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Typological proposals of integrated surface water management for an existing urban housing estate in Prague, Czech Republic based on a series of innovative case studies.

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Typological proposals of integrated surface water management for an existing urban housing estate in Prague, Czech Republic based on a series of innovative case studies

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Objectives of thesis

This diploma thesis addresses the topic of integrated and decentralized surface water management within the context of urban drainage. In today's society, water plays a great role environmentally, politically and socially. Water scarcities, floods, diminishing water quality and a lack of access to potable water are all threats that face today's societies around the globe. However, these threats can also pose as opportunities as far as innovative planning, management and future urban and semi-urban development is concerned. Taking a look at water management in the built environment offers an incredible opportunity to reevaluate the conventional methods of urban housing and community developments.

The study evaluates the existing hydrological conditions of a conventional urban housing development in Černý Most, Prague, and implements innovative water management techniques based on solutions discussed in published literature and observed at multiple precedent studies in Berlin and Freiburg, Germany. The results include schematic solutions representing typological solutions for surface water management based on the context of the site. The proposed typologies can be adopted as precedents not just for housing estates in Prague but globally as well.

Methodology

Literature review

Methodology: series of case studies and analysis, analysis of existing state of urban surface water management in Czech Republic, analysis of Černý Most housing estate's water management

Result: Schematic proposals of integrated surface water management for the Černý Most housing estate

The proposed extent of the thesis

min. 40/50 pages

Keywords

Surface water, Urban drainage, Integrated development

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Brown R. R., 2005: Impediments to Integrated Urban Stormwater Management: The Need for Institutional Reform. Environmental Management 36, No.3: 455-468.

Ferguson C. B., Frantzeskaki N., Brown R. R., 2013: A strategic program for transitioning to a Water Sensitive City. Landscape and Urban Planning 117: 32-45.

University of Arkansas Community Design Center, 2010. LID Low Impact Development: A design manual for urban areas. Fay Jones School of Architecture University of Arkansas Press. 227.

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Author’s Declaration

I, Dorsa Afsharjavan, declare that this master thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or processional qualification.

Prague, 18th April, 2017

Dorsa Afsharjavan

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--- Dorsa

Abstract

This diploma thesis addresses the topic of integrated and decentralized surface water management within the context of urban drainage. In today’s society, water plays a great role environmentally, politically and socially. Water scarcities, floods, diminishing water quality and a lack of access to potable water are all threats that face today’s societies around the globe. However, these threats can also pose as opportunities as far as innovative planning, management and future urban and semi-urban development is concerned. Taking a look at water management in the built environment offers an incredible opportunity to reevaluate the conventional methods of urban housing and community developments.

The study evaluates the existing hydrological conditions of a conventional urban housing development in Černý Most, Prague, and implements innovative water management techniques based on solutions discussed in published literature and observed at multiple precedent studies in Berlin and Freiburg, Germany. The results include schematic solutions representing typological solutions for surface water management based on the context of the site. The proposed typologies can be adopted as precedents not just for housing estates in Prague but globally as well.

Czech Abstract

Tato diplomová práce se zaměřuje na téma integrovaného a decentralizovaného rizeni povrchoveho odtoku destove vody v kontextu mestskeho prostredi. V dnešní společnosti voda hraje velkou roli z hlediska životního, politickeho a společenskeho prostředí. Nedostatek vody, záplavy, klesající kvalita vody a přístup k pitné vodě jsou hrozby, jimž čelí dnešní společnost po celém světě. Nicméně, tyto hrozby mohou také být příležitostí, v případě inovativního plánování, řízení a budoucnosti městského a příměstského rozvoje. Přehodnotit konvenční metody městského a komunitního plánování nabízí neuvěřitelnou příležitost při pohledu na hospodaření s vodou v zastavěném prostředí.

