Proposal for a Blue Green University Campus

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Faculty of Civil and Environmental Engineering
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Reykjavik, March 2012

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Abstract

This report aims to offer a balanced approach to sustainable development by re-designing the storm water systems of part of University of Iceland campus. Site specific conditions at the University campus were evaluated and a range of suitable “Green-Blue” solutions presented. This includes green roofs, ponds, swales and rain gardens which mimic the natural hydrological cycles of water (Blue) by using methods which elements are composed of the natural flora (Green) of the region. In addition, the option of collecting and reusing roof runoff water for toilet flushing is discussed. This “Green-Blue” campus design would help the University of Iceland solidify its status as a leader in sustainability and would promote the concepts of sustainable developments to all future generation attending the University of Iceland.

Preface

Traditional stormwater collection systems aim at collecting rainwater in underground pipe systems and transporting it away. Such systems are expensive in construction, and moreover, can drastically change the groundwater recharge in urban areas, leading to the lowering of water tables which can ultimately dry local wetland and ponds. To address these concerns, the new trends in stormwater management aim at collecting and using the water locally, making urban areas more “blue-green”, with more open waters and green areas. Local source solutions, including green roofs, ponds, swales, rain gardens, permeable pavements, infiltration basins and local stormwater treatment facilities have been implemented. Here in Iceland, the area of Urriðaholt is the first of its kind to implement these new sustainable solutions that mimic more the natural hydrological cycle.

The class UMV302M Water and Wastewater Systems decided to spend four weeks on research possibilities of different green-blue stormwater solutions to be implemented on the campus of University of Iceland. The focal area of the research was the area West of Suðurgata, where the most of the buildings of the School of Engineering and Sciences are located. Students teams worked and researched green-blue solutions and local site characteristics at the University. Finally, the students in junction with their advisors, Dr. Hrund Andradóttir and Dr. Sveinn Þórólfsson, generated a proposal of ideas on how to convert the University of Iceland campus into a blue-green campus. This proposal is intended to help the University become a leader in sustainable urban development.

These ideas were presented orally to local specialists and stakeholders on March 12th 2012:

- Ingólfur Aðalbjörnsson, Building Manager, University of Iceland
- Katrín Halldórsdóttir, MS. Environmental Engineering, focus on sustainable planning
- Sigurlaug Ingibjörg Lövdahl, Office Manager, Division of Operations and Resources, University of Iceland
- TraustiValsson, Professor in Planning, Faculty of Civil and Environmental Engineering

This report is the summary of the weekly assignments and findings of the student groups. Because of the groups working on individual assignments, the format is not always the same, and reference lists are provided by the end of each chapter.

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1 Introduction

After many decades of intense energy consumption and industrialization, we now realize that our actions weigh heavy on the planet we live on. After the 1987 Brundtland Commission, a new term was defined in order to prevent the constant degradation of our environment. It was the birth of Sustainable Development. Its definition was simple: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). Sustainable development is made out of three branches: Economic development, environmental development and social development. Intertwined these three branches create parameters important to respect in order to achieve sustainable development through planning.

Even if Iceland is at the moment producing renewable energy through hydroelectric and geothermal means, its water management system is lacking proficiency. Sewage lines that were installed before 1970 are combined storm water/wastewater systems. This old method of managing black and grey waters puts a lot of stress on the wastewater treatment plants. During large precipitation or snowmelt events, a big part of the incoming flow will be flushed out directly to the sea via combined systems overflows. Even in separate water management systems, grey water is directly flushed out to the sea by means of direct pipes, not contributing to local groundwater discharge. Considering the quality of storm runoff water, this method is quite questionable and directly affects the oceanic environment it is released.

Therefore, this project aims to offer a balanced approach to sustainable development by re-designing the storm water systems of the Suðurgata portion of the campus. The design process followed what is known as the “Green-Blue” solutions. It relies on implementing as much as possible the natural hydrological cycles of water (Blue) by using natural methods which elements are composed of the natural flora (Green) of the region. This “Green-Blue” campus design would help the University of Iceland solidify its status as a leader in sustainability and would promote the concepts of sustainable developments to all future generation attending the University of Iceland. This collective realization would help implement in the minds of the future generations the necessity of sustainability as a tool to mitigate the human impact on our ecosystem. Sustainable development is the challenge of our generation. The University of Iceland is an institute aimed at forging the mind of the future generations. Hence it is important for the University of Iceland to assume its role of leader and face the challenges of today in order to prepare the future generations to prevent the ones of tomorrow.

The organization of this report is as follows. First the study site, and relevant site specific conditions are presented in Chapter 2. Chapter 3 presents different blue-green solutions that may be implemented on campus. The Appendix A includes other ideas, that were not deemed too feasible for University Campus.

1.1.1 References

United Nations (1987), Report of the World Commission on Environment and Development: Our Common Future, Transmitted to the General Assembly as an Annex to document A/42/427 . Retreived March 10th from http://www.un-documents.net/wced-ocf.htm

2 Site Description

2.1 Geology and geography

2.1.1 Lay of the land

The area to be studied is the campus area of University of Iceland. The area as a whole, including the wetlands of Vatnsmýrin, can be seen in figure 1. The Suðurgata road is a ridge (~ 13 m asl.) that divides the water basin into two parts and directs the water runoff to different directions: The area West of Suðrgata slopes westwards, with slopes ranging from 1-2.5% The highest point is located on the corner of Suðurgata and Hjarðarhagi (~ 16 m asl.), as shown on Figure 1. The area between Suðurgata and Sæmundargata is more steep and slopes (average 4%) towards the wetlands of Vatnsmýrin.

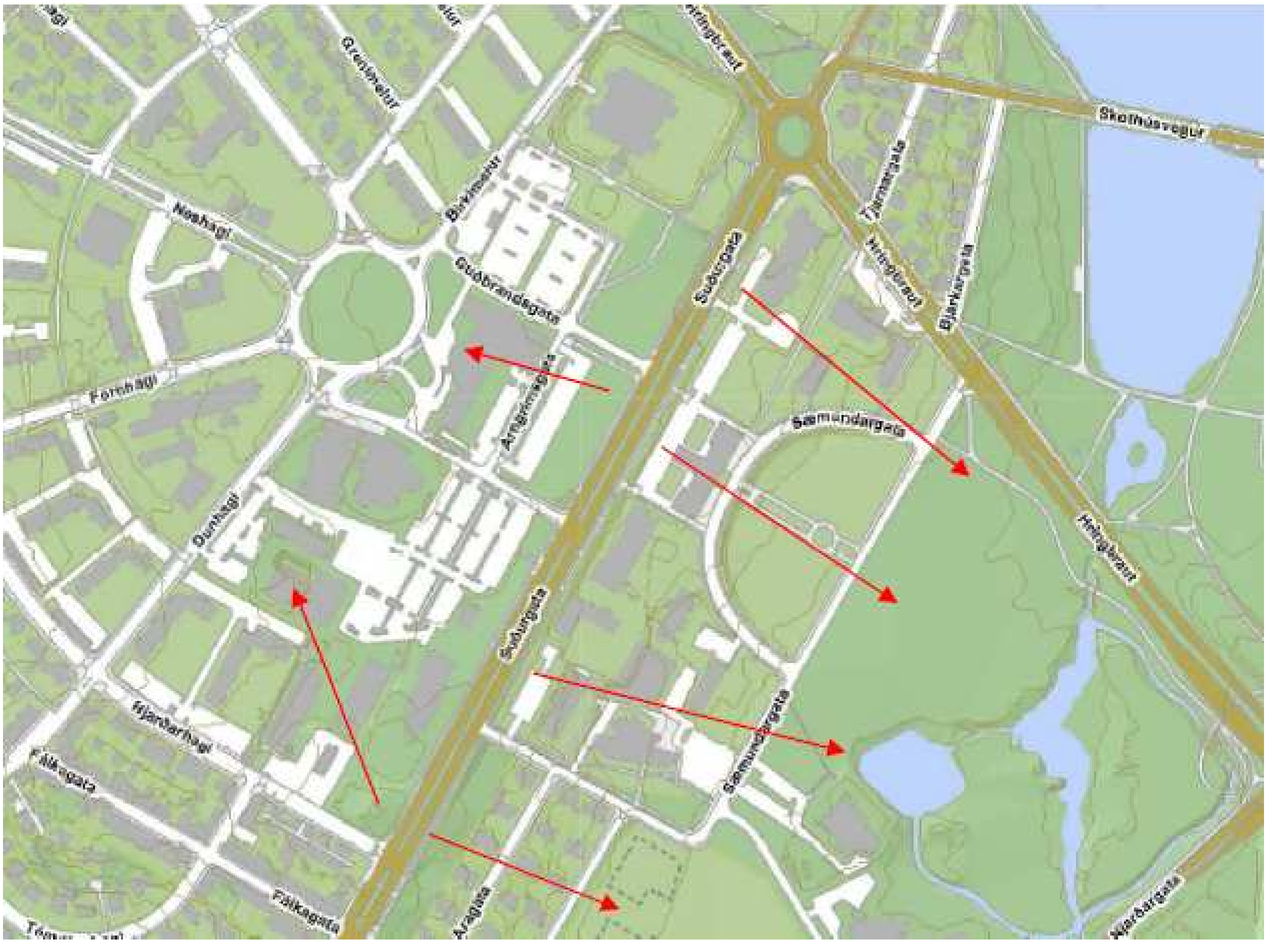


Figure 1: The campus area of University of Iceland, including the wetlands in Vatnsmýrin (http://www.maps.google.com).

2.1.2 Soils

In May 2009 a research was done within the campus area (Snorri P. Snorrason & Sigurður Gunnarsson, 2009). Two boreholes, ME-2 and ME-3, were drilled on a defined area situated close to the highest point of the area. The location of the holes can be seen in figure 2 below.

Figure 2: Two boreholes drilled in May 2009 on the campus area of University of Iceland (Snorri P. Snorrason & Sigurður Gunnarsson, 2009)

There is a slight difference between the cores of the two boreholes (Snorri P. Snorrason & Sigurður Gunnarsson, 2009) but the cores compare approximately with geology maps (Landmælingar Íslands (Iceland Geodetic Survey), 1997a; Landmælingar Íslands (Iceland Geodetic Survey), 1997b). We therefore estimate the soil layers to be as follows:

- Soil (0,0 m - 0,5 m)
- Marine deposits (0,5 m - 2,5 m)
- Till (0,5 m - 2,5 m)
- Fossvogur sediments and tillite (2,5 m - 3,6 m)
- Reykjavík olivine tholeiite compound lava (3,6 m +)

Photographs of the cores and borehole logs indicate that the soil layers are porous near the surface and become more dense and less permeable with depth. This should allow groundwater to easily flow through uppermost layer of the soil. According to borehole ME-3 the depth to solid rock is 6,6 m. Borehole ME-2 indicates a little more cracked rock. Based on hydrogeological map the rock in the area is permeable, with hydraulic conductivity in the order of 0,1 to 0,0001 m/s (Landmælingar Íslands (Iceland Geodetic Survey), 1994).

2.1.3 Groundwater

The boreholes ME-2 and ME-3 (Fig. 2) show some difference in groundwater table, even though they are close to one another. When the drilling was done, in May 2009, the distance down to groundwater table in ME-2 was 1.3 m, and 1.5 m in ME-3. However, it should be noted that there appear to be significant seasonal changes in the groundwater table, with higher groundwater table during winter than dry summers. At the end of summer 2010, the water table measured 4.3 m and 3.3 m below ground at ME-2 and ME-3 respectively (Snorri P. Snorrason & Sigurður Gunnarsson, 2009; Gunnar Orri Gröndal & Ragnar Hauksson, 2010).

The two boreholes already drilled, only provide information on a small section of the area. In order to better analyze the groundwater flow as a whole and the permeability of the superficial deposits and the bedrock, further studies should be made.

Based on the surface land slopes, it can be assumed that groundwater flow will be as shown by red arrows in Figure 1. While the study area West of Suðurgata slopes in the opposite direction of the Nature reserve Vatnsmýrin, there is a sufficient altitude difference to collect water from the furthest area (e.g. Háskólabíó) and transport via gravity (no pumping) it to the wetland. Part of the transport would be in sub-surface pipes, but East of Suðurgata could include ponds, creeks and waterfalls which would concurrently improve the attractiveness of the campus surroundings and benefit the ecosystem.

2.1.4 References

Gunnar Orri Gröndal, & Ragnar Hauksson (2010). Jarðvatn í grunni Húss íslenskra fræða,Forhönnun fráveitukerfis. Almenna verkfræðistofan.

Landmælingar Íslands (Iceland Geodetic Survey) (1997a). Berggrunnskort (Geological Map (Bedrock)). Landmælingar Íslands (Iceland Geodetic Survey).

Landmælingar Íslands (Iceland Geodetic Survey) (1997b). Jarðgrunnskort (Map of Superficial Deposits). Landmælingar Íslands (Iceland Geodetic Survey).

Landmælingar Íslands (Iceland Geodetic Survey) (1994). Vatnafarskort (Hydrogeological Map).

Snorri P. Snorrason, & Sigurður Gunnarsson (2009). Hús íslenskra fræða, Könnun á grunnvatni. Almenna verkfræðistofan.

Sveinn Þórólfsson (2012, February). Oral reference.

2.2 Current wastewater collection system

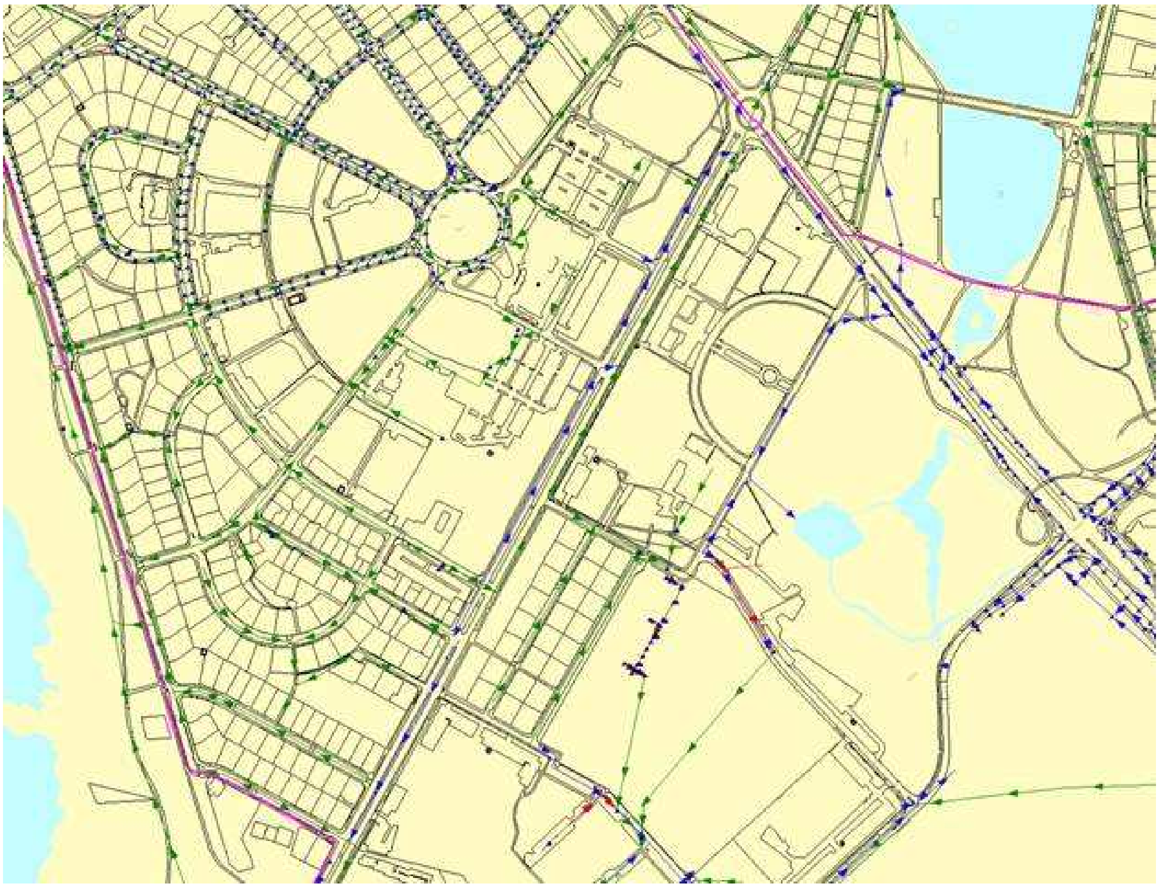


Figure 3: Drawing from Reykjavík Energy LUKR system, Tuesday February 18th, 2012

Figure 3 is a LUKR drawing received from Reykjavík Energy and shows the wastewater and storm water pipes in the streets owned and operated by Reykjavík city. The color code is the following:

- Green → Combined systems
- Blue → Storm water systems
- Red → Separate systems

Figure 3 indicates that the majority of the wastewater system in our study site West of Suðurgata has a combined system. The main road of Suðurgata, however, has a separate stormwater system which transports untreated stormwater, to the pond in Reykjavík Center, "Tjörnin". The fact that the water is untreated raises questions about the quality of the water reaching tjörnin. As will be discussed in Chapter 2.4, several pollutants exist in stormwater that may pose harm to aquatic systems.

To get better insights into how house connections at our study area are drained into the municipal waste water collection system, the following detailed drawing available at Byggingarfulltrúi Reykjavíkur were consulted:

- Raunvísindastofnun, Dunhagi 3; from 1987
- Tæknigarður, Dunhagi 5; from 1987
- Endurmennt, Dunhagi 7; from 1998
- Háskólabíó viðbygging north; from 1986
- Háskólabíó viðbbyging south; from 1986
- VR-1, Hjarðarhaga 4, from 1983

Since the plans are rather old and we didn´t find plans for all the building we are not sure how reliable the data is. On the plan for Tæknigarður the pipes from VR-1 and VR-2 are drawn in. The plans for VR-2, VR-3 and Loftskeytastöðin could not be found. The likeliest explanation according to an employee at Byggingarfulltrúi Reykjarvíkur it is hard to locate due to mix up of addresses. The house connection to VR-3 is based on the following assumption; the lay of the land and the fact that it is not drawn in the Tæknigarður plan as VR-1 and VR-2. No drawings were found with the stormwater drainage system in the parking lot by Háskólabíó. The storm water pipes in the parking lot are drawn therefore drawn as dotted lines after visually inspecting the parking lot, looking for manholes and stormwater inlets.

Figure 4: The current wastewater and storm water system made from our data. (Dotted lines are assumed connections, based on visual observations and lay of land)

Figure 4 summarizes the house connections that were inferred from the multiple plans gathered from Byggingarfulltrúi Reykjavíkur. The study area has a combined sewage system. The plans show single mixed manholes serving as junctions for the inflow of both wastewater and storm water. The wastewater and storm water are drained to the northwest and therefore of the campus area since that is the lay of the land. In simplified terms, the wastewater is gathered inside the buildings and drained out through one combined pipe into a manhole next to the buildings. The storm water is drained into a pipe lying around the building and diverted in the same manhole as the wastewater.

