

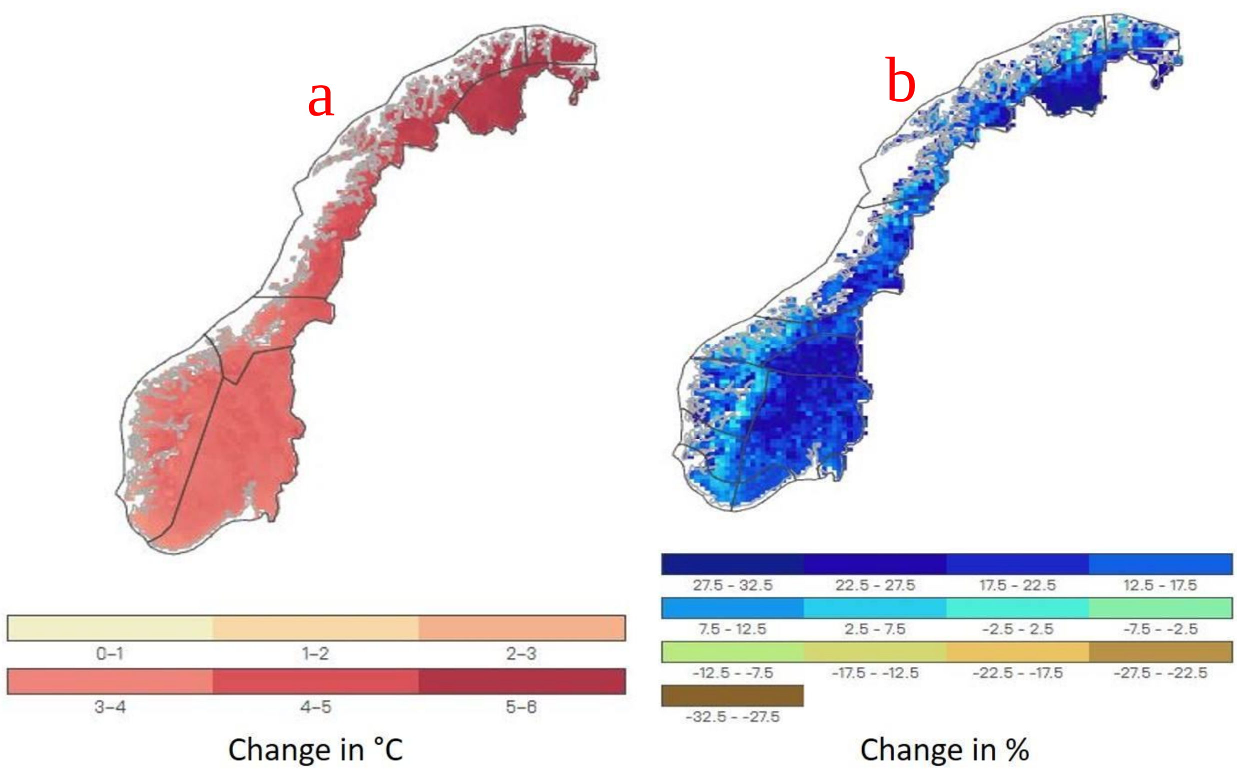
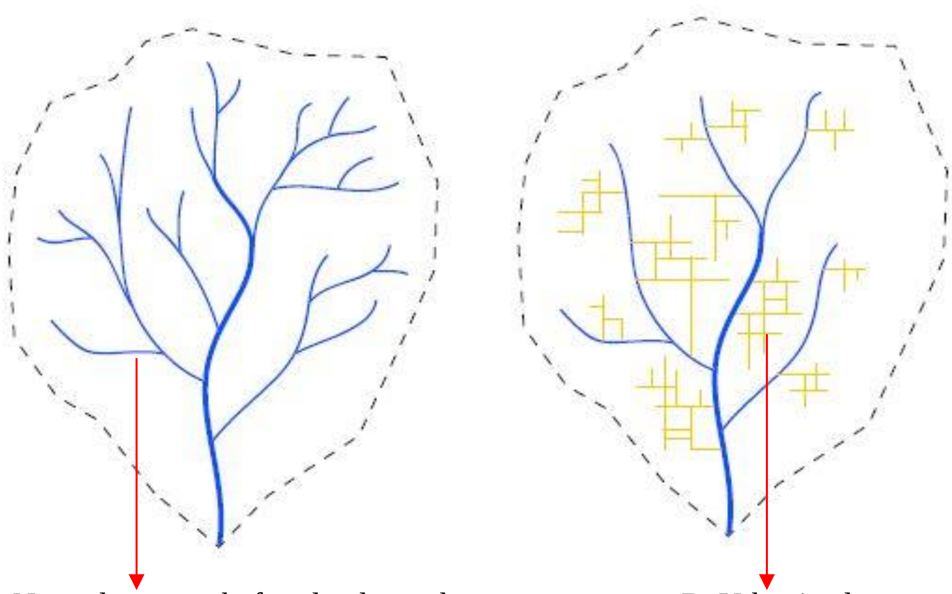


Figure 2: Expected change in temperature and precipitation the time period of 2071-2100, increasing by 4.5°C and 18%. Illustration is taken from (Hanssen-Bauer et al., 2015).

1.1.2 Catchment characteristics

Elevation gradient determines the stormwater flow direction. Water flows from the higher to lower elevation, following the collecting stream networks. Stream networks are defined as the systems through which water travels to the outlet (Zhu.X, 2016). The stream system is like a big branched tree (Figure 3). Small streams meet and join with bigger streams according to land-form and elevation. The streams meet and join more and more streams at different junctions and grow in to larger stream or river based on the size of the catchment area, topography and landscape form (Vadum, 2011). In each step of joining new streams, the size of the catchment area and the volume of the runoff increases. Runoff collects from smaller catchment areas during snow melting, precipitation, raining in small grooves and discharge to larger watercourses such as rivers and lakes following the stream orders through outlets and junctions. Some of the precipitation infiltrates in the soil and the rest contributes to runoff at the surface. So, the quantity of the runoff is influenced by infiltration capacity and time of concentration (Vadum, 2011).



A. Natural streams before land use changes B. Urbanized areas

Figure3: A. The stream network and catchment area elements before land-use change. B. The stream network and catchment area after land-use change. Illustration taken from Vadum (2011).

The illustrations in Figure 3, show the way urbanization alters natural stream systems by covering permeable surfaces with impermeable sealing, reducing or draining of stream and deflecting natural streams into pipe systems. Land use changes are causing for the runoff to discharge in faster speed and larger volume in urbanized areas than the undeveloped areas (Nie et al., 2009).

1.1.3 Runoff characteristics

Runoff characteristics are dependent on the catchment characteristics, topographic form, soil and climatic conditions (Nie et al., 2011). Rising intensity of precipitation is cause for stormwater accumulated on the site. Figure 4 shows a theoretical runoff event on urban, agricultural and natural surfaces. The red line of the hydrograph indicates high flood peak in short duration in urban area. Runoff in urban areas accumulates in short period of time and transported in high speed. The yellow line exhibit-runoff in agricultural areas. It has slower speed and less volume than urbanized areas, because it has better permeability than urbanized areas. The green line shows, low flood peak and spread out over longer duration in natural areas. Runoff is discharging in a slower speed and less volume in natural area than in urbanized and agricultural areas, because it has better infiltration ability than them (Vadum, 2011).

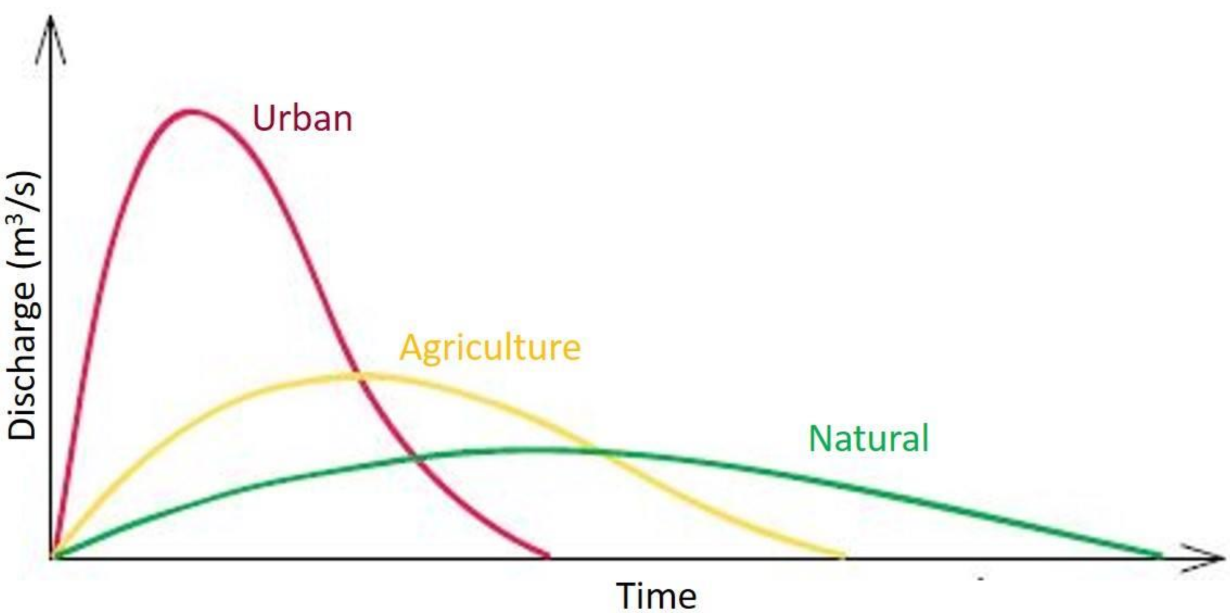


Figure 4: Changing runoff patterns by changing land-use. Time of concentration. urban area (red), agricultural area (yellow), natural area (green). Illustration taken from Vadum (2011).

To minimize the impact of runoff on environment, building and infrastructures it is necessary to monitor the pipe system, because it has limited capacity. According to Hailegeorgis and Alfredsen, (2017), pipe systems have challenges in many Scandinavians cities in the present. Additionally increasing precipitation in the future is expected to increase the stormwater challenges further. Sogndal municipality manages stormwater in the study site using a separated stormwater and sewer pipe systems, but to mitigate flood risks analysis on their pipe system management is crucial.

1.1.4 Challenges of stormwater management's pipe systems

In the second half of the 20th century, the urban stormwater management focused on land-use modification to promote efficient land development and pipe systems to improve hydraulic efficiency. The infrastructural engineering was not designed to cope with future land use and climate change. The planning sectors gave first priority to the human needs, while the landscape elements such as the ecosystem, deteriorated (Chen, Samuelson, & Tong, 2016). Engineers followed a single plan strategy in modification of the urban areas which exposed the environment to ecological deterioration, impervious surfaces and the increase of runoff by volume and rate in the cities (Chen et al., 2016). Modifying of the natural streams and environment, challenged the pipe systems and their ability to control the impact of climate change (Hailegeorgis & Alfredsen, 2017).

In most cities of Norway, stormwater is managed by traditional sewer system designs. Most of these sewer systems were designed 50-100 years ago. The increase in precipitation level, aging of materials, and the replacement of permeable surfaces with impervious surfaces, has created huge challenges for different cities (Nie et al., 2013). As a result, the pipe systems cannot handle the amount of runoff water collected from the surfaces. The runoff management, using the pipes to reduce pollutants and overflows has failed in many cities due to the old pipes being too small to manage the pressure of rising stormwater (Burns et al., 2012). For example, a study done in Fredrikstad, Norway (Nie et al., 2009), shows that the traditional pipe systems have not enough capacity to handle the runoff challenges in the future.

1.1.5 Sustainable stormwater management with urban infrastructures

To improve safety of infrastructures and conserve ecosystem elements in urban areas, we need to manage the runoff from its source up to outlet points (Roy et al., 2008). According to § 7, the safety requirement must include, risk and vulnerability analysis in accordance with section 4-3 of the planning and building act (TEK 17). Sustainable stormwater management have many principle to conserve ecosystems, to minimize the runoff volume, control water quality, increase infiltration processes by reducing impermeable surfaces which deliver runoff to the streams and increase green areas (Walsh et al., 2016).

It is important to use the strategy of sustainable stormwater management to reduce the future over-flooding challenges, create healthier environment and enhance the ecosystem's values. There are various stormwater management approaches. Grey solutions retain water in closed tanks thereby holding the flood peak further downstream (Wang, Eckelman, & Zimmerman, 2013), Blue-green solutions, Low Impact Development (LID) and Water Sensitive Urban Design (WSUD) are managing runoff using retention and detention ponds, infiltration swales and harvesting water at its source. They incorporating with the grey by re-using stormwater in an environmentally-friendly way also (Haghighatafshar et al., 2018). They are good alternative solutions in handling the stormwater, by re-opening the pipe systems and re-use the runoff in an environmental friendly way (Roy et al., 2008). Implementing the blue-green systems from the upper stream up to the lower level of the streams are efficient in controlling the local surface runoff in the urbanized areas (Haghighatafshar et al., 2018).

The blue-green solution handles the local stormwater using delay and infiltration stations such as detention and retention ponds and swales (Abry, 2016). The runoff follow through the open channels and delay stations. Due to the infiltration processes and holding the runoff at the detention ponds and open channels reduce the load, speed and water content of the flood peaks.

When the amount of runoff is small, they can hold in the detention and retention ponds and infiltrate slowly. When there is excess runoff, they handled by delay and infiltration processes in the various stages. Finally the excess runoff flow to the main rivers safely (Figure 5).

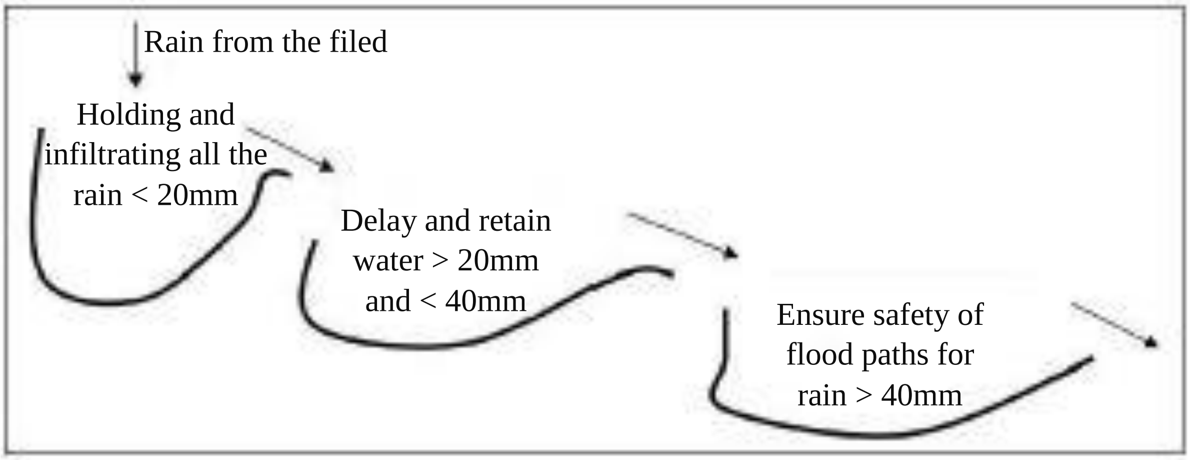


Figure 5: Three-step strategy for stormwater management. The precipitation values are examples and must be adapted locally. Illustration taken from Abry (2016).

Re-opening stormwater management systems started in the 1980's (Brown, Farrelly, & Loorbach, 2013). Restoration of catchments in urban and suburban areas are sustainable and effective strategy for improving ecological conditions (Bernhardt & Palmer, 2007). For example the blue-green solution implemented in in Malmo, Sweden gave a great achievement in reducing the runoff challenges by 70% and increase ecosystem elements in the city (Haghighatafshar et al., 2018). Water Sensitive Urban Design (WSUD), Low Impact Development (LID) and blue-green solutions are taken in to consideration the intensity, duration, magnitude of low and high flow rate and the components of ecosystems. Those strategies handling the runoff at its source in gutters and then transport to retention and detention dams and swales. Capturing the runoff at different stages is helpful in reducing the rate, intensity and frequency of stormwater, risks and damages on infrastructures and to infiltrate the pollutants (Roy et al., 2008). Due to its integrated solution, open drainage system have a positive value regarding human wellbeing, ecosystems and recreational benefits and manages the stormwater based on the local precipitation data, site condition and economic consideration (Chen et al., 2016).

At the municipal level, stormwater management is focusing on an integrated management, such as regulating water sources, develop building conditions, rehabilitating drainage networks and implementing the blue-green solutions (Nie et al., 2013). Managing the stormwater process in Norway must follow the following safety classes (Table 1), § 7-2 for flood consequences annual probability, (TEK 17, 2017, § 7-2).

Safety class for floods	Consequence	Largest possibilities to happen annually
F1	small	1/20
F2	medium	1/200
F3	big	1/1000

Table 1: Safety classes for structures in flood-prone areas according to TEK 17.

These three safety classes are defined according to an acceptable flood risk for infrastructures of different importance to society, with the flood sizes and considering which buildings are to be placed to which security class. These security measures help to aware of the risks and keep away the settlements from the waterways and implementing security measures. The safety classes, F1 apply to for example storage buildings, garages and living houses and F2 for accommodations, cabins, garages, school and kindergarten, official buildings and industrial buildings. The safety class F2, take in to consideration, the water velocity is greater than 2m/s. The safety class F3, applies to, those are vulnerable for pollutions, such as hospitals, fires station, police station, civil defense facilities and infrastructures of great social importance.

2. Study site and Methods

2.1 Study site northern side of Sogndal city

Sogndal is municipality in Sogn og Fjordane. The municipality has 8059 inhabitants (January 1. 2018). The total area is 746 km^2 and 9 km^2 of it is water area of rivers and lakes (Figure 6). The average temperature and precipitation of Sogndal is 6.6°C and 1070mm respectively in the period of 1900-2014 (Hanssen-Bauer et al., 2017). It is consist of fjord areas, and has highland characteristics in addition. The northern side of the city is hilly and steep terrain. There is a river called Sogndalselva which comes from the northern side of the city and pass to the fjord. Sogndalselva is the main river, where the study area discharges its runoff finally.

The characteristics of Sogndalselva catchment can be assessed through www.nevina.nve.no . The catchment has an area of approximately 175km^2 and extends for 28.6km from sea-level up to a maximum elevation of 1601 meters. Its annual temperature and precipitation are 2, 3°C and 1436mm respectively. The climate factors of the catchment are influenced by the topographic form and elevation. The orographic effect make the temperature cooler and increase precipitation. The catchment areas that discharge water to the river, have different land use elements with different areal size. They contain the following land use type: mountain above the tree line (47,92%), forest area (31,26%), glacier and lakes (5,49%), Agricultural land (4,21%), marsh area (1,52%), urban area (0,39%) and effective rivers (0,93%) www.nevina.nve.no.

The study area is found in the northern side of the city of Sogndal. Forest, agricultural land and urban area are the main land use elements of the site. The urban and agricultural areas are found in the gentler and lower part of the site. Elevation of the study site catchments rises from 1 up to 533 meters above sea-level and the area is approximately 2 km^2.