Studie hodnotí stávající hydrologické podmínky sídliště Černý Most v Praze a implementuje inovativní techniky vodního hospodářství založených na znalostech publikovaných v literatuře a vypozorovaných z praktických příkladů v Berlíně a Freiburgu v Německu. Výsledky obsahují schémata typologií řešených pro konkrétní lokalitu. Navržené typologie můžou být použity jako ukázky aplikovatelné nejen pro obytné oblasti v Praze, ale i v celosvětovém měřítku.

Key Words

Surface water
Urban drainage
Integrated development

Table of Contents

1.0 Introduction

The objective of this diploma thesis is to address the topic of integrated and decentralized stormwater or surface water management in urban developments. In today's society, water plays a great role environmentally, politically and socially. Water scarcities, floods, diminishing water quality and a lack of access to potable water are all threats that face today's societies around the globe. However, these threats can also pose as opportunities as far as innovative planning, management and future urban and semi-urban development is concerned. Taking a look at water management in the built environment offers an incredible opportunity to reevaluate the conventional methods of urban housing and community developments. This thesis will reflect on all aspects of water but will focus on the management and treatment of surface water within the context of urban drainage.

Most conventional urban housing developments focus on capturing and removing surface water off site as fast and efficiently as possible. This thesis urges a change in how surface water is managed - it advocates for a paradigm shift toward focusing the attention on water quality over water quantity management, as the treatment of water quality will have a direct impact on water quantity as a result. Using surface water management as a primary design goal and driving force has the power to influence other aspects of sustainable development including open space, circulation, ecosystem services and quality of life.

This study will include a review of the concept of integrated urban water management (IUWM) and newly introduced low impact development practices in Europe, America and Australia. These concepts will be looked at through literature reviews, as well as a series of precedent case studies of existing urban housing developments. The selected case studies are located in Germany, a neighbor country to the Czech Republic. The thorough analysis and evaluation of the case studies will influence a proposed redesign for an existing community development in Černý Most, Prague in the Czech Republic. The result of the proposed design will include schematic typological plans and sections representing the built and natural systems, showing different typologies of how existing housing estates in the Czech Republic and abroad can be retrofitted to allow for integrated water systems and a more sustainable and water balanced built environment.

The current lack of clear and direct surface water management regulations in the Czech Republic provides an opportunity to learn from neighboring countries in order to implement innovative practices into the Czech landscape planning approach. The goal of this proposed project, the application of water management techniques and schemes on an existing development is to show that the possibility exists to create common urban development typologies that can be used to integrate surface water as an integral part of the design for natural and built human systems. The result of these sustainable and environmentally sensitive developments will not only include proper water management, but will also reflect positively on other aspects of planning which are considered integral toward a healthy and successful urban community development.

2.0 Aims of Diploma Thesis

The aim of this diploma thesis is to evaluate the existing hydrological conditions of a conventional urban housing development in Černý Most, Prague, and to implement innovative water management techniques based on qualities and solutions discussed in published literature and observed at multiple German precedent studies. The results will include schematic solutions representing typological solutions for surface water management based on the context of the site. The proposed typologies can be adopted as precedents not just for housing estates in Prague but globally as well.

3.0 Literature Review

3.1 Introduction to Natural and Built Water Cycles

Water is one of the major environmental issues facing the 21st century. With over 98% of water on earth unsuitable for drinking, and an increasing growing population with higher numbers of citizens of the world losing accesses to potable water daily, the water crisis is essential to our growing society. An increasing demand of water as a natural resource and its finite supply have led many to believe that water is the next oil (University of Arkansas Community Design Center, 2010). An increase in urban pollution and surface water runoff has detrimentally impacted rivers and streams worldwide, altering the natural aquatic ecosystems and hydrological cycle to an almost irreversible state. According to the United States Environmental Protection Agency (US EPA), the contamination of our water sources is one of the greatest threats to nations worldwide (Sipes, 2010). Global water shortages, increasing episodes of droughts and flooding due to climate change, and an increase in urbanization puts an immense value on the "urgent need to reverse the deterioration in quality of surface waters and protect their functionality now and for future generations" (Woods et al., 2016). According to the Water Integrity Network, without water, "there can be no economic growth, no industry, no hydro power, no agriculture, and no cities" (Sipes, 2010).

