Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Landscape Architecture, Horticulture and Crop Production Science

Integrating Stormwater Management into Urban Space

– The Kvillebäcken Watershed as Testing Ground

Integrering av dagvattenhantering i den urbana miljön

– Kvillebäckens avrinningsområde som testbana

Scott Wahl

Degree Project • 30 credits
Landskapsarkitektprogrammet/ Landscape Architecture Programme
Alnarp 2014

Integrating Stormwater Management into Urban Space
The Kvillebäcken Watershed as Testing Ground

Integrering av dagvattenhantering i den urbana miljön

Kvillebäckens avrinningsområde som testbana

Scott Wahl

Supervisor: Allan Gunnarsson, SLU, Department of Landscape Architecture, Planning and Management

Co-supervisor: Jesper Persson, SLU, Department of Landscape Architecture, Planning and Management

Examiner: Ann-Mari Fransson, SLU, Department of Landscape Architecture, Planning and Management

Co-examiner: Bengt Persson, SLU, Department of Landscape Architecture, Planning and Management

Credits: 30 credits
Project Level: A2E
Course title: Master Project in Landscape Architecture
Course code: EX0545
Subject: Landscape Architecture
Programme: Landskapsarkitektprogrammet / Landscape Architecture Programme

Place of publication: Alnarp
Year of publication: 2014
Cover art: Name of photographer
Online publication: http://stud.epsilon.slu.se

Keywords: stormwater, green infrastructure, multifunctional, dagvattenhantering, Kvillebäcken, stream

SLU, Swedish University of Agricultural Sciences
Faculty of Landscape Architecture, Horticulture and Crop Production Science
Department of Landscape Architecture, Planning and Management

Preface

The mantra of many city planners is to densify cities like Gothenburg. This is so that communities will be more walkable, bike-able and can be served by public transportation more efficiently. Densification can reduce resource demand which is certainly important when designing sustainably. Another way, however, is to optimize ecological processes to provide us with services such as stormwater management. By providing space for ecological processes, density does not have to be lower (Lyle, 1985). Much can be done on land that is already green within a city. Natural landscapes provide ecological services such as cooling via evapotranspiration and shading; sequestering of carbon dioxide and production of oxygen via photosynthesis; filtering runoff and recharging of ground water. When the natural features that provided these services disappear, some of the services need to be taken over by machinery and grey infrastructure such as pipes, pumping stations and water treatment plants. In other instances the burden of providing these ecological services is simply put on other parts of the ecosystem which in turn become overburdened and fail. The concept of green infrastructure recognizes the valuable services nature provides to humanity. It attempts to mitigate our effect on the environment through maintaining, connecting and mimicking natural processes. Adapting our society to one that economizes with resources and balances the books with nature is necessary if we are going to be able to confront the challenges we are facing such as global warming and the depletion of easily accessible fossil fuels. We need to find a balance. Planners now have the chance to make space for natural processes that recycle resources when reprogramming the space left by defunct industries. A perfect opportunity lies within Kvillebäcken's watershed.

Table of Contents

Introduction

Background

Plans and development are underway to expand the Gothenburg urban center into the lower reaches of the Kvillebäcken watershed that today contain a mix of industrial and commercial properties. The land was once a productive wetland that filtered water on its way to the ocean. Today the area is largely covered by impermeable surfaces such as asphalt, cement and buildings. Much of the runoff from these impermeable surfaces is channeled through stormwater pipes to Kvillebäcken without any form of treatment. The contaminants in the runoff thus pollute Kvillebäcken and its receiving waters the Göta River and the North Sea.

Problem

Future development may not consider the opportunities available to manage stormwater with green infrastructure. Current stormwater management negatively affects Kvillebäcken and the Göta River. In addition to the stormwater issues, the riparian corridors that currently exist in the watershed are not optimized to promote biodiversity, be used as recreational corridors or filter runoff.

Objective

I would like to explore possibilities for managing stormwater with blue-green infrastructure in the Kvillebäcken watershed. I define blue-green infrastructure as a network or components of a network that use ecological and biological processes to provide ecological services such as stormwater management, outdoor-recreation and wildlife habitat. I would like to evaluate where this blue-green infrastructure could be put into the existing urban matrix and what form it could take.

Method

The method or workflow I used goes from inventory and analysis to proposal. Peter Stahre, who was a proponent of sustainable stormwater management and head ofVA Syd in Malmö, Sweden, points out that it is necessary to think broadly but act in small ways (Stahre, 2004). Furthermore he identified the need for looking at the whole watershed when managing stormwater (Stahre, 2004). Taking his advice, I studied Kvillebäcken's entire watershed in order to come up with a holistic solution to managing stormwater. I worked both in small and large scales to understand the watershed. In the higher elevations, characteristics such as land use, permeability, vegetation, topography and soil composition affect the hydrological conditions in the lower elevations. These characteristics thus need to be taken into account when designing a stormwater treatment facility anywhere in the watershed. An inventory was compiled from literature studies, online material, technical reports, GIS-data, historical images, personal communications with experts and my own observations. Since the Gothenburg municipality has been planning and is in the process of developing this part of the city, quite a few reports have been commissioned to examine the preconditions of the area. The reports have looked at stormwater management, flooding, contaminated soils, environmental consequences of new development and traffic. These reports became a good resource when compiling the inventory and analyzing the potential for managing stormwater with blue-green infrastructure.
I used Geographic Information System (GIS) software to produce themed maps instead of merely collecting maps. I did this since it provided the ability to combine data from a multiple of sources, which helped me gain a deeper understanding of the connections between various landscape attributes. The data for the inventory and analysis came from Gothenburg's planning authority, Gothenburg's water and sewage utility, the city owned development company Älvstrandens Utveckling, the Swedish geological authority (SGU) and Länstyrelsen's (GIS) website. Other data is from academic reports or reports commissioned by Gothenburg's municipality, Länstyrelsen, historical maps, Lantmäteriet, personal communications and on site observations.
In order to come up with a viable proposal, I have studied research on mechanisms that extract pollutants from stormwater such as heavy metals, hydrocarbons, nitrogen and phosphorous. I have also studied various stormwater infrastructure guides sourced mostly from governmental agencies in the USA. Cities such as Portland, Oregon and Seattle, Washington have implemented green infrastructure widely in recent years in their management of stormwater and have documented their work extensively.

Delimitations

I have limited the area of study to the Kvillebäcken watershed and its tributary, the Göta River. Actual stormwater volumes or economic calculations were not made. I have not considered information that was not available to me such as the location of underground utilities.

Figure 1. Orthophoto showing were Gothenburg is located in Scandinavia.

Figure 2. Orthophoto of Gothenburg with Kvillebäcken demarcated.

Inventory and analysis of Kvillebäcken's watershed

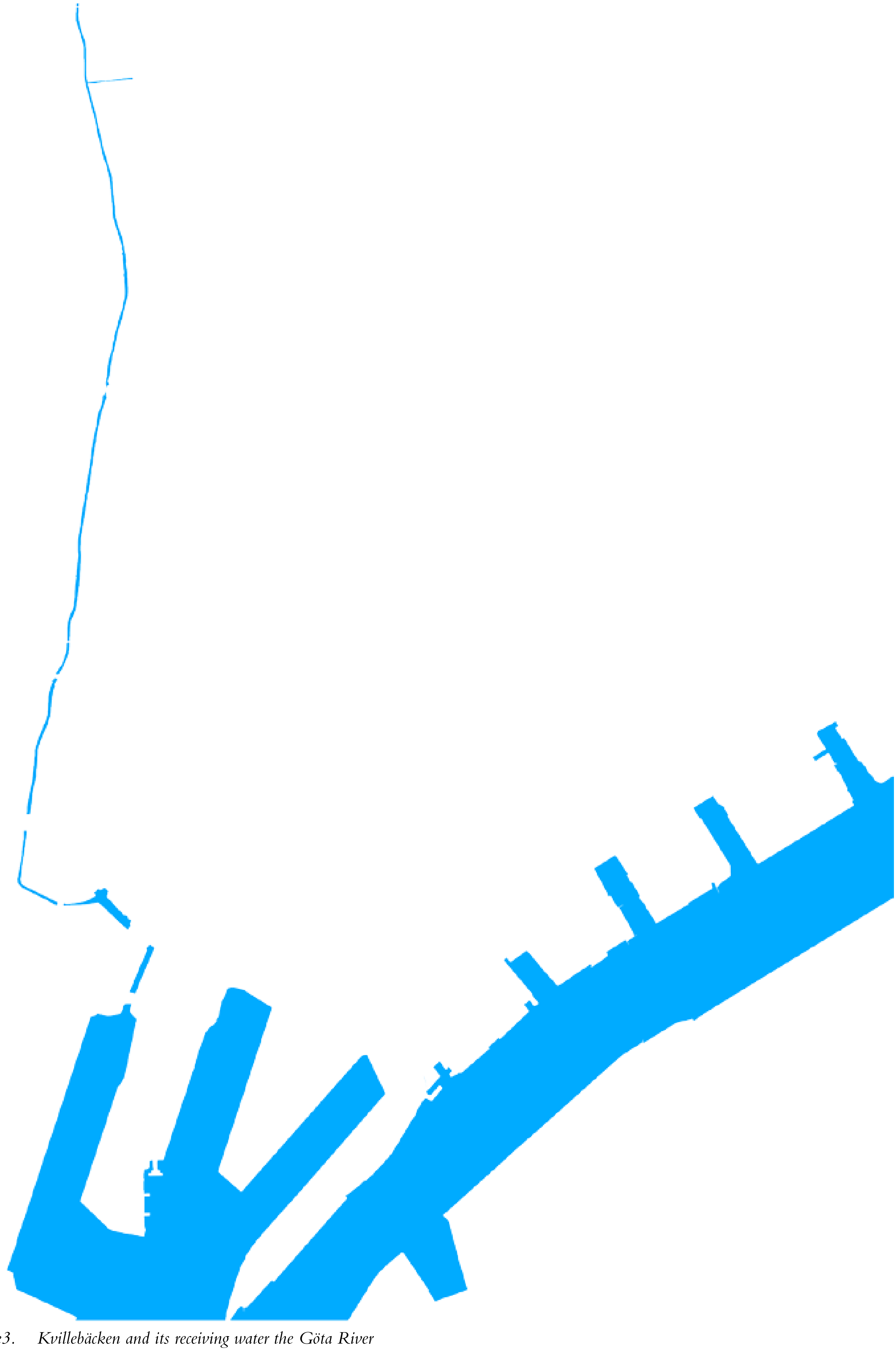


figure3. Kvillebäcken and its receiving water the Göta River

A Walk Along Kvillebäcken from Beginning to End

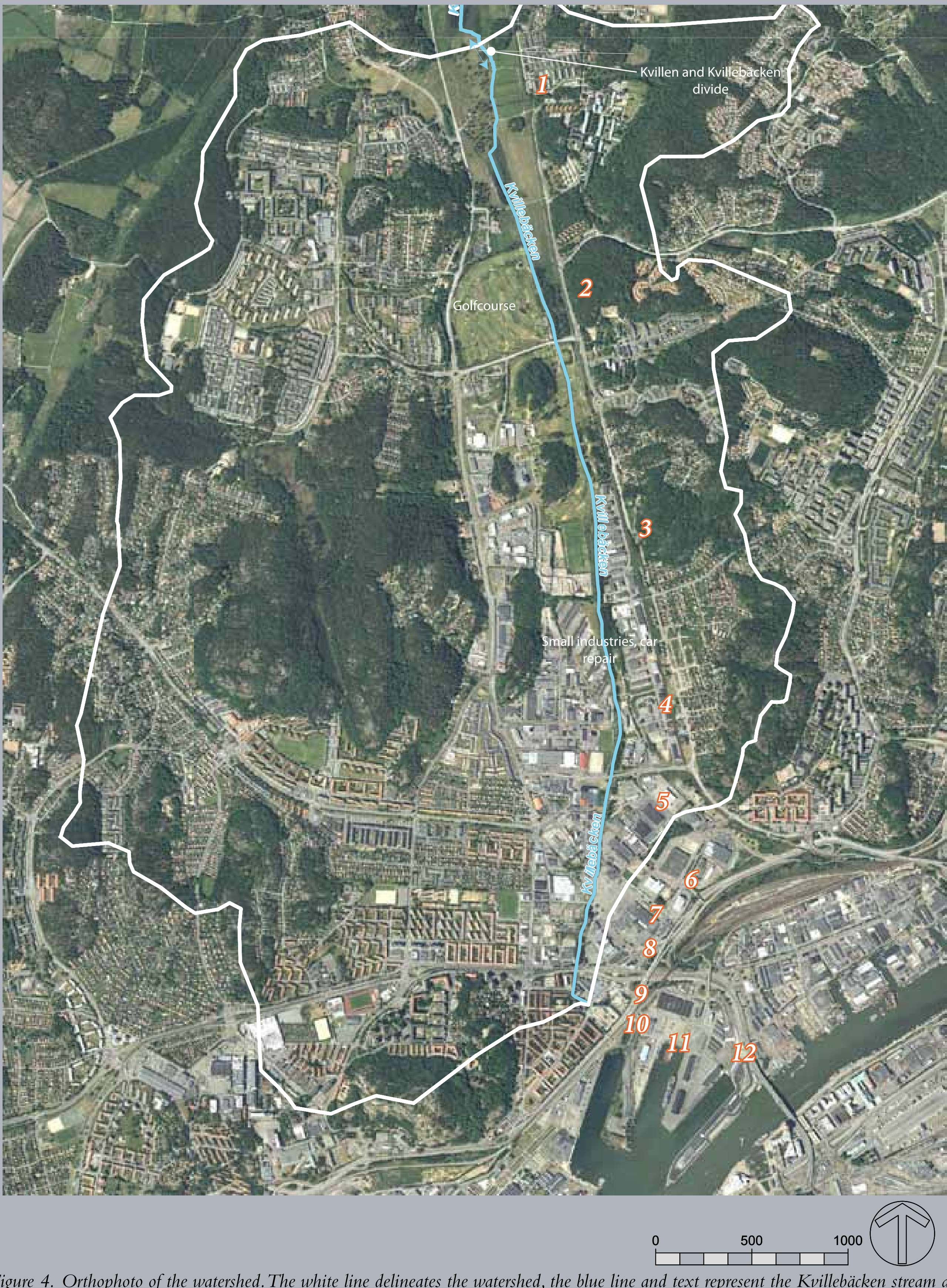


Figure 4. Orthophoto of the watershed. The white line delineates the watershed, the blue line and text represent the Kvillebäcken stream and the numbers correspond to numbering in the text in the Chapters: "A walk along Kvillebäcken from beginning to end" to aid in orientation.

The stream Kvillebäcken is part of a riparian corridor joining the Nordre River and Göta River estuaries. The corridor drains in two opposite directions making it a so-called bifurcation (see Figure 4). The stream draining to Nordre River is called Kvillen and the stream draining to Göta River is called Kvillebäcken. Kvillen flows through an agricultural landscape and is primarily edged by crop fields. Kvillebäcken's watershed is more urbanized and contains a much greater proportion of impermeable surfaces. At Hökälla, where the stream changes direction, the average water level is only two meters above the average water level in Göta River. That means that the stream has a change in elevation of only two meters along its nine-kilometer path and is thus very slow moving.

1. Hökälla (located at the top of the Kville Valley) is a 63 hectare area managed to support a diverse population of birds and animals. It functions as a recreational area, productive farmland and habitat supporting many species: especially bird species. In the heart of Hökälla lie three ponds that were created by damming and digging along Kvillebäcken. The ponds were designed to have broad shorelines and have varying depths to provide a variety of habitats for maximum diversity. Small "nesting" islands in the ponds provide protected areas where birds can hatch their eggs, safe from predators and humans (see Figure 5). As Figure 7 depicts, sheep and bovine livestock graze along the shore. Grazing improves conditions for birds that hunt insects in muddy flats by keeping down vegetation. Not only does grazing support several bird species but it also promotes a greater flora. By removing nutrients and shade from the ground, less vigorous vegetation gets a chance to thrive. In addition to the grazing livestock, people go in to cut and remove some of the vegetation where the grazers can't reach. Reed (Phragmites australis), bulrush (Typha latifolia) and young woody species are removed to maintain open water for the wading birds and to promote other vegetation in the wet meadows. Some reed and bulrush tufts are purposely left standing as some species depend on them.

As the water exits Hökälla it is relatively clean, however, it soon picks up copper ions from a joining stream (Lindberg and Ödegaard, 2011). In the hills to the east of Hökälla lies Lillhag's Park. This park has many very old oak trees and the fauna and flora that accompany them (Andreasson and Thulin, 2010). There are also

Figure 5. A pond at Hökälla designed to improve bird habitat
2011-04-28

Figure 6. Bird watchers gather at Hökälla to get a glimpse of the many species that either stop here along their migration or live here year round.
2011-04-28

Figure 7. Grazing animals near Hökälla increase biodiversity
2011-09-16

Figure 8. Golf course drains directly into Kvillebäcken and here it lacks any sort of riparian zone.
2011-04-20

Figure 9. Swampy forest adjacent to St. Jörgens Golfcourse. This biotope is very uncommon within the Kville Valley and an attractive habitat for a variety of species.

Figure 10. Area along Kvillebäcken is often used for illegal dumping 2011-05-12

Figure 11. Small industries that drain into Kvillebäcken 2011-04-20

Figure 12. Here drainage is led in open ditches that not only short-circuits the riparian zone but also drain it as well. 2011-04-20

Figure 13. Grass area along Kvillebäcken that tends to become saturated and is frequented by foraging birds 2011-06-19

Figure 14. Oily film and emerging reed in Kvillebäcken 2011-05-15

Figure 15. Parts of Kvillebäcken are overgrown with reed 2011-06-19

Figure 16. Riparian corridor is limited here 2011-04-20

Figure 17. Large oversized parking lots next to Kvillebäcken develop large amounts of runoff 2011-06-19

quite a few copper roofed buildings from which runoff negatively impacts Lillhag's stream: a tributary to Kvillebäcken. Raised levels of copper ions can also be found in Kvillebäcken downstream of Lillhag's stream, which is unfortunate since it is toxic to many organisms (Lindberg and Ödegaard, 2011).

2. Just downstream from the Hökälla nature-preserve, Kvillebäcken runs through Sankt Jörgen's golf course. As Figure 8 shows, the stream has little riparian zone to filter drainage water coming from the golf course that may contain fertilizers and pesticides. PVC drainage pipes emerge from the soil and run out into Kvillebäcken. The short kept green goes right down to the water's edge. A riparian zone would allow for ecological processes that prevent loss of soil and trap or transform nutrients and pesticides as well as provide habitat for many more species. The golf course has two forested hills that are grazed by livestock (Andreasson and Thulin, 2010). By grazing, nutrients are removed and grasses and brushwood are kept down thereby allowing less rigorous vegetation a chance to grow. Next to the golf course, there is a swampy forest (see Figure 9). The stream then crosses Finlandsvägen, the first of several roads that create a barrier for flora and fauna from migrating through the valley. The bridge here seems tall enough to allow for at least some species to pass underneath. After the bridge, the golf course spreads to both sides of Kvillebäcken.

3. After passing the golf course the path crosses Kvillebäcken and now follows the stream on its western side. Here the stream gains some tree cover. There are also solitary trees and small groups of trees within a grass area separating the stream from the pedestrian path parallel to Kvillebäcken. The tree layer is dominated by birch (Betula ssp.), Aspen (Populus tremula) and some wil-

Figure 18. Major Stormwater and sewage overflow outfall at Backaplan 2011-04-20

Figure 19. Dug whole at a former gas station that, with in a short time, was populated with cattail and reed 2011-05-15

Figure 20. New housing along Kvillebäcken 2011-05-15

Figure 21. New sewer being installed in the Östra Kvillebäcken development
2011-06-19

Figure 22. Nettles and other weeds growing along the edge of Kvillebäcken that is too steep to cut with a lawnmower
2011-06-19

Figure 23. Hjälmar Brantingsgatan is a barrier to the Kvillebäcken corridor
2011-04-20

Figure 24. Some buildings from the former nuts and bolts factory now used as office space, shops and restaurants
11-12-30

Figure 25. The endangered aquatic plant hairlike pondweed (Potamogeton trichoides) (Swedish: Knölnate)

Figure 26. The stream banks are fortified with pilings
2011-10-1

Figure 27. To the left is a parking lot before reaching Herkulesgatan approximately where Kvillebäcken once joined the Göta River. In the background is Porslinsfabriken apartment block being built and in the foreground the grass lawn of the park
2011-12-30

low trees and bushes (Salix caprea). A football field lies on the opposite side of the path. It was built upon the Grimbo landfill that filled a depleted gravel quarry.
4. The industrial area spreads out along both shores of Kvillebäcken. On several sites visible hazardous waste such as televisions and old refrigerators have been dumped (see Figure 10). As Figure 11 shows, drainage from these sites is directed to Kvillebäcken.
5. The stream passes another couple of football fields and then Minelundsvägen via a corrugated metal pipe culvert. Just upstream of the culvert there is a sewer outlet which drains into the stream. This outlet, aside from containing stormwater, may also contain household sewage since it is also used as a bypass for the combined sewage system. After crossing Minelundsvägen the pedestrian path again crosses the stream and follows it along its eastern bank. On the west side there is a small wet meadow that is popular with foraging birds (see Figure 13). Figure 15 shows Phragmites australis growing in the stream channel. After passing the meadow, the industrial lots come right down to the bank of Kvillebäcken which here has a predominantly ruderal character (see Figure 16). There are still trees lining the streams edge but the vegetated area along the banks has narrowed considerably.
6. On the east side of the path, large retail businesses with vast parking lots emerge (see Figure 17). The municipality would like this area to evolve into a more pedestrian friendly mixed-use (weighted toward city shopping) district (Kant, 2008). Today the large parking lots rarely seem full. Even though the streets are narrow here, cars move at a brisk pace. Pedestrian crossings are infrequent and feel unsafe. As a pedestrian or bicyclist, it is often necessary to cross these vast parking lots. The parking lots collect residue from cars that end up in Kvillebäcken when it rains.
7. Further south, just before crossing Färgfabriksgatan, the stream reaches a green area, which includes a small pond and a very large stormwater outlet and sewage bypass (see Figure 18). This outlet can release raw sewage from time to time to prevent the combined sewage system from backing up into basements. Here the municipality intends to build a large roundabout around this green area (Wiik, 2009).
8. Färgfabriksgatan's bridge is fairly open and would not be too much of a hinder for many water loving species to pass although there is, however, no dry ledge for animals to pass that do not want to get wet.
South of Färgfabriksgatan the green area widens into a park. Just west of the park, the construction of 1600 apartments is well underway (see Figures 20 and 21). The park was recently enlarged to also include a strip of land along the West bank of Kvillebäcken. The newly added area has a large playground that is shared by several new preschools in the neighborhood and was completed during the summer of 2013. Aspen stands were cleared to make way for the playground. Here the stream's abrupt edge has weedy vegetation uncharacteristic of wetlands such as the common nettle (see Figure 22). Since the playground will be heavily used, pour in place rubber has been chosen as the primary surface material. To the east of the park lies a shopping mall and parking lot. The endangered species-listed aquatic plant Potamogeton trichoides has its largest known population in Sweden in Kvillebäcken starting about here (see Figure 25).

Figure 28. The path will continue here between the apartment buildings and Kvillebäcken until Kvillebäcken reaches Lundbyleden 2011-12-30

Figure 29. Main sewage pumping station next to the new housing area Porslin's fabriken 2011-05-16

Figure 30. Stormwater drains to Kvillebäcken from the Porslin's fabriken construction site 2011-05-16

9. Kvillebäcken then reaches Hjalmar Brantingsgatan where there is no crosswalk across the 40 meter wide road (see Figure 23). One has to take a considerable detour to cross the road and get back to the stream.

10. An office building lays just South of Hjalmar Brantingsgatan on the West bank. On the East side there is a parking lot in front of buildings that were once a nuts and bolts factory (see Figure 24). A wooden pedestrian bridge crosses Kvillebäcken just after the office building. Figure 26 depicts old wooden pilings that were once driven down to strengthen the banks of the stream. After crossing to the West side of the stream one reaches some parkland consisting of a grass lawn and a row of willow trees that have been ruthlessly pruned back. Volunteer trees line the banks of the stream (see Figure 27). Kvillebäcken makes a sharp turn to the East within the park.

11. This place, where Herkulesgatan and Kvillebäcken meet today is where Kvillebäcken ran out into Göta River before the area was drained and filled (see Figure 27). The remaining stretch of waterway is called Kvillebäcken canal in older planning documents, however, today it is not well known that this part of Kvillebäcken is indeed a canal and not part of the natural waterway. Crossing Herkulesgatan one reaches the Porslinsfabriken area where hundreds of apartments have been recently built (see Figures 28-31). Also here is the main pumping station that pumps sewage and stormwater (from areas where there is a combined sewage system). A path continues along the canal up until the Lundbyleden freeway.

12. Passing the new development one is met with a Plexiglas wall protecting the new apartment dwellers from the noisy Lundbyleden freeway and Hamnbana (see Figure 33). Here Kvillebäcken's flow is directed into a culvert to daylight again in Frihamnen. As shown in Figure 32, a pedestrian bridge about 100 meters south of Kvillebäcken maintains a link to the Frihamnen area. Just before entering the Göta River it goes into three culverts once again to cross a road (see Figure 35). Here, Frihamnen spreads out like fingers of barren asphalt that reach out into Göta River (see Figure 34). Some buildings here have been repurposed and are now offices and one of the piers (fingers) periodically functions as a racetrack.