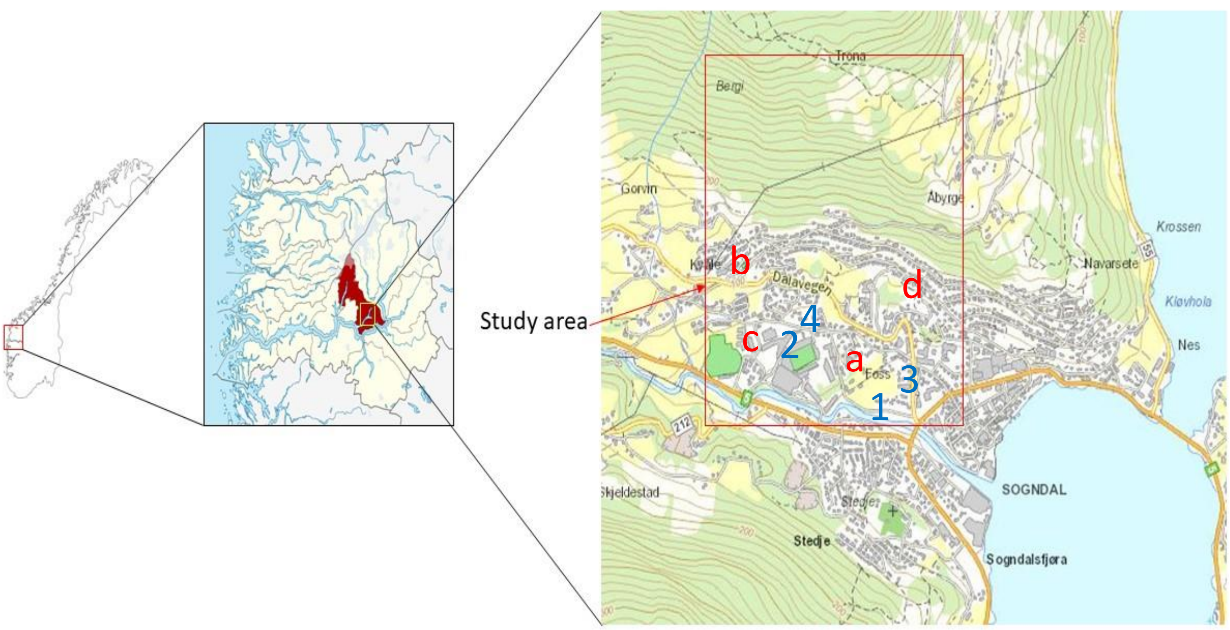


Figure 6: Map of study site in Sogndal in Sogn og Fjordane Norway

The pictures in Figure 7 (a, b, c, d) are representing the zones of Foss, Gurvin, Kvåle and Rutlin of the study site. They were taken in 1957 by Telemark Flyselskap A/S and published in the book of Sogndal bygdebok in 2007. While the pictures in figure 8 (1, 2, 3, 4) are representing the present situation of Foss, Kvåle and Fosshaugane, Dalvegen, Trolladalen and Lunnamyri. They were taken in14.03.2019 by Tewelde Mebrahtu Tesfay. The pictures of Figure 7 show, that the site was been dominated by agricultural and forest areas in 1957. With increasing population of Sogndal a drastic land-use change was made in the site as shown the pictures taken by the author. In between those time period the forest and agriculture on the site were replaced by impermeable urban elements such as private and public buildings and infrastructures.

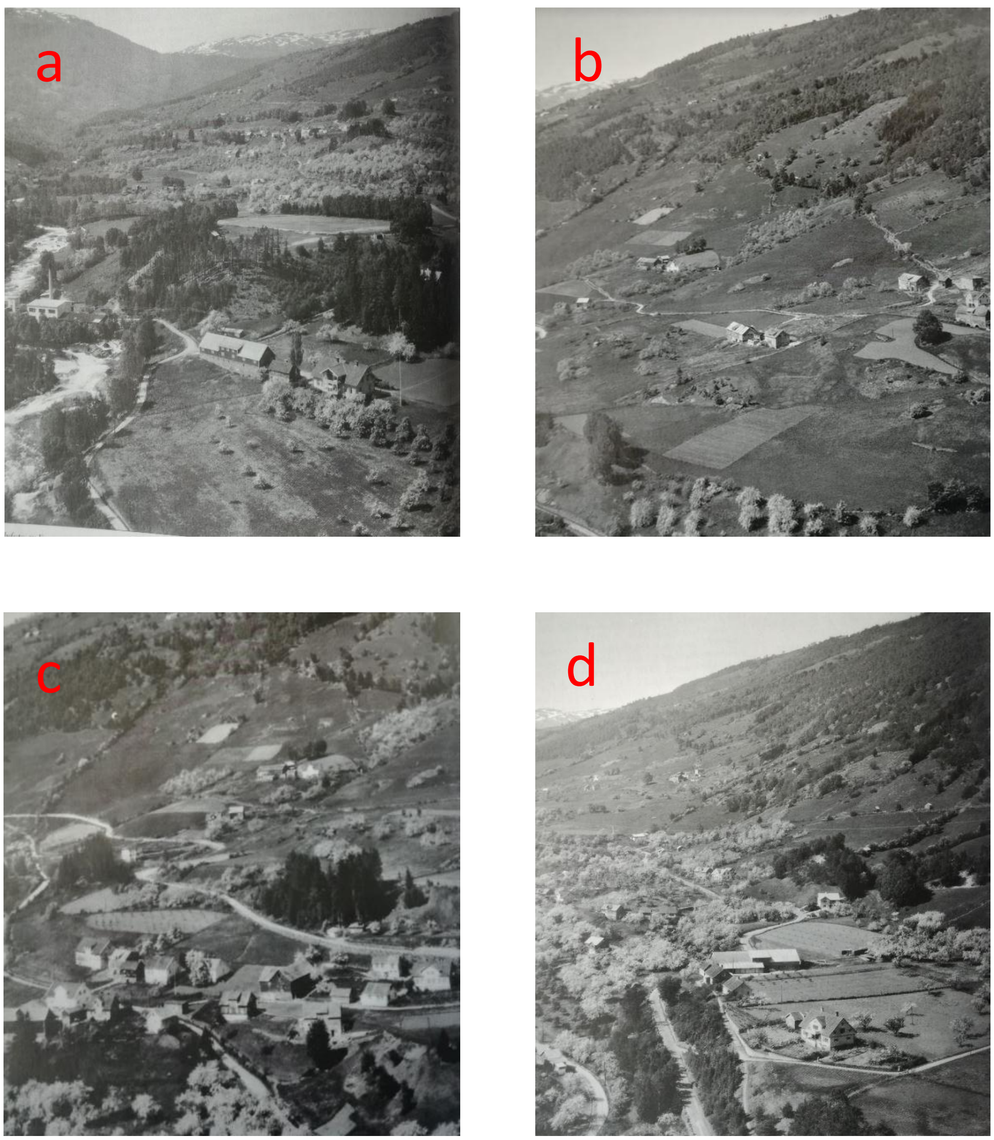


Figure 7: Pictures a, b, c and d are taken from Sogndal bygdebok, (2007)

Figure 8: Pictures 1, 2, 3 and 4 are taken by Tewelde Mebrahtu Tesfay in 14.03.2019

The pictures of Figure 8 are showing, how much the land use is changed today compared to the land use pictures in Figure 7. Those land-use changes increased the fraction of impervious surfaces and affect runoff in pattern, volume and time of concentration. The stormwater is removed using pipe systems.

2.1.1 Intensity of precipitation

The precipitation intensity depends on the time of concentration, i.e. the time need to discharge the runoff from the remote points of the catchment area to the stream outlets in the catchment areas. The precipitation intensity is determined from the Intensity-Duration-Frequency curve (IDF-curve), which shows duration and mean intensity for extreme rain events and return period, and is widely used in planning and designing infrastructures (Førland, Mamen, Dyrrdal, Grinde,

& Myrabø, 2015). There is no IDF-curve available for Sogndal municipality and they do not have documents with recommended IDFs. The only available IDF-curve from the Meteorological Institute, for the county Sogn og Fjordane is from Oppstryn (Figure 9 and 10, Table 2 and 3). In Norway precipitation is categorized in to orographic, frontal and convective (Dyrrdal, Lenkoski, Thorarinsdottir, & Stordal, 2015) and the orographic precipitation is dominating the climate of western coasts of Norway. Oppstryn and Sogndal are found in similar geographic location in the west coast of Sogn og Fjordane, therefore the data of Meteorological Institute Oppstryn (SN 58700) is chosen to be representative for Sogndal municipality. Oppstryn (SN58700) is found in Stryn municipality in Sogn og Fjordane. Which is located at 201 meter above sea-level. Measurement period for the station was 05.07.1968-01.11.1987, which means number of seasons in the IDF statistics is 20 years. As a result, this study is taken the Meteorological Institute Oppstyn IDF-curve as a source of precipitation data. The data duration for precipitation intensity is the same as the time of concentration for the area.

Duration presented in the IDF-curve covers the range 1minute to 24 hours (1440 minutes), and estimates the precipitation intensity expressed in l/s*ha for given return periods 2, 5, 10, 20, 25, 50, 100 and 200 years.

IDF-curve for OPPSTRYN, Stryn, Sogn og Fjordane

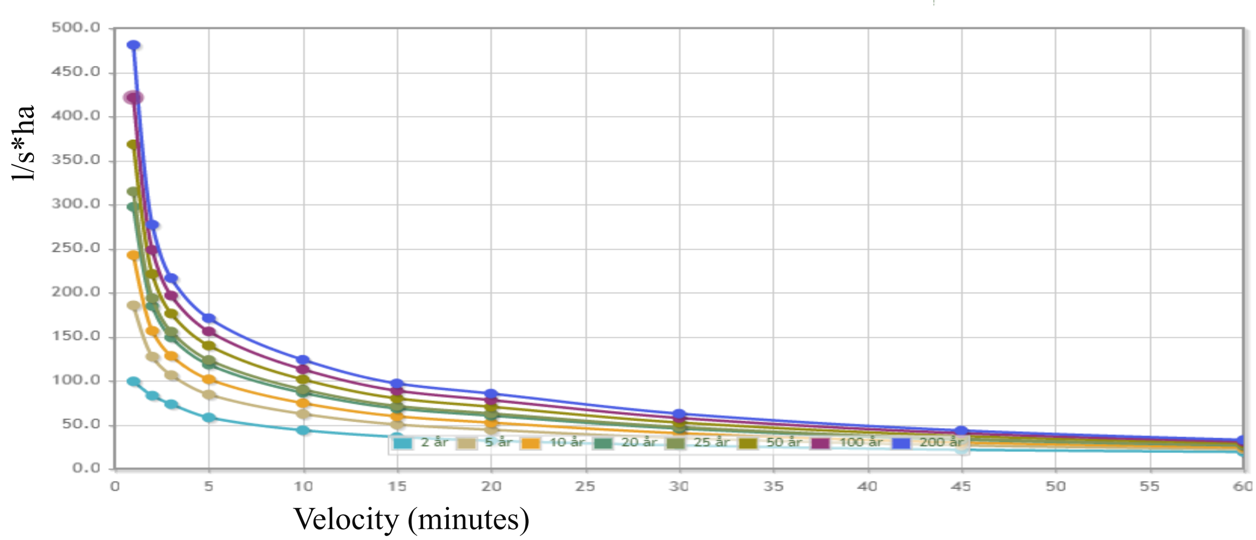


Figure 9: IDF-curve from 58700 Oppstrn based on the period of time 1968-1987 for 1-60 minutes (The Norwegian Meteorologist Institute).

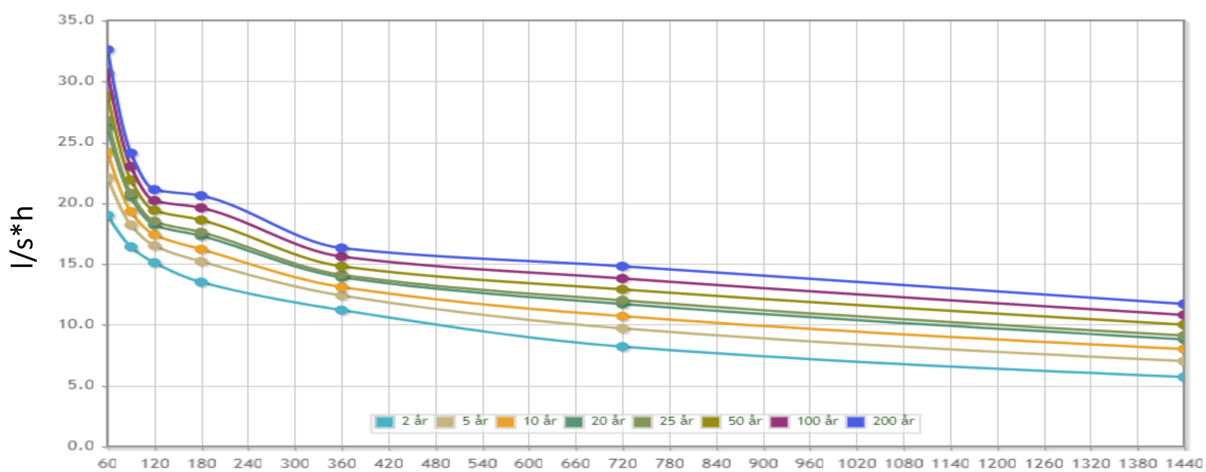
Return value of precipitation (l/s*ha)

Duration in minutes

Return period	1min	2min	3min	5min	10min	15min	20min	30min	45min	60min
2	99,10	82,90	73,20	58,10	43,60	36,00	31,70	26,40	21,40	19,00
5	185,40	127,20	106,20	84,20	62,10	50,10	44,10	34,70	26,40	22,10
10	242,40	156,50	128,00	101,50	74,40	59,40	52,20	40,20	29,70	24,20
20	297,20	184,60	149,00	118,10	86,10	68,30	60,10	45,50	32,90	26,20
25	314,60	193,50	155,60	123,40	89,90	71,10	62.60	47,20	33,90	26,80
50	368,10	221,00	176,10	139,70	101,30	79,80	70,20	52,30	37,10	28,80
100	421,20	248,30	196,50	155,80	112,70	88,50	77,80	57,50	40,20	30,70
200	481,00	277,00	216,40	170,80	123,60	96,70	85,20	62,40	43,30	32,60

Table 2: value of precipitation l/s*ha for the Return periods (2-200 years), in time variation of 1min-60min (The Norwegian Meteorological institute).

IDF-curve for OPPSTRYN, Stryn, Sogn og



Velocity (minutes)

Figure 10: IDF-curve from 58700 Oppstrn based on the period of time 1968-1987 for 1-24 hours (The Norwegian Meteorologist institute).

Return value of precipitation (l/s*ha)

Duration in minutes

Return period	60min	90min	120min	180min	360min	720min	1440min
2	19,00	16,40	15,10	13,50	11,20	8,20	5,70
5	22,10	18,20	16,50	15,20	12,40	9,70	7,00
10	24,20	19,30	17,40	16,20	13,10	10,70	8,00
20	26,20	20,50	18,20	17,30	13,90	11,70	8,80
25	26,80	20,80	18,50	17,60	14,10	12,00	9,10
50	28,80	21,90	19,40	18,60	14,80	12,90	10,00
100	30,70	23,00	20,20	19,60	15,60	13,80	10,80
200	32,60	24,10	21,10	20,60	16,30	14,80	11,70

Table 3: value of precipitation l/s*ha for the return periods (2-200 years), in time variations of 60min-1440 min (The Norwegian Meteorological Institute).

IDF-curves (Figure 8 and 9 and Table 2 and 3) are useful tools in calculating the runoff volume discharged per time and area. To assess "culmination floods", rain intensities are extracted for appropriate duration of rain-events, typically the time of concentration. Additionally they help to interpolate the value of precipitation in mm for each return period, based on the time of concentration.

2.2 Method

2.2.1 Hydrological analysis (in GIS)

Hypothetical natural catchments of the study site

Geographical Information Systems (GIS) are used to analyse and present spatial data from a particular area of interest. It also provides anumber of tools for hydrological analysis and modelling that were applied here. In that study ArcGIS 10.6.1 was used to determine the natural and modified catchments of the water streams that are present in the study site. Access to the software was provided by Western Norway University of applied science. The computation of the stream network for the catchments followed the manuals given in chapter seven "Terrain analysis" in "Zhu.X. GIS for environmental applications. A practical approach" (Zhu.X. 2016, p. 279-303).

The input base data for the analysis was a digital elevation model (DEM) of the site at 1 meter horizontal resolution. A DEM is a model of the terrain based on elevation data that is given as raster file. It was provided by hoydedata.no (https://hoydedata.no/LaserInnsyn/, 12.05.2018). There are several tools in ArcGIS that have to be used create the catchments. They are found in the toolbox "Spatial Analyst tools" and there in the sub-box "Hydrology". In that toolbox the following tools were used in the order of designation: "Fill" to correct the DEM from missing or wrong values. "Flow direction" to convert the DEM into a raster with general information about the direction of water flow in the DEM. "Flow accumulation" was used to convert the "flow direction" layer into a new layer that calculates potential flows based on the amount of flow per pixel from the "flow direction" layer. To generate a drainage network from that layer the tool "Con" is used from the sub-box "Conditional" in the "Spatial analyst tools". Here it is required to determine manually a threshold value for the detail richness of the drainage network. Dependent on the value more or less streams will be generated. In that study the value 1000 was used which is recommended as a default value by Zhu 2016. After that step the stream network of the site is generated. This theoretical stream network was confirmed by field observations of existing water streams using GPS at the 15.12.2018. The validated map of the stream network with GPS data is provided in (appendix figure 35).

Based on that stream network junctions of tributaries were identified that mark outlet points of individual catchments. These outlet points are referred as "Pour Points" in the following. The pour points are required to be set manually for the next steps in the computation of the final catchments. The identified pour points were added as point features to the project and used in the next tool "Snap pour points". Here the pour points are combined with the flow direction layer in a new raster layer. Based on that the catchments are generated with the final tool "Watershed" which computes the individual natural catchments based on the pour point raster and the flow direction raster. Finally the output watershed raster is converted into a polygon shape file for further analysis and data extraction in GIS.

Modified catchments due to land use change

Since the study site is no longer a natural drainage system due to urban settlements in the site, the natural stream network was changed, as described earlier. To compare the natural drainage network with the modified, artificial drainage network, organized through a stormwater pipe system alternative catchments need to be computed based on the pipe system.

For that the same base data and tools are used. But now the pour points are chosen based on junction between natural streams and the pipe system, meaning where runoff discharges into pipe inlets. These points were chosen based on a layer that combined the natural stream network created earlier with the pipe systems, provided by Sogndal municipality. Where the streams cross the pipes, pour points were set. To validate these points' field observations with GPS were conducted to confirm that there are inlets into the pipe system where the pour points were set in ArcGIS. Based on the new point dataset the modified catchments were computed.

2.2.1.2 Soil infiltration ability

To identify the soil type and its infiltration ability of the study site, soil data was used. The soil data used was provided by Geological survey of Norway (NGU). It was downloaded from the website www.ngu.no, Sogn og Fjordane county, Sogndal municipality. The soil type and infiltration ability data were extracted in 06.02.2019 from www.ngu.no.

2.2.1.3 Land use Elements

To classify the land use elements of the study site, in location, type and areal coverage and their permeability, data was extracted in 07.02.2017 from the website www.geonorge.no .

2.2.1.4 Municipal stormwater management systems

To compare the changes made by the municipal pipe systems management over the natural stream network system and to analyze the shortcomings of pipe system management in the study site, data are taken from the municipality (personal communication, Tola Bake, 11.12.2018).

2.2.2 AutoCAD

AutoCAD is a commercial design software for landscape planning purposes. In this study, it was used to develop an alternative stormwater plan for the study site. AutoCAD has 2D and 3D versions, but for this project only the 2D version was applied. Access to AutoCAD was provided by Western Norway University of applied science.

The official land use plan for the study site from Sogndal municipality was used as input data and imported into the program in the form of DFX file. It was provided by Sogndal municipality in 03.05.2019. To draw the runoff management plan with the updated municipality plan of the study site, was used the various tools of the software. The stormwater management plan was executed, by modifying the municipality land use plan. To adjust the processes, the plan was divided in to six areal zones. In each areal zone the specific part of the blue-green stormwater management was drawn. Finally they are saved as DWG files and exported in to Adobe Illustrator to modify the colour of the layers.

2.2.3 Field work

To compare the natural stream network with the municipality pipe systems management, field work inspections were executed in the study site. Most of the natural streams start from the terrain sides of Bergi and Tona (Figure 5). Some of the natural streams continue further down through the urban areas. Most of the natural streams are modified starting from the upper part of the residential areas and replaced by mostly pipe systems.

2.2.4 Rational method

Rational method is a simple technique, serving to calculate design flood for given return periods from catchment areas up to 5 km^2 (Thompson, 2006). Rational method calculate runoff based on the potentials of catchments, the average intensity of rainfall for a particular length of time (the time of concentration), and the catchment drainage areas (Thompson, 2006). Flood values are calculated with different formulas (Stenius et al., 2015), for a small precipitation fields are used a national rational formula using the data from stations and using GIS for time of concentration.

The formula is: $Q = C*i*A*K$

Q= discharge (l/s)

C= runoff coefficient (dimensionless)

i= precipitation intensity (l/s*ha) (from a IDF-curve)

A= Area (ha) (1ha = 10 000m^2)

K= climate factor/ safety factor

2.2.4.1 Runoff coefficient

Runoff coefficient is the fraction of precipitation that does not infiltrate in to the subsurface, but contribute to overload flow (Stenius et al., 2015). Infiltration ability of an area is classified between 0 and 1, based on the soil permeability, topography and climate factors (Thompson, 2006). The runoff always increases with precipitation and hard surfaces on the site, is low with thick soil's and high for thin soil's and vegetation covers. The runoff coefficient will be affected by climatic conditions in the future, because the precipitation level will increase by 15% up to the year of 2100 and short period intensity will increase by 40% (Hanssen-Bauer et al., 2015). So the increasing precipitation will be able to override all other factors and rise runoff in amount.