As all the pipes from buildings are expected to be collected in a combined sewer system, implementing blue-green solutions on campus requires cutting off each outlet from the roof and redirect them somewhere else. The site where the storm water would be collected would need either to slow down the infiltration before it reaches the pipe or it could be used as an inflow for future ponds. According to Sveinn Þórólfsson, in most of Europe, it is illegal, to have the grounds surrounding a building to slope towards the building. In order to obey to this regulation, one option we could have is to backfill the sides of the buildings that are "irregular" with a layered backfill in order to maximize filtration (Figure 5). Once filtered, the water could infiltrate the ground via a swale system and collect either to a pipe or a settling pond.

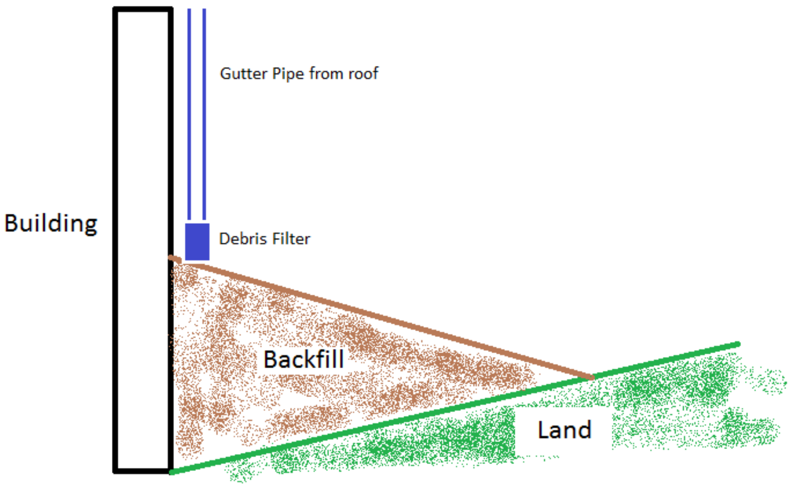


Figure 5: Schematic on how backfills must slopes away from houses.

2.2.1 References

Borgarvefjsá. (n.d.). City of Reykjavík. Retrieved from http://lukr-01.reykjavik.is/borgarvefsja/

Byggingarfulltrúi Reykjavíkur. *Fráveitukerfi*. (retrieved 2/2012)

Mark J. Hammer & Mark J. Hammer, Jr. (2012). *Water and Wastewater Technology* (7th ed.). Upper Saddle River, New Jersey, and Columbus Ohio: Prentice Hall

Reykjavík Energy (2012). LUKR drawing with wastewater collection system at University of Iceland.

2.3 Meteorology and runoff

Iceland is located at the northern most of the temperate climate and lies in the path of the North Atlantic current, which makes the climate more temperate than would be expected for its latitude. The climate of the coast where the Capital area is located is cold oceanic which features warm, but not hot summers and cool, but not cold winters, with a narrow annual temperature range. Precipitation is dispersed through the year.

2.3.1 Air temperature

Historical weather averages, showing what the weather was typically like each month, averaged over a range of years can be retrieved from the internet database WorldClimate. Time series from WorldClimate and Iceland Met Office are used to make a figure with the distribution of air temperature by months. The average year temperature from the time period 1901-1990 was 4.6°C compared to 5.5°C average over the last ten years.

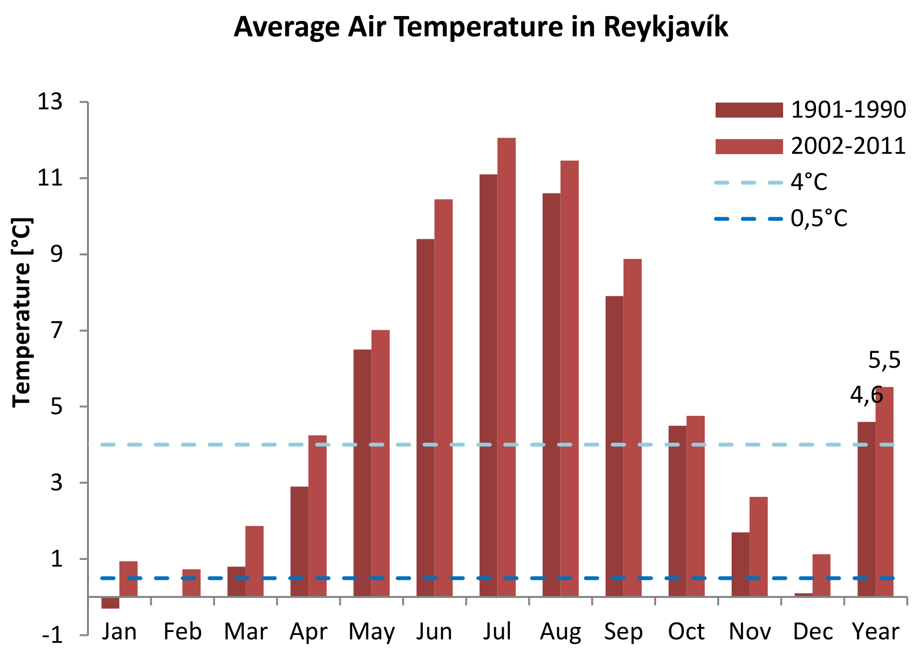


Figure 6: Distribution of air temperature by months (WorldClimate (2012) & Icelandic Met Office (2012)).

During snowfall the temperature is almost always below 0.5°C although snow will occasionally fall for a short time between temperatures of 2-4°C. Considering Figure 6, snow can be expected in Reykjavík from November through April although snowfall is also known to happen during other months. Normally the last frosty night in spring occurs May 10^{th}-11^{th} and the first at the end of September (Jónsson, 1986).

Cold climate complicates urban hydrology and urban drainage and focus has to be on methods and technologies that are appropriate for cold climates (Thorolfsson, 2010). According to Figure 7, the precipitation is more in winter than in summer. Due to winter frost and snow the precipitation remains on the surface and accumulates. When changes in temperature melt the snow all the water needs to get into the sewer system and sometimes the system does not manage the burden. If the ground is covered with ice, no water can leak into the ground. The storm water drain can also be covered with ice and then water cannot leak into the sewer system either. This means that the water searches for other directions, to the lowest point e.g. basements.

The quality of the water gets worse when the snow/water stays longer on the surface. The snow accumulates pollution, which becomes stormwater pollution while melting (Thorolfsson, 2010).

Road salt is a common method to de-ice our roadways, keeps roads safe and reduces the risk of accidents (Lost River Walks, n.d.). On the other hand road salt causes serious damages on nature and sewer systems (Thorolfsson, 2010). Salt makes the sewer systems rust and poisons our lakes, streams and groundwater (Lost River Walks, n.d.).

2.3.2 Rainfall and snow

The WorldClimate database has time series for average rainfall in Reykjavík at 52 m a.s.l. 64°N 21°W which is used in Figure 7 to show distribution of rainfall by months. The average annual rainfall in Reykjavík over the years 1829-1990 was 817.6 mm (WorldClimate, 2012). Comparing the Icelandic Met Office time series for the last ten years to average rainfall from 1829-1990 some change in seasonal evolution is noticeable. The lower rain season has moved to midsummer and the seasonal difference has become less but is still there.

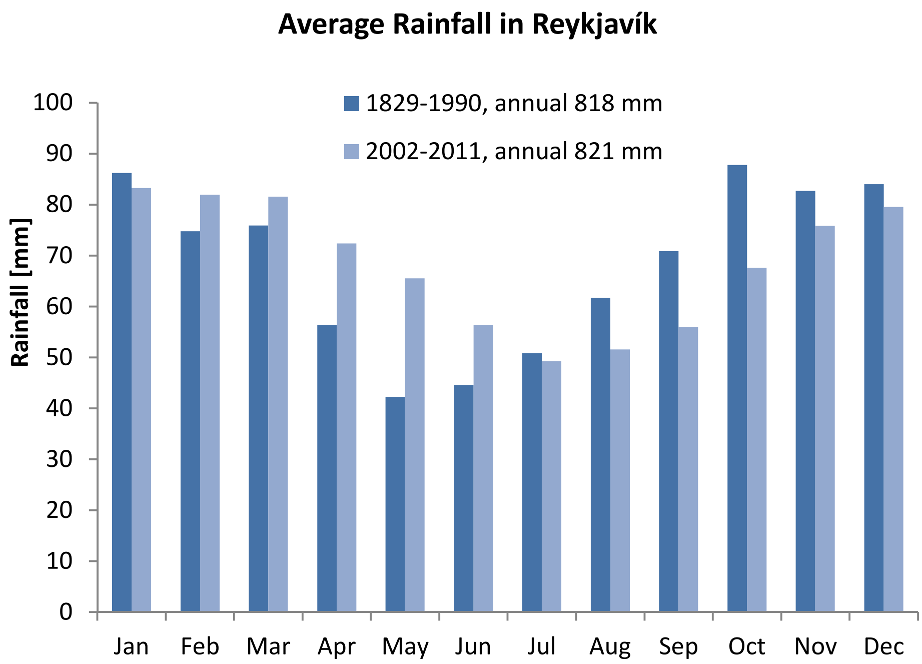


Figure 7: Distribution of rainfall by months (WorldClimate (2012) & Icelandic Met Office. (2012)).

There is a definite seasonal change in rainfall, 60% of the annual precipitation falls from October through March and 40% over the coldest four months. The Icelandic Met Office measures precipitation two times a day and classifies the precipitation as rainfall, sleet or snowfall. The distribution by months can be seen in Figure 8. Over the years 1961-1990 snowfall was 7% of annual precipitation or 54 mm/year and sleet was 33% or 265 mm/year, snow and sleet combined are thus 40% of the average annual precipitation or 318mm (Gísladóttir, G.Th. 2012).

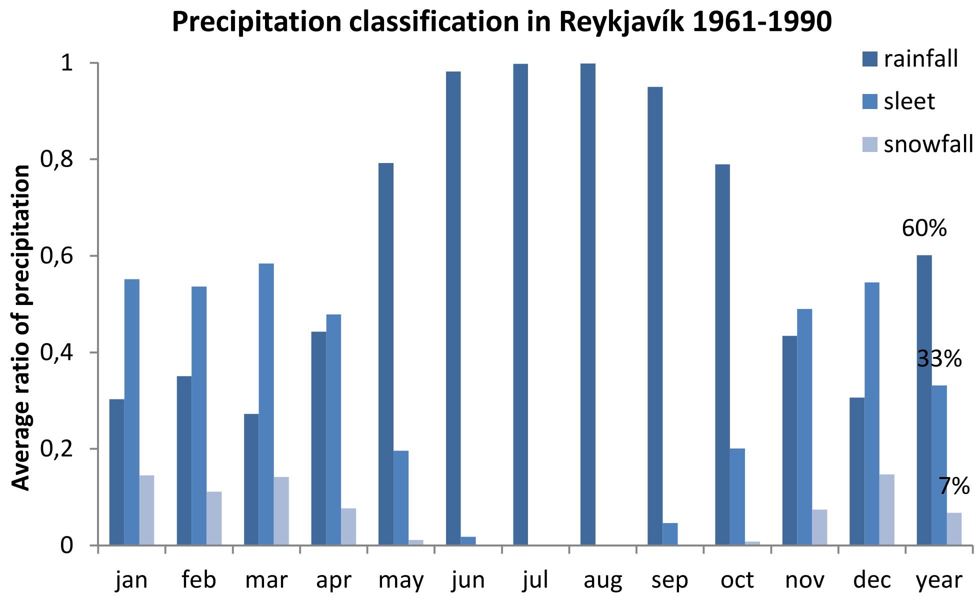


Figure 8: Classification of rainfall (Gísladóttir, G.Th. 2012).

2.3.3 Runoff areas and flow rates

The plan for the University of Iceland Campus, West of Sudurgata that was approved in 2009 is presented on Figure 9 (Teiknistofa Arkitekta, Gylfi og félagar ehf, 2009). The 4.9 ha area is on one hand bound by Dunhagi and Suðurgata (width 250 m) , and Hjarðarhagi and Brynjólfsgata (length 285m). Currently, existing buildings cover around 1 ha and 1.5 ha is under paved parking lots (Table 1).

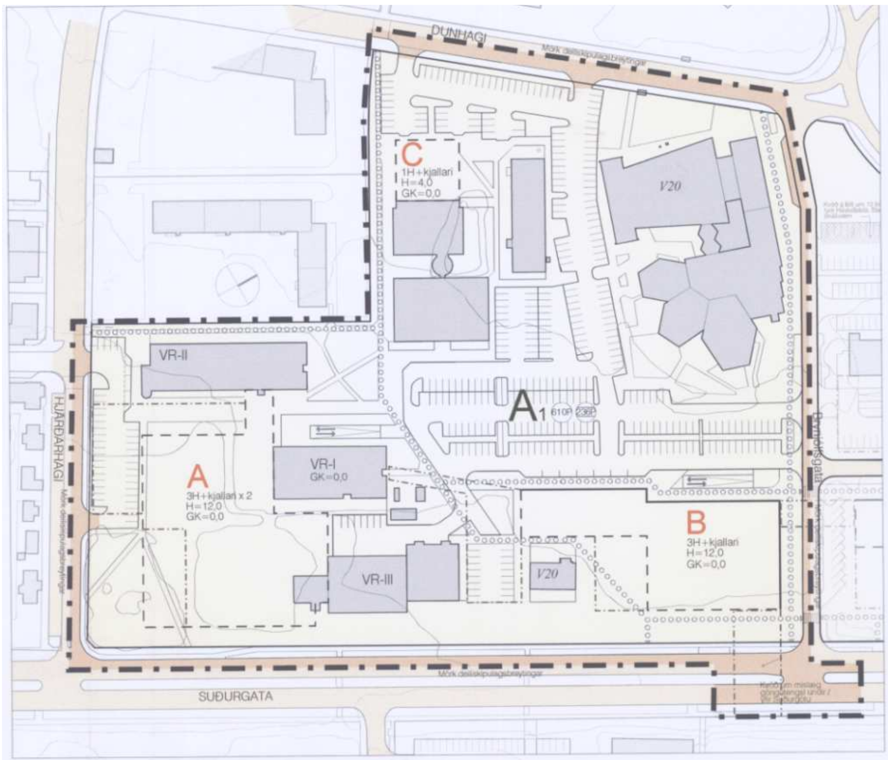


Figure 9: The planning document for University Campus area, west of Sudurgata (Teiknistofa Arkitekta Gylfi Guðjónsson og félagar ehf, 2009).

Figure 9 shows plans for three new buildings: The Shool of Education building (marked A), The Vigdís Finnbogadóttir Institute of Foreign Languages (marked B) and an extension west of Endurmenntun (marked C) (Teiknistofa Arkitekta, Gylfi og félagar ehf). Buildings A and B are allowed to be three storey high but C will be one storey high. All the buildings will include basements. To meet the demand of parking, three parking basements are planned:The biggest parking basement will be in the middle of the parking but two other basements will be located in buildings A and B. The capacity of the parking basements will be 236 cars total in addition to 374 parking lots in open air. Additionally two connection buildings are planned; one that connect building B to the University Center and another from building B to VRI. According to the plan the buildings may cover 2.7 ha and the parking lot will cover 1.7 ha (Table 1).Since the category “other” refers to pavings, e.g. in walking and biking paths, up to 95% of the 4.9 ha area may be covered with impermeable surfaces in the future.

The following equation was used to calculate the design flow:

$$Q = (I - ET)\, C\, A$$

where

Q = design flood
I = rainfall intensity
ET= Evapotranspiration
A = catchment area or runoff area
C = Surface runoff coefficient

The runoff coefficient C varies by surface type and its permeability. It can range from 0.2 for green areas to 0.9 for impermeable building roofs and asphalt (Orkuveita Reykjavíkur, 2008). The rainfall intensity is the annual average precipitation (WorldClimate, 2012). The evapotranspiration is assumed to be around 20% of the annual average precipitation in Iceland (Garðarsson, S.M. 2012). The size and type of the areas are estimated from the planning document (Teiknistofa Arkitekta, Gylfi og félagar ehf, 2009). The results summarized in Table 1 estimate the total current runoff as approximately 18,000 m^3/ year, which may increase to 27,000 m^3/ year in the future.

Table 1: Current and projected annual runoff generation at University of Iceland for traditional rainfall (I = 817 mm/year - both rain and snowmelt, ET = 20%).

		Current		**Planned**	
Surface type	**C**	**Area (ha)**	**Q_{runoff} (m^3/year)**	**Area (ha)**	**Q_{runoff} (m3/year)**
Buildings/roofs	0.9	1.0	5887	2.7	15894
Impermeable parking lots/sidewalks	0.9	1.5	8830	1.7	10007
Green areas	0.2	2.2	2878	0.3	392
Other	0.6	0.2	785	0.2	785
Total		4.9	18380	4.9	27079

To compare these runoff estimates in Table 1 to the annual flow in Vatnsmýrin, which is 41 l/s (Vatnaskil, 1989), that equals to $1.3*10^6$ m^3/year. The runoff of the area is then 1.4% of the annual flow through Vatnsmýrin, as the area is today, but could increase to 2.1% when the three new buildings have been built. The runoff water can also be reused for several other options, including greenhouse irrigation, toilet flushing and outdoors showers. The table below shows typical water usage for some of these ideas that came up on how to reuse the runoff water from roofs on the area.

Table 2: Water demand for reuse of stormwater.

Reuse	Water demand
Greenhouse irrigation	16 l/m^2/day
Toilet flushing	6 l/flush
Shower	12 l/min

2.3.4 Traditional stormwater collection design flow rates

The intensity-duration-frequency (IDF) curve for the University of Iceland area is found using the 1M5 method. The university is in the 40mm area as shown in figure 10, using this information along with Ci of 0,205 (Thordarson,1998) the IDF curve is found and presented in Table 3 and Figure 11.

	1M5						Ci
	40	Reiknuð úrkomugildi (l/s/ha)					0,205
	Varandi						
Ts		1	3	5	10	20	50
	10	34	45	50	57	64	73
	20	26	34	38	43	48	55
	30	22	29	32	36	41	47
	60	16	22	24	27	31	35
	120	12	16	18	21	23	27
	180	10	14	15	17	20	22
	360	8	10	12	13	15	17
	720	5	7	8	9	10	12
	1440	3	4	5	5	6	7

Table 3: 1M5 table for the university area

Figure 10: 1M5 map of Reykjavík

As a valuable and widely used area, a flood on Campus would disrupt the lives of many people and possibly damage valuable equipment. Therefore it is necessary to design the area with respect to a return period of at least 20 years.