Figure 31. New apartments at Porslinsfabriken are built very close to what is here called Kvillebcäcken kanal
2011-12-30

Figure 32. Pedstrian bridge over Lundbyleden and Hamnbanen
2011-05-16

Figure 33. Lundbyleden and Hamnbana create large barrier for the Kvillebäcken corridor
2011-05-16

Figure 35. Kvillebäcken drains out to the Göta River via these three culverts in the Frihamnen area.
2011-05-16

Figure 34. Frihamnen area consisting of three large piers built on the former marshlands along Götaälv
2011-08-26

Figure 36. Disused crane in the harbor is a reminder of Gothenburg's industrial past
2011-05-16

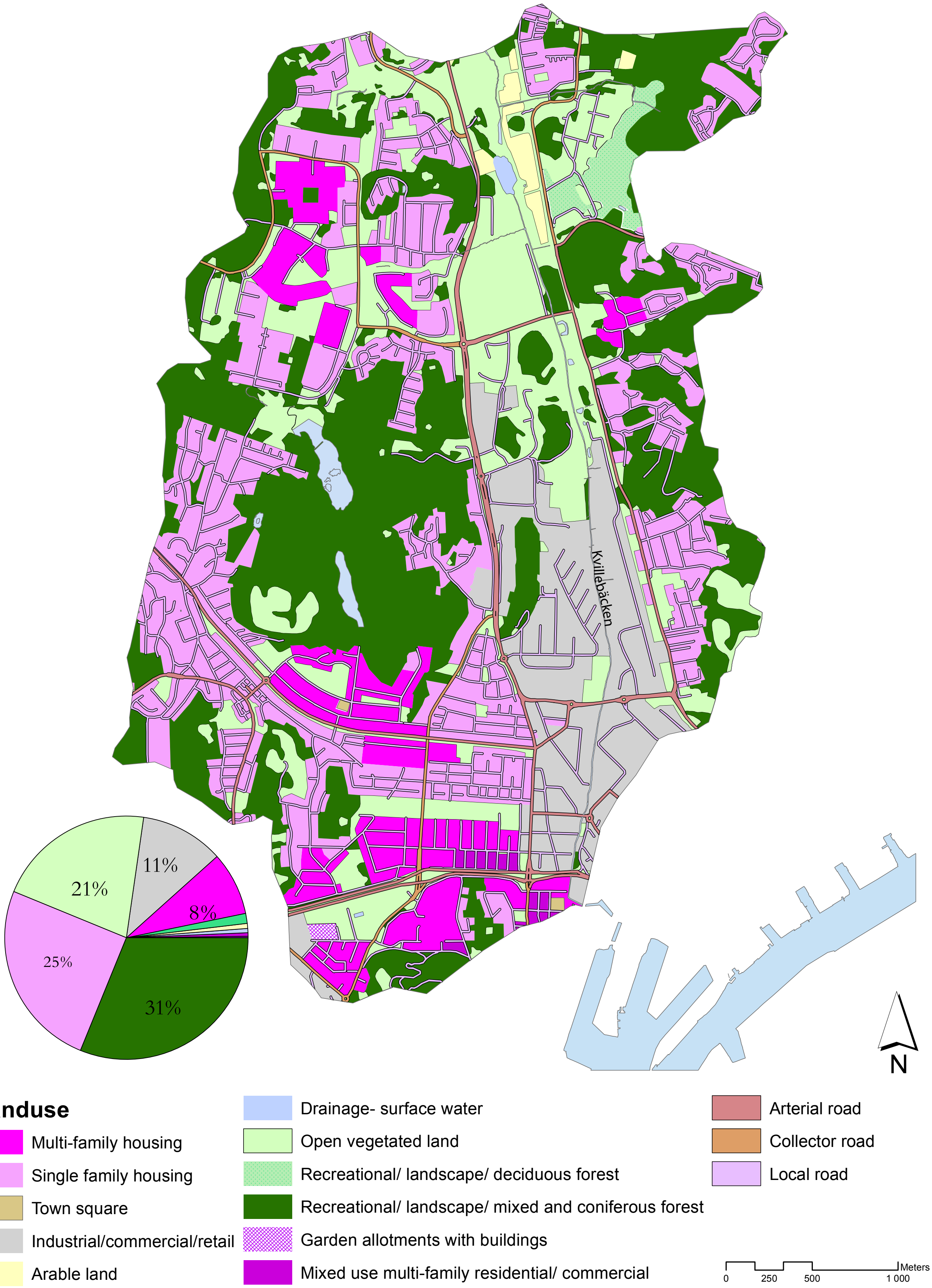


Figure 37. The land-use map and pie chart show the distribution of land uses in the watershed. As the map indicates, Kvillebäcken runs through areas where few people live. A greater need for recreational space comes hand in hand with the transformation from commercial/industrial to residential uses that is happening now.

History

Since the time when Hisingen was freed from ice around 10,500 B.C. it has risen about 90 meters due to post-glacial rebound (Andreasson and Thulin, 2010) . Up until 2,500 years ago the Kville Valley was a sound connecting Nordre and Göta estuaries but due to post-glacial rise, the sound developed into a slow flowing bifurcated river (see Figure 40). Even today the top of the valley is only a couple of meters above sea level. Kvillebäcken was an important waterway up until the 19th century but sediment accumulation in the waterway from draining, plowing and filling the land abutting the stream made it too shallow for most boats.

People have lived on the island of Hisingen for 7000-8000 years (Åsander, 1990). The earliest settlers' primary source of food came from fishing and hunting, however, agriculture eventually started to develop about 6000 years ago. The first crops were planted in well-drained gravelly soils on southerly slopes (Åsander, 1990). This is probably since more productive soil just wasn't available. More fertile soil such as moraine deposits containing a variety of particle diameters is fairly uncommon in the region. This is because most of the land is under the highest post-glacial shoreline and thus the soil has been washed out by wave action. In other regions such as in Sweden's Småland where moraine soils are more common, the crops were grown on moraine deposits (Åsander, 1990). The Gothenburg area had a considerably warmer climate than it does today up until sometime during the Bronze Age between 1500 and 500 B.C. (Åsander, 1990). During this warmer period a hardwood forest developed to cover much of the land (Åsander, 1990). Most of these forests were gradually cut down and the land grazed which also prevented the trees from growing back (Åsander, 1990). The weather became cooler and the growing season shorter making it necessary to provide winter hay (Cserhalmi, 1998, Åsander, 1990).

The clay soils of the flatter land were not tilled for cultivation until drainage techniques and the steel plow were developed in the 19th century (Åsander, 1990).

Figure 38. This map from 1658 dates from before the peace treaty of Roskilde. It shows how Kvillebäcken was the defining border between Norway to the East and Sweden to the West {Lindmark, #421}. Even in 1658 Kvillebäcken was fairly straight.

Before that these lands were grazed and used for hay production. This was the case on the valley floor of the Kvillebäcken watershed up until the middle of the 19th century. During the 18th century waste from Gothenburg was dispersed along Kvillebäcken to improve the soil. Through much of Gothenburg's history, Hisingen was the breadbasket to the city providing much of the food consumed there.

Dredging Göta River and filling the marshlands near Kvillebäcken

In Petterson's (1932) description of the harbor's development, by 1882, there was a dredged channel with a depth of five and a half meters and a breadth between 60 and 75 meters in the middle of Göta River. Further upriver, however, the natural depth was deeper and allowed a hull draft of three meters (Petterson, 1932). Only ships with a maximum depth of three meters could come up to the harbor from the sea (Åqvist, 1908). Ships with deeper hulls had to land at Klippan outside of town or even further away depending on the ships depth (Åqvist, 1908). In the narrower and deepest section between Stigberget and Lindholmen the natural depth was around six to seven meters (Petterson, 1932). In 1843 it was decided to dredge the river and build a stone pier to allow larger boats to land nearer the city (Åqvist, 1908). The width of Göta River between Tingstadsvass and Gullbergsvass was 237 meters (Åqvist, 1908). This area went from having a natural depth in the early 19th century of no more than three meters to six, seven, nine and eventually to today's 9,8 meters (Petterson, 1932, Åqvist, 1908). The dredged material removed to make the channel deeper needed to be disposed of. The apparently worthless marshlands along the banks of the river seemed like ideal places to dump the dredged up sediments since this would create additional land available for urban expansion (see Figures 41 and 53).
As Figures 57-59 show, up until the middle of the 19th century large reed beds such as the Tingstadsvass and the Lundbyvass formed a delta landscape in the Göta River basin between Gothenburg and Hisingen. (Andreasson and Thulin, 2010). Most of the river estuary was quite shallow. At its deepest the river between the city center and Hisingen was only about three and a half meters deep (Åqvist, 1908). The estuary had an incredibly rich fauna that essentially disappeared when filling in of the area with dredging material was completed (Andreasson and Thulin, 2010). Before drainage the marshlands flanking Göta River were a mecca for birds and fish. The marshlands were described as excellent hunting grounds. Today there are virtually no marshlands left.
Filling marshlands in estuaries was a common practice around the world when many cities grew exponentially during the industrial revolution in the first half of the 19th Century. Marshland was seen as useless and perceived to harbor disease. At this time decision makers did not know of the ecological services marshlands provided such as habitat for fish and birds, filtering drainage from land, conserving soil and mitigating the effects of flooding, weather and wind. James Keiler, a Scotsman and owner of the shipyard Göteborgs Mekaniska Verkstad, initiated draining and filling the vast reed beds on Hisingen Island's side of Göta River. His ship building business was expanding and so was central Gothenburg where they had been up until then. They were prohibited from expanding at their location at Skeppsbron and therefore were in need of a new location. Keiler decided to move his company to the opposite shore of Göta River to the island of Hisingen. At this time this shore was a vast marshland. In order to build his shipyard he needed to drain and fill the marshland. He successively drained the land, probably gaining inspiration from drainage of Gullbergsvass, which was marshland on the eastern shore of Göta River just north of the city center. By 1899 he had acquired as much as 90,000 square meters of land along Hisingen's shore: much of it created through draining the deemed worthless marshland. He was even able to make more money on the operation by charging to allow dumping of dredging material there. Göteborgs Mekaniska Verkstad eventually did move across the Göta River in 1867 where it still operates albeit to a much lesser extent than it once did. In 1867

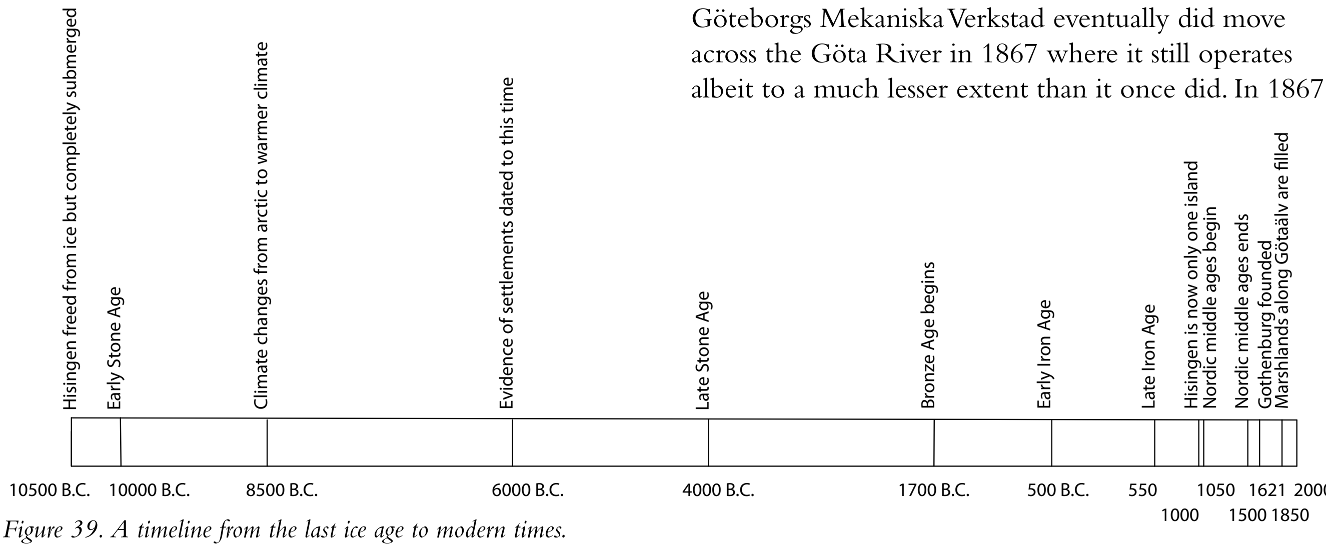
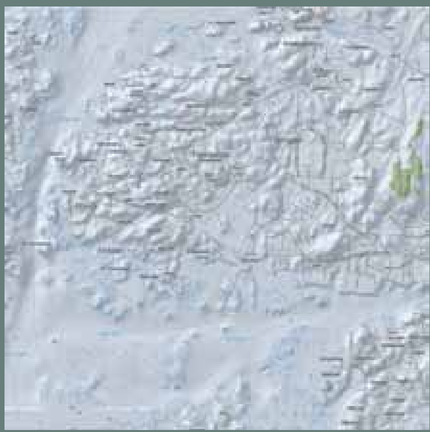


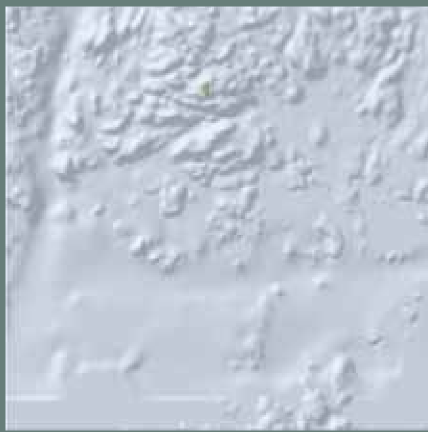
Figure 39. A timeline from the last ice age to modern times.

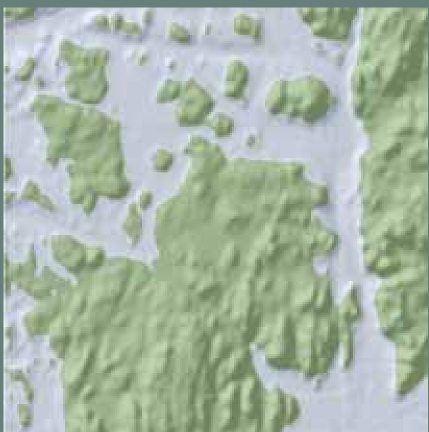
Land rise from 15,000 years ago

15,000 years ago Hisingen was covered with ice. Ice scraped along the rock beneath it, eroding and transporting the smaller fractions. This process of erosion, transportation and sedimentation created the well-sorted mineral soils in the region today. When the ice retreated, a sea of ice emerged. At this time the island of Hisingen was completely submerged. The clay settled over the land. Land that had been suppressed by the weight of the ice above it began to rebound. It has now rebound about 90 meters. As it gradually rose from the water, the

15000 years ago


14000 years ago


13000 years ago


9000 years ago


8000 years ago


7000 years ago

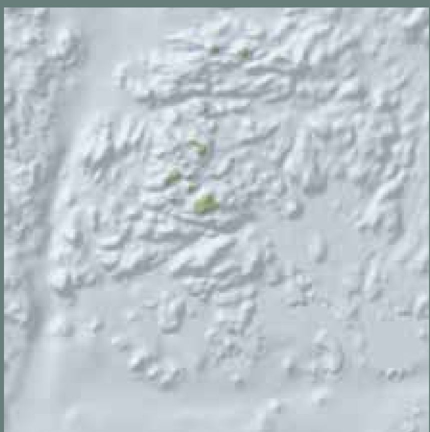

3000 years ago


2000 years ago

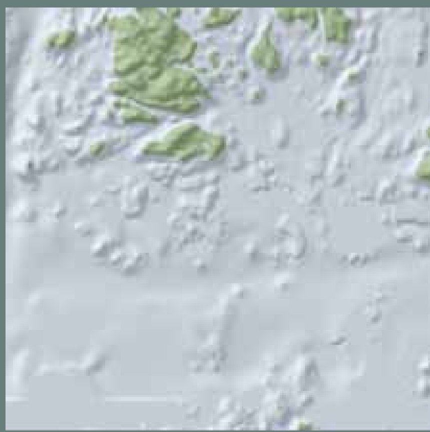

1000 years ago

to the present day

effects of waves and wind washed the soil it contained away. The clay particles which were most mobile were transported furthest away eventually settling in the valleys. This action has resulted in the hills having little soil and the valleys having thick layers of unconsolidated heavy glacial clay. The island of Hisingen was divided into several islands then. The valley in which Kvillebäcken flows was a fjord along which Stone Age and Bronze Age man settled.

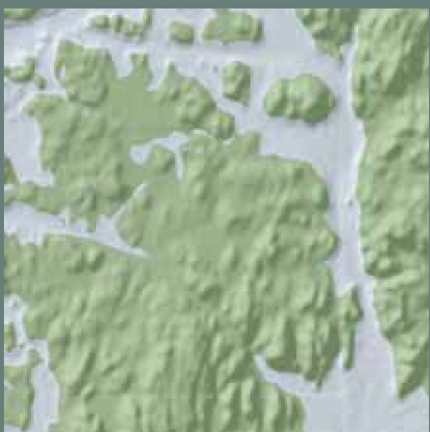


12000 years ago



11000 years ago

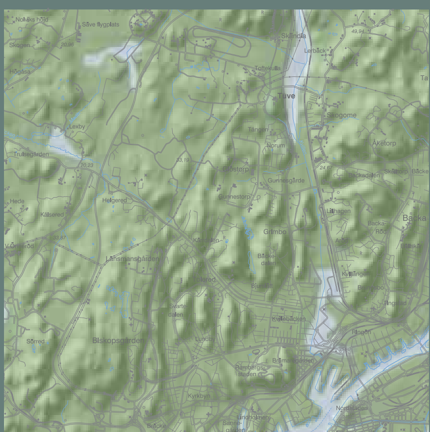
10000 years ago



10000 years ago

5000 years ago

4000 years ago



Present

Figure 40. This succession of maps was produced with SGU's online map creation tool. Although it is useful in seeing land rise in a small scale it is quite misleading when looking at areas where humans have artificially raised or lowered the land surfaces. For example Frihamnen, built in the 20th century can be seen in maps depicting the shoreline 10,000 years ago.

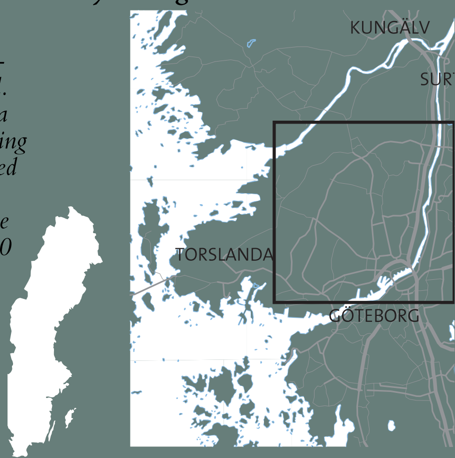


Figure 41. Photo taken from Ramberget over the filled marshland at the mouth of Kvillebäcken before the area was built up

it was surrounded by marshland. Approximately 800 meters of wetland lay between the new shipyard on Lindholmen and dry ground on Hisingen (see Figure 51). The land was drained by hydrologically isolating it from Göta River and Kvillebäcken similarly to the polders of Holland. The polders were built by driving pilings along the perimeter and building dykes behind them. Ditches and canals were dug, drainage tiles lain and pumps put into action further lowering the water table (Åqvist, 1908). These polders were then filled with dredging material. Newly drained and filled land was often used for factories, harbor activities or other industrial uses, however many filled areas east of Kvillebäcken were never fully exploited and were open ruderal fields up until the 1950s (Kjellson, 2009). In the 1960s areas such as Backaplan began changing from industrial area to shopping area (Kjellson, 2009). Today the former wetlands are primarily covered with asphalt, industrial buildings, offices, large stores and more recently residential neighborhoods. The mouth of Kvillebäcken near Kvilletorget was a major port into Hisingen. It was located several hundred meters inland from its current location. Buildings lined Kvillebäcken and the shore was fortified with pilings. Here goods would be loaded and unloaded and people would cross the Göta River either by a ferry or with a bridge (Hisingsbron) that extended the road Kvillegatan over the river. It is still possible to see the old wooden pilings along the banks of Kvillebäcken in many locations (see Figure 55). Back then, Kvillebäcken was dredged to facilitate boat transport between industries that existed along it.

The ice age, weather and land rise formed the canvas from which humanity has painted the landscape Kvillebäcken is a part of today. Humans went from being a part of the landscape as hunters and gatherers to molding the landscape as farmers, industrialists and consumers. Humanity has affected the Kvillebäcken Valley for millennia. From hunting and fishing grounds to grazing land to arable land to industrial land to shopping center to housing: the land has been put to work for the people who have lived there. Filling the marshlands and dredging the estuary erased a highly productive habitat for wildlife. Marshlands filtered runoff by trapping nutrients in biomass, and prevented soil from being washed out to sea. The landscape we have inherited no longer provides that function. With access to cheap energy, this has not prevented humanities exponential growth and technical development. In the future, however, we may need to get by with less energy. Restoring ecological functions in the landscape may be the best way forward.

Figure 42. Stately homes at the foot of Ramberget during the early 20th Century looking over the wet meadows that lye between them and the Göta river.

Figure 43. Postcard of Hising's bridge from the late 19th Century that connected Hisingen with Gothenburg. The bridge went from Kvillebäcken's mouth to Lilla Bomman.

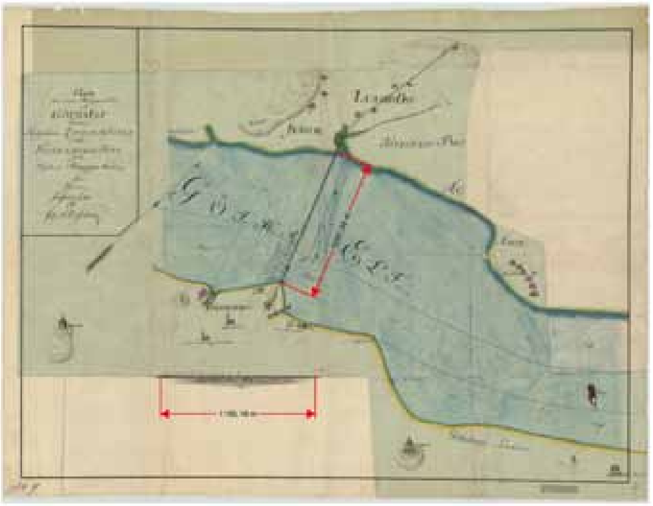


Figure 44. This plan from 1821 shows a proposed dock that would traverse the 1000 meters over Götälv to where Kvillebäcken joins the larger river. A black dotted line demarcates the marshland from the deeper parts of the Göta River. You can also see the bend in Kvillebäcken, how close Ramberget is to the marshland and the land use designation "Inägor" (Swedish: fenced-in land close to a village used to produce hay and grazing of livestock). The distance on the map is in aln. One aln equals 0.6 meters.

Figure 45. This is an orthophoto of where Kvillebäcken meets the Göta river. The red line is intended to aid in comparing this map to the historical map on the right and is a measurement in meters. Most of the land along Götälv seen here has been created by draining and filling.

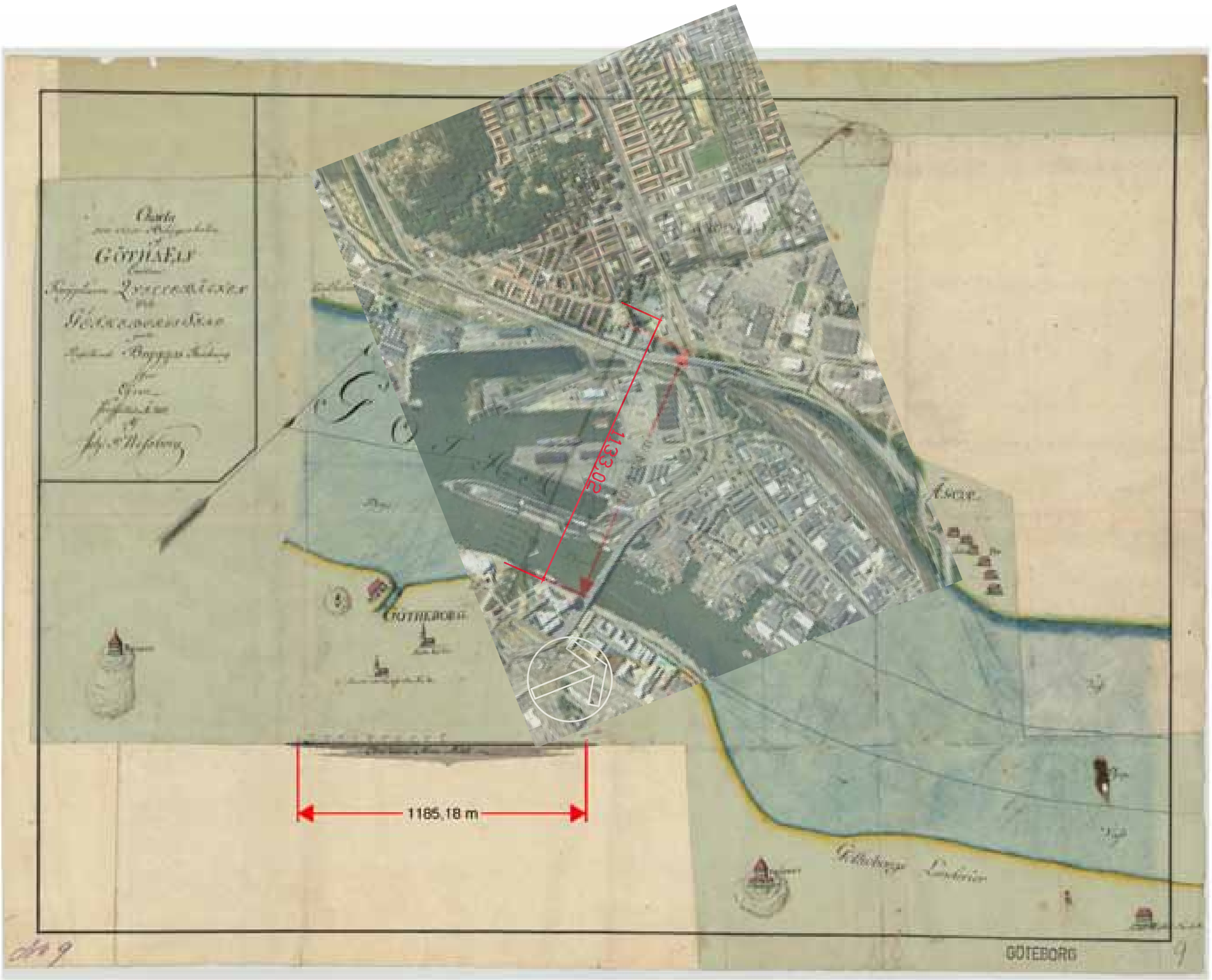


Figure 46. Here you see the orthophoto superimposed onto the map from 1821. You can clearly see how much land was reclaimed along the Göta River.

