Impediments and steps taken towards Green Infrastructure for stormwater management in Hamburg, Germany

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1 Introduction

With climate change, we are facing generally higher amounts of rain and extreme precipitation during storm events and therefore increased risks of flooding (Trenberth 2011, Sarhadi & Soulis 2017, Stott 2016, Nickel et al. 2014). At the same time, more than half of the worlds population lives in cities, and it is expected that this number will grow by another 2.5 billion people in 2050 (UN 2014). This increase in urban settlement generally comes with a corresponding increase in impermeable surfaces through congestion and urban sprawl (Scalenghe & Marsan 2009, Brabec et al. 2002). Further sealing of the earths surface gives those rainwater masses less opportunity to infiltrate the ground and replenish ground water levels (Howard 2002, Brabec et al. 2002, Gill et al. 2007). Today's sewage systems, with often ageing infrastructure, either carry combined or separated waste water, towards treatment and/or directly to water bodies (Nickel et al. 2014). The aforementioned factors of extreme precipitation and an increase in sealed surfaces put additional stress on the sewage systems in place (Pucher et al. 2018). The resulting combined sewage overflows (CSO), as well as directly conveyed stormwater lead to pollution of receiving waters (Nickel et al. 2014, Barbosa et al. 2012).

One strategy, several governments are adopting for mitigation of stormwater runoff volume is the development of green infrastructures (GI) like swales, rain gardens, porous surfaces or also green roofs (Nickel et al. 2014, Fletcher et al. 2015, Gill et al. 2007), one of them being the City Hamburg in Germany. The city Hamburg, with 1.8 million inhabitants, is facing population growth of up to 0.9 million inhabitants by 2035 (Statistisches Amt Hamburg und Schleswig-Holstein 2015). Hamburg is situated around two big water bodies, the Elbe river (one of the large rivers in Europe (Stachel et al. 2005)) and Alster (164 hectare (Schafer n.d.) in size). The city of Hamburg has developed several strategies to incorporate GI for dealing with stormwater runoff. Approximately $175 km^2$ of Hamburg is considered a paved area (Bertram et al. 2015).

This essay will talk about the necessity, current implementation measures, benefits and complications of GI, using the example of Hamburg, Germany.

Though related and a big topic in water management, flooding threats that Hamburg is facing through raised sea water levels due to climate change, wont be covered in this essay.

A question that this essay is aiming to examine: If GI are such a promising tool for regenerating natural water cycles, and if the current climate change and habitation situation are in need of such innovation, how come that we are not implementing them everywhere and in fast manner?

2 Main Part

2.1 What is GI?

Green infrastructure is seen as a measure designed to prevent, slow down, and reduce stormwater runoff (Nickel et al. 2014), from both flood and non flood conditions (Hoang & Fenner 2016). This is done by using the facilitating processes of hydrology, evaporation, and infiltration (Nickel et al. 2014). Examples for GI are green roofs, bioretention swales, porous pavements, rain gardens, and stormwater treatment wetlands spread in a decentralised network across the urban landscape (Fletcher et al. 2015, Jayasooriya & Ng 2014, Montalto et al. 2007, Everett et al. 2015). The term GI is often used interchangeably with low impact development (LID) (Fletcher et al. 2015, Jayasooriya & Ng 2014). Sustainable drainage systems (SUDS) are seen as a method within GI design (Hoang & Fenner 2016), and are sometimes discussed without mentioning green roofs (Fletcher et al. 2015), and other times including green roofs (Everett et al. 2015).

2.1.1 Benefits

Besides the reason of implementation for stormwater management, GI has many further benefits. In terms of nature regeneration, GI can help to restore natural water cycles and replenish groundwater levels, sequester and save carbon, provide important habitat for wildlife, and therefore increase biodiversity in the city, and furthermore reduce the pollution of receiving water bodies (Nickel et al. 2014, Ellis 2013, Hoang & Fenner 2016). In terms of benefits of human inhabitants, GI can ease the urban heat island (UHI) effect, provide amenities for the community, and reduce costs for investment into drainage infrastructure (Ellis 2013, Hickman 2013, Brown 2005).