The hydrological cycle is the global process of the earth's water movement (Harris & Dines, 1998). The natural water cycle is characterized as a balance of water circulation through precipitation, evaporation, infiltration, transpiration and groundwater recharge (Woods et al., 2015). The difference between the natural hydrological cycle and the urban hydrological cycle in built environments is an increase in variables and components. The once closed loop natural cycle has transformed into a more linear flow, with beginning and end of the pipe results, known as the urban drainage system. The urban hydrological "cycle" is comprised of three parts: water supply, wastewater disposal and stormwater runoff (Mitchell et al., 2001).

When broken down, the components in the urban drainage system include potable water, wastewater, gray water, black water, rainwater, surface water, stormwater and groundwater. Potable water is considered water that is safe to drink and eat, without the risk of health problems. Wastewater includes all water that has been negatively affected due to anthropogenic actions. These anthropogenic actions include, but are not limited to domestic, industrial, agriculture and surface runoff water activities.

Wastewater can be broken down into several levels including gray water, black water and stormwater runoff. Gray water includes household wastewater, which does not contain serious contaminants (ex. kitchen sink waste water), whereas black water is wastewater with serious contaminants such as feces and urine. Rainwater is water that originates from precipitation, which has not yet been exposed to pollution and soluble matter. Some regions and countries regard pure rain water as potable and safe for drinking and consumption.

Surface water is water that has not penetrated below the surface of the ground. For the purpose of this study, surface water and stormwater will be used interchangeably. Lastly, groundwater is a critical natural resource that is stored below the surface level in the soil. All components of the urban drainage system are considered key elements and factors influencing the current state of the natural water cycle. The quality and quantity of the surface and groundwater is undoubtedly one of the most important aspects of the hydrological system as a whole. Surface water and groundwater are "fundamentally interconnected and are integral components of the hydrological cycle. They have to be thought of as one cohesive system" (Sipes, 2010).

3.2 Conventional Urban Drainage System

Solutions to the urban drainage system can be dated back to the second millennium BC, during the Mediterranean Minoan civilization (Novotny et al., 2010). It wasn't until the Roman Empire when the first approach toward wastewater and surface water treatment were put into effect (Hlavinek & Zeleňáková, 2015). During this time, water was brought to cities with wells and aqueducts. Rainwater was collected and stored in underground cisterns, and clay pipes were used to distribute water to fountains in upper class societies (Novotny et al., 2010). Early phases of settlement of societies and communities were established around sources of natural waterways. Today, the increasing pattern of sprawling urban development has abandoned the fundamental importance of the natural constraints of water resources on development (Sipes, 2010).

Conventional urban drainage can be considered as the "conveyance approach". This approach toward urban wastewater focuses on getting rid of all wastewater (including gray, black, and stormwater) as quickly as possible. This approach was originally driven by the sake of public health and safety.

There are traditionally two archetypes of urban drainage systems: combined sewer systems or combined sewer overflows (CSO) and separated sewer systems. The CSO is the conventional urban drainage system found in older cities and regions beginning from the model developed by Minoan and Roman civilizations. The conventional CSO limits and complicates the possibility of sustainable stormwater uses (Bichai & Ashbolt, 2016). In CSOs, surface water runoff drains into a combined sewer where it is then mixed with and dilutes other urban wastewater including gray and black water. This stormwater system is most commonly called the "curb and gutter" approach. The "one pipe" approach toward wastewater management places a "significant and unpredictable burden on wastewater treatment works, triggering some of the untreated sewage to spill into receiving watercourses" (Woods et al., 2015) during times of high water quantities.

