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PRESERVING HERITAGE AND PROTECTING THE ENVIRONMENT:

Sustainable Stormwater Management in Gamle Stavanger

PREFACE

This Thesis marks the end of two years as a master's student in City and Regional Planning at UIS, and my five years of studying in the field of planning. The years have brought me many experiences and learning. My academic career to this point has relied on planning for human aspects, biological diversity, and cultural cultivation, integration, and protection. Water was the birth of life, and civilisation; the first cities were created on the basis of a constant supply of water. And because of this, water has a special relation to culture in my mind. Water creates new beginnings. And just as the biblical flood washed away our sins, sea level rise and increasing precipitation is here again because of our sins. And me personally, see it fit to hold back the flood for as long as possible.

The task at hand is not about math and construction, but protection in the intersection between Water, Culture, and Humans. Protecting cultural values by creating human-scale measures addressing a globally influential issue. And maybe with enough small interventions, we can influence the issue globally.
To address this issue in a proper way, the ways of the water must be known. And so, my career as a hobby water engineer has started. A totally new field for me. It has proven to be a lot of work wrapping my head around water dynamics, hydrological modelling, and statistical analysis of dimensioning precipitation values.

Fabio Alberto Hernandez Palacio, my supervisor, thank you for your insight, in this and other project courses, and for promoting common sense.

I walnt to thank Stavanger Kommune, and Byantikvaren for providing data and insight.

To my family, I want to thank you for your support, valuable insight and discussions.

Sign:

Name: Isak Planke

ABSTRACT

The heritage area Straen, also known as Gamle Stavanger is, due to heavy rain and climate change, in a position of stormwater flooding. The sewage system, that normally drains stormwater away from the streets, is old and cannot take on the increasing amounts of stormwater predicted in the future. This thesis explores how using local stormwater management (LSM) measures, sustainable drainage systems (SuDS) and nature-based solutions (NBS) can help mitigate the damaging effects of stormwater. The thesis also seeks to answer how this can be done without damaging the cultural-historical heritage. Through the use of literature studies, reference projects, visits to the site and GIS analysis, a proposal for a stormwater management plan using local measures is presented. To identify the suggested measures, an analysis of the area and how the area is affected by stormwater was done. Further, the thesis seeks knowledge from other projects that have addressed the same issues.

The stormwater's effect on Straen is in close correlation to its catchment area encompassing parts of Trehusbyen, the largest connected wooden house area in Europe. The measures proposed in this area can be upscaled and implemented in several parts of Trehusbyen, due to similarities in urban layout. Thus, the proposal suggests measures for the upper districts of the catchment, as well as for Straen.

The planning for measures in these areas, Straen and Trehusbyen, had to be approached very differently, due to the availability of spaces fit for measures. To illustrate the effectiveness of the proposed measures, a 20-year 10-minute event with a climate factor of 40% is used. This equals an event of 17,5 mm in 10 minutes.

For Trehusbyen, the thesis proposes an implementation of a range of solutions that together are capable of handling the precipitation of a 20-year event. The measures are implemented in between housing, in gardens, driveways and entrances, and in the streets. These measures are effective and will not damage heritage values connected to Trehusbyen. But rather increase the resilience and make the areas more attractive.

The streets and neighbourhoods in Straen are narrowly built and require a different set of measures. Focusing on the creation, and dividing of flood paths, may lead to lower pressure on individual streets, thereby minimizing the risk of damage.

The measures proposed makes Straen capable of handling the increasing precipitation, and stormwater flooding. There are however implications when implementing big scale infiltration measures. A problem of water running on the bedrock, entering basements trough the foundations already exist in Straen. An increased infiltration may lead to this issue being more widespread.

SAMMENDRAG

Verneområdet, Straen, også kjent som Gamle Stavanger, står overfor problemer med overvanns flom som følge av kraftig nedbør og klimaendringer. Det eksisterende avløpssystemet, som normalt skal lede overvann bort fra gatene, er gammelt og kan ikke håndtere de økende mengdene av overvann som er forventet i fremtiden. Denne avhandlingen utforsker hvordan bruk av lokale overvannsdisponerings tiltak (LOD), bærekraftige dreneringssystemer (SuDS) og naturbaserte løsninger (NBS) kan bidra til å redusere skadevirkningene av overvann. Avhandlingen søker svar på hvordan dette kan gjøres uten å forringe kulturhistorisk verdi. Gjennom bruk av litteraturstudier, referanseprosjekter, befaringer og GIS-analyser, presenteres det et forslag til en plan for overvannshåndtering ved bruk av LOD tiltak. For å identifisere mulige tiltak, ble det gjort en analyse av området og hvordan området påvirkes av overvann. Videre søker avhandlingen kunnskap i referanse prosjekter som har adressert de samme problemstillingene.

Overvannets mengde i Straen har tett sammenheng med nedbørfeltet. Dette omfatter deler av Trehusbyen, det største sammenhengende trehusområdet i Europa. De tiltakene som presenteres i denne avhandlingen kan utvides til å omfatte flere deler av Trehusbyen grunnet i en gjentakende bystruktur. Derfor foreslås det også tiltak for de øvre delene av nedbørfeltet, samt for Straen.

Utforskning av tiltak for disse områdene, Straen og Trehusbyen, måtte tilnærmes på forskjellige måter på grunn av tilgjengeligheten av egnede areal for implementering. For å illustrere effektiviteten til de foreslåtte tiltakene, brukes en 20-års hendelse med en varighet på 10 minutter og en klimafaktor på 40%. Dette tilsvarer en hendelse med 17,5 mm nedbør på 10 minutter.

For den øve delen av nedbørsfeltet foreslår avhandlingen implementering av en rekke løsninger som sammen er i stand til å håndtere nedbøren fra en 20-års hendelse. Tiltakene implementeres mellom husene, i hager, innkjørsler og inngangspartier, samt i gatene. Disse tiltakene er effektive og vil ikke forringe de kulturhistoriske verdier knyttet til Trehusbyen, men heller øke motstandsdyktigheten og gjøre områdene mer attraktive.

Gatene og nabolagene i Straen er derimot smale og krever en annen type tiltak. Ved å fokusere på å opprette og fordele vannet i sikre flomveier kan man redusere trykket på enkeltgater og dermed minimere risikoen for skade.

De foreslåtte tiltakene gjør at Straen er i stand til å håndtere den økende nedbøren og overvannsproblemet. Det er imidlertid implikasjoner knyttet til implementeringen av store infiltrasjonstiltak. Vann som renner på berggrunnen og trenger inn i kjellere gjennom grunnmurene er et allerede eksisterende problem i Straen. Økt infiltrasjon kan føre til at dette problemet blir mer utbredt.

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1. INTRODUCTION

On the 4. of October 2021, Stavanger had a rain event where over the course of 10 minutes, Andasmauet in Gamle Stavanger, became a river.

A mail received by "Byantikvaren" from an inhabitant of Gamle Stavanger stated:

> "Yesterday there was an incident where the street once again flooded. Andasmauet became a river where the water transported great amounts of slag, and gravel down towards Nedre Strandgate. We are not talking about extreme weather, but a normal local autumn downpour in Stavanger"
>
> -(Personal communication: Hanne Windsholt,10.02.2023)

Fig. 1. Rain event of 10 mm over 10 minutes caused a river to form in Andasmauet. Video was taken 28.07.2021 (Personal communication: Hanne Windsholt,10.02.2023)

The event in the photo (fig. 1) is of another event, bigger than the one reported in the mail; a 10-year interval rain event of 10 minutes. As we see in the mail received by Byantikvaren (The city preservation counsellor), this has happened before. In another mail from Byantikvaren, it was disclosed that there have been similar events in Clausegata.

As the area already has a history of water problems, how will it react to the changing climate? The climate profile of Rogaland (Norsk Klimaservicesenter, 2021), Predicts a 56-121% increase in rain events like these in 2100, and they will be over 20% more intensive. Making a rain event as seen in the image, happen every 2-3 years rather than every 10th.

How should these problems be solved? How are we to plan for the future to make sure neither material, economical, nor cultural values are destroyed?

This thesis is about the human and environmental aspects. The meeting point between water, culture, and human. It's about the preservation of a cultural resource protecting it from the damaging effects of water in a way that affects humans in a positive way, or at least does not affect the inhabitants in a negative way. The area is special because it has a high historical preservation value assigned to it. Because it is valuable to the inhabitants of Stavanger.

To do this in the best possible way, I have gotten to know the ways of the water through visual perception, an engineering approach, and the social sciences.

The setting of the thesis is Straen / "Gamle Stavanger" in Stavanger, Rogaland. This is a heritage site and the first area regulated for protection in Norway. It was supposed to be demolished in the 60's but ended up starting a "heritage revolution", which resulted in Stavanger having the biggest continuous wooden house area in Europe, called "Trehusbyen" (fig. 4) (Byantikvaren, 2022). The entire wooden structure of the city and many other buildings are protected under a "Conservation zone for cultural heritage" (Norsk: Hennsynsone). As the area is heavily urbanised, with building footprints and roads covering most of the city, and ate the same time is protected, there is a limited amount of measures that can be made. Working with the heritage to make solutions that result in a better urban standard and climate resilience will be key for the climate transition of Stavanger.

Fig. 2. Water flowing by a storm drain in Trehusbyen (IP, 2022).

Fig. 3. Clogged storm drains in the upper parts of Gamle Stavanger (IP, 2023).

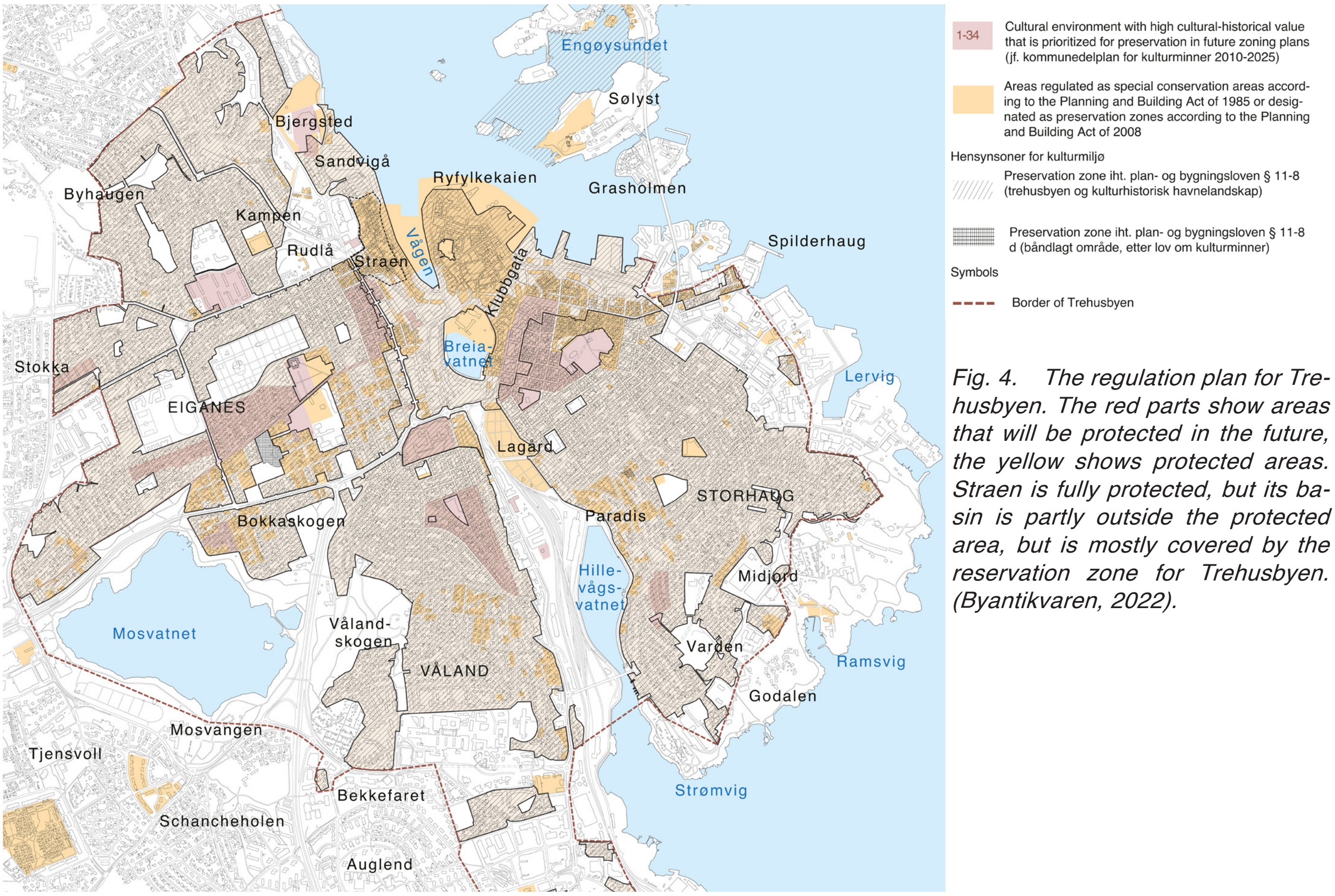
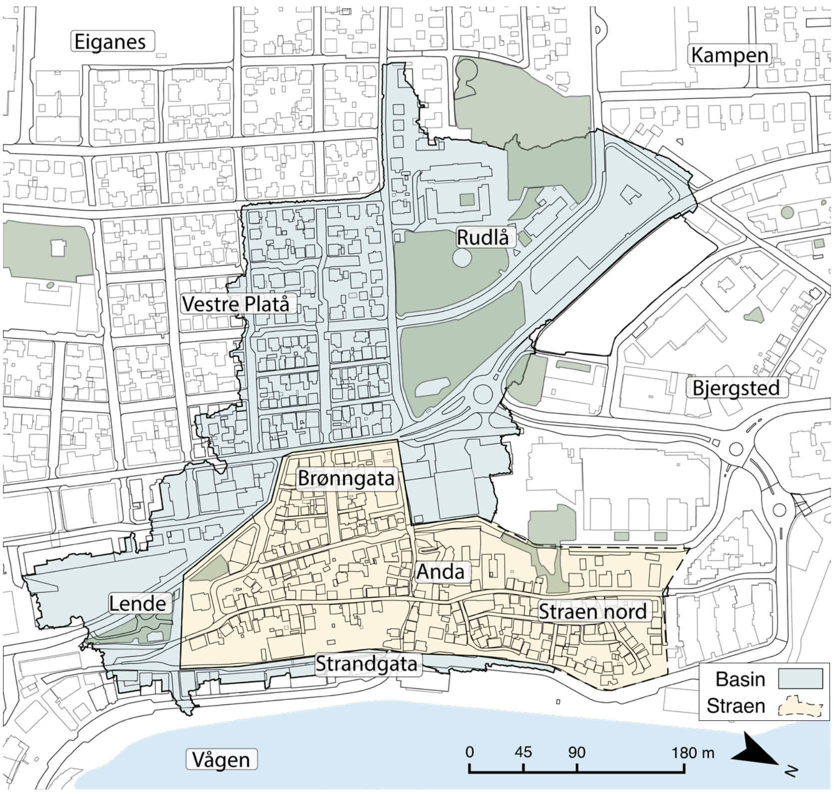


Fig. 4. The regulation plan for Trehusbyen. The red parts show areas that will be protected in the future, the yellow shows protected areas. Straen is fully protected, but its basin is partly outside the protected area, but is mostly covered by the reservation zone for Trehusbyen. (Byantikvaren, 2022).

Straen is situated just northwest of Stavanger city centre. Straen is the area of main interest in this thesis, but the water is not limited by heritage zones and so, the catchment area of Straen will be the natural delimitation of the study area. The basin of Straen is over 14 ha and covers half of Vestre Platå, and Rudlåparken (Fig. 5).

Fig. 5. Straen and its catchment area. The names are not the correct names in the area but shortened for easier understanding of the area (IP, 2023).



RESEARCH QUESTION

Because of the troublesome water, climatic changes, and heritage values, I have chosen to propose measures for handling the stormwater in Straen and Trehusbyen, using sustainable measures for local stormwater management.

The main questions this thesis is aiming to answer:

How can stormwater be managed in a sustainable way in a protected urban heritage enviromnet?
How can the stormwater in Straen be managed without damaging the cultural-historical values?

2.METHOD

This thesis is aiming to provide knowledge around the stormwater management in urban heritage areas. This will be done by a case study of Straen and its conected catchment areas. For doing the case studie multiple methods has been used. Literature studies, reference projects, sitevisits, hydrological and topological GIS analysis. Theese analysis are colected in a SWOT diagram for ease of use. The methods are used as a basis for a proposal of a stormwater management plan using local measures.

To answer the questions a pragmatic approach to finding the required themes has been utilized. First by defining the goal. This is done in the research questions. Based on this the futher qutestions are posed.

1. What is the area affected?

Aqure knowledge about the area, history, use and protection.

- Area analysis Sitevisits, & Literature studies

2. How will stormwater affect the area?

Aqure knowledge about about climate change, urban hydrology, stormwater effect on heritage. Aquire data on where the water goes

- Literature rewju on climate change, stormwater, hydrology.
- Gis analysis on topography and hydrology, runoff.

Required methods: Literature study, Sitevisit, Hydro analysis, GIS, Excel

3. How are others doing this, what is the standard?

- Literature review on reference projects, different apporoaches to stormwater management, municipal and national goals.

4. How can this knowledge be applied in the area?

Find solutions to the reaserch questions based on 1,2,3.

Area analysis:

The goal of area analysis is to gain insights and understanding of the area’s features and dynamics. This has been done through site visits and literature reviews.

Literature review:

The thesis is largely based on academic literature and documents related to the theme of stormwater management and planning. The literature used is mainly sourced from governmental documents and universities.

Sitevisit:

Through visiting the site multiple times over the semester, I have gathered information, assessed conditions, and collected data. Site visitation provides firsthand observation and allows for manual analysis of the characteristics, context, and potential constraints on the site. E.g. i have dotted the downspouts of all buildings in the area on a map to investigate where the water form the roofs are ending.

Hydrology:

Analysis of the hydrological properties of the site includes analysis of runoff, infiltration, paths of the water, and dimensioning values for precipitation events. This will partly be investigated through a literature review, and partly through a GIS analysis. The aim of this is to get a basic understanding of how the water functions in the area.

GIS (Geographic Information System):

To prosses geographic and hydrological information GIS has been utilised. The program used is ArcGIS Pro. The data used in the analyses are FKB vector maps colelcted form Geonorge (Geovekst, 2023) and height information from Høydedata.no. By combinding this data i have modeled the waterflow in the area. The method for analysis and discussion of map sourses is provided in Appendix 1. The results from this analysis are provided in the chapter: Way of the water.

To further analyse the data found in the GIS analysis and hydrological values, Excel has been used. This provides a clear structure and a way to work with a lot of data at the same time.

Source triangulation

To enhance the academic quality of this assignment, source triangulation has been employed, utilizing multiple sources covering the same topic to avoid errors from individual sources. As per example is the local literature, map data, and personal obervations compaired.

Reference projects:

Reference projects provide insightful knowledge about the problems and solutions that exist and have been tested. These are analysed, and remarks on how these projects can inform decisions in the area are made.

SWOT diagram

Tn this diagram the strengths, weaknesses, opportunities and threats, are sorted out.

In this project, I have chosen a mixed strategy. One strategy has been to be close to the landscape and the matreality, to follow the water and use common sence.

Another strategy has been to triangulate between different aspects, sources, and methods. This is reflected in the very structure of the thesis. It is structured three parts:

Discovery:
“Become aware of (a fact or a situation)”

Discovering the:

- underlying factors affecting an extreme precipitation event.
- the methods of water management
- the methods of the subject field

Analysis:
“Examine (something) methodically and in detail, typically in order to explain and interpret it”

Analysing the:

- water, its ways and proportions.
- areas, its history, and the situation as of today.

Proposal:
“A plan or suggestion, especially a formal or written one, put forward for consideration by others”

Proposing a

- Solution to the water management problems


3.DISCOVERY
ROGALAND
STAVANGER
IP, 2023

3.1 URBAN HYDROLOGY

In this chapter, the general knowledge base around the subjects of climate change and water management is explored. A list of wateremasures are provided and elaborated.

Urban areas and climate resilience

Cities are vulnerable to climate change. The risk for people and assets from hazards related to climate change has increased in all urban areas. Infrastructure, like water and sanitation systems are affected. The densification in urban areas, have created less pervious surfaces which, combined with more frequent heavy precipitation, increases the risk of flooding. Globally, surface water flooding are increasing, posing risks to urban systems. The risk depends on measures of adaptation to handle consequences, like drainage systems, stormwater management and green infrastructure (Dodman et al., 2022). Urban resilience entails the ability of urban centers, inkluding inheabitatns, enterprises and gorvernments, and the systems on which they depend to anticipate, reduce, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner (Dodman et al., 2022).

Climate resilience is defined as “the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation. It entails the ability to maintain function, structrues and identify, but also to sustain the capacity for transformation” (IPCC, 2022, p. 7)

Climate resilience can include the anticipation and preparedness to respond to a hazardous event related to climate (C2ES, n.d.). For climate adaptation the resilience of cities is imperative. The forecasted changes in climate are based on macro variables and global trends, but how this change applies to a local scale can vary greatly (Miljødirektoratet, 2022a). Whether the change is a benefit, or a hazard can vary even on a regional or local scale. In rural areas, a four-degree temperature change does not have the same im-plications as a four-degree change in heavily urbanised areas. Miljødirektoratet (2022a) has emphasised three key hazards from the IPCC AR6 workgroup 2 that can be specifically harmful to heavily urbanised areas: Heatwaves and rising temperature, flooding, and water security. Urban climate resilience can be built by applying multiple solutions to the same problems, as well as having solutions addressing multiple problems. This creates an intricate network of damage control.

Stormwater

In cases of heavy precipitation, stormwater can cause severe flooding and with it a lot of damage, (NVE, 2021) it all depends on the size of the basin, the intensity and length of precipitation, and to what degree the water can infiltrate into the ground (Pedersen et al., 2022, p. 9).

Stormwater is not that prominent in nature (fig. 6) due to the permeable nature of the ground, the water-storing capabilities of plants and natural terrain variations. Sometimes however due to different factors, the infiltration ability of the ground can be reduced, this can be due to persistent rain, or frost in the ground. If then a heavy rain occurs, the water can cause great problems (NVE, 2021).

In urban areas however the infiltration ability of the ground is already compromised, due to different factors (fig. 6). This can be the implementation of impermeable materials on the ground, the footprint of houses (NVE, 2016), or the soil having a reduced infiltration because of compression and disturbance of the ground (Solheim, 2017, p. 10).

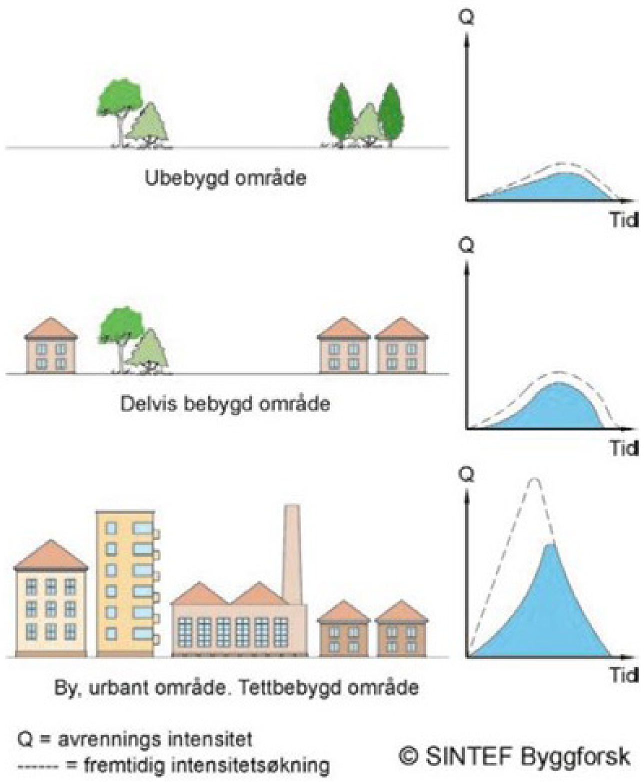


Fig. 6. Illustrates the effect densification has on stormwater runoff (from: NVE, 2016).

Due to climate change and increasing levels of precipitation (Andreassen et al., 2016, p. 107), increasing urbanization and densification, as well as population growth, the capacity in existing water distribution systems is not always sufficient to also handle stormwater (Miljødirektoratet, 2021). Overflow of the sewage system happens as the stormwater supply exceeds the system's capacity (Miljødirektoratet, 2021). Leading to potential health hazards, pollution, or property damage. The water must be managed before this happens.

Stormwater Management

Stormwater affects many sectors and actors. All actors affecting or affected by stormwater are responsible for dealing with the water. Thus, individuals, households, private enterprises, and authorities have a responsibility for handling the local stormwater. The municipalities have a major authority for stormwater management. The municipality is the planning authority and must take stormwater into account in the planning tasks. The municipality can determine premises for stormwater management, through zones requiring special consideration and other planning provisions, according to the Planning and Building Act § 3-3. (pbl, 2008). But at this point, 57% of the municipalities are expecting that the already installed stormwater systems are not adequate to manage the water volume of the future (Miljødirektoratet, 2021).

Gray way

Stormwater can be treated in different ways. What is normally considered the traditional solution is to remove the stormwater from the surface with storm drains and send it through underground pipes (Miljødirektoratet, 2021; Sivertsen, n.d.). These pipes can lead to different places. Often, stormwater management combines stormwater, wastewater, and sewage, and treats these together. Thus, the runoff water is included in the rinsing process. Stormwater can contain various types and concentrations of polluting substances (Hansen et al., 2015, p. 100; Miljødirektoratet, 2022b).

Treatment of wastewater reduces the amount of substances, e.g., excess nutrients, entering and polluting affected water bodies. However, as stormwater is supplied, the load on the treatment plant will increase and may lead to less efficient treatment (Hansen et al., 2015, p. 34). A treatment plant receiving the same amount of surface runoff as wastewater will release twice the amount of phosphorus as a plant without added stormwater (Miljødirektoratet, 2022b). The traditional method reduces the pollution of problematic substances in rivers and lakes. But this can however be problematic, as the water amount sometimes go beyond the capabilities of the treatment facilities, making sewage, surface runoff and wastewater overflow and gets directly discharged. One security method they have is spreading out the discharge, by having overflows in select locations. These are made to send water out directly where the problem is, often they discharge onto new pipes until it hits a safe location it can be deposited such as a river or the sea (Miljødirektoratet, 2022b). But it can also lead to overflowing to the streets or backup in cellar drains and toilets (Hansen et al., 2015, pp. 39, 55). Creating a new sanitary problem with sewage water hitting the human habitat.

Another way is to keep stormwater in a separate system, discharging into rivers, lakes, or the ocean. As mentioned, this can lead to pollution problems, but also solves a lot of other problems, you no longer need to be worried about overflowing sewage pipes or treatment facilities, nor backup in drains and toilets. The problem with harmful discharge can be addressed in some ways, using sand catchers in one solution, another is filters (Hansen et al., 2015, p. 103), more on this in the next chapter. Spreading the pollutants over more recipients will also reduce the concentration and thus the impact of harmful substances (Hansen et al., 2015, p. 102).