Summary

- *The Kvillebäcken watershed was completely submerged after glacial retreat resulting in little soil at higher elevations and heavy clay deposits in the valleys.*
- *Humans settled the area 7000-8000 years ago when it was still a sound connecting Nordre and Göta estuaries and have effected the vegetation and drainage of the land ever since.*
- *Kvillebäcken was a national border up until the treaty of Roskilde in 1658. Later it was a "socken" border.*
- *Vast marshlands that supported a rich fauna existed at the mouth of Kvillebäcken before the area was filled.*
- *Kvillebäcken has always been an important entry point to Hisingen*
- *Land along Kvillebäcken was drained and filled in the 19th century to make way for urban expansion and to get rid of dredging material from Göta River.*
- *Land along Kvillebäcken and Göta River was used for industry in the late 19th century and 20th century*

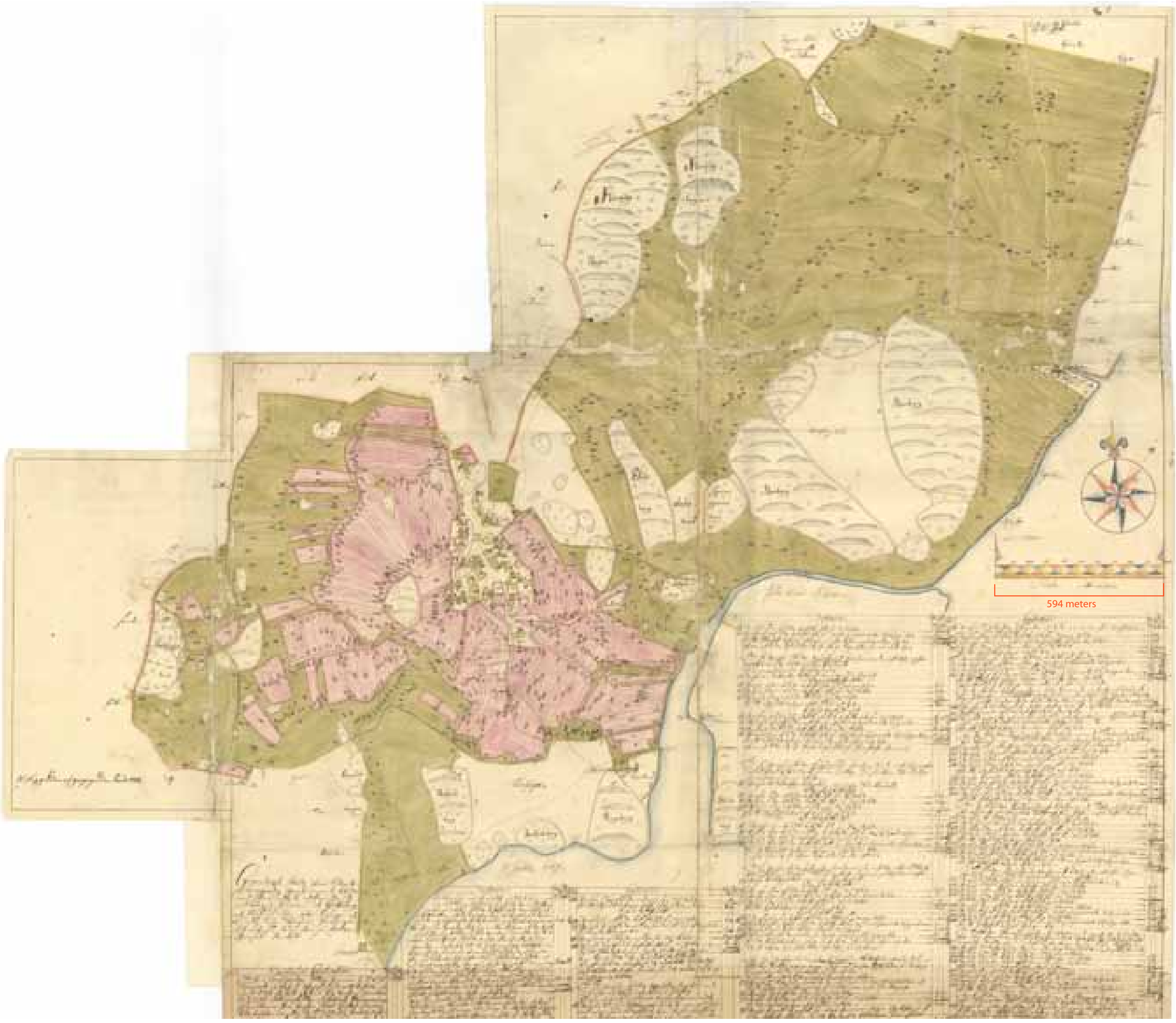


Figure 47. A map (Geometriskakarta) from 1722 showing the land at the mouth of Kvillebäcken. In the 1700's before the agricultural revolution of the 19th and 20th centuries heavy clay sediments were very nearly impossible to plow with the technology of the day. Nor had drainage tiles begun being used. That development came much later in the 19th century. The land in the Kville valley was primarily used as meadow which this map shows. The green is meadow and the pink areas would have been plowed fields {Cserhalmi, 1998 #48}. Beige colored areas are communal highland areas with low agricultural productivity. The nearly soilless hills were used for grazing and therefore lacked the tree cover they have today. Hay was produced in the meadows to feed the livestock in the winter and grazing was allowed after harvest. I suspect the very narrow divisions that go up all the way to Ramberget is because the land had varying degrees of wetness and this would make each parcel have similar proportions of wet and dry areas. Soil humidity impacts the parcels productivity. According to the map there was a good sized building where Kvilletorget is today. The land from that building to the Göta River and Kvillebäcken was well trampled. This was a major point of crossing between Gothenburg and the Island of Hisingen.

Figure 48. Map (Geometriskkarta) of Grimbo from 1756 upstream along Kvillebäcken. Kvillebäcken here also forms a border but in this case on the right of the map. The green is meadow and the pink is tilled cropland. The cropland was on well drained soil unusual for the area. A quarry to mine sand and gravel came here later that once retired was made into a landfill.

Figure 50. Map of Tingstadby produced 1829-1833. Green is meadow and pink is tilled land. Kvillebäcken is the border between Lundby and Backa districts on the left side of the map.

Figure 51. Planks are used to traverse the then recently drained wetland between Göteborgs Mekaniska Verkstad and Ramberget.

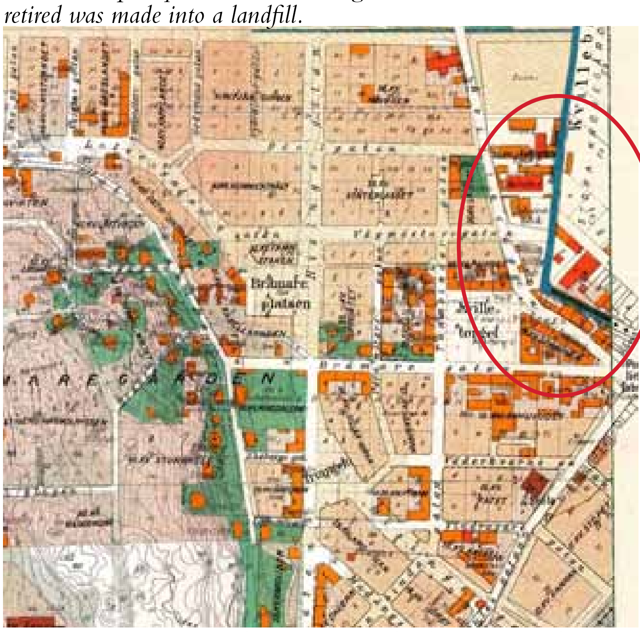


Figure 49. Here is part of a plan created for the 1923 Gothenburg exhibition. It shows the planned building lot division that was, however, never completely implemented. The orange buildings are wooden and red colored buildings are brick and had already been built in 1923. Note several buildings along Kvillebäcken that are now gone and where there is parkland today.

Figure 52. Here you can see a natural stream also called Kvillebäcken here, even though it is actually a tributary to Kvillebäcken coming down from another valley. This water now drains into the combined sewer and is pumped to the sewage plant rather than draining into Kvillebäcken. Today this area has problems with sewage backing up into peoples basements.

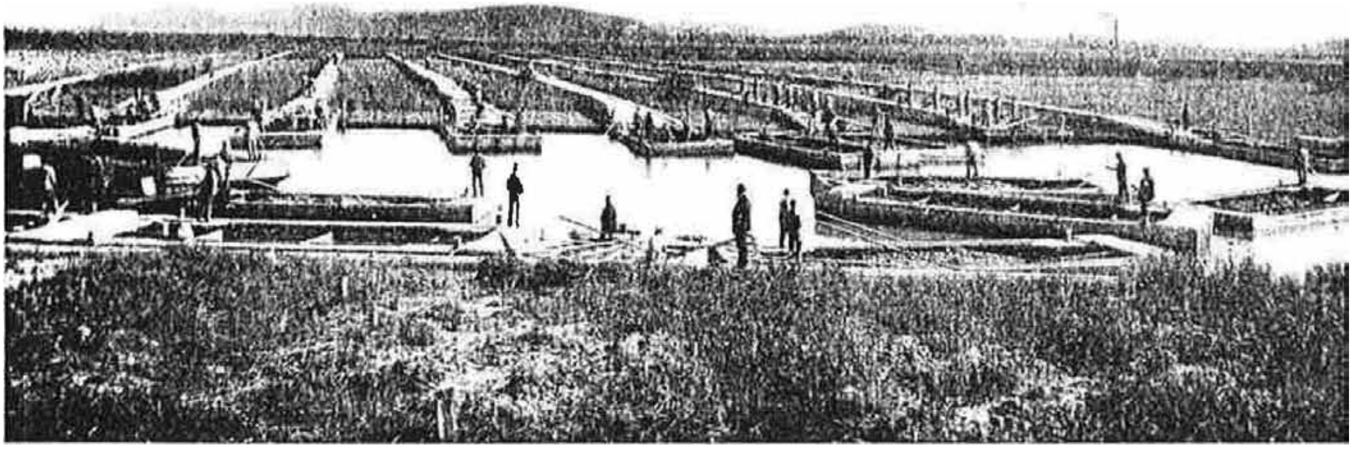


Figure 53. (Around 1850) Workers transported dredging material in wheel barrels pushed along boardwalks in order to fill the Tingstadsvass marshlands.

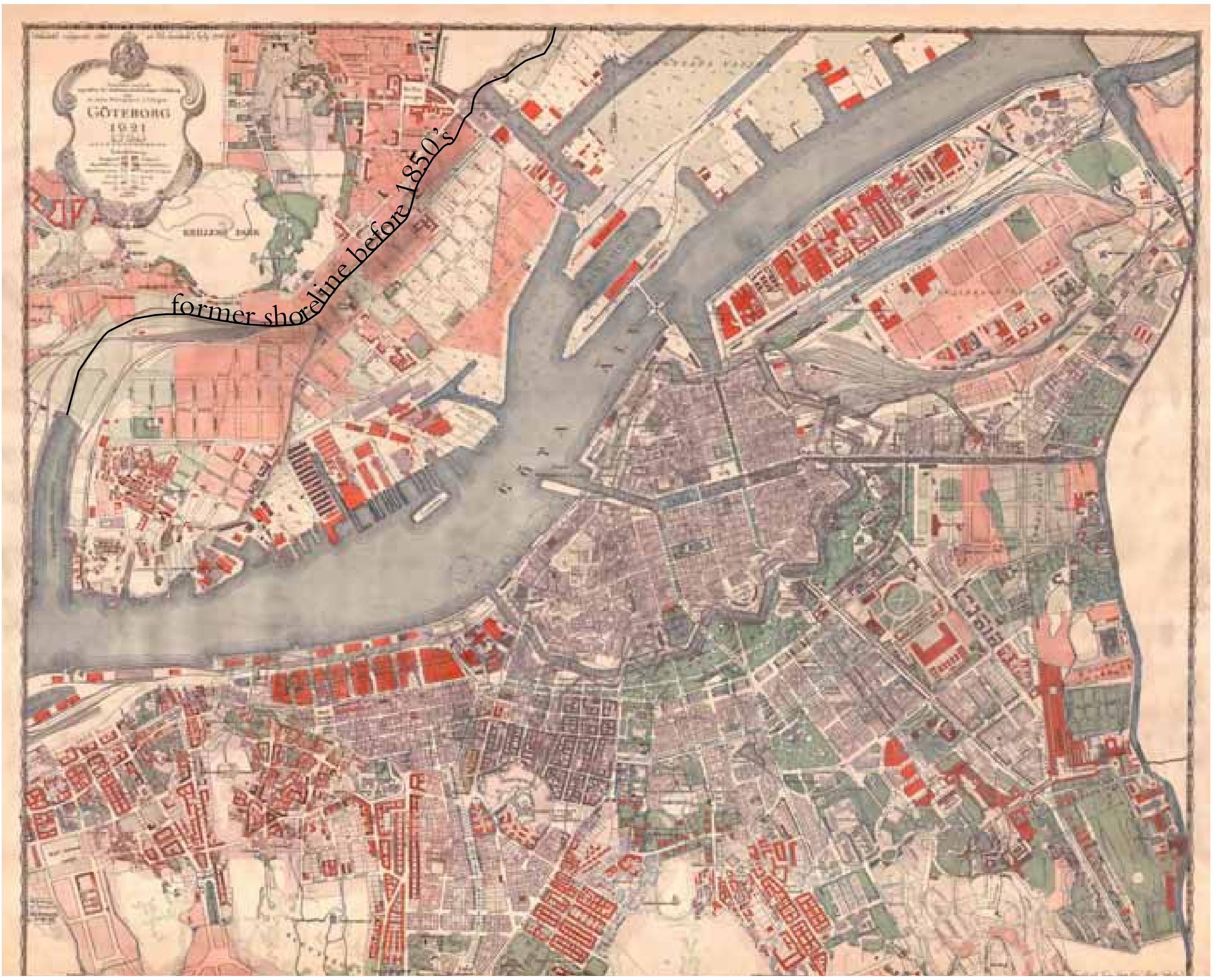


Figure 54. This is another map created for Gothenburg's 300 year anniversary with a plan from 1921 over a map from 1790. Here you can see the marshland and a dredged area coming out from the ferry dock at the mouth of Kvillebäcken. I have superimposed the pre-1850 shoreline to highlight the degree of change.

Figure 55.Pilings along the Kvillebäcken shoreline.

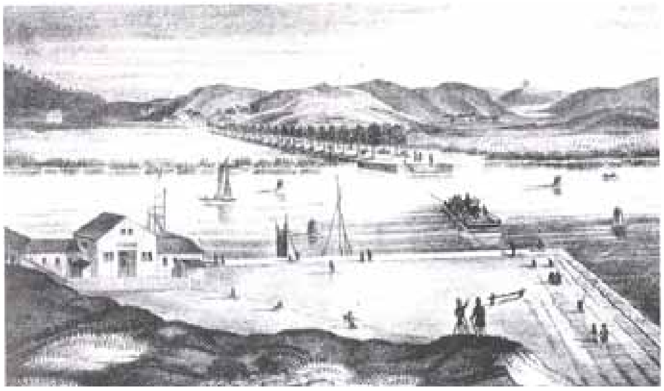


Figure 56.(Around 1850) View towards Hisingen from Gothenburg. At this time a ferry operated between a tree lined road that traversed the marshland between the mouth of Kvillebäcken and Gothenburg.

Figure 57. Map created for the 300 year anniversary of Gothenburg representing how the city had expanded up until 1820.

Figure 58. Map created for the 300 year anniversary of Gothenburg representing how far the city had expanded up until 1790.

Figure 59. Map created for the 300 year anniversary of Gothenburg representing how the city had expanded up until 1860. Here you can see that much of the marshland has been filled on both sides of Göta River.

Topography

Topography effects soil moisture, temperature, vegetation as well as the distribution of soil and water in a landscape. Finer soils tend to wash down from the higher elevations leaving courser sand, gravel and boulders behind. This is especially true in the Kvillebäcken watershed where the hills are below the highest coastal lines after the last glacial period. The courser soils that do remain provide fewer nutrients to plants and dry out more quickly. Gravity causes water on steep slopes to quickly drain. The direction of a slope determines how much solar radiation it receives which in turn affects the microclimate and the species that colonize it. Solar radiation will create warmer but also dryer habitat. The topography in the Kvillebäcken watershed is characterized by steeply sloping upper elevations and a very flat south facing valley bottom (see Figure 61). The lower area where most new development is occurring is very near sea level. Being so close to sea level puts many areas at risk for flooding especially since the sea level is expected to rise. Based on an analysis of future sea level rise and the implications of this on low lying areas, the municipality has come up with guidelines regarding what minimum elevations newly built areas should be built at (Stadskansli, 2006). According to their analysis, buildings should have a finished floor level of 12.3 meters and streets should be at 11.8 meters in the GH 88 elevation system (Stadskansli, 2006). 12.3 meters seems very cautious, however, it is really only about 2 meters above today's sea level. Generally elevation is defined as X meters above sea level. Up until January 2013 Gothenburg used its own elevation system or datum (GH 88), which set its 0 level approximately 10 meters below actual sea level. This was to avoid negative values in the low-lying filled marshlands along the Göta River. The municipality now uses Sweden's official elevation datum RH 2000 which puts the 0 level at an internationally recognized sea level. The data I am using, however, is still in GH 88 as the data was compiled before the change. Many existing areas are below 12.3 meters (GH 88). Aside from these existing built up areas being at risk for flooding, new development will require expensive and elaborate foundations to come up to the new minimum elevations. The clay soil in these areas cannot be overloaded and thus roads will need to be built on specialized lightweight aggregate that is significantly more expensive than common crushed rock aggregate (Sintorn, 2011). Another effect of this new policy is that new buildings in existing neighborhoods will have their entrances above street level. Ramps will be required to access these new buildings in order to be handicapped accessible and fulfill the new regulations.

Summary:

- *The topography is characterized by steep terrain in the higher elevations and flat land in the lower elevations*
- *Large areas are at risk for flooding.*
- *Expensive special foundation work is required to come up to the minimum elevation requirements.*

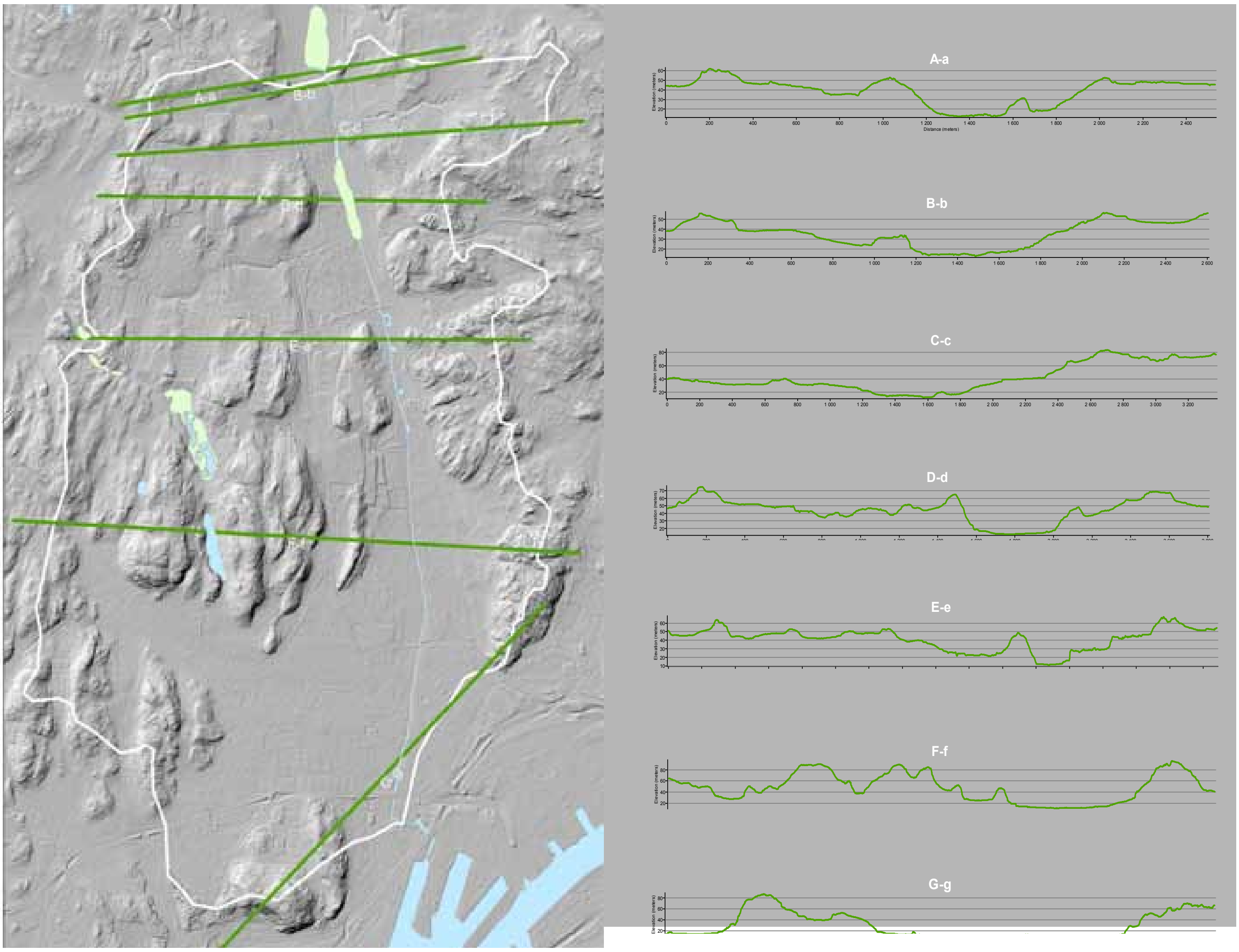
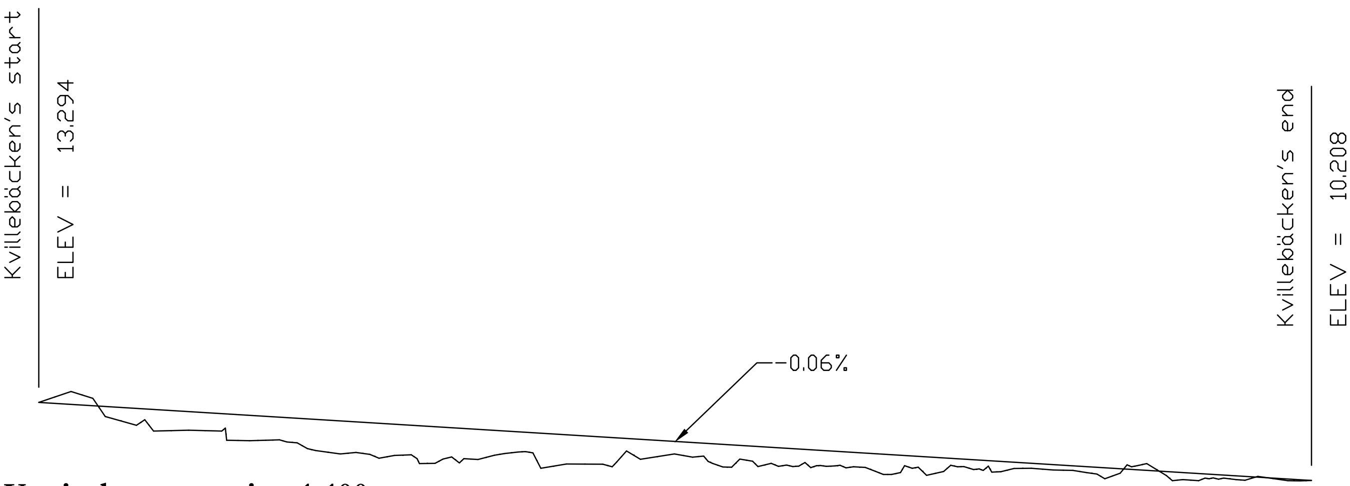


Figure 60. The topography is characterized by steep hills and low flats. Water from the higher ground runs quickly down to the lower ground where it only slowly drains. Pumps and underground sewers prevent this from being too much of a nuisance.



Vertical exaggeration 1:100

Figure 61. Kvillebäcken has a slope of only .06% from beginning to end. Even with the extreme vertical exaggeration used in this profile, there are no dramatic falls of elevation from beginning to end.

Soil & Geology

The watershed is a part of the greater Bohus rift valley landscape. Cracks in the gneiss and granite bedrock that primarily run in a north-south direction were made larger through erosion and weathering over millions of years. The well-sifted soils were deposited relatively recently during the retreat of glaciers from the last ice age (about 10,000 years ago) and thereafter. There are very few unsifted moraine deposits such as those commonly found in Sweden at higher elevations. This is because only small bits of land within Kvillebäcken's watershed are above the highest coastal elevation after the last ice age (about ninety meters above today's coast) (see Figure 64). Elevated areas within the watershed were washed clean as they rose from the icy sea that formed in the latter part of the last ice age. Today the higher elevations have little or no soil. Larger soil fractions were deposited on the slopes and the finer clay particles settled further afield in the then submerged valley. Small pockets of gravel and sand as well as organic soils are the soil types and fractions to be found there. On a few slopes, however, post-glacial clay has settled. These slopes are prone to landslides. The Tuve landslide of 1977 on an eastern slope in the Kvillebäcken watershed killed nine people, destroyed sixty seven homes and made 436 people homeless (Älfvåg et al., 2008). The landslide was caused by the clay soil becoming oversaturated in combination with vibration turning it into a liquid form called quick clay (see Figure 62).

A very thick layer of clay up to 100 meters deep settled in the lower elevations. Clay has many qualities that benefit vegetation but is less than ideal to build upon. When clay soils are loaded or otherwise disturbed they become impermeable and changes in soil moisture makes clay expand or contract. Large buildings in this area are usually supported on friction pilings. They do not settle as much as the surrounding ground. This causes problems with utility connections breaking and entrances that need to be retrofitted with stairs or ramps (see Figure 63). Uneven settling also causes problems with surface drainage not functioning as intended result<meable surfaces are placed over clay soils, they tend to dry out and shrink. Areas may settle about a meter over a 100 year time period (Alén, 2010). Disturbed clay soils usually lose their cracked structure. Since the cracks are where water is transported, disturbed clay soils are poor conductors of water making them generally unsuitable for stormwater management strategies that attempt to infiltrate stormwater. Clay soils can function well as a substrate for wetlands and ponds where a surface of water is desirable. Closer to Göta River, alluvial silty sediments were deposited where Kvillebäcken meets the larger river. This nutrient rich substrate once provided conditions for an extensive marshland.

Even today water, wind and humans disperse soils. The Göta River carries soil from upstream, some of which flocculates and settles within the harbor area. It carries much less sediment today, however, due to several dams that trap sediment behind them. The mouth of Göta River is a so-called salt wedge estuary (Eriksson, 1999). Seawater pushes into the estuary as a wedge below the fresh water (Eriksson, 1999). When clay and silt reach this wedge they flocculate and sink to the bottom (Eriksson, 1999). Flocculation occurs most at the edge of the seawater wedge (Eriksson, 1999). In the Göta River the wedge migrates between the Göta River Bridge and the Älvborg Bridge (Eriksson, 1999). The flocculated soil is regularly removed by dredging the channel. Previously the dredged up soil was used to fill the marshlands that were once prevalent in the Göta Estuary but today it is dumped at sea.

Summary

- *Shrinking and swelling of clay soils cause uneven settling of buildings and infrastructure.*
- *The predominant clay soils are not good for infiltration.*
- *Soil is lost by dredging the Göta River and dumping the soil at sea.*

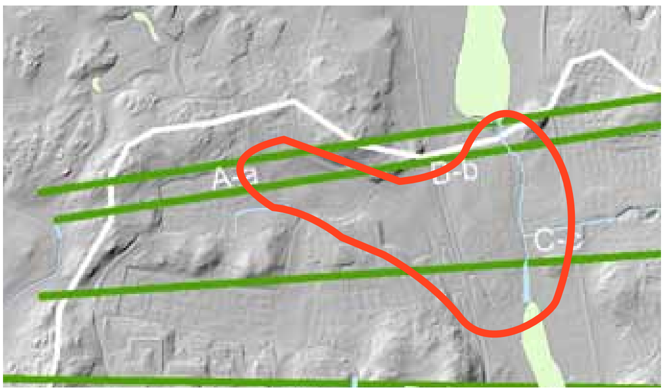


Figure 62. Tuve landslide of 1977 is one of the worst natural disasters to hit Sweden within modern times.

Figure 63. Settling pavement and cracked building in Brämaregården caused by the changed hydrology and increased load put on the soil below.