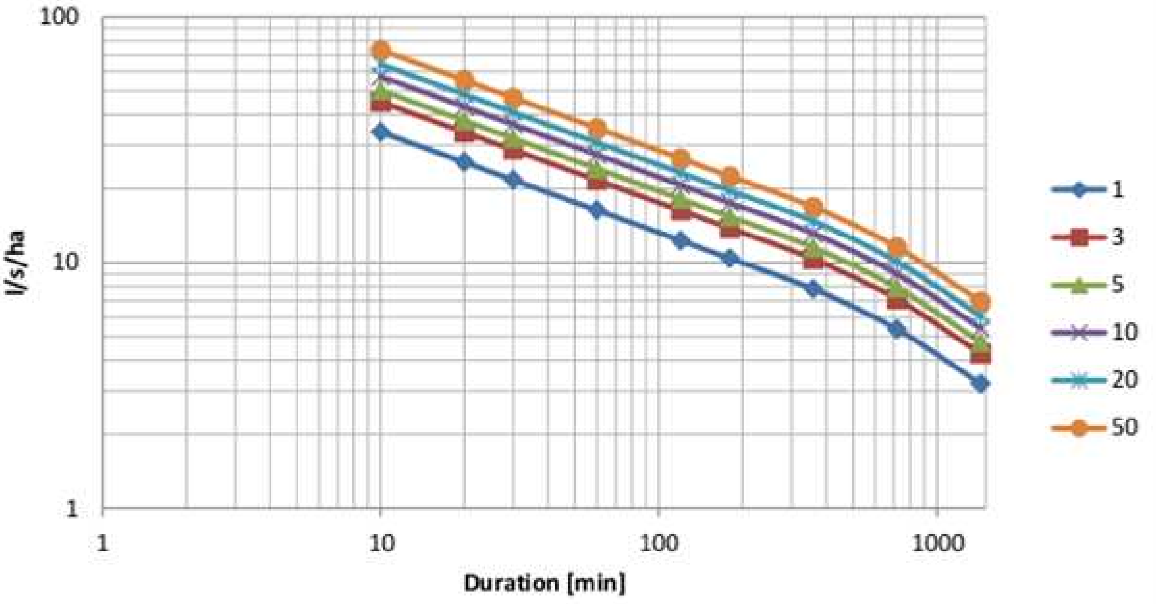


Figure 11: IDF curve for the University area (1M5 = 40 mm), rain fall intensity as a function of duration for different return periods

Comparing 20 years return period event IDF curves for Reykjavík, Trondheim and Oslo (Fig. 12) it becomes clear that Reykjavík has less rainfall intensity than in the two Norwegian Cities. Moreover, rainfall intensities in short events (duration < 10 min) are not available for Reykjavik.

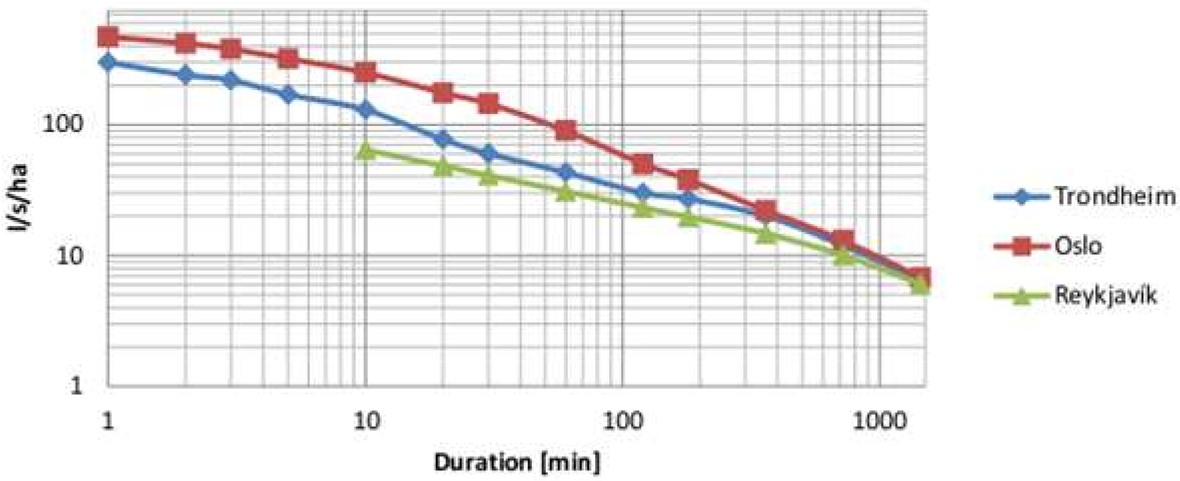


Figure 12: Comparison of rainfall intensity as a function of duration for 3 cities (20 year return periods)

Time of concentration

Time of concentration "is defined as the time needed for water to flow from the most remote point in a watershed to the watershed outlet. It is a function of the topography, geology, and land use within the watershed."(Haan, 1994). This time is the sum of two components: Time to inlet and time in pipe. The time of concentration for an area is generally used as the duration for the design storm for an area.

Time to inlet is the time it takes the most remote water drop to flow in to a drain. This is calculated using:

$$T_{inlet} = \frac{\text{Length to drain}}{\text{speed of surface water}}$$

The speed of surface water is found using Manning's equations

$$V = \frac{Q}{A} = \frac{1}{n} \cdot R^{2/3} \cdot S^{1/2}$$

where

Q = flowrate
A = cross sectional area
n = Mannings roughness coefficient
R = hydraulic radius = A / P, where P is the wetted perimeter
S = land slope

According to borgarvefsjá (Reykjavíkurborg, 2012) the slope of the land is estimated to be S = 1%. According to Table 1, the area is currently approximately 50% grass/natural, and 50% buildings/paved parking lot. In the long run, when buildings occupy future building lots, the green areas may only be approx 5% of the 4.9 ha area. The Manning´s roughness coefficient for asphalt is n = 0.013 and for grass is n=0.03. Assuming 30% grass and 70% asphalt, corresponding to an intermediate between current and projected land use of the site (Table 1), the combined Manning's number for the area is n=0,018.The hydraulic radius R for an open area, that is a rectangle with infinite width, is the water depth. This value is hard to predict so it is necessary to look at values from 5mm up to 25mm, unlikely that it will be higher than 25mm. Assuming that no point is further away from a drain than L=50m, Figure 13 calculates the time to inlet for varying water depths ranging between 5-25 mm. For 30% grass, 70% asphalt and a water depth of 5mm, the time to inlet is found to be 310s, or 5 min.

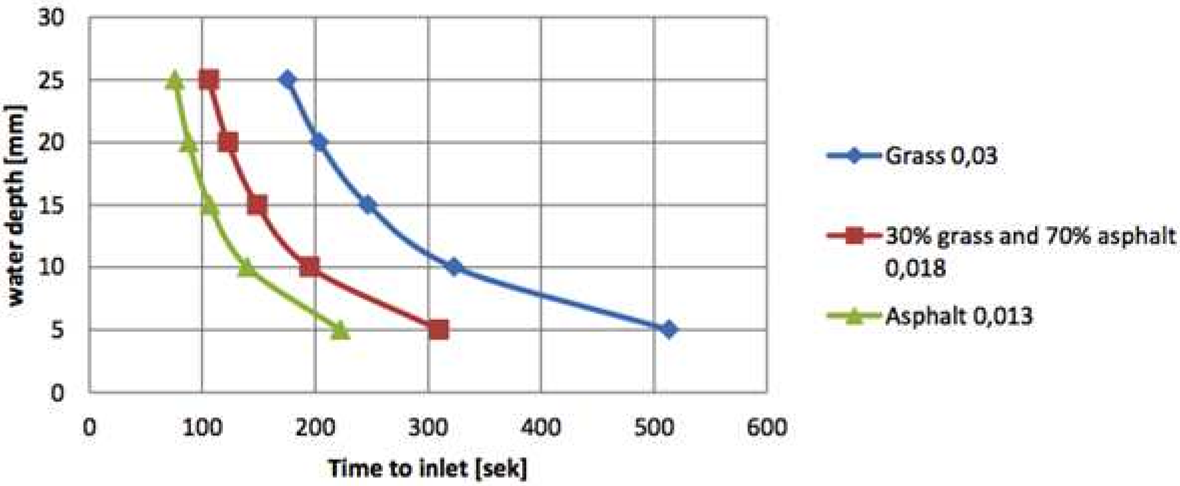


Figure 13: Time to inlet as function of water depth, for different manning´s n

The time in the pipe is estimated as the ratio of length of stormwater pipe and typical speeds in stormwater pipes. The longest possible pipe is 250m and storm water pipes have to have a minimum speed of 0,9m/s in order to be self-cleaning (Reykjavik Energy). Making the assumption that the speed is 1 m/s we find a time in pipe of 250s, or 4 min. Hence the time of concentration, is then 560s or 9.3min.

Design flow rate

The design flow rate is found using the the Rational equation:

$$Q = C\ I\ A$$

The runoff coefficient (C) and areas (A) for the Campus area are documented in Table 1. The effective runoff area (CxA) is 2.8 and 4.1 rha for the current and planned land use respectively.

The rainfall intensity (I) is found using the IDF curve with a duration (time to inlet) of 560s (9.3min). According to Table 3 (and Fig. 11-12), the 10 min rainfall intensity for Reykjavik is 64 l/s/ha. Using the slope of the IDF curve for Trondheim as comparison (Fig. 14), the extended Reykjavik curve gives I= 68 l/s/ha for a duration of 9.3 min. The rational formula yields the design flowrate of 0.19 m^3/s for the current land use on the area and 0.28 m^3/s or the planned.

Figure 14: IDF curve for Trondheim

Emergency flow rate for a 100 year event

The IDF curve for Reykjavík does not consider events with a return period of more than 50 years and does not have duration under 10min. Using the Trondheim and Oslo IDF curve for comparison, the rainfall intensity of the 100 year event is roughly 79 l/s/ha.

The emergency flow rate for the 100 year event is therefore 0.22 m^3 /s for the current layout and 0.33 m^3/s for the planed one.

2.3.5 Impact of Blue-Green solutions

Blue-green solutions may alter the runoff pattern in various ways, e.g. by altering the runoff coefficient and time of concentration for stormwater design. Table 4 considers possible impacts of green roofs and groundwater infiltration methods on the runoff. As seen from Table 4, previously impervious surfaces (e.g. parking lots and road) can become almost entirely pervious to infiltration, and as such their runoff coefficients would be close to 0 if replaced with permeable pavement, concrete or asphalt. As such, times of concentration are irrelevant, since the small amount of stormwater that would runoff would get absorbed by the material within minutes (State of Pennsylvania, 2006; Backstrom, 1999).

Green roofs however have seasonal variations which imply runoff coefficients ranging from 0.2 in summer up to 0.8 in winter when ground absorption is minimal. Except in case of short and heavy storms (events unlikely in Iceland), the water which will not infiltrate or evaporate will drain through the ground over periods of 30minutes or more (Kohler, 2001).

In the eventuality of replacing every runoff surface on campus by groundwater infiltration and green roofs, the resulting flowrate could be drastically reduced to almost nothing in summer, as the quasi totality of water would infiltrate the ground.

The main conclusion is that groundwater infiltration methods and green roofs are in direct conflict with retention and reuse methods, and therefore water use and needs should be compared and used as a base to the amount of water that needs not to be infiltrated.

2.3.6 References:

Garðarsson, S.M PhD., Civil Engineering. Oral communication, March 2nd, 2012.

Gísladóttir, G. Th. Geographer at the Iceland Met Office. Oral and e-mail communications, February 28th, 2012.

Icelandic Met Office. (2012). *Meðaltalstöflur fyrir stöð 1 – Reykjavík* [Table]. Retrieved February 27th 2012, from: http://www.vedur.is/Medaltalstoflur-txt/Stod_001_Reykjavik.ManMedal.txt

Jónsson, T. (1986). *Veðurfar á höfuðborgarsvæðinu.* Reykjavík: Skipulagsstofa höfuðborgarsvæðisins. Retrieved from: http://www.vedur.is/media/vedurstofan/utgafa/greinargerdir/1995/Vedurfar.pdf

Lost River Walks. (n.d.). *Salt Dome.* Retrieved February 28th, 2012 from http://www.lostrivers.ca/points/saltdome.htm

Reykjavík Energy. (2008). *Leiðbeiningar um hönnunarrennsli skólps og ofanvatns (Guideline for the design flow of sewage and surface water).* Reykjavík Energy, Reykjavík.

Teiknistofa Arkitekta, Gylfi Guðjónsson og félagar ehf (2009). *Háskóli Íslands: deiliskipulag vestan Suðurgötu.*

Thorolfsson, S. (2010). *Cold Climate Urban Hydrology Examples from Norway and Iceland.* Department of hydraulics and environmental Engineering, Norwegian University of Science and Technology (NTNU) Trondheim, Norway.

Vatnaskil. (1989). *Mælingar á rennsli og grunnvatnshæð á vatnasviði Reykjavíkurtjarnar*. Verkfræðistofan Vatnaskil. Fjölrit nr. 89.10. 17 bls.

WorldClimate. (2012). *Climate Data for 64°N 21°W* [Tables]. Retrieved from: http://www.worldclimate.com/cgi-bin/grid.pl?gr=N64W021

Australian Department of Water (2004). S*tormwater Management Manual for Western Australia* . Retrieved from: http://www.water.wa.gov.au/Managing+water/Urban+water/Stormwater/Stormwater+management+manual/default.aspx.

Backstrom, M. & Bergstrom, A. (1999). *Draining function of porous asphalt during snowmelt and temporary freezing*. Canadian Journal of Civil Engineering Vol. 27, pp. 594-598.

Haan, C.T., Barfield, B.J. & Hayes, J.C. (1994). *Design Hydrology and Sedimentology for Small Catchments*. Oxford, UK: Academic Press.

Köhler, M., Schmidt, M.,Grimme, F.W., Laar , M. (2001). *Urban Water Retention by Greened Roofs in Temperate and Tropical Climate* . Singapore: International Federation of Landscape Architects .

Lian, C. & Zhuge, Y. (2010). *Optimum mix design of enhanced permeable concrete – An experimental investigation* . Construction and Building Materials Vol. 24, pp. 2664-2671 .

MacIvor , J.S. & Lundholm, J. (2011). *Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate* . Ecological Engineering Vol. 37, pp. 407-417 .

Reykjavíkurborg (2012). *Borgarvefsjá*. Retrieved from http://lukr-01.reykjavik.is/borgarvefsja/

Roseen, M., Ballestero, T., Briggs, J. & Houle, J. (2006). *A Performance Evaluation of Porous Asphalt as a Stormwater Treatment Strategy* . UNH Stormwater Center presentation.

State of Pennsylvania (2006). *Pennsylvania Stormwater Best Management Practices Manual*. Retrieved from: http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

Thordarson, S. & Eliasson, J (1998). *1M5 Program*. Reykjavik: Vatnaverkfræðistofu Verkfræðistofnunar Haskoli Ísland.

Surface type	Runoff Coefficient C	Times of concentration	Miscellanous	Restrictions
Green roofs in general	Winter: 0.81[1] Summer: 0.20 – 0.25 (precipitation <700mm/year)[1]	>30min for low to moderate rainfalls[1]	The evaporation is porportional of the size of the substract [1] Green roof run off doesnt depend on specie[2]	Extra weight of 100kg/m2 best slope 4% max slope 12%[2]
Natural infiltration methods	See Part 2.1			
Porous asphalt (summer)	Summer: 0-0.5 (precipitation <300mm/min)[3] Winter: temperature> -5°C : absorption 5mm/min. Runoff 1 if temperature < -10°C (if the asphalt is not clogged with ice and the ground is not frozen underneath[3]) Snowmelt: runoff 0.9-1 (max absorption of 1-5mm/min)[3]	6 min for slope = 1% for an average sized parking lot[6].	Loses 90% of its absorptions capacities after a few years[3]	Not useful for sediment-filled waters [4] Requires vacuum cleaning every few years to maintain absorption capacities[3]
Permeable pavement	0.03[3]	5min[7]	Low maintenance required[3]	
Porous concrete	~0 (absorption 4-12mm/s)[5]	N/A if unsaturated.	Conventional porous concrete is hard to work with, but high performance PC is 10-20% more expensive[4]	

Table 4: Comparison of diverse Green-Blue technolgies in terms of runoff coefficients, times of concentration and restrictions

(1) Kohler, 2001 ; (2) Maclvor, 2011 ; (3) Backstrom, 1999 ; (4) State of Pennsylvania, 2006 ; (5) Lian, 2010 ; (6) Roseen, 2006 ; (7) Australian Department of Water, 2004

2.4 Stormwater pollution

2.4.1 Types of stormwater pollutants

Water and rain in Iceland is very clean and not polluted (Umhverfisstofnun, 2012). That means the pollutants in stormwater do not come with the rain but from the surfaces the rain lands on. The stormwater in the study area currently comes mainly from man-made structures: Most runoff is generated from roads and parking space and a significant portion comes building roofs (see Table 1). All these places are a source of pollutants that get mixed with the stormwater. The pollutants we are most interested in:

- **TSS** or total suspended solids are not dangerous by themselves but high concentration of solids makes the water dirty and if allowed into the environment they can cover the bottom of streams/lakes which affects the quality of the water and all life in the water. TSS also carry with them heavy metals and other harmful substances. (Vollertsen, 2010).
- **Nutrients** consist mainly of nitrogen (N) and phosphorus (P) and if found are a indicator of organic pollution. Organic pollution can lead to excessive algal blooms and deplete the water of oxygen with very harmful effects on the quality of life in the water. Stormwater flushes nutrients of green areas and also from impermeable areas such as streets and parking lots. Nutrients are also released by car traffic as the burning of fossil fuels produces nitrogen oxides (NOx) (World Resources institute, 2009).
- **Heavy metals** can be very dangerous to the environment. The main metals expected to be found in Icelandic surface runoff are As, Cd, Cr, Cu, Ni, Pb and Zn. The main source of heavy metals in stormwater can be traced to car traffic. Paint on roofs is another possible source of heavy metals (Malmquist, Ingimarsson, Ingvason, & Stefánsson, 2008)
- **Oils** products, which may include **PAHs** which are toxic
- **Harmful microorganisms,** such as E.coli, that are harmful for human consumption

In the following chapters, information of stormwater pollutant concentrations is gathered from different research conducted on residential road and roof runoffs in Iceland and in Europe.

2.4.2 Measured road runoff pollution in Reykjavík

Table 5 summarizes pollutants and total suspended solids measured in two different studies in residential Reykjavík. First results taken at the inlet water to the detention pond in Grafarholt residential area, by Vollertsen (2010) are presented. The values are maximum values obtained from a storm event in 22.12.2008, what Vollertsen considers a worst case scenario in 2.8.2008. Second, nutrient and heavy metal concentrations for outlet water from residential area of Breiðholt by Gíslason (1998) are presented. Values are maximum and minimum values from 2 different pipes on 5 different time occasions during year 1998.