NBS, SuDS, LOD and LSM

A third way of dealing with water is with what is called Sustainable Drainage Systems Sustainable Drainage Systems (SuDS). Suds are defined as “drainage solutions that provide an alternative to the direct channelling of surface water through networks of pipes and sewers to nearby watercourses" (British Geological Survey, n.d.). The Norwegian term for this is LOD (Lokal OvervannsDisponering) (NVE, 2016) The terms are however loaded differently. Where "SuDS" drainage carries a meaning of getting rid of. The LOD's "disponering" means to use or have access to. Local Stormwater Management Measure (LSM) is a translation of the Norwegian term.

Nature Based Solutions (NBS) is another term often used alongside SuDS and LOD, which focuses on implementing natural processes. However, NBS has a wider scope, addressing other aspects such as heat mitigation, health benefits, and food management making it a to broad term. In this thesis, the term LSM will be used consistently.

LSM refers to ways of dealing with stormwater without transporting it to other locations and discharging it. This can be done with help or inspiration from nature in nature-based solutions (NBS). There are multiple ways or dealing with water. One is infiltrating the water into the ground, to recharge groundwater, and to water plants. Another way is retaining water, and this can be done in combination with infiltration. It can also be stored for later use or be used to regulate the amount of water in an area. LSMs and nature-inspired solutions can use grey infrastructure, concrete basins, pipes, etc. to mimic nature. Creating a network of solutions can in an effective way slow down, and mitigate risks connected to stormwater, by retention, load distribution, and filtration. Nature-based solutions are using natural (biological, and geological) infrastructure, to do the same thing. By adding nature back in urbanised areas, the infiltration and retention will happen naturally (Aarrestad et al., 2015, p. 52). By implementing specific "nature types" to address specific problems such as implementing wetlands in an area prone to flooding (Aarrestad et al., 2015, pp. 48-54) or designing new nature compositions to address certain problems, such as a rainbed (Hansen et al., 2015, p. 68).

Stormwater to treatment facilities

Strengths	Weaknesses
Water gets treated properly and disposed of safely	Can cause backup and overflow in sewage system and facilities. Expensive to make changes

Seperate stormwater system

Strengths	Weaknesses
Specified Easily adapted. Can implement simple treatment options. Does not affect sewage. Water can be stored and used later.	Does not get "purified" often discharged in urban locations. Expensive to make changes

Local Stormwater Management

Strengths	Weaknesses
Able to process a lot of water. Good for filtration Esthetical Biological & ecological benefits	Uses big areas

Management strategies: The three-step approach

The best way to manage water depends greatly on a few different variables. The amount of precipitation, the size of the area, terrain, and local discrepancies (surface material, obstacles, free space, etc.) are the most influential variables when managing water and it can be boiled down to: How much, how quick. Bigger, steeper, means more and faster water at the same place at the same time.

One of the accepted practices for stormwater management is the three-step approach. The approach is described in Lindblom (2008), and further in NOU2015:16 “Overvann i byer og tettsteder” (Hansen et al., 2015, p. 67) (Fig. 8).

There is no required way of separating the steps. But there seems to be a consensus on delimiting the steps using frequency intensity intervals from IVF curves in combination with climate factors, provided by the national metrology institute (Meteorologisk institutt) (found in Apendix 2). When using the IVF curves there are no specific delimitations between the three steps. One accepted way of limiting the steps is by 1) infiltrating precipitation events with an intensity equivalent to 95% of the annual downpours, 2) retaining runoff from precipitation events up to a 20-year interval, 3) managing the remaining runoff safely up to a 200-year return interval.

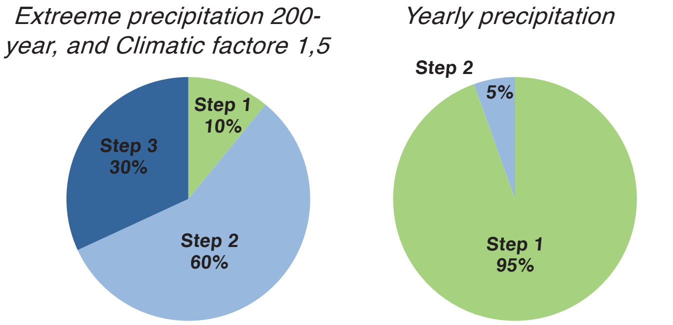


Fig. 7. Illustration showing where the water is handled through the tree steps. in extreme events (left) and on a yearly basis (right) (Paus, 2018, p.73).

The three steps

1. Reduce runoff by infiltration.
2. Reduce runoff by retention.
3. Create safe floodways to recipient waterbody.

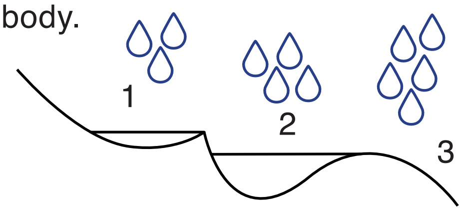


Fig. 8. Illustration of the three-step approach, (IP, 2023).

Dimensioning the first step

The limitation of step one was proposed by Kim H. Paus (2018) in: “Suggestion for design values for step 1 of Norwegian Water’s three-step strategy for stormwater management”. Hourly precipitation data from Våland weather station (Meteorologisk institutt, 2023) between 2008 and 2023 can be used to find the 95th percentile of precipitation events (Fig. 7). The hourly data shows that a rain event of 3mm in one hour and an event of 17mm in 24 hours happens in less than 5 % of the annual average rain events.

Step one can be limited to 3 mm/hour. or 17 mm/ 24 hours.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IP, 2023

3.2 STORMWATER MANAGEMENT: CATALOGUE & EXAMPLES

This chapter will give an intrduction to available stormwater measures. first trough an catalogue, then a description of the main measures wil be provided, and than two example projects are presented. The measure list is based on a list and elaboration from “Cost and benefit of stormwater management measures” by Vista Analyse and COWI (Magnussen et al., 2015). They are categorised by the type of measure. They further analyse the cost and benefit of the different measures. The cost will not be discussed further in this thesis. But is a theme that is highly relevant for the implementation of the measures.

Table 1. catalogue of stormwater measures is based on table 2.1 from “Kostnader og nytte ved overvannstiltak” M305/2015 (Magnussen et al., 2015).

Measure	Type of measure: 1-Infiltration 2-Retention 3-Flodway 4-Transportation	Description
ON BUILDINGS		
Downspout disconnection	1,2	Roof-runoff is disconnected from pipe networks, water is discharged onto lawn/ planting or infiltration/retention measures at ground level.
Downspout overflow	2	Makes less pressure build up in pipes
Directional valve on attachment pipes	4	Less potential water damage from back-ups in drains and toilets.
Green roofs	1,2	A green roof is a roof covered with vegetation consisting of sedum, mosses, perennials, shrubs or trees.

Green walls	1,2	Climbing plants planted in the ground or in container on their own wall.
AT GROUND LEVEL		
Infiltration covers	1,2	The surface is permeable so that surface water can seep into the ground (open joints/grass cover).
Retaining infiltration surfaces	1,2	Save natural vegetation, protect the infiltration site.
Creating infiltration surfaces, opening up impenetrable surfaces.	1,2	Demolish uninhabited houses, dense surfaces, replace existing dense surface masses with infiltration material.
Infiltration zone /ditch	1,2 (3)	An infiltration ditch is an elongated artificially built infiltration solution in areas with poor natural infiltration conditions (dense masses). Can also be used as a floodway.
Raingardens	1,2	Raingardens is a planted depression in the terrain that is supplied with surface-runoff for infiltration and purification.
Infiltration basin	1,2	An infiltration basin is an open basin that combines surface-runoff storage and subsequent infiltration into the ground filtering the water
Thresholds with spillway	2,3	Narrowed overflow that holds back stormwater
Stormwater dam	2	Has a permanent water level (dry weather volume). In addition, the pool has a volume for retention of runoff.
Wetland	2	Shallow pools (depth 0.2 – 0.5 m) are referred to as wetlands or wetland-filters and normally have a dense vegetation cover.
Open dry retention basin	1,2,3	The basin reduces the risk of flooding and limits flooding impacts in watercourses by temporarily withholding a volume of water from a precipitation episode by having a reduced outlet capacity (throttled outlet).

Dry ditch	2,3	Constructed fixed ditch with or without vegetation for retention and transport of stormwater.
Closed retention basin	1,2	The function is the same as for open dry drainage basin with the difference that the water is collected in a closed underground pool.
Sand Catchers	2,4	Catches pollution and retains water in smaller amounts, often in connection to stormwater drains.
Reopening of streams	1,2,3	Open streams that have previously run in pipes or culverts.
Vegetation-covered rivers and creaks	1,2,3	Vegetation-covered area along streams and rivers.
Reduced use of curbstone	2	Bring water from solid surfaces directly to vegetated, infiltration areas.
Permanent flood barriers	3	Floodwall.
Temporary flood barriers	3	Fences or sandbags.
Securing buildings	3	Raising houses above street level, preventing water from flowing in.
Measures on private connection pipes	4	Separation of waterpipes.
Measures on the public stormwater pipes	4	Replacement of pipes due to capacity, or retention of stormwater.
Measures on Combined sewage pipes	4	Separation into stormwater and wastewater pipes or a larger combined sewage pipe.
Measures at pumping stations and treatment plants	4	Upgrades

Measures in depth:

Downspouts have the possibility to store water with potential energy putting pressure on the VA system. Disconnecting downspouts lightens the load on combined sewage, making backups less common. Alternatively, an overflow/leaf filter can be installed. Disconnecting the downspout and leading the water directly to a lawn for infiltration is a good option, however, in heavenly densified areas there may not be enough space for infiltration.

Connecting the downspout to a retention measure (fig.9) can be a good way to both handle stormwater and utilise the water. They can also be directly fed into raised flowerbeds (fig.10).

Fig. 9. A Rain barrel is used to retain rainwater for later use (Ribbey, 2017).

Fig. 10. A raised rainbed can provide great potential for water retention and infiltration (New Jersey Future, n.d.).

Separating combined sewage to stormwater and sewage lightens the load for each type of pipe and makes stormwater easier to manage. The separate stormwater pipe often leads to discharge in a local body of water, making pollutants from surface discharge a possible problem. This can be addressed with LSMs or sandcathcers.

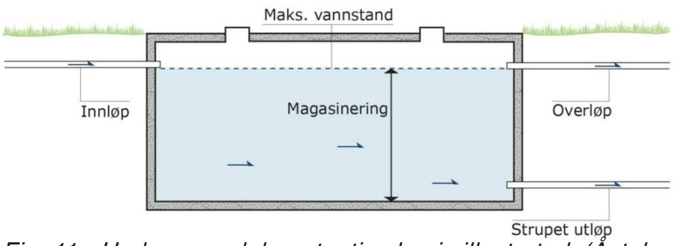


Fig. 11. Underground dry retention basin illustrated, (Åstebøl et al., 2013).

Closed retention basins are covered volumes designed to retain as much water as possible (Åstebøl et al., 2013). (fig.11) in a way that lightens the load on the stormwater pipes to reduce the risk of overflow .

Sand catchers are designed to catch material heavier than water and let water go on, as a lot of harmful residues are "sticking" to sediments they get retained (fig. 12). These are also designed to be easy to clean out, so the material can be disposed of in a proper

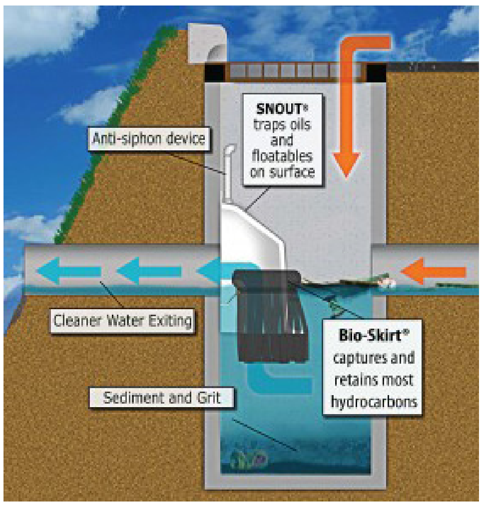


Fig. 12. Sand catcher with a bio-retention filter (Good, 2014).

way. Sand and gravel filters can also be used, these are designed to let water flow through leaving the sediments behind.

Some traditional stormwater solutions can easily be transformed to store water for later use for greywater purposes, such as watering plants, or cleaning purposes (fig.13). These can however also easily be adjusted to Green local management measures.

Green roofs have the potential for slowing down runoff and retaining water, the water can then be combined with a system for greywater reuse for benefits, and further storage, this is however hard to retrofit into existing building environments (fig.14,15). Measurements from Oslo show that green roofs can reduce the runoff by approximately 50-75% (Braskerud, 2014, p. 58) depending on rain intensity and the construction of the green roof. It's estimated that for a 10 min event, the runoff is reduced by 55% and for a 60min event the runoff is reduced by 43% (Braskerud, 2014, p. 61).

Green Walls have the effect of slowing down and catching water but do not have that big water retaining potential. Green walls can also have other ecosystem services (Bothner & Aanderaa, 2017).

Infiltration covers are permeable surfaces that are able to infiltrate water (fig. 16). This can be vegetative soft covers (grass, plants), or grey hard covers (Gravel, nature slabs, permeable asphalt or cobblestone). In-

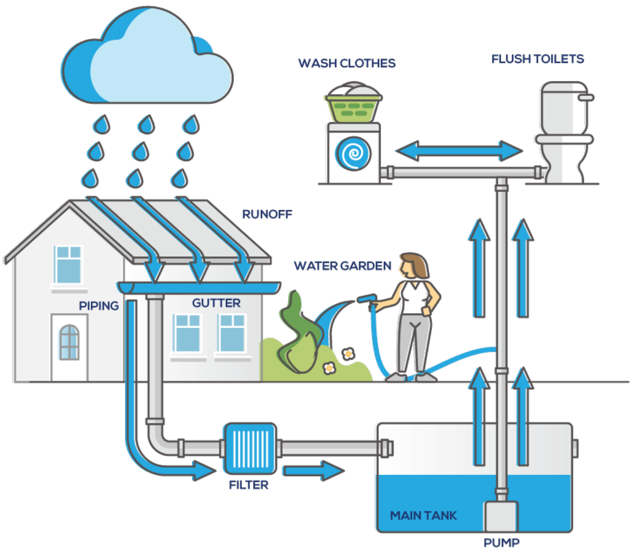


Fig. 13. Reuse of rainwater water from the roof, this can be connected to a greywater system as well (UPP Group, n.d.).

Fig. 14. Traditional Norwegian green roof in Lærdal (IP, 2021).

Fig. 15. Green roof at Campus Ås uses local Norwegian species for stormwater management IP, 2023).

Fig. 16. The use of spacing and gras between the cobble stone ensures infiltration. Campus Ås (IP, 2023).

filtration is heavily dependent on the porosity of the underlying material and the in-between fill material. Dependent on the infiltration efficiency of the cover it can be an effective method for dealing with surface runoff given the multipurpose nature of this kind of measure. These types of covers can infiltrate from between 95% of rainwater until saturated (Grass), all the way down to 30% or elss with tightly packed cobblestone (Magnussen, 2015, p. 8). Restoring open areas for infiltration can be an effective measure, exemplified by changing the material in the driveway from asphalt to gravel.

Infiltration zones are areas normally on a lawn or similar specially designed for the purpose of retaining and infiltrating runoff water.

Infiltration ditches are elongated terrain sinks that are designed to catch a lot of water from areas with poor infiltration qualities (fig.17.). These are especially normal around roads where water is expected to be removed quickly from the area, as well as being filtered.

Fig. 17. Infiltration ditch collecting water from nearby parking in San Mateo, USA (Flows to bay, n.d.).

Rain gardens are flowerbeds made with the purpose of retention of large volumes of water through infiltration and drainage (Egeberg et al., 2021). The efficiency of such measures is dependent on the bed volume, infiltration speed (Ksat) and density of the used material. These can be designed to flood, having the bed sunk into the ground to make it retain even more water (fig.18). Infiltration directly to the ground can lead to water damage on parts of buildings underground (fig.19) (Stenberg, 2011). Moving the rain gardens away from buildings, introducing drainage or implementing impenetrable membranes can address this problem. Rain gardens can have a Ksat of up to 0,4m/hr. And normally require 4-10% of the catchment area for proper water management.

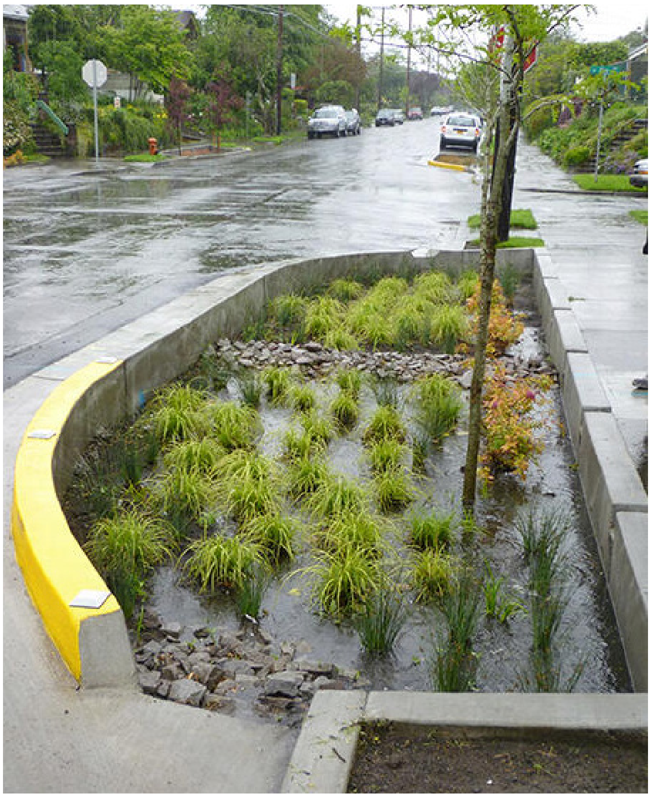


Fig. 18. The deeper the beds are situated in the ground, the more water can they detain, but not all plants can manage the water, from Portland, USA (Portland.gov, n.d.).

Fig. 19. A rainbed situated close to a building, a membrane is protecting the underground structures form water damage. water can flow directly into the bed form all sides because it does not have a raised edge (Egeberg et al., 2021, p. 35).

Infiltration basins are sunk vegetative structures, the same as rainbed and infiltration ditches but designed to flood, retain more water, and often have bigger areas than rainbands (fig. 20). These areas have the benefit of being multipurpose. These are requiring 7% of the area to the connected rain basin and an area able to infiltrate 7,2m/24hr 0,3m/h (Åstebøl et al., 2013). A variation of this is a filter basin which incorporates drainage pipes underneath the cover making infiltration quicker, this can take up to 4,5m/24hr.

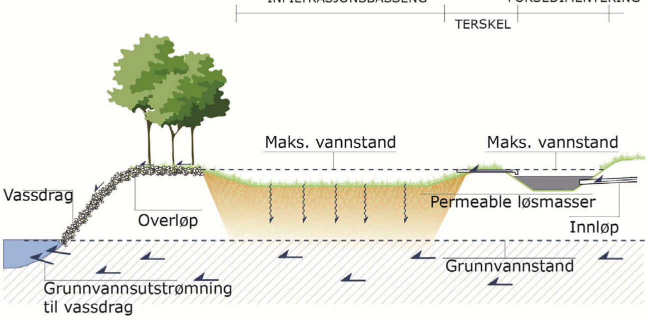


Fig. 20. Infiltration pool illustration. The water goes fist into a small pool where it realises its sediments then overflows into filter plane. where it will infiltrate over time, filtering the water (Åstebøl et al., 2013, Temablad. 6).

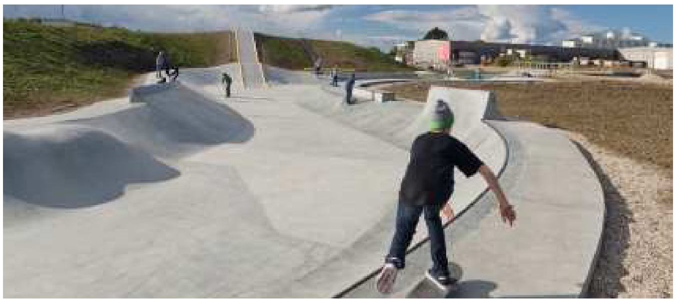


Fig. 21. Skate bowl in Roskilde, it has multiple functions, as a flooding way and retention pool (Åstebøl et al., 2013, Temablad 5).

Open dry retention basins are designed to retain bigger volumes of water has a dimensioned outflow to make less impact downstream. These can be made in many forms, for example, a sunk gras plane or a skate bowl (fig. 21) (Åstebøl et al., 2013.)

Stormwater dams have a permanent water level and have extra capacity for stormwater. It has a fixed outflow so it can retain water and an overflow. They are normally area intensive, requiring 15% of the area they are supposed to retain (fig. 22).

Wetlands are in principle the same as stormwater dams but have flooding-friendly vegetation.

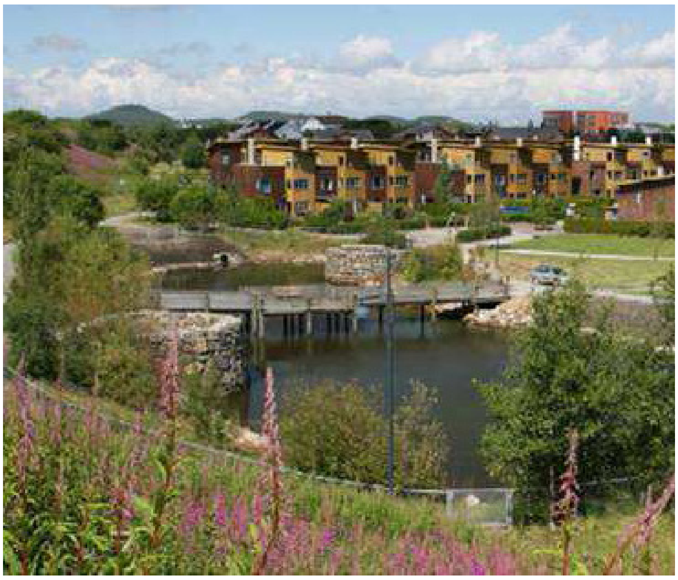


Fig. 22. Open stormwater dam in Sandnes, Rogaland (Åstebøl et al., 2013, Temablad 1).

3.3 REFERENCE PROJECTS

Reference projects are good to get an understanding of the measures, and how they are implemented in different settings. I have chosen two projects, that are comparable because they have some similar aspects to Straen, with density, and heritage.
These are “Deichmans gate og Wilses gate”, and “Regnbed, Bryggen I Bergen”.
Asplan Viak has also written a report on the implementation of raingardens in urban environments, based on the Deichmans gate project, named “Urbane regnbed” (Egeberg et al., 2021).

I have also looked at many other projects, among others among others have these two has provided much insight in the potential for artful multifunctional stormwater design:
Before the flood - (master thesis) (Bothner & Aanderaa, 2017)
Artful Rainwater Design: Creative Ways to Manage Stormwater (Echols & Pennypacker, 2015)

Deichmans gate og Wilses gate

Year: 2017

Area: 3750

Company: Asplanviak

Location: Oslo

Deichmans gate is a street in Oslo which in 2017 was rehabilitated as a stormwater pilot project. The street was projected by Asplan Viak and won the Norwegian landscape architects union (NLA) landscape architecture price in 2018 (Asplan Viak, n.d.). The project is a collection of 9 rain gardens, 7 flowerbeds, art installations, and waterways (Asplan Viak, n.d.). It is made to manage up to 60 cubic meters of water. The rain gardens have a footprint of 200 m² and a combined basin of 4227 m². This makes up 4.61% of the area (fig. 23) (Sivakumar, 2020, p. 14).

The rain gardens have three main impacts on water management 1. They filtrate surface runoff before it gets to the waterpipes. 2. Recharging groundwater with infiltration. 3. Retaining water to decrease flood tops and reduce the water flow in wastewater systems (Sivakumar, 2020, p. 9).

In combination with the rain gardens, there are 7 flowerbeds, and the ground material has been exchanged from asphalt to penetrable groundcovers. These measures are meant to both increase the biodiversity and aesthetics of the area and reduce the overall runoff normal beds effectively reduce the water runoff to near 0 and the change of groundcovers can reduce the runoff by 10-20% (NVE, 2016). The raingardens in Deichmans gate have a “free” depth of 25cm for water collection. A risk assessment of water depth and drowning shows 25 cm as an acceptable height for raingardens (fig. 24), but should be assessed when placed in areas where small children wander alone (Egeberg et al., 2021, p. 22)

Fig. 24. The gardens are sitting in the ground, water goes trough a sedimentation chamber to reduce sediments in the bed (Egeberg et al., 2021, p. 21).

Fig. 23. Gardens and rain garden cover a big part of the area (Sivakumar, 2020, p. 9).

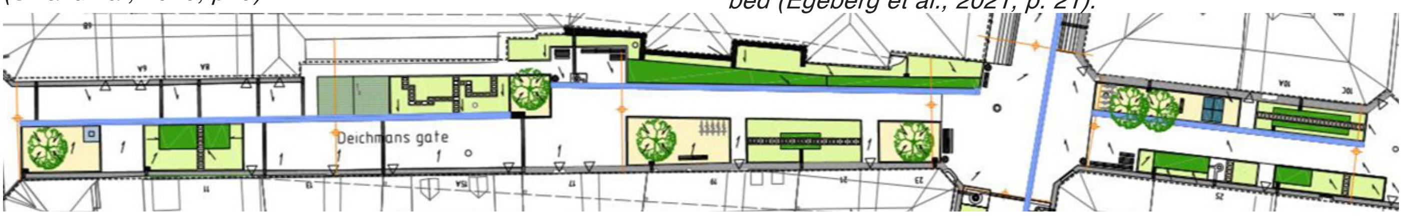


Fig. 25. Deichmans gate Photo: Janicke Ramfjord Egeberg (Asplan Viak, n.d.).

Fig. 26. Water feature in Deichmans gate Photo: Åse Holte (Asplan Viak, n.d.).

What can be learned from Deichmans gate?

Compared to the project areas basin (14.42 ha) the basin of Deichmans gate is considerably smaller (0.42 ha). But as this is a pilot project, the results should be scalable. The rain gardens of Deichmanns gate cover 4,6% of the area but a lot of the remaining area is also covered by normal flowerbeds. One of the effects of this transformation was the removal of most of the established street parking. This may not be possible to do in the Straen Basin. Reducing the number of flowerbeds can be a way to retain some street parking, mostly focusing on rain gardens and surfaces. Changing all of the ground cover will not be a viable option for the Straen Basin due to the size of the area. This can however be done in portions of the basin. One positive effect of this can be a closer relationship between Old Stavanger and the surrounding areas. One of the problems relating to rain gardens in Deichmans gate was maintenance, both with the removal of sedimentation and the maintenance of plants due to human and animal deterioration.

Technical retention systems in rain gardens increase water retention. This can reduce the area cover needed for rain gardens in the Straen basin.

The rain gardens were constructed with impenetrable PVC. membrane towards the buildings, protecting basements from water damage. This reduces the need for a buffer towards housing, increasing the area where it’s possible to construct rain gardens.

Raingardens Bryggen I Bergen

Year: 2014

Area: 150 m²

Company: Multiconsult, Statsbygg

Location: Bergen

The raingardens at “Bryggen i Bergen” are a part of a bigger project for recharging the groundwater due to conservation problematics. The gardens are the second step of this project, the first part was actively pumping water into the ground to recharge. The rain gardens are made to keep the groundwater balance, by infiltrating water. The infiltration areas consist of two rain gardens that combined cover 150m² and ca 100m green swales. The area projected is an urban heritage area and a part of the UNESCOs World Heritage List (NLA, n.d.).