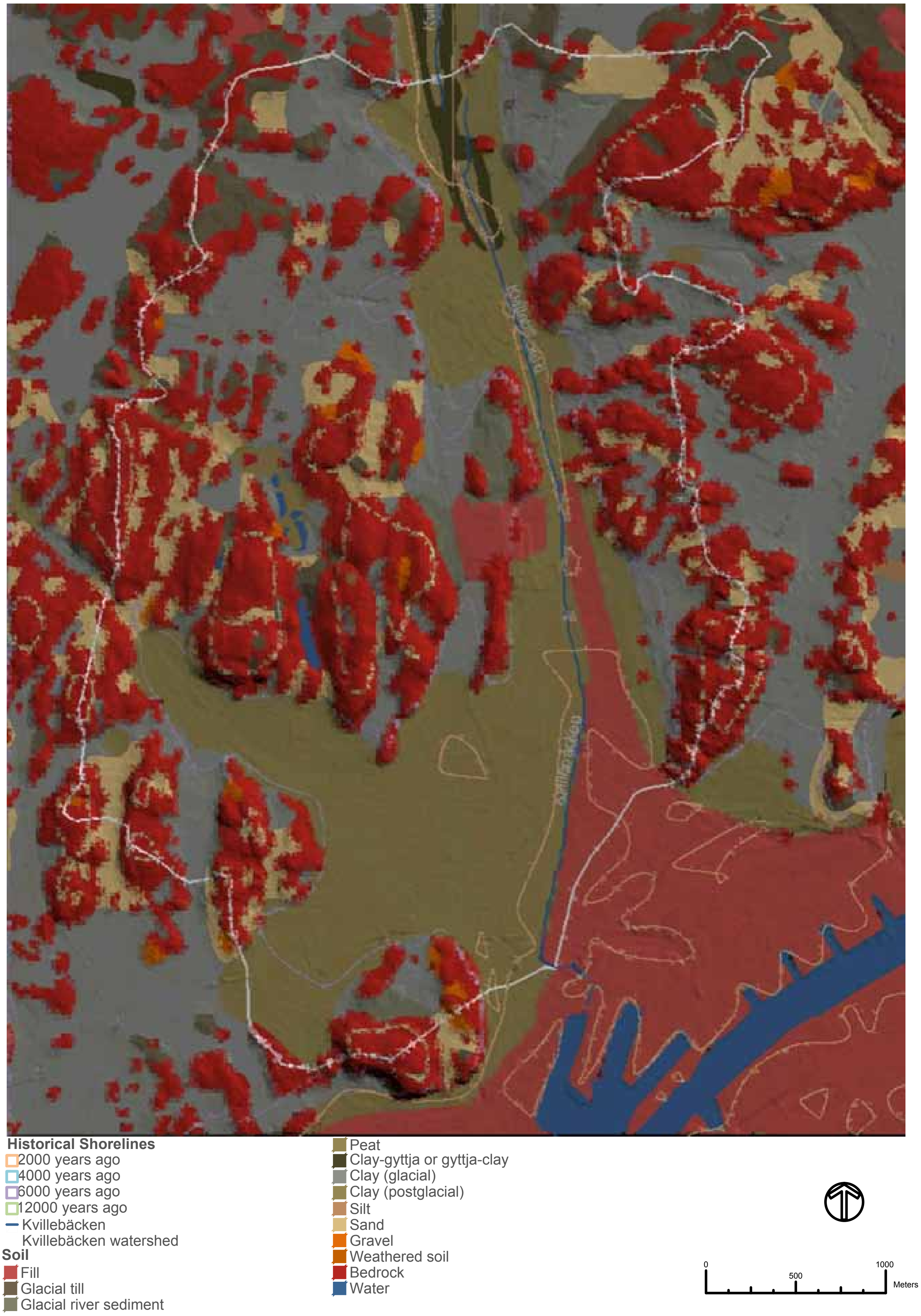


Figure 64. The map shows only the first half meter of soil. Layers below may or may not be the same type of soil.

Hydrology

Kvillebäcken is the remnants of a sound that joined the Nordre River and the Göta River Estuaries. This unusual fact partly explains why there are few meanders in the stream. The stream channel is quite wide relative to the amount of water in it and the elevation change is very little (only two meters from beginning to end). The stream has, however, also been dredged, canalized and straightened to hasten drainage.

Today the actual watershed varies in size depending on whether the combined sewer system is pumping to the sewage works outside of the watershed or if it is overflowing into Kvillebäcken. The natural area of the watershed is about 15 square kilometers but, when removing the area with the combined sewer, it shrinks to only 10,5 square kilometers (Risberg, 2008). Kvillebäcken transports about $4{,}3\times10^{6}$ cubic meters of water per year (Risberg, 2008). This results in an average drainage of 147 l/s (Risberg, 2008). Flow rates up to 4600l/s are, however, likely to occur within a 100 year time frame (Risberg, 2008).

Some ground water, tributary streams, stormwater outfalls, ditches and drainage tiles feed the stream. The higher elevations retain more precipitation today than before due to the increased tree cover. Up until about 100 years ago, the hills were so heavily grazed that only grasses and heather could survive. Rain quickly turns to surface water in the Kville Valley. This is due to the topography, impermeable surface cover and non-conductive clay soils. The rural areas in the North have more ditches that channel stormwater runoff. In the more urbanized South, most runoff is lead to underground pipes.

There are few wetlands in the watershed compared to before the major drainage and filling projects of the 19th Century. One would have seen large marshlands along Göta River as well as ephemeral wet meadows and grazing land between the rocky hills that delineate the watershed. Typically, however, land was drained and filled for agriculture and not urban development (Williams, 1990). Many streams have also been put into pipes and buried underground as shown on Figure 65. Many of these streams are even pumped to the sewage treatment facility. In the higher elevations there are peat and other organic soils in depressions but very little mineral soil to retain precipitation. Bedrock is visible or not far from the surface in most places. A few sheltered areas have or had pockets of gravel and sand that could also be a source of ground water. These pockets are not very large or common and have, for the most part, already been mined of their contents. Vegetation in green areas consumes about fifty percent of the total rainfall through evapotranspiration. The plants' decomposition also produces peat and muddy soils that store water. Because the hills have thin soils and the Kville Valley has heavy clay soils and is close to sea level, much of the precipitation would have never penetrated deeply into the soil. Clay is not a good conductor of water. In clay, ground water travels most efficiently via cracks and root corridors (Grip and Rodhe, 1988). There would have been considerable surface water even in a predevelopment state. The water would have drained via surface streams from the hills and spread out across the flats of the valley. The organic peat and muddy soils would have acted as a sponge slowing down the flow of water. The heavy vegetation would have also intercepted precipitation. Due to the lack of water conducting soils such as sand and gravel that would make a sub-surface aquifer, the Gothenburg water utility extracts municipal water from surface water sources such as the Göta River.

Summary:

- *Precipitation quickly develops into runoff.*
- *There are few wetlands relative to the natural topographical conditions since they were drained and filled to make way for agriculture and later urban expansion.*
- *Many tributary streams to Kvillebäcken have been put into pipes.*
- *Five square kilometers of the watershed is does not reach Kvillebäcken but is pumped to the sewage plant.*
- *Disturbed soils in the watershed prevent infiltration.*
- *Ground water is difficult to extract due to the lack of water conducting soils.*
- *Vegetation consumes 50 percent of the yearly precipitation falling on it through evapotranspiration.*

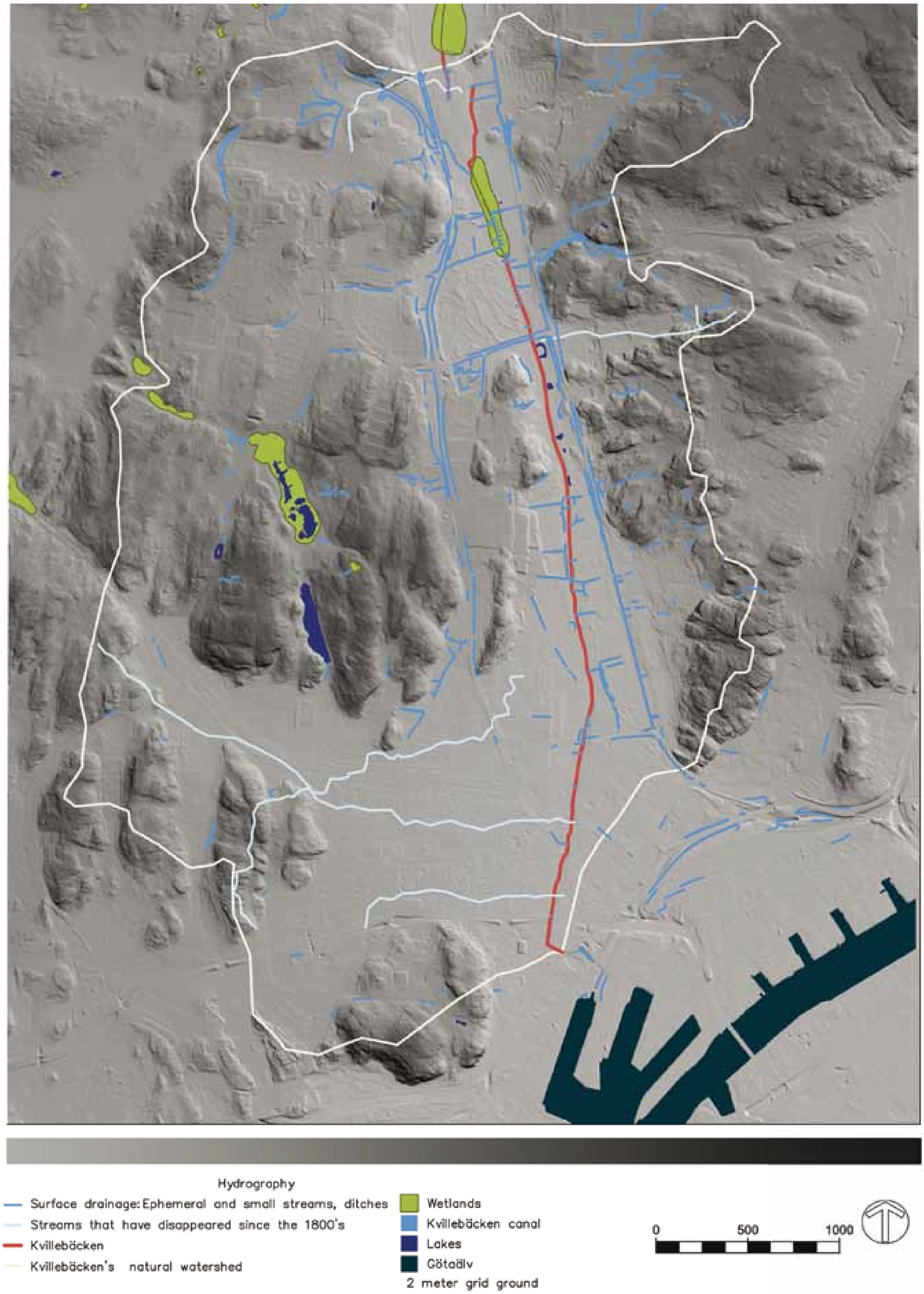


Figure 65. The hydrography map shows the surface water and topography in the watershed and includes natural streams, streams that have disappeared, lakes, wetlands as well as dug ditches and ponds. The dark areas indicate higher elevations and the lighter shades of grey indicate the lower areas. The map shows a high contrast between the upper elevations (dark grey) and the lower elevations (light grey). There are fewer mid-grey colored areas indicating that there are many low and high areas but few areas in between. The higher areas generally drain quickly to the lower elevations where water ends up in underground sewage pipes.

Meteorology

Since the Kville Valley is low lying and close to the sea, rain and sea level rise can quickly flood large areas of it. Westerly winds are known to raise the sea level at the mouth of the Göta River that results in the Göta River rising and pushing up its tributaries such as Kvillebäcken. This dams up Kvillebäcken preventing it from draining. During the storm "Gudrun" January 2005, the sea level rose to +11.44 meters in the local elevation system or 1.5 meters above normal at the mouth of Göta River (Stadskansli, 2006). During the storm the city was just able to secure important functions during this temporary rise in water level (Stadskansli, 2006). In December 2006, however, Gothenburg was even more greatly affected by weather that caused extensive flooding, high levels of precipitation and a temporary rise in sea level due to a storm surge (SMHI). At the same time that the Göta River and all its tributaries had flow rates that are only likely to happen once every fifty years, seawater was pushed up the Göta River (SMHI). This flooding caused disruptions in road and rail networks over several days as well major damage to property (SMHI).

There is much debate surrounding the amount of sea level rise we should expect within the next 100 years but most experts agree that a rise is inevitable. Thermal expansion and melting ice from the arctic regions will likely result in a sea level rise of 0,5-1,0 meters (Falk, 2008). A storm surge like the one caused by Gudrun that raises levels 1,5 meters above an already higher sea level will greatly effect the Kville Valley (Stadskansli, 2006).

Table 1: Average monthly precipitation (mm)

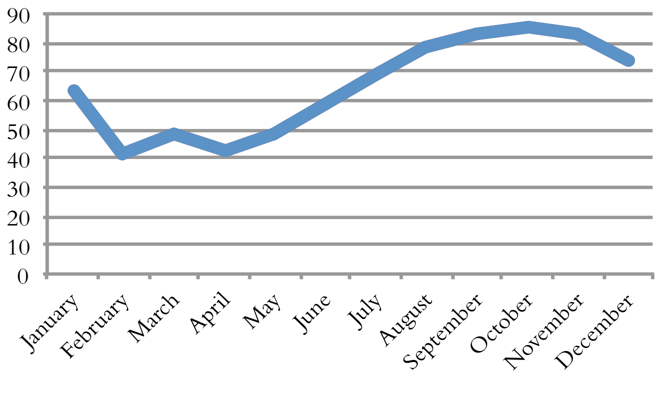


Table 2:Total yearly precipitation in Gothenburg (mm) 2003-2011

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
848	859	907	819	1264	1036	758	855	849	1032

Gothenburg has a considerable amount of precipitation every year, most of it coming as rain. From 2002-2011 yearly precipitation has been greater than average (see Table 2, SMHI). It is expected that this trend will continue because of global climate change.

In order to dimension a stormwater facility so that it will be able to manage most future storm events it is necessary to know how much rain can come within a time interval equivalent to the time of concentration within a watershed. Time of concentration is how long water from the most distant hydrological point in a watershed takes to reach a specific point. The time of concentration decreases when the amount of impermeable surfaces increases.

Another important aspect is the frost depth in various soil fractions. Water conductivity in frozen soil may be reduced considerably (see Table 5, SMHI).

Summary:

- *The Kville Valley is vulnerable to the effects of weather such as precipitation that causes flooding as well as storm surges that push water up Kvillebäcken.*
- *Predicted global sea level rise will make future storm events cause greater flooding.*
- *Rainfall intensity is important when dimensioning stormwater facilities*
- *Frost depth is important when designing stormwater facilities since conductivity is greatly reduced.*

Table 3: Precipitation statistics (mm)

Average 1961-90	Most precipitation since 1901	Year	Least precipitation since 1901	Year	Days with precipitation
758	1264	2006	421	1922	181

Table 4: Rain event intensity

Duration of storm event (minutes)	5	10	60	120
Likelihood of recurrence of storm event (years)	Intensity of rain liters per second per hectare (l/s,ha)			
0,5	116,2	85,1	22,9	13,1
1	145,6	109,0	32,2	18,8
2	176,3	134,4	42,1	24,7
5	221,4	171,8	56,9	33,3
10	259,8	204,0	69,8	40,5

Table 5: Maximum frost depth in Gothenburg in various soil types (meters)

	Gravel	Sand	Silt	Clay	Peat
snow free	2.2	1.6	1.4	0.9	0.8
snow covered	2.1	1.4	1.2	0.8	0.7

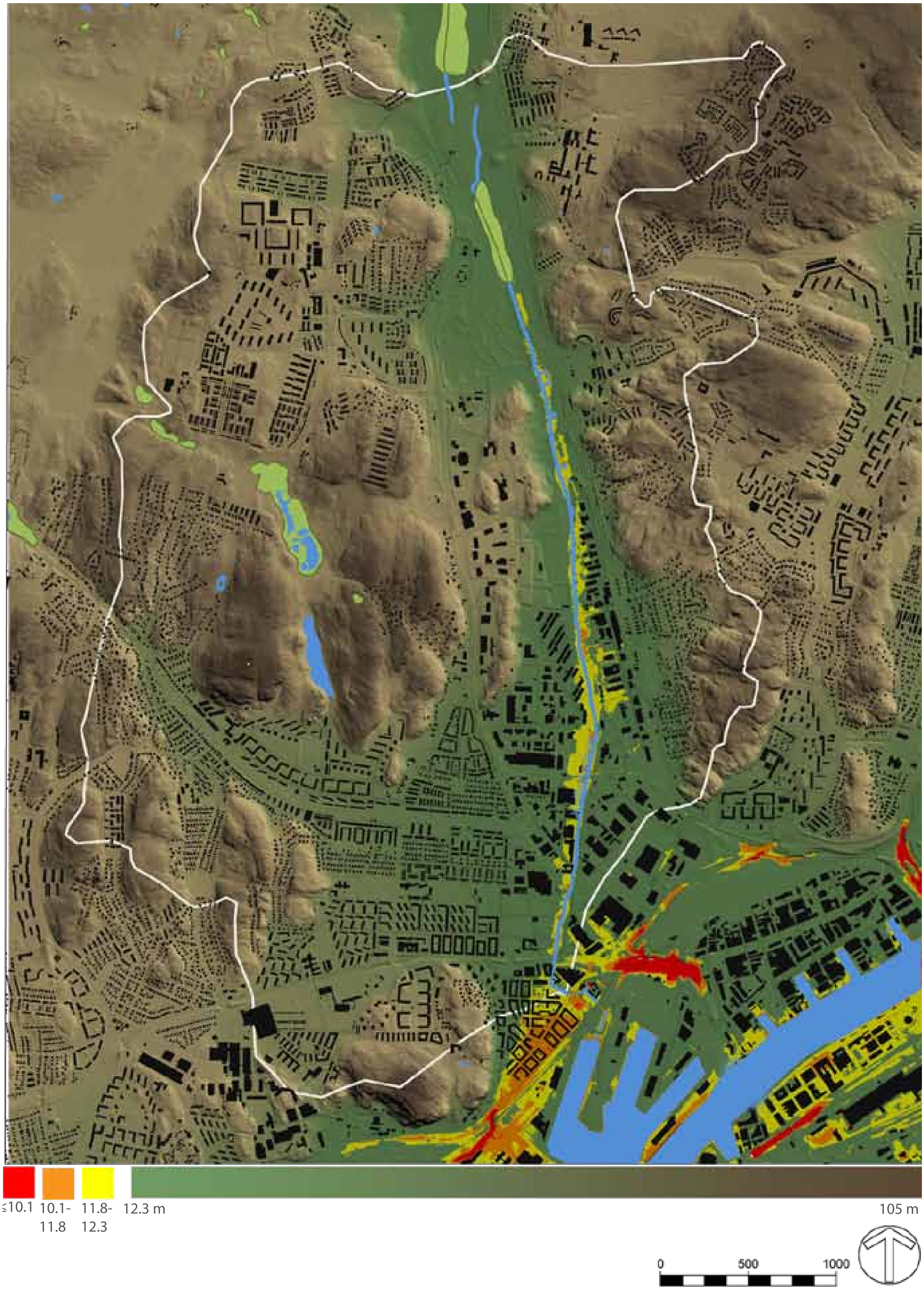


Figure 66. Elevation map with critical elevations: shows the areas likely to be flood in the invent of extreme weather conditions.. The red color on the map indicates areas at or below 10.1 meters in GH 88. This is the normal water level of Göta River, which is nearly sea level. These areas are entirely dependent on pumps to keep them from flooding. The orange color indicates areas below 11.8 meters and yellow indicates areas below 12.3 meters.

Present stormwater management and its effects

From available information, it seems that stormwater management within the watershed is exclusively focused on flood prevention. There does not seem to be any filtering of stormwater aside from that which is pumped along with household sewage to the sewage plant. As already mentioned, the Kvillebäcken watershed has both areas with combined sewage/stormwater networks as well as areas with separated networks. The combined networks are found in the areas urbanized earliest. Thanks to pumps that began operating in 1948, the areas with combined systems have been, for the most part, spared from serious sewage backups (Kant, 2008). In some areas, however, like along Björlandavägen, where there is a combined sewage network, there have been frequent instances of basements flooding (Nilsson, 2011). In areas that were developed after 1948, stormwater is lead directly to Kvillebäcken and only sewage is pumped to Ryaverket. At least twenty stormwater outfalls from roads drain untreated into Kvillebäcken. Numerous other outfalls exist coming from industrial sights along the banks of Kvillebäcken.

When everything is operating properly, all stormwater and sewage from the areas with a combined system is pumped to the city's treatment facility Ryaverket. When the combined system reaches overcapacity during major storm events, both storm and sewage water is deliberately discharged into Kvillebäcken or Göta River just outside of Kvillebäcken's outlet to avoid backups within the system (Ljunggren, 2011). The primary sewage pump house is located near the mouth of Kvillebäcken right in the middle of the new Porslinsfabriken housing development (Björgaas, 2011)(see Figure 67). A pipe draining out to the Frihamnen harbor from the pump house was recently laid in Kvillebäcken to expel sewage from overflow events into Göta River (Ljunggren, 2011). Before this pipe was laid, the overflow outfall was located just outside the pumping station (Ljunggren, 2011). The new pipe out to Frihamnen was probably laid in expectation of the new housing development around the pumping station completed in 2012.

Effects of present stormwater management

According to many reports over the years, the Kvillebäcken stream is not healthy (Engdahl, 2006). Kvillebäcken is the recipient of high levels of contaminated runoff (Ljunggren, 2011). Environmental studies have been made on Kvillebäcken analyzing the sediment, the level of heavy metals in water moss, levels of phosphorous and nitrogen as well as an inventory of the fauna in the stream. In the northern more rural parts, the nutrient contaminants phosphorous and nitrogen predominate whereas further to the South in the urban and industrial areas, hydrocarbons and heavy metals are the most common pollutants (Ruist and Lagergren, 2010). Large amounts of heavy metals build up in the sediment or are released into Göta River (Bäckström and Hallinder, 2011, Eriksson, 1999, Johannesson et al., 2003). Samples of the water coming from the Hökälla ponds show that water quality in Kvillebäcken has improved after the wetland and ponds were created. The wetlands have also been especially effective in trapping phosphorus although levels in Kvillebäcken's waters are still higher than desired (Ruist and Lagergren, 2010). Just downstream of Hökälla, a tributary stream Lillhag's stream joins Kvillebäcken. This stream receives unfiltered runoff from copper roofs (Lindberg and Ödegaard, 2011). Analysis shows that higher values of very toxic copper ions exist in Kvillebäcken's sediment and water downstream of Lillhag's stream than upstream (Lindberg and Ödegaard, 2011). Kvillebäcken also gets unfiltered drainage water from St. Jörgen's Golf Course that potentially contains pesticides and fertilizers (Andreasson and Thulin, 2010). Kvillebäcken later flows passed the Grimbo landfill, which is not hydrologically isolated from Kvillebäcken or ground water (Johansson and von Wachenfeldt, 2011). Large parts of the former landfill are now covered with permeable grass soccer fields. Precipitation thus enters the landfill and exits it via drainage pipes and ditches to Kvillebäcken taking with it contaminants (Johansson and von Wachenfeldt, 2011). Analysis shows that there are higher concentrations of the heavy metals copper and lead in the sediment downstream from the landfill than upstream (Johansson and von Wachenfeldt, 2011). In Bäckstöm and Hallinder's analysis of the sediment just south of Hjalmar Brantingsgatan in the lower part of the watershed, sampled in April of 2011, Four hundred times the recommended level of lead contamination in residential soils was found (2011). Granted the test was of Kvillebäcken's sediment near to a stormwater outfall but the results are alarming especially since this is one of the few places were the endangered hydrophyte Potamogeton trichoides appears to thrive in Sweden (Jacobson, 2009). Not surprisingly, Kvillebäcken becomes more and more contaminated with heavy metals on its way toward the Göta River. Heavy metals that accumulate in the sediment definitely do affect the flora and fauna today (2006). According to a study of the fauna living on the bottom of Kvillebäcken it was concluded that the fauna was severely affected by pollution (Engdahl, 2005). As

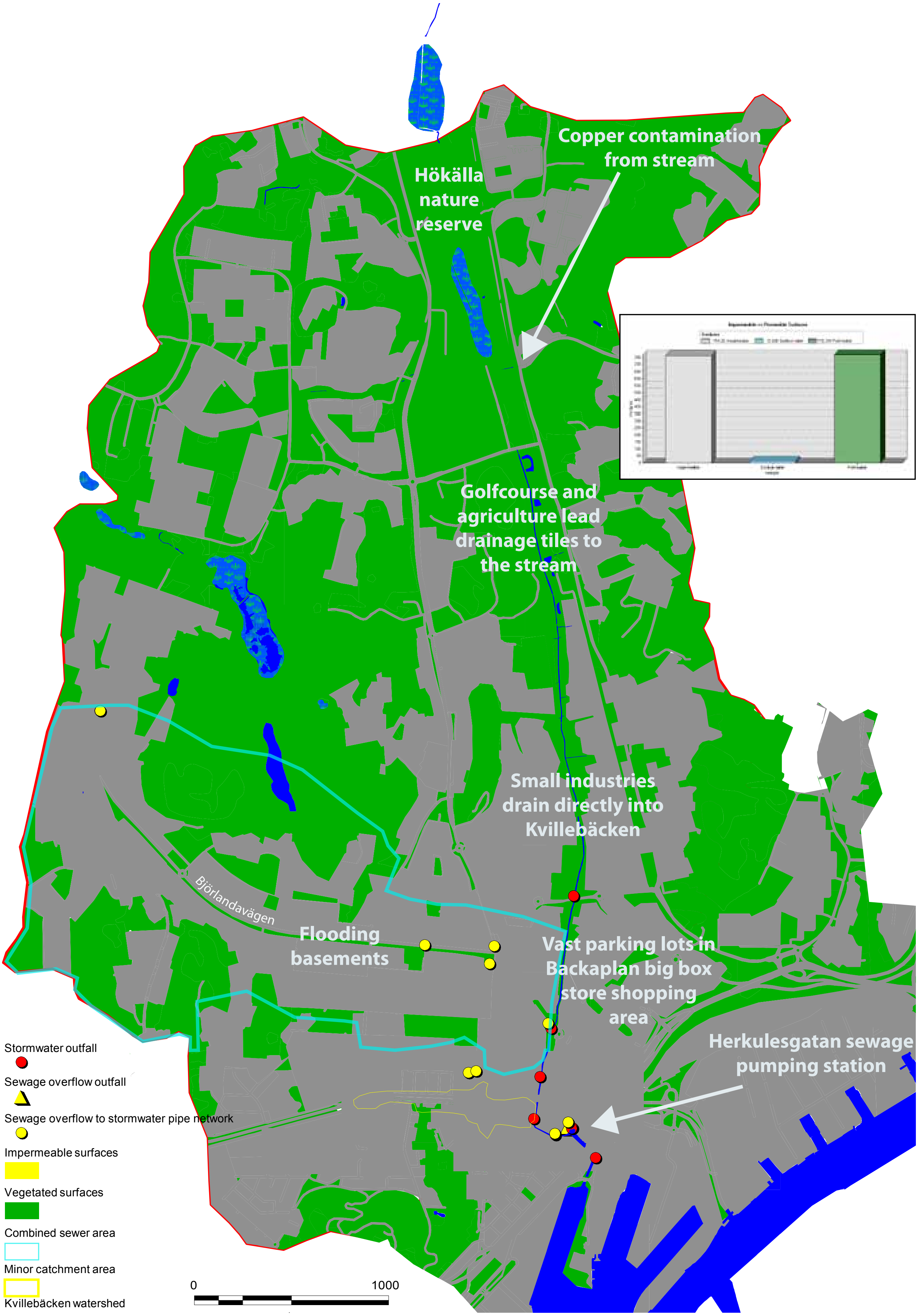


Figure 67. This map describes the level of permeability vs. impermeability in the watershed in a very general way. Residential gardens come under impermeable surfaces. A more detailed map separating gardens from buildings and paved surfaces on a plot would be desirable but unfortunately was not possible within the scope of this report. Sweco {Risberg, 2008 #438} determined impermeable surfaces to be approximately one third of the watershed excluding the part that has a combined sewer.

the heavy metals concentrate in the sediment, they may also reach a critical toxic threshold for Potamogeton trichoides as described by Ericsson (1999).
Pumping to Ryaverket and treatment there requires a lot of infrastructure, energy and raw materials (Davidsson, 2011). Treatment at Ryaverket is primarily designed to remove organic matter, oils, fats, and pathogens and to a lesser extent nitrogen and phosphorous before it is released into the environment (Davidsson, 2011). A by-product of this treatment is sludge. Heavy metals, suspended solids, deicing salts and hydrocarbons are the most common contaminants in urban run off (Grant, 2003). If the sewage is contaminated with heavy metals it will end up concentrated in the sludge. The sludge is being used to produce planting soil as well as amend agricultural soil. The more the sludge is contaminated with heavy metals, the less it is suitable for planting soil or agriculture (Davidsson, 2011), (Kant, 2008). The existence of heavy metals in sludge is one of the major objections to the use of sludge for soil improvement in agriculture.