Table 5: Pollution levels in residential road runoff in Reykjavík

		Heavy metals							Nutrients		
		Cu (µg/l)	Zn (µg/l)	Pb (µg/l)	Cr (µg/l)	Ni (µg/l)	Cd (µg/l)	As (µg/l)	Total N (µg/l)	Total P (µg/l)	TSS (mg/l)
Vollertsen (2010)	**Dec 2008**	9.4	48.6	0.97	7.8	2.99	-	-	-	-	100
Gíslason (1998)	**Max**	10.2	270	2.04	1.230	1.250	0.113	(1100)	759	352.7	-
	Min	0.616	4.970	0.058	0.088	0.596	0.007	0.010	123	3.1	-

2.4.3 Measured roof runoff pollution in Europe

Two surveys were consulted for chemical and biological pollution in roof water runoff.

Survey Vienna - The first study was carried out in Vienna from 1991 to 1995. For this survey 4 different roof water runoffs have been analyzed. Two of them were taken from highly dense residential area and the other two from areas close to the city boarder. 45 rain events have been evaluated.

Not one of the samples reached drinking water standard and all of them failed to satisfy the requirements set by the AAEV (Regulation for passing rainwater into flowing waters).

Survey Gratz - The second survey was conducted in Graz in the year 1997. The survey compromised measurements of the roof runoff of one residential buidling. In total two samples were taken one at the start (sample 1) of the rain event and one 20 minutes later (sample 2).

The findings of the survey were high concetrations of copper, Potassium permanganate ($KMnO_4$) and high numbers of microorganism. The amount of copper found in the samples is caused by the copper overhead wire next to the building.

Table 6 shows the combined result of the surveys. Most of the data is based on the survey in Vienna, because of the higher amount of measurements and rain events the values should be more accurate. Just missing values for KMnO4 and amounts of different microorganism were taken from the survey done in Graz. (Reinhold 2002)

Lastly, it is important to note that site specific conditions at the surveyed locations differs from those in Reykjavik. Wind speeds and percipitation in Vienna and Graz are lower than in Iceland. In addition the population density is higher than in Iceland (Wien: 1.7 million people, Graz: 300.000). Therefore the measured amount listed in Table 6 are expected to be to high for the municipality of Reykjavik but can still give maximum value for pollutants.

Table 6: Pollutants in roof water runoff according to surveys from Vienna and Gratz

parameter	Unit	Peak value incremental sample	Peak value composite sample	Minimum value composite sample	Range of the average values of composite samples
pH		4,3	8,3	5,8	6,3-7,7
settleable solids	ml/l	0,6	0,6	<0,1	-
Ammonium	mg/l	6,9	5,7	0,3	1,4 - 3,1
Nitrite	mg/l	2,31	1	0,1	0,3 - 0,5
Nitrate	mg/l	30,2	16	208	5,3 - 9,5
PO_4 - P	mg/l	1,2	0,1	0,003	0,007 - <0,06
PAHs	µg/l	5	3	<0,05	0,48
Cadmium	mg/l	0,34	0,13	<0,001	-
Lead (Pb)	mg/l	0,07	0,033	<0,005	-
Zinc (Zn)	mg/l	8,64	4,1	0,57	1-2,39

parameter	Unit	Sample 1 (time: 13.10)	Sample 2 (time: 13.30)
$KMnO_4$	mg/l	9,03	11,60
Number of aerobe colonies (22°C)	Colonies/100ml	5.800	5.300
Number of arobe colonies (37°C)	Colonies/100ml	440	370
Escherichia coli	Germs/100ml	110.000	64.000
Coliforme	Germs/100ml	121.000	72.000
Enterokokken	Germs/100ml	88.500	81.200

2.4.4 Impact of pollution on water quality

The impact of the stormwater pollutant concentrations, presented in Tables 5 and 6, on water quality may be assessed using the classifications specified in the Icelandic water regulations (796/1999), listed in Tables 7 and 8.

Table 7:Heavy metal classes regarding Icelandic regulations

Heavy metals	
I	Very little or no impact from pollution
II	little impact from pollution
III	Some impact on pristine environment from pollution
IV	Impact from pollution expected
V	Always unsatisfactory

Table 8: Nutrient classes regarding Icelandic regulations

Nutrients in Lakes	
I	To little of nutrients
II	low on nutrients
III	Rich of nutrients
IV	Very rich of nutrients
V	Too much of nutrients

Maximum heavy metal concentrations measured in residential stormwater runoff in Iceland have high or medium impact on the quality of water. Corresponding classes for maximum contaminations are; Copper (Class IV), Zink (Class IV), Lead (Class III), Chrome (Class III), Nickel (Class II), Cadmium (Class III). The maximum concentration of Arsenic measured in the 1998 study is an outlier and will not be used. Maximum nutrient values in runoff water, correspond to shallow lake rating of Class V for total phosphorus and Class V for total nitrogen. The Icelandic regulations do not consider TSS values or other pollutants.

No information could be found on roof water pollution in Iceland. Contaminations obtained from Austrian measurements seem to be unsatisfying if compared to Icelandic regulations: Runoff water from roofs is rich in phosphorus nutrients (Class III) and heavy metal concentration (Zn) is unsatisfactory (Class IV). In addition, the runoff of the roofs is contaminated with a high concentration of micro-organisms, PAHs, Ammonium and other pollutants that are not considered in the Icelandic regulations, but that affect the usability of the water. Like said before, none of the samples satisfied the AAEV regulations.

If runoff water is to be used in new campus design, information about pollutants in it in Icelandic environment needs to be gathered. Stormwater runoff from residential areas is considered to have bad or average quality, considering the heavy metal content, if this water is to be used, additional information about other pollutants in this water is to be obtained. These findings highlight the need for treating stormwater, e.g. locally, before re-using it or draining it towards local surface or groundwater sources.

2.4.5 References

City of Reykjavik. (2009). *Environment and Transport*. Retrieved February 26, 2012, from City of Reykjavik: http://www.reykjavik.is/desktopdefault.aspx/tabid-3822/6631_view-2953/

Gíslason, S. R. (1998). *The chemical composition of Elliðaár 1997-1998 - Efnasamsetning Elliðaánna 1997-1998.* Reykjavik.

Malmquist, H. J., Ingimarsson, F., Ingvason, H. R., & Stefánsson, S. M. (2008). *Mengunarflokkun á Reykjavíkurtjörn.* Kópavogur: Náttúrufræðistofa Kópavogs.

Umhverfisstofnun. (2012, February 13). *Vatnið okkar og stjórn vatnamála.* Retrieved February 25, 2012, from Umhverfisstofnun: http://www.ust.is/library/Skrar/Einstaklingar/Vatnsgaedi/Vatnatilskipunin/Kynningabla%C3%B01%20stjornvatnamalaalmennt-%C3%BAtg%C3%A1fa.pdf

Vollertsen, G. E. (2010). *Removal of heavy metals in a wet detention pond in Reykjavik.* Reykjavík: University of Iceland.

World Resources institute. (2009). *Sources of Nutrient Pollution*. Retrieved February 27, 2012, from World Resources institute: http://www.wri.org/project/eutrophication/about/sources

Kobencic Reinhold (2002), Verunreinigung des Regenwasserabflusses von Dachflächen, University of Graz

2.5 Summary

The initial assessment of site specific conditions at the University of Iceland campus, presented in this chapter, suggests that there are several opportunities in implementing Blue-Green stormwater solutions:

- Substantial annual runoff is currently generated at the study site West of Suðurgata:
  - Roof runoff : 6000 m^3 /year
  - Parking lot runoff: 9000 m^3 /year
- Currently, none of this runoff is used for any purposes. Instead, it is collected in combined sewer system and transported to the nearest waste water treatment plant. Combined systems have possible risks of flooding basements and combined sewer overflows harm local water quality
- Currently, the road runoff from Suðurgata is collected in a separate stormwater system, and channeled untreated to the pond “Tjörnin”. It is necessary to implement local water treatment, as road runoff may have significant amounts of heavy metals and nutrients.
- The on-site land slopes (1-2.5%) are favorable to collect water and store locally, e.g. in ponds and swales
- Sufficient altitude difference is present to collect water from the furthest area in the West (e.g. Háskólabíó) and transport it via gravity (no pumping) to the Vatnsmýri wetlands in the East.
- The runoff at the site will increase substantially in the future with new buildings such as the The Vigdís Finnbogadóttir Institute of Foreign Languages and the undertunnel connecting this building to Háskólatorg. Because of this, stormwater management must be re-thought on the site which provides huge opportunities in implementing blue-green solutions.

There are several considerations that must be taken into account and may put constraints on certain blue green solutions at the University of Iceland campus site West of Suðurgata:

- The water levels have been measured to be only 1.3 m beneath the surface in winters. This high water table may enhance flooding risks in future planned basements.
- Only the top soils are permeable, and the bedrock is estimated at 6.6 m. This along with the high groundwater table, limits the use of blue-green solutions focused on groundwater infiltration and recharge (discussed in Appendix A).
- The roof and road runoff is polluted with heavy metals, organic pollutants and microorganisms, and hence cannot be reused without appropriate treatment.
- More research is necessary on local conditions on site.

3 Possible green-blue solutions for University of Iceland campus

The students researched several “Green-Blue” source solutions:

1. Green roofs
2. Ponds, swales and rain gardens
3. Reuse
4. Groundwater infiltration and recharge
5. Treatment

After considering the site specific conditions, discussed in Chapter 2, the first three solutions were considered more closely and a proposal for possible implementation was generated. More information on the latter three solutions are presented in Appendix A.

3.1 Green roofs

3.1.1 General information

Green roofs, otherwise known as living roofs or eco-roofs, are the wave of the future in sustainable design. Environmentally-sensitive roofing systems allow plants to grow on the surface of what would otherwise be just a protective covering for houses and commercial buildings.

The benefits of having green roofs are:

- Reduce the runoff of rainwater, retain 50-60% of the total annual runoff volume
- Trap and filter dust particles and other pollutants from entering our storm water
- Reduce heating up to 40%
- Keep homes cooler during the hot seasons because of evaporative cooling => lower electricity cost for air condition.
- Reduce noise pollution in houses
- Average green roof last for an average of 40 years as opposed to the 17-year life expectancy of roof installed with standard roofing
- Green roofs vegetation absorbs negative air toxin, purifying urban air
- Aesthetically pleasing
- Green roofs are part of the Norse cultural heritage

Possible disadvantages of green roofs are:

- Roots can penetrate the waterproofing membrane
- If roof leaks, it is harder to find and fix the leak
- Complex drainage systems
- Insects, bugs, rodents and even small reptiles can and will set up house in green roofs, and can and up burrowing or damaging the building

3.1.2 Types of Green Roofs

There are two general types of green roofs: extensive and intensive.

Intensive green roofs, commonly thought of as "garden roofs," are the more complex of the two, exhibiting much greater plant diversity, and a greater need for design expertise. Planting media for intensive green roofs are a 30 cm deep at minimum, and have saturated weights ranging from 400 to 600 kg/m^2, depending on type and depth of planting medium and the type of plants. Almost always used for new construction but not placed on an existing roof. Intensive green roofs can be anything from a public garden to an entire park (www.facilitiesnet.com, n.d).

Extensive green roofs, with a saturated weight of 60-250 kg/m^2, are the most common. With planting media of 3-12 cm thick, most extensive green roofs are not designed for public access or to be walked on any more than a typical membrane roof would. Several modular extensive green roof products have emerged in the last few years that allow plants to be grown at the factory prior to actually being installed on a roof (www.facilitiesnet.com, n.d).

For maintenance Design Guidelines for Green Roof, chapter 3.10 can be studied (Peck, S., & Kuhn, M, n.d.).

Whether the roof is intensive or extensive, facility executives should consider the details of green roof design and construction carefully. There are a few more layers of complexity with a green roof than with traditional construction. That complexity, as well as cost, and the misperception that green roofs are more leak-prone, are the main reasons facility executives wouldn't seriously consider green roofs for commercial projects.

3.1.3 Green roof constructions

All green roofs are comprised of the same basic components, a waterproof layer, a drainage layer, the growth media (soil) layer and the vegetation layer (Figure 15).

Waterproof Layer - The most expensive and important layer on a green roof is the waterproof layer. As its name suggests, it will prevent water from leaking through your roof as well as protect it from root penetration.

Drainage Layer - The drainage layer can also vary from simple fabrics to systems that channel water through v –shaped troughs.   A drainage layer is necessary for roofs with a pitch less than 5 percent, and could be gravel, pumice, lava rock, or other porous material.

Growth Media - The growth media layer is the soil layer. Soil for green roofs must be lightweight and meet required saturated weights.

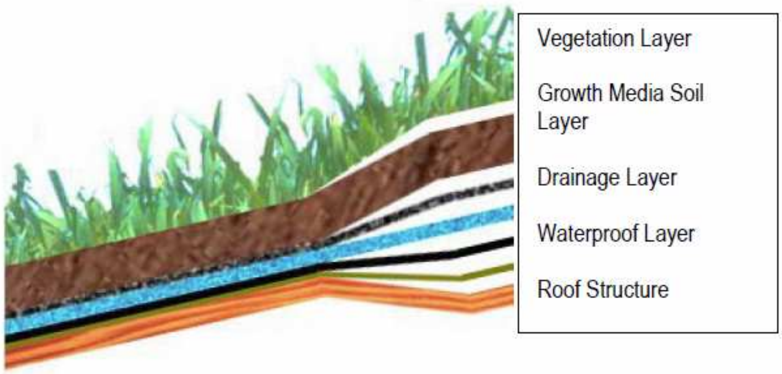


Figure 15: Green roofs structure. (Pomegrante-Center-Greenroof-Manual-2005, n.d)

Before installing a green roof system, several features must be taken into considerations.

Slope - The slope of roof is a major factor when considering a green roof. Roofs with pitches greater than 7:12 (30 degrees) do not do well as green roofs. They suffer from slippage and slumping of materials as well as swift release of runoff water. However, flat roofs are not always the best for green roofs either. Actually, it is possible to have a roof that is too flat. On flat surfaces, poor drainage can lead to roof damage, root rot and damage to plants. The ideal slope is about 1:12. It is known that roofs can be as steep as 60 degrees from the horizontal but it is important to consider the climate where the roof is being installed. The steeper the slope is the more care should be taken. Some special precautions need to be taken if the slope is more than 10°, following are figures of two examples (Pomegrante-Center-Greenroof-Manual-2005,n.d and Green Roofs - Slope Stabilization, n.d.).

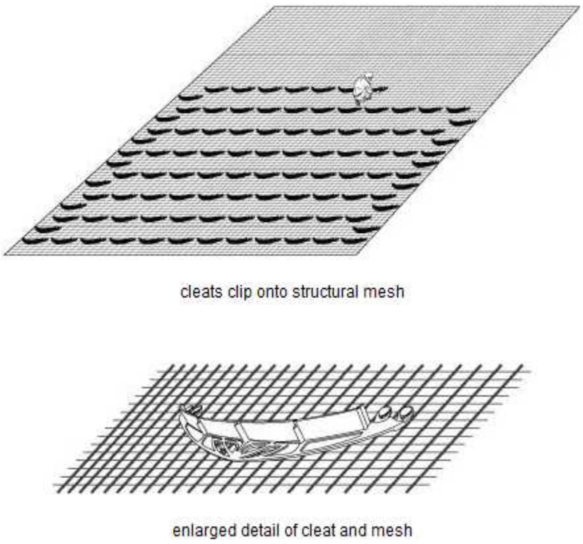


Figure 16: Anti slip cleats for green roofs

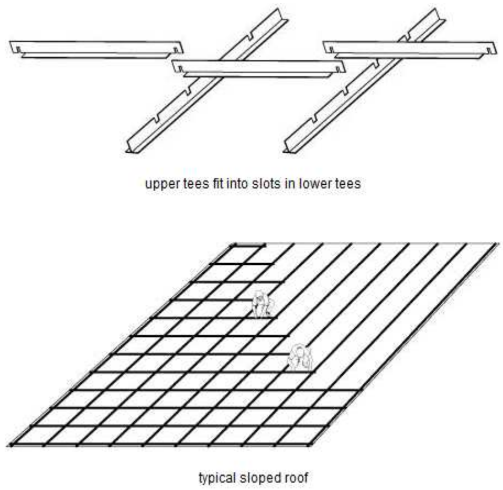


Figure 17: Anti slip tees for green roofs

Climate - local climatic factors like wind, sunlight, shade and temperature, need to be taken into consideration before building a green roof. Plants can struggle in extreme climates or in windy areas and green roofs have not been overly successful in sub-tropical or tropical environments, but we don´t have to worry about that (Pomegrante-Center-Greenroof-Manual-2005, n.d).

Construction - the structure of a building needs to be checked to see if the roof can support the extra weight of a green roof. If the roof is extensive the roof weight could be approximately the same as a roof of clay tiles (Pomegrante-Center-Greenroof-Manual-2005, n.d).

3.1.4 Proposals

Figure 18 presents the proposal for installing green roofs on the University of Iceland Campus West of Suðurgata. Currently one roof, for the house Endurmenntun, is a green roof. The remaining roofs are traditional roofs drained to the underground sewage collection system.