2.2 Hamburg City

2.2.1 Pollution

Human activity creates the main pollutants in stormwater runoff, for instance heavy metals like zinc and copper. (Dierkes et al. 2015, 2002, Lucke & Nichols 2015, Elliott & Trowsdale 2007, Barbosa et al. 2012). Further components in stormwater pollution are total suspended solids, nutrients like phosphorous and nitrogen, as well as hydrocarbons (Dierkes et al. 2015). Road traffic, as well as associated parking lots, industrial and commercial areas, all resulting from car use are seen as the main source of pollution in urban environments (Heß 2018). Pollution, as well as high peak runoff volumes, impact water quality as well as the aquatic systems balance (Barbosa et al. 2012, Nickel et al. 2014, Brown 2005).

The 1700km long rainwater network of Hamburg discharges the collected water into the surrounding water bodies (Hamburg Wasser 2019*b*). This separate rainwater network conveys stormwater directly into Hamburgs water bodies without further treatment (Hamburg Wasser 2019*b*) and can therefore be susceptible to the aforementioned pollution and is therefore an environmental hazard.

A different source of pollution occurs whenever the combined sewage system overflows at times when its capacities are exceeded. CSO's are a major cause of pollution in water bodies (Montalto et al. 2007). One quarter of the sewege system in Hamburg consists of combined infrastructure, transporting rain water, grey, and black water together towards the wastewater treatment (Hamburg Wasser 2019*b*). See Figure 1 for the distribution of drainage systems in Hamburg. Despite retention basins Hamburgs sewage system faces documented CSO when over burdened, as for example in February 2011 (Ackermann 2011).

Green Infrastructure, such as SUDS, have the ability to reduce the pollution of receiving water bodies by trapping it at the source (Nickel et al. 2014, Ellis 2013, Hoang & Fenner 2016, Dierkes et al. 2015). The implementation and choice of methodology for GI is dependent on the specific space, budget and legal situation and not per-se trivial (Nickel et al. 2014, Brown 2005).

2.2.2 The legal situation in Germany

The European Water Framework Directive (WFD) from 2000 (WFD 2000), which regulates the protection and management of both surface and groundwater, is incorporated in the German Federal Water Act (Wasserhaushaltsgesetz; WHG) (WHG 2009). The WHG prioritises the infiltration of stormwater close to source (§55, (WHG 2009)).

Furthermore in Germany, stormwater runoff is categorised by where the water is received. Stormwater that infiltrates the soil and subjacent groundwater is called "Groundwater Runoff" (GR) and stormwater runoff which is discharged into receiving water bodies is called "Surface

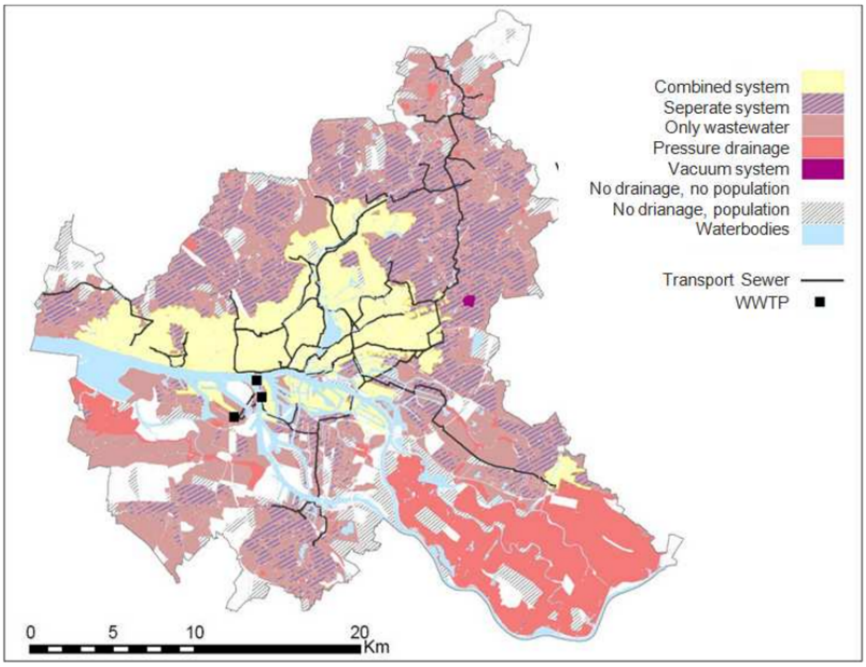

Figure 1: Spatial distribution of drainage management in Hamburg (Bertram et al. 2015)