Summary:

- *Stormwater management is exclusively focused on flood prevention not treatment.*
- *Flooding of basements occurs in areas with combined sewers.*
- *Controlled sewage overflows occur both in Kvillebäcken and Göta River.*
- *Kvillebäcken is severely degraded by pollution in stormwater.*

Recreation

Kvillebäcken could offer great recreation but falls short today. It is well documented that we benefit from access to nature (Ulrich, 1981), (Kaplan, 1995). Unfortunately, however, access to large parks is poor within the low-lying areas where most of the future development is planned. The two main parks within the watershed: Hising's Park and Keiler's Park are up on higher terrain and require a hike to get up to them that is not for the light of heart (see Figure 68). Furthermore there are poor connections between them and Kvillebäcken. The owner of the Göta Mekaniska Verkstad James Keiler donated Keiler's Park, otherwise known as Ramberget, to the city in 1903. Today the park contains mixed woodlands with beautiful mature trees that were planted in conjunction with the founding of the park. Although the park does have high recreational value, it is not easily accessible due to the steep topography. The park is like an island cut off from Kvillebäcken, the Göta River and the other green hills in the area.

Hising's Park is a very large park also above the urban sprawl below. It contains a diversity of biotopes. There is also a 4H farm here with grazing animals. This park is also a great resource but not very accessible due in part to the topography but also due to the lack of adequate connections to other areas and a lack of well defined entrances.

Hökälla is the only natural park in the low-lying areas and is a considerable distance from where most people live. There is a bicycle and footpath that follows along the length of Kvillebäcken and connects the Hökälla wetland area with the lower more populated areas but there are some poorly bridged barriers along the way. Many industrial properties' back-lots go all the way down to the water's edge and are inaccessible to the public.

There are two small-unnamed parks along Kvillebäcken. The largest one is between Hjalmar Brantingsgatan and Färgfabriksgatan (nr. 1 in Figure 68). This park was recently enlarged to accommodate a new neighborhood with 1600 apartments that is sprouting up next to it. Much of the new park is a fenced-in playground to accommodate the new day-care centers that will be required in the new neighborhood. The playground is also open to the public. The fence was deemed necessary due to the playgrounds proximity to Kvillebäcken with its steep edge posing a danger to small children (Sintorn, 2011). The older part of the park on the East side suffers from traffic noise. The park has lawns, trees and a few park benches but not much else of interest. The murky water is not accessible anywhere along the stream due to the steep edge and tall weedy vegetation in most places. The other park (nr. 2 in Figure 68) follows the Southwest side of Kvillebäcken between Vågmästaregatan and Herkulesgatan. Here the grass is regularly mowed all the way up to the steep edge of the stream. The stream is well shaded here and the tall trees at the streams edge give character to the park. A bike and footpath runs parallel to the stream. Willow trees that line one side of the path are so severely stunted by pruning that they are quite ugly today. The park has a fenced in AstroTurf sports court. The park is used as a transport corridor but people don't spend much time in the park.

The busy roads Hjalmar Brantingsgatan and the Lundbyleden Freeway break the natural connection Kvillebäcken has always made between the rural hinterland and the Göta River. Where Kvillebäcken meets these roads there are no crosswalks thus requiring major detours.

Ways to improve recreation

- *Better and safer access to the water's edge would be a great asset. A more gradual slope and a shallow ledge would improve safety as well as provide better contact with the water.*
- *Improve acoustics. Those areas, which are close to noisy traffic, would gain lower noise levels by lowering the land there.*
- *Clean up the water to make it safer for children to play in.*
- *Increase heterogeneity by allowing a soft gradient from dry to wetland. More species and more biotopes increase interest.*
- *Improve connections between the parks and Kvillebäcken via green/blue corridors.*

Figure 68. The map presents the watershed's recreational features

Summary of Inventory and Analysis

In the previous chapters I attempted to portray a picture of the Kvillebäcken watershed, how it became what it is today and some of the problems with the management of its hydrology. I did this in order to gain insight into what one could do to make improvements to the way stormwater is managed there. Humanity has affected the watershed for 7000-8000 years but it was not until about 170 years ago that we made changes that would severely limit biologic activity. Within the last 170 years or so, the wetlands along Kvillebäcken and where it joins the Göta River have been eradicated to make space for industry and urban expansion. This has resulted in ecological processes being severely marginalized. Impermeable asphalt and buildings have displaced many species, especially wetlands species. Precipitation and soil transported by the Göta River were once used as resources by this ecosystem but are now nuisances to society. Precipitation allowed the wetlands to produce biomass from solar radiation. Soil eroded and carried by Kvillebäcken and the Göta River provided a growing medium and nutrients for marshland vegetation. The marshland vegetation stabilized the rivers banks, lessened the impact of ocean storm surges, transformed nutrients into useful forms that fed fish and birds, provided wildlife habitat and lastly provided protein to people living nearby.

Major points compiled from the inventory and analysis that are relevant to my stated objective.

"…explore possibilities within Kvillebäcken's watershed that will improve the quality of water exiting Kvillebäcken's 15 square kilometers watershed, prevent unwanted flooding, improve habitat for a variety of species, and create outdoor space that can be used for recreation (Page 3)."

- *Wetlands, that once provided a host of ecological services, have been eradicated from most of the watershed.*
- *Parks and natural areas are disconnected from each other.*
- *There is a risk of flooding from sea surges as well as backups in the combined sewer system.*
- *Contaminated stormwater and drainage water is released into Kvillebäcken without treatment.*
- *Soil conditions in the area make infiltration not viable.*
- *Sewers have replaced some tributary streams.*
- *Kvillebäcken's riparian edge is bypassed by stormwater and drainage pipes.*
- *A large portion of the watershed is within the combined sewer system adding to operating costs and reducing the efficiency of the system.*

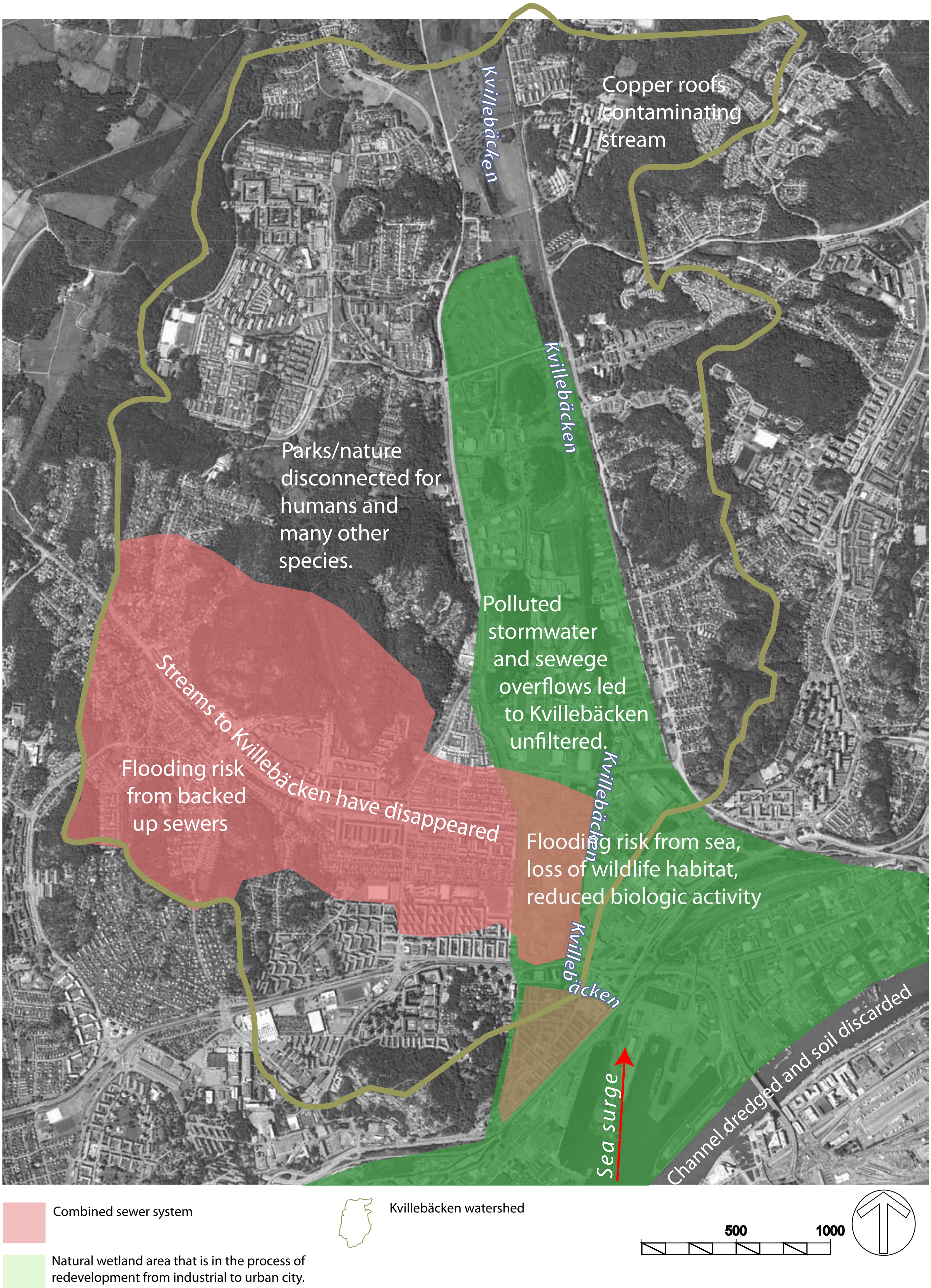


Figure 69. Map summarizing the major issues taken from the analysis and inventory.

What can be done?

It is not possible to turn back the clock to stop the destruction of the wetlands that were once prevalent along Kvillebäcken. We can, however, enlist ecological processes in current and future development to improve water quality, habitat and recreation within the watershed. We can also reconnect broken corridors as well as strengthen and protect existing connections.

Sustainable Stormwater Practices

Sustainable stormwater practices mimic natural ecologies in the way they use runoff as a resource rather than as a waste product. A natural stream corridor is usually an ecological hotspot within a landscape. It is indeed water, which all life needs for survival. Typically, however, the built environment we live in produces a great deal of runoff that carries our waste to water bodies that cannot deal with it. A full overview of all the methods to manage stormwater is beyond the scope of this paper. There are, however, some general processes that reduce pollutants in stormwater as well as reduce the quantity of runoff. A successful system should allow for many of these processes to occur.

Basic functions of stormwater management systems

- *Retention: consumes stormwater, prevents flooding. Example: infiltration to ground water, evapotranspiration by vegetation*

- *Detention: slows the flow to allow for sedimentation, minimize erosion, and prevent flooding. The slower water travels, the less it causes erosion or soil and nutrient loss from land (Forman and Godron, 1986). In addition, it prevents other parts of the system from being overburdened reducing unwanted flooding or combined sewage overflows (CSOs). Example: pond.*

- *Pollutant removal: traps nutrients, heavy metals, hydrocarbons and other contaminants. Example soil and vegetation*

Sustainable stormwater systems often perform all of these functions to a lesser or greater degree. Since the Kvillebäcken valley's clay soils have a very low infiltration rate, one cannot rely on infiltration into the natural soil. I have chosen to focus on technics that remove pollutants, slow the flow and retain stormwater via evapotranspiration and interception by vegetation.

Pollutants are removed from stormwater through the following processes:

- *Sedimentation: The process of suspended particles settling out in a catch basin or pond. Important pollutants such as phosphorous are left in the sediment*

- *Filtration: The process of straining out particulate matter through a filter media like a sieve.*

- *Adsorption: Removal of dissolved pollutants when they adhere at the molecular level to other particles creating a film. High cation exchange capacity and neutral PH are usually required*

- *Microbial action: Bacteria and other microorganisms consume nutrients such as nitrogen. Denitrification is a microbial process that turns nitrogen into harmless nitrogen dioxide gas. For denitrification to occur both aerobic and anaerobic conditions need to exist as it is a two-step process in which both aerobic and anaerobic bacteria play a part.*

- *Volatilization: Pollutants, especially hydrocarbons are allowed to evaporate*

- *Absorption: Pollutants soak into the soil*

- *Plant resistance and uptake: Plants slow down runoff increasing the chances of filtration and sedimentation from occurring. Plants also add decaying material (detritus) to the system, which promotes absorption and microbial action. Plants can also be harvested removing pollutants from the system.*

Some Inspirations

Portland green streets

The Green streets initiative in Portland, Oregon is an initiative to manage stormwater with vegetation and soil in stormwater planters, daylighted stream corridors, swales, green roofs and other green infrastructure rather than pipes. The initiative's primary purpose is to improve water quality in the Willamette River, and to reduce unwanted flooding. The city of Portland is one of the leaders in implementing green infrastructure for stormwater management. They have built planters along streets that are designed to infiltrate stormwater into the soil. The planters are designed to infiltrate most storm events. The soils in Portland are generally well drained which facilitates stormwater infiltration. Often the planters are placed in curb extensions. These have a traffic calming effect and have improved pedestrian safety. The planters are designed with an emergency overflow that either drains to the existing sewer or is connected to other planters down the line.

Portland has also been a leader in the adoption of ecoroofs. Ecoroof technology can easily translate to Gothenburg. It does not depend on the permeability of soils. They function as a bioretention facility that very easily

Another way Portland, Oregon has managed to improve stormwater management is by changing the way they finance it. They introduced a new charge specifically for the actual stormwater a site produces whilst at the same time supporting property owners in reducing their stormwater volumes. They offered to evaluate a property for the viability of onsite stormwater management and to disconnect and divert roof downspouts to onsite vegetation for free. Homeowners could also do the disconnection themselves and receive 53 dollars for doing it. This campaign has been the most effective means Portland authorities have used to reduce the amount of stormwater entering the combined sewer system.

Another thing they have done in Portland is daylighted streams. In one example a stream called Tryon Creek that once ran in a pipe under a parking lot was brought back up to the surface and made a primary feature of a new apartment development. It was planted with native riparian vegetation.

Seattle, Washington

Another city that is at the forefront of implementing sustainable stormwater practices is Seattle, Washington. One project that particularly inspired me was the Thornton Creek Water Quality Channel. Thornton Creek is a stream that had been buried in a pipe under a parking lot. The stream was daylighted to improve water quality, regain lost habitat and as an outdoor space. It not only dramatically improved water quality but also spurred on urban development around it

Suggested sites for improvement

Today, many of the low-lying areas that have been abandoned or under utilized by industry are being redeveloped. This gives us an opportunity to reform them in a way in which ecological processes are harnessed to provide us with services that otherwise have to be provided with pipes and pumps. By reintroducing ecological processes, we get into a better cyclic balance. There are no wastes in such a system in contrast to the linear extract and discard process that has been prevalent during modern times.

In this work my aim has been to explore ways stormwater could be better managed to improve water quality, reduce the risk of flooding, increase biodiversity and improve recreational qualities. The project areas are therefor chosen based on the following criteria:

In Figure 70, I have marked areas where various methods could be suitable to achieve these goals. Table 6 on pages 50-51 goes into greater depth. The projects are then presented with illustrations in the pages following Table 6.

Choice of project area

The project areas are chosen based on the following criteria:

- *Land use not in conflict with stormwater management*
- *Stormwater is produced onsite or runs through it.*
- *Potential for improving Kvillebäcken as a recreational corridor*
- *Potential for improving Kvillebäcken as a biodiverse ecological corridor*

Stormwater Management Methods Applied in the Kvillebäcken Watershed

Day-lighting streams

In the hydrology chapter, I noted that, previously, many more tributary streams existed in the watershed than do today. They have been put into pipes underground. Some streams are now even pumped to the sewage treatment facility. By day lighting streams (bringing them back up to the surface), several ecological services could be regained. Removing them from the combined sewer system would also reduce the cost of sewage treatment and improve the quality of treatment of sanitary sewage. There would also be fewer combined sewage overflows like those discussed in the chapter: "Description of present stormwater management and its effects".

In the ecology chapter I explained the benefit of streams as ecological corridors that provide migration routes as well as habitat to many species. Daylighted streams could offer other ecological services such as filtering of runoff, preventing flooding and increasing recreational qualities. Unfortunately though, there have not been any comprehensive studies made on their effect on aquatic ecosystems (Maas-Hebner, 2014).

Riparian buffer zone

A riparian buffer is an area along a stream that filters runoff before it enters the stream. Riparian zones are often eradicated or short-circuited through the use of drainage tiles and culverts that drain directly into the stream. As explained in the chapter: "A walk along Kvillebäcken" this is the case from the golf course down to the Göta River. Creating riparian buffers is one of the most effective things one can do to improve flood control and water quality in a stream (Watson and Adams, 2011). Between 10-25 meters of riparian width gives maximum nutrient retention (Vought et al., 1994). This amount of "free" space exists along much of Kvillebäcken. Nitrogen can be removed year-round below ground through denitrification in saturated riparian soils (Vought et al., 1994). Riparian buffers have aerobic and anaerobic soils thus offering favorable conditions for denitrification. Even phosphorous is effectively trapped in riparian buffers; however, this is through being trapped above ground as runoff passes through vegetation (Vought et al., 1994). The key here is to make sure that the water table in the riparian buffer is not artificially lowered through drainage tiles or ditches. Runoff should also enter a riparian buffer as sheet flow which slows down and disperses the water over a larger surface (Vought et al., 1994). Riparian zones are important migration corridors as well as habitat to many species. By reconnecting the riparian zone to runoff on its way to Kvillebäcken the habitat will be improved for riparian species. This would also increase the diversity of biomes, which is not only good for biodiversity but also provides greater interest to people.

Vegetated sand filter

A vegetated sand filter is designed to filter heavily polluted stormwater that is released via a stormwater outfall in an existing dense urban environment. A sand filter can be very effective at removing heavy metals and hydrocarbons (Wagner, 2004). Very polluted stormwater is produced in the lower reaches of the watershed as mentioned in the chapter: "Description of present stormwater management and its effects". Existing soil is excavated and replaced with sandy soil. Sandy soils can bind heavy metals and microorganisms in the soil can break down hydrocarbons. The filter is planted with vegetation that can extract heavy metals that have been trapped in the soil filter. The vegetation is occasionally harvested to remove the contaminants from the site.

Increase vegetation

The quantity of runoff can also be reduced by interception. Deciduous trees in an urban or suburban environment can intercept between two thousand and three thousand liters per year (Cotrone, 2008). A mature evergreen tree can even intercept fifteen thousand liters per year (Cotrone, 2008). Trees, of course, also consume water. Mature trees can consume up to one hundred and fifty thousand liters per year via transpiration (Cotrone, 2008). The uptake of water in the soil by tree roots increases the capacity of the soil to store more rain before it becomes runoff. Tree roots also significantly help to improve infiltration in compacted soils. In a forest the understory is also very important for infiltration. The understory acts as a sponge for rain, allowing it to eventually infiltrate the soil. In one case in North Carolina, when a forest understory was replaced by turf, the infiltration rate reduced from 12,4 in/hr. to 4,4 in/hr. (Kay, 1980 sited in Cotrone, 2008). When adding tree cover to a watershed, however, the best way to decrease runoff is by putting it over impervious surfaces (Wang et al., 2008).

Disconnect residential roof-runoff and divert it to lawns

The simplest way to reduce runoff from residential areas is to disconnect their roof downspouts and divert it to the lawn. A well-established grass lawn can take up most of the stormwater from a roof one half to equal size of the lawn (Stahre, 2004). This method can even be used where there is an impermeable layer of clay underneath since the lawn can absorb most of the water (Stahre, 2004). In Portland, Oregon USA the city has created a program to get residential properties' stormwater out of the sewage system. They have done this by offering to disconnect roof downspouts for free or by paying homeowners fifty-three dollars to do it themselves. Utility customers have also gotten a reduction in a stormwater fee the utility imposes based on the area of impervious surfaces on a property. Tom Liptan from the City of Portland who spoke at the Urban Flooding conference in Malmö in March 2012 said that this program was the most successful measure the City of Portland has implemented to reduce the negative effects of stormwater within the city (Liptan, 2012).

Rain gardens

A raingarden is a growing bed in a depression that is designed to infiltrate stormwater to underlying soils. The raingarden vegetation needs to be able to tolerate periods of flood and dry conditions. The raingarden should be able to manage most of the flows coming to it. They often have amended soils that have good water storage and infiltration capacity yet still support vegetation. It is often thought that rain gardens cannot be implemented in areas with clay soils. Clay soils, whose structure has not been disturbed, infiltrate quite well (Thomas, 2010). Unfortunately though, urban soils are often disturbed. Deep rooting vegetation can further improve the structure of clay soils and aid in infiltration. An underdrain can also be installed. When designing a rain garden for infiltration, tests need to be done to measure the rate of infiltration and how quickly the soil will become saturated. This should be done several times through out the year. In one recent installation in Seattle, Washington, the engineers miscalculated how quickly the rain gardens would drain. They did not drain as expected which caused a public outcry (Stiffler, 2011).

Stormwater curb-extensions

Stormwater curb-extensions use some of the roadway to treat stormwater. Besides treating stormwater, extensions narrow the roadway, which provides greater pedestrian safety. Curb-cutouts allow stormwater to flow into the curb extension where it is treated and detained. Some systems such as those created in Portland are designed to infiltrate into the underlying soils; however, this depends on the ability of these native soils to infiltrate. Stormwater curb-extensions can also be designed to convey stormwater from one planter to another where infiltration into existing soils is limited.

Pervious pavement

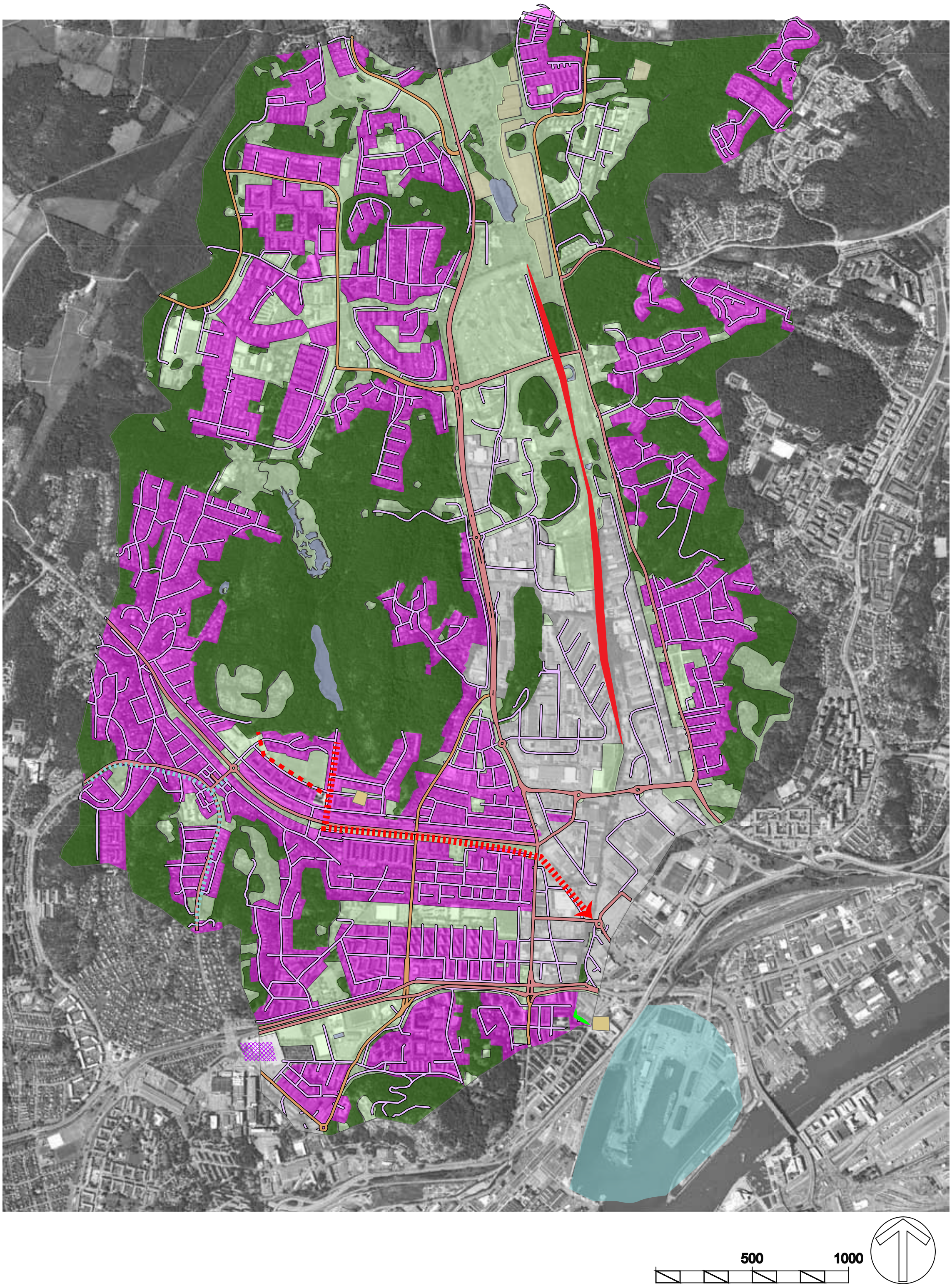
Pervious pavement allows water to run through it and into the supporting layer. The supporting layer supports the road surface but also filters, stores and conducts stormwater. Pervious pavement does not require more space than the road itself. It reduces traffic noise and requires less salt and sand to maintain friction during the winter. It is also less likely to be damaged due to freeze/thaw issues. Where steep grades exist there is a risk that stormwater may resurface through the pervious pavement at the bottom of a hill. Pervious pavement and each underlying layer should consist of stones that are of one diameter to maximize empty space between the stones. In areas with permeable soils the stormwater infiltrates until it reaches groundwater. In areas with underlying impermeable clay soils an under-drain can be fitted that drains to an appropriate location.

Things to consider:

- *Pervious asphalt needs to cool longer after installation than standard asphalt in order to maintain its porous nature.*
- *Maintenance is different from impervious asphalt surfaces*
- *Care should be made to prevent soil from coming on to the pervious surface potentially clogging it.*
- *Pervious surfaces may need to be vacuumed occasionally to remove fine particles.*
- *Pervious asphalt is said to cost about 20% more than conventional asphalt.*
- *Where retrofitted the underlying gravel may need to be replaced or sifted so that each layer has only one diameter crushed rock.*
- *If it is installed on slow draining soils like clay, special care needs to be made that the underlying layer drains to an appropriate recipient*
- *Will significantly disrupt traffic while under construction*

Green roofs

Green roofs are essentially roofs with vegetation growing on them. They are divided into two major groups: extensive and intensive green roofs. Extensive green roofs are homogenous surfaces planted with undemanding plants such as sedum and cover large areas. They are not intended to be used as outdoor space. They are designed to require little maintenance. Intensive green roofs are similar to gardens on the ground. They frequently require intensive maintenance but also provide greater amenity. Both intensive and extensive green roofs can provide many benefits. Both types are designed to retain, detain and filter stormwater. They can be used as outdoor-space in heavily built up areas or replace habitat that may have been lost when the building was built. They can filter stormwater and the air from pollutants as well as convert CO^2 to oxygen and biomass through photosynthesis. Green roofs can even help to improve the indoor climate by reducing thermal gain in the summer and thermal loss in the winter (MacMullan et al., 2008)



Residential areas should divert roof runoff and impermeable surfaces to gardens.

Forested recreational areas at the higher elevations should drain to Kvillebäcken in vegetated stream corridors.

Riparian zone going through Golf course and industrial area should be reconnected to drainage from adjoining land

Frihamnen: where Kvillebäcken joins the Göta river should be restored to a marshland park

Industrial areas with large impermeable surfaces should have green roofs, impermeable paved surfaces and vegetated swales.