The rainbed is not directly in the way of the water but connected to the nearby road through a storm drain (fig. 27).

The rain garden consists of 700 herbs and perennials based on naturally growing species in the region (fig. 28).

In the unplanted areas, there has been used river gravel (fig.x) these can reduce maintenance of the gardens while still being good for infiltration.

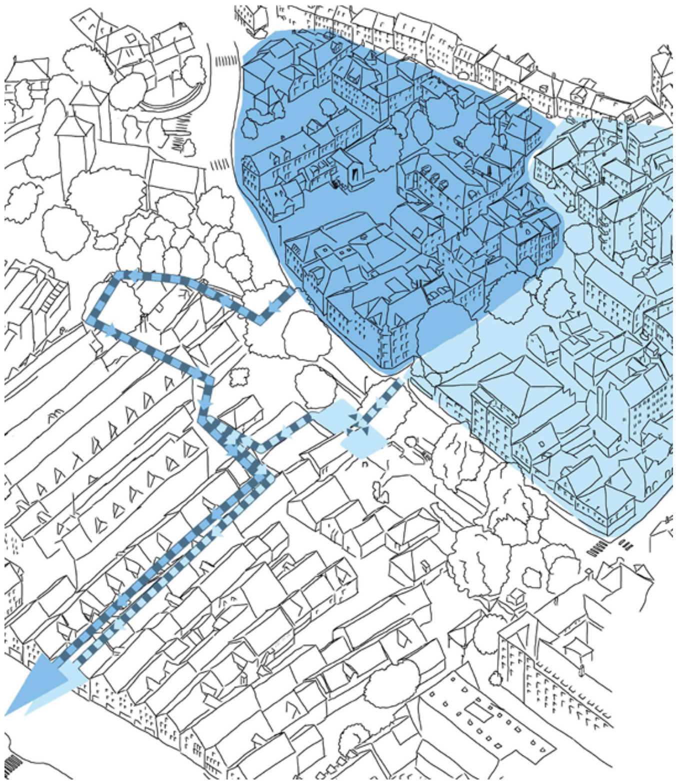


Fig. 27. The basin of the rainbed illustrated, (Multiconsult AS, 2014)

What can be learned from the rain gardens on "Bryggen i Bergen"?

The rain gardens are in a heritage area, and they are designed to mimic the period of the area. They have therefore a close resemblance to cloister gardens. This can be used as inspiration for rain gardens in the heritage areas of the Straen basin.

The use of river rocks in the beds leads to faster infiltration.

Although Bryggen i Bergen also is a heritage the measure taken here cannot be replicated in Straen. This is because this measure is made to introduce water to the groundwater keeping the balance, whereas in Straen the water underground is one of the problems.

Fig. 28. The rain garden at Bryggn in Bergen, Photo: Tone Muthanna.

3.4 WEATHER AND CLIMATE

This analysis aims to get an understanding of the changes in climate that will impact the planning area. There are two goals with this analysis. It's the understanding of precipitation and the climate effect on heritage environments.

The Analysis Concludes:

There has been an increase in temperature from 1850 – 2021 of 1,2°C. The temperature in Rogaland may increase by 3,5°C in 2100. Extreme precipitation events lasting under 24hr. are going to be over 20% more intensive. And are going to come twice as often (56-121%)

Climate change

Between 1850 (preindustrial times) and 2021, the global average temperature increased by 1.2 degrees Celsius. The continuation of this rise in global temperature will probably impact our lives in more ways than first anticipated. This change in climate will not only make us hotter, but it will also make us colder, wetter, and dryer. It will push the limits of the extremities we know, and the ones we don't know yet.

The IPCC (Intergovernmental Panel on Climate Change) has composed an extensive report on climate change, projections, and mitigation. In their AR6 report by workgroup 3 (Skea et al., 2022) they presented scenarios in 8 categories ranging from C1- a col-

Fig. 29. The weather is getting more extreme. Coast of Jæren, Rogaland (IP, 2022).

lection of scenarios where global warming is limited to 1,5 degrees by the exit of 2100. To C8, containing scenarios that exceed 4 degrees. The Norwegian government is recommending using the highest climate projection (Kommunal- og distriktsdepartementet, 2018: 4.3, 2) since there is no downscaled model for the scenarios in AR6 to fit the climate of Norway the projections of RCP8.5 from IPCC AR5 will be the most locally accurate (Norsk Klimaservicesenter, 2021) (Pachauri et al., 2014). The projections of RCP8.5 are used in downscaled models published in national and regional documents such as “Klima i Norge 2100” (Andreassen et al., 2016) (Climate in Norway 2100), and “Klimaprofil Rogaland” (Norsk Klimaservicesenter, 2021) (Climate profile Rogaland) and will be used in this regard.

Fig. 31. The degree of urbanisation can affect the climate changes on a local level. Old intersection at Charles de Gaulles, France (IP, 2022).

Fig. 30. Heavy rain episodes are becoming more frequent. Rain event on E18 creating difficult driving conditions, Oslo (IP, 2022).

In the near future, natural macroclimate variations will be dominating over the effects of human-made climate change. It is suggested in Klima i Norge 2100 that planning for a shorter time period than 10-20 years should be done from up-to-date climatic observations and calculations, not from predicted climate models (Andreassen et al., 2016, p. 89).

These climatic models represent the worst-case scenarios, but still, scenarios that are fully plausible. If we fulfil the pathway of the C8 category the climatic impact will be huge, and we can expect more rain, drought, sea level rise, and air humidity. Although the goal of the Norwegian government is to stay below 2°C.

“Hope for the best, plan for the worst”
- Known proverb

The climate in Rogaland:

Norsk Klimaservicesenter (2021) has in the report Klimaprofil Rogaland presented predictions for the expected future climate near the end of this century based on models in Klima i Norge 2100 (Andreassen et al., 2016).

The mean temperature will rise by 3,5°C, and that the days with extreme cold will be reduced (Norsk Klimaservicesenter, 2021).

In 2100 the yearly precipitation will have increased by 20% in winter, 10% in spring, 5% in summer, and 10% in autumn. A 20% increase in precipitation is expected for days with heavy rain. For precipitation with a duration of under 24 hours, an even bigger increase is expected (Norsk Klimaservicesenter, 2021).

Because of sea level rise, storm surges will have a bigger impact. It's estimated that the sea level will rise by 62-81 cm.

The days with heavy precipitation (days that are in the 0,5 highest % precipitation in the reference (roughly 1 -2 times/ year) in Southwestern Norway are expected to increase by 56-121% (Table 2), and at the same time the amount of precipitation is expected to increase on these days (Table 3).

Table 2. Increase (%) of the days per year with heavy precipitation from 1971–2000 to 2071-2100 (Andreassen et al., 2016, p. 168)

Increase (%) of days with heavy precipitation in Southwestern Norway						
	RCP 4.5			RCP 8.5		
	Med	Low	High	Med	Low	High
Year	33	14	66	81	56	121
Winter DJF	75	29	156	154	100	212
Spring MAM	28	-20	72	36	20	98
Summer JJA	30	5	57	58	0	79
Autumn SON	25	-14	68	81	32	159

Table 3. Increase (%) of precipitation on days with heavy precipitation in Southwestern Norway from 1971–2000 to 2071-2100 (Andreassen et al., 2016, p. 176)

Increase (%) of precipitation on days with heavy precipitation in Southwestern Norway						
	RCP 4.5			RCP 8.5		
	Med	Low	High	Med	Low	High
Year	4	0	8	6	3	10
Winter DJF	6	1	16	7	2	19
Spring MAM	3	-6	9	4	-2	12
Summer JJA	6	-5	16	7	-2	16
Autumn SON	1	-3	10	7	-3	12

The models used by Klima I Norge 2100 estimate that there will be a 3,4% increase in year precipitation for every extra degree (Andreassen et al., 2016, p. 107). The report then points to the observed average increase in precipitation per degree over the last 100 years, which is 8-11% per 1°C.

Precipitation events can come in many forms, underneath are the two biggest events between 2008 and 2023 (fig. 32,33), and the rainevent that caused the flooding in the first figure (fig. 34). the first one had 32 mm in one hour. (That is equivalent to a 200-year interval), the second had 99.2mm in 29 hours (approximately a 30-year interval).

Weather events with extreme downpours in 1 hour will act differently from events lasting over a longer time. Impacting soil saturation, increasing runoff. Runoff coefficients are increased when the event is longer than 3 hours. And is also increased by between 10 and 30 per cent between a 25 and a 200-year event.

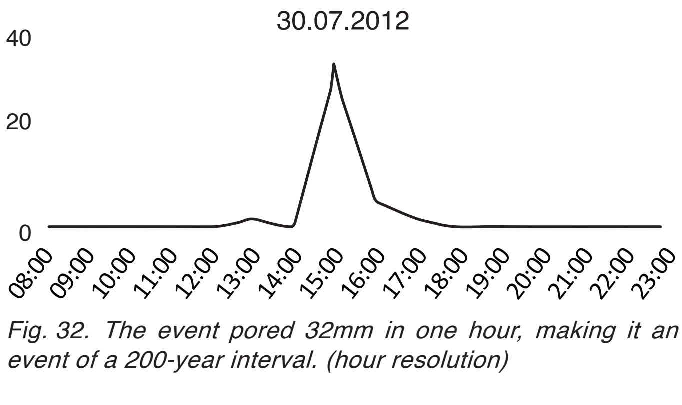


Fig. 32. The event pored 32mm in one hour, making it an event of a 200-year interval. (hour resolution)

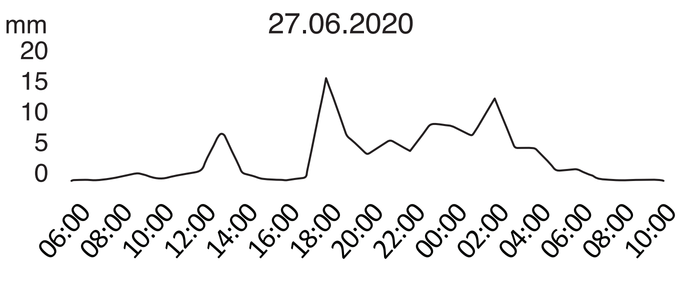


Fig. 33. 99,2mm over 29 hours. (hour resolution)

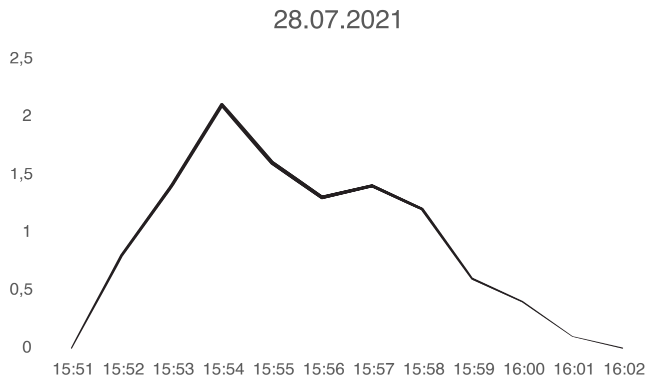


Fig. 34. The event of figure 1. 10,9 mm in 10 minutes. A 10-year interval (minute resolution)

3.5 STAVANGER TREHUSBYEN

This analysis explores Trehusbyen, its protection and its possibilities. First, an introduction to Trehusbyen will be made, and then using a master thesis by Hagen (2022) the possibility of implementing sustainability measures in Trehusbyen will be explored.

Fig. 35. Part of Trehusbyen around Våland, houses mostly from early- to mid-1900 (IP, 2023).

Trehusbyen

The wooden house district of Stavanger (Trehusbyen) is the largest interconnected wooden house area in Europe (Byantikvaren, 2022)(fig. 35). The oldest housing is situated in the centrum, and the houses get "younger" the further out it gets, this can be referred to as the growth rings of Stavanger (Skogland et al., 2016) (fig.36). It was however not always supposed to be this way. In 1946 a regulation plan named "Demolish and rebuild" was approved by Stavanger municipality. This met a lot of resistance by engaging cultural protectors. In 1957 they managed to overturn the demolition of Gamle Stavanger, leading to the first protection plan for area protections in Norway (Skogland et al., 2016, p. 14). Today most of the wooden housing in the city is reg-

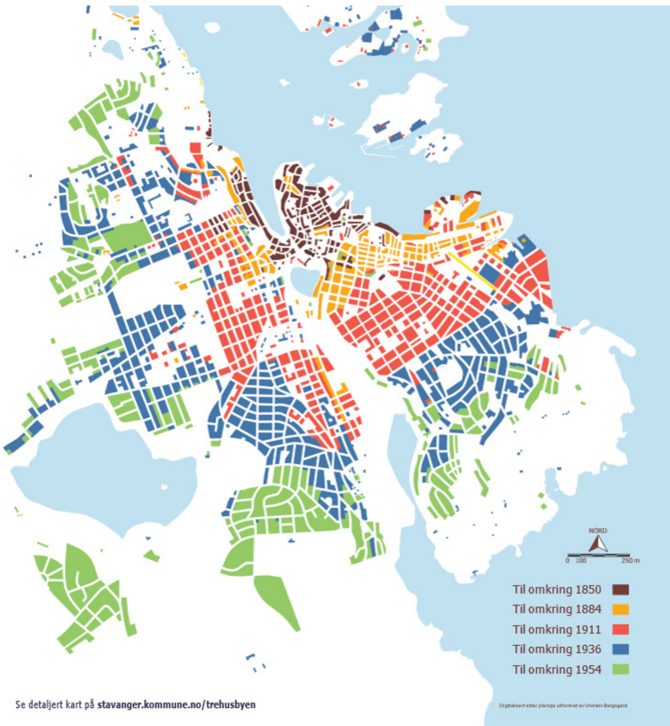
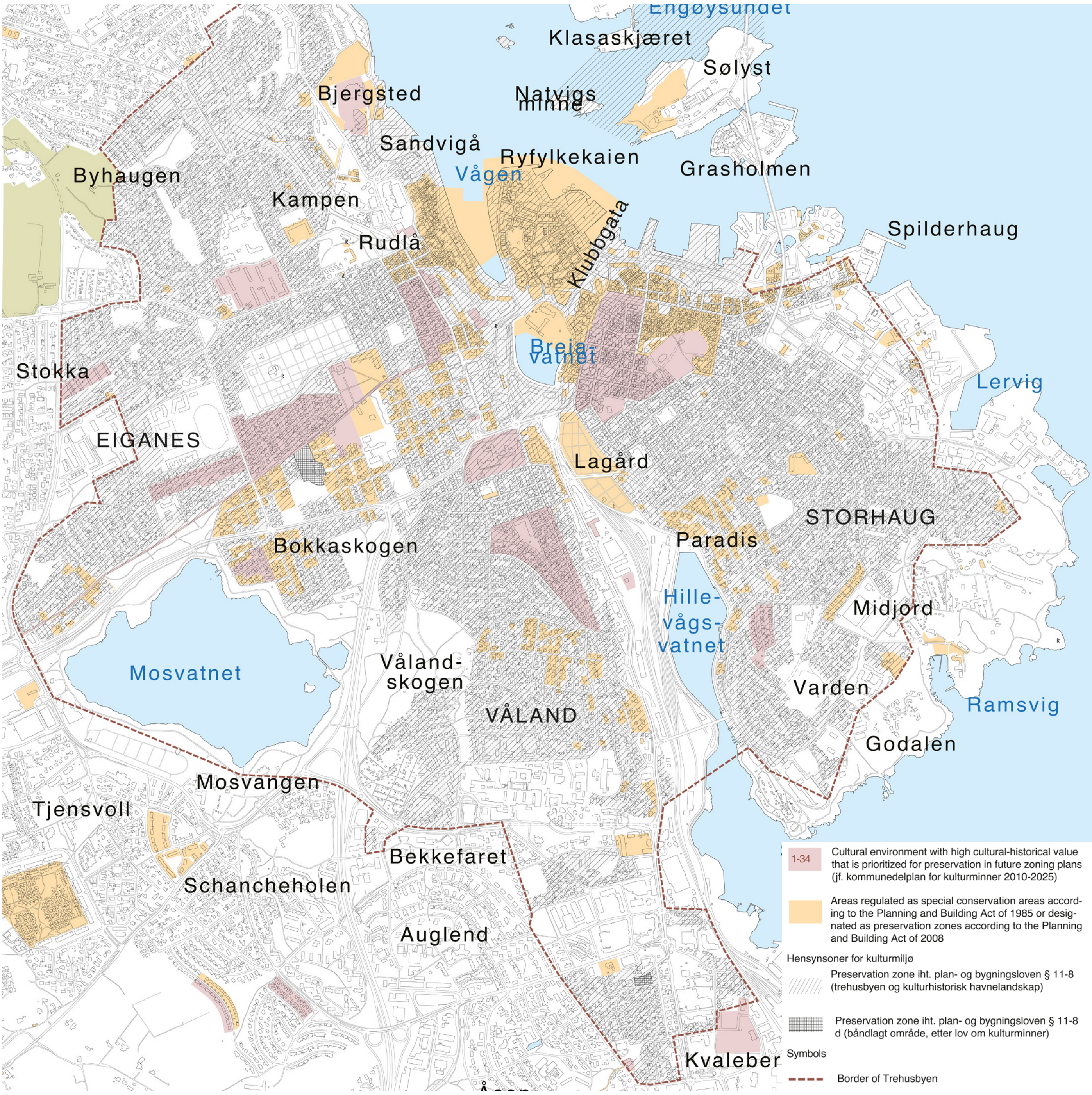


Fig. 36. The growth rings of Stavanger. The centre is oldest and the city gets younger further out. (Byantikvaren, 2022)

ulated for some kind of protection eighter by zoning plans for “special areas of protection” or as cultural heritage consideration zones. More areas are planned for future protection in zoning plans (Byantikvaren, 2022)(fig. 37).

Taking the problems of climate change and the goals related to it (e.g., cuts in emissions, increased densification, and increased energy efficiency) into account, a city-scale protection might seem counterintuitive. Ensuring a sustainable city development, while not being able to change most of the buildings. And the added need for protection of the heritage environment does not make it easier.

Fig. 37. Map of the heritage zoning of Trehusbyen (Byantikvaren, 2022). Removed points and numbers from the original.



Protection of Trehusbyen

Stavanger places a conservation effect in the term “Trehusbyen” (Stavanger Kommune, 2010, p. 16) The Cultural Heritage Plan highlights important conservation values in Trehusbyen:

Main goal

Strengthen Stavanger’s identity as a wooden house city, communicate knowledge about cultural heritage and cultural environments in Stavanger, and provide a framework for the preservation of these for posterity.

At city level:

• The amount of houses and the identity as a wooden house town
• The pattern of development, the structure with streets, gardens, etc
•Scale

At building level:

• The wooden house itself; The Timber Box
• Original building elements
• The building aesthetics; Style and detailing
(Stavanger Kommune, 2010, p. 16)

Trehusbyen:

• Conserve the contiguous wooden housing
• Continue the wooden house tradition in our own time
• Safeguarding authentic spaces and buildings, including shop fronts in the centre, against unwanted changes
• Return altered buildings to their former appearance
• Ensure adaptation of extensions and new buildings to the existing whole
• Meet new technical and functional requirements for as long as possible, without compromising the cultural heritage value
• Keep gardens green, preserve valuable vegetation
• Keep courtyards open and preferably paved with natural materials (gravel, slate)
(Stavanger Kommune, 2010, p. 23)

Guidelines for the protection of Trehusbyen:

1 Efforts shall be made to preserve the culturally historically valuable buildings and safeguard and further develop the distinctive environment of the areas.

2 Block structures, street courses, parks, garden areas, and valuable trees shall be preserved.

3 All construction works affecting the appearance of buildings, including roofs, must be notified. As a basis for processing, the necessity of the measures shall be explained. It should be described how the change relates to the buildings' original style expression and appearance. Conditions relating to neighbouring buildings shall be stated in the situation plan and façade outline.

4 Original building elements such as windows, doors, moldings, façade cladding, and roofing material should only be renewed when they no longer satisfy reasonable technical requirements or are so damaged that repair is out of the question.

5 If renewal is necessary, building elements shall be adapted to the house's original building style and use of materials. This applies, in particular, to window types, exterior doors, moldings, façade equipment, façade cladding, and roofing material.

6 Extensions shall be adapted to existing buildings and subordinate to them. Extensions can be given a modern design. The same applies to new construction.

7 A new balcony or porch shall only be constructed in connection with houses where it is included as a natural stylistic historical element. Patios should primarily be arranged on the ground floor.

8 Walls, fences, gate posts, outdoor lighting, and exterior coverings shall, with regard to design and choice of materials, be in line with the original or dominant design tradition in the area.
(Stavanger Kommune, 2010, p. 27)

Urban sustainability strategies for the heritage environment of Stavanger Trehusbyen

This part of the analysis uses the master thesis of Hagen (2022) where she explores Urban sustainability strategies for the heritage environment of Stavanger, Trehusbyen. Her findings can help enlighten the possibilities for the creation of a sustainable system for handling water.

Annika Hagen (2022, p.77) concludes:

Densification is the general strategy for enhancing urban sustainability of Trehusbyen. But it is not the only one.

"Combining the potential for densification with increased energy efficiency, improving resilience against climate events, encour¬aging soft mobility, and a reduced car use through the redesign of streets and public spaces is the ideals that development in Trehusbyen can enhance. For Trehusbyen to be able to cope with new urban sustainability standards without damaging the heritage values, the cultural heritage must be seen as the starting point for reducing the carbon footprint and ensuring living communities in cities of high quality."

Fig. 38. Trehusbyen in the eastern part of Stavanger (IP, 2023).

A Selection of principles for sustainable development of Trehusbyen:

Private Property

The buildings in Trehusbyen were found to be flexible and adaptable to change (fig. 41).

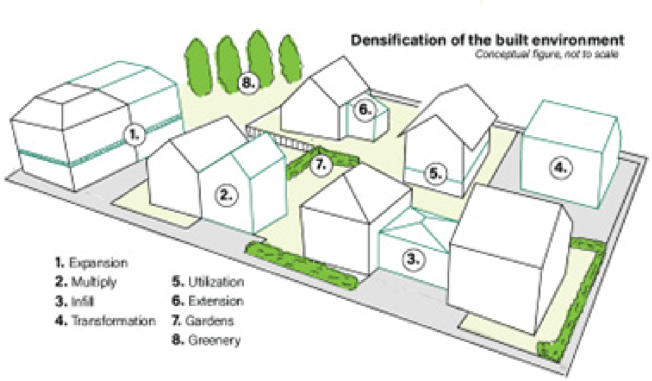


Fig. 39. Conceptual map of the building environment, by Annika Hagen (2022).

As an alternative to the separated backyards of the blocks, there is a possibility of creating a shared courtyard, where the area is joined and available for all residents of the block (fig. 40).

Fig. 40. Private and semiprivate gardens, by Annika Hagen (2022).

Streets and public spaces

Designated areas for pedestrians increase the feeling of safety and allow for efficient thoroughfare.

With reducing access for cars in the streets they will be more attractive for pedestrians. The use of greenery in streets was also shown to have benefits for attractiveness, as well as climatic management and protection, and biodiversity.

By defining some collection routes for vehicles and public transport that have connections to important areas of the city, it is possible to prioritize other streets for pedestrians.

When densifying there needs to be capacity for the necessary functions, such as public spaces. Taking advantage of the street and smaller unused pockets of space can contribute to more diverse public spaces in the neighbourhood.

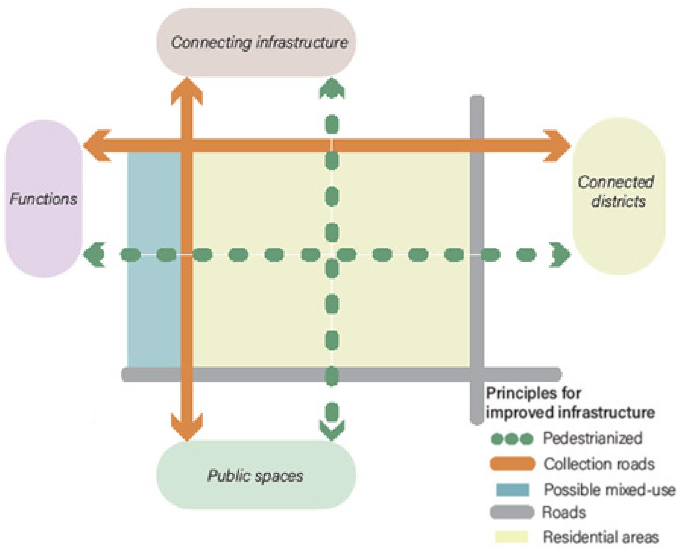


Fig. 41. Connections Concept map, for improved infrastructure, by Annika Hagen (2022).

How to protect heritage

There is a movement in the conservation field, going towards protecting cultural heritage, with cultural heritage. In so-called Culture Based Solutions (CBS) (Haugen et al., 2022, p. 30). CBS studies historical approaches and solutions in local climate adaptation and re-applies them or introduces them in a new location. There was a project in the Netherlands where forgotten water channels were restored and new strategies were implemented. This solved the problem of stormwater flooding in the city of Kampen. As the climate is changing, one may think that measures taken in preindustrial times do not provide the necessary protection from the climate today. As the climate analysis states, the human-made climate change of the near future will be overpowered by variations in the natural microclimate. But we are already struggling. Implementing proven solutions tailored to the area is a good place to start.

The Netherlands Commission for UNESCO (2021b) states in: Statement on culture-based solutions to climate adaptation.