Water Runoff" (SWR) (Dierkes et al. 2015). Any development which receives GR has to comply with the German Federal Soil Protection Law (BBodSch 1999). According to Dierkes et al. (2015), there is no current law that regulates the discharge of SWR in Germany. The German Institute for Construction Techniques (Deutsches Institut für Bautechnik: DIBt) developed a testing protocol for decentralised SUDS devices which receive stormwater runoff from streets, including the requirements set forth by the Federal Soil Protection Law (Welker 2014).

2.2.3 Risa Project

Rainwater management in Hamburg is a municipal joint task (Forssberg et al. 2014). The water supply and sewage disposal is performed by the company "Hamburg Wasser." In 2009, the "RISA" (Rain InfraStructure Adaptation) project was started by Hamburg Wasser and the State Ministry for Urban Environment and Energy (BUE) with the aim to establish a new, integrated way of stormwater management (Forssberg et al. 2014, Hamburg Wasser 2019*c*, Waldhoff et al. 2015). Besides flood protection, the other two main goals of RISA are continued water protection and near-natural local water balance (ibid.). RISA is a big project, including teams from domestic water management, town and country planning, traffic planning and water planning (ibid.). Furthermore, the project receives scientific support from universities and engineering offices (Hamburg Wasser 2019*c*). The project involves the development of an emission-potential map, done by the categorisation of emission groups (see Table 1) combined with land use typification (Waldhoff et al. 2015), for the comprehensive estimation of pollution in stormwater per area for all of Hamburg.

Table 1: Categorisation of emission groups for the emission potential map, accessed from (Waldhoff et al. 2015)

Exposure Category	Specification
Low	Green and garden spaces Courtyards and parking areas, low pollution Streets and traffic areas, low pollution Roof areas, low pollution
Moderate	Courtyards and parking areas, middle pollution Streets and traffic areas, middle pollution Roof areas, middle pollution
Heavy	Courtyards and parking areas, high pollution Streets and traffic areas, high pollution Roof areas, high pollution (metal roofs)

Table 2: Example of calculations for percentage of stormwater fee in Hamburg by how much surface area of property is sealed. Translated from (Hamburg Wasser 2019*a*)

Area	Type	Calculation
Completely sealed	Asphalt, concrete, paving (with tight gaps)	100%
Partially sealed	Grass paving, paving (open gaps > 15%), tartan track	50%
Unsealed	Gravel, sand, clay, loam, grass	0%
Normal roof	Tiles, roofing felt, metal, glas, foil, slate, fibre cement	100%
Green roof	Min. growing medium layer > 5cm	50%
Drainage system (with emergency overflow)	Several SUDS like infiltration ditches, swales or pipe infiltration systems	50%
Drainage system (without emergency overflow)		0%

2.2.4 Stormwater Fee

In earlier times in Germany, only one wastewater fee was levied, and it was calculated upon the volume of consumed potable water (Dierkes et al. 2015). Through several successful legal disputes against the old system, a separate stormwater fee was introduced, beginning in the 1970's (Dierkes et al. 2015, Keeley 2007). Hamburg belongs to the two thirds of districts in Germany who have already implemented this stormwater fee per individual parcel assessment (Nickel et al. 2014). Implementation of the separate stormwater fee was done concurrent with the RISA project (Bertram et al. 2015). The fee is calculated based upon the surface area that drains into the sewage system. The stormwater fee in Hamburg is 0,74 €, calculated per square meter of fee-relevant parcel area per year (Hamburg Wasser 2019*a*). The fee can be reduced depending on how much area of the parcel allows rainwater to infiltrate into the ground (see Table 2).