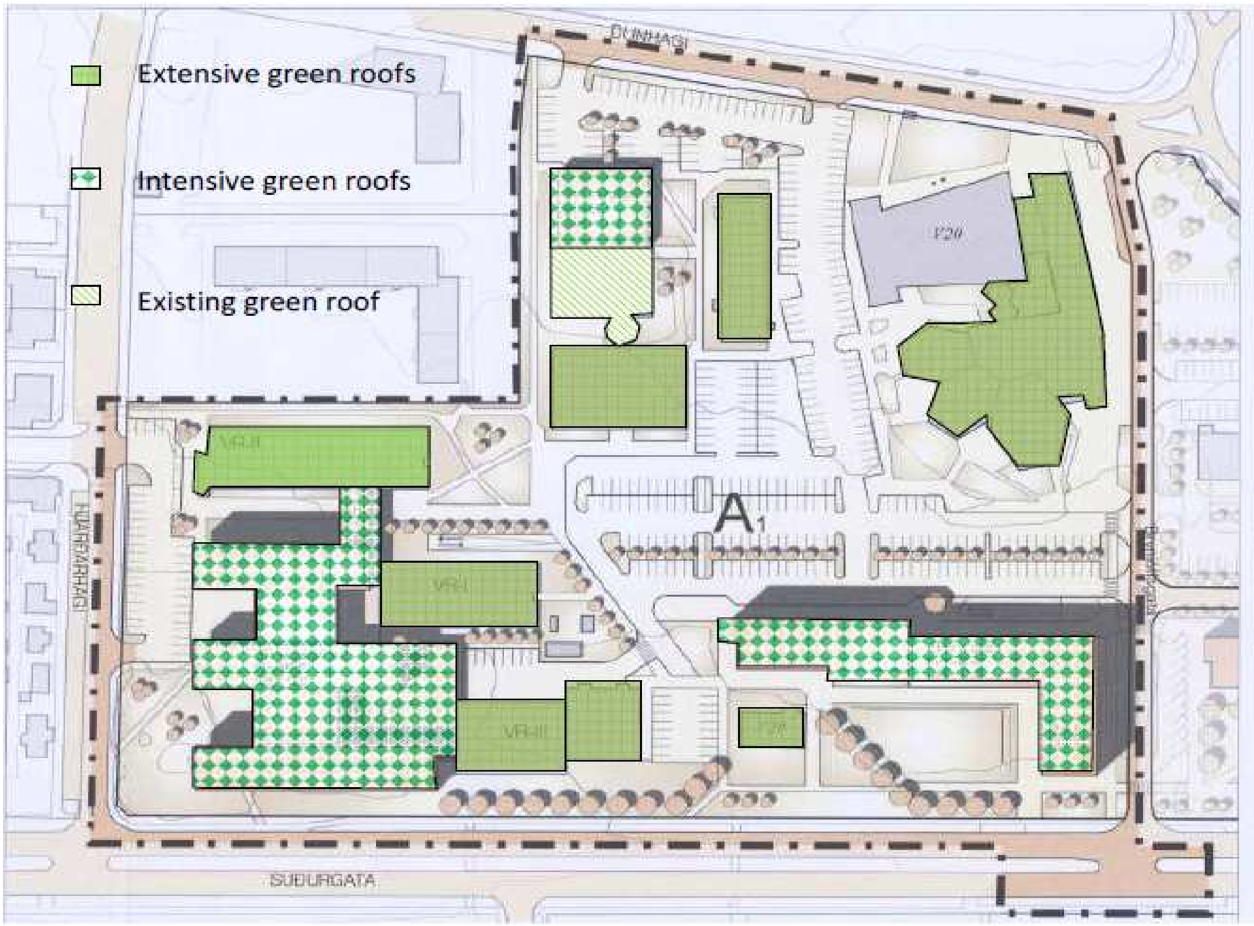


Figure 18: Proposed changes of plan (Deiliskipulag) from april 2009 with existing buildings marked as extensive roofs and planned buildings marked as intensive roofs.

Many existing buildings on the University Campus West of Suðurgata are feasable options for installing the light weight extensive green roofs (Figure 18).

- Top left: VR-1 and VR-2 with fairly big roofs and relatively mild slopes especially on the east side, therefore extensive green roofs are possible.
- Top right: Tæknigarður has a flat roof just as the connected building Endurmenntun does which has a green roof.
- Bottom left: VR-3 which would be more challenging to put a green roof on than the others. But it could have a certain reference to the old norse houses (í. Torfbær) which would be interesting.
- Bottom right: Háskólabíó as VR-1 and VR-2 has a large roof areas with mild slopes (the hexagons). The big hall´s roof is one of the roofs on the lot that is propably not possible to put a green roof on because of its harmonica shape.

Figure 19: Possible buildings for installing extensive green roofs (Photos: Guðbjörg Brá Gísladóttir).

Lastly, with new planned buildings in the study area, the annual runoff will increase drastically on site (see Table 1). Installing intensive roofs, or garden roofs, is a viable option for the planned buildings, which not only will reduce the runoff, but also create nicer natural look and recreational options on the roofs. Intensive green roofs would promote sustainability on the site, and make the site more "Green"

3.1.5 References

Extensive or Intensive? Green Roofs Explained - Facilities Management Roofing Feature. (n.d.). Retreived Feb 22, 2012 from http://www.facilitiesnet.com/roofing/article/Extensive-or-Intensive-Green-Roofs-Explained--10074#

Green Roofs - Slope Stabilization. (n.d.). Retreived Feb 22, 2012, from http://www.conservationtechnology.com/greenroof_slope.html

Green Roofs: Pros and Cons. (n.d.). Retreived Feb 22, 2012, from http://www.house-energy.com/Roof/Roof-green-costs.htm

Nophadrain - green roof systems. (n.d.). Retreived Feb 22, 2012 from http://www.nophadrain.nl/EN.html

Obendorder, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K., & Rowe, B. (Nov. 2007). Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services.*JSTOR,* Vol. 57, No. 10. Retrieved from. http://www.jstor.org/stable/10.1641/B571005

Peck, S., & Kuhn, M.(n.d.). Design Guidelines for Green Roofs.*Ontario Association of Architects*. Retrieved from http://www.cmhc-chl.gc.ca/en/inpr/bude/himu/coedar/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=70146

Peter Stahre(Malmo Water, Malmo Sweden) and Govert D. Gelldof(TAUW Deventer, The Netherlands) (2003), *New Approach to Sustainable Stormwater Planning,* Augustenborg´s Botanical Roof Garden, Publication NO 005

Peter Stahre (2008), *Blue - Green Fingerprints in the city of Malmö, Sweden*, Malmö Sweden, VA SYD

Peter Stahre (n.d), *Sustainable in urban storm drainage, planing and examples*, No informations.

Peter Stahre (2005), 15 *Years Experiences of Sustainable Urban Storm Drainage in the City of Malmo, Sweden,* City of Malmo, Department of Water and Wastewater, S-205 80 Malmo, Sweden

Pomegrante-Center-Greenroof-Manual-2005.pdf. (n.d.). Retreived Feb 22, 2012 from http://www.pomegranate.org/wp-content/publications/Pomegrante-Center-Greenroof-Manual-2005.pdf

Pros & Cons of Green Roofs | eHow.com. (n.d.). Retreived Feb 22, 2012 from http://www.ehow.com/list_6907004_pros-_amp_-cons-green-roofs.html

3.2 Ponds

3.2.1 General information

Water is the main foundation for life so it is not a surprise that ponds are popular in urban planning. But the benefits of ponds are more than just visual. Settling ponds are an effective way to treat stormwater in the area. They are designed with gentle slopes and some wetland plants near the shores to dilute the pollutants from the water. The solid particles settle to the bottom, which consists of lava or some kind of permeable bedrock. It is important that the underlying layers are impermeable so that the water from the ponds is separated from the groundwater. This way the stormwater can be cleaned within the area in an inexpensive and environmentally friendly way. Ponds are beneficial for the biodiversity of the area since they provide a good habitat for birdlife that can then be an attraction for people. In wintertime it could also be a recreational since it would be possible to use the frozen ponds for ice-skating.

Typical depth of a settling pond is around 1-1.5 m (H. Ingvadóttir, n.d.) but the size depends on the runoff flow of the area and the treatment efficiency requirements. It may vary from 40 m^2/ha to 240 m^2/ha. Convenient size for the University Campus Area is 120 m^2/ha. The removal efficiency for that size is assumed to be around 75% of solids and 55-60% of heavy metals (Pettersson, T.J.R 1999). The length from the main inlet to the outlet of the pond should be 2-3 times the width of it (H. Ingvadóttir, n.d). Figure 20 shows a typical design of a settling pond (H. Ingvadóttir, n.d).

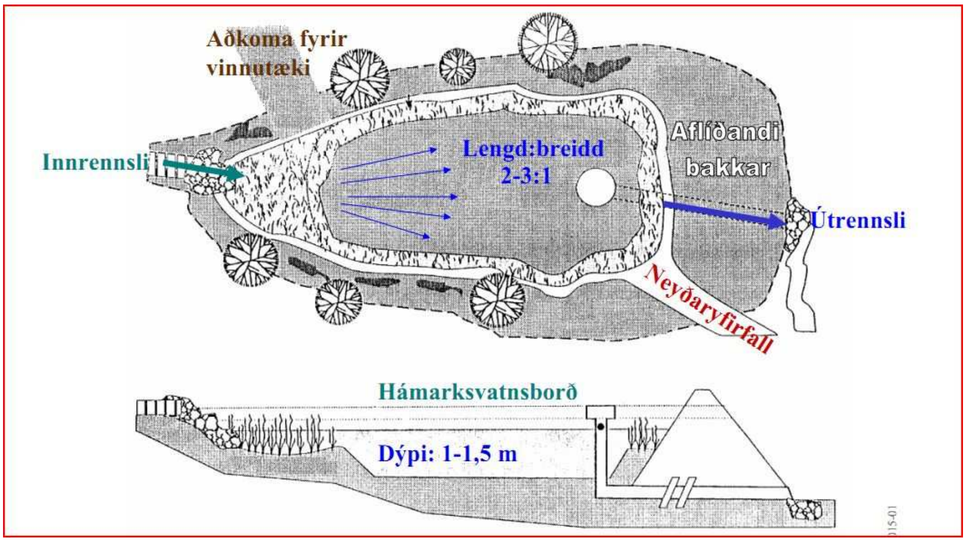


Figure 20: Typical design of a settling pond (H. Ingvadóttir, n.d)

3.2.2 Proposals

Several locations are suitable for ponds in the area West of Suðurgata. First, the area north of VRII is proposed as a suitable location for a pond (Figure 21, top right). It is a low point and the water could be gathered in a small piping system and let to the pond. The outlet would be let under Suðurgata, in a pipe with sufficient slope, and from there it could flow in a creek with waterfalls on the way to Vatnsmýrin. Today the area is shadowy and a pond would increase aesthetics of the area and make it more enjoyable. Proposed size of the pond is 300 m^2, split in two parts with a bridge for pedestrians to pass over it.

Another pond is suggested to be put in the green area between Loftskeytastöðin and Suðurgata (Figure 21, bottom right). This area is not in a low point so design of the piping system for the inlet would have to allow for that. The area is though very flat so this would not be a problem. The outlet of the pond could be combined with the outlet of the other pond and the water is led to the Vatnsmýri. If some sheltering is put up around the pond, this could make a nice outdoor area. Proposed size of this pond is also 300 m^2 but the ratios should be close to 3:1 to fit the area.

Figure 21: Proposals of locations for ponds (Teiknistofa Arkitekta; Gylfi og félgar ehf, 2009).

The third possible location would be west of Háskólabíó (Figure 21, top right). The area is sufficiently big to room a pond and it is the lowest point of the whole study area. The distance for the water to travel to Vatnsmýri is rather long so it might be a better solution to direct the outlet towards the sea in south. That could be done in pipes or by an open channel.

3.2.3 Reference

Hildur Ingvadóttir (n.d.). *Settjarnir í Reykjavik.* Reykjavik: Verkfræðideild Orkuveitu Reykjavíkur. Cited February 22, 2012 at URL: www.or.is/media/files/**settjarnir**.pdf

Petterson, T.J.R, 1999. *Stormwater Ponds for Pollution Reduction.* Chalmers University of Technology. Cited March 6th, 2012 at URL: http://swepub.kb.se/bib/swepub:oai:services.scigloo.org:821?vw=short&tab2=abs

3.3 Swales

3.3.1 General information

In general swales are broad, shallow channels used to collect storm water in a natural way and lead it to the location it is needed (e. g. to a pond). In addition, swales slow off the runoff, promote infiltration and can treat the runoff through filtration and bio-retention. According to the "Pennsylvania Stormwater Manual" a vegetated swale can reduce the TSS, TP in the water by 50 % and the NO_3 amount by 30% (Pennsylvania, 2006). Those pollution and sediment removal mechanism are depending on the material and plants used and can be chosen from local materials. Depending on the amount and characteristic of pollutants special plants and soils can be used. In Iceland lava stones, characterized by high permeability and good pollutant removal mechanism can be used. As vegetation the local grown Icelandic grass is reasonable.

Figure 22: Vegetated swale next to a parking lot (http://www.werf.org/livablecommunities/images/truckee2.jpg)

A typical vegetated swale (Figure 22) is underlined by at least 24 inches of permeable soil or rocks with a minimum infiltration rate of 0.5 inches/hour. In addition a 12 to 24 inch aggregate can be used to reduce the stormwater conveyance rate. Depending on the used material the run off rate towards a pond or the infiltration rate can be increased. The maximum allowable ponding time of 72 hours should not be exceeded (Pennsylvania, 2006).

Typical cross section and profiles of a vegetated swale is presented on Figure 23. When designing a swale the fact that excessive storm water flows and slopes can lead to erosive flows, which can damage the vegetation and the swale itself, have to be considered. Generally, the longitudinal slopes for swales range from 1% to 6% and the side slopes form 3:1 to 5:1, the bottom width should be in between 2 to 8 feet (Pennsylvania, 2006).

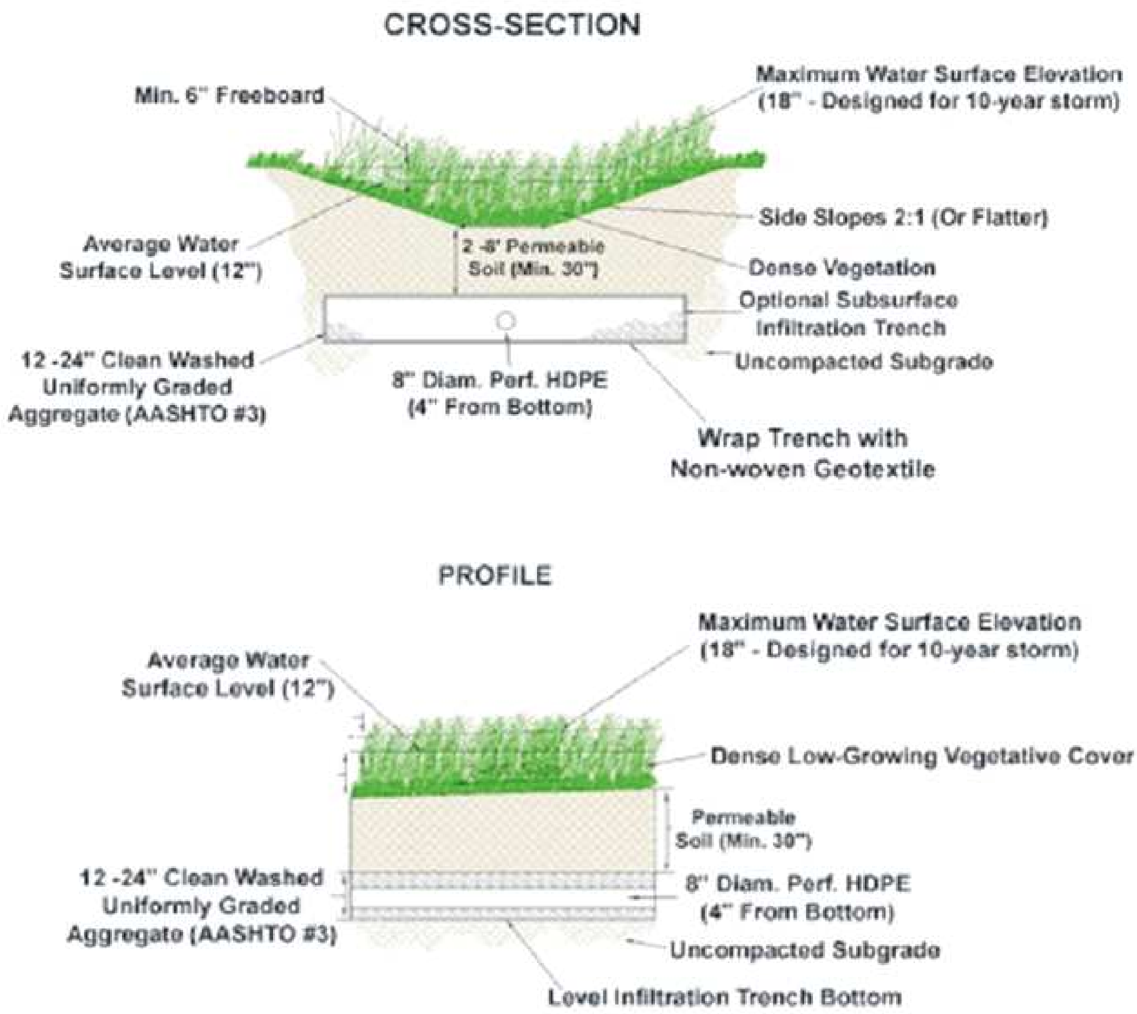


Figure 23: Cross-section and profile for a vegetated swale (Pennsylvania, 2006).

Another approach is using Grass Swales (Figure 24), they normally have milder side and longitude slopes than the vegetated ones. The missing vegetation leads to less infiltration and pollutant removal opportunities but come along with decreased costs. Going by the "Pennsylvania Stormwater Manual" grass swales should only be used as pretreatment structures (Pennsylvania, 2006).

Figure 24: Typical grass swale (Pennsylvania, 2006).

3.3.2 Proposals

The University of Iceland study area is well suited for the use of swales. Figure 25 illustrates how swales can be located along the streets and parking lots to gather surface runoff from nearby areas. The water will be transferred into proposed ponds in the area (Figure 21).

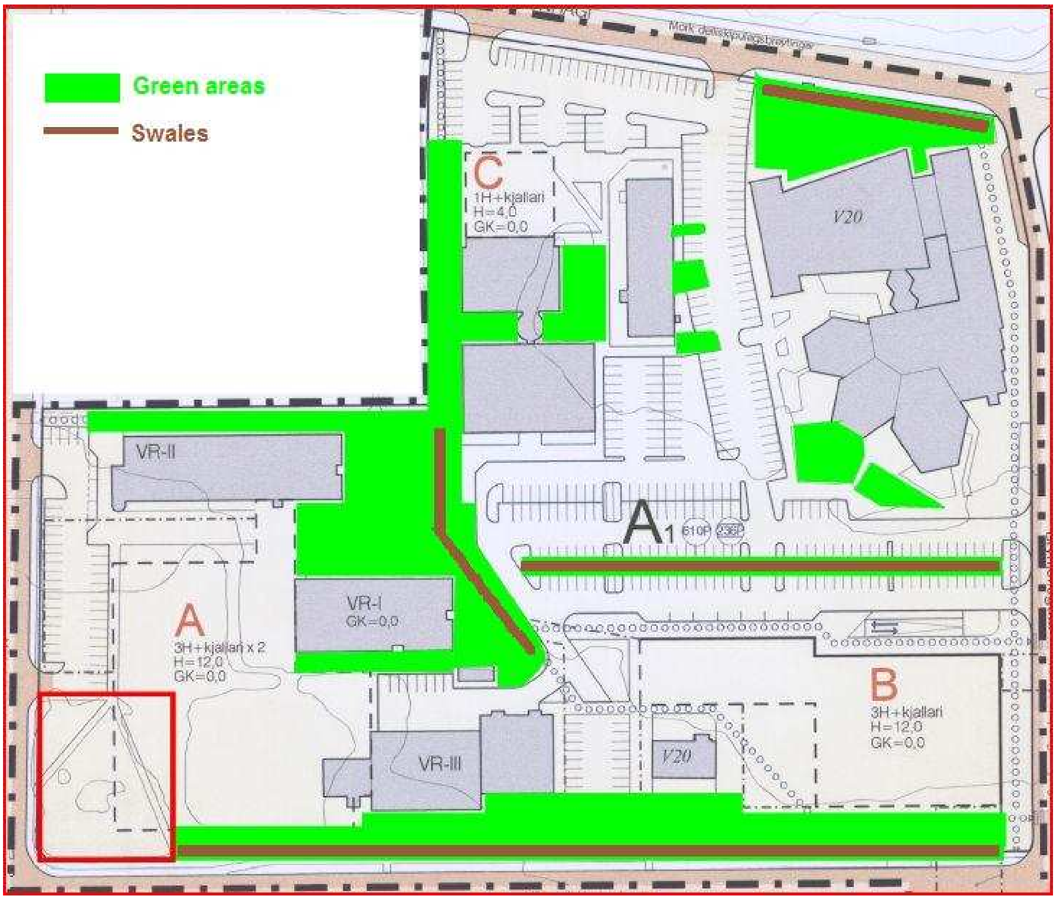


Figure 25: Proposed locations of swales at University of Iceland Campus

Figures 26 and 27 show in more detail two implementation ideas of swales in the campus area.