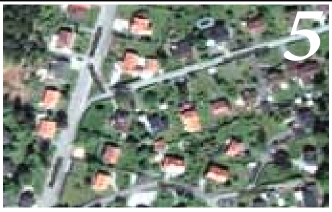
Stormwater outfalls from heavily trafficked areas can be filtered of hydrocarbons and heavy metals via multi-functional parks.

Björlandavägen: Daylight stream that once flowed here and divert drainage from Hisingsparken and stormwater along the way to it.

Toredalsgatan: Divert drainage from parks and roads to an open and vegetated drainage channel on grass strips that line Toredalsgatan.

Figure 70. Map showing what and where I think changes could be made to improve stormwater management within Kvillebäcken's watershed.

Table 6. Overview of Proposal Locations			
Location	Green area along Björlandavägen	Vegetated land along Kvillebäcken between Minnelundsvägen and Hökälla	Toredalsgatan in a single-family home area that has a combined sewage network.
Current land use	Buffer between Björlandavägen and bike path and recipient of some storm-water from adjacent road.	Industry, recreation and stormwater drainage	Collector road and grassy road edge
Stormwater problem	Streams from Hising's Park have been diverted to the combined sewage system put-ting a large burden on it.	Industrial sites lead their stormwater directly to Kvillebäcken without being filtered. Illegal dumping occurs here.	Runoff from natural streams, streets and houses go to the combined sewer system.
Suggested change	Reconnect streams from Hising's Park to Kvillebäcken by day-lighting a stream along Björlandavägen to Kvillebäcken.	Reconnect riparian zone by spreading drainage across it with a level spreader.	Direct stormwater to linked stormwater curb extensions along Toredalsgatan.
Potential complications	Existing trees located along the proposed corridor could be damaged when recreat-ing the stream. Underground infrastructure may come into conflict with the design. Part of the stream will go through parking areas reducing parking space. Roads will need to be crossed.	The proposal will make the riparian edge wetter which would make it less accessible. Footbridges would likely be required to get to the stream. Salts in the stormwater may also negatively effect vegetation.	Some people use the grassy strip along the edge as guest parking. The stormwater curb extensions may not drain adequately.
Potential for flood prevention	Removing run off from Hising's Park will significantly reduce the risk of backups in the sewage system and sewage overflows into Kvillebäcken.	The effect on flooding of built up areas could potentially be improved since it would slow down the flow of water entering Kvillebäcken thus reducing the risk of overflows downstream.	The reduction of volume to the combined sewer would be significant thus reducing the risk of it backing up and sew-age overflows
Potential for uptake of contaminants	Stream corridors can effec-tively filter stormwater.	The reconnected riparian buffer could filter out many of the contaminants entering the stream from industrial sites draining to it.	The soil and vegetation in the curb-extensions could remove pollutants.
Potential for improving Kvillebäcken as a recreational corridor	This will reconnect Kvillebäcken to Hising's Park making getting to either place easier and more interesting.	By improving access to the water as well as adapting the habitat for more typical ripar-ian vegetation it could attract more people.	The curb-extensions would redefine the path to Kvillebäcken strengthening ties to it.
Potential for improving Kvillebäcken as a diverse eco-logical corridor	A stream corridor will provide habitat and a migration corri-dor to a variety of species.	The improved riparian edge would support more wetland species.	The vegetated curb-extensions would contain a diversity of species as well as make the water cleaner and less toxic to sensitive species.

			
Park area along Kvillebäcken adjacent to Kvilletorget.	Single family home areas throughout the watershed	Backaplan: Parking lots, large buildings like Hornbach and Coop in the lower elevations.	The Frihamnen area is at the outlet of Kvillebäcken.
Park	Single-family residential	Parking, Shopping	Car racing, offices, dock for cruise ships, bus depot.
Stormwater from heavily trafficked Hjalmar Brantingsgatan and other roads is released into Kvillebäcken via an outfall here. Sediment is severely contaminated with heavy metals.	Stormwater gets pumped and treated at the sewage plant at a considerable cost. The additional stormwater causes sewage overflows into Kvillebäcken.	The large parking areas and rooftops create a lot of stormwater in a location that was once a wetland that managed runoff from higher elevations.	Polluted water coming from the Kvillebäcken watershed enters the Göta River here.
Redesign the park replacing soils and vegetation to filter stormwater, add sitting steps leading down to the water and a beach path along the water's edge.	Redirect stormwater from rooftops to lawns that can absorb most of it.	Create a tributary drainage corridor to Kvillebäcken. Install green roofs on large buildings. Redesign parking lots to retain and filter stormwater.	Create a marshland park containing marshlands, bike/footpaths, bridges and sandy beaches.
The bike/footpath is adjacent to a building so one would need to insure that it is not damaged. There is a risk of damaging trees. Care must be taken to ensure the endangered aquatic plant P. trichoides' survival.	There are clay soils on some slopes within the watershed that could slide due to increased loading.	The property owners have little economic incentive to make changes. Existing buildings may not be able to support a green roof.	There is great pressure to build Gothenburg's "Manhatten" here. It may be difficult to finance the project.
Since there will be less soil, more gradually sloping slopes and pore volume within the soil, the area will be able to hold more water than the existing park.	Reducing pressure on the municipal sewer would reduce the risk of it backing up.	Stormwater from these sites runs off quickly. By slowing the flow down, Kvillebäcken and the sewer has a chance to drain.	The marshland could become a natural barrier from sea surges that would dissipate their strength thus lessoning their impact on built up areas.
The vegetated sand filter should take up a large part of the contaminants entering the stream from the stormwater outfall.	Yes, although runoff from roof tops is not very contaminated.	Parking lots collect residue from cars. These pollutants could be filtered out with green infrastructure.	The marshland vegetation is effective in adsorbing pollutants.
The proposal would provide a more diverse vegetation, seating looking over the stream and the ability to come down to the water. Safety is improved since the slopes are not as steep.	The proposal would improve the water quality in Kvillebäcken making it more attractive.	The drainage corridor would lead to Kvillebäcken making a clear connection to it.	The park would make Kvillebäcken once again the grand entrance into Hisingen. The park would be the start or destination of exploratory treks along Kvillebäcken. The ability to once again safely swim in central Gothenburg would be hugely popular.
The vegetated sand filter would clean up stormwater as well as increase habitat diversity making it suitable to a larger range of species.	Fewer combined sewage overflows being released into Kvillebäcken would protect sensitive species.	The drainage corridor would be planted with local species creating new habitat as well as making the water that enters Kvillebäcken cleaner.	The marshland would provide habitat and food for many fish and migrating birds.

Location 1. Vegetated strip along Björlandavägen

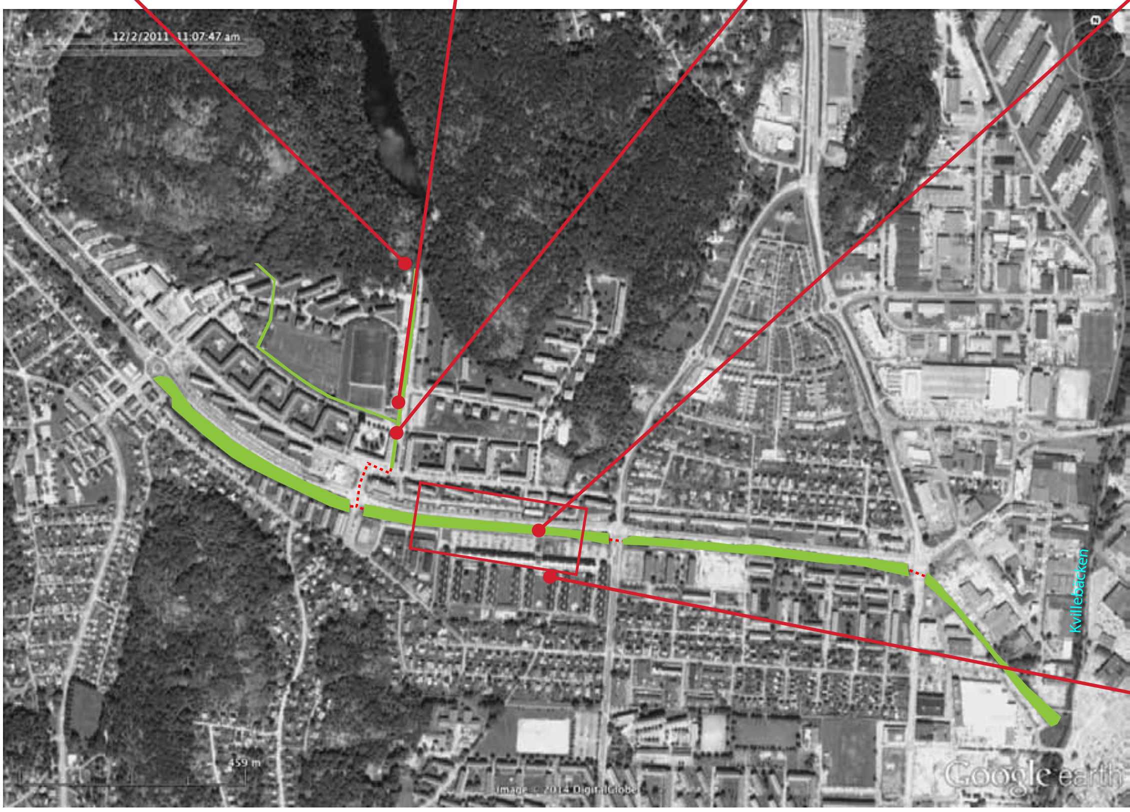
It does not make a lot of sense to pump clean water from Hising's Park to the sewage treatment plant (see Figure 71). One could install a stormwater pipe for this purpose but that would not provide any other benefit. A stream once ran to Kvillebäcken through this valley. I propose to daylight this stream perhaps not along its exact original path but along reasonable one. A wide green corridor along Björlandavägen that was earmarked for an extension of Gothenburg's tram network fifty years ago but is now not likely to be built could be used for this purpose (see Figure 74). The stream would join Hising's Park (the largest park in Gothenburg), which today lacks a clear entrance with Kvillebäcken (where Gothenburg is growing the most) in more ways than one. The day lighted stream could act as an ecological corridor providing transport possibilities for flora and fauna as well as a recreational corridor leading to Hising's Park. Today the green strip is graded to receive some stormwater from Björlandavägen. Björlandavägen does not have a curb along this side so runoff can drain to the vegetated strip instead of the combined sewer. The other side of the road does have a curb and sewer inlets. In some places there are trees within the vegetated area. It would be desirable to keep as many trees as possible since they provide many ecological services of their own. My proposal therefore suggests that meanders be created in the stream that gives a large berth to existing trees (see Figure 77).

Figure 71. Location where a stream draining the Hising's Park goes into the combined sewer system.

Figure 72. View facing the park. The trees (Sorbus intermedia) along Slättadammsgatan look to be in poor health.

Figure 73. View facing away from park along proposed path for daylighted stream.

Figure 74. Stretch along Kvillebäcken were the daylighted stream would transport water once again to Kvillebäcken.



Proposed location of recreated stream

Culverted area

0 500m

Figure 75. Orthographic view encompassing the entire site.

Figure 76. Existing ground profile of the proposed stream. The stream would descend 24 meters over the two kilometer distance from Hising's Park to Kvillebäcken..

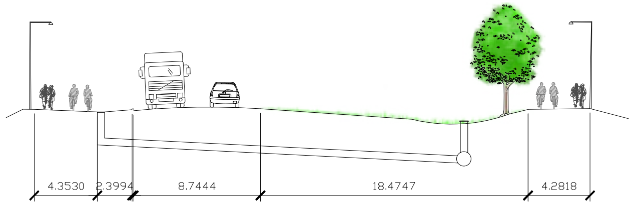


Figure 78. Existing ground profile of corridor: Stormwater from half the road drains onto the wide grassy area. The other half of the crowned road goes in to the combined sewer system.

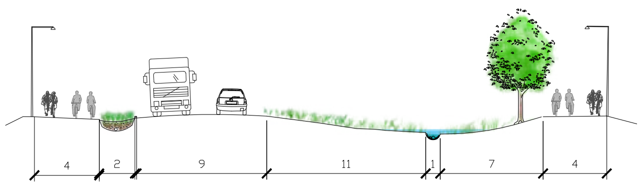


Figure 79. Proposed ground profile describing how this area could look. The water level would very. A narrow (approximately 1 meter wide) stream with a rocky bed meanders through the meadow. The stream will spread out over its banks during periods of heavy rain.

Figure 77. Plan view of a part of the proposal area. The stream starting at Hising's Park must go into a culvert to cross Björlandavägen. Meanders in the stream imitate natural streams and avoid existing trees. The stream can overflow to accommodate more water when needed. The main channel is narrow in order to ensure a minimum water level of about 0,5 meters that would provide habitat to aquatic species even during dry periods.

Location 2. Vegetated land along Kvillebäcken between Minelundsvägen and Hökälla

Polluted runoff from the golf course, industrial properties and the Grimbo landfill drains via ditches and outlet pipes directly to Kvillebäcken. The riparian edge is thus circumvented preventing it from filtering and making use of the runoff. I suggest creating a level-spreader parallel to Kvillebäcken that would spread out the polluted water and allow it to filter through the riparian edge as sheet flow (see Figures 86-89) A level-spreader is essentially a ditch with one horizontally level edge that is lower than the other edge of the ditch. Water entering the level-spreader will spread out in the ditch and then exit it by breaching the level edge as sheet flow instead of channeled. Water travelling as sheet flow spreads across the ground in a thin sheet. This slows the flow down thereby reducing erosion and providing maximum contact with the vegetation and soil in the riparian zone. Berms running perpendicular to the level spreader allow the level spreader to "step" down in increments. I also suggest filling in the last 10 to 25 meters of existing ditches and shortening drainage pipes so that they drain into the level-spreader.

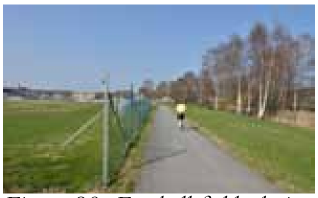


Figure 80. Football fields drain into Kvillebäcken one of which has a landfill under it.

Figure 81. The industrial sites like the one to the left drain directly to Kvillebäcken. A grass area between the bike/footpath is mowed.

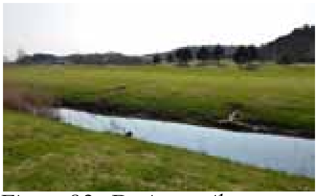


Figure 82. Drainage tiles on the golfcourse surface just before entering Kvillebäcken.

Figure 83. Ditches coming from the landfill are colored red do to the high iron content. The ditches short-circuit the riparian zone where contaminants could be trapped.

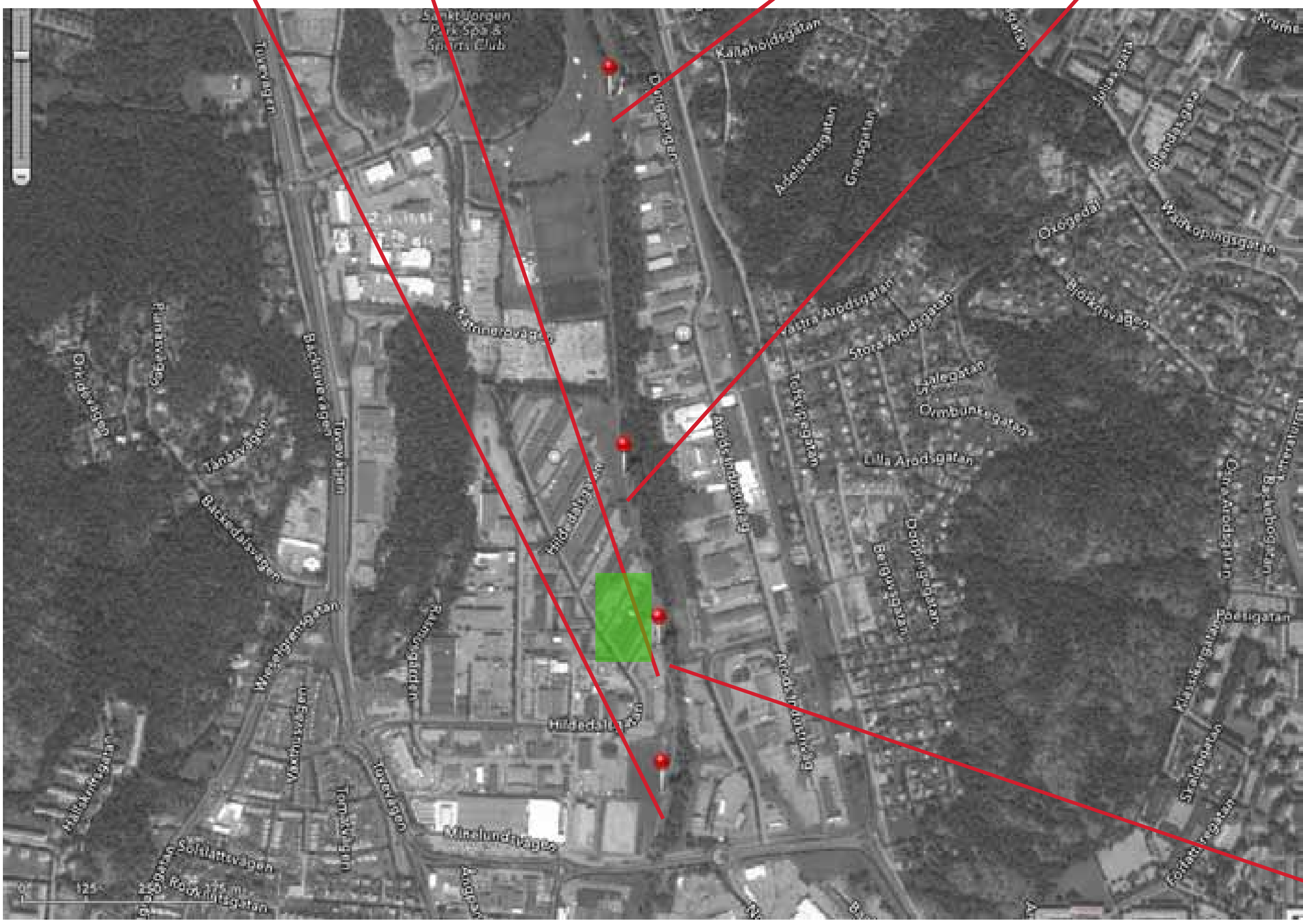


Figure 84. This is an overview map of the part of Kvillebäcken's corridor that contains the golf course and industrial area.

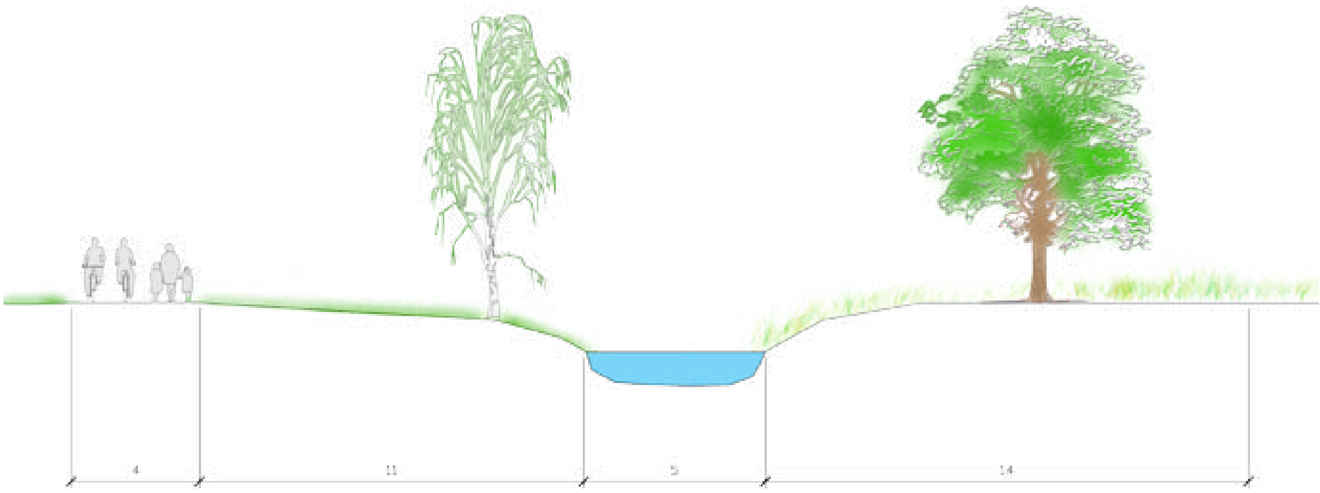


Figure 85. Existing ground profile A-A

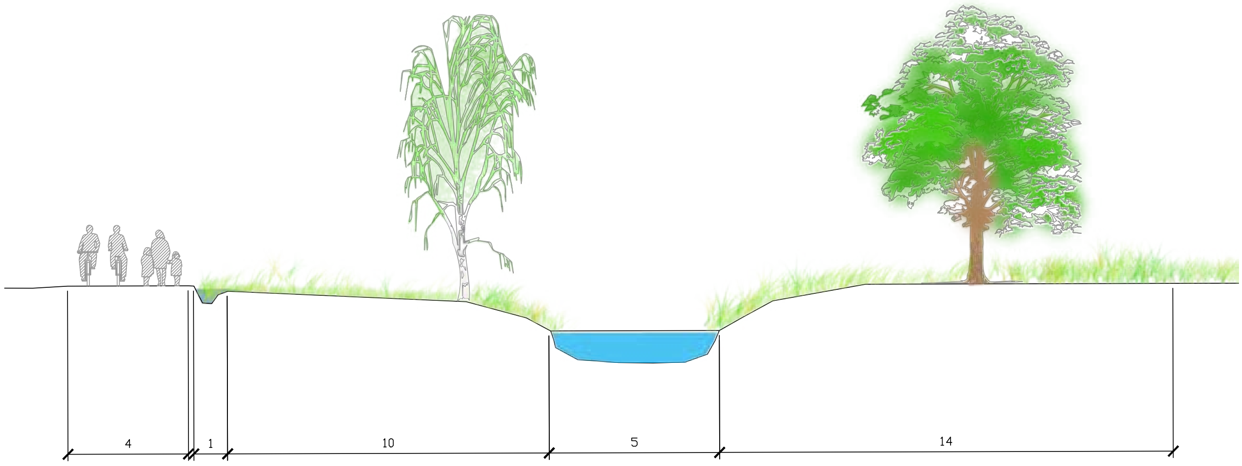


Figure 86. Proposed ground profile A-A displayed in plan view in figure 87. The major change is the introduction of a level spreader which is essentially a ditch dug along a contour line. It is important that the lower lip have the same level to avoid short-circuiting.

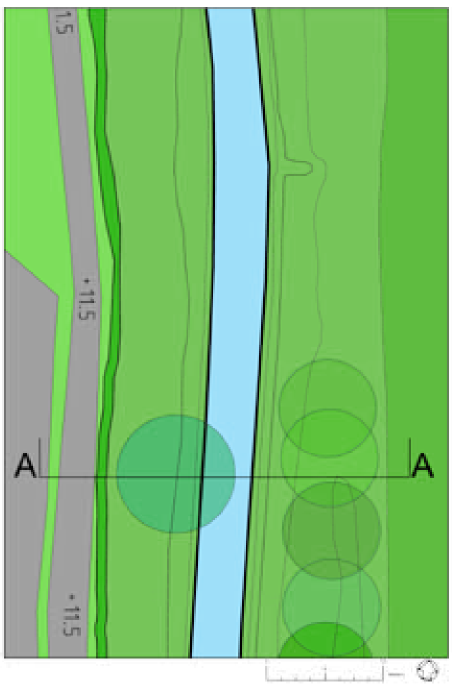


Figure 87. The plan view of a part of the proposed design area. The lower lip of the level spreader follows a contour line so that when water goes over the edge it will run into the riparian edge as sheet flow.

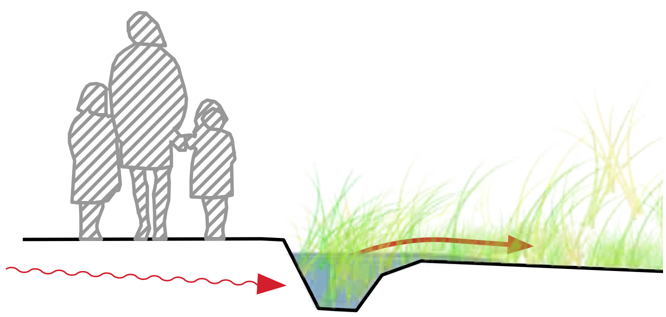


Figure 88. A close up of the level spreader and how it functions. Runoff coming from the industrial area flows via pipes or through the supporting layer of the bike and foot into the level spreader. The arrows indicate the path of stormwater as it enters the level spreader.

Location 3. Toredalsgatan

Toredalsgatan is a wide collector road within the combined sewer network. The 18 meter wide road corridor runs through the center of the valley with grass strips and broad sidewalks on both sides of it (see Figure 91). The roadway, at over 9 meters wide, is over dimensioned for the desired speed of 30 km/hour. There are several islands in the road put in place to slow down traffic (see Figures 93-94). The forested hills that define the upper reaches of the valley drain into the combined sewer system. Single-family homes lie between the forested hills and Toredalsgatan. They too drain to the combined-sewer network.

Figure 89. A stream coming down from one of the hills

Figure 90. Profile and plan view of the path between a major natural stream and where it could connect to a daylighted stream along Björlandavägen as described in the Location 1 proposal

I suggest directing drainage and stormwater runoff to linked stormwater curb-extensions along both sides of Toredalsgatan (see Figures 95-96). By reducing the width of the roadway to 6,5 meters, the sidewalks could be widened to include bicycle paths and still accommodate automobile traffic. The stormwater curb-extensions could be placed between the road and the bike/foot-paths. Stormwater could enter the curb-extensions via curb cutouts. Once in the curb extension, the stormwater moves downhill through the amended soil as well as on the surface. Here it would get filtered, detained and consumed by vegetation. The stormwater could cross impediments such as driveways and streets via narrow surface channels as well as through an underground channel of crushed rock (see Figure 97).

Figure 91. Toredalsgatan looking north from Äpplegatan

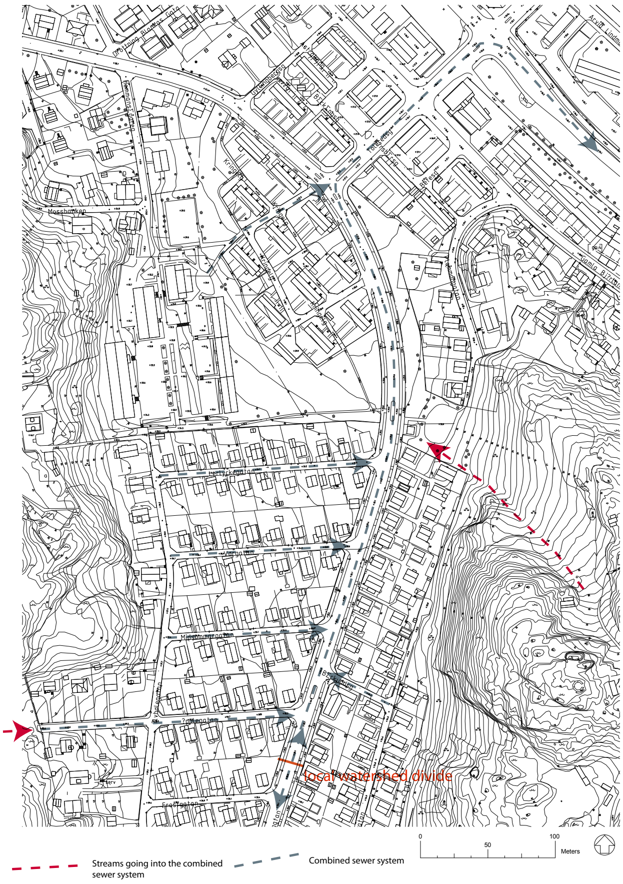


Figure 92. Stormwater from roads, single-family homes and streams from the surrounding hills goes into the combined sewer network.