> *“When climate adaptation is built on local traditions and customs it provides agency for community groups to be in the driver’s seat of change, and as such, it helps to democratize climate action. Moreover, building on the identity of a community is a necessary ingredient for the acceptance of climate policy measures, and therefore their successful implementation. Taking a multidisciplinary approach and bringing culture and heritage into mainstream climate policymaking will enhance public support for such policies.”*

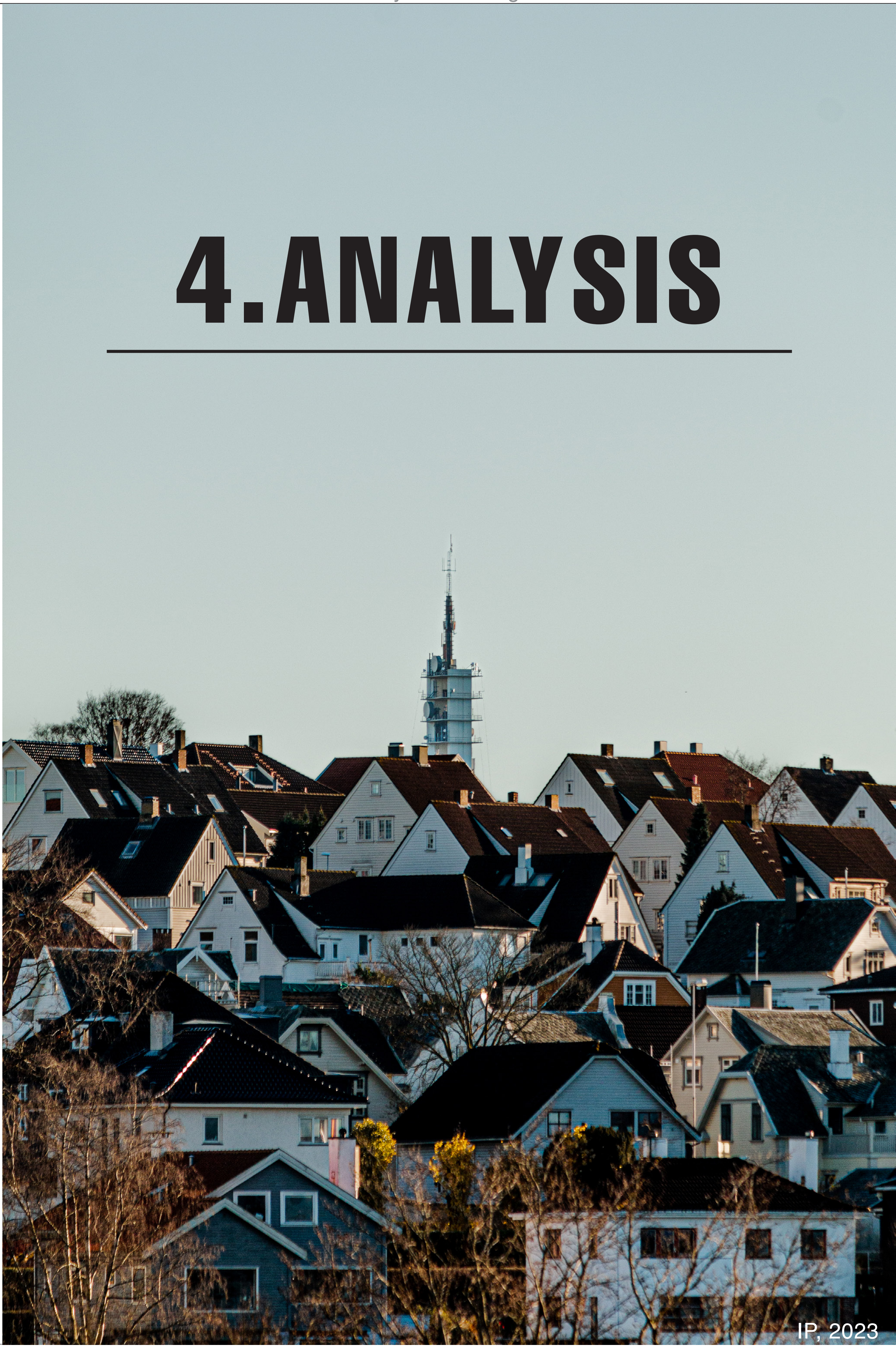
The importance of allowing the inhabitants to join in the planning, use, and maintenance of measures will increase the acceptance of the implementation especially in a protected environment, where sometimes it feels like the homeowner is not able to change anything outside its own walls.

What counts towards the engagement of CBS is apparently not the historical element of a cultural measure, but the human connection to the solution.

“Climate adaptation should be viewed as a human process, taking place in a cultural context, requiring a change of mind”
- Netherlands Commission for UNESCO, 2021a, p. 6).

Fig. 42. Straen. (IP, 2023)

4. ANALYSIS


IP, 2023

4.1 HYDROLOGICAL ANALYSIS

The basins in connection to Straen cover an area of 14,42 ha. This includes Straen, parts of the area known as “Vestre Platå” It encompasses mainly singular housing in a block structure. Nearly all of the houses are a part of the heritage zone of Trehusbyen. The heritage and possibilities for development will be explored in the next chapter. This chapter will explore the topography’s effect on rainwater.

Infiltration potential:

The infiltration of the area is dependent on some different factors, 1. Geology and sediments. 2. Permeability of the groundcover. 3. Water density in the upper soil layers.

Infiltration is the water’s ability to penetrate the ground cover and join with groundwater. Areas with high groundwater can infiltrate less water before its saturated. With a higher water saturation, the infiltration reaches a sturdy flow called hydraulic conductivity (Solheim, 2017, p. 10). This is the speed normally used for measuring the infiltration speed of the groundcover.

Fig. 43. Cut-out of the map basis used for the calculations of area. FKB Arealbruk AR5 & Fkb Byggninger (Geovekst, 2023).

Groundcover

Permeability is the water’s ability to penetrate the groundcover. A higher percent of impermeable areas Leads to more runoff.

Map analysis shows that 25,9% of the basin is Roads, 32,8% is Houses 11,9% is parks, and 29,4% is unmapped (fig. 43).

The unmapped areas are mostly consisting of private backyards, driveways, parking spaces, out housing, small public green spaces, and flowerbeds. The permeability and covers of these uses vary greatly.

The road cover is mostly asphalt. In some select streets, there are different kinds of cut cobblestone. In Straen there is mostly traditional cobblestone. Cobblestone is normally considered a permeable groundcover, but this can vary greatly, depending on the distance between each stone, and the infill sediment. In Straen the infill sediment is often of a so fine grit that the water cannot penetrate it easily (fig. 44). The cobblestone does however increase the roughness of the groundcover and retains water in micro variations.

Houses are considered fully impermeable (as they should be).

Fig. 44. From left to right the transition between permeable cobblestone with dirt and sand filling to impermeable cobblestone using a cement mix. Trying to protect the foundation of a heritage building from water damage in Straen. The supporting mass of the cobblestone is however scrubbed away from eroding water under the stones and the pavement is falling apart, feeding water under the protective measure (IP, 2023)

Geology and groundwater

The infiltration potential in Stavanger centrum is not classified (fig. 47) and must be further inquired before any proper calculations of infiltration can be done. From the measurements (fig. 45) in the nearby area the depth seems to vary between 7- and 1-meter depth. Water measurements after boring show for the points in Lendelunden the depth from the ground to the water is 4 meters leaving 1 meter of groundwater on top of the rock layer. From the point under Rudlå, the depth of the soil is 4 meters. The groundwater start-

Fig. 45. Map from NGU showing boring wells and samples. Numbers represent depth to bedrock. In the bottom of Vågen the soil layer is deep, but in the area, it appears to be between 1 and 7m (NGU, n.d.).

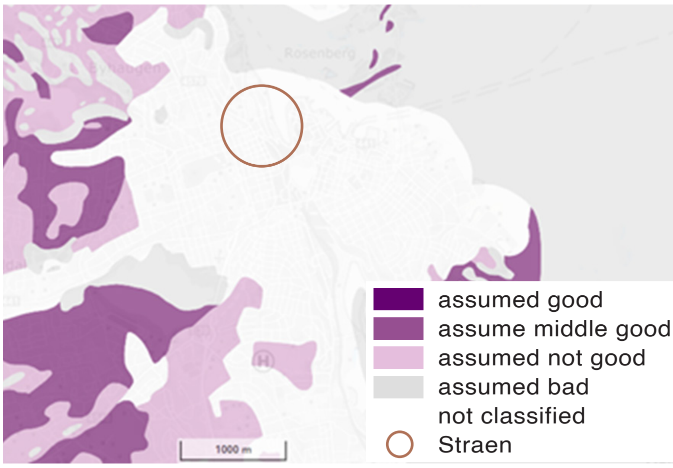


Fig. 47. Map with assumed infiltration estimated from Sediment composition (GeoNorge, n.d.)

ed at a depth of 6 meters underground. The measurements indicate that the groundwater has a nonuniform depth. Infiltration in areas where the soil layer is thin may not be effective without interventions. But in areas with a thicker sediment layer, the soil should be suitable for infiltration. Areas close to the bedrock should also be investigated for groundwater depth, so the infiltration does not increase the groundwater to such a degree it could lead to damage to underground parts of the housing.

Sediment tests taken from Norsk Grafisk Museum (IDDIS) indicate that the sediments are of a grit that should be capable of infiltrating water. The sediments are a combination of gravel (39,5%), sand (28,7%), silt and clay (19,4%) (Fürst, 2017). The composition is mixed and can be interpreted as satisfactory for infiltration. Urban soil however normally has a lower conductivity than natural soil (Solheim, 2017, p. 9).

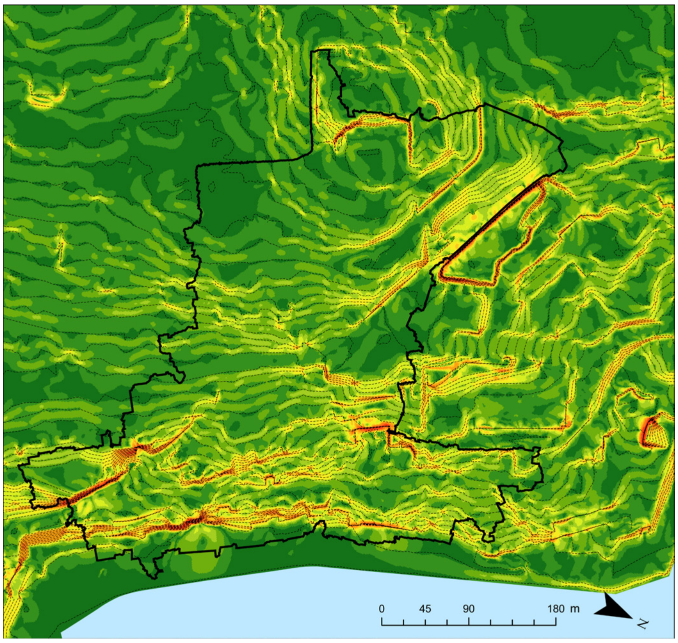


Fig. 46. The area gets steeper towards the fjord Sloping of the Catchment area shows that the bottom part is much steeper than the top part, although the area is sloping all the way. Slope map made from FKB contour lines (Geovekst, 2023).

The area has a subtle slipe towards the fjord in the upper parts and gets steeper closer to the fjord (fig. 46). The steepness increases the runoff Speed and reduces infiltration ability. The area has a total height difference of ca 50m. The lowest point is at 1.8m (by the docks), and the highest is at 52m (in Rudlå Parken).

There is however a problem with water preasure form the groundwater in Gamle Stavanger (Stavanger Kommune, 2021, p.10).

Hanne Windsholdt, the City antiquary wrights in an email:

> “The buildings are directly situated on the rock, and it is not uncommon for people to have running, or at least trickling, water through their basements. There are examples of both interior and exterior “channels” carved into the rock, intended to divert water around the house or along the wall inside the basement.”
> - (Personal communication, Hanne Windsholdt 3. February 2023).

This means that even though the infiltration in the soil is good, the water can still damage the buildings. The problem is just moved from above ground to underground. This is not the case for every building. And the problems infiltration can create should be assessed for every measure.

Summary

We can see that a lot of the area is covered in impermeable materials: roads, and housing. together making up 58,7% of the total basin. With another 29,4% of the area unmapped. This can lead to great challenges with natural infiltration. Measures must be taken to improve the amount of water the area can infiltrate. The soil layer is adequate for infiltration; however, the natural infiltration speed of individual areas is hard to say anything about without testing. The placement of infiltration measures must also be assessed for potential damage to the building laying further down in the terrain.


IP, 2023

4.2 STRAEN
Historical Analysis

The aim of this analysis is to uncover values in the area to understand how these can affect the choices related to stormwater management solutions.

This analysis is mainly based on two documents, one is the municipal sub-plan for cultural heritage in Stavanger 2010 (Stavanger Kommune, 2010) the other is Outdoor areas at Straen (Uteområdene på Straen). This plan has been prepared by Stavanger Municipality and is referred to as an action plan (Stavanger Kommune, 2021). The analysis also relies on visual, inspection of the material heritage.

Fig. 48. Detailed drawing of Straen by Einar Hedén, unknown year. From (Stavanger Kommune, 2021, p. 25)

The plots on Straen originally belonged to the church but were attached to townspeople from the late (Kulturminnesøk, n.d.). Straen was developed as a housing estate during a rapid population growth in the 16-1700s, largely due to herring fishing (Source). Most of the houses here have since been rebuilt, burned down or demolished. (Kulturminnesøk, n.d.) Most of the buildings of today can be traced back to the early 1800s. Some houses here are fully protected and many are protected.

Fig. 49. Haugvalds Gate towards Lendeparken (IP, 2023)

Straen has a distinctive character that for a long time has been dynamic and adapted to the times. The pattern of change is based on the fact that the area is closely connected to the harbour and the workers and has over time followed the fluctuations in the economy around fishing, sailing, canning, and oil. And even though Straen itself is protected, there is leeway to put your own stamp on street life (fig.xx).

> “From an antiquarian perspective, it can be difficult to decide exactly what should be protected or regulated, since the area’s character has emerged over the course of several hundred years and is probably still changing. Part of the charm, according to city antiquarian Hanne Windsholt, is that the area is not perfect or the same everywhere. For example, it is not relevant to micromanage what type of plants or pots are used.”
>
> - Conversation with city antiquarian Hane Windsholt, referenced in “Outdoor areas on Straen” (Stavanger Kommune, 2021).

In the 1940s, a zoning plan for Stavanger was politically adopted. The plan facilitated the redevelopment of large parts of the area. This led to a countermovement led by Einar Hedèn that had Straen gradually protected, first with 33 buildings in 1956. At the end of 1974, 150 houses were protected (Stavanger Kommune, 2021, p. 25).

Fig. 50. The inhabitants are effective, filling pots and pans with flower when spring comes (IP, 2023).

Fig. 51. A private backyard gives a cosy impression (IP, 2023).

Topography and morphology in a historical context

The area is located on the western side of the inner bay (Vågen) of Stavanger. The main roads and street network on Straen have been fixed since the 1600-1700s and probably longer. They grew organically along with the housing development. The area is sloping from west to east. The main roads make a network of horizontal paths, from north to south. The vertical roads are running down the hills. There are some smaller pathways (Smau) in between the roads, especially the vertical ones. Øvre Strandgate is the main artery between north and south, while Andasmauet cuts Straen in the middle.

Straen is laid in 3 elevation layers separated by the roads. In the first, and lowest layer, between Nedre- and Øvre Strandgate, most buildings are in the north end. In the second elevation layer, between Øvre Strandgate and Haugvaldsgate, the building mass is concentrated in the southern part. The third elevation layer only includes the two blocks in the southern part, between Haugvaldsgate and Tanke Svilands gate.

Horisontal
1. Løkkeveien
2. Haugvaldstads gate
3. Borgermester Middelthorns gate
4. Lars Hertersvigs gate
5. Øvre Strandgate
6. Mellomstraen
7. Litlegata
8. Nedre Strandgate
9. Strandkaien

Vertical
I. Tildegeilen
II. Sømmesmauet
III. Brønngata
IV. Andasmauet
V. Klausegata
VI. Bergsmauet
VII. Blidensolstredet
VIII. Rosenbergbakken

Fig. 52. The names of roads in Straen (top to bottom, left to right). Most of the roads in Straen are slim, and cobbled (IP, 2023).

Asphalt
Cobblestone
Straen

Roads

The wide main streets are probably from the Middle Ages, but the finer street network and streets like MellomStraen probably came with the major development in the 16-1700s. At first, the roads were probably made of dirt, but later became cobblestones with curb stone, the qualities of the time are evident by e.g., horse steps up the steepest hills. Where the roads traverse the terrain, there are 10 cm high curbs on each side of the street. in the vertical streets, the cobblestone stops right in the house wall or foundation. In some places where the streets become wider, the road retains its path while opening up a sidewalk, often with natural slate slabs. Natural slate slabs are also common in the smaller streets, where either the ground is so shallow that it goes straight onto the rock or where there are difficult micro topographical changes.

In Nedre Strandgate there is asphalt pavement on the road.

The three roads leading down Haugvaldstads gate have asphalt coating.

Fig. 55. Horse steps in the cobblestone to help horses with iron shoes walking in the steep streets. An iron railing helps the visitors of today (IP, 2023)

Fig. 53. The paving changes from cobblestone to cut nature slabs in the smug leading to the cherry orchard (IP, 2023).

Fig. 54. The cobblestone pavement stops directly in the wall, the closest part is often made with concrete in between the stones, The hole in the stair is to ease the passing of the water so there won't be any built up on the upper side of the stair (IP, 2023).

Objects and elements

As a part of analysing the (historical) values, we could ask "What traits does each element/ value have about them, what elements can be changed and what can be utilized?" In the following part, we will examine the public parks, then the buildings and roads.

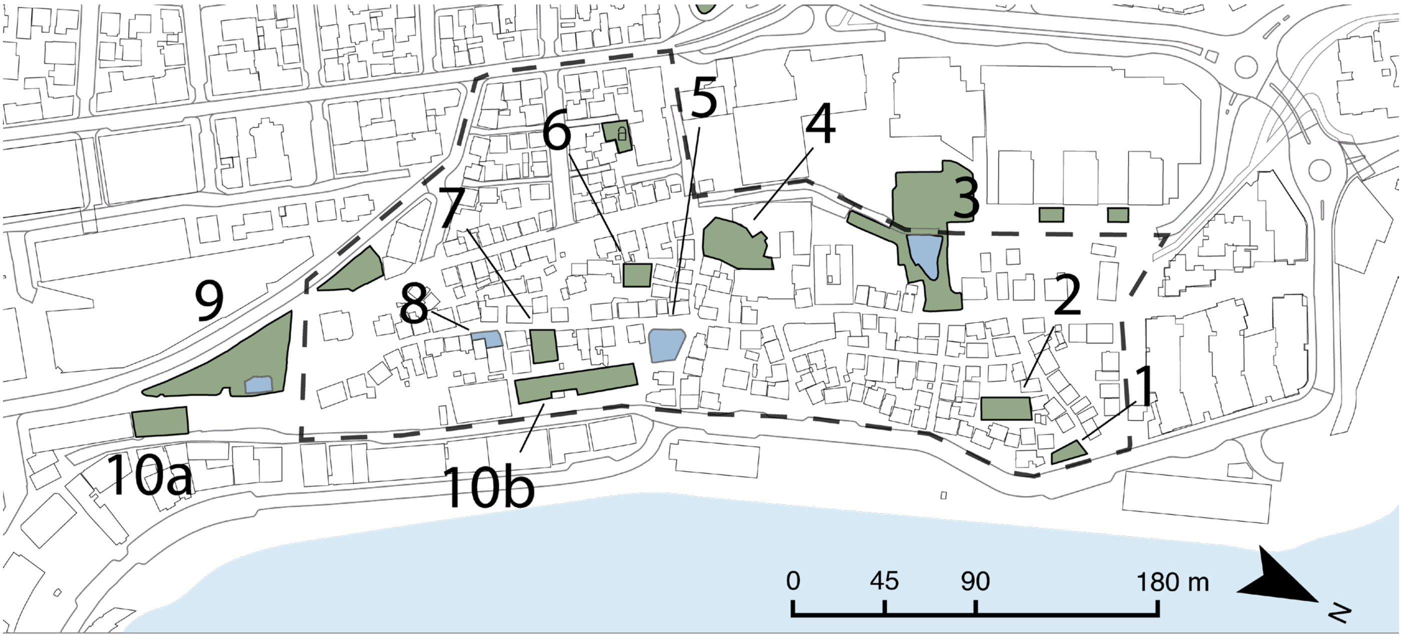
Public parks

In the Straen area there are 9 public parks and outdoor spaces that are important for the cityscape, these are more or less open to the public and are of varying sizes and functions. The parks have come about both intentionally and randomly. Some small parks have arisen in the absence of houses after a fire or similar incidents (Stavanger Kommune, 2021, p. 19)

The parks serve as gathering points for residents, and as places to stay for visitors. The small parks (labelled from 1 to 9) are scattered around in the area, seemingly without a deliberate plan. In the perspective of handling rainwater, their location might be of great importance.

Fig. 56. Down Andasmauet (IP, 2023).

Fig. 57. The parks of Straen are small and scattered (IP, 2023).



1 THERE HORVE’S PLASS

This square is a small urban space adjacent to Nedre Strandgate. A statue and a couple of cannons and two benches inhabits the area. The pavement consists of cobblestones, there are grass slopes down towards Nedre Strandgate. The space is lined with hedges and shrubs. Facing the road there is a natural wall with a cast iron fence. Just outside is a bus stop.

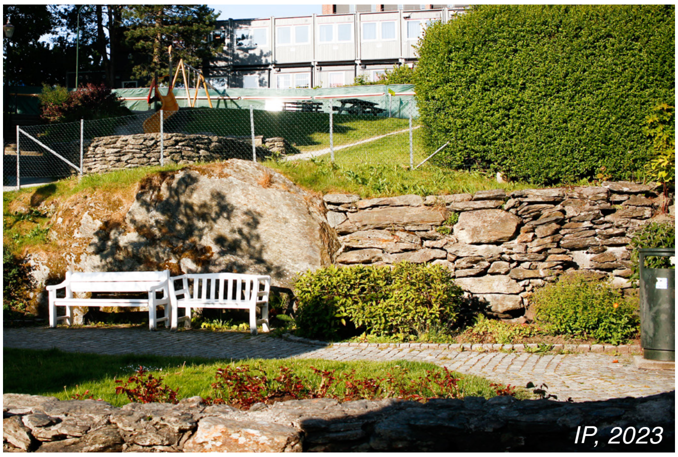
2 RODAL’S PLASS

Neighbourhood Park, located between Litlegata and a row of houses. It is grass-covered, edged with beds at the south end. Some benches and a seating area with tables of stone are placed in the area. Good sun conditions.

IP, 2023

3 LEKEPARKEN

Terraced Park on three to four levels and crosses a road. The terraces are made of rock with natural masonry. Consists of lawn, paths and play elements. Today, the upper part of the park is filled with building rigs and construction barracks.



IP, 2023

4 NORWEGIAN PRINTING MUSEUM

The outdoor area of the IDDIS museum. Designed with a universal design to the museum area, open perennial beds with drainage from the path to the beds, large open courtyard with modern paving stones.

5 EINAR HEDÉNS PLASS

Open space between residential houses. It has a good view and a cherry tree in the centre of the square with accompanying planting. The surface is of gravel and is edged with a flower bed. Small playground in the corner.

6 THE CHERRY ORCHARD

Small park in-between buildings. It has a very private feeling. The area appears neglected, but this may change over the season. The orchard consists of some small trees, a lawn, and some bedrock protruding from the ground.

7 Eplehagen

Lawn and slate slabs, benches and picnic tables. A couple of apple trees and two flower beds.

8 LITLATORJÅ

Small open space with carved stone, groundcover is natural slate. It is located outside a pottery workshop, that used to be a coffee shop. Small planting beds.

9 LENDEPARKEN

The largest park in the area, with a “proper” park design. It consists of walkways in a grassy landscape with some beds. Sculptures are scattered around the park and an information sign is located in the middle of the park. Some benches are placed out in the area. The park borders Lars Hertervigs gate to the west and protected terraced gardens to the east.

10a THE TERRACED GARDENS SOUTH

The terraces may appear as the lower part of Lendeparken, these were built between 1600 and 1700 and are protected (Stavanger Kommune, 2010, p. 123). The terraces were originally private merchant gardens, and the area was full of them. There are unfortunately only two left today because of the demolition in the mid-1900 (Stavanger Kommune, 2021) p.26. These are landscaped gardens with nature masonry, and rock ivy growing in the wall. Principal sketches from C.W. Schnitler made in 1916 (fig. 58) depict how the terraced gardens in the area could have looked like (Stavanger Kommune, 2021) p.27. There are steep slab stone stairs leading down to Nedre Strandgate. Here there is a protected well called Groombrønnen from ca. 1800 around a spring that has been used since the Middle Ages (Stavanger Kommune, 2010, p. 134). Between the terraces, there are wide walkways with cobblestones.

10b THE TERRACED GARDENS NORTH

North of Sømmesmauet there is another set of terraced gardens. These are derelict and overgrown, but also protected. It's possible to walk through the terraced gardens, but some stone stairs are missing.

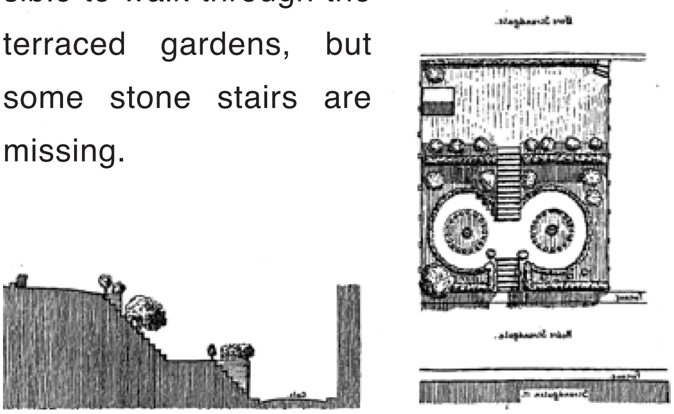


Fig. 58. The terraced gardens of Stavanger end of 1800, by C.W. Schnitler.

The buildings

Most of the buildings in Straen are from the period between the 1750s to the early 1900s (fig. 61) (Stavanger Kommune, 2021, p. 12). Some have elements of buildings that may have stood in the same place all the way back to 1600. Such traits can be identified by traces in the foundations or reuse of materials. The area at large is protected, but not every house is faithful to how they were when they were built. Some have received, either before or after the conservation plan, a minor facelift (Skogland et al., 2016, pp. 88-91). It is notable that more or less all the houses today are white, this is probably not historically accurate, but changes have occurred in recent times (Stavanger Kommune, 2021, p. 12). It is likely that the colour style of Øvre Strandgate 60 with ochre yellow and red is to be more historically accurate than white. The colours often relied on what kind of paint the sailors found and brought with them from other ports around the world. After white became cheaper around 1850, it became a common colour (fig. 59).

Fig. 59. Three Phots of the same Building row in Nedre Strandgate From top to bottom the pictures were taken in 1965 (photo by: Jacob Kvæstad), between 1970-80 (Photographer unknown, from Stavanger byarkiv), and 2023 (photo by IP). The buildings change colour between every photo. The blue building is the only one whose window-panes has not been changed between 1965 and 2023. The sidewalk has been upgraded form a rough dirt path to a cobblestone walkway.

There are two building styles that are particularly prominent, this is the Empire style and the Louis Seize style. Of these two, the Louis Seize style is least spread out in Straen. Øvre Strandgate 90 is a good example of this style. The Empire style is the most widespread style (fig. 60), both in Straen and in most of the wooden houses near Stavanger city centre (Stavanger Kommune, 2010, p. 49).

Many of the buildings are protected under the Planning and Building Act of 1985/2008. and most are SEFRAK registered. This means that they are from before 1900, and most of these again are from before 1850, which means that an assessment of the protection value must be made before any application for demolition or alteration can be approved (Riksantikvaren, 2020).

Most houses are made of wood except for a few. Like Øvre Strandgate 79; Art Nouveau style (the building was extended in 1914), Øvre Strandgate 35, 1876, and Øvre Strandgate 51, 1918.

Fig. 60. Andasmauet 5 in 1989. Empire style. (Foto: Stavanger Byarkiv, Byantikvaren)

Roofs

The roof cladding in the district of Straen appears as traditional single-curved roof tiles of varying quality and age. The single-curved clay tiles were common roofing in the 1700s and 1800s and are still very normal. There are also examples of Falsett bricks that were common from the late 1800s to the 1900s. For the roof shapes, it is mainly pitched roofs that are prominent, but also poppy roofs and semi-pitched roofs. On the newly built part of Hermetikk Museet, there is a flat sedum roof.