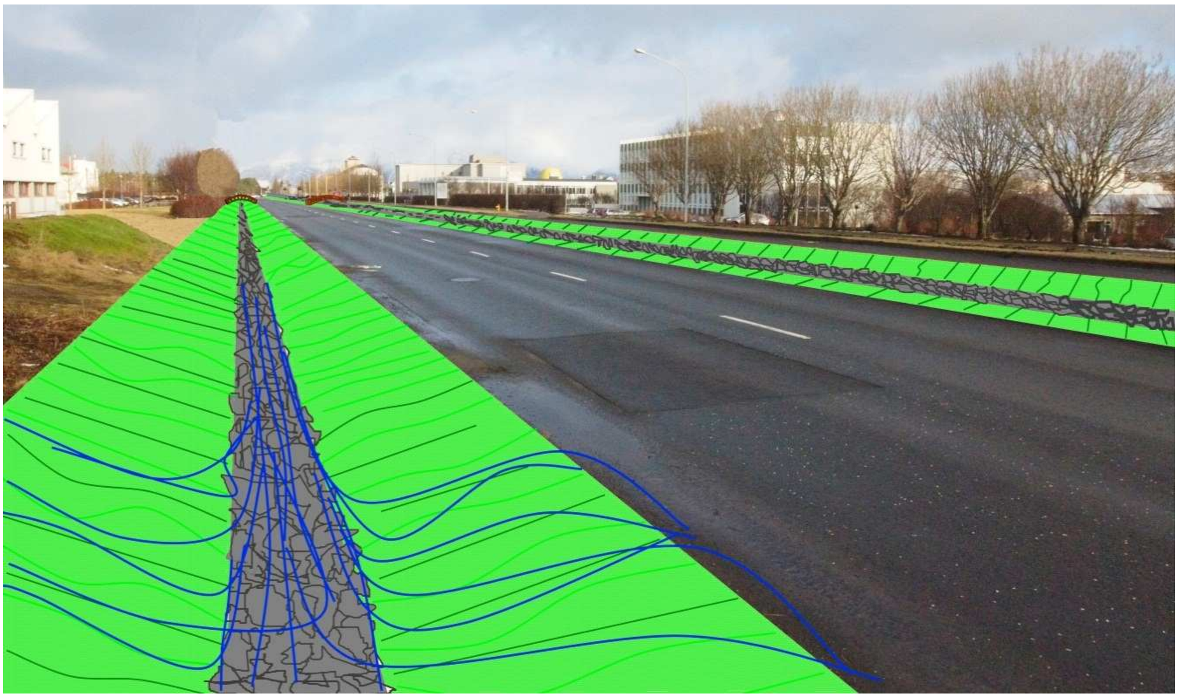


Figure 26:Possible swales along Suðurgata

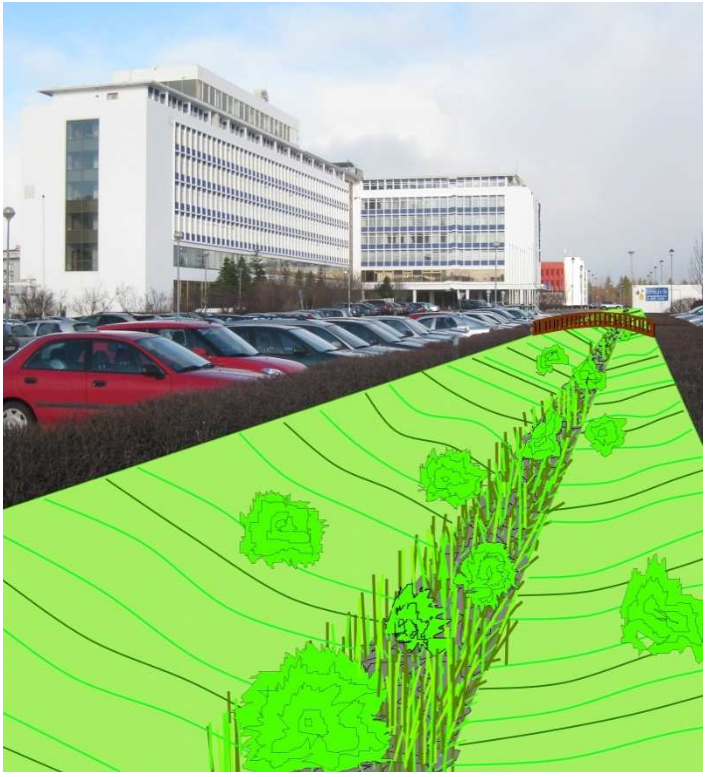


Figure 27:Possible swale on the parking lot of Háskólabíó

3.3.3 References

Pennsylvania, S. o. (2006). *Pennsylvania Stormwater Best Management Practices Manual.* Harrisburg: State of Pennsylvania

3.4 Rain gardens

3.4.1 General information

Rain garden is a vegetated depression in the ground with an underlying filter medium where the surface water from urban areas is collected, stored and infiltrated. The purpose is to lower the hydraulic load on the storm water systems and treat the water (Dalen, n.d.). Rain garden collects water run-off from roofs, driveways, walkways and parking lots. It holds the water for a short period of time and allows it to naturally infiltrate into the ground (Rain Garden Network, n.d.).There are two possibilities; to infiltrate runoff water to groundwater or collect the water into a pipe, see Figure 28 below. If the water would be collected to pipes it could be diverted to Vatnsmýri.

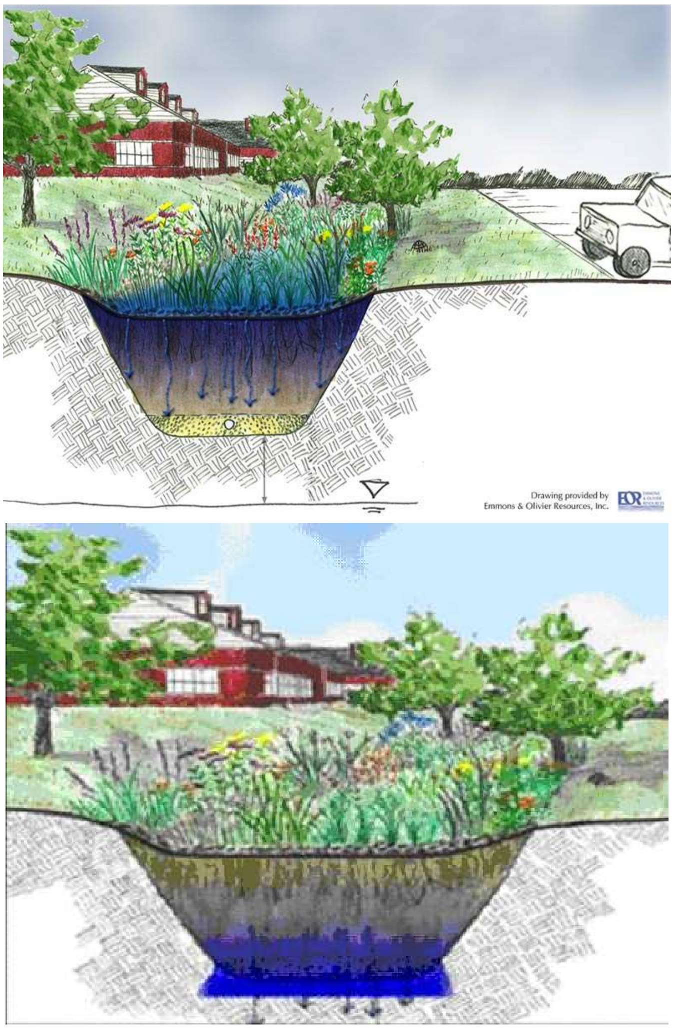


Figure 28: Rain gardens that infiltrates to pipe (top) and groundwater (bottom) (Emmons & Olivier Resources, Inc).

The garden should be planted with deep-rooted native plants and grasses, since they are best applied for the climate. Plants with deep fibrous roots tend to have a competitive advantage in a rain garden and provide the most cleaning and filtration benefits to the environment (Rain Garden Design Templates, n.d). The underlying medium should consist of sand and compost. Laboratory studies have shown that the pollutant removal rates are independent of depth beyond a certain depth. The test rain gardens were classified as sandy loam with mulch on top vegetated with Creeping Juniper, both showed excellent metal removal, exceeding 90%. Studies will have to be made in the University area to find an optimum earth media and appropriate local vegetation (Muthanna, 2007).

There are few technical issues about rain gardens. The garden needs to be located at least 3 meters away from houses and it has to be located in a naturally occurring low spot. It is preferable to choose a location in the sun, either full or partial. When sizing the rain garden the runoff area needs to be estimated. Guidelines from the US give a ratio for runoff area and size of rain garden for different earth materials. The rain garden should be

- 20% of the runoff area for sandy soil
- 30-35% of the runoff area for loam
- 45-60% of the runoff area for clay

(Rain Garden Network, n.d.)

Rain gardens are not completely maintenance free. It is necessary to weed, clean up and re mulch the garden in the early spring and fall (Rain Garden Network, n.d.).

In cold climates the performance of rain gardens is not well known. Interchanged snow and rainfall events in winter are the most problematic issues, creating rain-on-snow events, resulting in ice formation, then melting and refreezing. Rain gardens can offer a great possibility for use both as a snow deposit and retention of pollutants from the melt water (Muthanna, 2007).

Rain gardens are beautiful and colorful way for the campus area to help ease storm water problems and to incorporate natural processes to help relieve flooding and pollution. Rain gardens are one of the simplest ways of storm water treatment. However, research needs to be done on what Icelandic soils and vegetation are suitable.

3.4.2 Proposals

Creating a rain garden is a relatively simple process. It requires disconnecting downpipes from roofs and adding an impermeable canal diverting runoff water to the rain garden or in the case of draining parking lots, the curbstone needs to be adjusted. There are several places that are suitable for rain gardens on the University of Iceland campus area. One possible location for a rain garden is the depression between VR2 and VR1 which could collect runoff water from the walking paths and roofs (Fig. 29, bottom left). Another location is by the southern part of VR2, next to the parking lots and could collect runoff water from them (Fig. 29, top left). A rain garden can also be constructed on the site west of Háskólabíó. There is a big green area and the rain garden could collect runoff water from the parking lot next to Háskólabíó but also from the roof (Fig. 29, top right). Rain gardens do not require a lot of space. Next to Raunvísindastofnun is a small lot where a rain garden could be put. The rain garden could collect the runoff water from the roof (Fig. 29, bottom right).

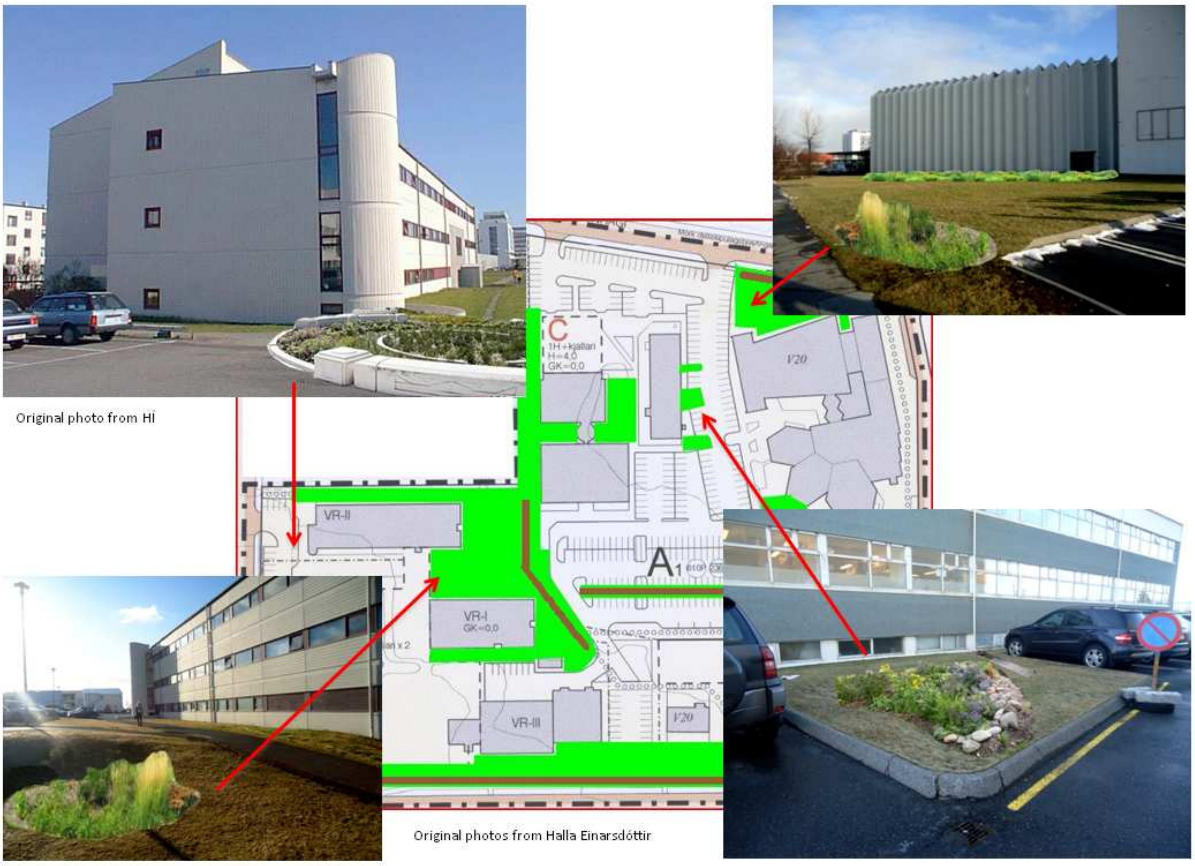


Figure 29: Proposed locations for rain gardens at University of Iceland Campus

There are more possibilities with rain gardens than just to plant vegetation. An idea is to put benches around the garden like shown on Figure29, upper right corner. That could make the garden even more beautiful, draw attention to the garden and people could relax sitting on the benches.

3.4.3 References

Dalen, D. (n.d.). *Hydrologic performance of rain garden in cold climate.* Poster, NTNU.

Muthanna, T. M. (2007). *Bioretention as a sustainable storm water management option in cold climates.* Retrieved March, 9 2012 from http://ntnu.diva-portal.org/smash/record.jsf?pid=diva2%3A122211

Rain Garden Design Templates. (n.d). *What is a rain garden.* Retrieved Mars, 6 2012 from http://www.lowimpactdevelopment.org/raingarden_design/whatisaraingarden.htm

Rain Garden Network. (n.d.). *A Rain Garden is....* Retrieved Mars, 6 2012 from http://www.raingardennetwork.com/

3.5 Water reuse

Progressing toward sustainable use of water on campus involves implementing the “3R”: **Reduce, Reuse and Recycle**. Linking the first 2 together on the issue of stormwater can be made easy by integrating collection and reuse: instead of using freshwater, stormwater can be removed from the sewage system and integrated for everyday use.

3.5.1 Different methods to collect/use water

Once the drains have been disconnected from the roofs and parking lots, the runoff water can be used for many applications: injected in the toilets to supply toilet flushing, used for irrigation of greenhouses or used for its aesthetic values, e.g. in fountain or ponds.
The amount of collected water and the quality of the stormwater will be decisive in determining the potential uses of the water. Reclaimed water, reject water and/or blow-down water can be integrated into certain systems with appropriate care.

Supplying water for toilet flushing is an option that reduces the demand and may lead to operational cost savings.

Figure 30: Toilet flushing for reusing stormwater

Ponds and fountains are another option, which both would improve the aesthetics and could help decrease the pollution in stormwater, as discussed in Chapter 3.2.

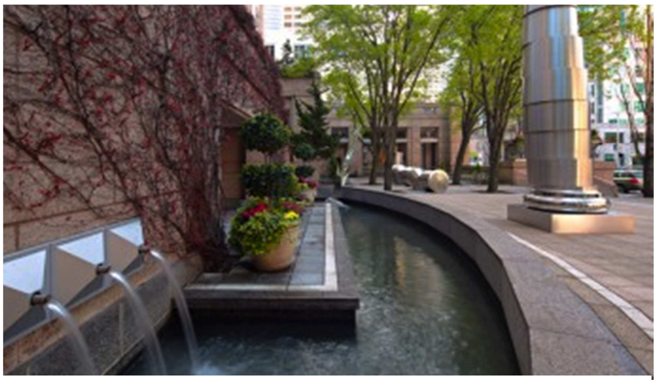


Figure 31: Fountains for reusing stormwater

Another option of potential interest in Iceland, is greenhouse irrigation. This method is, however, restricted with the quantity and quality of the stormwater. As discussed in Chapter 2.4, runoffs from roofs and parking lots can be polluted and not suitable for every use. Parking lots runoffs for instance, can be filled with sediments and heavy metals. Roof runoffs are usually "cleaner", yet the heavy metal concentration can be similarly high. Birds fooling and bacteria can be also present. Therefore, untreated runoff water is not suitable for greenhouse and food production, as pollutants would be accumulated in the vegetables.

Figure 32: Stormwater reuse in greenhouses.

More ideas on water re-use options are discussed in Appendix A

3.5.2 Proposal

Being unsafe for replacement of freshwater, untreated stormwater can be used for its aesthetic values, for instance in ponds, fountains or water walls. However even if the entertainment qualities of such systems are undeniable, they are nothing but a mean for water to be transported to another place or stored, and might not help reaching the sustainable goals set up by this university. Therefore, in this section the proposed reuse for the University Campus roof water is for flushing toilets. In principle, this consists of redirecting the water from roofs and collecting it in tanks. This tank will supply toilets by pumping the water in flushing tanks instead of freshwater. It will be the best way to save water and it is explained later inn future perspective saving money.