Surface roughness	Runoff coefficient (C)
Concrete and asphalts	0,6-0,9
Gravels	0,3-0,7
Agricultural and green sport area	0,2-0,4
Forest	0,1-0,5

Table 4: surface roughness and Runoff coefficient (Stenius et al., 2015).

According to NVE's guidelines (Stenius et al., 2015), the lowest value of runoff coefficient is used for precipitation events less than one hour and the highest value is used for precipitation values with a duration greater than three hours (Table 4). NVE recommended also the runoff coefficient value increases with the precipitation events higher return period greater than 10 years.

For 25 years: increases by 10%

For 50 years: increases by 20%

For 100 years: increases by 25%

For 200 years: increase by 30%

2.2.4.2 Time of concentration

Time of concentration (Tc) is the time used by the runoff to flow from the remote point in the catchment area to the outlet (Stenius et al., 2015) and provide in minutes.

To calculate time of concentration (Tc), for natural catchments (undeveloped fields) is given by:- $Tc= 0{,}6*L*H^{-0.5}+3000*ASE$

- To calculate time of concentration (Tc), for urban catchments (developed fields) is given by: $Tc= 0{,}02*L^{1,15}*H^{-0,39}$
  Where L: the longest flow path in meters (m) in the catchment area

  H: the height difference in the catchment area (m)

  ASE: Effective lake percentage (%)

2.2.4.3 Climate factor

Climate factor is the factor used in getting future dimensioning values of precipitation. It depends on return period, rainfall duration and locality (Førland et al., 2015). Climate factors estimated the short duration rain events in Sogn og Fjordane will increase by 40% by the end of the century. Climate factor have set a safety margin 1.2 for Sogn og Fjordane county (Førland et al., 2015).

2.2.5 Manning equation

Manning's equations is a formula used to calculate the velocity of flow in open channels, based on discharges (Q), slope (S), radius (R) and Manning's roughness coefficient (n) (Mangin, 2010). According to (Bengtson, 2012) it is used for a uniform flow in a pipe also. For the flow filled up more than half, parameter is calculated as h= 2r-y. H is segment height, r is radius of pipe and y is depth of the flow. The roughness coefficient (n) value depends on the material type.

$Q = VA$

$V = 1/n (R^{2/3} * S^{1/3})$

V is average velocity of the cross-sectional area (m/s)

n is Manning's coefficient

R is hydraulic radius (m), which is expressed as $Rh = A/p_w$, where A is area (m^2) and p_w is wetted perimeter (m)

S is slope in hydraulic head, which is the channel bed slope, when the water depth is constant.
The runoff discharge through the pipe can be calculated using the equation,

$Q= (A (R_h^{2/3} * S^{1/2}))/n.$

Where A is area of the pipe in m^2, Rh is hydraulic radius of the pipe A/P, S is slope of the pipe calculated for: ($\Delta H/L$) and n Manning's coefficient related to surface roughness.

3. Results

In that section land use catchment characteristics and modification due to stormwater management of the study site are presented. Further on hydrological analysis of the natural and artificial catchments is done

3.1 Land use categories of the study site

The main land use categories of the study site are forest**,** agricultural land, urbanized area, sport fields and open areas. In total all those land use categories cover 155,5 hectares area (Figure 11).

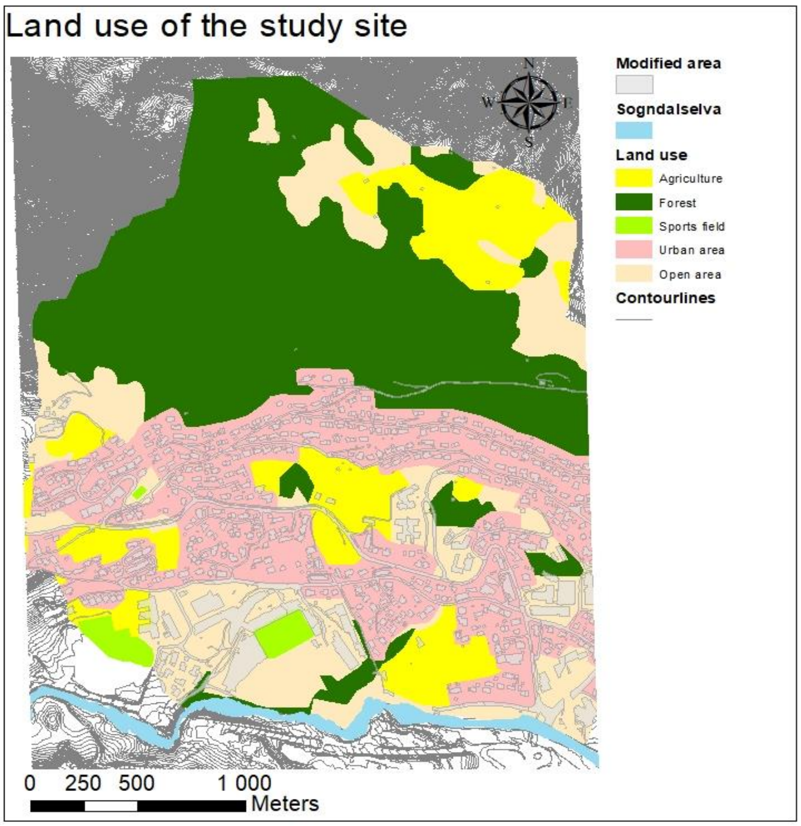


Figure 11**:** Land use elements of the study site. Data is extracted from www.geonorge.no and figure is made by Tewelde Mebrahtu Tesfay.

Forest covers approximately 37% of the study site and is distributed mostly in the elevated faces of the northern part of the site (Figure 12 A). The urbanized area and sport fields are found in the lower and gentler areas (Figure 12 C). Open areas and agricultural lands (Figure 12 B) are scattered in patches across the study area and they share 21% and 12,5% of the total land use of the study site.

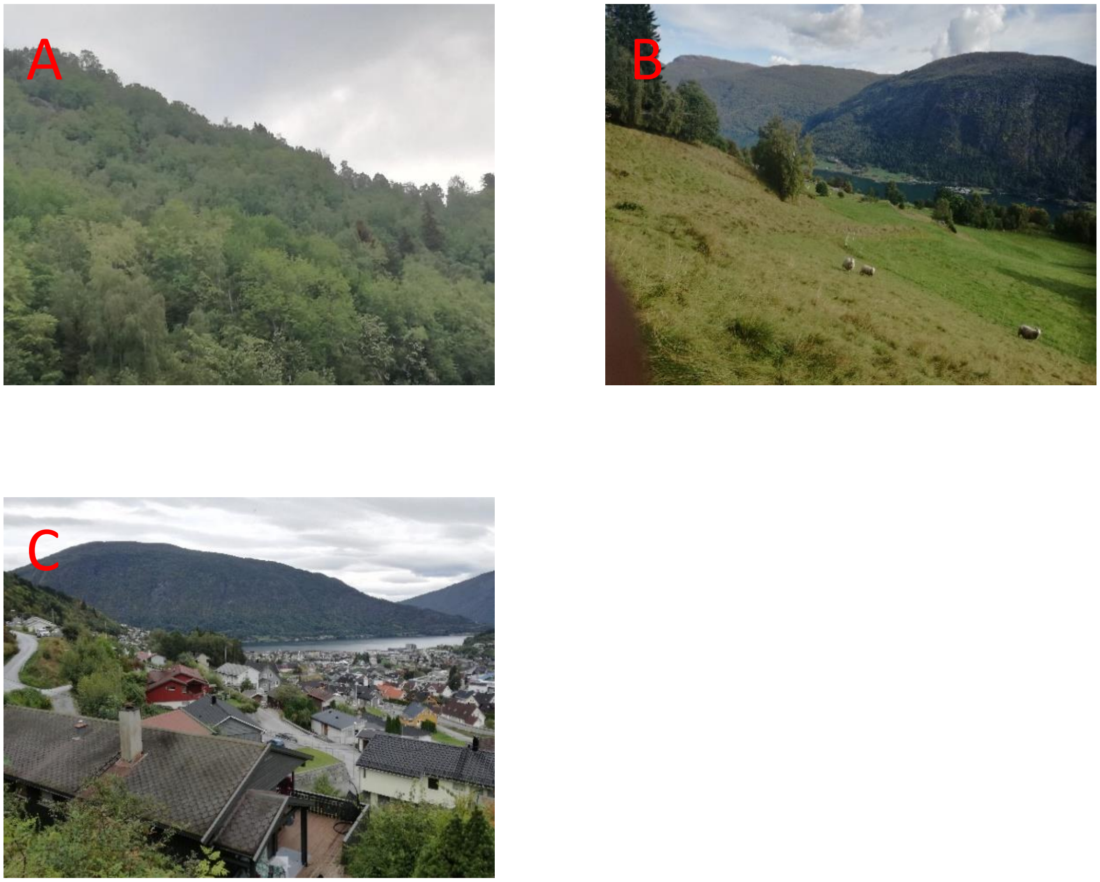


Figure 12: Pictures A, B and C show examples for forest, agricultural land and residential area of the study site. Photos taken by Tewelde Mebrahtu Tesfay.

3.2 Soil infiltration ability of the study site

To infiltrate stormwater, it is important that the soil has high infiltration ability. Soil infiltration capacity is influenced by both geological factors and land use elements (Greenwood & Buttle, 2018).

Soil types of the study site are; thin moraine, thick moraine, thick seabed and glacial sediments (NGU, 2016). Moraines consist of material/debris transported and deposited by glaciers. They transformed from active to stable form by the influence of colonizing plant species, geomorphic processes and material properties, while the glacial fluvial sediments are results of the water actions in glacial deposits (Eichel, Draebing, & Meyer, 2018).

Figure 13 illustrates the infiltration ability of the study site. Orange colour represents low infiltration and corresponds with thin moraine soil. It accommodates 41,41% of the study site. Thin moraine soil is covered most of the terrain which have forests and some part of the residential areas. The red coloured areas represent impermeable ground and with the thick seabed soil type, meaning that it is mainly bare rock. It covers 17,76% of the total area. Thick moraine soil type corresponds with medium good infiltration ability(yellow colour) and covers 2,44% of the study site. Good infiltration ability is shown in green colour and consist of fluvial glacial sediment type of soil. They coccur on 10,58% of the entire area. The lower areas of the study site noticed by grey colours are not classified in terms of the infiltration ability. The soil type here is fluvial river sediments. They covers 28,46% of the site. According to Eichel et al, (2018) this soil type can be classified with good infiltration ability. But the respective area is modified in large part with impermeable infrastructures and buildings.

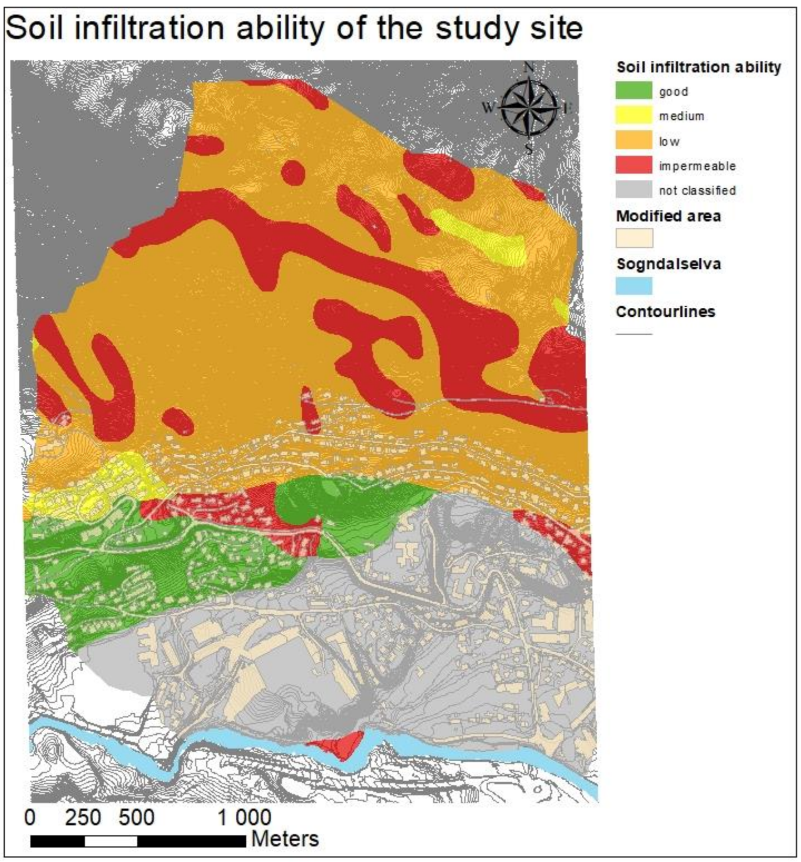


Figure 13: Map of infiltration ability of the study site. Data is extracted from www.ngu.no and figure is made by Tewelde Mebrahtu Tesfay.

3.3 Study site natural catchments and their characteristics

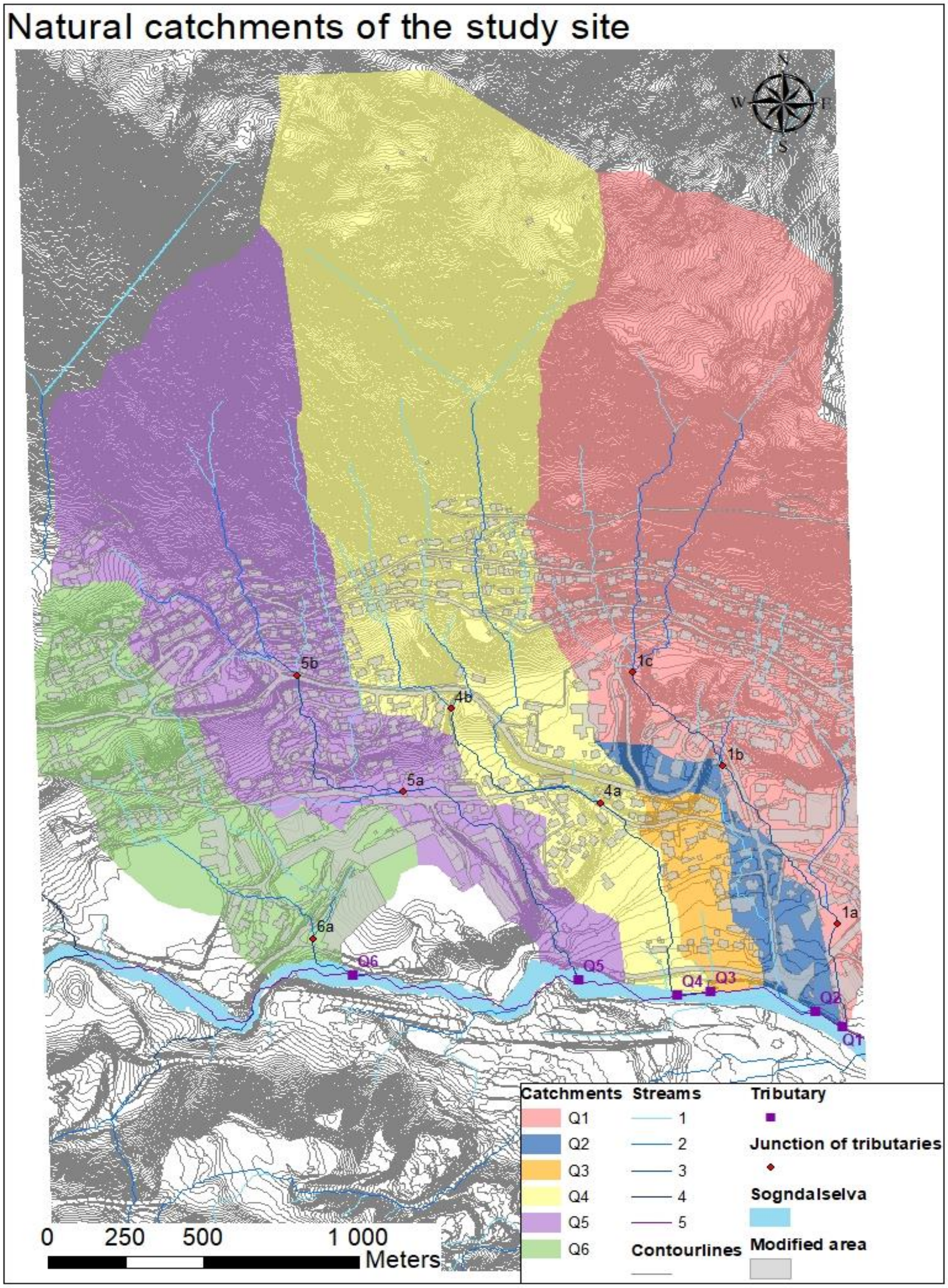


Figure 14: Map of natural catchments and stream networks of the study site

The total study area (155,5 ha) consists of six sub-catchments with outlets discharging in to Sogndal river (Sogndalselva). The outlets of the sub-catchments are numbered Q1 to Q6 upstream from east to west along Sogndal river (Figure 14). Each sub-catchment is joined at its primary, secondary and tertiary junctions and are marked by red dot at their main junctions. In each step of joining new streams, the size of the catchment area increases and volume of the runoff rises.

The catchment area which discharges its runoff to the outlet Q1 is 41,9 hectares large and to Q2 and Q3 are 5 and 3,4 hectares respectively. The outlet discharge to Q4 and Q5 are found in the central part of the study site and covers 45,4 and 37,7 hectares respectively. The catchment area, which discharges to the outlet Q6 is 16,5 hectares large, found in the eastern part of the study site. The area around the campus between Q5 and Q6 is uncoloured in Figure 14 because it does not collect runoff in a sub-catchment and discharges directly to Sogndal river and covers 5,6 hectares of the total area of the study site. The areal fraction of each land use element differs for each catchment (Table 5). Open areas are the most dominant land use type in each sub-catchment, except sub-catchment Q4 and Q1 (Table 5).

Catchment ID	Total area (hectares)	Agricultural area %	Forest area %	Open& sport areas %	Asphalt &Concrete %	Total area in % for each catchment
Q1	41,9	16,47%	36,23%	33,56%	13,60%	100%
Q2	5	-	-	78%	22%	100%
Q3	3,4	17,65%	-	58,82%	23,53%	100%
Q4	45,4	12,99%	56,39%	22,69%	7,93%	100%
Q5	37,7	7,96%	36,60%	42,44%	13,00%	100%
Q6	16,5	18,18%	1,82%	49,09%	30,91%	100%
Campus area	5,6	-	12,5%	60,71%	26,79%	100%

Table 5: Land use elements in percentage of areal cover of the study site

3.3.2 Stormwater discharged from the natural catchments

To calculate the stormwater that discharges from each natural catchment time of concentration and average runoff coefficient (C) are calculated, based on the formulas:-

Tc= $0,02*L^{1,15}* H^{-0,39}$, this formula is used for the urbanized areas.

C= ((Agricultural area (A) %* 0,2) + (Forest area% (F)*0.1) + (Open area and sport fields area (OS) %*0,2)+ (Asphalts and concretes area (AS) %*0.6))/Total catchment area%

Catchment ID	Length of each sub-catchment	ΔH (H_2-H_1) of each sub-catchment	Time of concentration (Tc) in minutes	Average runoff coefficient (C)
Q1	1405m	287m	9,17	0,21
Q2	372m	19m	6,14	0,29
Q3	136m	9m	2,40	0,29
Q4	1564m	406m	9,06	0,18
Q5	1367m	262m	9,21	0,22
Q6	831m	99m	7,59	0,32

Table 6: Time of concentration and average runoff coefficient for each catchment area

The catchments, which discharge their runoff through the six outlets have different time of concentration and runoff coefficient (Table 6). Some catchments respond quicker, while some others slower, because they have differences in length of streams, type of land use elements, the areal size and their permeability.

The potential volume of stormwater discharge from each catchment is calculated using the formula Q= C*I*A*K. The precipitation unit liter per second per hectare has an interpolated value for each catchment. The interpolation process is done by re-calculating the values of IDF from Table 1 at the time of concentration from Table 6. Additionally, the size of each catchment is taken from Table 5 in hectares and the climate factor for Sogndal is constant 1.2.