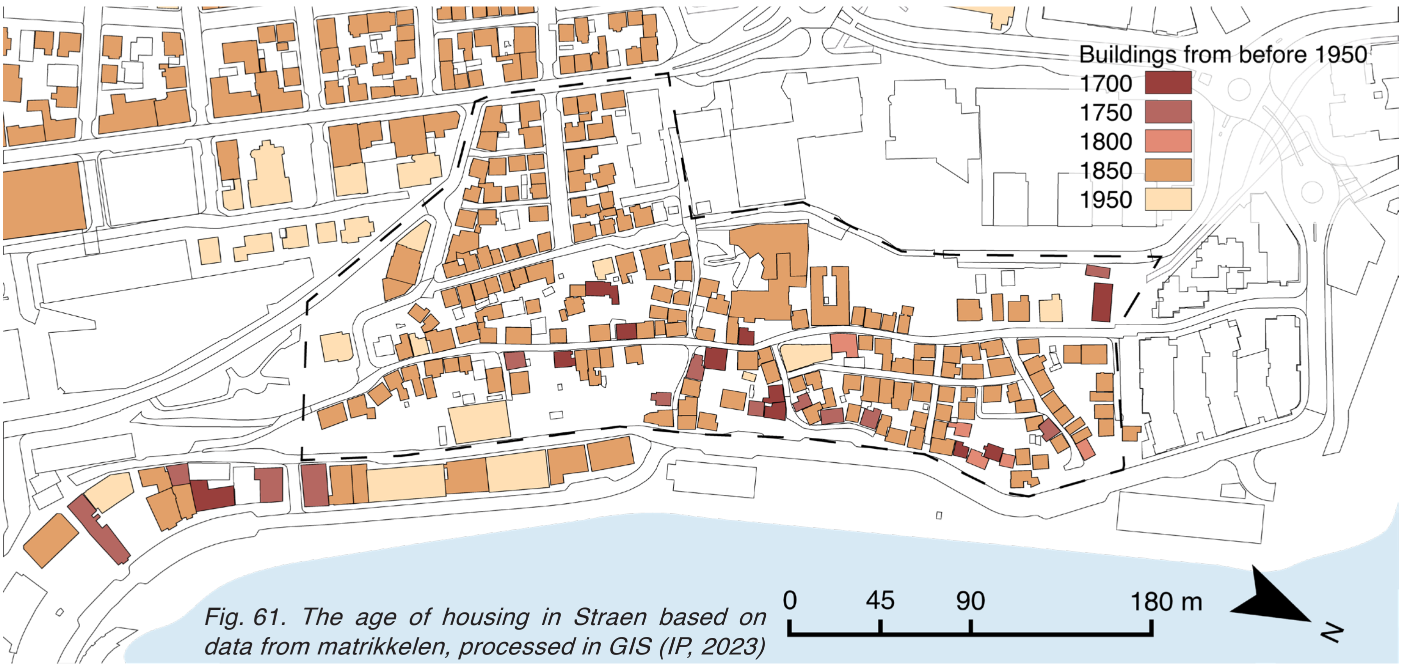


Fig. 61. The age of housing in Straen based on data from matrikkelen, processed in GIS (IP, 2023)

Historical and new water measures

> "There has always flowed a lot of water down Andasmauet, it is confirmed by multiple sources"
> (Stavanger Kommune, 2021, p,28)

From site visits, a lot of small interventions done by the inhabitants to defend their houses from water have become evident.

Disconnection of downspouts releases pressure from the VA system.

Small stone slabs put against openings between buildings or windows prevent water from flowing in.

Holes in the stairs allow for free water paths.

Small interventions in the cobblestone cover lead water towards the drains. Some drains are however not optimal.

Underneath is an example of housing given little care. Even though the house is derelict, it's prominent where the downspout has directed the water and water spray.

How To Protect Straen

Going back to “How to Protect Heritage”, we can see that Straen is an area protected by the engagement of the public. This has given a special connection between Straen and its inhabitants.

> “In a study presented in book form in 1977, it was concluded that the rehabilitation of Old Stavanger – as the only example the authors had found – had succeeded in combining antiquarian interests with the desire of the residents to improve their housing conditions.”
>
> \- Johanne Sognnæs (2015, p. 186) (translated from Norwegian)

We see that Straen is a cultural heritage that works in close cooperation with the inhabitants. Creating “Dugnadsånd” and Protection through allowing practical use of the area. Inviting the same groups, to protect Straen from the changes the climate provides may be necessary for a good for all intervention.

But the way Straen is protected may also have created a wedge between the area, and the general population of Stavanger.

> “Today, this beauty is perceived as problematic in the area. Some may experience it as nostalgic, gentrified, “museum-like,” and overly embellished, and therefore distance themselves from it.”
>
> \- Johanne Sognnæs (2015, p. 185-186) (translated from Norwegian)

Fig. 62. Cruise ship at the end of Litlegata (IP, 2023).

Tourism

One group that especially gets value for the Nostalgic Gentrified and Museum-like Straen, is the Cruise ship tourists. Throughout summer, cruise ships lay docked to Strandkaien, just below Straen (fig. 62,63). A constant wave of Guided tours is flowing through the area. Excessive use by tourists can lead to excessive wear and tear (Stavanger Kommune, 2021, pp.23,25).

Fig. 63. P&O Cruises fully blocking the morning sun in Roldals plassen (ca.08:00) (IP, 2023).

Summary

From the analysis, we can see that the values in the area mainly centre around the protection of wooden houses in the wooden house city, but the actual conservation value we appreciate today may have been neglected. Although this area has great historical values, the area's focus appears to lean more towards the aesthetic and economic values, as white painted, cosy district, for dwelling and for tourism, especially the cruise line traffic.

Because the area appears aesthetic and has attractive visitor activities such as museums and parks, the area's economic value increases by attracting visitors, especially because it looks good in travel brochures. This brings with it greater economic gains, also in the area's proximity.

The historical aspects of Straen are already to a degree adjusted to the water. Evidently, there has been flowing a lot of water in the area for a long time; visible in measures taken, and from sources.

4.3 HISTORICAL SOLUTIONS FOR STORMWATER MANAGEMENT

This chapter explores the historical growth of solutions for water management in Stavanger, and the dimensioning, and functionality of the stormwater system as they are today.

From the start of the industrial era, we have built and shaped the terrain around us to improve habitability, the natural paths of water have been altered, and stormwater has, along with wastewater, run in the streets and gutters. Odour, health problems, and discomfort have led to the need to control the paths of water, from households and businesses. This is reflected in, among other things, public regulations, also from the city of Stavanger:

> «I alle Gader skal der for Kommunens Regning, efterhaanden som de fornødne Midler dertil bevilges, saavidt mulig paa begge Sider av Gaden, anlægges Rendestene, ligesom paa hensiktsmæssige Steder større dels aabne, dels lukkede Render (Kloaker) til bortledning af Grund- og Overvand, samt Skylle- og Spildevand.»
>
> - Sundhetsforskriftene (healthregulations) of 1865 sited in Gjerde (2015, p. 26).

Here we see how the transition from handling all water on the surface is first systematized into gutters, and further collected in both open and closed systems. After the supply of water was improved by waterworks and direct supplies to private houses, water management also became more important. In Stavanger, domestic water was for the first time discharged directly into public sewer pipes in 1869 (Byhistorisk forening Stavanger, n.d.). The development of water and sewage took place quite unsystematically but in parallel (Gjerde, 2015, p. 27). The pipelines were constantly being improved. After the WC was introduced in Stavanger in the early 1900s, the need for water management and purification increased (Gjerde, 2015, p. 29). But it was not before 1989 the construction of the chemical sewage (or wastewater) treatment plant for Stavanger and the surrounding area started (Gjerde, 2015, p. 82).

Wastewater and stormwater are in the same pipes.

After the pipe network for wastewater and sewage came into use, stormwater was also connected. This works out well until it doesn't work anymore. Something that at times has led to big problems. Since the piping cannot adapt to large volumes of water, the water will find other paths towards the sea. The amount of water sitting in downspouts and higher up in the system can put pressure on pipes that are not designed for it and cause setbacks in drains and toilets and send water from manhole covers and storm drains into the streets. This can lead to large volumes of water in places that are not designed to handle it, such as houses, garages, and basements, and even sewage going astray.

Fig. 64. The construction of sewage pipe down Andasmauet in 1987 (Foto: U.B. Stavanger Byarkiv)

The condition of the sewage

It is not easy to find good articles or sources on the state of the local sewage system in Stavanger (fig. 64). The municipalities often have a lack of overview of what lies in the ground, as the instalment appears to have been poorly documented. However, there have been some reports of poor maintenance and late replacement of water pipes and sewer pipes, in Norway in general, and also for Stavanger (Søndeland, 2013). It is pointed out that much of the pipeline system has not been replaced since it was laid 50 years ago . And with the rate of replacement going at about 1% annually it will take a long time before all old pipes are replaced, it can take up to 100 years (Nedrebø, 2008; Stavanger Kommune, 2019c, p. 45). Poorly maintained pipes can reduce the effective runoff on drains. Corrosion on wastewater pipes can also lead to contaminated ground, which together with corrosion in the water mains can lead to contaminated drinking water in some cases. Wear and corrosion on water pipes can also lead to premature water saturation of the ground, which can lead to low filtration during heavy downpours.

Lack of treatment and maintenance can also lead to a reduction in the effective dimensions of wastewater and stormwater pipes. These carry with them diversified substances that can get stuck and build up over time. Without effective unclogging, pipes can in the worst case become totally blocked.

Dimensioning and the future.

From Stavanger municipalities water plan from 2019 (Stavanger Kommune, 2019c, p. 56) is the AF system mostly capable of taking runoff at 140 litres per second per hectare (l/s*h) over a 10-minute period; where else is not clarified (Stavanger Kommune, 2019b) This corresponds to, urbanized, steep, or water-saturated areas approximating 6.5mm of precipitation in 10 min. In areas with more permeable ground material, this corresponds to approx. 13mm per 10 minutes, which according to the IVF values corresponds to a repeat interval of 2 to 5 years after today's rain intensity and, corresponds to less than a 2-year repeat interval with climate impact (Meteorologisk institutt, 2023). In the new master plan for water in Stavanger, it is proposed that the 140-litre target should be increased to 200 l/s*ha (Stavanger Kommune, 2019c, p. 56). This corresponds to heavy rain with a five-year return interval (climate impact included).

The water arriving at the treatment plant consists of the desired water, i.e., wastewater from households and other planned discharges. In addition, there are unwanted discharges from stormwater and other sources (Stavanger Kommune, 2019c). The distribution of different water sources is shown in the illustration. Approximately half of the unwanted water arriving at treatment plants is from sources other than surface water (Stavanger Kommune, 2019c, p. 44).

In the flowchart for water distribution (fig. 65) (Stavanger Kommune, 2019c), we can see the volumes of water used and cleaned, and overflown. It's clear that Stavanger wants a reduction in unwanted water in the water network. The chart shows a goal of 30% reduction in stormwater between 2019 and 2030.

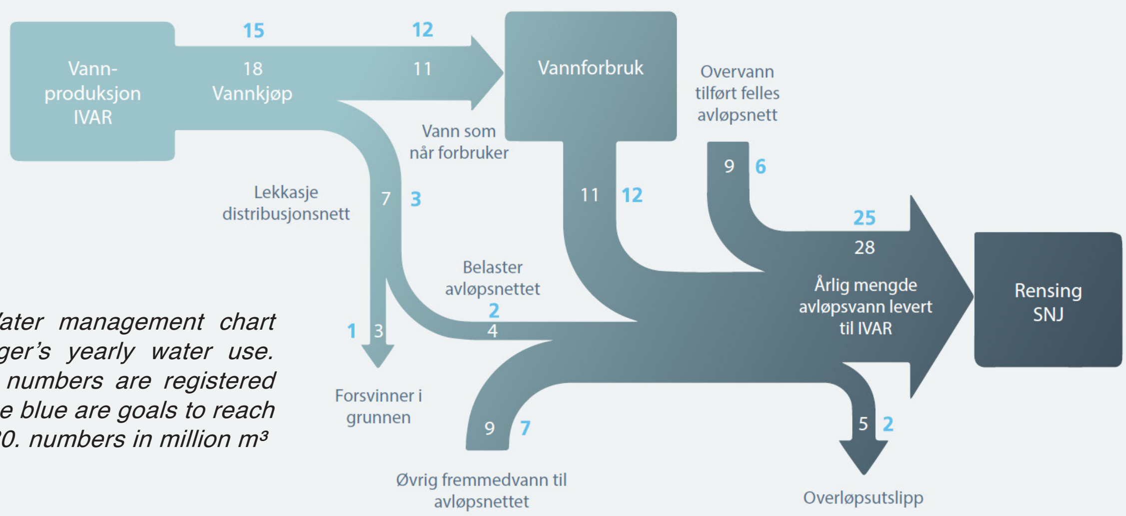


Fig. 65. Water management chart of Stavanger's yearly water use. The white numbers are registered amount, the blue are goals to reach before 2030. numbers in million m³

Summary

As shown in thsi chapter the water management of Stavanger is organically grown out of necessity due to health hazards and the growth of the city. When the spill water got managed the stormwater followed. A lot of the first laid pipes in the 1960-80's are still operational but are not of a dimension capable of handling the stormwater amount of the predictable future. Therefore, Stavanger municipality aims to both reduce the water intake on its pipelines and upgrade the capacity.

Regulations

There are several plans in and near Straen (red outline in fig.66). These will presumably change water handling and the runoff in the area. A big project at Tanke Svilands gate will probably be able to capture runoff from the road. At the top of Andasmauet (fig. 67), there is a big project regulated to living and business premises, it has a lot of outside green space regulated and is proposed with green roofs. In Nedre Strandgate, there are two buildings regulated for mixed-use. One of these will be taking up half of the area "Terrasser north".

New projects generate a lot of possibilities for water handling.

Fig. 67. New Blocks at the side of Andasmauet, just above IDDIS museum. The use of green roofs can indicate a strong focus on water handling (Illustration: Bykronen.no, 17.04.2023).

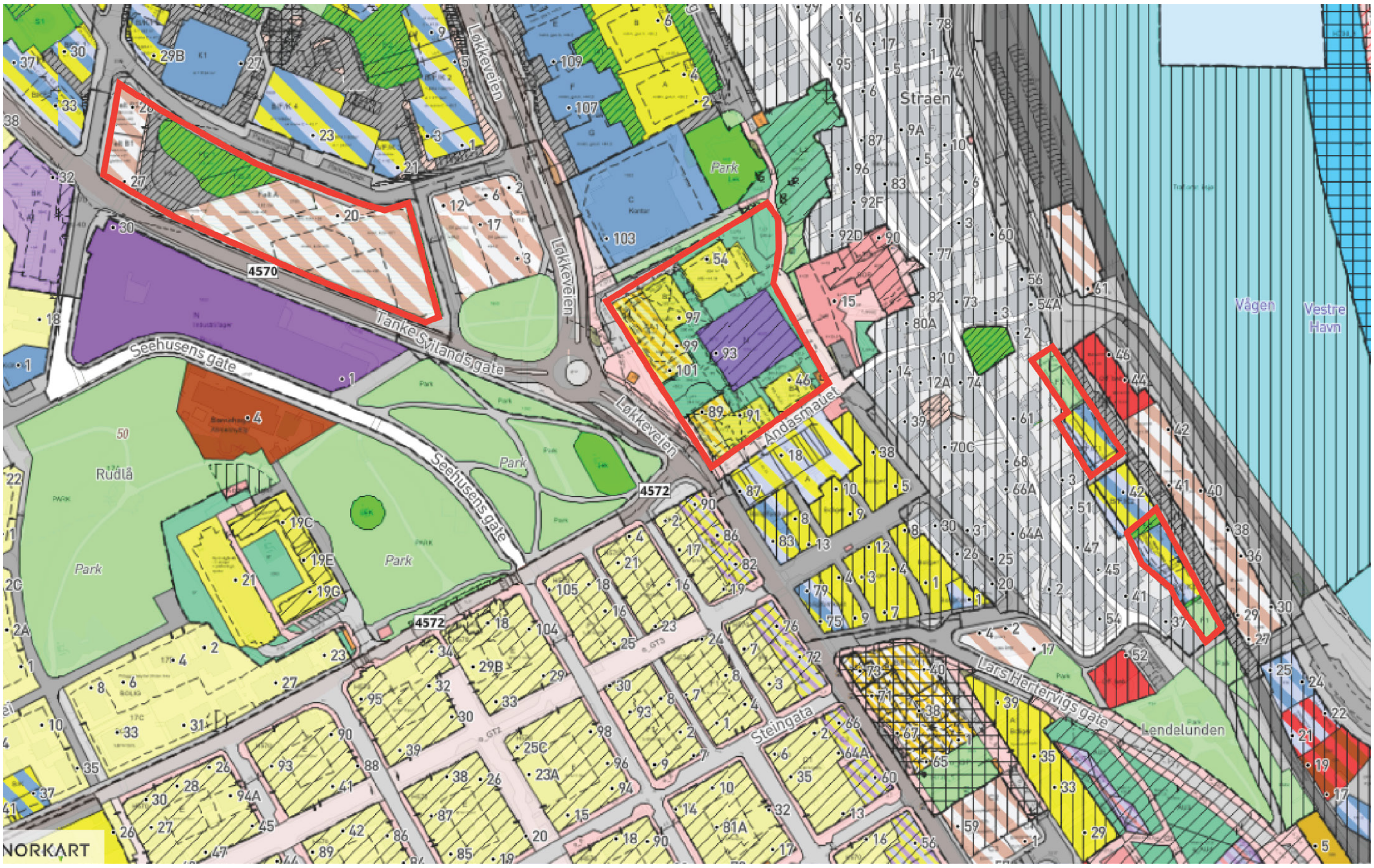


Fig. 66. Regulation plan for Stavanger. The new building areas are outlined in red (Nordkart.no, 17.04.2023).

4.4 ANALYSIS SUMMARY

For analysing the situation for water handling, the findings in the analysis can be evaluated in a SWOT- analysis. A SWOT-analysis is feasible for identifying both internal and external factors that can affect to which extent the area can handle excessive amounts of rainwater on the surface, rather than in the ground through grey solutions.

Strength	Weaknesses
• Straen is covered in cobblestone, making water travel slower and retaining more water than smoother surfaces. The cobblestone may also increase the infiltration of the water through the grout. • The waterways are obvious and open and thereby easy to detect through mapping and observation. The openness makes it easier to implement good measures for improvement.	• The terrain is at times steep. This can lead to potential damage to structures, and erosion and scrubbing underground. • Water running on the bedrock can lead to damage to buildings. • The area protection of cultural heritage limits which measures can be limited. • There are several places with protruding bedrock. This can be limiting for the implementation and placement of infiltration measures. • There is not a lot of Space to implement measures.
Opportunities	**Threats**
•The open spaces available make good opportunities for transformation to stormwater management measures. •The basins are big and can be split up into multiple small LSM areas. •The area protection can provide opportunities for measures that are historically more viable. •The ground cover of Straen can give precedence for the introduction of permeable groundcovers in streets further up in the catchment area. •New projects have a lot of opportunities to create good water measures.	• The V/A system is old, combined, and under-dimensioned. Potentially leading to sewage backflow in toilets and drains. • The rainwater basins make Andasmauet, Sømmesmauet, and Lendeparken especially woundable in a stormwater event. • Implementing measures can lead to unforeseen problems potentially damaging protected houses.

In the analysis, the problems with water have been uncovered. The ground seems capable of handling water infiltration, but how an increased infiltration will impact the building masses is unknown. Straen is split into three interest groups: Inhabitants, Protection & Tourism. Each gaining from the area in different ways. The VA is old and is not fit for the increasing precipitation.

4.5 THE WAY OF THE WATER

This chapter will explore the waterways of Straen and its rain catchment area. Runoff calculations, Dimensioning values, and precipitation data will be presented.

To analyse the water the goals and methods must be established.

There are two goals, protecting the buildings of Straen from excessive water flow through the streets, as seen in figure 1. And reduce the load of the water network, reducing overflows, backups, and pollution.

Both goals can be reached by implementing the three-step approach. The Three steps are to be limited as follows.

Step 1: **Highest 5% yearly**
Step 2: **20-year interval**
Step 3: **200-year interval**

To make a plan for the handling of water, the basins are divided into many small watersheds, these are then categorised by layout, and geographic extent, so that there can be made an individual plan for each area, based on a common understanding, and theme. One such group is Vestre Platå. These areas will be the basis of the local measures, and the aim is that no water from Step 2 escapes each area into the next one unless it's planed for. In extreeme events surpasing the 2. step its purposefull to have the water flow in the street, but this has to be done in a safe way, with designed flodways.

The three steps

1. Reduce runoff by infiltration.
2. Reduce runoff by retention.
3. Create safe floodways to recipient waterbody.

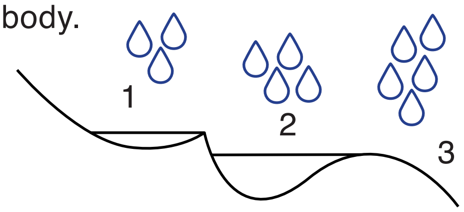


Fig. 68. Illustration of the three-step approach (IP, 2023)

Dimensioning Values

Intensity Duration Frequency (IVF)

As Stavanger municipality aims to be able to handle 200l/s (12,5mm) over 10 minutes (20-year event). The 20- year 10-minute IVF will be delimiting the second step (table 4).

Dimensioning water measures in step 2 to this value will effectively double the water management capacity of the Straen basin if needed.

Rain events do not come consistently over the course of the rain event, Its often releases a lot in a little time.

Calculations for dimensioning of Raingardens show that a 10-minute event causes more problems than a longer event as the water will not get infiltrated quickly enough. Because of this, and the requirements from the municipality, the dimensioning time length will be 10 minutes .

The IVF values used are from Våland (SN44640) (Meteorologisk institutt 2023), this is the weather station with IVF data closest to Straen (Appendix 2).

Climate factors

According to Meteorologisk institutt (2023), rain events lasting under an hour should have an added climate factor of 40% if it's more frequent than every 50 years and a factor of 50% if it's less frequent. For rains lasting longer than three hours, the factor should be 30%.

Table 4. IVF values for Våland (Meteorologisk institutt 2023) distrebuted in the three step approach.

Step	IVF	Dimentioning value	Value with climate factor	Value in l/s*ha
1	5% percentile	1 mm	1,4 mm 40%	23,3 l/s*ha
2	20 year	12,5 mm	17,5 mm 40%	291,6 l/s*ha
3	200 year	19,2 mm	26,88 mm 50%	480 l/s*ha

Creating the Basins

The terrain used for the analysis is a DSM map from 2014 collected from Høydedata.no. I have used this data to calculate catchment areas, runoff amounts, permability and pathways. The map has multiple shortcomings which to the best of my ability has been accounted for. Method for map analysis and discussion around the map can be found in Appendix 1.

Using ArcGIS the basin and streams are uncovered. A basin, and flow accumulation analysis (hydro analyst tools) can provide a simple analysis of the water paths and maximum area of a catchment basin (fig. 69).

From the analysis, the area consists of two main basins, one running down Sømmesmauet, and the other down Andasmauet. The basin where Lender is marked in the map should run down in Nedre strange, but the map data is old, and blocked by trees so it runs out of the map instead.

In the northern part of Straen, there are 3 small catchments collecting in Nedre Strandgate.

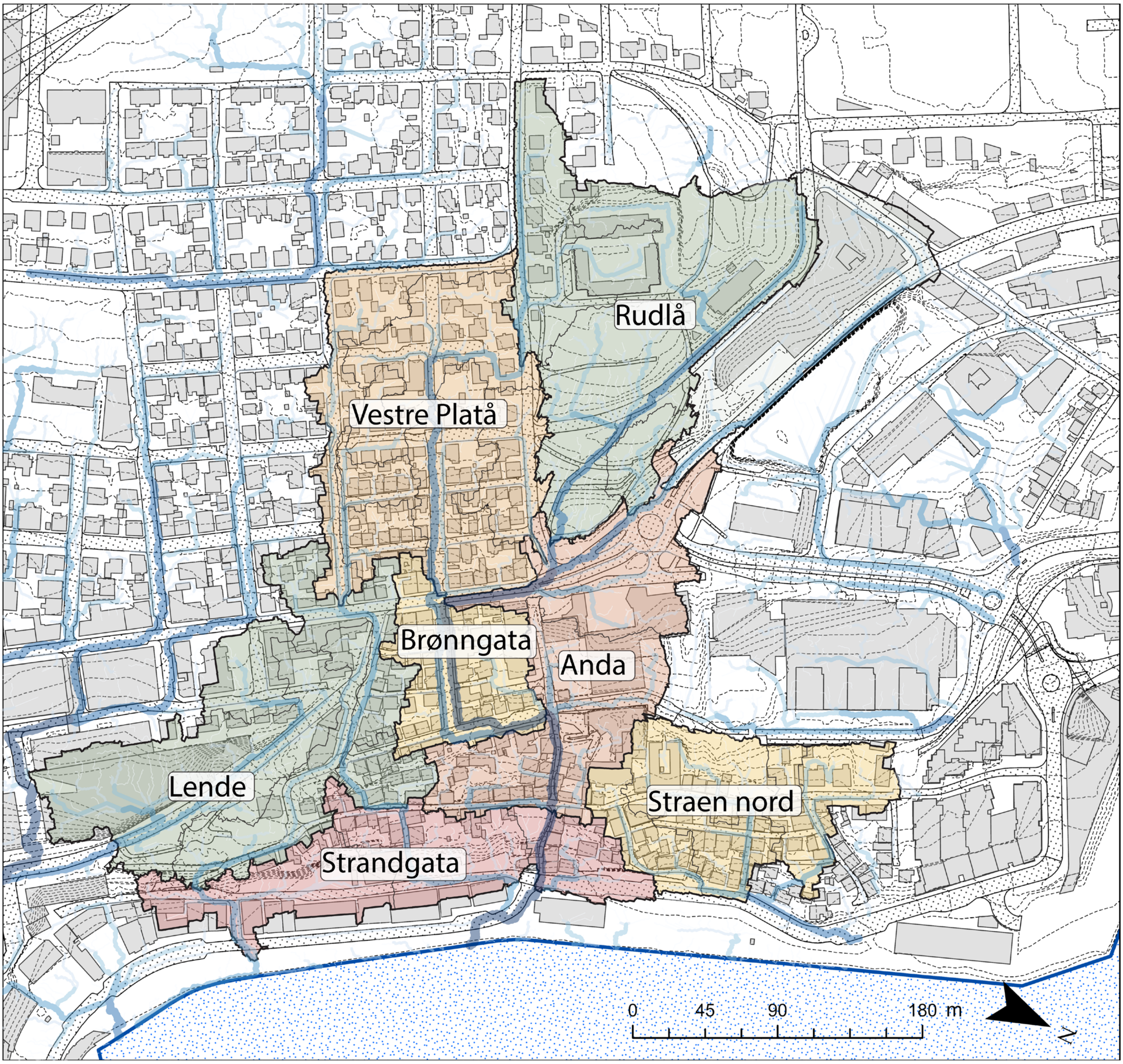
The water stream analysis gives a good indication of the water paths in the area, but these can be changed by water of high velocity, making it not an absolute path.

From the analysis map made in GIS, three main basins of Straen were discovered. As seen in the map (fig. 69), the stream that goes down Andasmauet has the biggest collection area.

The stream in the “Lende” watershed is interpolated to go down to Nedre Strandgate through Lendeparken. “Straen Nord” does not have a watershed outside of Straen but is a collection of three separate basins.