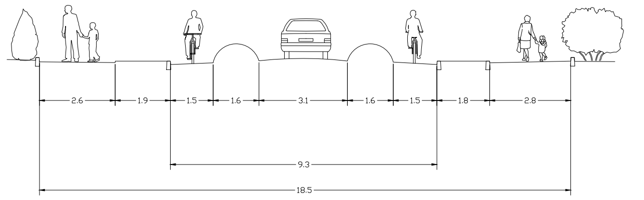


Figure 93. Here is a section view showing the existing situation. Islands temporarily reduce the width of the roadway to force oncoming traffic to wait. Cars swerve to avoid the islands.

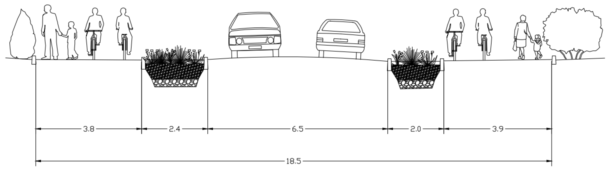


Figure 95. This is a section view of the proposal. The roadway is reduced which makes it more intuitive for drivers to keep their speeds down. The sidewalk now includes a bike path. The joined planters filter and convey the stormwater removing it from the combined sewer network.

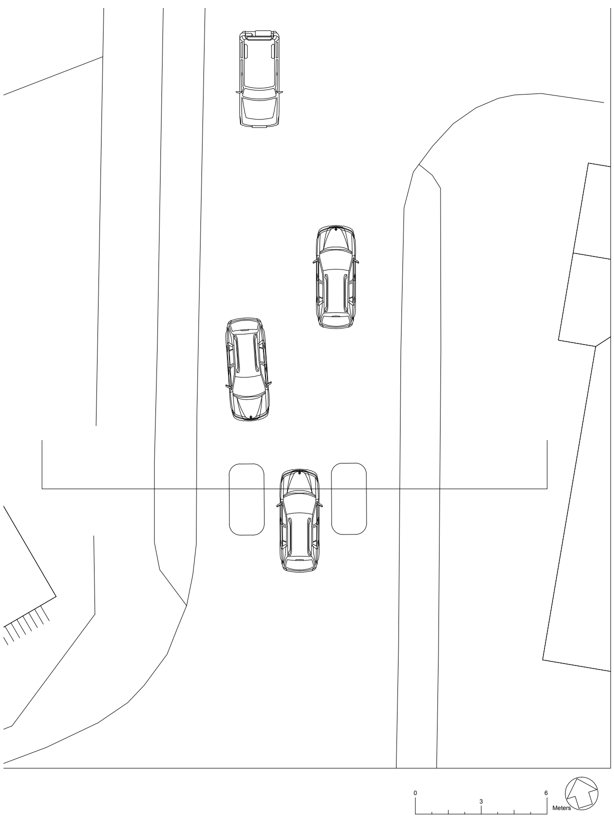


Figure 94. Plan view of a part of Toredalsgatan depicting the current situation. Cars swerve around traffic islands which are intended to keep speeds down. Bicyclist share the roadway.

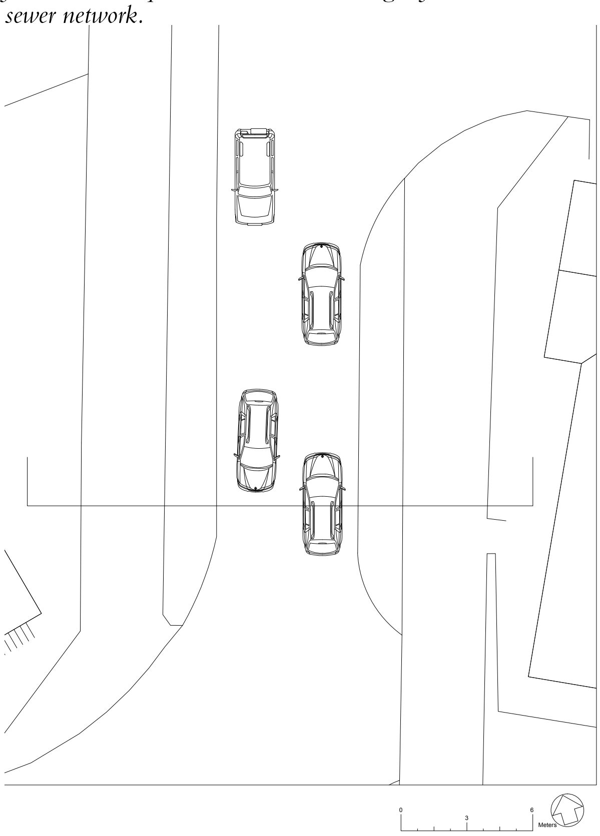


Figure 96. Plan view of a part of Toredalsgatan depicting my proposal.

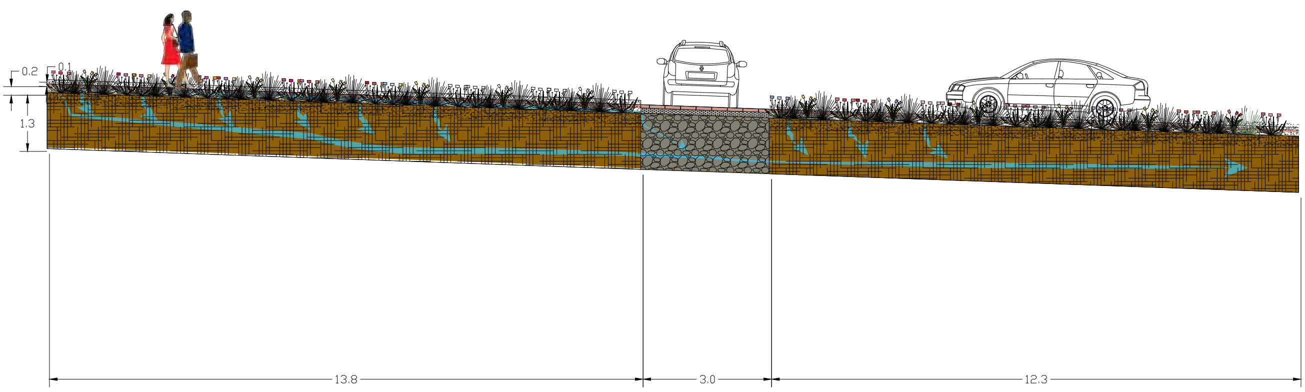


Figure 97. Profile view of a section of the proposal. The stormwater enters the stormwater planter through curb cutouts where it infiltrates and continues to flow through the amended soil.

Location 4. Park along Kvillebäcken adjacent to Kvilletorget

In the chapter: "Description of present stormwater management and its effects" I described how the lower parts of the watershed were the most polluted. The area surrounding the park has the most road traffic and impermeable surfaces. The unnamed park which lies along Kvillebäcken's southwestern bank between Hjalmar Brantingsgatan and Herkulesgatan is the last public space Kvillebäcken goes through before entering a semi-private newly built apartment complex, a culvert under the freeway Lundbyleden and out into the Göta River (see Figure 100). The park also ends in the approximate location where Kvillebäcken once met the Göta River before the between-lying area was drained and filled in the middle of the 19th Century.

Today the park is primarily used as a transport corridor for people on foot or bicycle. It is the shortest distance between Kvilletorget and Hjalmar Brantingsplatsen (a major public transport hub). Some people come here to feed the ducks that one often sees here. Older children use the fenced in sports court. A nuts and bolts factory once lay on the opposite or northeastern bank. Today these buildings house doctors' offices, shops and restaurants and a commercial indoor playground (see Figure 105). Where the park stands today, there were once buildings as shown in Figures 103 and 104. This area was once the main entrance into Hisingen. Kvilletorget was an important commercial square and goods were loaded on and off here. The stream banks are fortified with old wooden pilings as well as remnants of a concrete dock from when this was a place for loading and unloading goods.

Figure 100. Overview of the watershed to the stormwater outfall and the location of the park.

Trees of mixed age and species line the edge of the stream. These self-sewn trees stabilize the banks, provide green views from the windows of near lying buildings, as well as shade the stream (see Figures 98 and 105). There are also some planted willows and mountain ash that line the bike and footpath. Most of the willow trees that line the path are now coppiced yearly although apparently only after many years of not being pruned. This has resulted in stumpy unattractive trees. The leaves show signs of disease, which may be why there was a change in maintenance. Another reason may have been a desire to increase the amount of sunlight reaching the grass lawn.

Figure 98. The stormwater outfall is located in the lower center of the photo.

Figure 99. The side of the stream get scoured clean of vegetation and slowly erodes.

Figure 101. The eroded sides of the stream expose brick rubble, metal pipes and tires.

Figure 102. A ditch draining the bike and footpath.

A stormwater outfall from a 9,5 hectare area that is one of the most heavily trafficked and impermeable areas in Kvillebäcken's watershed drains unfiltered into Kvillebäcken here (see Figure 100). Downstream of the outfall, very high levels of lead were found in the sediment (Bäckström and Hallinder, 2011). Other studies here have shown that the bottom fauna is severely affected (Engdahl, 2005). This also happens to be one of the few locations in Sweden where you can find the rare and endangered hairlike pondweed (Potamogeton trichoides). Heavy metals will continue to accumulate in the sediment unless action is taken. When will a level of heavy metal contamination that is lethal to hairlike pondweed be reached?

Since there is very little space to treat the stormwater elsewhere within the watershed, I propose that the park be redesigned so that it will be able to treat the stormwater from the outfall. In addition to improving water quality, recreational qualities and conditions for biodiversity will also be improved. To achieve these goals, I suggest replacing some of the soils with adequately pervious ones that will allow water to move through it, trap pollutants as well as provide sustenance to plants. Heavy metals will be trapped in the soil and be absorbed by the vegetation. When the perennial vegetation is harvested once or twice a year, some of the heavy metals are also removed. The harvested biomass can be burned in a district heating plant or digested to produce biogas. The heavy metals will remain in the digested biomass or ash if it is burned. These heavy metals can be extracted, however, this does not seem to be the case today (Olsson, 2008), (Hong et al., 2000). Microorganisms in the soil can also digest hydrocarbons especially when nitrogen rich and aerobic conditions exist (Pratt et al., 1999). To retain most of the existing trees along Kvillebäcken I suggest retaining the soils in most of the areas that have trees. A new path next to the stream at water level gives access to the water (see Figures 106-109). Today it is not possible to touch the water's edge without actually getting in. The terrain in the proposal will slope more gradually toward the water making it safer for children. A gentler slope will also allow for greater biological diversity.

Figure 103. Photo taken 2011-10-20 at the intersection of Kvillegatan and Herkulesgatan. The park can be seen in the upper right.

Figure 104. Photo taken in 1935 from the Kvillegatan and Herkulesgatan intersection. Here you can see buildings where the park stands today.

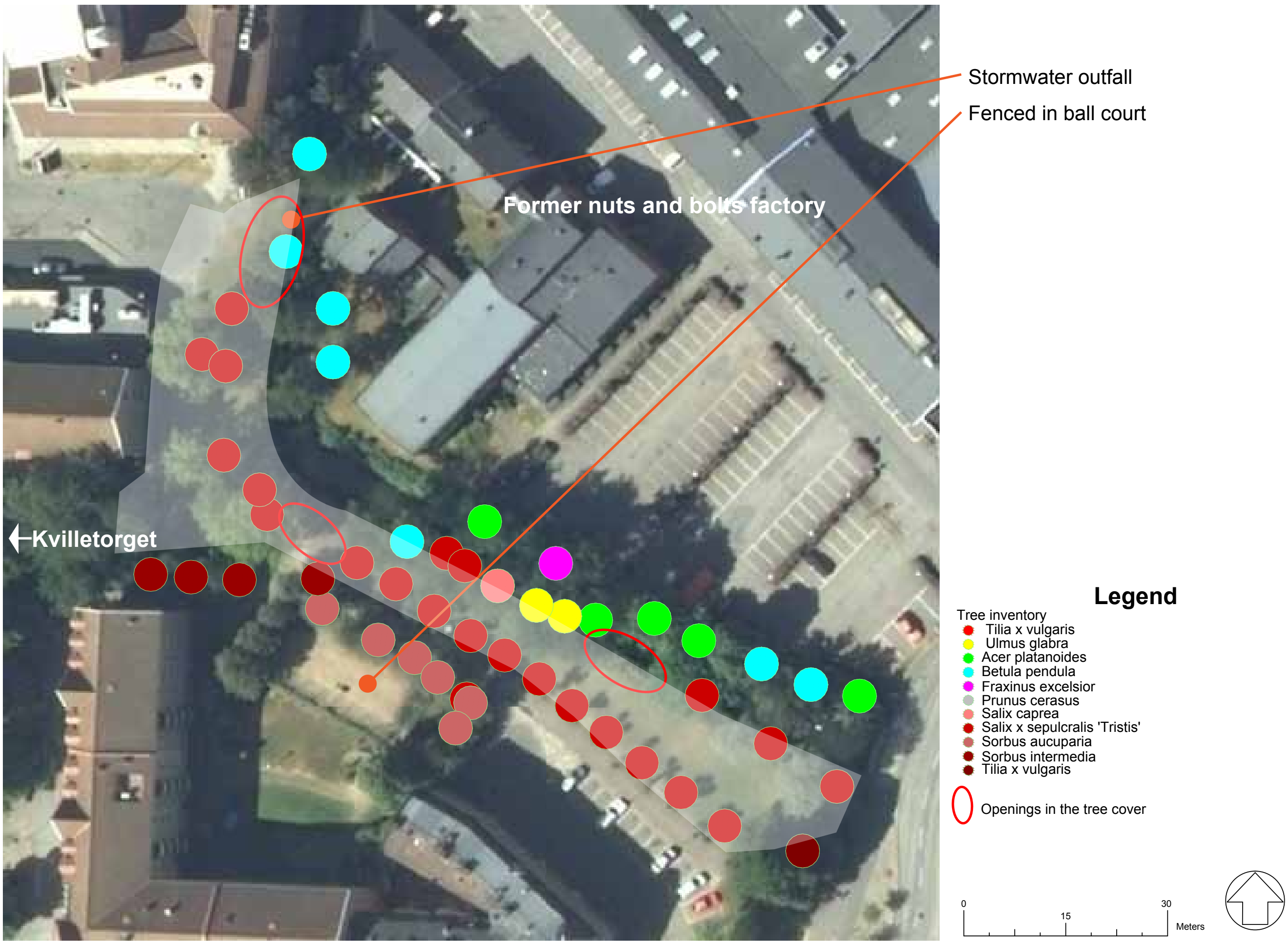


Figure 105. Inventory of the Kville Park site.

Figure 106. Illustrative plan describing a proposal to make this park treat stormwater, increase its recreational value and increase the potential for biodiversity

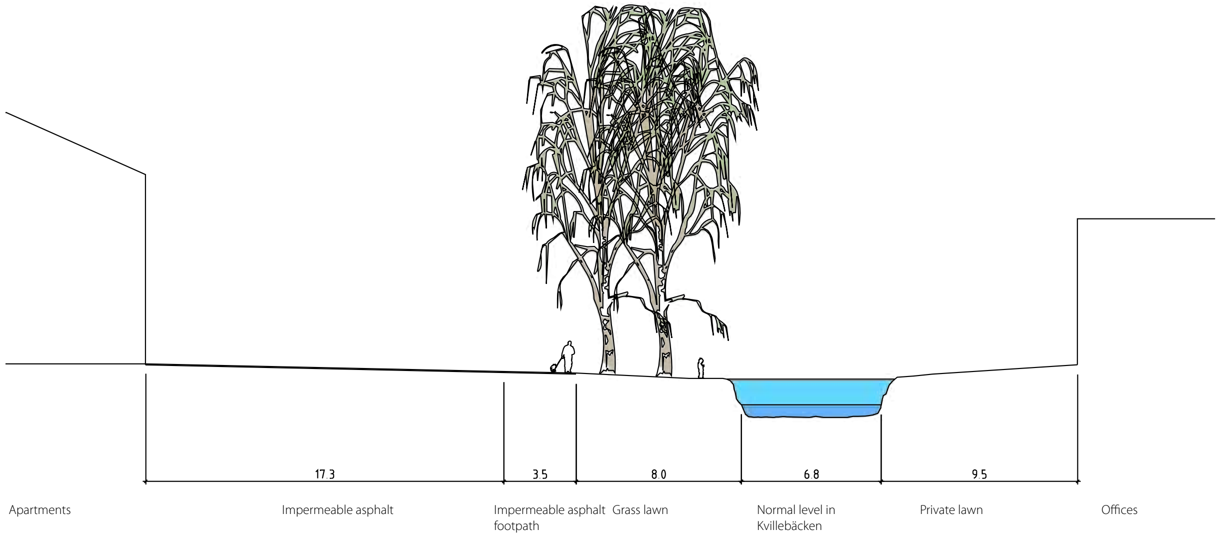


Figure 107. Existing ground Section A-A

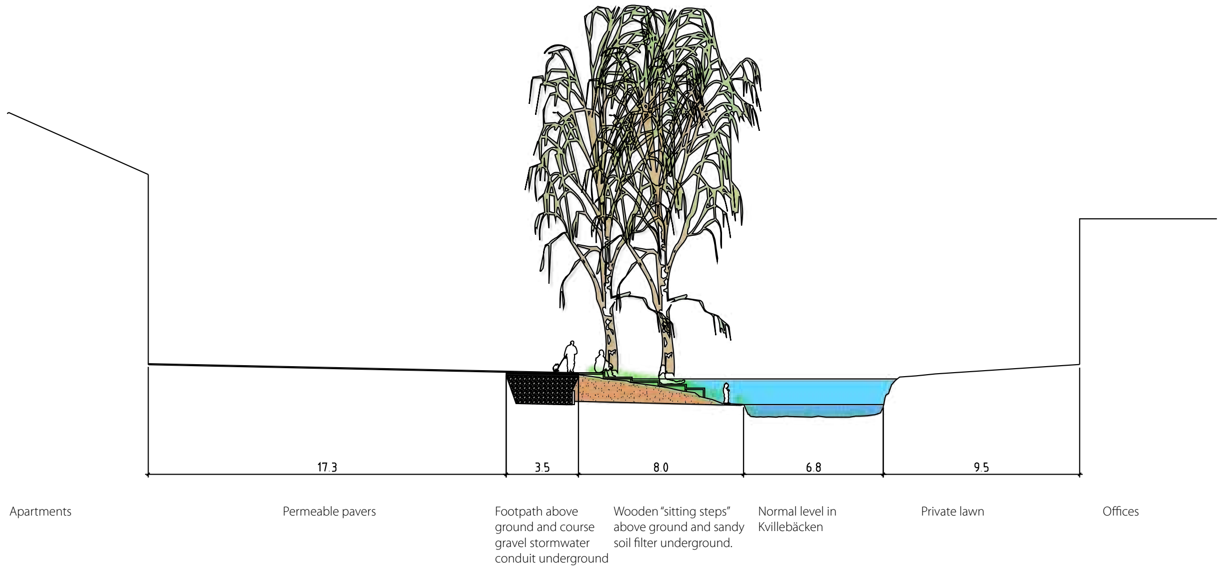


Figure 108. Proposed ground Section A-A

Figure 109. Perspective looking over the redesigned multi-functional park.

Location 5. Predominantly residential areas

As explained in the chapter: "Description of present stormwater management and its effects" the combined-sewer network serves many of the residential areas within the watershed. By reducing the runoff from these properties, there will not only be fewer combined-sewage overflows but money will also be saved since this water will not need to be pumped to the Ryaverket sewer plant and be treated there (see Figure 110). Costly upgrades of infrastructure could also be avoided. I suggest redirecting runoff from these residential properties to on-site vegetation. This is an effective and low cost way of removing stormwater from the sewer (Stahre, 2004). As explained in the Chapter on soil and geology, clay soils predominate in the watershed. They are not good for infiltration but vegetation and topsoil over clay soils can still absorb a lot of the stormwater on the average residential property (see Figure 11). Depending on the conditions at a particular site one might not need do much more than to disconnect the roof downspout from the sewer and redirect it to a lawn or planting. In some situations, a raingarden with amended soils may need to be installed.

Some variables are:

- *Where are the impermeable surfaces on a site in relation to the vegetated areas?*
- *Are there any natural depressions on the property?*
- *What types of soil are on site?*
- *What slopes are present on site?*
- *In some situations it may be better to reduce the amount of impermeable surfaces. An asphalt driveway could be made permeable.*

Figure 110. Primarily residential areas where I recommend diversion to landscaping.

Figure 111. Image: Google Maps. Residential areas have a large proportion of vegetated area.

Figure 112. Author's own downspout located within Kvillebäcken's watershed that has been disconnected for a year without incident.

Location 6. Parking lots large commercial buildings in the lower elevations

The vast expanse of impermeable surfaces in the lower parts of the watershed is unfortunate (see Figure 113). As mentioned in the chapter: "Description of present stormwater management and its effects" the roads and parking lots produce large amounts of polluted stormwater that ends up in Kvillebäcken. As highlighted in the history chapter, this area was once a wetland that was drained and filled in the middle 19th Century. I propose that existing large buildings that are not going to be torn gain green roofs. This would provide large expanses of undisturbed habitat as well as reduce stormwater runoff. A central drainage corridor leading to Kvillebäcken should be put into place that can filter and detain stormwater as well as function as a park for the expected new inhabitants (see Figure 114). New buildings can be built along the drainage corridor. Parking lots that are not built upon should be able to filter and detain the stormwater they produce. This could be done by repaving them with permeable asphalt and an underground storage. Stormwater could also be led to raingardens or vegetated swales. Trees with structural soils could also be planted in the parking lots that could consume the stormwater.

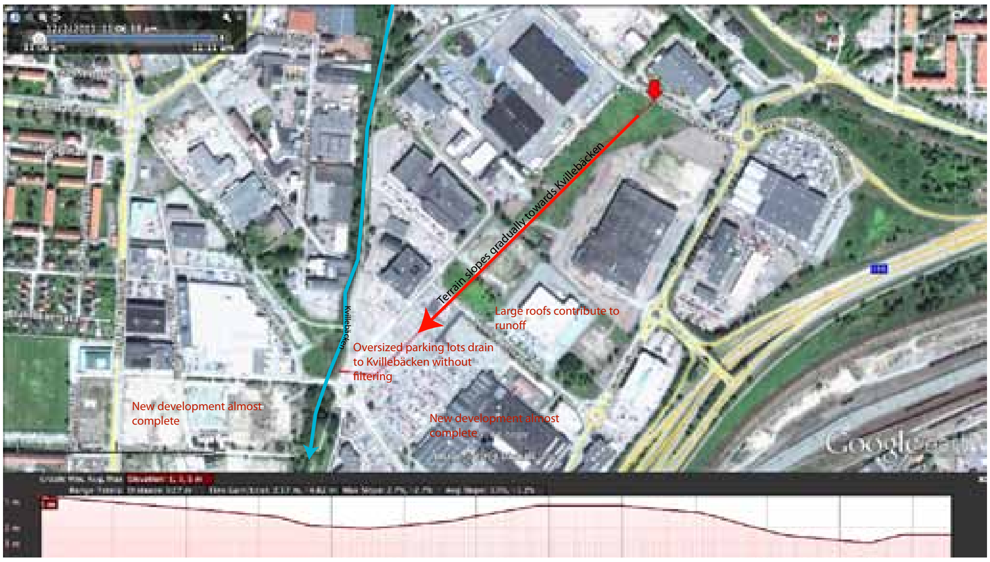


Figure 113. Inventory and terrain profile of the Backaplan site

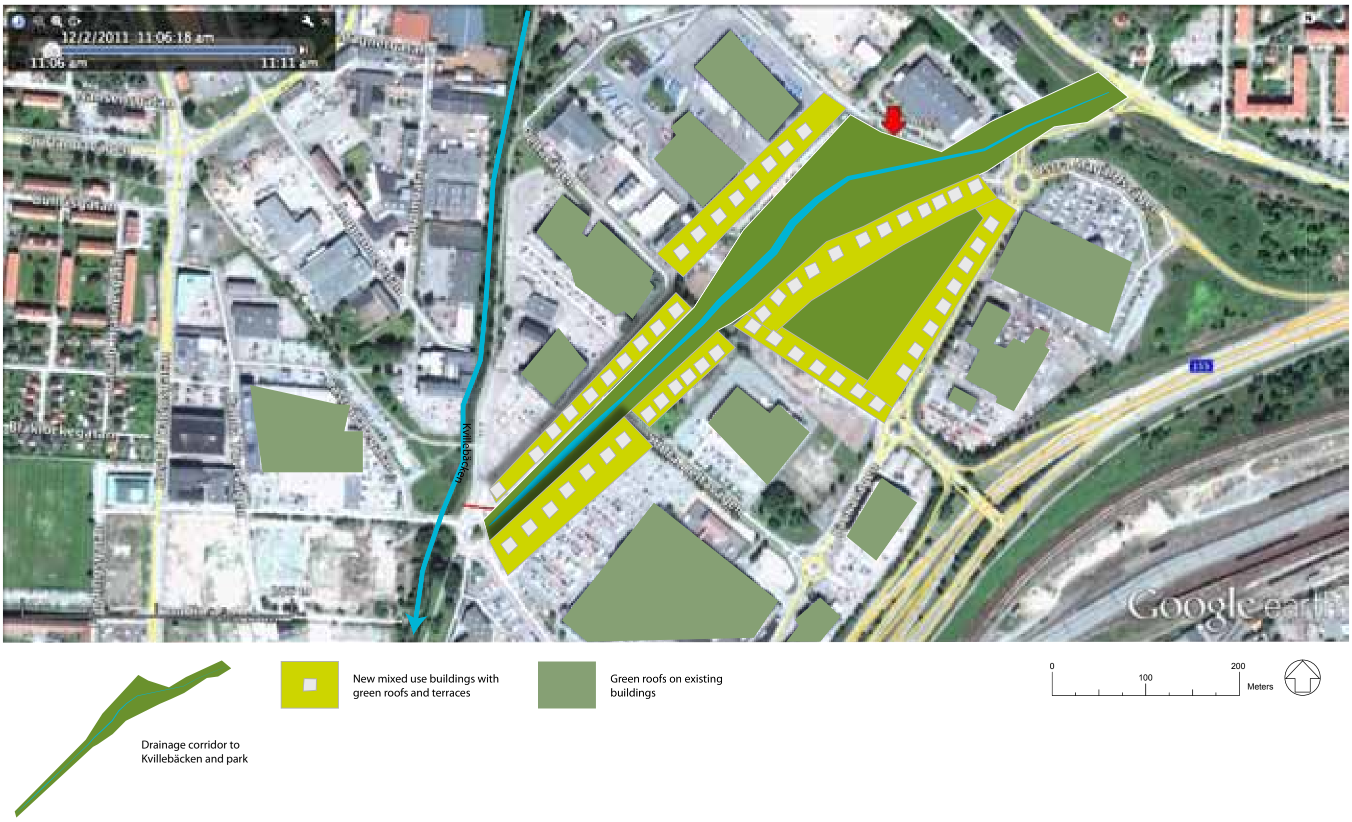


Figure 114. Plan view of the proposal

Location 7. The Frihamnen area: where Kvillebäcken meets the Göta River

At one time most of the bananas consumed in Sweden went through the Frihamnen harbor. Today, however, the piers forming the harbor are underutilized. Even before the area was a commercial harbor, it was a marshland with very high ecological productivity (Andreasson and Thulin, 2010). A vast reed population (Phragmites australis) was able to use the nutrients coming from Kvillebäcken to create biomass from solar energy that fed an estuarine food chain. Now there is little vegetation to make use of the nutrient rich runoff. The harbor has been dredged to depths beyond which reed can grow.