There are two ways of implementing this concept: each building having its own tanks, or having one massive tank for the whole area. These two approaches got their own advantages and disadvantages. Having a common tank for instance allows for better planning and monitoring of the water used overall, and makes it easy to switch back to freshwater use in case of drought. However such a method is harder to implement, as it will involve heavy construction in order to place the tank and the piping required. Individual tanks on the other hand, are pretty easy to implement and require little adaptation. A case by case study is however necessary in order to compare the water available with the needs.

Taking the example of VR-II, the surface of the roof allows for a stormwater collection of 600 m^3, compared to a consumption of freshwater little over 2000 m^3 per year (Bjornsdottir, S. and Rousseau, Y., personal communication, March 7, 2012). Even considering that only a portion of that freshwater is actually used to flush toilets, it is unlikely that the roof of VR-II will enable collection of enough water to supply its toilets all year long. However, the whole existing roof area West of Suðurgata can collect up to almost 6000 m^3 per year (see Table 1, Chapter 3.3.3). Figure 33 compares the runoff water available for collection all through the year with the average water use for toilets. It is shown that the use of 50% of the runoffs from roofs West of Suðurgata should supply the necessary water for 1000 students and staff flushing twice a day.

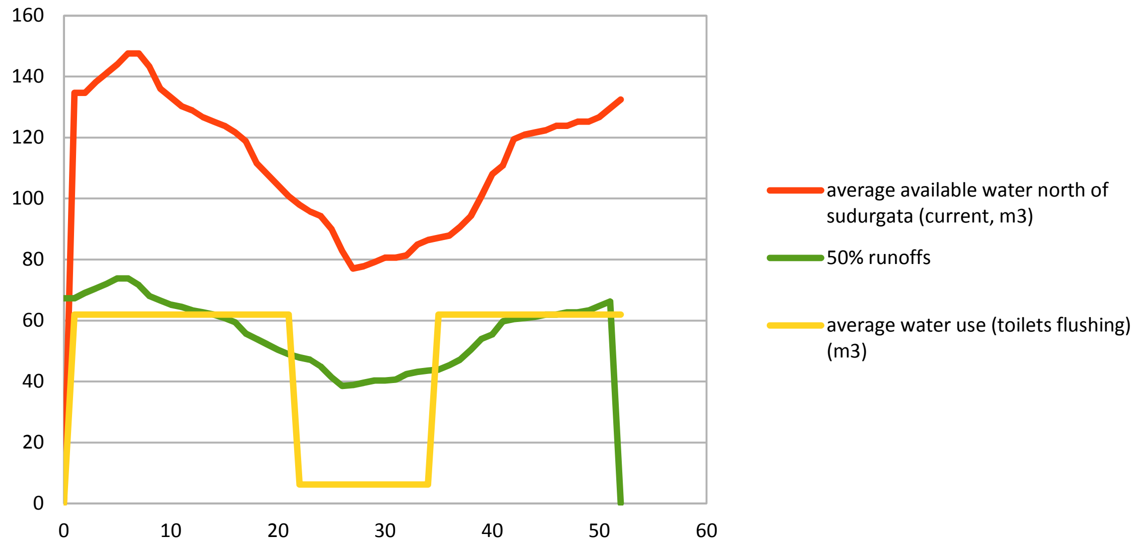


Figure 33: Comparison between available stormwater and average water use.

Another argument in favor of using runoff water for toilet flushing is an economical one. Till the end of the 1990s wastewater was untreated in Iceland (EEA, 2010). 50% of the population is still not connected to wastewater treatment, and treatment consists quasi exclusively of primary treatment.

In Sweden, the price of water treatment adds 14SEK/m3 (SWWA, 2000), that is over 250 ISK per m3. (1SEK ~ 18.2 ISK) At the moment, water pricing in Iceland doesn´t account for consumption and treatment knowing the high supply, quality and abundance of freshwater resources in Iceland. But if Iceland were to follow the European Urban Waste Water Treatment directive, the cost of water would sensibly increase, probably around 500ISK/m3. Economical factors should be taken into account when dealing with sustainable use of water.

3.5.3 References

European Environmental Agency (2010). Changes in wastewater treatment in Northern European countries between 1980s and 2006. Retrieved from http://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment/urban-waste-water-treatment-assessment-2

Swedish Water & Wastewater Association (2000). Facts on Water Supply and Sanitation in Sweden. Retrieved from http://www.svensktvatten.se/Om-Svenskt-Vatten/Om-oss/In-English/

4 Conclusions

Urbanization alters the natural hydrological cycle. Conventional methods, focused on collecting all runoff and transporting it away from the source in underground pipe systems, reduce the groundwater recharge and may contribute to the drying of wetland and ponds. The latest trend in stormwater management is to collect the runoff on site and using it locally.

This report compiles local information on the University of Campus and possibilities of implementing Blue-Green solutions. It finds that many blue-green solutions may be suitable for the University of Iceland campus. Light weight green roofs can be added to existing buildings and more extensive green gardens can be designed for new buildings. Green roofs reduce the runoff of rainwater, trap and filter pollution and reduce heating cost. Swales can be used to treat and transport runoff water to different locations on site. Runoff can be temporarily stored and treated in ponds and rain gardens, before being redirected to natural wetlands such as Vatnmýrin and Tjörnin. Such ponds and gardens will improve the aesthetics of the Campus, while also improving biodiversity. Another option is to collect the roof water, store it in tanks and re-use it for flushing toilets. The reuse of water will reduce the magnitude and costs of delivering pure drinking water to the University. All these projects will provide field research laboratories for the University to generate new knowledge and technical expertise in Blue-Green stormwater solutions.

In the coming years, new buildings are to be constructed on the University campus. These new constructions provide a golden opportunity to re-think the stormwater management on the site and implement some of the Blue-Green solutions suggested in this report.

The University of Iceland is an institute aimed at forging the mind of the future generations. Hence it is important for the University of Iceland to assume its role of leader and face the challenges of today in order to prepare the future generations to prevent the ones of tomorrow. By implementing blue-green solutions to all new and existing buildings, the University of Iceland sends out a clear signal that it is a leader in sustainable development.

5 Appendix A

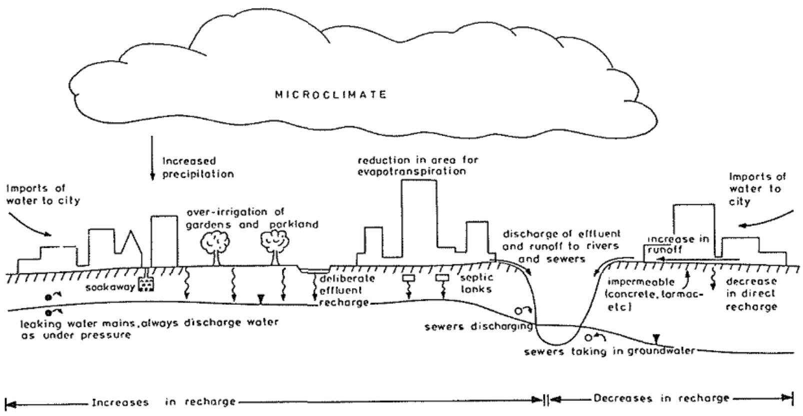
This section summarizes preliminary literature review work done on the following blue-green source solutions.

- Groundwater recharge possibilities
- Collection and reuse of runoff water

Groundwater recharge possibilities

Urban hydrology cycle

Urbanization changes the natural hydrology cycle. Those changes are in the frequency, volume and quality of the groundwater recharge. Cities are modifying the natural recharge mechanisms and introducing new ones. A big issue occurring measuring the changes in the recharge is the time needed to affect the aquifer. In general aquifers react slow to external changes or factors, hence the changes due to urbanization cannot be seen directly after conducting the action. (S.S.D. Foster 1990)



Sketch 1.1 - urban hydrology cycle

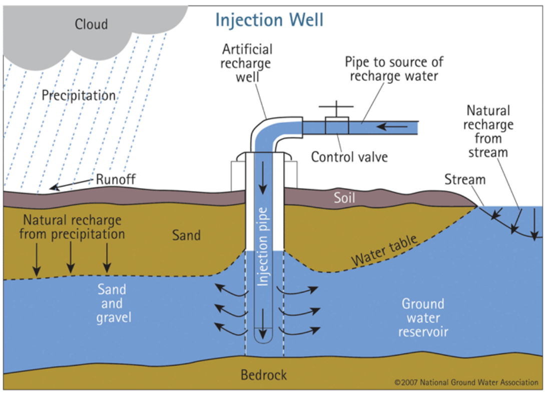
The concept of rainwater harvesting involves the tapping of the rainwater where it falls. A major amount of rainwater ends up as runoff into the sea. An average of 8 to 12% of the total rainfall is actually recharging the aquifers.(Sharma 2009)

The following chapters discuss different techniques to increase groundwater recharge. At then end, the benefits and weeknesses are evaluated, followed by a discussion on the implementation in Iceland.

Technological solutions

Roof top rain water harvesting

This approach uses the areas of roofs to collect rain water. The outlet of the storm water pipes from the roof top have to divert the water to existing wells/tube or designed recharge wells (Picture 2.1).



Picture 2.1 - injection well

(http://www.ngwa.org/Fundamentals/hydrology/PublishingImages/injection_well.gif)

Park type structures (Infiltration basin)

In urban areas parks are common and hence they can be utilized for ground water recharge. To maximize the amount of collected water, the park is excavated in a basin type depression. The collected water can be recharged through recharge wells or a pit depending on the geological formations found. The depth of the excavation of the park area is chosen that the ratio of the slope is 8:1 in the collector basin and 4:1 in the recharge basin (Sharma 2009). Pollutants like TSS are removed by 85%, TP by 85% and NO_3 30% (State of Pennsylvania 2006).

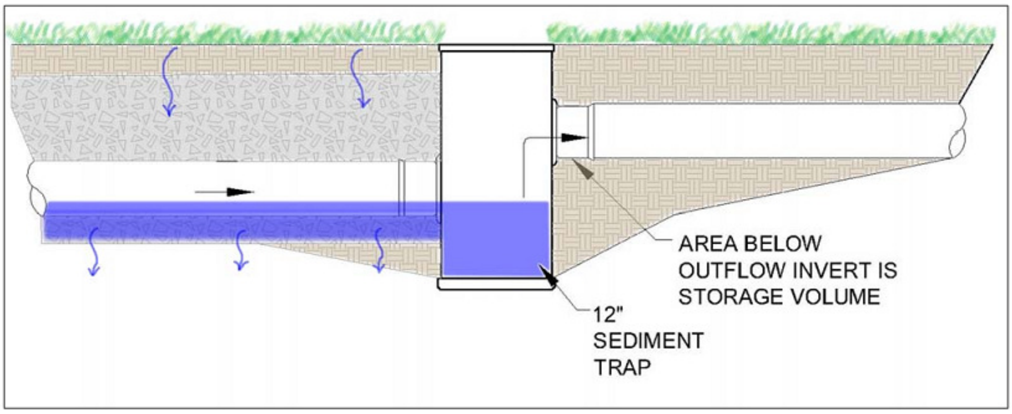
Picture 2.2 - Infiltration Basin (State of Pennsylvania, 2006)

The following characteristics of the aquifer are needed for a basin recharge operation (Sharma 2009):

- A minimum of ~18 m depth to the groundwater is required to allow for the geo-purification process, before the water hits the groundwater level.
- The unsaturated zone must realize an infiltration rate not less than 0,25 m/day
- The saturated zone transmissivity and porosity have to be high (effective porosity >0,1 and transmissivity >500m³/day). If those values are not adhered to, water can mounting below the basin bottom and can lead to a decrease in infiltration rate and recharge capacity
- Do not install on recently placed fill (<5 years)
- Allow 3 ft buffer between bed bottom and seasonal high groundwater table and 2 ft buffer for rock

Infiltration Trench

Infiltration trenches are shallow excavations that are filled with certain materials to create an underground reservoirs for stormwater runoff. Infiltration trenches require pretreatment of stormwater in order to remove as much of the suspended solids from the runoff as possible. Sketch 2.4 is showing a typical trench constructed with a perforated pipe in a stone-filled trench. After the state of Pennsylvania trenches are in general part of a conveyance system, so that large storm events are conveyed through the pipe with some run off reduction. (State of Pennsylvania, 2006)



Picture 2.3 - infiltration trench with perforated pipe

The following key designs have to be considered:

- Minimum cover over pipe is 12-inches
- A minimum of 6" of topsoil is placed over trench and vegetated
- Limited in width (3 to 8 feet) and depth of stone (6 feet max. recommended)

Recharge from mega urban structures

Roads or other huge areas with concrete are preventing natural recharge to take place. Caused by a high runoff coefficient they generate a large amount of runoff. Especially from roads a lot of rain water and so potential ground water get lost through storm water drains. To harness this runoff, shafts or trenches are constructed with recharge wells along the road (Sharma 2009). The spacing between them is chosen regarding the amount of runoff. Going by S.K. Sharma (2009) the spacing lays in between 100 to 300 m.

As the runoff will consists a lot of sand or clay, a construction like de-siltation chambers are recommend. The main advantage of trenches is that they can be used for a large area with a great amount of runoff (Sharma 2009).

Water bodies using recharge shafts

Ponds and lakes can be used for the storage of rainwater, by using recharge shafts excess water can be recharged into the ground so that just a minimum water level stays back in the lake or pond. Before those water bodies can be used for recharge to ground water, it is important to clean the ponds and silt removal from the bottom of the ponds.(Sharma 2009)

Sewerage and waste water recharge

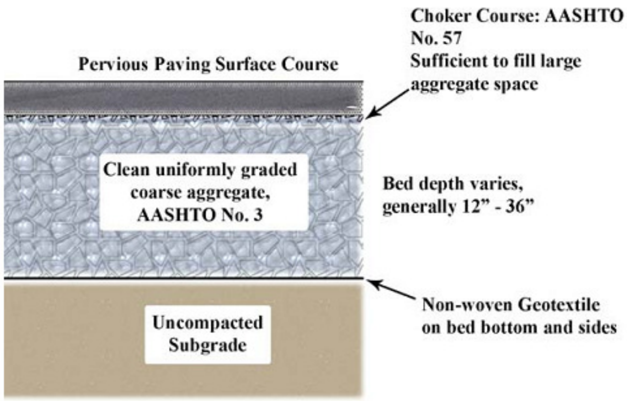
Where soil and groundwater conditions are favorable, treated waste water can be allowed to infiltrate the soil and recharge the groundwater. In this process (Soil-Aquifer Treatment [SAT]) the unsaturated zone acts as a natural filter and can remove suspended solids, biodegrable materials, bacteria, viruses and other microorganisms. Significant reductions in nitrogen, phosphorus and heavy metals concentration can be achieved by using this method.(Sharma 2009)

Permeable materials:

Based on the SAT process permeable materials in road or pavement construction can help increasing the groundwater level. By going through the natural process of water purification contaminants associated with air pollution particles, spilled oil, detergents, fertilizer,.. can be controlled. (State of Pennsylvania, 2006)

Porous asphalt/pavements

The only difference between porous and usually used asphalt is that the formula for the paving material changes. Porous paving's consists of a permeable surface, which is underlain by a uniformly- graded stone bed. Due to lower load bearing capacity than conventional pavement, permeable paving is not ideal for high traffic/high speed areas. 85% of TSS, 85% of TP and 30% of NO_3 is removed through the filling materials used. (State of Pennsylvania, 2006)



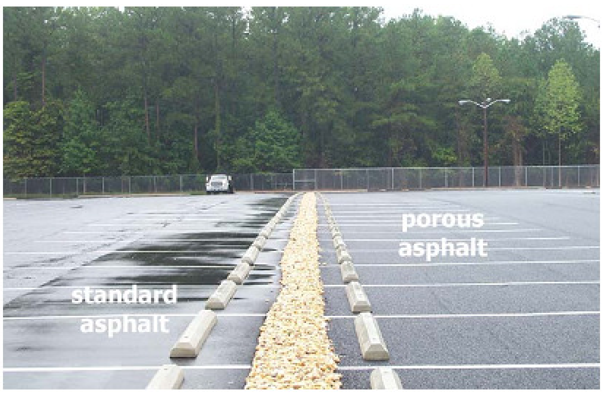
Picture 2.4 - Cross-section permeable pavement

The following key designs have to be considered:

- not recommend for traffic surfaces with slope >5%
- Protect from sedimentation while construction
- Allow 3 ft buffer between bed bottom and seasonal high ground water table and 2 ft for bedrock

Porous Bituminous Asphalt and Porous Concrete:

Porous asphalt is standard asphalt with reduced fines, therefore it is similar in appearance to standard asphalt. It is suitable for all constructions were normal asphalt is used.



Picture 2.5 - standard asphalt vs. porous asphalt

In contrast to porous asphalt the appearance of porous concrete has a coarser appearance than it's conventional counterpart. While placement is it necessary to avoid working the surface otherwise the permeability is lost. (State of Pennsylvania, 2006)

Picture 2.6 - standard concrete vs. porous concrete

Maintenance: All permeable materials introduced have to be prevented from fine sediments which lessen the permeability (e.g. by vacuum cleaning).

Benefits achieved by groundwater recharge

Environmental and Water Resources Institute and American Society of Civil Engineers (EWRI-ASCE) (2001) list many objectives that can be fulfilled by implementing artificial groundwater recharge:

The groundwater table can be increased which would result to stable, reliable and clean drinking water supply. Groundwater quality can also be increased due to filtering effect of the soil.

Recharging the aquifers can also be an efficient way to store water for seasonal, long-term or emergency storage.

It can also be used as a way to distribute water from the recharge site to the site where it is pumped to the surface for use, thus saving in expensive water distribution and pumping systems.

By inserting groundwater recharge wells to the seawater barrier, groundwater supply can be protected from mixing of the sea and fresh water.

Water quality in the final destination; rivers, ponds, lakes and seas increases when rainwater is filtered through layers of land. This leads to better habitat for fish species and wildlife, as well as to plants and trees.

Weaknesses of groundwater recharge method

Cases where groundwater quality is tried to increase by filtration through the soil can be problematic because of unknown long term effectiveness of the filtration. Also filtration design is hard because of strict laws when it comes to the ground water. Large amount of data has to be collected conserning the water supply and demand on the area. The location and the flow of the ground water, the height of the table and soil types on the recharge area has to be studied to be able to estimate the effect of the recharge. This information can be expensive or hard to obtain. (EWRI-ASCE, 2001)

According to Jiang Li (2011) groundwater recharge is linked to many geological hazards. Land subsidence, sinkholes and ground failures have been happening on the areas where groundwater level is changing due to over exploitation and recharge. Earthquakes are also triggered due to bad groundwater management design.