The runoff values of each area are calculated using FKB map data and multiplied with a climate coefficient. That means that you can use an IVF value of today multiplied by the Runoff coefficient (with safety and climate coefficient) and get the Runoff in the future as an output.

From table 5. you can see that the most permeable area is Rudlå. And the least permeable area is Vestre Platå. Even though these areas are of ca. the same size, the amount of water they “produce” during a rain event is very different.



Nr	Name	m²	Runoff (φ)	φ with safety and climate coefficient
1	Rudlå	27842,3	0,47	0,72
2	Vestre Platå	25618,8	0,79	1,22
3	Lende	26105,6	0,65	1,01
4	Anda	14508,8	0,73	1,13
5	Brønngata	7634,8	0,77	1,19
6	Strandgata	18363,5	0,66	1,02
7	Straen Nord	14261,1	0,71	1,1

Fig. 69. This map shows the seven watersheds made in the analysis. The proper district of Straen is marked with a red line based on GIS analysis (Appendix 1).
Table 5. Shows the asigned runoff values to each area, based on GIS analysis (Appendix 1).

The Basins

The three main basins dicovered in the GIS analysis were divided into 7 strategic watersheds. This is presented in fig. xx based the water streams, and the morphological characteristics of the neigbourhoods, of the individual areas uncovered in the analysis of Trehusbyen, and Straen.

1- Rudlå consists of a big park and some big buildings with different functions.
2- Vestre Platå consists of a “trehusby” composition of houses in a block structure consistent with spacious, and tight neighbourhood blocks.
3- Lende consists of a mixed structure with some parts of Straen, some parts of Trehusbyen, and a big mall (herbarium). All of which leads the water to Lendeparken.
4- Anda consists of a stretch of road, a new building project and the organic environment of the buildings making up the “immediate” watershed of Andasmauet.
5- Brønnagata consists of a tight neighbourhood block structure. This area is where the streams from Vestre Platå and Rudlå meet and go down into Anda.
6- Strandgata consists of a long stretch of road where all the water from Lende and Anda meets before entering Vågen.
7- Straen Nord consists of organic neighbourhoods found in Straen. This area has no overlying watershed.

Neighbourhood morphology

The different building morphologies found in the area

Fig. 70. Big Structures: *The buildings in basin 1. Rudlå are mostly big structures standing alone. (kart.finn.no)*

Fig. 71. Open block: *In basin 2. Vestre platå there is mostly between open block neighbourhoods. (kart.finn.no)*

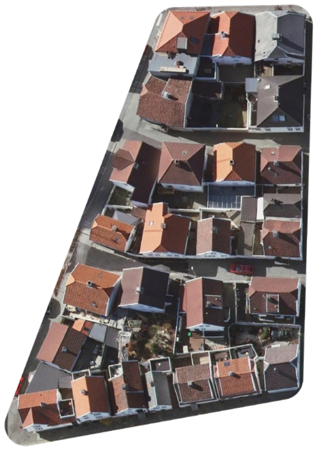


Fig. 72. Tight block: *basin 5. Brønngata in Straen, has a tight block neighbourhood. This is also found in the lower parts of 2.Vestre Platå. (kart.finn.no)*

Fig. 73. Tight Organic: *The district of Straen consists mostly of a tight organic neighbourhood layout (kart.finn.no)*

IP, 2023

5. PROPOSAL

This chapter aims to display one way of implementing local stormwater measures for the mitigation of runoff based on the information and the analysis. The recommendations will be based on the basin division and the neighbourhood morphology. The diversity of typologies creates the need for a diverse set of solutions for management of the stormwater. This means that each area is analysed separately to make specific recommendations that will fit with the characteristics of the area

This chapter will be divided into two main parts. One uses the "upper districts" of the basin e.g., Vestre Platå, Brønngata, and Rudlå to propose measures that can be implemented throughout Trehusbyen. The other part will look at how the water can be handled in the lower districts of the basin e.g., Lende, Anda, Straen North, and Nedre Strandgate which is a tighter and steeper area.

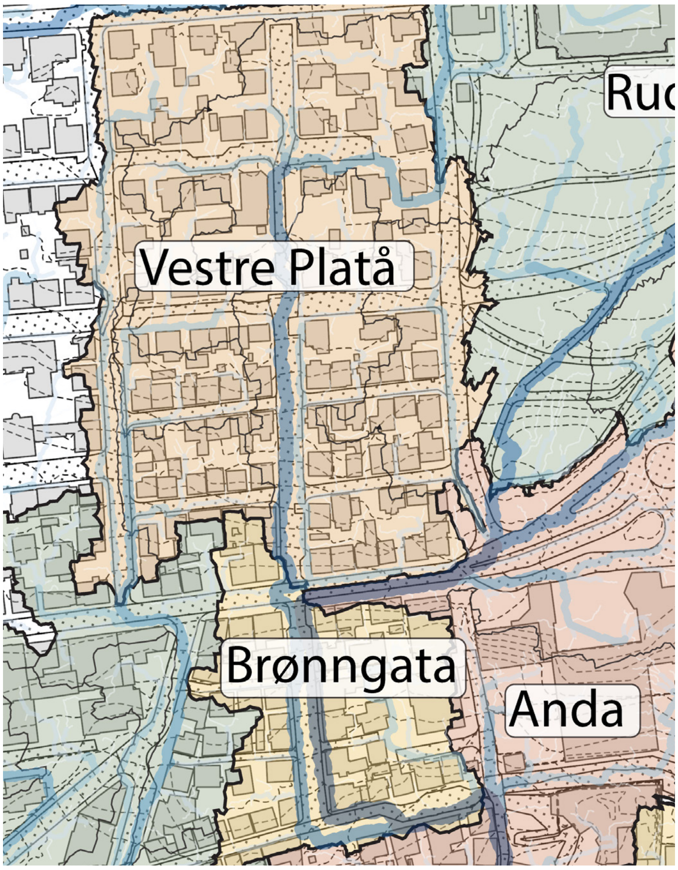
Whereas one can divide the area into separate water management divisions for Step 2 of the three-step approach. This is not possible for Step 3 where the areas must be seen as a whole. Without looking at the paths of the water, it's likely to under or over-dimension local measures. Managing and dividing the water properly between the water measures will be important.

To illustrate the effectiveness of the proposed measures, a 20 -year 10- minute event with a climate factor of 40% will be used. This equals an event of 17,5mm in 10 minutes.

All the dimensioning and designs are assuming there is no direct drainage to VA, it's easier to downscale the emasures than upscale them.

5.1 Proposal for upper District / Trehusbyen

Vestre Platå, Brønngata & Rudlå



First the measures will be implemented and explained in the context of Vestre Platå, then they will be transferred to Brønngata. Showing the adaptive ness of the measure. Rudlå will be handled separately.

For the implementation of stormwater mitigation measures in Trehusbyen, the area can be divided into different area types.

The main area types found are:

1. Open block neighbourhood
2. Tight block neighbourhood
3. Roads

This proposal is for Vestre Platå but is representative for the measures that can be taken throughout Trehusbyen.

Using the information and conclusion found in Hagen (2022) a foundation for the proposal can be made. For a full management strategy, it’s important that not only measures are implemented at a public and municipal level in the streets, but that private persons, and neighbourhoods also join in the efforts.

1. Open block neighbourhood

The open block neighbourhoods have many possibilities for implementation. A lot of the block structure has small out housing and gardens. Following the example of Hagen (2022) combining the gardens into a common area, the space will be enlarged, and a common water handling can be implemented. The areas will however not be capable of handling water coming from outside the property without the measures being excessive for a private garden as proposed by Hagen (2022, p.59)).

As an example, the block pictured underneath is Investigated for its transformability to better handle stormwater as a collective (fig. 74).

The measures implemented:

Transforming driveways, and entrance paths to permeable materials, this is a simple measure, which is already done in many areas of Trehusbyen.

Giving sheds green roofs can reduce the yearly roof runoff by 20%. For an intensive event (50 -years, 10 -min) the roofs can hold back up to 89% of the water (Braskerud, 2014, p. 64).

Making a collective garden, which will ensure little runoff, and make a place for roof water to be handled in a rain garden. In this example, the rain garden is 6 m² (2 x 3 m) (Formula used to asess rainbed retention can be found in Appendix 3)

These measures will reduce the runoff from the 20-year event by 20% (compared to before the intervention) assuming that the rest area is a mix of permeable and impermeable areas.

This proposal keeps all the sheds in the yards, but these could easily be removed, and upgraded to a common shed, with a green roof.

- **Stormwater retention from each open block neighbourhood will be 40% of a 20 Year event in 2100.**

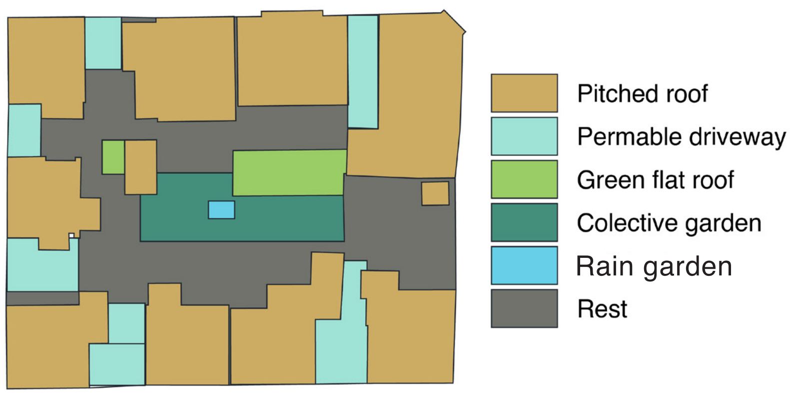


Fig. 74. Proposed measure on plot scale (left from: google.com/maps, 2023, above IP, 2023).

2. Tight block neighbourhood

In tight neighbourhood blocks, the outdoor areas are limited, often consisting only of entrance areas, patios, or tiny gardens (fig. 75). Landscaping options like rain gardens and collective gardens are not feasible. Many of these blocks rely on roadside parking rather than garages or driveways making little space for permeable areas. Less space-intensive measures must be considered.

Measures implemented

Rain barrels can hold 150 to 300 litres of water or even larger sizes like 1000 litres. Multiple rain barrels can be placed on the property. If each house had a 300-litre barrel, a block with 10 houses could collect 3000 litres from the roofs. This measure would reduce the runoff from the block by 17% in a 20-year event, assuming the barrels are empty. Implementing additional ground-level measures where feasible would further reduce the runoff. The measure would completely capture the runoff from a 4mm rainfall on the roofs.

Flowerbeds serve as attractive features and natural water storage areas. Diverting runoff to flowerbeds can be done either through a permanent water feature or hidden piping. However, directly channelling heavy rain into an open flowerpot is not ideal, as it can harm the plants. Implementing a passive watering system utilizing a permeable water pipe inside the bed benefits both the plants and the neighbourhood. The plants can access a specific amount of water, while the pipe acts as a retention system during stormwater events. One pipe with a diameter of 15-20 cm is suitable for this purpose. Having such flowerbeds on 1/5 of the walls can capture 536-953 litres of water, reducing plot runoff by an additional 6.5%. The measures reduce runoff by 22,5% compared to before the measures.

- Stormwater retention from each tight block neighbourhood will be 40% of a 20 Year event in 2100.

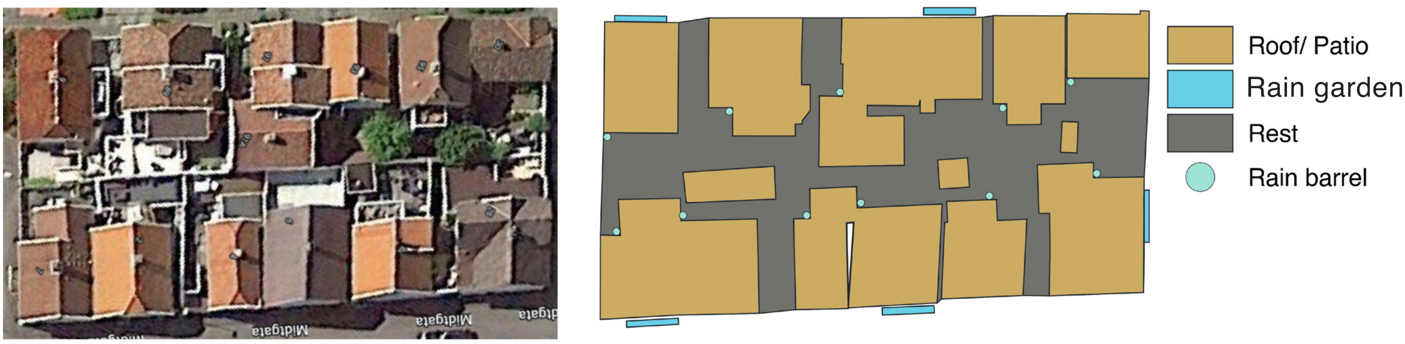


Fig. 75. Proposed measure on plot scale (left from: google.com/maps, 2023, above IP, 2023).

3. Streets

According to Hagen (2022, p.72) a pedestrianisation of specific roads in Trehusbyen would come with a lot of benefits. Pedestrianisation of block structures leads to greater potential for water management through measures that can seem positive to pedestrians, e.g., green infrastructure and waterplay. A reduction of car use and parking can create possibilities for a blue-green structure throughout the streets.

The area already has one path mainly focused on bike traffic. But not directly for pedestrians. This street does however also have cars moving through it. Removing the cars fully can create a better opportunity for water management. Using Hagen's principles for improved infrastructure we can divide the streets into three categories, here with an existing bike lane (fig. 76).

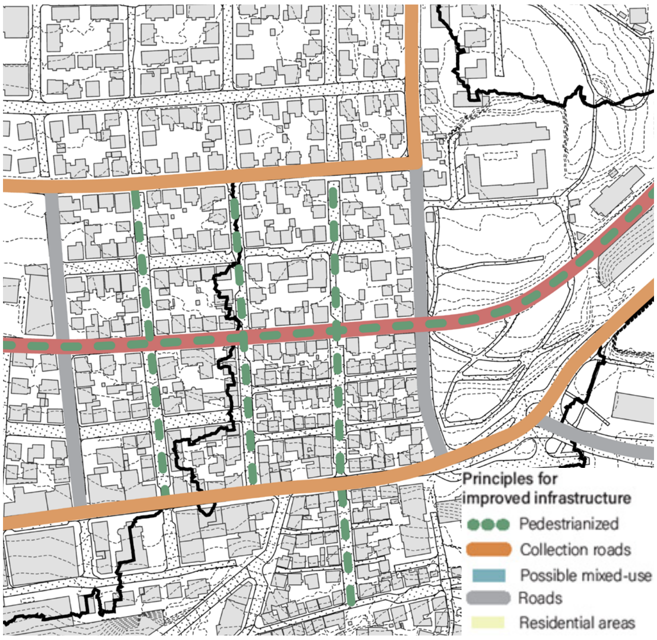


Fig. 76. The principles for pedestrianization by Hagen (2022) is here applied to the area, this can be utilized to establish a green structure through the walking axes (IP, 2023).

Using the map as a guide, a green network of trees, rain gardens, and flowerbeds can be created to reduce runoff and increase the infiltration and retention of the area.

Raingardens

A rule of thumb is that the Raingardens should cover 10% of the basin, however, as we have seen in Deichmans gate, the beds covered, 4%. Using the same properties for the rain gardens (e.g., infiltration speed and depth), and subtracting the already managed water (30% reduction from each neighbourhood), the total rain garden footprint can be 3,8% (fig. 77).

As some of these streets already have a lot of green-structure and are operational, I consider the extent of the proposed meas-

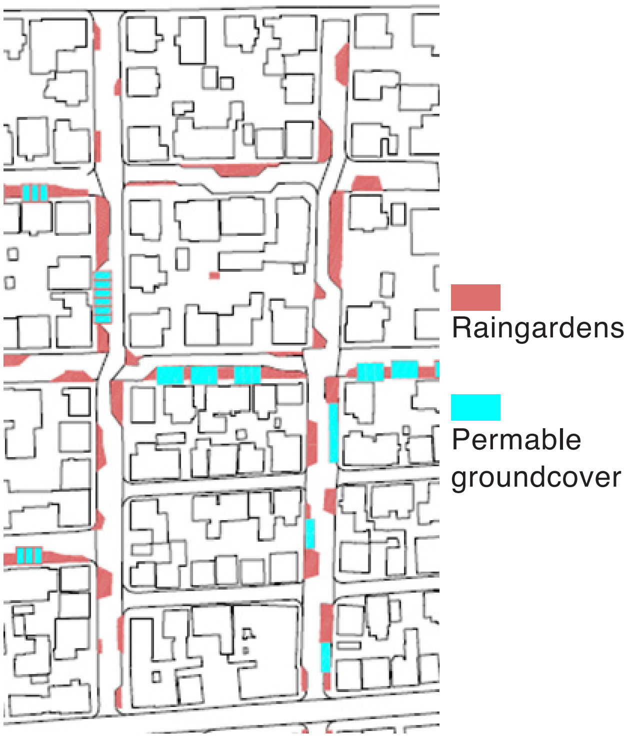


Fig. 77. Proposed density of 3,8% coverage in the streets (IP, 2023).

ures possible. In the area, most of the roads have street parking on each side of the road. Making the road twice as wide as it has to be. Dividing this parking with green structures will increase the greenery in the area. Further introducing permeable materials in this street parking will reduce the runoff.

For short stormwater events, rain gardens are almost interchangeable with retention basins as the water will not have much time to infiltrate.

The implementation of 950 m² of rain gardens will capture all the runoff water produced in the area after the measures in the blocks are introduced. In figure 77, the rain gardens cover 1038 m². At least 90% of the suggested (red) areas in figure 77 must be rain gardens or retention basins. The rest can be grass, or normal beds (103m²).

The Raingardens should be able to take all the rest runoff from the area in the figure. (If the measures at the individual block level are implemented). This, is however an extensive use of raingardens, covering 3,8% of the total area, but removing 16% of the street area.

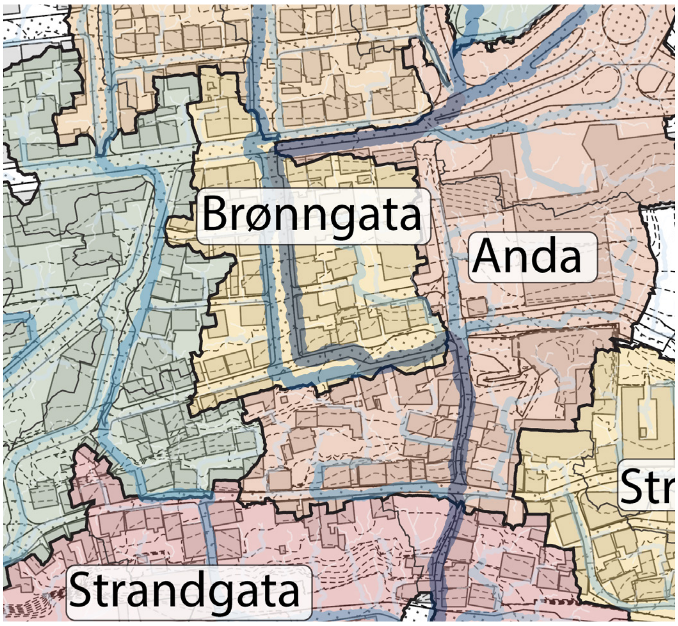
Increasing retention

By changing half of the rain garden area to a river rock retention basin, with a porosity of 40% and a depth of 0,5 m the immediate, water storage would be increased by 50%, this can be used to take the first overflow from the rain beds. In this way, there can be a more diverse composition of flowerbeds and rain gardens. This is a visual way of doing it, another way is to have an underground infiltration basin/ chamber as used in Deichmans gate. These can be any size. Using two pipes /meter with a diameter of 30 cm would produce a volume of 0,14m³ /m² implementing this in the beds, also increase the retention ability of the beds by ca 50%. By implementing both, the area of the rain gardens could be reduced to 45%, meaning the Street coverage would be down to 6%, and total coverage down to 2%. These measures can increase retention and maintain the same amount of infiltration. Or more water can be let on by the blocks.

- **Stormwater retention capacity of the streets in Vestre Platå will be more than 100% of a 20 Year event in 2100.**

Fig. 78. The already existing green structure has been transformed to water channels and rain garden. (Picture and manipulation: IP, 2023)

Proposal for Brønngata



Brønngata is consistent of tight block structure. As the measures implemented in the tight blocks in Vestre Platå are scalable. We can assume a 40% retention of a stormwater event. The area also has a building that can be fitted with a green roof, it's expected that this building can implement measures in its private garden and parking space, reducing the runoff from the building by 80%. One of the main goals of implementing measures in this area however is reducing the amount and speed of the water before it comes to Andasmauet.

Infiltration

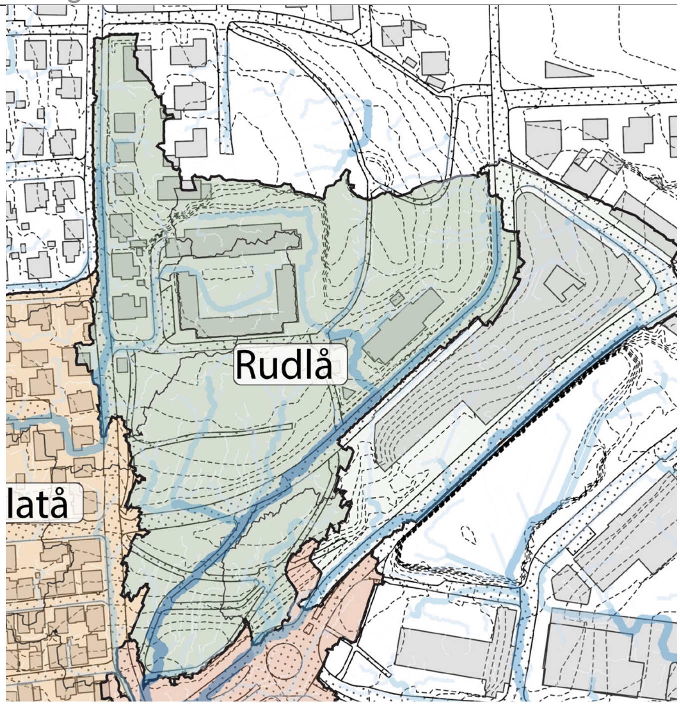
Measures dependent on infiltration may not be a good choice in this area because of the problems of water damaging the houses in Straen, mentioned by Byantikvaren. The water can, however, be stored, using rain beds with an impermeable casing, and choked drainage to the VA system or back out on the street. In this way, the water can be retained when needed and filtrated for substances without increasing the flow of water over the bedrock.

Brønngata is wide and has street parking at the side, some of this can be changed for rain gardens. Using the estimations from Vestre Platå 2% of the area must be covered with rain gardens, or if there are no underground retention measures 3,8%.

Fig. 79. An example of how the measure-density of brønngata could be, 3,8%. Half of the measures can be removed if underground retention is implemented (IP, 2023, Backgorund: Nordkart, 2022)

Raingarden
Green Roof
Retention basin

Proposal for Rudlå



Rudlå is mostly a park. A couple of houses are in the western part of the area, and close to them is an apartment block. In the northern part of the park, there is a big building. The park is surrounded by roads and has a bike lane through it. Since the area is a park, it will have little runoff. But in a stormwater event with a 20-year return interval, the entire area will produce 439l/s.

Measures taken in this area can be bigger and require less than in Vestre Platå. I will suggest three medium rain gardens and sedum roofs on the two large buildings. Reducing the runoff by 100%. A rained coverage of 350 m² with a retention basin of 517 will be able to take the area's runoff (fig. 80, 81). The area could be good for taking on more water from other places, this cannot be done because it's situated on a hill.

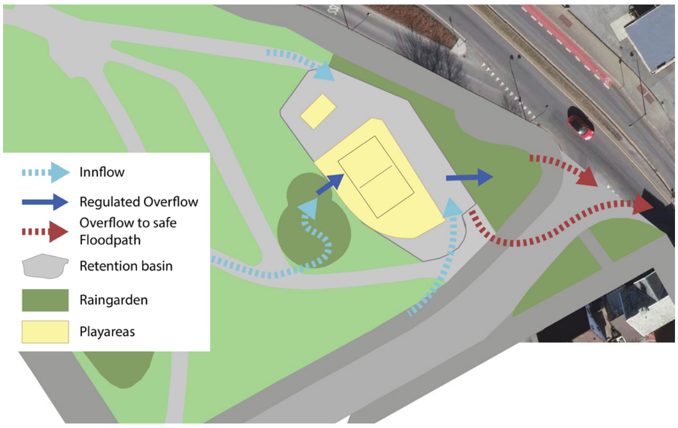


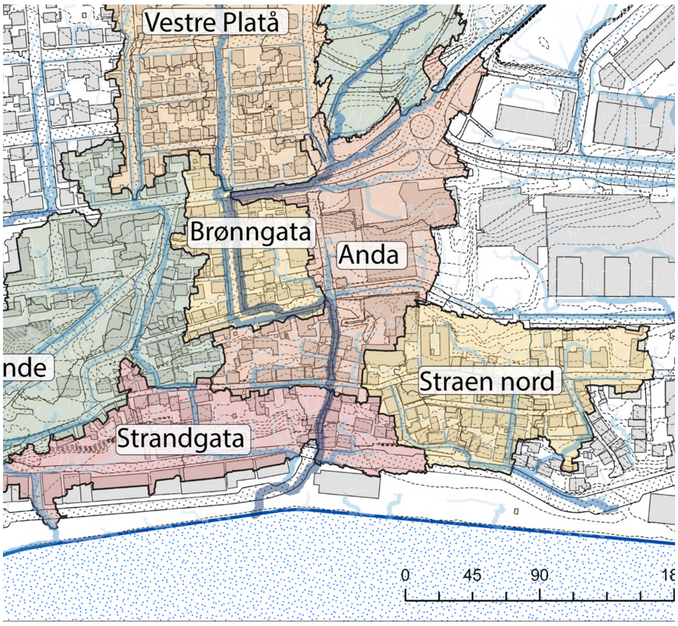
Fig. 80. Proposed rainbeds and retention basin, with inflow, choked outflow, and overflow marked (IP, 2023).

Fig. 81. Illustration of the play area in Rudlå, lowered to be able to collect 129m³ of water (Picture and manipulation IP, 2023).

Fig. 82. This street is in Trehusbyen, Stavanger. The pavement is semipermeable, and the sides are filled with foliage. A Street like this will have little runoff and creates a space that feels designed for the pedestrian, even though cars are free to drive here (IP, 2023).

5.2 Proposal for lower District / Straen

Anda, Straen nord, Strandgata & Lende



Even though the area is divided into smaller watersheds the area can be considered as a whole when implementing certain measures. As the morphology, topography and visuals are similar throughout the area. As previously mentioned, the area has an organically grown tight neighbourhood, where the open spaces are spread and public.

Infiltration

Infiltration may not be a good idea in this area because of the negative influence on the built heritage. The measures are also space intensive whereas there is little room for this in a tight neighbourhood structure. In Straen the roads are also tight, and the implementation of retention measures will not be possible.

Retention measures can however be implemented in the parks. Many of these can room either a retention basin or a rain garden of some kind (fig. 83).

For some of the open spaces, transportation to and from the measures is not so easy.

Fig. 83. The entrance to Eplehagen (IP, 2023).

The spaces fit for intervention

The spaces most fit for intervention is selected based on position, the GIS analysis, and site visits. There are few open spaces in Straen. The public parks must be considered for measures here each park is presented based on to witch degree it is fit for intervention. The figures are represented in the map below.