Return period	2	5	10	20	25	50	100	200
Q1=l/s	477,15	678,93	812,50	940,68	981,65	1106,98	1231,58	1348,57
Q2=l/s	96,88	140,10	168,75	196,22	205,01	231,94	258,60	283,50
Q3=l/s	92,35	138,08	168,31	197,36	206,53	234,92	263,14	291,90
Q4=l/s	480,02	688,61	826,68	959,16	1001,53	1131,17	1259,73	1380,54
Q5=l/s	441,90	629,02	753,13	871,87	910,08	1025,84	1141,29	1250,67
Q6=l/s	332,01	478,05	574,80	667,56	697,15	788,07	878,17	962,38

Table 7: The design floods from each natural catchment for a given return period

3.4 Municipal stormwater management systems and modified catchments

Stormwater pipe systems were developed since the second half of the 20th century. This management was focused on the engineering system to promote efficient land development and hydraulic efficiency (Chen et al., 2016). The municipality of Sogndal has managed stormwater, in the study site using pipes such as Betong Muff (BMU) and Plastic Pipe (PVC).

Figure 15: Pipe types used in the study site: Betong Muff (BMU) and Plastic pipe (PVC). Pictures taken from www.google.no.

Betong muff is made from concrete. Plastic pipes are made from polyvinylchloride (PVC) and helpful to flash liquids and small solids. The stormwater pipes are represented by yellow lines in Figure 16. The size of the pipes varies from 75 mm up to 1000 mm.

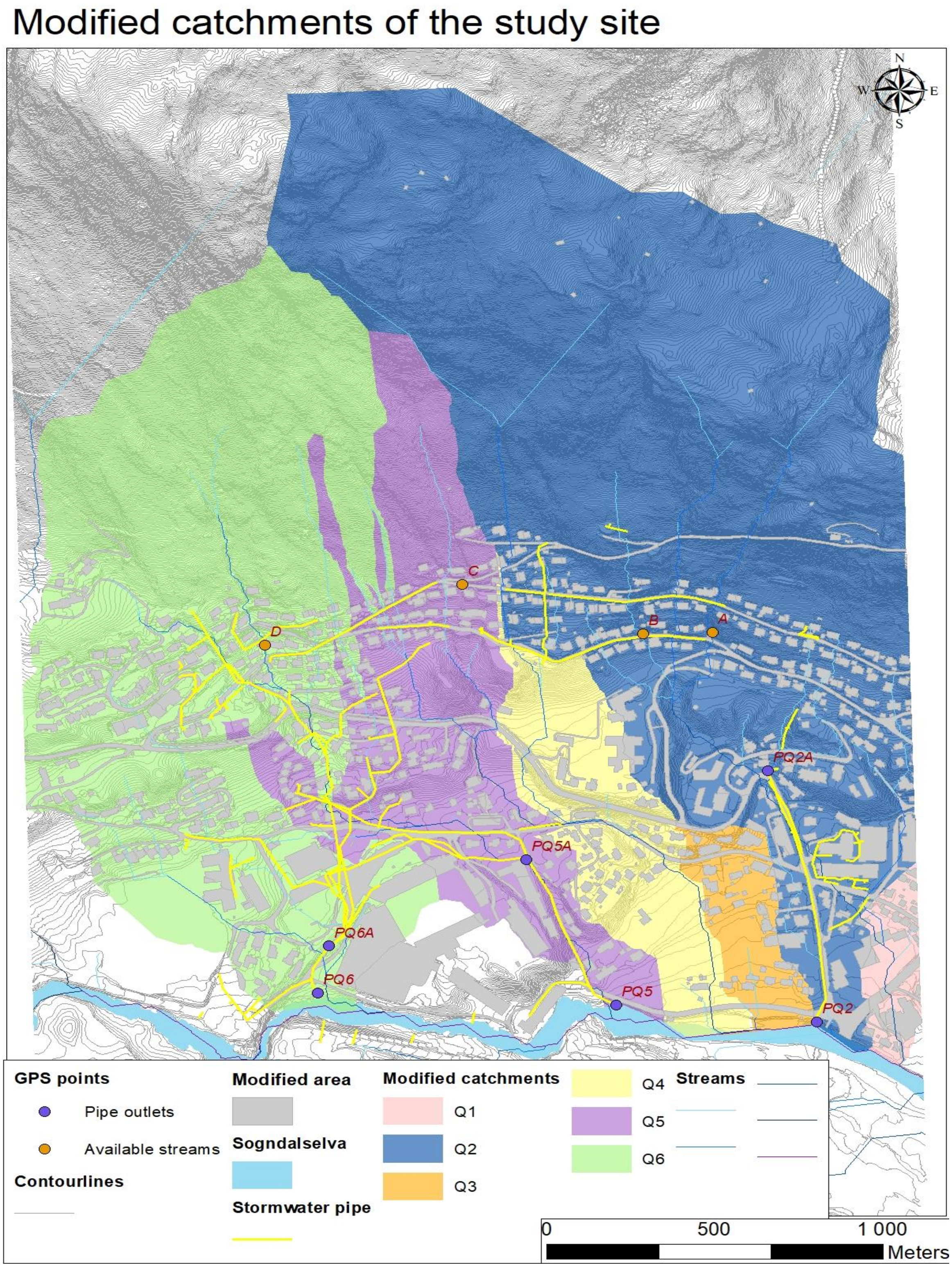


Figure 16: Municipal stormwater management system (yellow lines) and the modified catchments of the study site.

The pipe systems stormwater management replaced; many of the natural streams on the site. The runoff accumulated from the forest, open areas and residential areas is connected systematically with the pipes. The municipality managed the runoff from the study site with three main pipe system outlets at the northern bank of Sogndal-river. The pipelines are built in the lower part of the study site in catchment Q2, in the middle part in catchment Q5 and in the upper in catchment Q6 (Figure 16). The infrastructural modification made in the land use elements caused the changes in flow directions. The natural streams of catchment Q4 and Q5 are deflected towards the catchment of Q2 and Q6 in the upper northern side of their catchment area.

In the northern part of the study site, as the runoff discharges from the forest. Some streams are deflected in ditches next to the roads, some streams are discharged directly into stormwater pipes and some remain as natural open streams. For example in Q2, the runoff discharge from the forest flows beside of the roads in the upper roads and then in to the pipes beside of the next roads. Then, the pipes discharge in to the open stream, (Figure 16, point A and B; Figure 18a and b). Finally they discharge it to the main pipe outlet PQ2 through PQ2A (Figure 17 PQ2). The runoff discharge to PQ6 is taken directly in to the pipe when the water comes from the forest. Some of the water discharge to the open stream marked by letter D in Figure 16 and shown in figure 18d. Finally, all the pipes join at PQ6 (Figure17 PQ6). The runoff management of Q5 is similar to Q2 and Q6. The open channel in point C is deflected from the natural stream by an artificial open channel (Figure16, Figure 18C). All water from Q5 is discharged through PQ5 (Figure 17 PQ5).

Figure 17: Pictures of PQ2, PQ5 and PQ6 show the three pipe outlets of the municipality stormwater management system. Photos taken by Tewelde Mebrahtu Tesfay.

Figure 18: pictures of a, b, c and d show all still available streams of the study site that are located at the respective points A-D in Figure 16. Photos taken by Tewelde Mebrahtu Tesfay.

3.4.1 Characteristics of the modified catchments

The pipe system management has changed the catchment areas of the study site tremendously (table 8). The diversion of the natural streams, with the pipe systems has increased the size of the catchment areas, which discharge runoff to the outlets of PQ2 and PQ6. The natural catchment, which discharges runoff to the outlet Q2 was 5 hectares large, but with the pipe system management, the catchment area which discharge to outlet PQ2 increased to 71,37 hectares. The natural catchment area, which discharged to Q6 increased from 16,5 hectares to 45,93 hectares, after modifications was done in the land use elements of the site. The natural catchment areas which discharge to Q5 and Q4 decreased from 37,7 hectares to 19,11 hectares and from 45,4 hectares to 9,3 hectares respectively. The catchment area of Q1 is deflected to Q2, there is only 0,77 hectares discharge to Q1 after the modification processes. The changes of the outlets direction, using the pipe system were constructed mostly in the upper part of the study site. As a consequence, the catchment area of Q3 remains constant. In summary, it is visible that the total number decreased from 6 natural catchments towards 3 modified extended catchments with only one natural catchment remaining untouched.

Catchment ID	Total area in hectares	Agricultural area %	Forest area %	Open, garden and sport area %	Asphalt andconcrete area %	Total area in % for each catchment
Q1	0,77	-	-	52,51%	47,49%	100%
Q2	71,37	11,95%	47,26%	29,61%	11,18%	100%
Q3	3,42	17,84%	-	59,06%	23,10%	100%
Q4	9,3	47,42%	1,29%	38,92%	12,37%	100%
Q5	19,11	14,60%	23,44%	41,81%	20,15%	100%
Q6	45,93	7,79%	38,06%	37,43%	16,72%	100%
Campus area	5,6	-	13,21%	60,18%	26,61%	100%

Table 8: Areal size of the modified catchments and land use elements in percentile.

Due to the modifications in stormwater management systems, the forest dominance in catchment area Q1 and Q2 (Table 5) are replaced by open area and agricultural land dominance (table 8). The dominance of open area in catchments of Q2 and Q6 (Table 5) replaced by forest dominance in the modified catchments (Table 8).

3.4.2 Stormwater discharge from the modified catchments

Time of concentration and average runoff coefficient (C) of the modified catchments are calculated in similar way to the natural catchment, using the formula:-

$Tc= 0,02*L^{1,15}* H^{-0,39}$, this formula is used for the urbanized areas.

C= ((Agricultural area (A) %* 0,2) + (Forest area% (F)*0.1) + (Open area and sport fields area (OS) %*0,2) + (Asphalts and concretes area (AS) %*0.6))/Total catchment area%

Time of concentration and average runoff coefficient differ in most of the modified catchments compared to the natural catchments, see Table 6 and 9.

Catchment ID	Length of each sub-catchment in meters	ΔH (H_2-H_1) for each sub-catchment in meters	Time of concentration (Tc) in munities	Average runoff coefficient (C)
Q1	415	16-1 = 15	7,31	0,39
Q2	1552	503-3= 500	8,28	0,19
Q3	136	12-3= 9	2,40	0,29
Q4	605	164-4= 140	7,37	0,25
Q5	1123	283-6= 104	7,19	0,26
Q6	1303	476-25= 451	7,05	0,23

Table 9: Time of concentration and average runoff coefficient for each of the modified catchments.

That is due to the changes happen in the length of streams and elevations with the changes appear in the catchment size and characteristics as visible in Table of 5 and 8 above. The average value of runoff the coefficient also changed, because the changes happened in the contents of the land use type and size of catchments (Table 5 and 8).

The volume of runoff discharged from each catchment are calculated using the formula Q= C*I*A*K. The precipitation intensity value is interpolated from the IDF curve of the time of concentration (Table 8). The size of catchment area was taken from Table 8 in hectares and climate factor is 1.2 for Sogndal.

Return period	**2**	**5**	**10**	**20**	**25**	**50**	**100**	**200**
Q1=l/s	17,15	24,54	29,42	34,13	35,63	40,22	44,79	49,06
Q2=l/s	742,47	1059,71	1269,45	1470,84	1535,07	1731,87	1927,36	2111,71
Q3=l/s	92,89	138,89	169,30	198,52	207,74	236,31	264,69	293,61
Q4=l/s	201,41	292,20	352,18	409,96	428,13	484,54	540,67	595,27
Q5=l/s	297,28	426,48	512,10	594,15	620,32	700,75	780,41	855,18
Q6=l/s	690,63	997,40	1200,86	1395,70	1458,07	1649,24	1838,50	2015,59

Table 10: The runoff discharges from modified catchments

The quantity of stormwater discharge through the outlet of Q2 and Q6 increased. However, the discharges to Q1, Q4 and Q5 are decreased, while runoff discharged through the outlet of Q3 does not show any changes. The runoff discharge to Q2 is increasing from 283,50 l/s/ha to 2111,71 l/s/ha and the discharge to Q6 is increasing from 962,38 l/s/ha per to 2015,59 l/s/ha. On the contrary the runoff discharge to Q5 is decreasing from 1250,67 l/s/ha to 855,18 l/s/ha. The volume of runoff shows huge change in all the outlets after the modifications were done.

3.4.3 Total runoff from the modified catchments and the capacity of the pipes on their outlets.

The quantity of runoff from the modified catchment (Table 10) was compared with the capacity of the existing pipe system. That was done to analyse the critical value the stormwater pipe system can handle in each catchment. To estimate the pipe capacity, at the pipe outlets of catchments Q2, Q5 and Q6 are calculated volume of runoff in m^3/s, using the Manning equation. Manning's equation is useable, for open channels and for a pipe which is filed below half and above half using its own formula (Bengtson, 2012). Here, 90% of the pipes diameter was used as wetted parameter depth because 100% would imply already an overload of the pipe (table 11). The diameter and elevation of the pipes were documented during field work. The calculations are done at the pipe outlets. The pipes have Betong Muff (BMU) type of material and their roughness is 0,011 (Bengtson, 2012). The pipes ID are taken As PQ2, PQ5 and PQ6 based on their catchments name. If the pipes are filled more than half hydraulic radius the following equations are applied: $R_h = A/P$ and h=2r-y. Where A is area of the flow and P is the wetted perimeter of the pipe. The velocity of runoff is calculated using V=Q/A, $A= 2\pi r^2 – r^2(\Theta\text{-sin}\Theta)/2$, $P = 2\pi r\text{-}r\Theta$ and Θ= 2 across (r-h)/2.

Pipe ID	Pipe Diameter	Flow depth	Area	Wetted perimeter	Hydraulic radius $(R_h)= A/P$	Slope = $\Delta H/l$	Velocity	Q=VA
PQ2	0,6m	0,54m	0,281 m^2	1,877m	0,15m	0,0514	5,78m/s	1,63598m^3/s
PQ5	0,6m	0,54m	0,281 m^2	1,881m	0,15m	0,1119	8,53m/s	2,3969m^3/s
PQ6	1m	0,9m	0,782 m^2	3,129m	0,25m	0,091	10,84m/s	8,4826m^3/s

Table 11: Maximum potential of these three pipes in handling runoff discharges.

The pipes have different level of handling capacity. PQ2 have not a capacity to handle the runoff, if the runoff challenges can happen at the return period of 50,100 and 200 years. The pipe have a maximum capacity of 1,636m^3/s and the runoff potential at return period of 200 year is 2,112m^3/s. The pipes systems in PQ5 and PQ6 are resilient and sufficient enough to handle the runoff challenges.

3.5 Stormwater management plan of the study sites

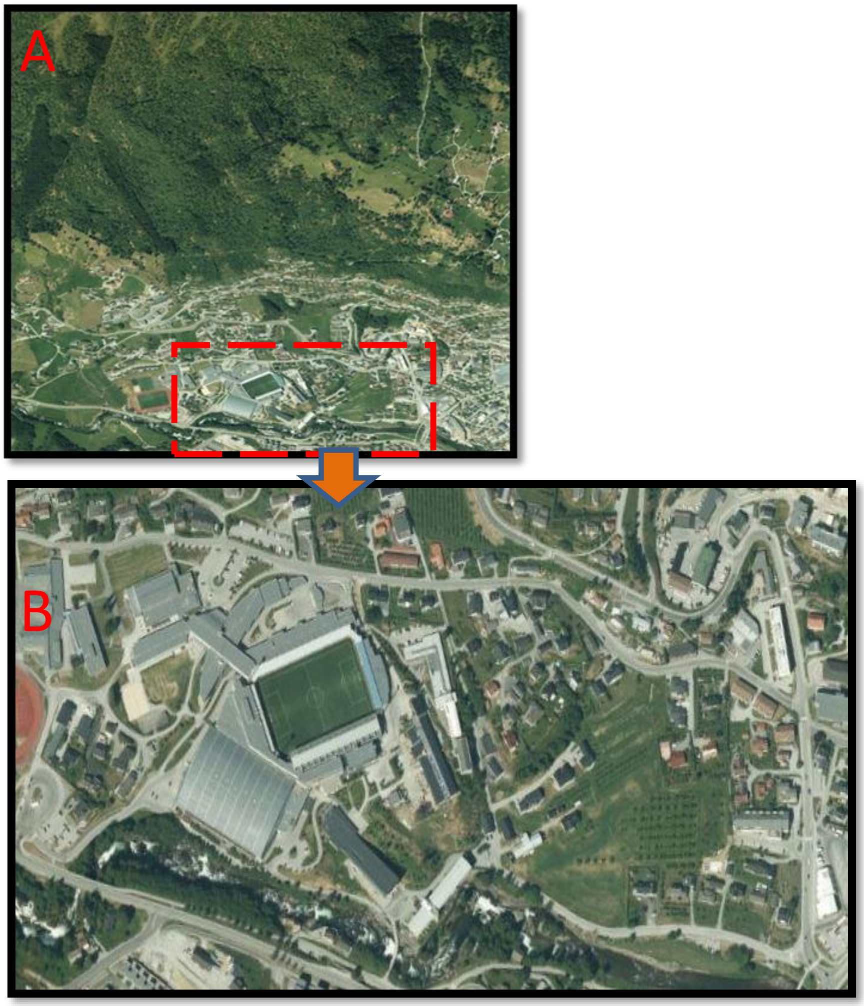
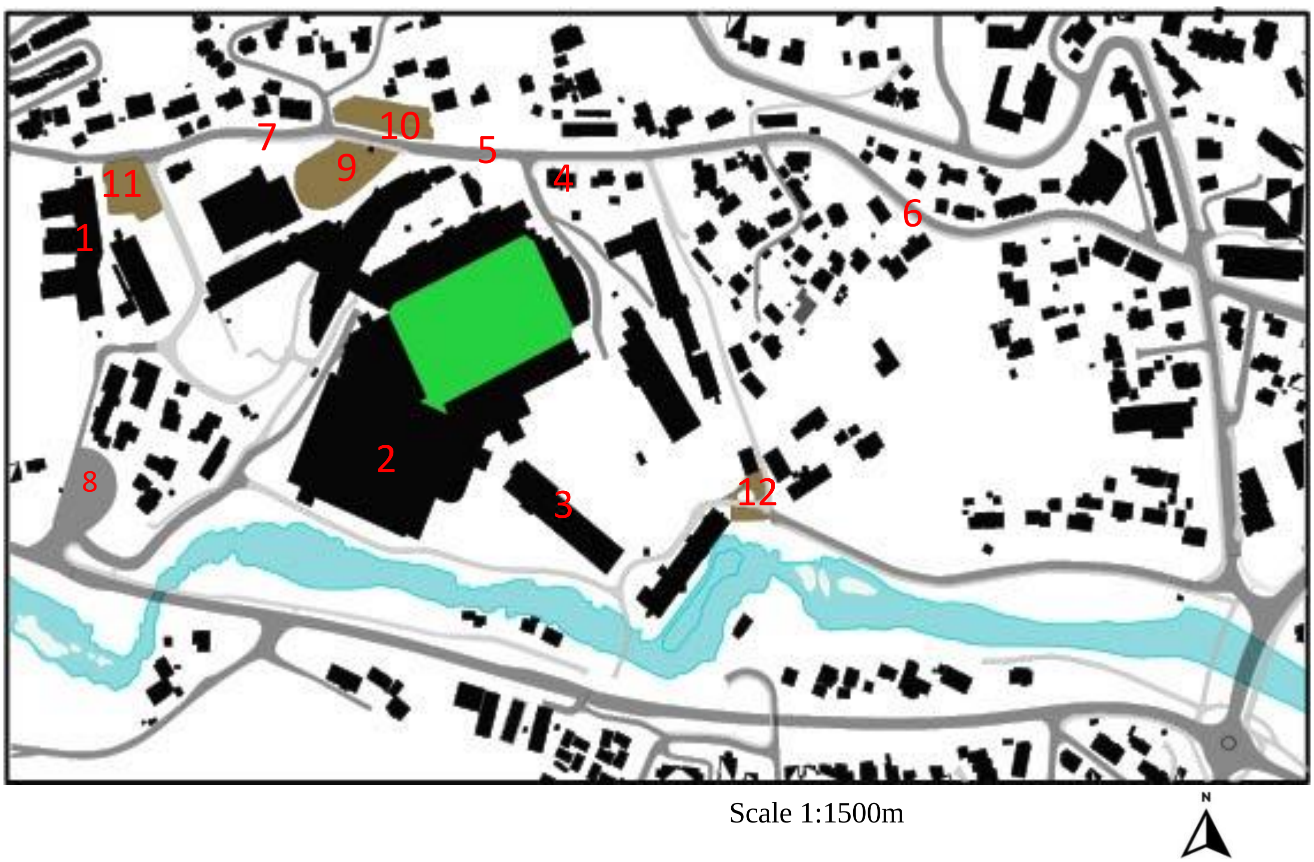


Figure 19: An overview of the whole study site. B the sites of Foss and Fosshaugane. Photos taken from Fylkesatlas, (2015).