The combined sewer overflow outfall through which most overflows occur is also in the Frihamnen area (see Figure 116). With all the impermeable surfaces within the Kvillebäcken watershed, a marshland is needed more than ever to take up pollutants.

Another problem affecting the area are barriers that limit movement. The Lundbyleden freeway and the Hamnbana freight train line are major barriers to accessing Frihamnen and the Göta River (see Figure 115) There has been discussion about putting the Lundbyleden freeway and the Hamnbana rail road into tunnels (Svensson, 2012).

Besides these issues, Gothenburg also needs and wants to build new housing, preferably in central locations. The

Figure 115. Lundbyleden and the hamnbana are major barriers.

Figure 116. Combined sewage overflow in the last section of Kvillebäcken .

Figure 117. Kvillebäcken looking North to before Kvillebäcken disappears into a culvert to reappear in a new apartment complex.

Figure 118. One of the buildings on the middle pier that is used as offices.

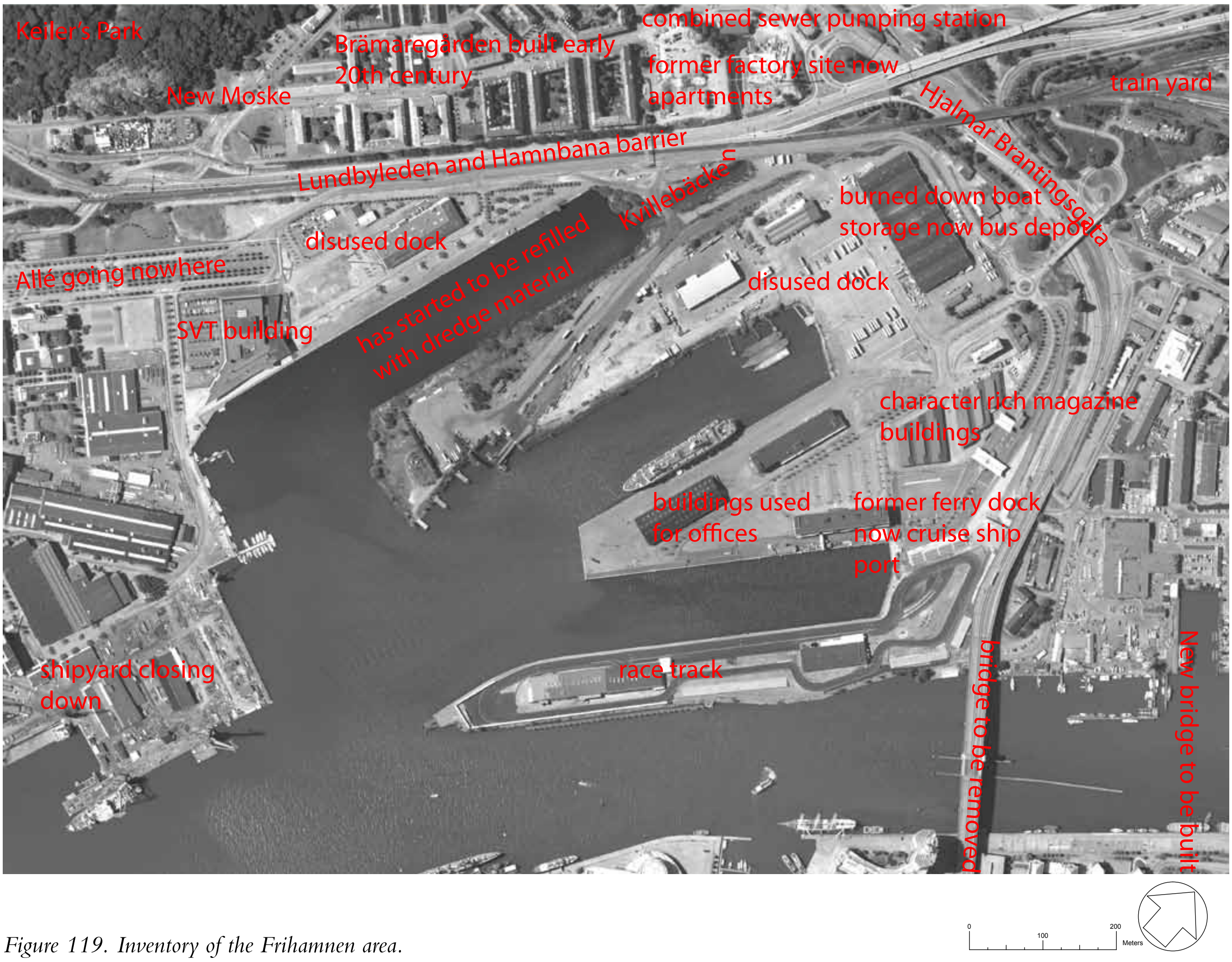


Figure 119. Inventory of the Frihamnen area.

geotechnical conditions for building in Frihamnen are, however, poor (Alén, 2010).

I propose that part of Frihamnen once again be a productive marshland (see Figure 122). The marshland could not only filter the water from Kvillebäcken but also be part of a large city park that could make near lying land more attractive for development. Instead of building in the Frihamnen area, one could build on its landside edges. If the Lundbyleden freeway and Hamnbana train tracks were to be put into a tunnel then one could build many buildings on the freed-up space above the tunnel. The marshland could be part of a new city park in the Frihamnen area that would invite people from all over Gothenburg to come to it. By adding a low pedestrian bridge across the Göta River, Frihamnen could become the attraction that brings Gothenburg together.

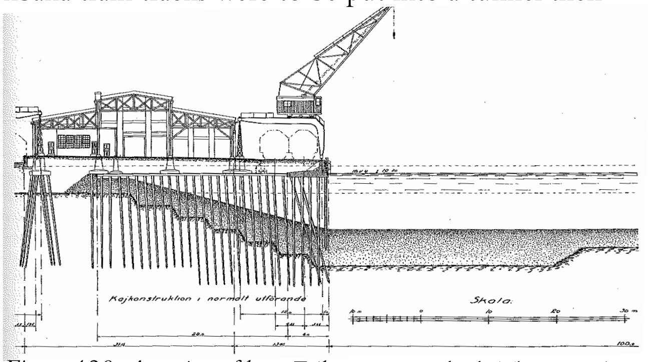


Figure 120. A section of how Frihamnen was built. The ground was terraced filled with gravel after which wooden pilings were driven through the gravel and into the clay below. Notice how it is not filled land but a pier construction.<

Figure 121. This aerial photograph probably from the early 1920's shows two of Frihamnen's piers before the third closest to Hisingen was built. Here you can see that Kvillebäcken has a much wider opening than today. The old Hising's bridge over the Göta River as well as one crossing Kvillebäcken as an extension of Kvillegatan can also be seen.

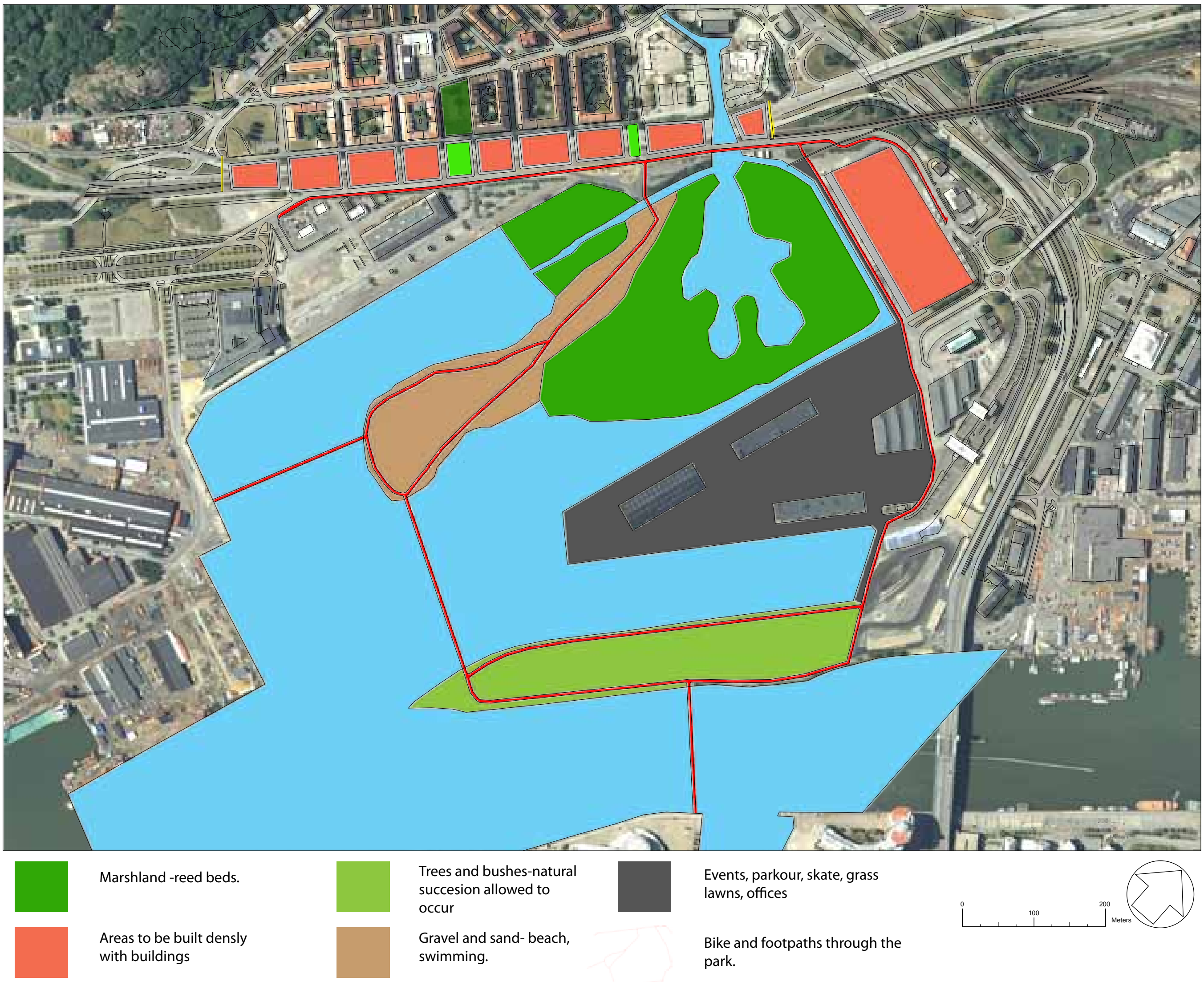


Figure 122. Illustrative plan of the Frihamnen proposal

Discussion

There is a lot of talk about sustainability and environmental responsibility. When areas are built or rebuilt the words sustainable and ecological are often used in their marketing. In handbooks on stormwater management such as the municipality's stormwater handbook "Dagvatten, så här gör vi!" it says "För att minska föroreningstransporten till recipienterna ska dagvattnet tas omhand lokalt, där så är möjligt (page 7). Translated to English it says that, wherever possible, stormwater should be managed onsite in order to reduce the transport of pollutants to receiving water bodies. Apparently this is rarely possible since so few instances of onsite stormwater management have been put into practice from what the author can see in Kvillebäcken's watershed.

Method of inventory and analysis

It can be difficult to understand the effect mankind has had on a landscape. In the Kvillebäcken watershed, a place where people have been a dominating force for thousands of years, this is especially true. I wanted to peel back the layers of human manipulation to reveal opportunities for restoring ecological function within the existing and future urban matrix. Was it possible or already too late? To find out, I thought it necessary to make a thorough inventory and analysis of the watershed. I wanted to have a strong foundation on which to base my proposals of how to improve stormwater management there. This entailed compiling a broad range of information. It turned out that some of the information I wanted to include was more difficult to acquire than I had anticipated. Detailed information about the functioning of the stormwater network was not accessible to me. Other data, like from biotope inventories, was simply not available. Again, other information, like the raw point-cloud data I received from the municipality, was time consuming and difficult to process and yet offered a new and exciting opportunity to study the landscape. Point-cloud data is compiled when a laser scanner is flown over the land. A massive amount of points with three dimensional coordinates are created during the scanning that together represents surfaces in the landscape. A problem, however, arises when vegetation buildings and land are undefined. To be more useful the point-cloud should be categorized into vegetation, buildings, water, etc. This was not the case with the data I received. I wanted to analyze the collected data using GIS and civil engineering computer programs of which I had little or no prior experience. The thesis project, I thought, would provide a good opportunity to learn how to use these tools. To some degree, I got caught up in the learning of these tools and trying to produce the material I had originally envisioned. I spent a large portion of time creating themed maps that described the physical conditions and land-uses. Ready-made land-use, soil and hydrology maps were in fact already available from Lantmäteriet and SGU (Sveriges Geologiska Undersökning). I chose to create my own maps with their data in order to limit the scope of the maps to only the watershed, overlay additional layers and to use the data they contained for computer analysis. With the GIS software, I was able to do all these things as well as determine the percentage of land area for the respective land-uses: a task that would have been difficult to calculate otherwise. When producing the soil map, I was also able to layer an elevation model and historical coastal lines on the map. This helped me to better understand the geologic processes involved in the distribution of soils within the landscape. The map in the Chapter: "Description of present stormwater management and its effects" is supposed to show, amongst other things, the level of impermeability verses permeability of surfaces. This is an important parameter in determining the hydrological characteristics of a watershed. The GIS software allowed me to determine the percentage of each surface type. Unfortunately though, the data I used lacked the granular detail that would have made it truly useful. The reason for the lack of detail was because many of the impermeable areas had not been digitized. I consider this map a proof of concept more than an accurate description of the level of permeability. Through creating that map, I was able to test a useful method that could be applied to future projects with better data to input.

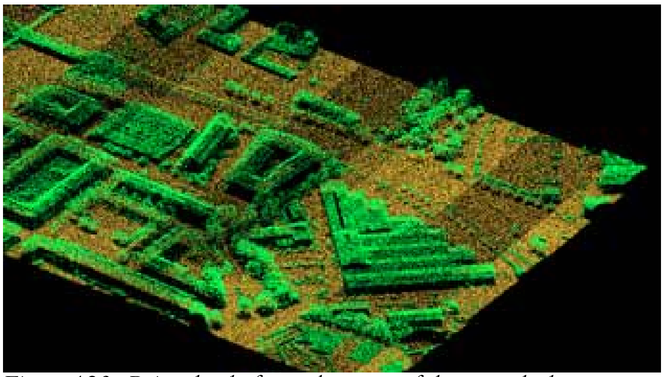


Figure 123. Point cloud of an urban part of the watershed

Design choices

Before starting the project I had envisioned a grand wetland park at the mouth of Kvillebäcken. After continued study I thought that design interventions could and should also be made along Kvillebäcken. I was both disturbed by all the stormwater pipes draining into Kvillebäcken and inspired by other projects that were multifunctional and fit into an existing urban framework. Could underutilized green space along Kvillebäcken be transformed to filter stormwater, increase biodiversity and provide greater recreational opportunities? As the project progressed even more, I realized that my perspective should be widened once again to encompass the farther reaches of the watershed. I decided that it would be more meaningful to show a variety of options throughout the watershed with less detail that just one very detailed proposal. The broad inventory and analysis that I did over the entire watershed needed to be justified with a design approach encompassing it. The wide green corridor along Björlandavägen seemed like an obvious choice for developing a blue-green corridor that had the potential of connecting to Kvillebäcken. In the single-family home areas, opportunities for change are more limited and mundane like diverting roof downspouts from the sewer to gardens but can make a major impact. A simple change like that could have the greatest bang for the buck of all the proposals. In my original work plan, I had intended to show how my proposals would change over time and develop maintenance schedules. Since the projects became more conceptual and increased in number, this level of detail was no longer possible. Had I focused on one design alone, I could have developed it much more and learned the ins and outs of the process through doing. I researched many details that I later abandoned because I no longer thought they fit into the thesis. Making more conceptual solutions has advantages and disadvantages. Conceptual proposals invite discussion more than finished looking proposals.

Another difficult design choice revolved around existing trees. Should trees be taken down to create a blue-green corridor? Along Björlandavägen there are many very large trees that already provide ecological services. It would be difficult (maybe even impossible) to place a stream in that greenway without fatally damaging many of those trees. Was it better to provide a blue-green corridor or save the trees that also provide ecological services? In the project area Toredalsgatan, I can imagine that many of the homeowners there will have strong opinions about the changes made in front of their homes. It would be important to involve them in the design process.

Many of the projects from which I had gained inspiration have soils with good infiltration capacity. Although it was said in the literature that flow-thru systems were possible in areas with poor conditions for infiltration, examples of this nature were much less common. Solutions become not as straightforward. If the stormwater flows through the system, it needs somewhere to go to. Will it go back into the sewer where it originally would have gone anyway or would it be possible to create a continuous path all the way to the receiving waterbody?

Some of the proposals fulfill more of the intentions than others. Diverting downspouts in residential areas to on site vegetation reduces the quantity of stormwater that needs to be dealt with by the municipality whether it is in the combined sewer, a stormwater sewer or an open system. On the other hand though, recreational qualities are not affected nor need be biodiversity on site. Improvements in water quality further down the line could improve recreation and biodiversity there.

In order for more property owners to choose sustainable stormwater management practices, there needs to be a change in they way stormwater management is financed. In Gothenburg there is a disconnect between costs and gains when building a green roof (Engel, 2012). It saves the sewage utility money when stormwater is dealt with using a green roof but costs the developer more to install one compared to a conventional one. At present customers are charged a water and sewage bill based solely on the amount of drinking water consumed on-site. The cost of stormwater runoff management is, therefore, not reflected in the bill.

It costs 5,2 Swedish crowns for every cubic meter of stormwater that enters the combined sewer system (Adrian, 2010). A treatment plant needs to have five to ten times greater capacity because stormwater and still combined sewage overflows are commonplace (Widarsson, 2007). The benefit of removing stormwater from the combined sewage network is not difficult to see. Green spaces in the city cost money to maintain. By combining functions like stormwater management and recreation, savings can be made. In some areas, removal of stormwater from the sewage system can reduce the need to replace pipes with larger ones. For these savings to be realized, however, the various departments need to think outside of their own focus areas. Park planners should think stormwater and drainage engineers should think recreation and biodiversity. For there to be a significant change, the real cost of stormwater management should be charged to property owners. This could spur property owners to implement stormwater water reducing measures. Better cooperation is necessary.

Bibliography

ADRIAN, M. 2010. Slätta Damm Förprojektering dagvattenledning. Göteborg.
ALÉN, C. 2010. Utbyggnad i Frihamnen - Geotekniska förutsättningar?
ANDREASSON, B. & THULIN, J. 2010. Från Kvillesund till Kvilledal : historia, nutid och framtid, Göteborg, Tre böcker.
ÅQVIST, P. 1908. Göteborgs hamn under åren 1882-1907, Göteborg.
ÅSANDER, L. 1990. Inventering av ängs- och hagmarker i Göteborgs kommun, Göteborg, Länsstyr.
BÄCKSTRÖM, E. & HALLINDER, S. 2011. Kvillebäcken canal – An environmental geology case study project. Gothenburg.
BJÖRGAAS, B. 2011-08-25 2011. *RE: Kvillebäcken.* Type to WAHL, S.
COTRONE, V. 2008. The Role of Trees & Forests in Healthy Watersheds
Managing Stormwater, Reducing Flooding, and Improving Water Quality. *In:* RESOURCES, P. S. S. O. F. (ed.). Penn State School of Forest Re.
CSERHALMI, N. 1998. Fårad mark : handbok för tolkning av historiska kartor och landskap, Stockholm, Sveriges hembygdsförb.
DAVIDSSON, F. 2011. Miljörapport enligt miljöbalken 2010: Gryaab rapport 2011:1. Gothenburg: Gryaab.
ENGDAHL, A. 2005. Bottenfauna : en undersökning av bottenfaunan i Göteborgs kommun 2004. *R / Miljö Göteborg, 1401-2448 ; 2005:2.* Göteborg: Miljöförvaltningen.
ENGDAHL, A. 2006. Metaller i vattendrag : en undersökning av metallhalter i vattenmossa i Göteborg 2005, Göteborg, Miljöförvaltningen.
ENGEL, S. J., SAGA. 2012. *Gröna tak - En studie om hur gröna tak kan vara en del av en hållbar stadsplanering.* Kandidatrupsats i Kulturgeografi och geografi med kulturgeografisk inriktning, Göteborgs Universitet.
ERIKSSON, K. 1999. Metal geochemistry in the Kvillebäcken stream and the Lundbyhamnen-Frihamnen dock, Göteborg, Sweden, Göteborg, Univ.
FALK, M. R., ANDERS 2008. Havsnivåhöjning och samhällsviktiga anläggningar. *In:* TRAFIKKONTORET (ed.). Göteborgs stad.
FORMAN, R. T. T. & GODRON, M. 1986. *Landscape ecology,* New York, Wiley.
GRANT, S. R., NITIN PISE, NIYATI REEVES, RYAN MATSUMOTO, MARK WISTROM, ANDERS BAY, STEVEN KAYHANIAN, MASOUD 2003. A REVIEW OF THE CONTAMINANTS AND TOXICITY ASSOCIATED WITH PARTICLES IN STORMWATER RUNOFF. California Department of Transportation.
GRIP, H. & RODHE, A. 1988. *Vattnets väg från regn till bäck,* Uppsala, Hallgren & Fallgren.
HONG, K. J., TOKUNAGA, S., ISHIGAMI, Y. & KAJIUCHI, T. 2000. Extraction of heavy metals from MSW incinerator fly ash using saponins. *Chemosphere,* 41**,** 345-352.
JACOBSON, A. 2009. Åtgärdsprogram för hotade natearter 2008-2011 [Elektronisk resurs] : spetsnate (Potamogeton acutifolius) bandnate (potamogeton compressus) uddnate (Potamogeton friesii) styvnate (Potamogeton rutilus) knölnate (Potamogeton trichoides) : hotkategori: spetsnate, starkt hotad (EN) bandnate, sårbar (VU) uddnate, missgynnad (NT) styvnate, starkt hotad (EN) knölnate, starkt hotad (EN), Stockholm, Naturvårdsverket.
JOHANNESSON, L. J., STEVENS, R. S. & ERIKSSON, K. E. 2003. The influence of an urban stream on sediment geochemistry in Göteborg Harbour, Sweden. *Environmental Geology,* 43**,** 434-444.
JOHANSSON, V. & VON WACHENFELDT, T. 2011. The effects of Grimbo landfill on Kvillebäcken. Gothenburg: Gothenburg University.
KANT, H., HANSSON, EVA 2008. Fördjupad översiktsplan for Backaplan-samradsyttrande. *In:* SVENSSON, S. A. (ed.). Gothenburg.
KAPLAN, S. 1995. The restorative benefits of nature: Toward an integrative framework. Journal of Environmental Psychology, 15, 169-182.
KJELLSON, E. 2009. BACKAPLAN MILJÖKONSEKVENSBESKRIVNING.¨ *VERSIKTSPLAN FÖR GÖTEBORG, FÖRDJUPAD FÖR*
BACKAPLAN. Göteborgs Stad: Stadsbyggnadskontoret.
LINDBERG, A.-S. & ÖDEGAARD, L. C. 2011. Spreading of copper to Kvillebäcken. Gothenburg: University of Gothenburg, Department of Earth Sciences.
LJUNGGREN, O. 11 oktober 2011 2011.
LYLE, J. T. 1985. *Design for Human Ecosystems,* New York, Van Nostrand Reinhold.
MAAS-HEBNER, K. G. 2014. Rehabilitating aquatic ecosystems in developed areas. Wild salmonids in the urbanizing

Pacific Northwest. Springer.
MACMULLAN, E., REICH, S., PUTTMAN, T. & RODGERS, K. Cost-Benefit Evaluation of Ecoroofs. Low Impact Development for Urban Ecosystem and Habitat Protection, 2008. ASCE, 1-10.
NILSSON, A. 23 februari 2011 10:19:47 CET 2011. *RE: Ang. Re: Ang. Kvillbäckens dagvatten ledningar.* Type to WAHL, S.
OLSSON, S. 2008. Livscykelperspektiv på återvinning av askor. Svensk Fjärrvärme AB.
PETTERSON, K. E. 1932. Göteborgs hamn under 50-års-perioden 1882 till 1932, Göteborg.
PRATT, C. J., NEWMAN, A. P. & BOND, P. C. 1999. Mineral oil bio-degradation within a permeable pavement: Long term observations. *Water Science and Technology,* 39**,** 103-109.
RISBERG, A. 2008. Översvämningsberäkning för Kvillebäcken
delområdena Östra Kvillebäcken samt Backaplan. Göteborg: SWECO VIAK AB.
RUIST, E. & LAGERGREN, R. 2010. Från Bäck till vik
En miljömålsutredning av Bohusbäcksprogrammets mätningar av fosfor och kväve till havet 1988 till 2008.
SINTORN, A.-K. 2011.
SMHI. 2006 - Översvämningar och jordskred i västra Götaland [Online].
Stadskansli, G. T. 2006. Extrema vädersituationer - Hur väl rustat är Göteborg? -. *In:* Stadskansli, G. T. (ed.). Gothenburg: GÖTEBORGS Stadskansli.
STAHRE, P. 2004. En långsiktigt hållbar dagvattenhantering : planering och exempel, Stockholm, Svenskt vatten.
STIFFLER, L. 2011. Is a 'green' idea discredited by a Seattle drainage project gone awry? Crosscut [Online]. Available: http://crosscut.com/2011/04/22/environment/20845/Is-green-idea-discredited-by-Seattle-drainage-proj/print/.
SVENSSON, S. A. H. F. L. A., CENTRALA ÄLVSTADEN BO 2012. Älvstaden Diskussionsunderlag – utbyggnadspotential, fördelning bostäder/arbetsplatser. Göteborg.
SYVERSEN, N. 2005. Effect and design of buffer zones in the Nordic climate: The influence of width, amount of surface runoff, seasonal variation and vegetation type on retention efficiency for nutrient and particle runoff. *Ecological Engineering,* 24**,** 483-490.
THOMAS, A. 2010. Clay Soil: Green Infrastructure: Opportunities for Pittsburgh Fact Sheet Series. In: CLEAN RIVERS CAMPAIGN, E. (ed.).
ULRICH, R. S. 1981. Natural Versus Urban Scenes: Some Psychophysiological Effects. Environment and Behavior, 13, 523-556.
VOUGHT, L. B. M., DAHL, J., PEDERSEN, C. L. & LACOURSIÈRE, J. O. 1994. Nutrient Retention in Riparian Ecotones. *AMBIO,* 23**,** 342-348.
WAGNER, F. 2004. Sand Filter. Soil and Water Conservation District of Clermont County, Ohio.
WANG, J., ENDRENY, T. A. & NOWAK, D. J. 2008. Mechanistic Simulation of Tree Effects in an Urban Water Balance Model1. *JAWRA Journal of the American Water Resources Association,* 44**,** 75-85.
WATSON, D. & ADAMS, M. 2011. Design for flooding : architecture, landscape and urban design for resilience to flooding and climate change, Hoboken, N.J., John Wiley and Sons.
WIDARSSON, L.-E. 2007. Drivkrafter för hållbar dagvattenhantering.
WIIK, J. 2009. Detaljplan för Östra Kvillebäcken, Södra Delen inom stadsdelarna Kvillebäcken och Brämaregården i Göteborg. Stadsbyggnadskontoret Göteborg.
WILLIAMS, M. 1990. *Wetlands : a threatened landscape,* Oxford, Blackwell.