1. There Hoves plass, will not have any effect.

2. Rodals Plass, can be used for water retention. The water gets easily to this place, removing the water from here on the other hand is harder.

3 Lekeparken, has little areas running to it. The area should be able to retain its rainwater locally not discharging it out in the street.

4. IDDIS museum, this area is a hole in the ground, it could be transformed to take on some water from the area above, the removal of the water is however difficult.

5. Einar Hédens Plass can be a good place for retaining water before it goes into the lower parts of Andasmauet.

6. The cherry orchards, have protruding rocks and are located in between a lot of old buildings, the measure should not take on more water than from the surrounding buildings. it's important to have a designed overflow here.

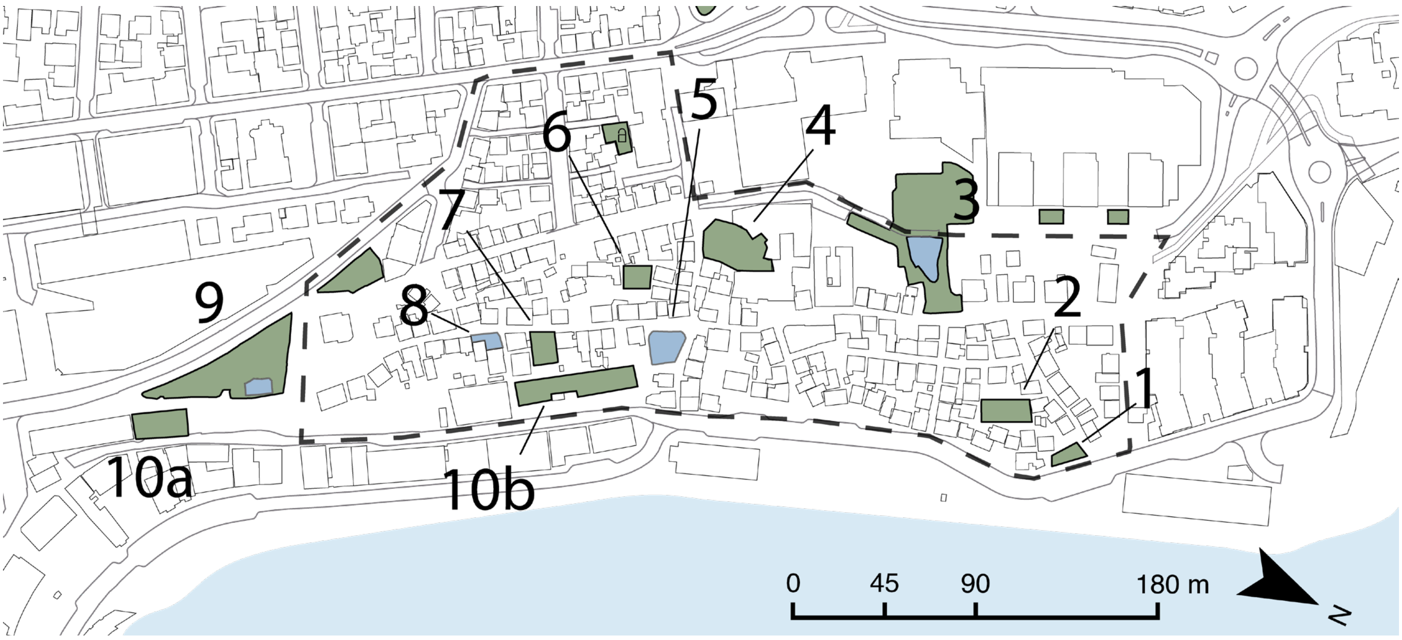
7. Eplehagen, can be a good place to retain water on its way to Andasamauet, the water can then be led through the terraces into Strandgate creating a new flooding path.

8. Litlatorjå must be properly secured and does not have the ability to retain.

9. Lendeparken has a lot of areas. Water from other places could be led here.

10a. Terraces due to their historical value should be restored, not used as a water measure.

10b. Terraces north is already getting built on, the area can be built to have a flood path, into Nedre Strandgate. maybe building a permanent water measure here.



Water ways

To implement the measures, we are restricted to using the existing parks. However, since these parks are limited in number and spaced apart, the effectiveness of the measures may be limited. Transporting the water to treatment areas can also potentially cause damage to the area, both due to unforeseen water issues and the measures themselves. The water accumulates on roads and follows their paths, resulting in large volumes of water converging in specific locations, particularly vertical roads (see fig.44). All the vertical roads seen in the name map at the start of the analysis of Straen seem to have a water path within them. As the image of Andasmauet shows, has also other roads have been transformed into rivers (Personal communication, Hanne Windsholdt 3. February 2023).

One goal of the water paths should be to disperse the water, spreading it out over several pathways.

In figure 85 the paths have been divided to lessen the load on individual spaces. These divisions are to be dimensioned, so only a set amount of water separates.

Fig. 84. The main paths the water will take towards the water. Simplification of the stream analysis shown in figure 69 (IP, 2023).

Fig. 85. The streams are separated to lighten the load in individual areas (IP, 2023).

Securing floodways

Before the floodways will be discussed a choice must be made.

The water from Vestre Platå comes down in two streams, should they be separated, where one goes down Brønngata to Andasmauet, and the other goes down to Lende parken? Or should the path of the water be removed from Straen?

In the case of a 200 -year event, the measures implemented in Vestre Platå will overflow. The measures will have reduced the amount, but stormwater rivers will be created and run towards Vågen.

To mitigate the damage to buildings from this effect a good choice could be to send it down Lars Hertvigs gate. This is a wide street, and it should be easy to implement dimensioned measures. The street is however steep and if a lot of water comes down here it could cause damage to the storefronts at the bottom of the street. There is also a question about transporting the water (even for a short) distance on a “main road”, and the interventions that must be done to redirect the water on the road.

Keeping the water in Brønngata, down Andasmauet will require measures directly on the buildings, reducing the historical value.

There is little information to be found on stormwater floodways in small pedestrian streets without using retention measures or having separated floodways. Studies have been done on the transportation of water on roads. These show that flat or V-shaped profiles are the most adequate. The V-shaped roads will be able to transport a higher volume of water (Ghetahun, 2019).

The waterways should do two things,

1. Slow the water down, to minimise damage to the road, and housing.

2. Keep the water away from the housing to decrease damage from water running down the foundation.

Edges

The streets in Straen’s horizontal axis have edge stones, the vertical does not (fig. 86). Having protection along the walls of the buildings in the vertical streets should be considered especially along the intended waterways. So the paths can handle both an everyday rain event and an extreme one.

Fig. 86. The edge here has been washed out, by rain events or other kinds of erosion (IP,2023).

As Straen is a heritage and protected. The use of the VA system should be considered. It can be used for drainage, of the streets or for implemented measures.

Fig. 89. An entrance in Andasmauet, that may be exposed to water problems (IP, 2023).

Fig. 87. This little bump interferes the water changing the direction of water into the drain (IP, 2023).

Fig. 88. On the side of the road there is a little cobblestone edge sitting a little lower than the rest, the stone will slow down the water, and lead it along the curb (IP, 2023).

Intervening the floodways

For both a visual appeal, and to spread out the load of a heavy stormwater event, the paths of the water have been divided into smaller streams, that can be treated with smaller measures. The division of the stream requires interventions. On the next page is a rundown of the interventions as well as a map showing the placements. Following this, some of the interventions will be elaborated.

1. Infiltration from the close by housing. should have drainage piping to lead the water out between the buildings onto Nedre Strandgate.

2. Smal rain garden to mitigate some of the water before it runs down the street.

3. in this place there is a Staircase, interventions must be done for this to become a floodway.

4. Andasmauet must be secured. A full stop measure in the top reduces the water flow into the smau. Water speed interventions, and measures keeping the water away from the buildings. At Einar Hédens plass water-retention measures can be implemented, stopping the water before the lower part of Anda, slowing it down and dividing it into two overflows. One going back into Andasmauet, the other one down into the Terrases north.

5. The cherry orchard will be fitted with a retention measure that can take the overflow for the surrounding housing.

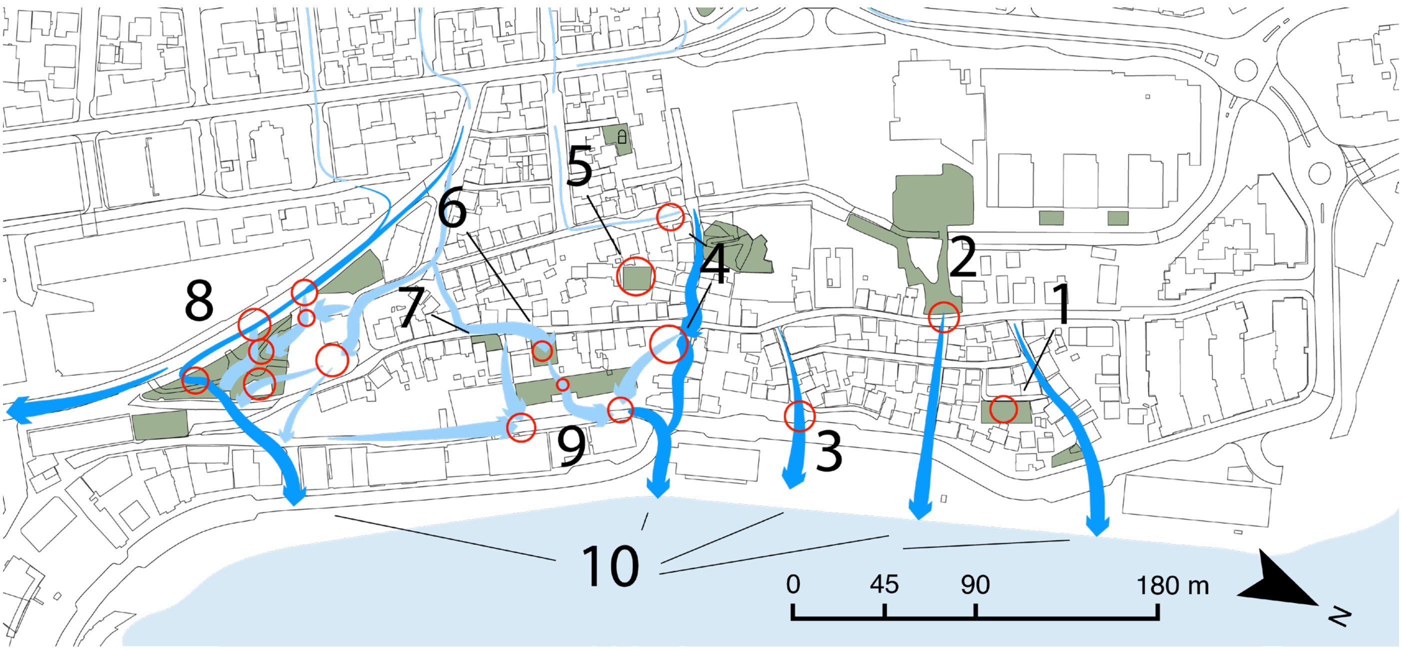
6. Eplehagen will take on water from the road, retaining some, then overflowing into the Terrases north.

7. Litlatorjå will have a flooding measure that changes the direction of the water, leading one part of it down Sømmersmauet, and another one to Eplehagen.

8. Lende Parken will be a big intervention area. Having a stepped swale down between the road and the sidewalk at the side of the park. In certain steps, the water can be separated. Flowing into rain gardens, flood paths and retention measures, collecting again underneath the park and flowing controlled into Vågen.

9. Terrases north, here interventions will be done with the new regulated housing, creating water-paths down into Nedre Strandgate. In Nedre Strandgate the water can either be treated in raingardens for filtration or go out into Vågen.

10. Creating safe Floodways over the road and into Vågen.



4. Andasmauet

Andasmauet has already had a lot of water flowing through it at times. For a big event, the water must flow here, but in smaller e.g., 20 - years or less the water can be intervened. Stopping water from entering Andasmauet from Brønngata, and the new building project at the top right. Reduces the runoff into the Smau. The water that gathers, will flow down Andasmauet, and be directed into Einar Hédens Plass. Water coming from Øvre Strandgate will also be sent here. The park can be lowered to create a small retention basin. The main goal of this measure is to slow the water down and to lay off some sediments. From here the water can take two paths. First, a choked drainage towards the terraces will remove the initial water sending it into Nedre Strandgate, a good place for filtration measures. If the amount of water entering the place exceeds the designed capacity of the terraces, the excess water will overflow back into Andasmauet.

The drainage can be visualised by cultural elements found in the area, such as cutting it into stone. Or it can be done by implementing heritage elements from outside the area, leaning into the philosophy of Héden. Implementing a flume from an old waterwheel in Rogaland could be one way to do this. Another way to do it could be in a vegetated

Fig. 91. There are many ways a water pathway could be implemented in this terrain. It could be playful and nice to look at from Einar Hédens Plass. It can even made a permanent water feature. From the outer corner at Einar Hédens plass towards Nedre Strandgate (Photo and manipulation, IP, 2023).

Fig. 90. The proposed solution for dividing retaining and filtrating the water going through Straen into Nedre Strandgate. The floodway will be secured, choked inlets and outlets will ensure a safe water treatment (IP, 2023).

waterway (fig. 91).

The overflow into the terraces goes over private property. This can be a problem for the implementation. If the owner does not agree to such an open water path over its property, it will have to go through piping, or not be done.

To change the direction of the water so it flows into Einar Hédensplass will require a road intervention, there is already a measure that does the same thing, but in the other direction, this can be adjusted to flow into Einar Hédens plass. Having a small channel in the cobblestone even more water can be led into this area.

Hédens plass must have a slope towards the drainage point so water does not gather for long times in this place.

Andasmauet must be secured as a floodway, Andasmauet is probably the street that in a big event will take on the most water, since the water can flow from Vestre Platå down Brønngata and inn here.

Therefore, measures to properly secure this smau should be taken. In several locations small interventions have been done to secure building openings from water damage, such measures can be replicated in along other flood paths, and may be enlarged (fig. 92).

The upper part of Andasmauet has a lot of greenery (fig. 93), this can be implemented in the strategy to create ways for the water to slow down.

Fig. 92. A small intervention can be enough to keep the water out of cellar (IP, 2023)

Fig. 93. Andasmauet with a lot of vegetation (IP, 2023).

6. Eplehagen

From the floodway down Sømmesmauet some water will be redirected to Eplehagen. This area can be fit for infiltration as it has no old building down slope. The newly planned building should be able to plan for it and handle the groundwater. The measure will be able to handle small rains, discharging water further down the terraces, and around the new building.

To prevent garden overflow, a choked inlet can be implemented where the water paths separate at Sømmesmauet. The inlet can be dimensioned to release only the amount of water that the garden can handle on its own or with additional measures implemented in the terraces. And divert the rest of the water down a safe flood path in Sømmesmauet (fig. 95).

This flood path should be secured when planing for the new building.

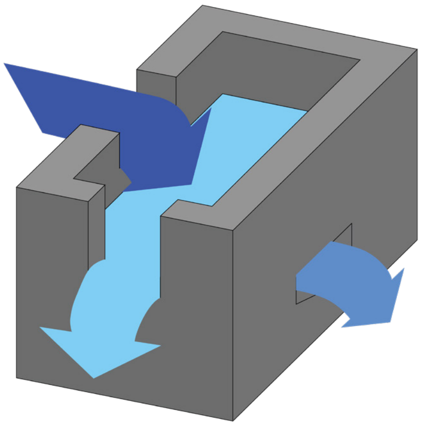


Fig. 95. Concept illustration of a choked diverter. Water goes inn, a dimensioned amount is released in one direction. An overflow releases in the other. This way the water can get a full stop, and be diverted at the same time (IP, 2023).

Fig. 96. Above: Diverter in Deichmans gate. makes some water go into the raingarden, while some water passes the threshold dependent on velocity. (Egeberg et al., 2021)

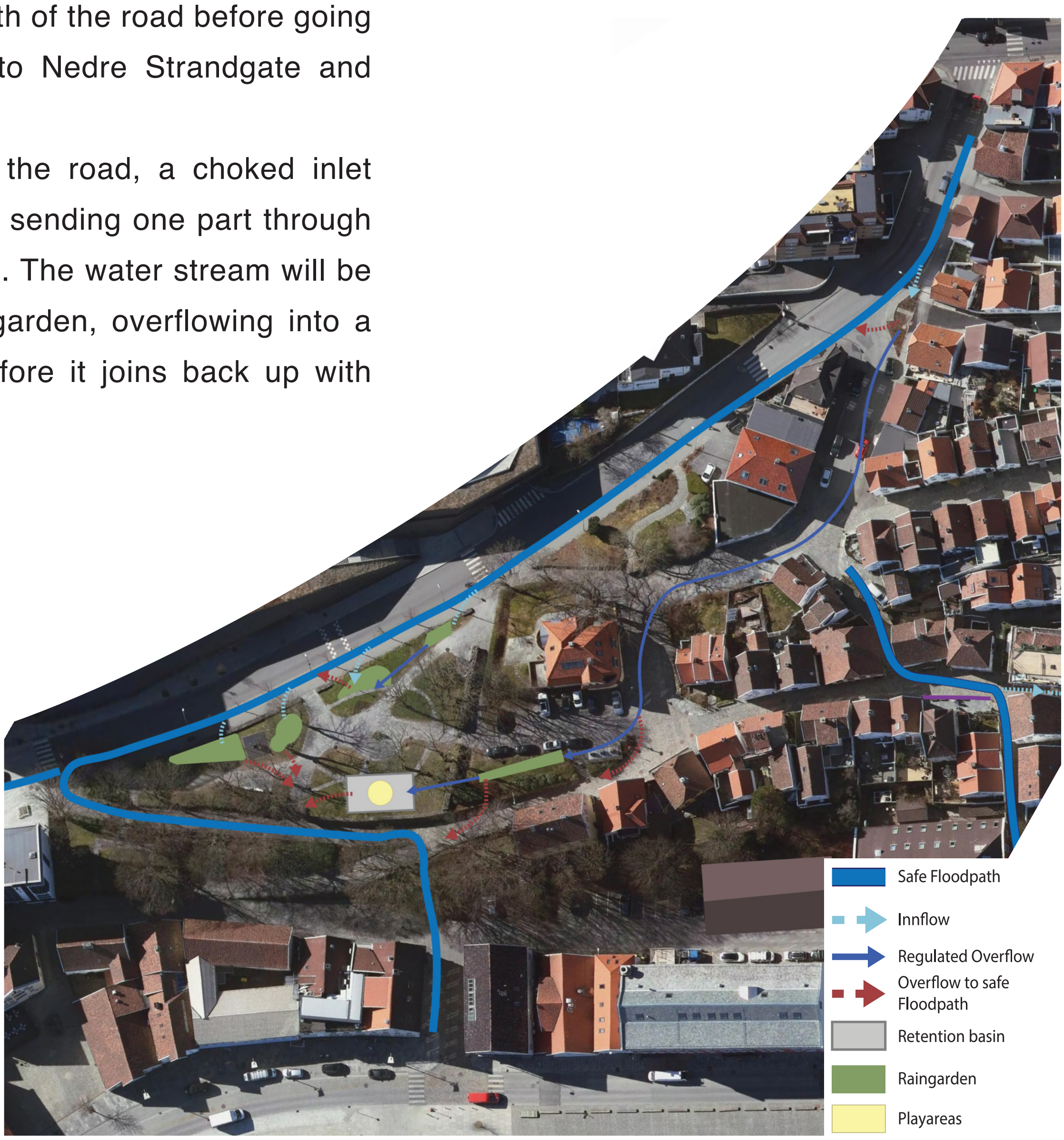
Fig. 94. Right: The proposed solution for dividing retaining and filtrating the water going through Straen into Nedre Strandgate. The floodway will be secured, choked inlets and outlets will ensure a safe water treatment (IP, 2023)

8. Lende Parken

As the road leading down alongside the park is steep the water should be slowed down. This can be done in a series of retention basins, and rain gardens overflowing into each other (fig. 97). In some of the steps choked outlets into Lende parken can divert water into rain gardens with overflows back into the floodway. The floodway can eighter be sent towards the city centre for combining with another floodway. Or be let down the path in Lendeparken. There should be a slope towards the centre of the path so water can travel the length of the road before going over the edge onto Nedre Strandgate and into Vågen.

At the top of the road, a choked inlet will split the water, sending one part through Straen on the road. The water stream will be caught by a rain garden, overflowing into a retention basin before it joins back up with the main floodway.

Fig. 97. The measures can be used both to retain water and slow it down. (Photo : Carl-Erik Eriksson (Egeberg et al., 2021)



9. Nedre Strandgate

As there will become new apartment buildings in this street, new green structure could be expected in the street. As this area has flood paths in it, rain gardens should be considered. Here water can be filtrated instead of flowing directly into Vågen. This street can in many ways resemble how Deichmans gate. And a similar fashion of rain gardens should be considered (fig. 99). This will also be the final stop for many water paths from Straen.

Retention measures do not need to be implemented here for other reasons than filtration. However, an effective flood path should be implemented. The road should have a constant slope towards the bottom of Andasmauet. Permeable streetside parking should be implemented.

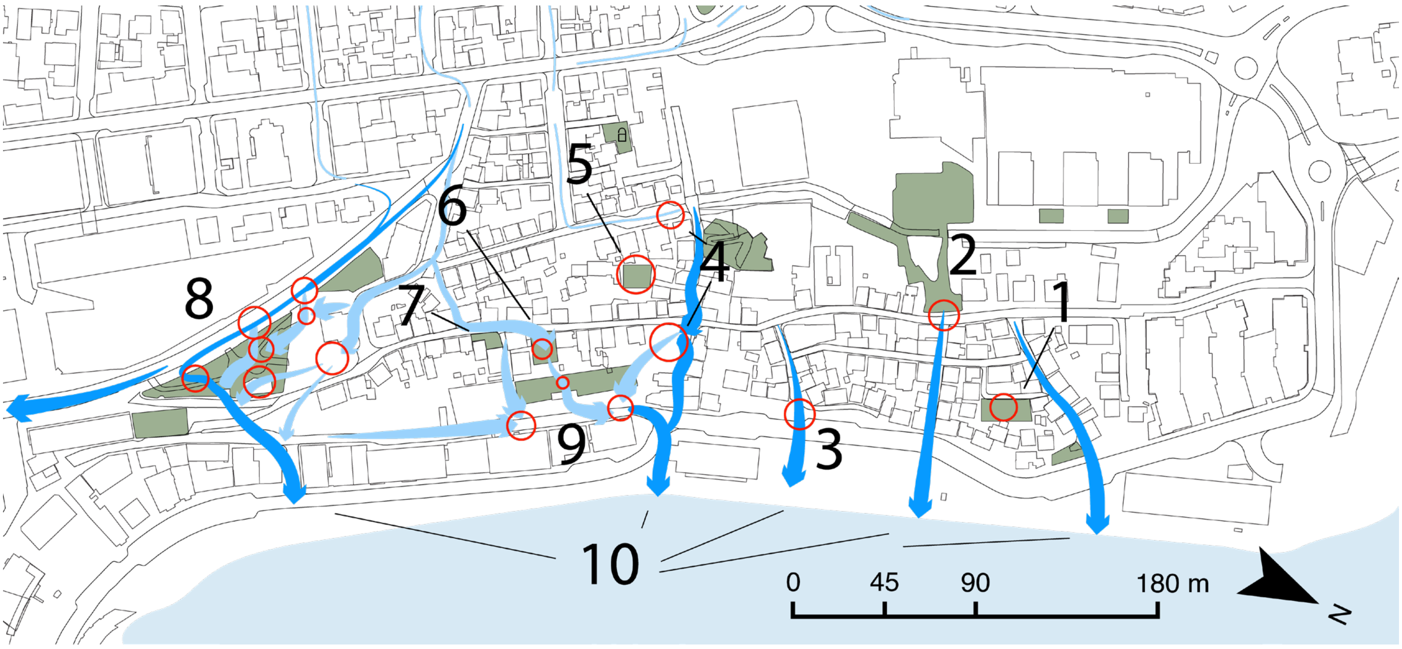
Fig. 99. Depiction of how a raingarden could look in Nedre Strandgate. A floodway leads the water towards the bed (Photo and manipulation: IP, 2023).

Fig. 98. Proposed solution for retaining and filtrating the water in Nedre Strandgate. the water from the floodway can be transferred into the Vågen (IP, 2023).

10. Vågen

When making a floodway into Vågen there are several things to consider. Floodway into Vågen can potentially create problems for road traffic. Today as the water does not have the ability to collect, it will spread out. This can both be good and bad.

The flood ways can be drainage points for the dock when storm flood events are inbound. Flood ways can be lowered into the ground with a grid over top making the roads safe and operational even when heavy rain.



Water potential

As discussed has this area some trubbles with groundwater preasure (Stavanger Kommune, 2021), and trubble with water running over the bedrock. This can cause damage to the housing. The implementation of rain gardens and infiltration measures in the upper district of the basin can worsen the problematic situation. To account for this measures should be taken. Both on induvidual property, and in the public. One consept could be to drain the groundwater to the surface. And implement it as a feature in the streets (fig. 100).

This could potentially be made form two sets of bariers one in the top along Haugvaldsgate and Borgermester Middelthornsgate. And one along Øvre Strandgate. Here the water can be pushed to the surface, and be transported trough the systems of Epplehagen, and Einar Hedensplass. Making almost permanent water ways and water features in the area.

Fig. 100. A water figure in the northern most part of Straen. Where the water is supposed to come from, I do not know. maybe it could be fitted to transport groundwater (IP, 2023).

Sumamry

Trough the proposal the runoff from the upper district has been reduced, through retention and infiltration measures in the streets and on private property. The Measures are capable of handling a 20-year rain event.

In the lower district of Straen however, there is a problem with the infiltration potential, and space for retention measures, here the measures are focused on the treatment of the water in the best way possible. On the path of the water down to Vågaen it will get separated to lighten the load on any specific area. The water that can be treated will be filtered and then sent onward. The groundwater situation mentioned could be handled by drawing the water back up on the surface and sending it in water paths and features through the streets of Straen.

Fig. 101. House in Trehusbyen with a flower garden. The water from the roof could be connected to this garden, reducing runoff from the plot (IP, 2023).

Fig. 102. Pathway down from Lendeparken. On the left side the Terraces are visible (IP, 2023).


IP, 2023

6. DISCUSSION

This thesis seeked to answer two questions:

How can stormwater be managed in a sustainable way in a protected urban heritage enviromnet?

How can the stormwater in Straen be managed without damaging the cultural-historical values?

From the image in chapter 1, an understanding of the problem is gathered. The problem with water running in the Streets of Straen. This was the result of a 10 -year 10-minute rain event. Through this thesis I have looked at the water, terrain and built heritage, and how they are interconnected. From this, the different factors that have an effect on, and are affected by the water have been brought to light. I have assessed and analysed the water situation. Stormwater floodways will without a doubt gather in Straen. However, the amount of water and the controllability of the situation can be adjusted.

I have studied the subject matter, employing a comprehensive and analytical approach based on an understanding of the field of study. Trough visual and academic exploration, and geographical analysis, I have discovered and gained an understanding of the area and underlying factors. The strength of my work lies in the crossing of the different methods making up the fields this thesis touches.