Local stormwater management is one of the requirements in the municipality land use planning objectives, even though it is not specified in the existing and updated areal zoning plan of the site (personal communication, Marcus Mohn Werner, Sogndal municipality 25.04.2019). The existing pipes have a capacity to handle the runoff challenges for 200 years return period, except the pipe PQ2 (see Figure 16 and Table 10). The municipality has done a risk and vulnerability analysis in Fosshaugane 22.03.2018 (Hilde Helene Bjørnstad, 2018). Fosshaugane is estimated to have has medium level of flood risk, even though their study have not a detailed analysis.

3.5.1 Existing situation of Foss and Fosshaugane

The existing situation of the study site is a combination of forest, impermeable infrastructures, buildings, agricultural area and open green areas (Figure 19). Areal size of each land use elements is explained in percentages per catchment in Table 5 and 8. The land use elements contain public buildings such as Sogndal football AS, Sogndal stadium, Fosshaugane campus, Kvåle school and living houses, agricultural land, parking areas and open green areas. The sites are connected with Kvåle and the city center by the roads of Lunnamyri, Trolladalen and Fossvegen (Figure 20).



Scale 1:1500m

Figure 20: Map of buildings, roads and river, data was taken from sogndal municipality (11.12.2018)

3.5.1.1 Building

The buildings have increased the fraction of impervious surfaces. They have different shape and structure. For example Kvåle school (Figure 21 number 1) is as it built in a flat area, with skewed roofs and has asphalt and green corridors. Sogndal football AS (Figure 21 number 2) has an arc shape. It has large asphalt outdoor areas. It is connected with Fosshaugane campus and both covers large impermeable surface. Høgskole bygget (Figure 21 number 3) is the main building of the collage nowadays. It has rectangular shape, with a flat roof. It is built in small area, with five floors. It has impermeable concretes and open green outdoor area. The private houses (figure 21 number 4) are villa type of houses. Their roofs are skewed and they have large green garden for some of them and asphalt type entrance and parking.

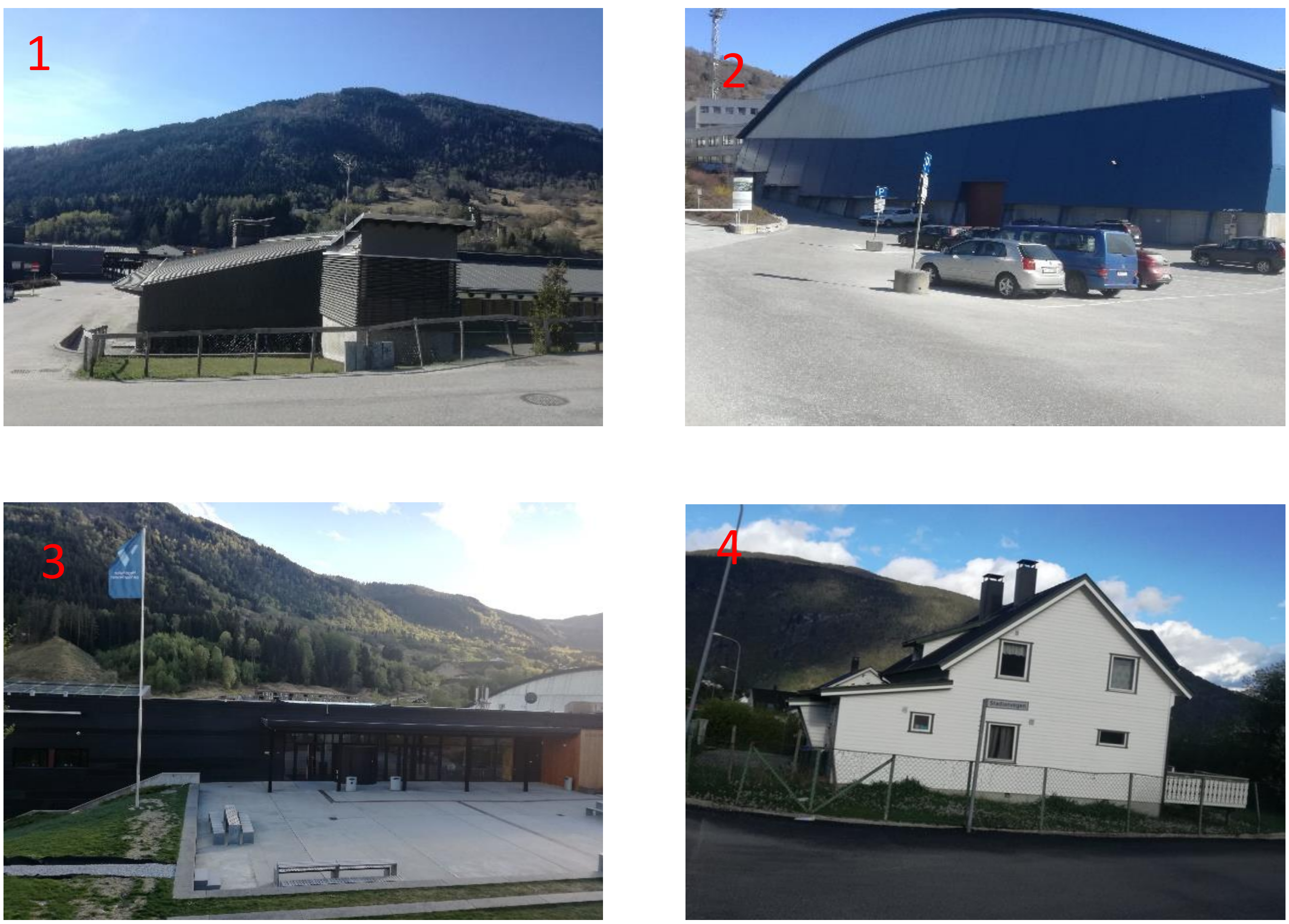


Figure 21: Pictures of 1, 2, 3 and 4 show the Kvåle school, Sogndal football As, Høgskole bygget and House Nr.4 in Figure 20. Photos taken by Tewelde Mebrahtu Tesfay.

3.5.1.2 Roads

The sites meet with Sogndal city, through the roads Dalavegen, Fjærlandsvegen, Lunnamyri, Trolladalen and Fossvegen. The sites have not traffic problems at present situation, but are proposed to increase by 25% in the future (Norconsult, 2019).

The roads have 5 -7.5 meters width and 2.5-4 meters wide sidewalks. Most of the roads have one side, foot and bicycle path. The sites have two bus stops. One is in Lunnamyri (Figure 22 number 5) approximately 3 meters wide and second is Ingafossen accessible by the Fjærlandsvegen road (Figure 22 number 8). It is found in a large flat area, approximately 38 meters wide.

Figure 22: Pictures of 5, 6, 7 and 8 show the road of Lunnamyri, Trolladalen, Fossvegen and Ingafossen in Figure 20. Photos taken by Tewelde Mebrahtu Tesfay.

3.5.1.3 Parking

There are a lot of parking areas in Fosshaugane, Foss and Kvåle, in front of buildings, beside roads and in flat areas (Figure 23, 9-12). The parking lots cover large impermeable area and have different size. Fosshaugane-campus parking is approximately 1800m^2 large (Figure 23, Nr.9) and Kvåleslid parking is approximately 995m^2 large (Figure 23, Nr.10). Parking of Kvåle school (Figure 23, Nr.11) and Foss (Figure 23, Nr.12) are approximately 520m^2 and 350m^2 large. All those impermeable asphalt parking areas discharge their runoff to pipes.

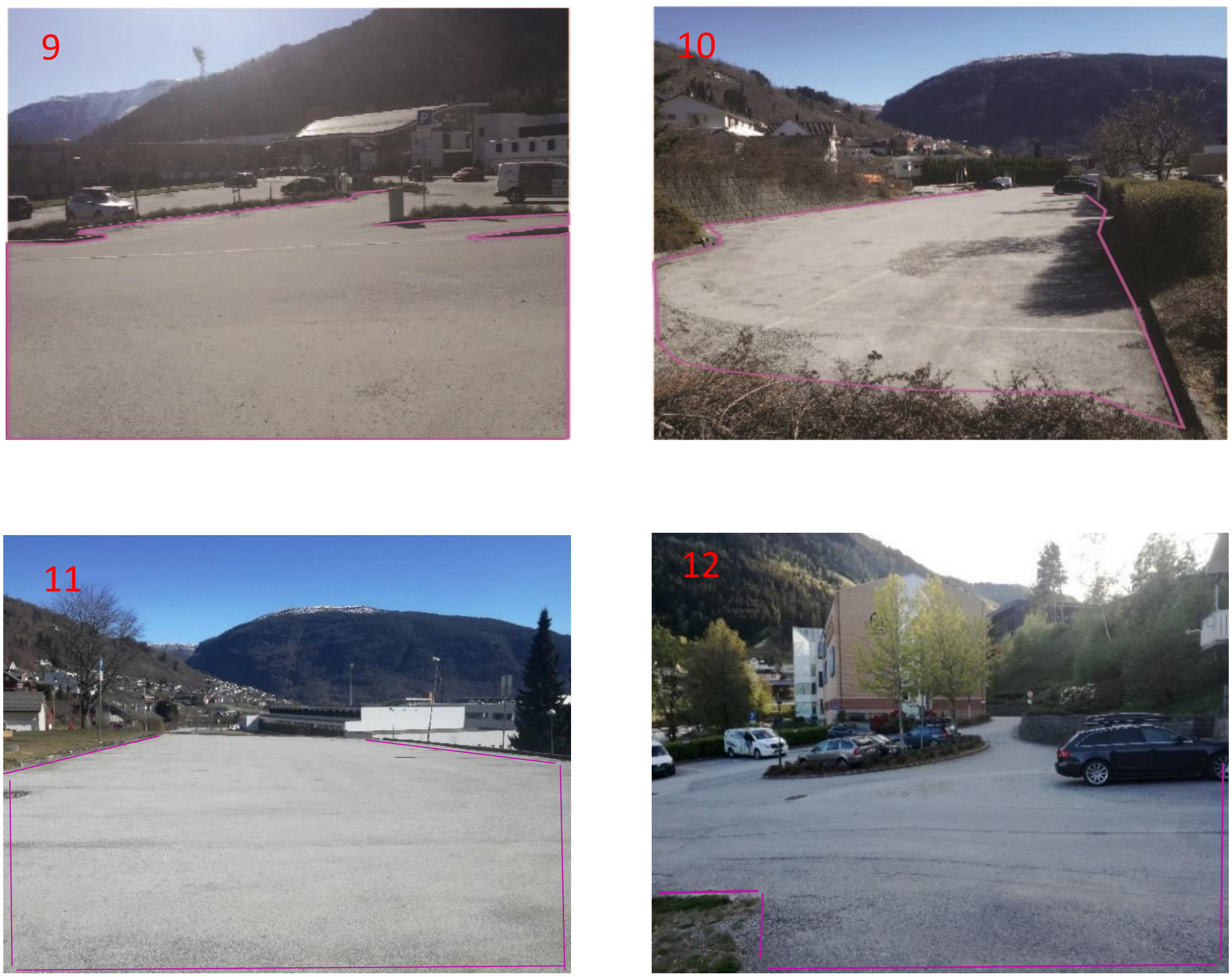


Figure 23: Pictures of number 9, 10, 11 and 12 show the parking of Fosshaugane-campus, Kvålestid, Kvåle school and Foss in Figure 20. Photos taken by Tewelde Mebrahtu Tesfay.

3.5.2 The planning situation

The existing plan of Foss was approved in 25.01.1996 (Sogndal kommune,1996) and Fosshaugane plan was approved in 10.06.2004 (Sogndal kommune, 2004). The plan has made requirements, which say that new constructions must unite and adapt to the existing buildings, analyzing how new constructions are relating with the existing infrastructures and all outdoor elements. Additionally, it includes requirements to reduce traffic, expanding pedestrian and bicycle paths, adjoining traffic areas and roads with new buildings and good parking coverage (Sogndal kommune, 2004).

The municipality of Sogndal has approved a new areal zoning plan of Sogndal campus area in 25.04.2019. The plan is extended from the site of Kvåle to Prestdalen of the town. The entire plan has educational buildings, detached houses, terraced houses with large gardens, blocks, large sport halls, new kindergarten, roads, bicycle and footpaths, parking, free green areas and green parks (figure 24). Some of the contents of the revised plan are to build new path for the pedestrians, cyclist, making the area easier to travel without cars, connecting Kvåle with the town center by bicycle and footpaths. Additionally, the municipality has goals to improve runoff management systems, opening the existing pipes and making free from cars for the campus area until 2025 (personal communication, Markus Mohn Werner, Sogndal municipality, 03,05, 2019).

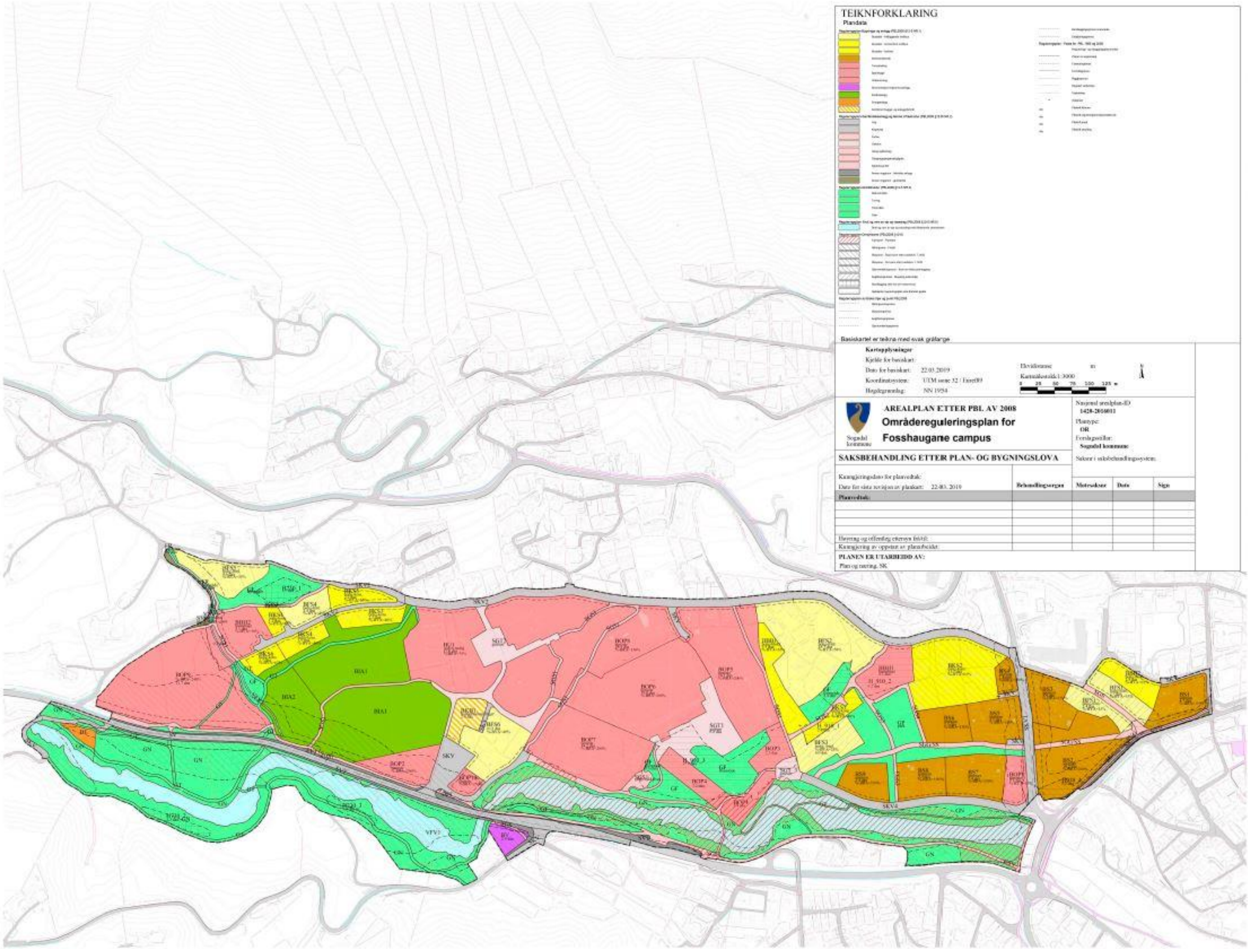
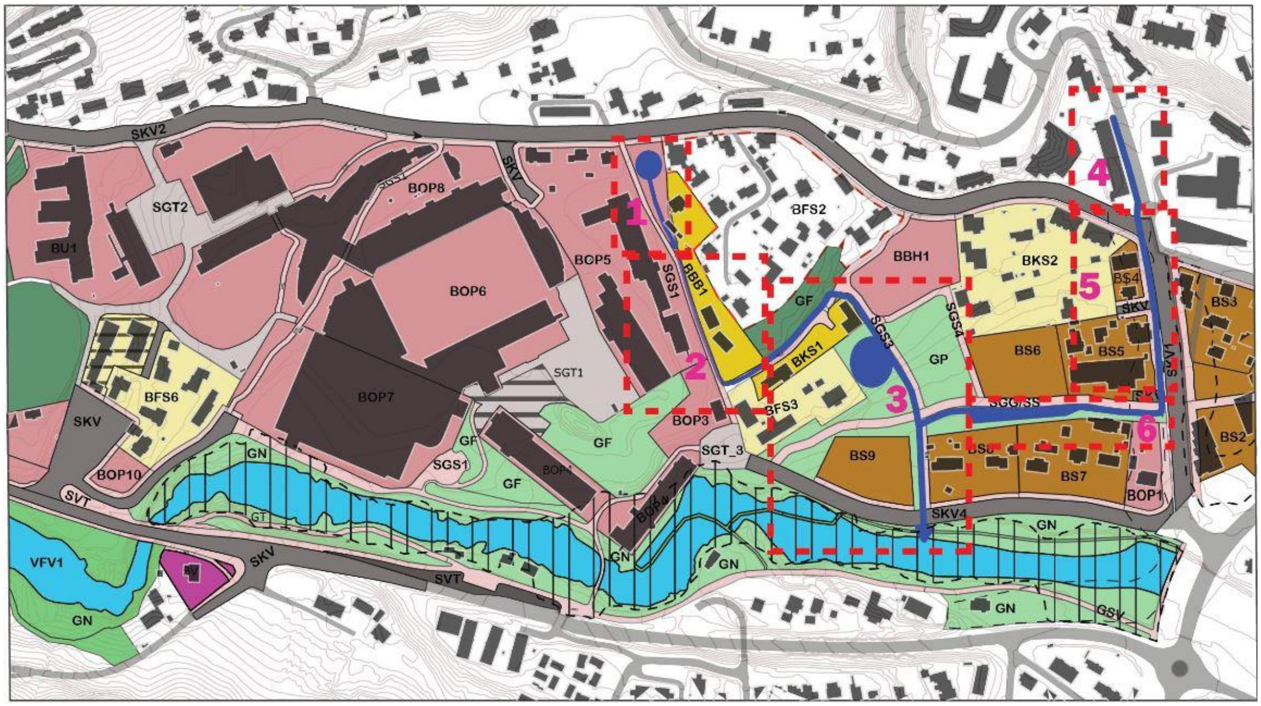


Figure 24: Fosshaugene and Foss zoning plan approved by the municipality council 25.04.201. (See appendix figure 36-39)

This plan connects the city center with the areas Foshaugane and Kvåle through bicycle and foot paths. According to the plan map of Foss and Fosshaugane (Figure 24) a new kindergarten and a Park (GP) will be build and the city center will expand. New blocks will also be built in Fosshaugane and Foss sites.

3.5.3 Principal plan for opening existing pipes

This project is planning to manage the stormwater discharge to the pipes of PQ2 and PQ5 (Figure 16) using blue-green solution, because of the runoff challenges for PQ2 and due to the open channels importance for biodiversity in the Green Park (GP) and aesthetic interest also in PQ5. Opening of these pipes will transport the runoff slowly, with temporal at certain points.



Legend Scale 1:1500m

Open channel	living and cultural areas
Detention and retention ponds	Planned area for new blocks
Public areas	Green park and Green Nature
Planned area for centrum	Private and public buildings
Roads	Pedestrians and bicycle paths
Sogndal river	

Figure 25: Principal plan for opening existing pipes, data taken from Sogndal municipality (03.05.2019) and partially planned by Tewelde Mebrahtu Tesfay, (2019).