2.2.5 Green Roof Strategy

Since 2014, Hamburg City is a pioneer with its "Green Roof Strategy" (Gründachstrategie), which is considered to complement the RISA project (see 2.2.3). The aim is the greening of 70% of all new constructions aas well as building restauration with flat or 30% sloped rooftops. This program provides incentives for construction. The BUE is facilitating this strategy with 3 million Euro. The goal is to generate a 100 hectare area of green roofs by 2020, and the strategy is supported by the

(a)

(b)

(c)

(d)

Figure 2: Examples of green roofs in Hamburg, Germany. Sourced from (Hamburg.de 2019) (a) Green roof of the Generali insurance company (Foto by: E. Böhmer) ; (b) Extensive green roof on the Albertinen hospital (Foto by: Optigruen); (c) A private green roof (Foto by: Sönksen) ; and, (d) A green roof with terrace on an office (Foto by: Sönksen).

"Hafencity University" (Hamburg.de 2019). The funding is available to private and commercial sectors if certain conditions are met (see Table 3). If the growing-media of a green roof exceeds 5cm, the property owner can save 50% of the stormwater fee (see Table 2). For examples of green roofs in Hamburg see Figure 2.

2.3 Discussion

As can be read above, Hamburg City municipality has taken several measures to facilitate the implementation of GI. As Brown (2005) points out, even though a lot of development in the sector of "integrated urban stormwater management" has been made, the implementation of GI on a broad scale has yet to be done. The scientific literature delivers a few arguments that shine some light upon why GI is not yet the norm.

Table 3: A summary of the funding available for green roof constructions in Hamburg. Data is taken from (IFB Hamburg 2018) Used abbreviations for this table: Net Vegetation Area (NVA); Growing Medium (GM); Gross Collector Surface (GCS)

Private		**Commercial**	
Conditions	**Funding**	**Conditions**	**Funding**
NVA $20m^2$-$100m^2$	40% of eligible costs	NVA $> 100m^2$	basic funding 6 €/ m^2
NVA > 100%	basic funding 6 €/m^2	each cm of GM (max. 50cm)	additional 1€/m^2 NVA
max. basic funding per green roof measure is 50.000€			

Possible additional funding	
Conditions	**Additional funding**
extensive green roof combined with solar panels	100% of mounting costs, max. 5€/m^2 GCS
for increased discharge delay	50% of constructive elements up to 2€/m^2

2.3.1 Pollution

The pollution potential of surface and ground water by storm water runoff is high (Pucher et al. 2018). As explained above, GI can help mitigate this pollution potential (see 2.1.1 and 2.2.1). One problem that Hoang & Fenner (2016) raise, is the potential of pollutants trapped in GI, like bio-retention systems, of becoming a "risk hot-spot" for residents. Furthermore, Dierkes et al. (2015) raise the concern that an accumulation of pollutants in soil and the groundwater below might be worse than the high peak pollution of receiving waters in storm events.

With the stormwater fee in Hamburg (introduced here: 2.2.4), property owners all pay equal prices for their sealed ground area, but the amount of pollution in the stormwater is not currently calculated in. Dierkes et al. (2015) suggest, that the removal of pollutants from storm water runoff, for example from industrial areas could be paid for by the responsible party, by having SUDS on-site. This would avoid the unfair payment for this pollutant removal by the central sewage system for the community. The question arises though: If installation and maintenance costs of such SUDS are higher with higher pollution (Dierkes et al. 2015), and using the municipal sewage system does not calculate stormwater pollution into its prices, then what incentive do industrial sites, that are considered to have high pollution potential, have for installing GI/SUDS? As explained in section 2.2.5 the implementation of green roofs is partially funded for both private and commercial property owners, which can be an enticing incentive for installation of such systems.

The stormwater fee in Germany (see 2.2.4), has lead to a prompt decrease of stormwater discharges with the implementation of GI by many land owners (Dierkes et al. 2015). Considering the pollution that can follow CSO's, these measures which Hamburg has implemented could therefore already lead to positive results. As a recent study from Richter & Dickhaut (2016) shows, the green roofs installed in the district "Hafen-City" in Hamburg retain more than 50% of the rainwater, measured over several seasons. Weather or not Hamburg achieved their goals set forht the Green Roof Strategy (see 2.2.5) by 2020, has yet to be seen.