My methods have changed between calculation, literature studies physical fieldwork and working with analysis, and proposals. The movement back and forth between all these elements has enabled the development of sustainable and resilient, yet simple solutions. Studying Trehusbyen and Straen, using it as a case study, has shown to be a good choice. The complexity of the self-grown milieu of buildings, streets and parks have given resistance, but also possibilities for solutions. The methods from the field of planning has been challenged by and mixed with situated common sense.

Proposal

I have through this thesis proposed a set of solutions for the water management problem in Straen, and its connected catchment area.

In the proposal, it is visible that for Trehusbyen, measures can be taken in between the housing, in gardens, driveways and entrances. These measures are effective, and will not damage heritage values connected to Trehusbyen. When the neighbourhoods grow tighter the measures must be adapted, simple measures such as rain barrels can lessen the load of water in the streets, but if there is no garden, there may be little incentive for rain barrels, as they will stand there half full or half empty for years before it’s needed. The streets of Trehusbyen are wide, there is plenty of room for a "greenification" and in some places a makeover is overdue, raingardens could do this. From the available space, rain gardens is the obvious choice. If the goal is to retain the precipitation of a 20-year event, normal rain gardens will have to cover 16% of the streets. If all have added functions of retention, they could cover as little as 6-8% or less depending on the size of the retention measures.

For the lower part of Straen however there is neither room for intervention between the buildings, nor in the streets. The implementation of retention measures has to be restricted to the public parks and spaces. Infiltration in Straen is however a subject that must be investigated thoroughly. Especially since one of the water problems comes from water running on the bedrock. A measure of extracting the water and using it in the area as an active element has been proposed as a measure to protect or secure the foundations and basements. The problem with groundwater must be further investigated.

As shown in the reference projects, a 150 m² rain garden is put in place to uphold the groundwater balance at Bryggen in Bergen. The biggest extent of this thesis proposes 934 m² of rain garden infiltration in the catchment area of Straen. This may lead to an amplification of the groundwater problems in Straen. If infiltration measures are to be implemented upstream of Straen the implementation should happen gradually, so problems can be discovered, and accounted for.

Approaches to the area

The planning for measures in the two areas, Straen and Trehusbyen, had to be approached very differently. Whereas in the Trehusbyen part of the basin, the water is predictable, and there is enough space for intervention, a mathematical approach by CAD and Excel was viable. But in Straen the lack of space makes the approach go the other way around. First finding where it's possible to implement a measure, then finding out how much the measure can take. As there is little potetial for infiltration, and retention requires a lot of space. The measures suggested will not be sufficient to handle a bigger event. Thus, the water must be discharged in safe flood paths, or have a choked inlet where exceeding amounts of water is diverted to a safe path.

Water balance in the measures

The proposed measures for step 2 in the upper districts of the basins have not individually been assessed for position and potential. Therefore, the placements might skew the result of an analysis of this. The basins have been seen as a whole unit. A problem this can cause can be that a big measure in the upper parts does not have a big enough catchment zone to utilize its potential, and small measures in the bottom of the area can have a too big catchment zone. Even if they together cover the correct percentage of the basin, they will not be able to manage the amount of water.

Floodpaths

There are few readings to find on how to make a floodway in tight areas, such as Andasmauet. This is maybe because it's not a smart move, or maybe it's just obvious (securing the walls). Most floodways use large spaces at the side of the road, or use a trench. This will not be possible here. It's hard to know the actual impact a bigger rain event would have on a street like Andasmauet.

For me, the main reference to a situation like this is the video referred to in the introduction. That was of a 10-year event, what would a situation with three times the amount of rain look like? I do not know. And I do not have the tools to figure out, so the actual feasibility of allowing runoff from a 200-year rain event into Andasmauet I cannot be sure about. I however know that in an event like that, the runoff from Vestre Platå has been reduced by 60%.

Dimentioning for the 2. step

For me, and my understanding of planning practice, risk, and investments the measures proposed in the thesis, are over-dimensioned and probably overly complex, and too expensive to be implemented in this area. Instead of dimensioning retention and infiltration to step 1 (1,4 mm/ 10 min), I decided to dimension the retention and infiltration measures for step 2 (17,5 mm/ 10 min), a 20-year precipitation event. This is due to the lack of downstream areas capable of housing a singular step 2 measure (except for Vågen). And the runoff gathered reduces the potential for damage in Straen. This choice is however underbuilt in the dimensioning of Deichamns gate. The pilot project shows that small measures can take on a lot of water, here some of the beds are designed to take on a 20-year event as of today. The design can however be downscaled to take on a step 1 event and transport the rest of the water Vågen.

I have dimensioned for the stormwater to only be treated and transported on the ground, and in LSM solution. If these are connected to the VA grid the measures could also be downscaled. Utilizing a combination of the LSM measures implemented and the capacity of the VA grid, a 200-year 10-minute event in 2100 at Vestre platå could be mitigated, infiltrated, retained, and removed. Fully. While the VA grid still has rest capacity. This constitutes the fact of my over-dimensioning of the measures in the area. But also, to the strengths of managing water in complex green urban systems.

Further research on the subject

When finishing this thesis, a few new questions have become evident.

1. The consequences on big infiltration measures, especially in this area. It is to me unknown what the effect of replenishing the Groundwater will be, in this area and similar areas, whit a thin soil layer, and building foundations directly on the bedrock.

2. Flood ways in closed urban environment. How can tight streets be fitted as flood ways, what measures must be taken.

Too these remarks, I have no answers for the time being, and the questions should be dealt with in further research.

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Appendix 1. Map data:

This type of analysis does not take into account any technical solutions for stormwater management.

The analysis does not take water speed or water volume into account in extreme events the speed of the water can lead to new pathways.

The analysis does not take into account that runoff varies greatly between summer, autumn, winter, and spring, because of frost preventing infiltration, and evaporation.

Maps

Maps used in this analysis is:

- Basisdata_5972_FKB-Arealbruk_SOSI
- FKB-AR5
- FKB-Veg
- FBK-Høydekurve
- FKB-Bygning

FKB maps are gathered form Geonorge (Geovekst, 2023)

- DEM (DTM) & DSM(DOM) from Høydedata.no (Høydedata.no, 2014)

1.1. GIS- Hydrological survey

The terrain used for the analysis is a DSM map from 2014 collected from Høydedata.no. the map has multiple shortcomings which to the best of my ability has been accounted for. Discussion around the map can be found in 1.2.

Summary: Map DSM 2014 Gives an accurate elevation display with obstacles. But does however not penetrable structure from barriers. E.g., cars, foliage, outcroppings. A contour map has to little information, and a DEM has all obstacles removed.

A comparison of two stream analysis shows that the maps can give huge differences in result. Site visits are used to establish which map gives the right result. Most of the times the DSM provides the “truer” path. Because of the age however both maps give a wrong outcome in certain areas. faults like this are hard to find without having knowledge about the area. Simple visual interpolation is used in these instances.

Basin and Streams

Basin and flow accumulation are two hydro analyst tools found in ArcGIS. These can provide a simple analysis of the water paths and maximum area of a catchment basin. The process is described below.

Using a hydrological fill operation removes dimples in the terrain and areas the water gets caught.

Using spatial analysis Flow direction, an 8-directional (D8) raster has been generated, it represents the slope direction of the ground. A flow accumulation action makes streams that follows the slope direction of the terrain. Streams shorter than 125m are hidden for readability. The streams are then made features for analysis and presentation. From the flow direction raster, basins can be created indicating the entire catchment area. There are 5 individual catchments registered in Straen. Model for this analysis is in figure 1

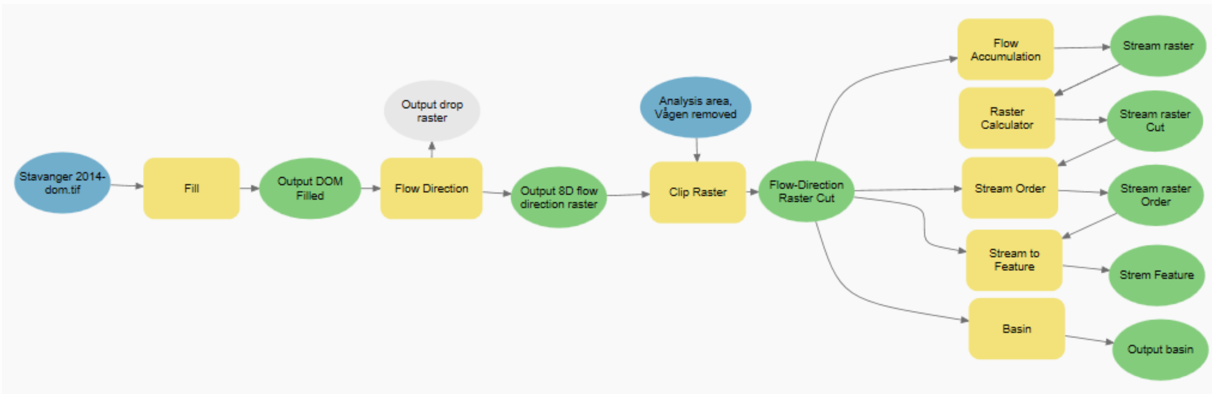


Figure 1. For me to easily do the analysis multiple times with different maps. I have structured the entire analysis in models. Blue is input variable. Yellow is analysis. Green is output.

The catchment areas were then divided into smaller watershed to be able to analyse different parts of the catchments individually, in total 31 catchments were made.

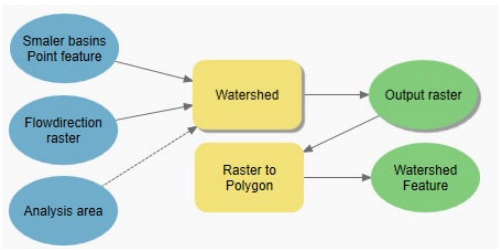
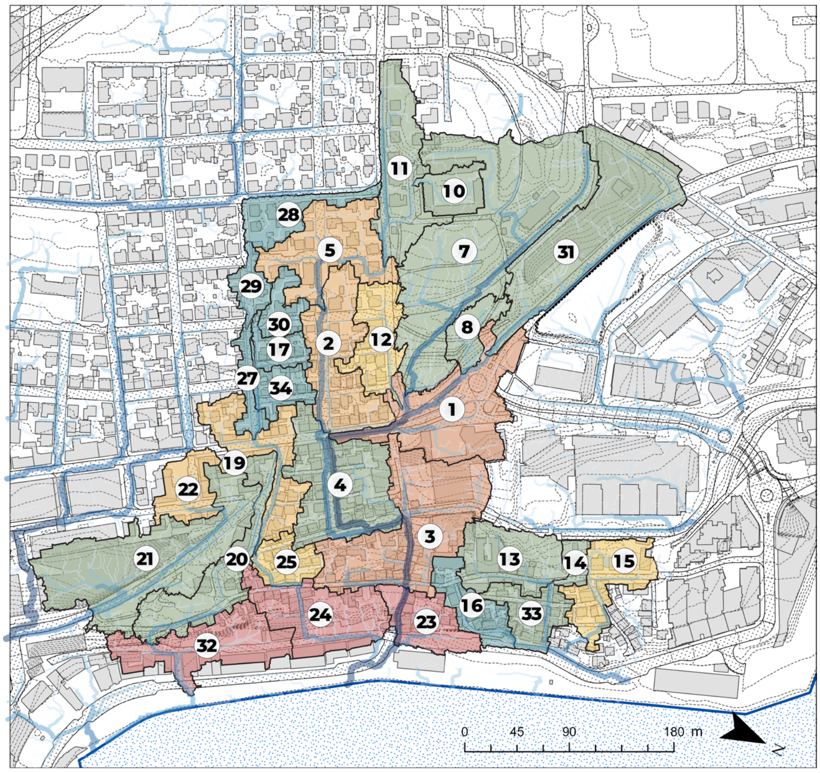


Figure 2: Model used to make watersheds based on point placement allowing division of the Catchment area. Blue is input variable. Yellow is analysis. Green is output.

Under neat is the current result of the analysis.



A cutout of the FKB features Road, Houses, and Parks was done for each induvidual watershed. And exported to Excel

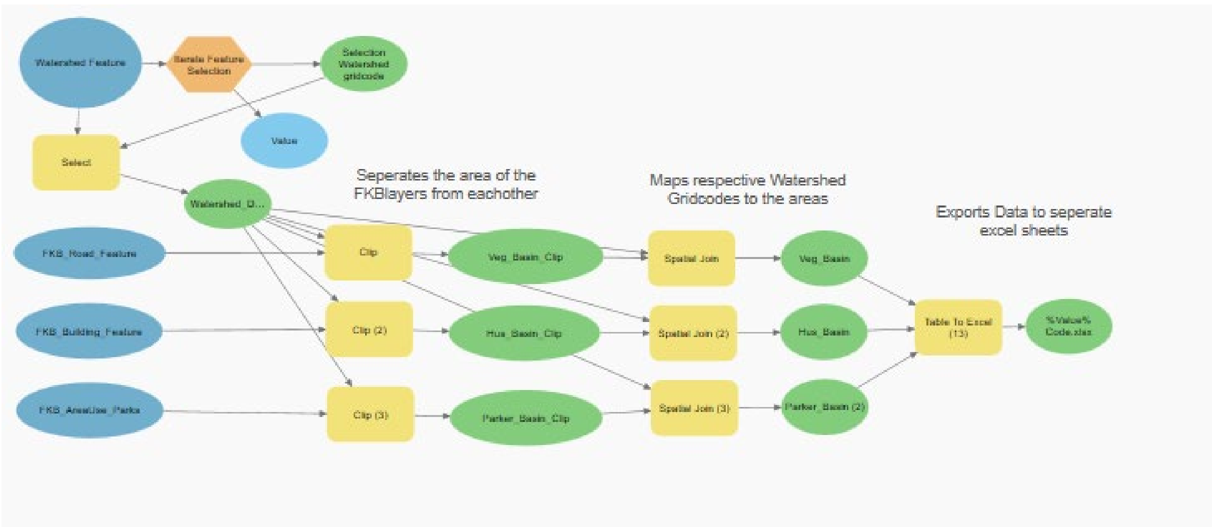
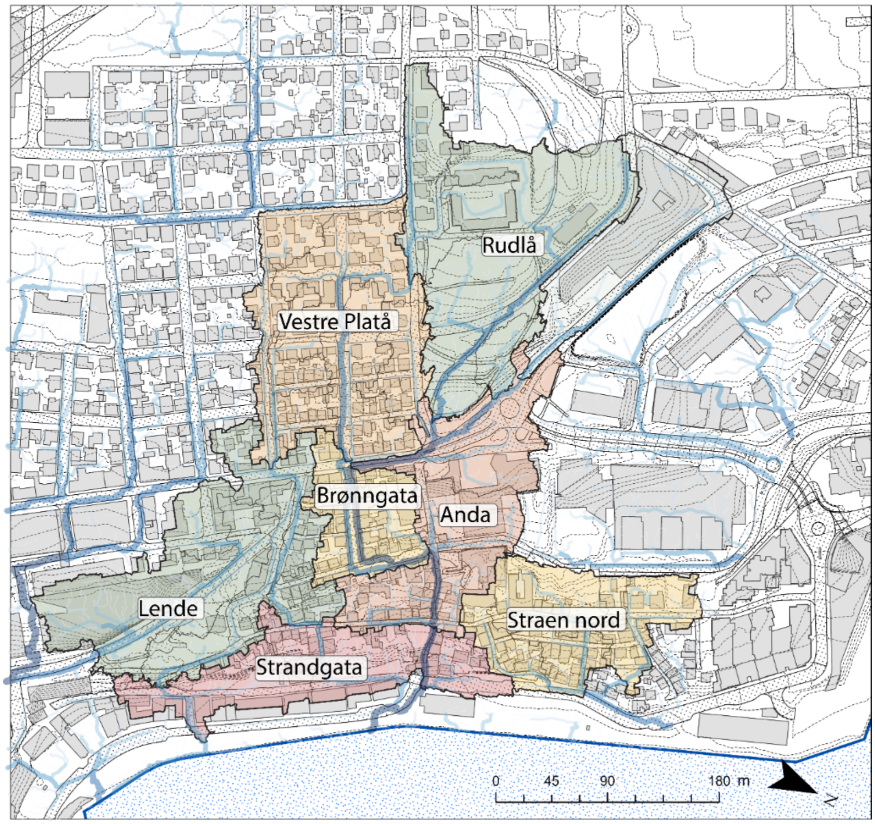


Figure 3: This model divides the individual watersheds into the differen area types from FKB map and exports them to excel for futher analysis. Blue is input variable. Yellow is analysis. Green is output.

In excel a runoff value was given to the individual area types (e.i. roads, houses, parks) and a value was given to the rest area (unregistered data in the FKB maps). These where then used to calculate the average runoff coefficient. Underneath is an example of one of the watersheds. The values and formulas used are presented in the next chapter.

Watershed:1		Total Areal->	8048,7	m²
Arealer	**Areal**	**Runoff coefficient**	**Precent cover**	**Average Runoff coefficient**
Tak	1327,79424	0,9	0,16497068	0,148473616
Asphalt	4675,20198	0,9	0,58086656	0,522779903
Coblestone	0	0,9	0	0
Grass	723,40851	0,17	0,08987929	0,015279478
Sum ^	6726,40474			
Rest area	1322,2631	0,55	0,16428347	0,09035591
Total:	8048,66783	0,72	1	0,776888907

These where then combined and organised into 7 main areas based geographical placement and Topographical and morphological similarities, and visual interpolation of the streams correcting missing data in the maps.



Runoff:

To determine runoff from basins smaller than 2 – 5 km², the rational formula is adequate. For bigger basins the formula comes with great uncertainties (Statens vegvesen, 2023, p. 54).

The rational formula:
$Q = A_{basin} \cdot \varphi \cdot \mathrm{I} \cdot K_f \cdot S_f$

Q	- surface runoff [l/s]
A_{basin}	- size of the basin [ha]
φ	- average runoff coefficient of the Basin
I	- dimensional amount of precipitation [l/(s*ha)]
K_f	- climatic factor
S_f	- safety factor

Average Runoff coefficient (φ) is calculated by assigning a runoff coefficient for each type of ground cover.

$$\varphi = \frac{\Sigma(C_i\, A_i)}{A_{basin}}$$

A_{basin}	- size of the basin [ha]
φ	- average runoff coefficient of the Basin
C_i	- Runoff coefficient of individual area
A_i	- Size of individual area

Example:

Runoff = $\frac{(Asphalt\ area * Asphalt\ coefficient)}{Basin\ Area} + \frac{(Grass\ area * Grass\ coefficient)}{Basin\ Area}$ + ...

The runoff coefficients are provided by (Statens vegvesen, 2023), but has been simplified.

‘Safety factor is normally set to a place between 1 and 1,3 based on the return period of the precipitation event used (Statens vegvesen, 2023, p. 55).

Runoff Values:

The runoff values used are collected from table 7.4.2-2 in N-v240 'Water management' Statens vegvesen (2023, p. 56). As the average slope of the area is 5,7% (Høydedata.no, 2014) the middle values will be used (2-10%). The table does not display a value for cobblestone, the value for impermeable gravel will be used for this.

Tabell 1: List over runoff coefficients used. Based on table 7.4.2-2 – Statens vegvesen (2023, p. 56)

Surface	Slope		
	< 2%	2 - 10%	> 10%
Road			
Asphalt/paved road surface (impermeable)	0,90	0,90	0,90
Gravelled road surface (impermeable)	0,85	0,85	0,85
Road Shoulder - compacted soil	0,50	0,50	0,50
Land use- general			
Moderately densely populated residential area (750 - 1500 dwellings/km2)	0,50	0,55	0,60
Very densely populated residential area (> 1500 dwellings/km2)	0,70	0,75	0,80
Land Use - Detailed			
Roof surface	0,90	0,90	0,90
Lawn and park areas	0,17	0,22	0,35

Using an "area use" map (FKB Arealbruk) in GIS, the different surface areas can be assigned runoff values. There are however multiple shortcomings with this map as well. Sidewalks, and private areas are not mapped. To account for this an estimation of sidewalk has been made, and a median value of 0,55 has been assigned to the rest area (all unmapped areas).

1.2. Map Shortcomings

FKB discussion

Using the map "FKB Arealbruk" area of each surface type can be found, some surfaces are however not mapped this includes private areas, and sidewalks.

To give an estimate of the sidewalks area the roads (with sidewalks) were divided into three different groups, categorized by average width (1)5-7m, 2)7-10m, 3)10-12m). Multiple example spots were chosen and relation coefficient for road sizes and connected area between buildings was made (1) 0,46, 2) 0,9, 3) 0,5). The road groups areas were then multiplied with the relationship coefficient. (Bias can occur from the choosing of measurement spots)

Unregistered areas in the FKB map makes up 30% of the basin area (excluding the approximated sidewalks. Most of this is private areas between buildings and have a lot of material variation. An average coefficient of 0,55 was decided for the remaining area. Giving the total basin a runoff of 0,72 approximately that of an heavily urbanised area (Statens vegvesen, 2023, p. 56).

Using orthophotos some surfaces such as roads can be further divided into asphalt and cobblestone.

Figure 4: The same area in an orthophoto (NordKart, 2022) and FKB map. The use of in between areas varies greatly.

The choice of coefficient source can have a great impact on the dimensioning surface runoff.

Report	Total coefficient of basin	Runoff m³ 5-year 10 min interval of today
N-V240(Statens vegvesen, 2023)	0.72	934,67
N200 Veibygging 2014 (Statens vegvesen, 2014)	0,68	882,75
Midlere avrenning (Magnussen, 2015)	0,59	765,91

Terrain data discussion

For the terrain, multiple surface maps are available, FKB contour lines is probably the most general, DSM (digital surface model) is the map type with most data. This however makes barriers of trees and registers cars in the roads. A middle way is the DEM (digital elevation model) which is a DSM where the terrain is interpolated underneath obstacles. This however removes all obstacles. Using a trial-and-error approach with some requirements for the terrain map shows that the DSM map is most suitable for the specific task.

Other options for this are: 3d model of the area. This is too time consuming. Or a combination of cad files and DEM/DSMs.

<u>Goal: Create an accurate watershed, and water path analysis.</u>

Requirements

- Register obstacles (houses, walls).
- Register micro variations in the terrain (e.g., height difference from road and sidewalk).
- Portray water ways most accurately.

As the Countour map does not display microvariation in the terrain, it will be to general. The DEM does not take housing into account as barriers and will not be accurate enough. The DSM displays vegetation, cars and overhanging structures as obsticals that can disturb the waterpaths. A cutout of the buildings form the DSM was plased on top of the DEM map to generate a hybrid. This hybrid does hovever miss variations on the plots between housings. Making it posible for water to take paths that does not work.

Figure 5. the same geographical area, in different map formats. From left: Contour map, DEM (Digital Elevation Model), Hybrid of DEM and DSM (Digital Surface Model), DSM

One of the main issues with the maps are not the microvariations getting lost in the data. The Laz maps avaleble for me are from 2014. Major and minor changes that alter the flow of water has happened since then, and such the waterpaths may not represent reality. To adress this and other issues, varriations in the data basis are registered and analysed by map, and on site visual aproximation of the terrain, to deside on the must accurate waterflow.

Main issues with the map data:

DSM: creates obstacles of vegetation cars, and overhanging structures

Hybrid: Regains buildings from DSM map while keeping topology from the DEM map without vegetation and overhanging structures. But loses manmade structures between buildings and other man-made structures.

Summary

Variation in data can affect the way of the water greatly. In most cases the differences create little complications as the water gathers further down the path. The map below accentuates parts where the difference in data creates notable difference in the results. Some places the choice of data can lead to a difference in multiple ha of basin area as evident in the most southern accentuated result. This one is major, but does not impact the area, and will therefore not be further discussed.

Some places the only separation between an extended basin and the current is a height in the middle of the road, this however can be bypassed by water with speed. For this analysis its assumed that the water will not reach such speeds, and that the surface runoff is addressed before running over into to the modelled basin.

From site visits it is evident that the DSM gives the most accurate result. The DSM will be the basis of the work in GIS. And manual divisions of watersheds will provide accuracy where the data fails to portray the situation. The visual comparison of the water paths is provided below.

Figure 6: Highlighted areas where the paths differ substantially, Light blue: stream analysis on DEM map, Dark blue: Stream analysis on DSM map. Red: Visual interpolation.

Appendix 2. Dimensioning IVF Values

The IVF values in this thesis will be taken from the local weather station in Stavanger at Våland (SN44640). This is the weather station with IVF-values, closest to Straen. Våland weather station has 21 years of data (1999-2022) and has the quality grading: Somewhat uncertain (2) (Meteorologisk institutt, 2023). This is good enough to use on its own (Dyrrdal et al., 2022).

	Dimensjonerende gjentaksintervall < 50 år	Dimensjonerende gjentaksintervall ≥ 50 år
≤ 1 time	40 %	50 %
>1 – 3 timer	40 %	40 %
>3 – 24 timer	30 %	30 %

Cutout from Seklima, Nedbørintensitet (Meteorologisk institutt, 2023)

IVF-verdier for Stavanger - Våland (SN44640), 72 moh.

Data fra 1999 - 2022, 18 ses. Oppdatert 31.12.2022.

	Varigheter (minutter)															
Gjentaksintervall (år)	1	2	3	5	10	15	20	30	45	60	90	120	180	360	720	1440
2	1,6	2,7	3,7	5,0	6,7	8,0	8,7	9,8	11,6	13,0	16,0	18,4	23,1	33,0	44,3	53,5
5	2,1	3,4	4,7	6,7	9,0	10,9	11,8	12,5	14,3	15,7	19,6	22,6	28,4	40,5	56,8	68,3
10	2,4	4,0	5,4	7,9	10,7	13,0	14,1	14,6	16,5	17,9	22,4	25,8	32,2	45,3	65,5	78,8
20	2,7	4,5	6,1	9,1	12,5	15,1	16,5	16,9	18,8	20,3	25,4	29,2	36,2	50,2	74,4	89,0
25	2,8	4,6	6,3	9,5	13,1	15,8	17,3	17,7	19,6	21,1	26,4	30,3	37,5	51,7	77,5	92,5
50	3,1	5,1	7,0	10,7	15,0	18,0	20,0	20,2	22,2	24,0	29,7	34,0	41,8	56,4	87,3	102,7
100	3,5	5,6	7,7	11,9	17,0	20,4	22,7	23,2	25,4	27,3	33,5	38,0	46,5	61,0	97,2	113,7
200	3,8	6,2	8,4	13,2	19,2	22,9	25,6	26,4	28,8	31,0	37,8	42,6	51,7	65,6	107,3	125,1

Cutout from Seklima, Nedbørintensitet (Meteorologisk institutt, 2023)

Appendix 3. Raingarden formula retention and infiltration

Formula for calculation the required dimensioning of raingardens (Braskerud et al., 2013, p. 43)

$$A_{bed} = \frac{Q}{H_m + K_{sat} \cdot t_d}$$

A_{bed}	- size of raingarden (m²)
Q	- surface runoff of connected basin [l/s]
H_m	- maximum water level at the surface of the bed before the water goes into overflow (m)
K_{sat}	- saturated hydraulic conductivity of the filter media (m/h)
t_d	- dimensioning duration of rain (h)

To generalise I have used for all raingardens a depth (H_m) of 0,25m and an infiltration speed (K_{sat}) equivalent of what found in Deichmans gate 0,35 m/h (Egeberg et al., 2021) (this is in the upper range of infiltration speed values.)

The formula can be adapted to measurements without options for infiltration by setting the Ksat to 0.

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