The process of managing runoff in the sites is divided in to six sub-areas, as noticed by red squares of number 1, 2, 3, 4, 5 and 6 in Figure 25. This plan is a base plan for further planning of each sub-area. This division was done based on the existing land use situation and the new plan. Opening of the channels depends on the land use situation, topography and runoff conditions. The reasons for opening this channels are first, the critical capacity limitation of PQ2 (Figure 16) second, the fraction of impervious surfaces is expected to increase in the future and third, to enhance biodiversity in the Green-Park. It has delay stations such as detention and retention ponds and infiltration swales and discharge through pipes at some points to manage the runoff safely. A detention pond is a pond which holds the runoff temporarily and infiltrates it slowly in dray period it is empty. A retention pond is a pond which hold the runoff for infiltration. It is wet permanently and upgrades the biodiversity level of the site. A swale is a vegetative channel, which infiltrates the runoff and removes the pollutions (Astebol, Hvitved-Jacobson, & Simonsen, 2004). The blue line in figure 25 shows channels where the runoff is transported through to the main river and the blue circles show places where the runoff will be collected, delayed and infiltrated. This kind of stormwater management is a more sustainable strategy regarding the changes in land use and climate.

3.5.3.1 Areal zone 1

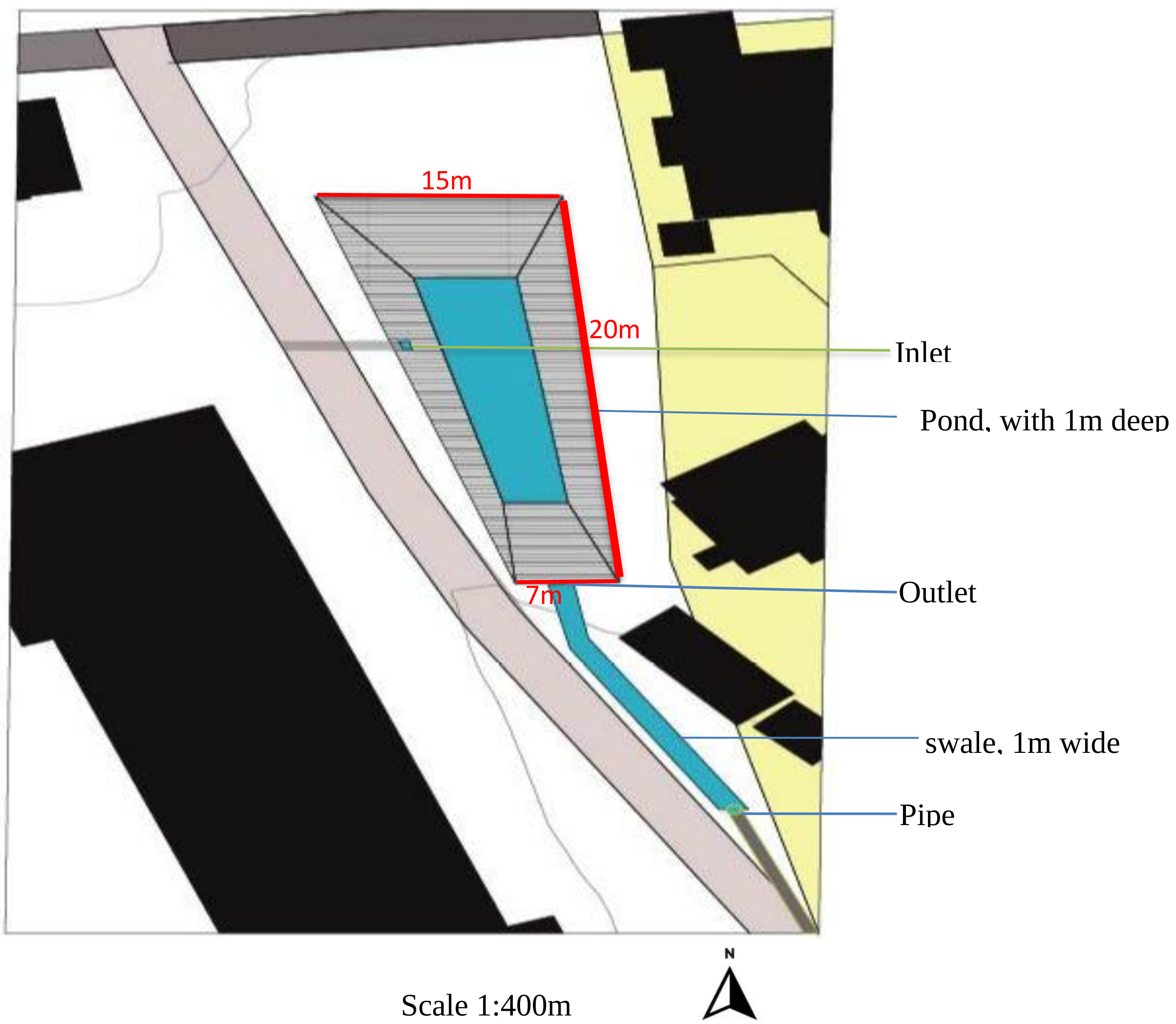


Figure 26: Area of zone 1, made by Tewelde Mebrahtu Tesfay, (2019)

Areal zone 1 is represented by number 1 in Figure 25. It is located where all the pipes that discharge into PQ5 join. At this stage, when the pipes are opened, the runoff will be collected temporarily in the detention pond (Figure 26).

The runoff will discharge to the pond through the pipe inlet. The pond has a width of 15 meters in its northern side and 7 meters in its southern side, length of 20 meters and 1 meters depth. That means it has a capacity to hold 220m^3 water. The runoff discharged from the pipe at PQ2A (Figure 16) is 0,855m^3/s. That means the pond is able to hold the runoff which discharge for 4 minutes and discharges the rest to the swale. The shape of the pond is designed, based on the situation of its area. In all sides of the detention pond, there are buildings, roads and this marked by yellow colour in Figure 26 will be built in the future. The existing situation of the pond area is open green area with some apple trees, but in the new municipal plan, it is part of the public area. The detention pond has an outlet, which is connected to the succeeding swales. According to the Norwegians safety classes (TEK 17, 2017, § 7-2), runoff velocities greater than 2m/s need to be taken in to consideration. The volume of the runoff discharge to Q5 is 855.18 l/s and the swale has 0,5 depth and 1 meter wide.

So Area (A) = Length* Width

A= 0,5m *1m

A= 0,5m^2

According to Manning's equation, Q=VA, where Q is the runoff discharged, V is velocity of the runoff and area is the swale size.

Q=VA

Q= 855,18l/s = 0,855m^3/s

V= Q/A

V= 0,855m^3/s/0,5m^2

V= 1,71m/s

So the 1 meter wide and skewed form of the swale will slowing the speed of the runoff to 1,71m/s, infiltrate it and help to discharge slowly to the pipe in zone 2. The type of soil in the site is glacial soil (Figure 13) and it has good infiltration ability. The swale type and the glacial materials will give good infiltration process of the runoff discharge from the site. Additionally the swale is efficient to improve the water quality, by removing pollutants. So when they are dry, they used for recreational area and growing various plants.

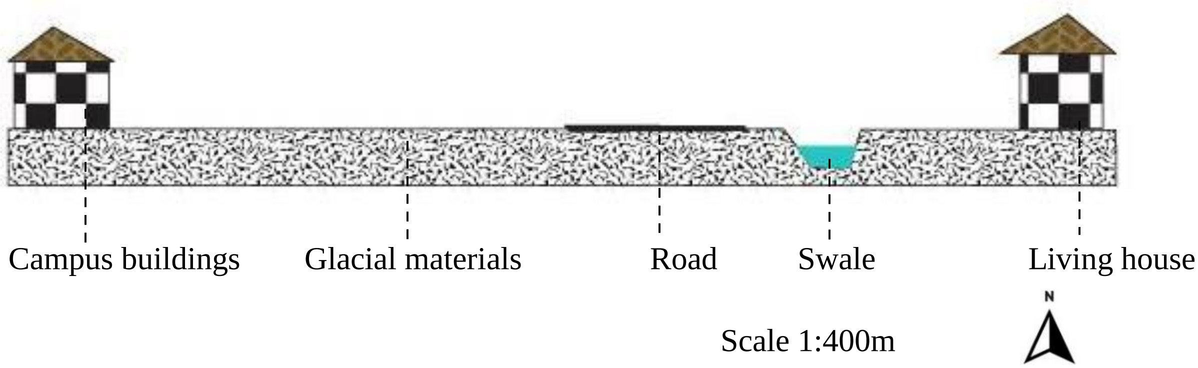


Figure 27: Section for the plan of areal zone1 (Figure 26), Made by Tewelde Mebrahtu Tesfay, (2019)

3.5.3.2 Areal zone 2

Zone 2 is receiving runoff from zone1 and surrounding area (Figure 28). It handles the runoff by using a pipe system **b**ecause the area is narrowed and has a lack of free outdoor area. It is crowded with hard infrastructures, buildings and the municipality has a plan to build new buildings on this zone also. Consequently, the runoff management system in this area will handled using a pipe management system. The pipe receives the runoff discharged from the swale on zone1 and discharges it further to the swale of zone 3. Its diameter will be widened to 1 meter, because widens of the pipe is important with increasing the impermeable surfaces area (Figure 28).

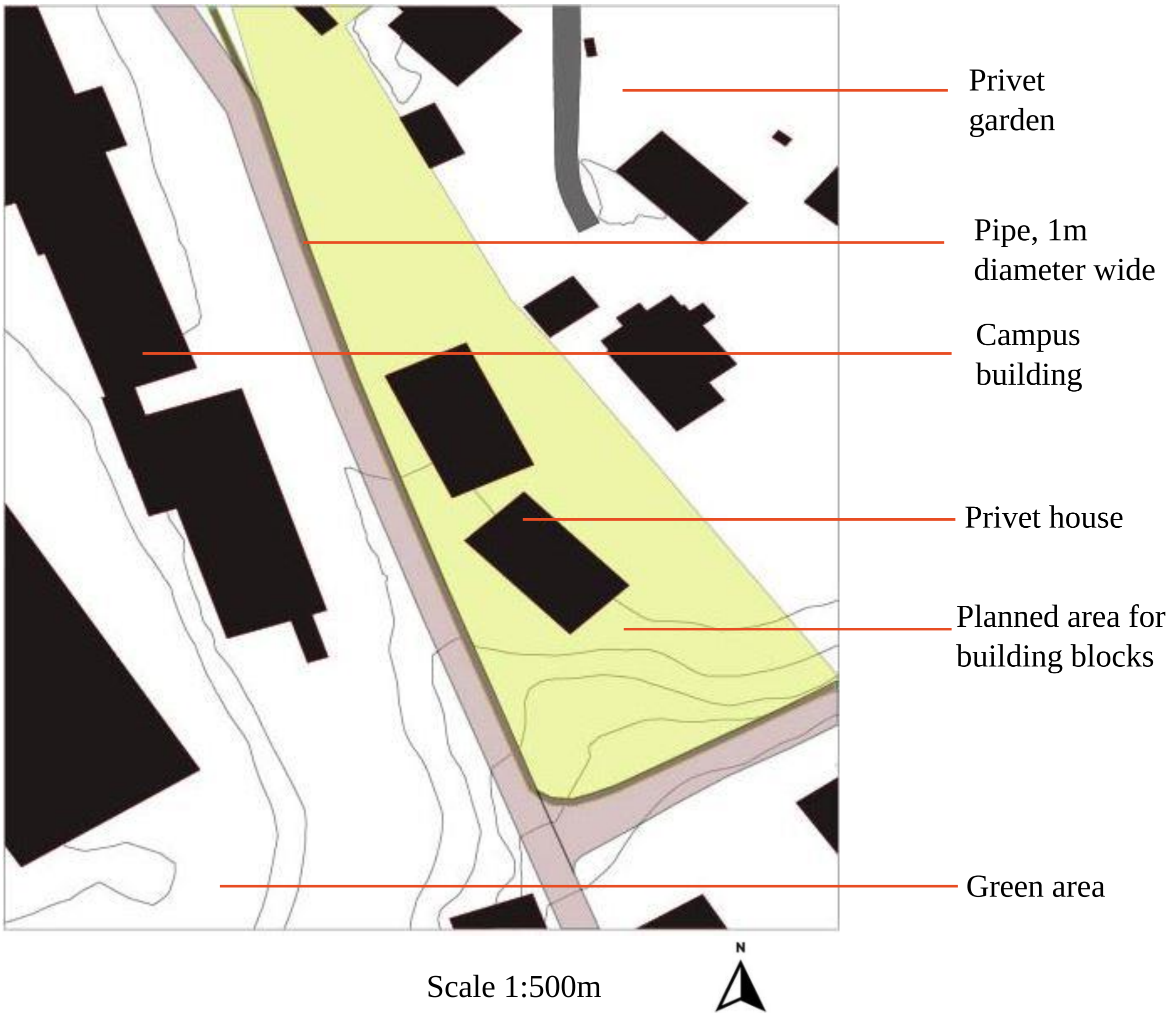


Figure 28: Areal zone 2, made by Tewelde Mebrahtu Tesfay, (2019)

3.5.3.3 Areal zone 3

Area zone 3 is receiving the runoff that accumulated from zone 2 through the pipe and from its surrounding areas (Figure 29). This zone include, bicycle and pedestrian paths, Green Park, kindergarten, living blocks, cultural buildings, some part of the centrum and open green areas. Zone 3 differs from the other zones, because the paths on this area will give services only for pedestrians and bicyclers, also it will have a green park.

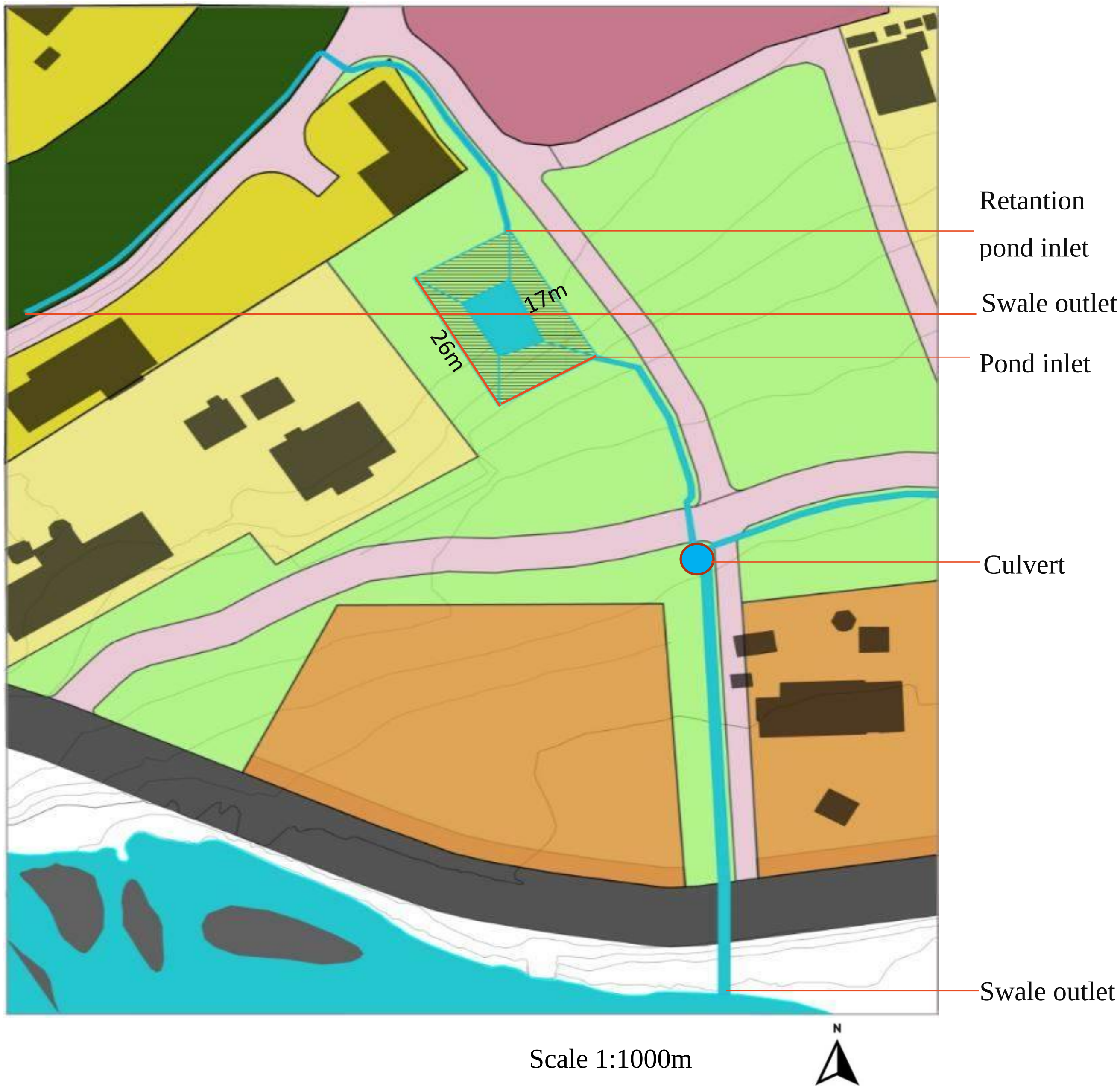


Figure 29: Areal zone 3, made by Tewelde Mebrahtu Tesfay, (2019)

The site has gentler topographic form. The gentler topographic form of the area will help in slowing the flow of runoff that accumulate from the pipe of zone 2 and its surrounding areas. The swale has similar width and character like the swale of zone 1. It will infiltrate and improve the water quality before it discharges to the retention pond.

The retention pond in the Green Park has 26 meter length, 17 meter width and 1 meter depth. It has a capacity of storing 442m^3 water. The retention pond is planned there, because the area is a park area, it is good to have wetted area for recreation purposes and to increase biodiversity. Additionally the area will be part of the city center and near the main river, so the pond will improve the water quality and decrease the speed of the runoff. The runoff discharged from areal zone 6 joins with the runoff discharged from areal zone 3 at the culvert (figure 29) and they discharge together to the main river.

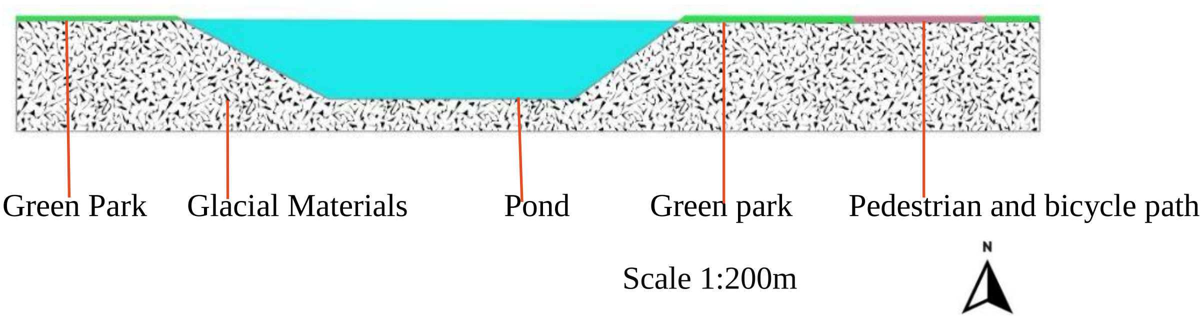


Figure 30: section for the plan areal zone 3 (Figure 29), made by Tewelde Mebrahtu Tesfay, (2019)

3.5.3.4 Areal zone 4

The infiltration swale of areal zone 4 receives the runoff discharged from modified catchment area Q2 (Figure 16 and Table 10), that collected at the junction PQ2A and from its surrounding areas. The areal zones 4, 5, and 6 all discharge the runoff accumulated form the catchment area Q2. The swale of zone 4 will open not at the junction point of PQ2A, due to the kindergarten located below the junction PQ2A. The swale of zone 4 will discharge its runoff into the pipe of zone 5 (figure 31).