Maintenance of the groundwater filtration system can be expensive and even hard to execute, and if the groundwater recharge area has privately owned properties it can be hard to control the maintenance. Open filtration system has to be cleaned from silt and contaminants annually. It can be hard to exclude an area with undesired surface-waters from the groundwater recharge area so that the waters from that area would not inject the system. If there is no need for groundwater recharge or if the recharged amounts are small, the system is not economically feasible. (Amartya K. Bhattacharya, 2010)

Implementation to Iceland

According to European Environment Agency (EEA) (2011),

> "Over 95% of Iceland's drinking water is untreated groundwater extracted from springs boreholes and wells. Surface water constitutes around or less than 5 % of Iceland's drinking water. Surface water used for drinking is obtained from mountain lakes and from river basins. The freshwater resources are estimated to be around 170 000 million m^3 of which 6 000 million m^3 of groundwater are available for extraction."

Thus we can say that Icelandic groundwater resources are large, affluent and there is no need to recharge the resources. Icelandic lava stone cold be considered to be very good aggregate for open system filtration, thus making the implementation of open systems less expensive. Groundwater recharge could be implemented for residential areas to introduce clearer water to lakes, rivers and to the sea through the soils. This could also reduce the wastewater load of the treatment plants or prevent treatment plants in small villages.

References:

S.S.D. Foster 1990, Hydrological Processes and Water Management in Urban Areas, IAHS Publ. no. 198

S.K. Sharma 2009, Proposal for groundwater recharge in national capital region (NCR), Delhi, India

State of Pennsylvania, 2006, Pennsylvania Stormwater Best Management Practices Manual, DEPARTMENT OF ENVIRONMENTAL PROTECTION Bureau of Watershed Management.

Bhattacharya, Amartya Kumar, (2010), *Artificial Ground Water Recharge with a Special Reference to India*, Bengal Engineering and Science University

Environmental and Water Resources Institute & American Society of Civil Engineers (EWRI-ASCE), (2001), *Standard Guidelines for Artificial Recharge of Ground Water,* American Society of Civil Engineers, Reston, Virginia, USA

European Environment Agency (EEA), 2011, *Freshwater Iceland*, Accessed online: http://www.eea.europa.eu/soer/countries/is/soertopic_view?topic=freshwater

Li, Jiang & Sheng, Zhuping, (2011), *Groundwater Management Practices/Geological hazards due to groundwater pumping and/or artificial recharge,* CRC Press, London, UK

Collection and reuse of runoff from roofs

Stormwater runoff from roofs is normally collected in roof gutters and downpipes and led to the public stormwater system in the street. The sewer system for the University Campus is a combined sewer (Borgarvefsjá) that collects sanitary sewage and stormwater runoff in a single pipe system. The combined sewer goes through a primary treatment plant and is then discharged to the sea in Faxaflói.

Runoff from roofs is relatively clean compared to other sources of stormwater and is therefore the most feasible for reuse. Other sources, particularly runoff from streets may be too polluted and require special treatment. There are some concerns about the water quality, a possibility of heavy metals and fecal bacterias from bird droppings. The first few litres of runoff during a rainfall event, the "first flush" appear to be the most heavily polluted (Exall et al, 2004). Since precipitation is frequent in Iceland the first flush should not be very polluted.

By disconnecting runoff from roofs from the traditional stormwater system the danger of overflow during rainy periods becomes less. The waste water going to the treatment will be of less volume. Using 800 mm average annual precipitation in Reykjavík (Vilhjálmsson, 2002) and an estimation of 13.000 m^2 current surface area of the University buildings west of Suðurgata the roof runoff is approximately 10.400 m^3 annually.

Where there is an establishes lawn the simplest way to disconnect runoff from roof is cutting off the downpipe near the ground and divert to the lawn. To prevent the water from reaching the foundation of the building an impermeable canal should be installed to carry away the water at least two meters from the building. From the diversion canal the water is spread to grass areas where it infiltrates. As a rule of thumb, the infiltration area should be at least twice as large as the connected roof area. Potential excess water that will not infiltrate can be taken care of by installing a sub drain connected to the storm water system (Stahre, 2006). Beware of erosion of grass and stagnant pool in depressions.

Although Iceland has abundant water sources we should use it wisely by giving rainwater runoff a second run. Collecting water for campus use has some options, for example: irrigation, fire protection, toilet flushing, ornament fountains, impoundments and with cleansing of the water giant fish tanks and even public showers.

Instead of collecting storm water runoff from roofs and put it into the sewage system it would be possible to collect the water together in one place and exploit it. It could, for example, be used for irrigation in greenhouse. All storm water runoff from roofs on campus would be collected in one place, for example by leading the water in rhine or open trenches. To make the campus more sustainable it would be possible to set up greenhouse and have local production of food. Harvest could be sold in Háma and other canteens on campus. The stormwater runoff from roofs is more nutritive than the water that comes out of taps and can therefore be good for vegetation growth.

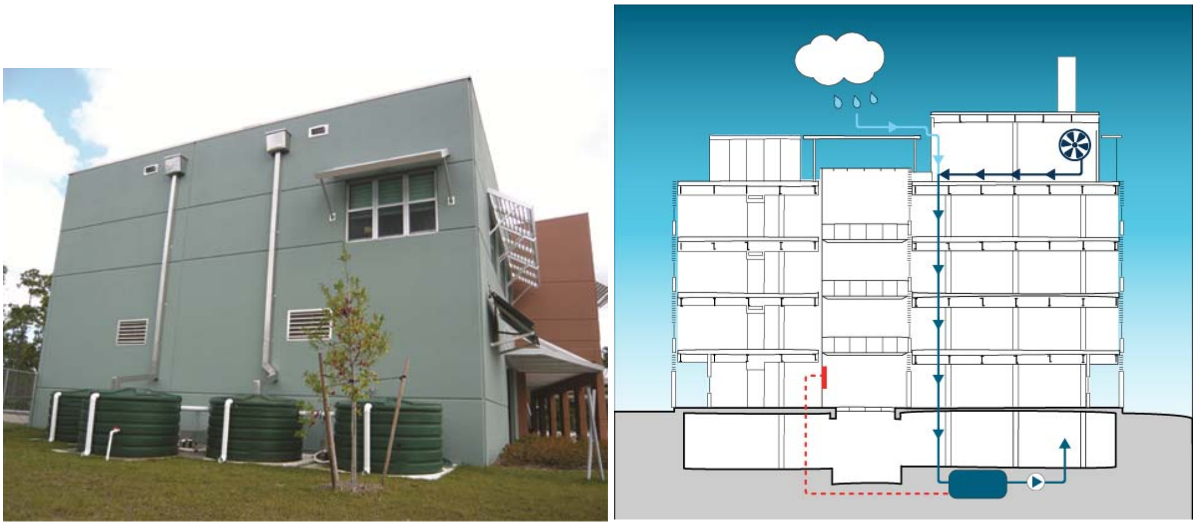


Figure 1: Example of roof collection system used for toilet flushing

Figure 2: Examples of recreational reuse

However, the water would need to be treated before it could be used, e.g. with filter, especially if the water was used directly to irrigate vegetable or fruit, but not required if it was used to irrigate the ground (EHow, n.d.).

Use of collected water for fire protection and toilet flushing leaves higher quality water available for other purposes. The rainwater is collected on building roofs and stored underground in a cistern where it is treated and reused for toilet flushing. The level of treatment has to be decided by checking the quality of the water, is bypassing the first flush enough? If 6 litres are flushed every time in a single toilet flush the roof runoff of VRII would cover 430 flushes per day using average annual precipitation. An assessment should be made of how much water is needed to decide the size of the cistern. If there is not enough rain water available the normal flush water will be used. The collected water could also be used for the fire protection system. A further possibility is to give wastewater from sinks another life circle in the new toilet flush fire protection system. The pipe system would have to be changed and therefore this would be easier to carry out in future buildings.

To decorate the University Campus runoff water could be led in small surface streams through ornamental fountains. One idea is to have the rain water flow through loops in see-through pipes down a building wall for example for the building of sciences. This could also be inside, then people would be aware of the reuse of water and also use it to follow the weather. Having the down pipes in bright colours would also draw bypassers attention to the reuse of water.

Another option to use storm water runoff from roofs would be to collect the water together in one place and create a small pond. As before, the water would be lead to one place in rhine or open trenches. One option would be to have a small pond in the campus area above Suðurgata. Water from that pond could then be piped down to the pond in Vatnsmýri. That would increase the water flow in the pond in Vatnsmýri. Water from the pond in Vatnsmýri could then be piped down to Tjörnin, the pond in Reykjvík, which would increase the water flow in Tjörnin. To little water flow has been a problem there. It would probably be hard to lead the water aboveground across Suðurgata so it would be lead in pipes down to the pond in Vatnsmýri.

With treatment of the water a giant fish tank could be filled with runoff water, for example on the glass wall of Askja.

Another idea to use storm water runoff from roofs would be to make outdoor shower. There are ideas about make sport areas on the campus. For example make a field to play basketball, football or volleyball and even a skating rink. It would be good idea to have outdoor shower by this facilities. The shower would need to be in some kind of shed with walls and roof and it would need to be divided into cubicle for men and women. People could use these showers after playing sports. It is though obvious that this would not be used all year around. It would need to be closed during the winter, from oct/nov to ap/may. System to heat up the water would probably be required and also a system to clean the water.

References

City of Reykjavík. (n.d.). *Borgarvefsjá*. Retrieved February 20, 2012 from http://lukr-01.reykjavik.is/borgarvefsja/.

EHow. (n.d.). *Is it safe to use roof runoff for a vegetable garden?* Retrieved February 20, 2012 from http://www.ehow.com/facts_7905331_safe-roof-runoff-vegetable-garden.html

Exall, K., Marsalek, J. & Schaefer, K. (2004). *A Review of Water Reuse and Recycling, with Reference to Canadian Practice and Potential: 1. Incentives and Implementation. Water Quality Research Journal of Canada: Volume 39, No.1. p. 1-12, 21-23*. Retrieved February 20, 2012 from: http://www.cawq.ca/journal/temp/journal/3.pdf#.

Hollustuvernd Ríkisins. (2002). *Val og hönnun minni vatnsveitna, p. 7.* Retrieved february 22, 2012 from http://www.mast.is/Uploads/document/itarefni/Val_og_honnun_minni_vatnsveita_08.09.02_SH.pdf

Stahre, P. (2006): *Sustainability in Urban Storm Drainage. Svenskt Vatten. ISBN 91-85159-4*. Retrieved February 20, 2012 from http://www.svensktvatten.se/Medlemmar/Vattenbokhandeln/.

Vilhjálmsson, Þ. (2002). *Hve mikið rigningarvatn kæmi á ári að meðaltali af hallandi þaki sem er 100 fm?* Vísindavefurinn. Retrieved February 20, 2012 from: http://visindavefur.hi.is/svar.php?id=2475.

Vísindavefurinn. (2007). *Hvort notar maður meira vatn í sturtu eða baði?* Retrieved february 22, 2012 from http://visindavefur.hi.is/svar.php?id=6582

Innovation Project Part 2.1: Research of individual source control solutions Natural Water Treatment Solutions

Yannick Rousseau, Miren Telleria Ajuriaguerra, Karl Róbert Gunnarsson

Introduction

As weather events such as floods and droughts become increasingly frequent, the importance of water management rises. In particular, as freshwater literally falling from the sky, stormwater presents a double-edged sword: how to manage it without wasting it or being flooded? Necessary for the regeneration of groundwater and expansion of wildlife, stormwater is often disregarded and unused. But how to make the best of it? How to integrate it in an efficient and sustainable use of water resources?
This paper focuses on stormwater treatment, its different faces and their relevance to water management in Iceland: unused, not only are we wasting a valuable resource, but polluting it. Runoffs from roads and other surfaces collect heavy metals, hydrocarbons, oils and other micro and macro pollutants (American Rivers, 2008). How to integrate stormwater catchment and treatment facilities in urban environment?

1) Main techniques of stormwater treatment.

Unlike wastewater, stormwater is usually preferred to be treated on site, as its pollution is usually lighter, and the treatment facilities can easily be integrated in the environment (American Rivers, 2008). For that matter, there are 4 main techniques used and implemented:

- *Bioretention & infiltration basins*: It is less a specialized method than a general concept. A depression is filled with sand or other soils conductive to infiltration, on which plants and shrubs are planted. Water is filtered both by the bedding material and plants roots before infiltrating into groundwater sources. The retention area must cover at least 5% of the surface to drain (American Rivers, 2008), and located at the lowest point of the runoff area to efficiently drain the water. Retention is not recommended for areas with a slope superior to 20%, or with groundwater less than 1.8m from the surface (EPA, 1999). Plants and soil types are function of the chemical composition of the water to drain, as well as to minimize maintenance (mostly leafs and branches removal). Soils must be chosen so to allow for infiltration rate greater than 2.5cm/h and their pH to range between 5.5 and 6.5 to favour micro-organisms growth, necessary for decay of hydrocarbons and fats (EPA, 1999).

- *Filter strip*: a path of water covered with specific (pollutant absorbing) vegetation is placed on a slope between the runoff area and the stormwater collection site (bassin, infiltration, river, …). A pea gravel should be located on top of the slope, in order to pre-treat the water by collecting sediments and litter/trash, as well as to ensure a regulated flow to the strip (EPA, 2006). Slope of the latter must be between 2 and 6 %, to ensure minimal flow while allowing water to be efficiently filtered; length of vegetated strips is required to be at least 8m long to have any effect.

- *Urban trees*: a specific method of bioretention, involving the growth of native trees as the draining/filtration agent.

- *Filters*: downstream of a catchment (basin, swale, pound, …) filters are biomechanical systems which reproduce and condense the effects of bioretention. Unlike the latter, the water is not infiltrating in the ground (although it can be), but collected to an outlet for posterior use. Filters size vary on the chemical composition of the water to be treated, ranging from units smaller than 40 cm in diameter up to 3-4m wide basins (Washington DoE, 2011). They are used in runoff areas where the water is concentrated in a flow (stormwater inlet).

2) Benefits and weaknesses

All of methods mentioned can be used only with low to moderate levels of pollution. As such, they cannot be located around industries, where the potentially heavy pollution of stormwater cannot be fully removed and lead to contamination of the groundwater (American Rivers, 2008). They however are relatively efficient to reduce heavy metal, hydrocarbons, nutrients and bacteria pollution.

Most of these methods are cost effective, and require little investment. The major exception for this are filters, since most are proprietary, patented systems. Integrating bioretention basins in heavily urbanized areas can add to costs as well, as it induces working on building materials (concrete, asphalt). Size of the different vegetated patches is an important factor, as directly linked with the amount of water that can be treated and the efficiency of pollutants removal (EPA, 2006). Smaller vegetated filter strips in particular have a very low efficiency and should be avoided in areas where density is an issue. The efficiency is also linked to seasonal variations (except for some filters) as during winter the absorption capacities is drastically reduced.

The aesthetic value of the different options is undeniable, but vegetated areas might require some low maintenance, both to keep the scenic qualities, not getting invaded by vegetation (branches blocking pathways for instance) and prevent clogging of the filters/retention areas with sediments (EPA, 1999; Washington DoE, 2011).

The advantages of vegetated patches go beyond simple treatment, as vegetation massively decreases risks and damages due to flooding, protects soils from erosion and impoverishment of soils (UNFD, 2010). Trees planted in the aim for bioretention also have a carbon sequestrating capacity, and as such can be included in countries mitigation process under LULUCFs agreement of the Kyoto Protocol (UNFCC, 2008).

3) Relevance to Iceland

The main problematic aspect of bioretention and vegetated filters strips for Iceland is the climate. A long winter reduces the growing period for plants, thus lengthening the time before efficiency of the patch is attained, as well as reduces absorption capacities when vegetation is dormant (American Rivers, 2008). Introduction of non indigenous species can be an issue since tree/bush diversity is low compared to other areas (UNFD, 2010). For that matter filters could be a preferable, more efficient option.

However, as noted before, the added effect of helping against erosion and carbon mitigation are important factors that should be kept in mind in a country facing these 2 major challenges.

Conclusions

Treatment of stormwater can easily be integrated in urban planing, as it requires minimal adaptation and add aesthetic qualities to the land. In Iceland, especially in cities, a mix of different treatment solutions would be both easier to implement and more efficient, as the country faces challenges from natural and man made conditions.

References

American Rivers (2008). *Catching the Rain : A Resource Guide for Natural Stormwater Management in the Southeast*. American Rivers publication. Retrieved from http://www.americanrivers.org

United Nations Forestry Department (2010). *Global forest resources assessment country report - Iceland*. United Nations Report for the Food and Agriculture Organization.

United Nations Framework Convention on Climate Change (2008). *Kyoto protocol reference manual : On accounting of emissions and assigned amount*. UN guidance document.

United States Environmental Protection Agency (1999). *Stormwater Technology Factsheet – Bioretention*. EPA publication.

United States Environmental Protection Agency (2006). *National Pollutant Discharge Elimination system*. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Washington State – Department of Ecology (2011). *Conditional use level designation for basic (TSS) treatment - models with stormfilter cartridges*. Private submittal report. Retreived from http://www.conteches.com/Products/Stormwater-Management/Treatment/UrbanGreen-BioFilter.aspx

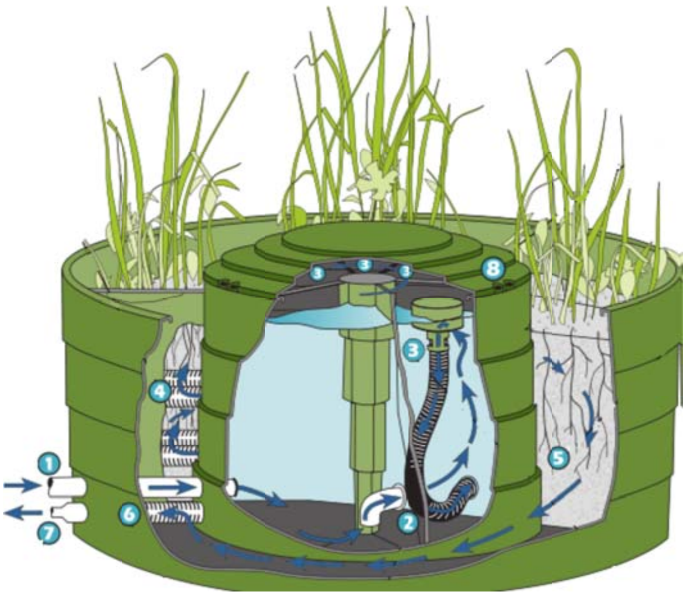


Figure : Example of Filter with bioretention