Even though these outcomes are generally seen to be positive, Chocat et al. (2007) warn of the possibility that the responsibility of sustainable management of stormwater is being transferred from local authorities to the end-user.

2.3.2 Institutional lock-in

First of all, it is to be said that the water sector has high capital investment for maintenance and renewal of their sewage systems. Hamburg for example spends 60 million Euros each year for renewal and maintenance (Bertram et al. 2015). Resulting from the high capital intensity, several studies emphasise a path dependency or risk aversion, and therefore inflexibility towards innovation, in the water sector in general (Schramm et al. 2018, Water 2014, Brown 2005). Considering the innovative approach of Hamburg, with respect to starting the RISA project and implementing the separate stormwater fee at the same time, it is questionable if this argument is valid here (see 2.2.3 and 2.2.4).

Secondly, it should be mentioned that there is the fragmentation of administrative responsibilities in the water sector and consequential institutional barriers (Brown 2005, Barbosa et al. 2012, Schramm et al. 2018, Nickel et al. 2014, Hoang & Fenner 2016, Heß 2018). The responsibilities for stormwater treatment in Hamburg is distributed into several departments. For the stormwater management of road drainage, the respective authority which is also responsible for the construction of the road, is held accountable (Heß 2018). For central rainwater treatment, Hamburg Wasser holds the authority. And for rainwater systems that are integrated in water bodies, the respective water authority is responsible (Heß 2018). Table 4 shows how the responsibilities at roads are allocated. This fragmentation of authority lead to sometimes unclear responsibilities, if for example the inlet of stormwater lays in a different area then the treatment (Heß 2018). Part of the RISA project aims (see 2.2.3) is the explicit clarification of responsibilities for stormwater treatment (Waldhoff et al. 2015, Heß 2018). A second example for this fragmentation can be found in the law sector. As Dierkes et al. (2015) claim there is a "lack of clear guidance," considering the treatment of surface water runoff; as there is no law yet on discharge requirements for it (also see 2.2.2).

To reduce fragmentation, an integrated planning approach for GI with close cooperation of several city departments including spatial planning, traffic, recreation and education, as well as the participation of the public is essential (Nickel et al. 2014, Chocat et al. 2007, Barbosa et al. 2012). The RISA project involved all aforementioned parties for an integrated adaptation of the rainwater infrastructure (see 2.2.3).

Table 4: Responsibilities for road construction in Hamburg, translated from (Heß 2018)

Roads	**Authorities responsible for road construction**
Harbour Area	Harbour Port Authority (HPA)
Main roads	Ministry of economy, transport and innovation (BWVI)
District roads	District
Highways and federal highways	Federal government

3 Conclusion

Summary

This essay encompasses the presentation of the necessity of GI and the impediments sourrounding its implementation. It discusses, which measures Hamburg City has implemented (the RISA project, the Green Roof Strategy and the Stormwater fee) and how they might play out regarding the main barriers to the adoption of GI. Those hindrances have been discovered to be pollution through vehicle use, and institutional barriers through the fragmentation of authority in the water sector.

Limitations

As the aformentioned strategies and projects are still quite young, not many peer reviewed papers have been accessible for evaluation. For example, the specification of the Green Roof Strategy to green a 100 hectares of Hamburgs roofs until 2020 can not yet be evaluated.

Potential implications

Considering that man-made urban pollution endangering water bodies through stormwater runoff is primarily ascribable to vehicle use, the ecological transformation of the transport system should go hand in hand with the planning of GI.

Gaps in Knowledge

The aforementioned strategies and projects for Hamburg's stormwater management and GI implementation are relatively new (from 2009 and 2014), therefor further studies will need to show if the adaptation results which they foresaw will occur. Furthermore, it could be of specific interest to research if a payment for pollution amounts can be integrated into the Hamburg stormwater fee for example by using the pollution-potential mapping of the RISA project.

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