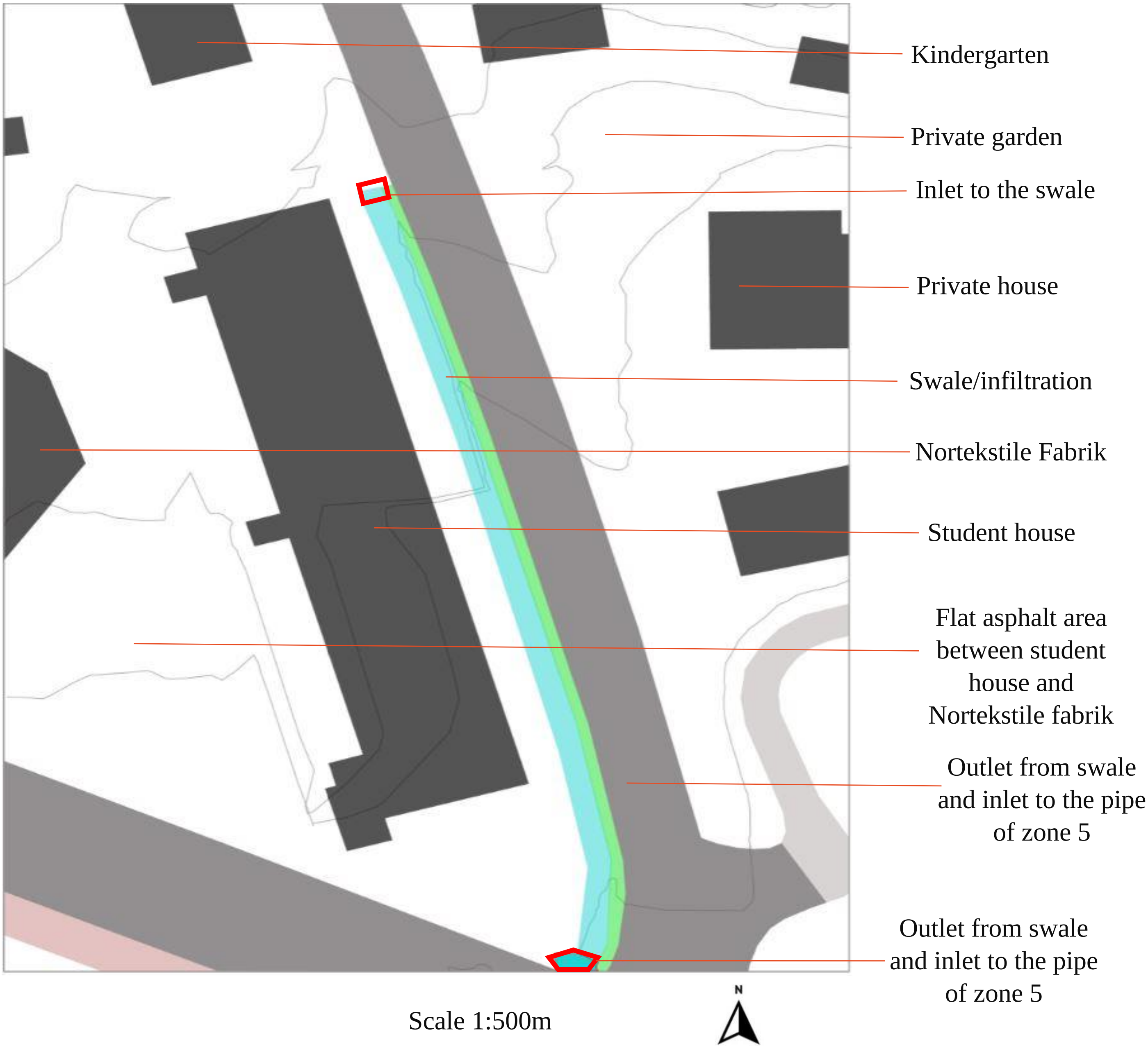


Figure 31: Area zone 4, made by Tewelde Mebrahtu Tesfay, (2019)

3.5.3.5 Area zone 5

The area of zone 5 is covered by public buildings, private houses, roads and open green areas (Figure 32). It is part of the future centrum area. Due to lack of open areas and narrow hard infrastructures, runoff will be handled with a pipe system. It will receive runoff from the infiltration swale of zone 4 and from its surrounding areas. The amount of runoff discharged to the pipe in Figure 32 for the return period of 200 years is 2,11m^3/s. The diameter of the pipe will be 2 meter, in order to handle the potential runoff challenges in the future time.

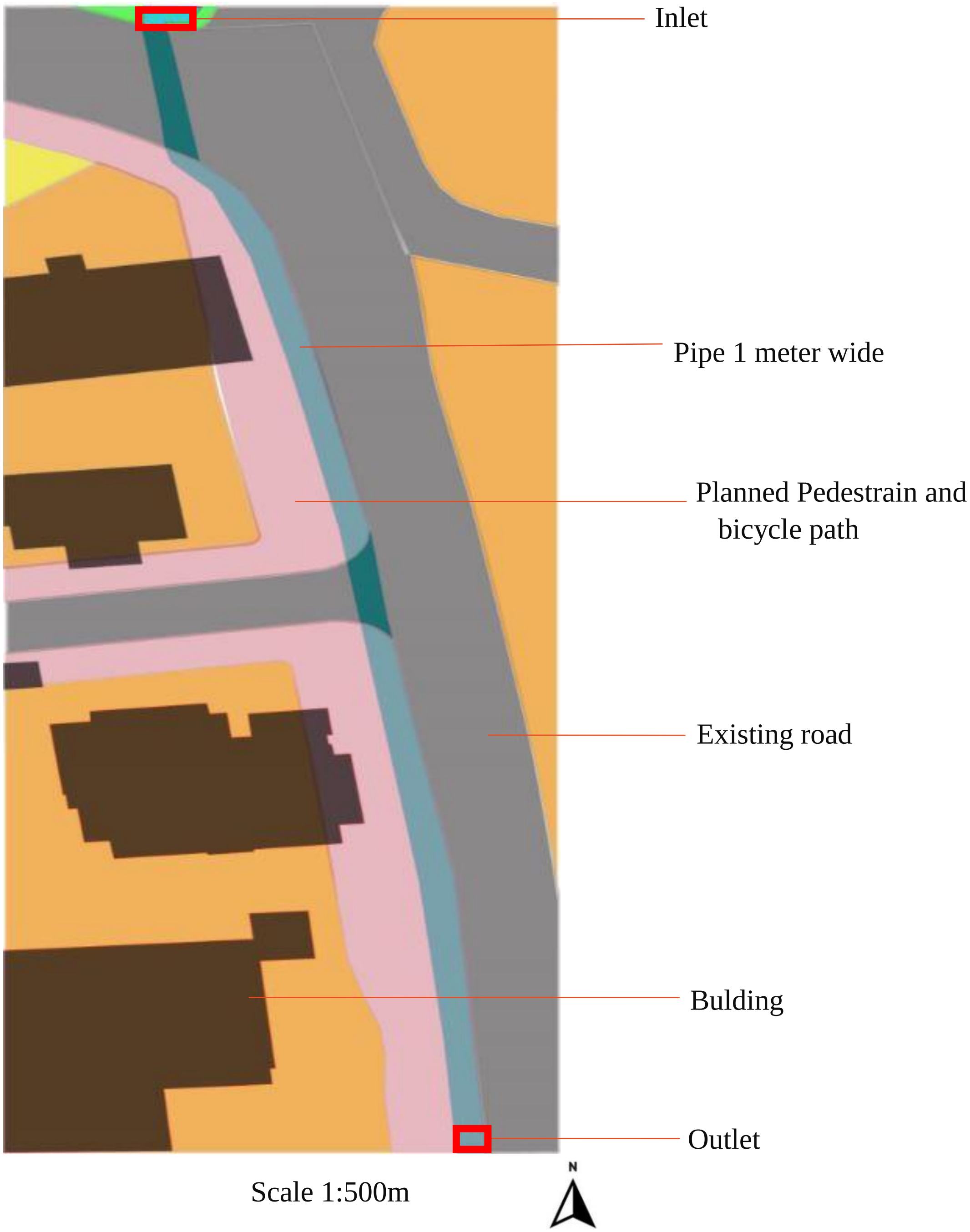


Figure 32: Areal zone 5, mad by Tewelde Mebrahtu Tesfay, (2019)

3.5.3.6 Areal Zone 6

Zone 6 receives runoff from the pipe of zone 5 and from its surrounding areas. Land use elements of this zone are the Green Park, parts of the city center, living areas, road and pedestrian and bicycle paths (Figure 33). It handled the runoff discharged from zone 5, using swale system.

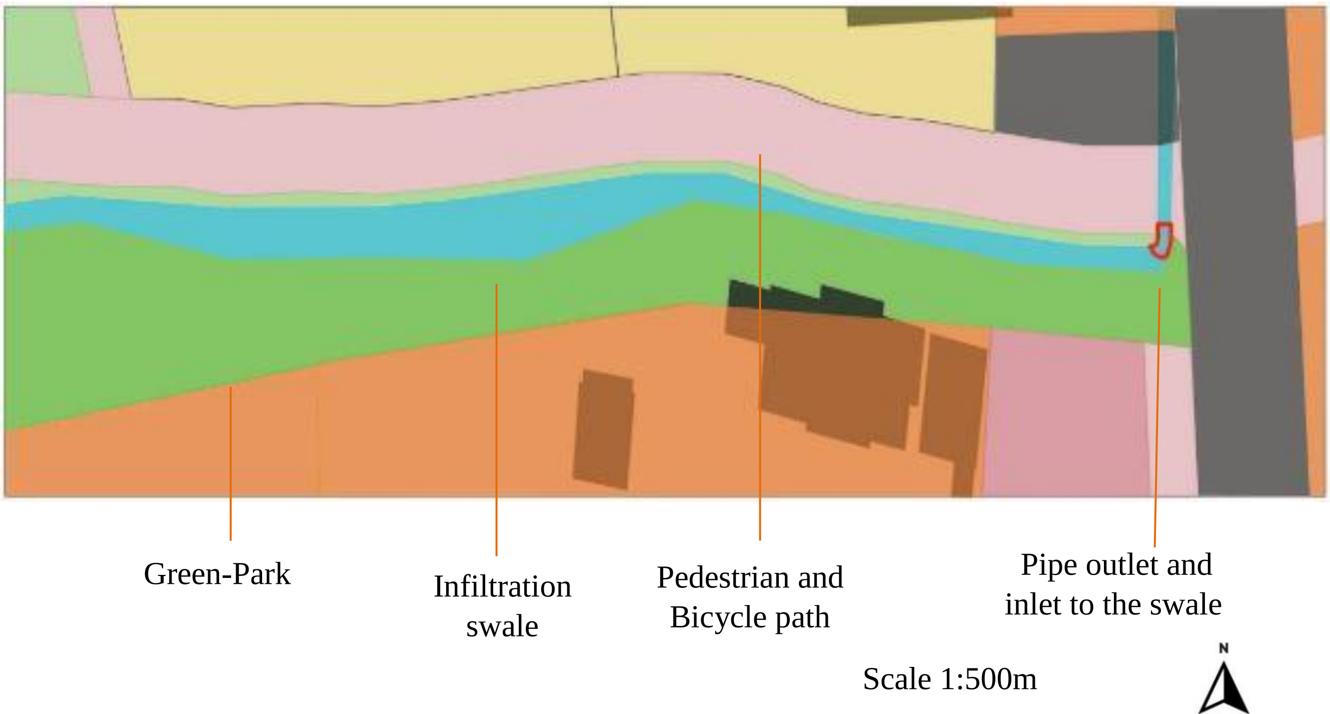


Figure 33: Areal zone 6, made by Tewelde Mebrahtu Tesfay, (2019)

The infiltration swale is located in the planned Green park area. Due to its narrowness, it is difficult to build retention pond there. As a result infiltration swale are planned to handle the runoff. Width of the infiltration swale varies from 2-4 meters and its length is 150 meters. The width and length of the infiltration swale will help to reduce the speed of the runoff, improve the water quality and the soil has time for infiltration. The runoff discharged from zone 6 and zone 3 joins at the culvert (Figure 29) and discharges to the main river through the 2 meter wide swale.

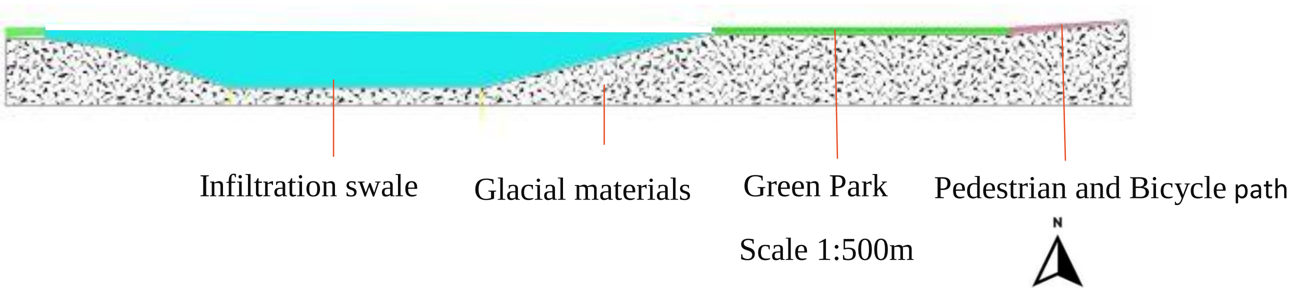


Figure 34: section for the areal plan zone 6, made by Tewelde Mebrahtu Tesfay, (2019)

4. Discussion

In the following section, the results and limitations of the various data and methods of the study will be discussed.

4.1 Results interpretation

The findings from this study show that stormwater management is influenced by land use modifications. Interestingly the natural catchments have good potential in managing the runoff (Figure 14 and Table 7). But due to the municipality stormwater management system the catchments were modified. By using the pipe management systems, the six natural outlets (Figure 14) reduced in to three pipe system outlets (Figure 16).

Since the analysis indicates, modifications of the land use based on the pipe system stormwater management made a big change in the catchments size. The catchment area Q2 and Q6 increased by 1427%, and 278% respectively and Q5 decreased by 51% as compared between the natural and modified catchment areas (Table 5 and 8). These changes revealed the volume of runoff discharged to the pipes of PQ2 and PQ6 (Table 10) increased by 745% and 209% respectively at the return period of 200 years, as compare to the runoff discharged from the natural catchments (Table 7). The existing pipe PQ2 (Table 11) have a capacity to handle 1,636 m^3/s only and the runoff volume discharged from the modified catchment PQ2 is 1,732m^3/s, 1,927m^3/s and 2,112m^3/s respectively for the return periods 50, 100 and 200 years (Table 10). This results explain, the infrastructures and buildings located around PQ2 are under a big threat in the future. Sogndal municipality is in charge to find a solution for that threat as soon as possible since the pipe system does not fulfil the requirements for the Norwegian building act in terms of flood hazard mitigation (Table 11).

The fact is that replacing of natural streams with pipe systems and permeable surfaces with impermeable sealing's increased the runoff in volume and speed (Vadum, 2011). Many cities used runoff management systems differently. It depends on the climatic conditions, land use and topographic form of the cities. But the blue-green solution is proposed to be most sustainable method to handle stormwaterl (Astebol et al., 2004). According to (TEK 17, 2017 §7-2), stormwater risk and vulnerability requirements, the building and infrastructures in areal zone 4, 5 and 6 (Figure 31, 32 and 33) are under threat. Blue-green solution is most important solution, to manage runoff threat on those areal zones, by opening 2 meter wide swale (Figure 31) and widening the pipe up to 2 meters in (Figure 32). Furthermore by transporting the runoff in to the 2-4 meters wide swale in areal zone 6 (Figure 33), enhances the infiltration processes. For example in Veumdalen, Fredrikstad municipality stormwater was been managed using pipe systems, but due to climatic conditions and land use modifications the runoff challenges increased beyond the pipes capacity. As a result the municipality of Fredrikstad managed those challenges using blue-green solutions (Vadum, 2011). Additionally to manage the runoff challenges in the future and to provide co-benefits, such as better aesthetic, biodiversity and recreation, in the areal zones 1, 2 and 3 (Figure 26, 28 and 29) this project applied a blue-green solution to deal with the stormwater. In these zones the detention and retention ponds in Figure 26 and 29 regulate the speed and volume of runoff by holding it temporarily. The retention pond holds and infiltrates the runoff slowly and the rest is discharged to the river by merging with the runoff discharge from areal zone 6 (Figure 33). In managing the stormwater sustainably at Fornebu, the city of Oslo, Norway, the municipality is using a blue-green strategy. They built detention ponds, swales and retention ponds, to regulate and infiltrate the runoff before it discharge to the main river (Astebol et al., 2004).

4.2 Uncertainties and limitations of the input data

The stream outlets and junctions pointed out on the map in Figure 14 and 16 to delineate the catchment areas are created based on the digital elevation model (DEM). The data of the DEM is functional up to 256 meters above sea-level and resulted in some missing values in the stream flow calculation. Consequently the upper most part of some streams looks like straight lines and do not express the real extension of them (Figure 14 and 16). The lack of the digital elevation model data for registering the highest level of the mountains elevation are some of the limitations of this study. The limitation are not so strong limitation see Appendix (Figure 35).

The Intensity Duration Frequency (IDF) is uncertain due to the length of data, method of extraction and extreme change in events and parameters. This study used the IDF-curve data from 58700 Oppstryn, and interpolated due to the time of concentration, because Sogndal have not its own IDF-curve data. Even though, Sogndal and Styrn are found in similar topography and climatic conditions, their IDF-curve value will have some variations due to their locational variation.

The climate factor is varied from region to region and among municipalities, In this study the climate factor was taken from NVE, the Sogn of Fjordane county 1,2 (Førland et al., 2015),due to the short duration rain will increase by 40% in the county. The climate factor is uncertain because the climate projections are always dealing with high degree of uncertainty since projections in to the future cannot be safe. Since the climate factor is based on a specific choosen climate projections it is uncertain. Climate can change much stronger or weaker then the factor 1,2 would take in to account.

The incomplete inventory of municipal stormwater management system/ pipe system is another limitation of this study. The pipes which implemented to manage the runoff in the site are not fully registered. The municipality stormwater management system show, that the runoff is discharged only through three pipe outlets (Figure 16). For example in the catchments of Q3 and Q4 there is no available pipe system data. Even though the amount of runoff is calculated, the reliability of the pipes is unknown. That means there is a need for a corrected analysis on the pipe systems management of the study site on the future and probably for the rest of the city as well.

4.3 Uncertainties and limitations of the methods

To calculate the amount of runoff per catchment, catchment size, precipitation intensity from the IDF curve, the runoff coefficient and climate factor were taken into account. For the runoff coefficient the lowest value of surface roughness (Table 4) were selected, because the highest values are used for precipitation events longer than 3 hours, (Førland et al., 2015). NVE recommended the runoff coefficient can increase by 10% -30%, for precipitation events with return periods 10-200 years(Stenius et al., 2015), but even though it is recommended in the rational method, it is not added in the calculation.

In calculating the capacity of existing pipe outlets, Manning’s equation was used. It was developed for an open channel flow, but was adopted for uniform flow pipes (Bengtson, 2012). To estimate the capacity of the pipes 90% of the diameter of the pipes was applied as wetted parameter. Even with this size the existing pipe of PQ2 (figure 16) have not a capacity to hold the runoff discharge in 50, 100 and 200 years return periods. The pipes depth in the ground and direction are additional limitations of the calculation, because the pipes measurements was taken from the surface and streetline using the GPS from the outlet.

4.3 Recommendation

According to the findings, infrastructures and building in the catchment area PQ2 are under stormwater challenges, because the existing pipe of PQ2 (Figure 16) have not a capacity to handle stormwater of 50, 100 and 200 years return period. So it is recommended that the municipality react on that threat immediately. This result suggests that the other parts of the pipe systems in Sogndal municipality that were not implemented into this study and other municipalities in comparable topography and climate have to do investigations on their stormwater infrastructure and connected buildings. With the expanding of the city of Sogndal and the need to expand the stormwater management and increasing precipitation due to climate change, blue-green solution is recommended to be applied in the city's stormwater management, giving aesthetic quality for the city and recreational activities.

5. Conclusion

Increasing precipitation due to climate change and land use modifications has a great impact on urban stormwater management systems. Without careful planning and consideration, the natural environment, infrastructures, and cities will suffer greatly. Therefore it is time to develop a safer and more reliable stormwater management system, by analysing carefully and regularly, the situations of urban modification and climate change. By taking the past, present and future impacts of climate change in to consideration, it is possible to find a more sustainable and beneficial method to reduce stormwater as it increases.

Based on the hydrological analysis, the stormwater was been discharged by six natural streams outlets (Figure 14), but due to modifications done on the catchments, the municipality stormwater management system replaced them by pipe systems and reduced them in to three pipe system outlets PQ2, PQ5 and PQ6 (Figure 16). The existing pipes of Q5 and Q6 have a capacity to handle the present and projected future stormwater situation, even though changes were made in their catchment areas. But the catchment PQ2, due to the modification that was made in the runoff management systems is not able to handle the runoff from the catchment for 50, 100 and 200 years (Table 10). The existing pipe has a capacity to handle 1.636m^3/s, so if the municipality does not take action, the site will be in danger due to the runoff pressures on the existing pipe.

As solution for the existing hazard risk of one catchment a development plan was designed. There, the insufficient pipe system is partly substituted by an open drainage system, known as blue-green infrastructure. Designed to accommodate heavy volumes of runoff, the blue-green solution uses different stages in its process, harvesting the stormwater, diverting it in to detention ponds, followed by swales, then to retention ponds and finally to the river. Since the area of the threatened pipe system is planned to be developed further according to the recent areal development plan, it would be cost efficient to substitute the insufficient pipe system by the blue-green infrastructure. This strategy is beneficial in managing stormwater and enhancing ecosystems in the study site of the city and can be adapted in other comparable cities. The swales will minimize the pollutions which can enter or harm the river water ecosystems. As co-benefits the blue-green infrastructure is supposed to increase attraction to both, recreation and biodiversity in the city.

Regarding the results of this study, recommendations for sustainable city planning are given that imply blue-green infrastructure into the development plan and takes the restoration of ecosystem in the urban environment into account.

6. References

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7. Appendix

Map of stream network with GPS data

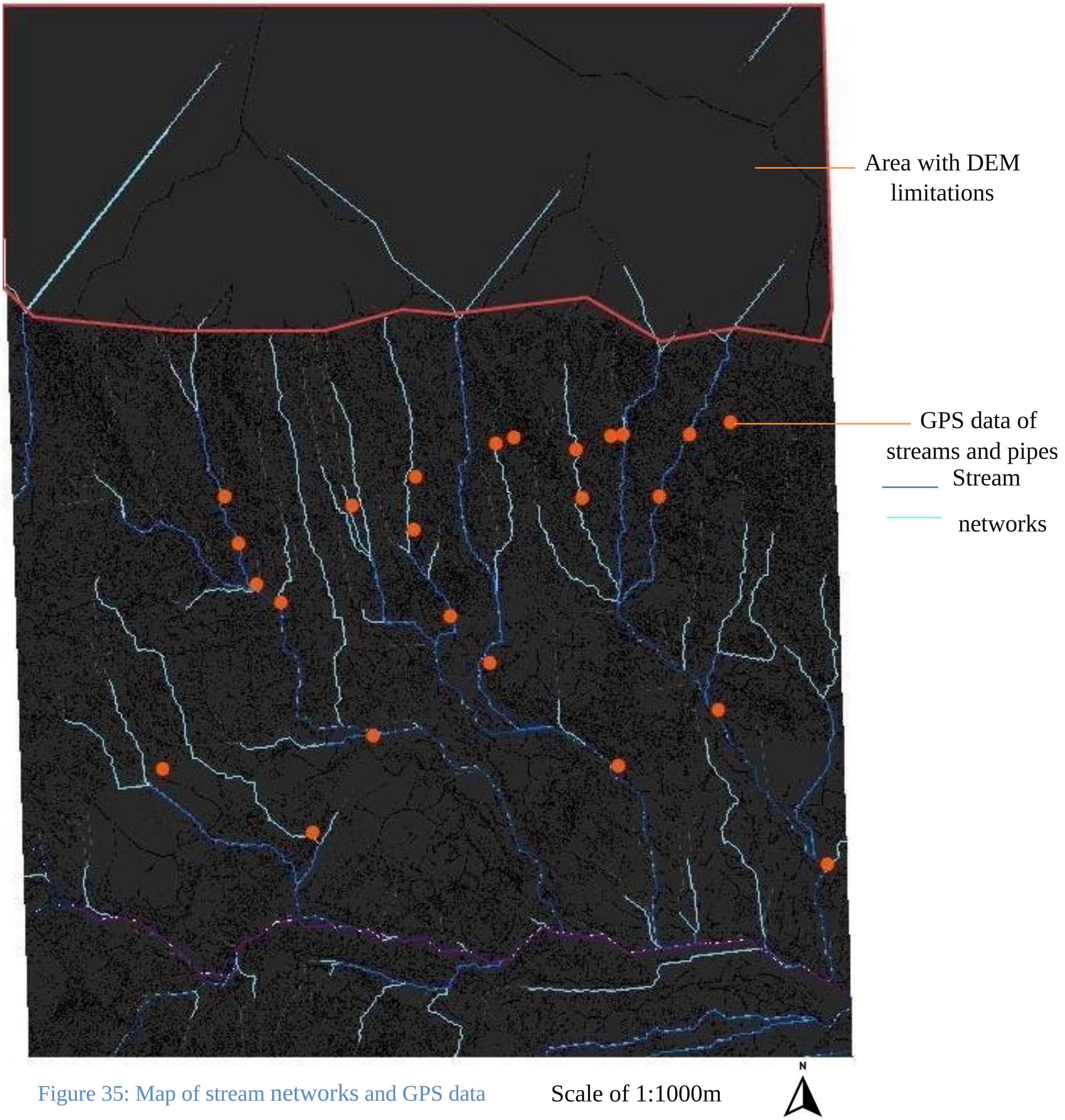

Figure 35: Map of stream networks and GPS data

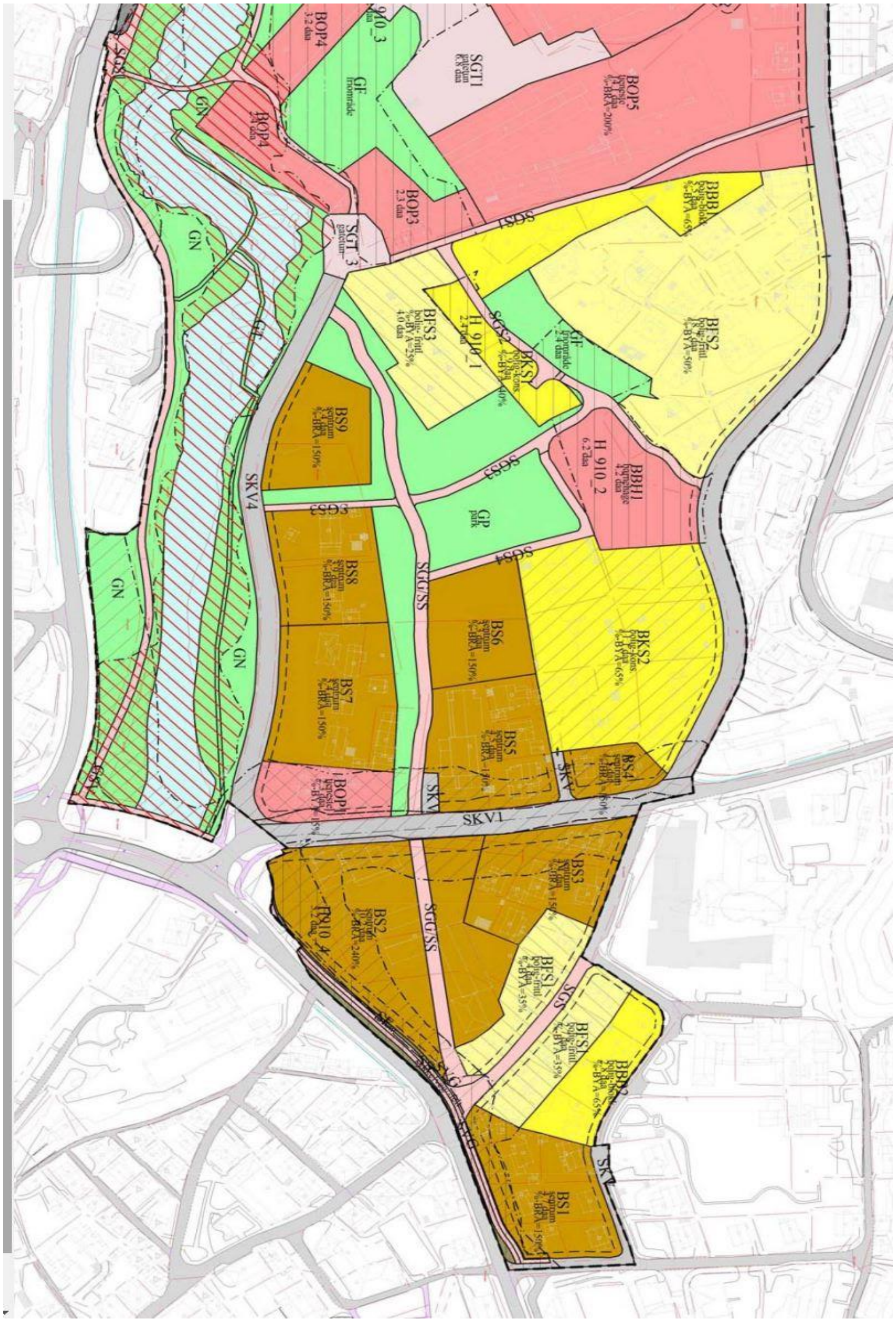

Figure 36: Fosshaugene and Foss zoning plan approved by the municipality council 25.04.2019. It is referred to the municipal map of figure 24.

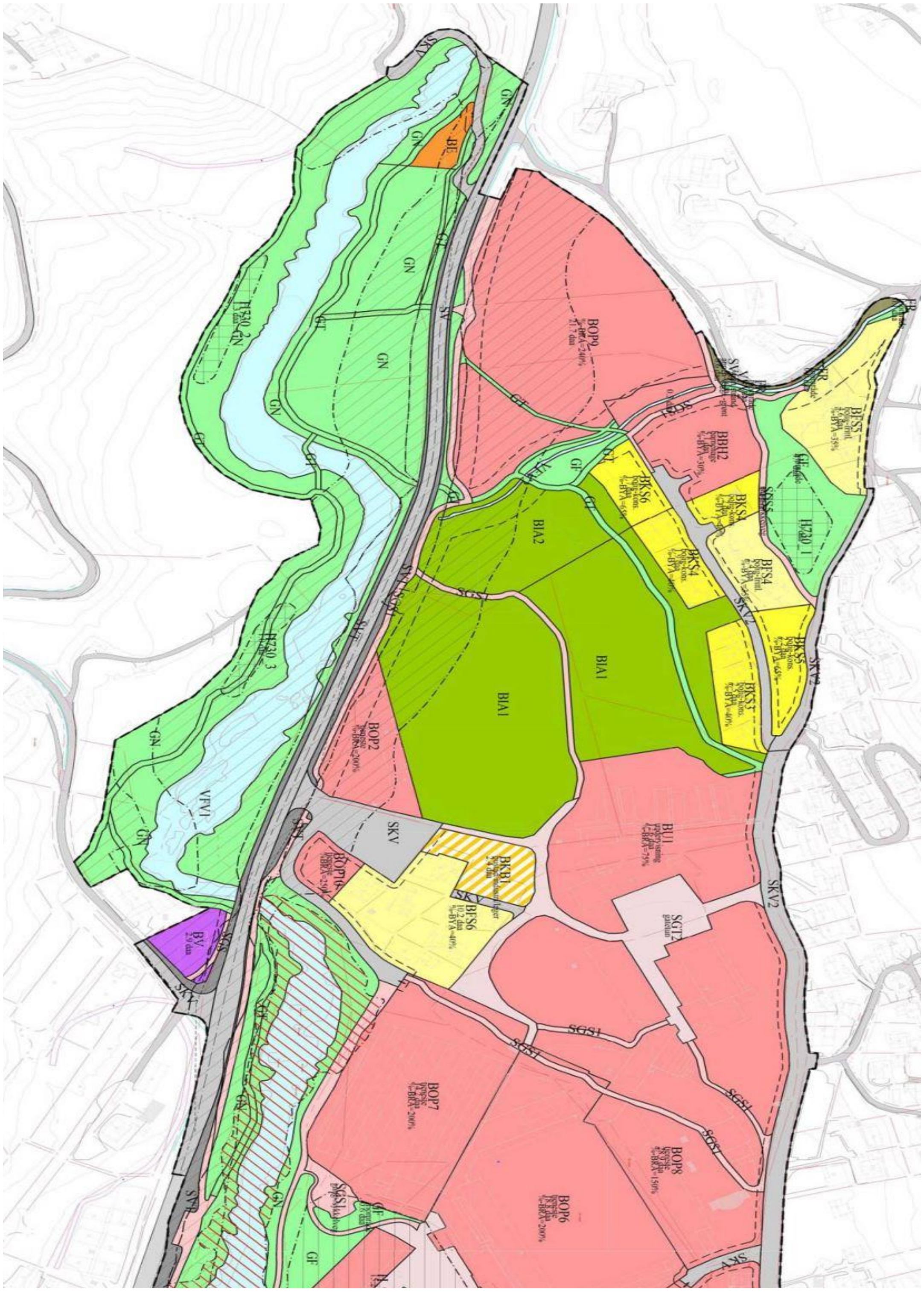

Figure 37: Fosshaugene and Foss zoning plan approved by the municipality council 25.04.2019. It is referred to the map of figure 24.

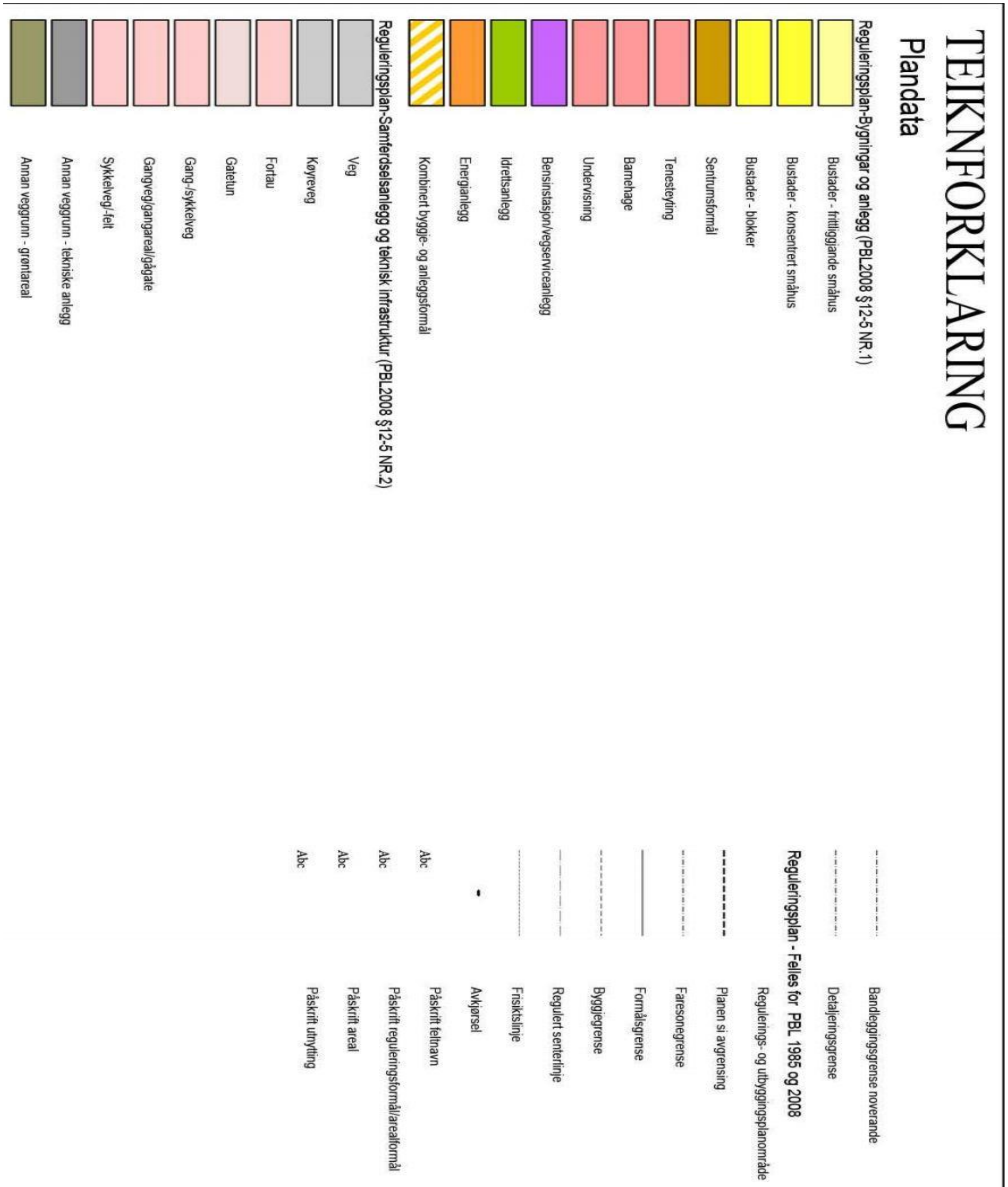

Figure 38: Legend for figures 36 and 37.

Figure 39: Legend for figures 36 and 37.

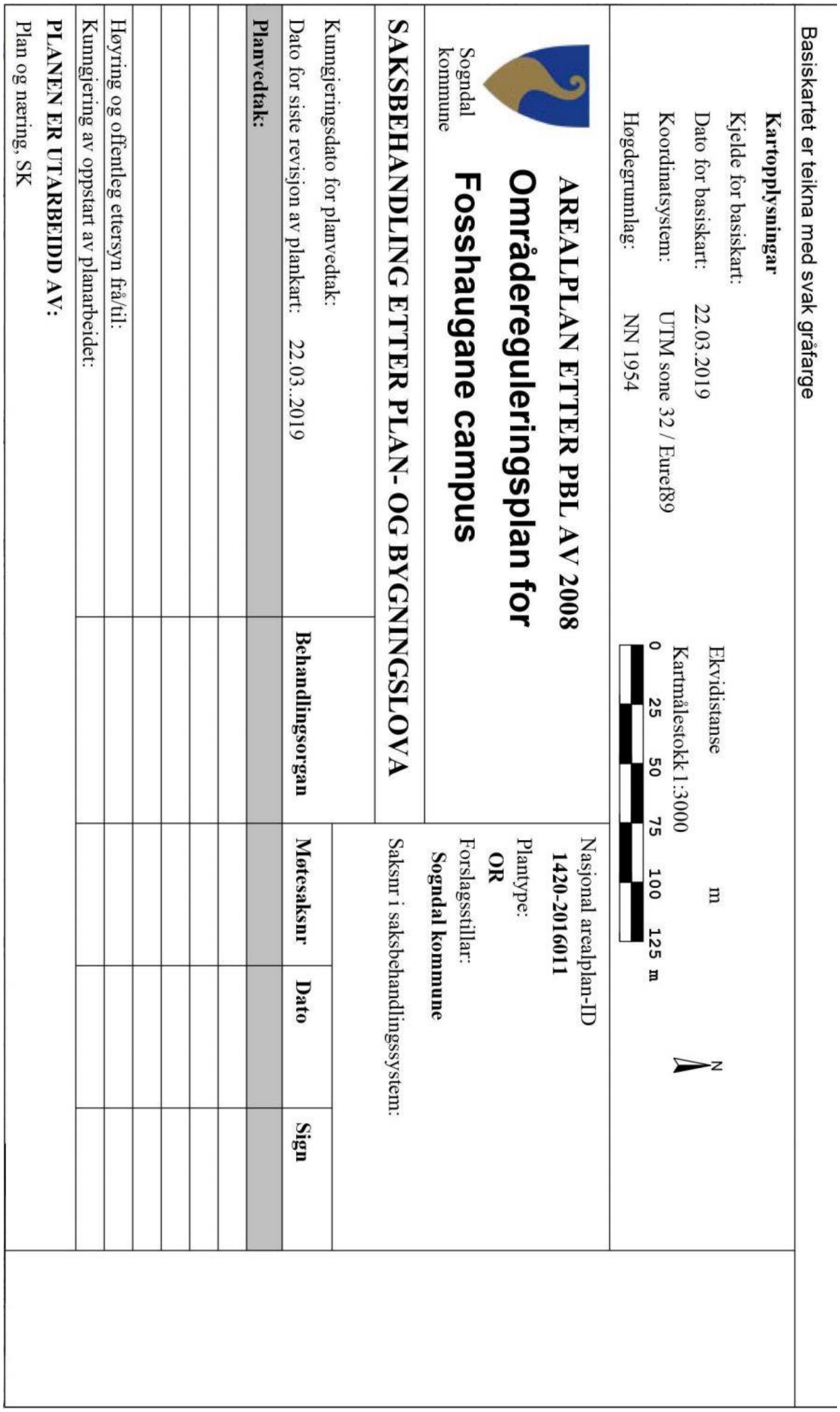

Figure 39: Legend for figures 36 and 37.