In newer cities and developments, separate sewage systems have been preferred and are increasingly being used as common practice. In the separated sewage system, the foul water (gray and black wastewater) is piped to the wastewater treatment plant, and the surface water is piped directly to the nearest watercourse, with little to no treatment. These separate surface water sewers "reduce the risk of CSO spills, but still transfer the pollutants present in urban runoff from the urban surface directly to receiving waters" (Woods et al., 2015).

The benefits of the traditional conveyance approach, CSOs, is that it solves immediate flooding problems on the surface, as the runoff is immediately redirected into ditches or underground pipes and off site to either be treated or released back into the local waterway. However, by diverting the water directly to the local waterway with no primary treatment, more drastic problems are created downstream including pollution and high erosion of water bodies due to a high volume and velocity of the wastewater (Sipes, 2010).

In sever events, the untreated water dumped into receiving water bodies through a combined sewer overflow system can have detrimental effects on the hydrology, morphology and chemistry of the water, acting as the primary cause of what is commonly known as the urban stream syndrome (USS) (US EPA, 2013). Urban stream syndrome includes unhealthy stream networks with "chronic flash flooding, altered stream morphologies, elevated nutrient and contaminant levels, excessive sedimentation, loss of species diversity, and higher water temperatures"

(University of Arkansas Community Design Center, 2010).

Conventional water treatment together with population growth and a continuous expansion in urban development contribute to an increase in pollutants in rivers, streams, lakes and coastal waters. The conventional drainage approach which relies on peak flow does not target the increasing amount of pollutants in urban environments. Peak flow "causes changes in hydrology and water quality that result in habitat modification and loss, increased flooding, decreased aquatic biological diversity, and increased sedimentation and erosion" (US EPA, 2016). Urban runoff generally consist of water at higher temperatures, depending on the urban surfaces the water is exposed to, with sediments, oil, grease, toxic chemicals from motor vehicles, pesticides, bacteria, nutrients from pet waste, road salts and heavy metals. These pollutants pose threats to fish and wildlife, native vegetation, drinking water supplies and recreational areas exposed to people (US EPA, 2013).

It can be said that the greatest cause of degradation of urban surface water quality is the increase in impervious surfaces, specifically effective impervious areas (EIA), which are located close to surface water runoff outlets. According to Sipes (2010), "the percentage of impervious cover in a watershed is a pretty good indication of water quality." When the impervious area in a watershed reaches 10 percent, the stream ecosystems begin to degrade. At 30 percent, the degradation begins to reach irreversible levels (University of Arkansas Community Design Center, 2010).

Minimizing imperviousness and maximizing the use of pervious soils and vegetation is a fundamental approach toward achieving sustainable integrated surface water management. The greater opportunity for infiltration and groundwater recharge, the closer the system is to a natural hydraulic environment (Elliott & Trowsdale, 2007). This replenishment of groundwater by infiltration is known as recharge, and is essential toward the status and future viability of the groundwater table (Harris & Dines, 1998).

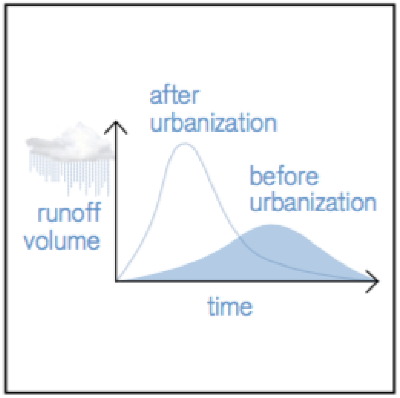


Figure 1: This graph shows the influence of urbanization on the amount of stormwater runoff over time (University of Arkansas Community Design Center, 2010).

3.3 Importance of Sustainable Surface Water Management

The term "urban metabolism" is used to define the "sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy et al., 2011). Cities take in raw material such as fuel and water and transform it into the built environment, producing human related biomass and waste. It is important to analyze and regulate the urban metabolism on a local and regional level. In terms of water management and the urban hydrological cycle, it is important to address the issue on several levels: unit block, cluster and catchment levels (Mitchell et al., 2001). The "urban being" as an organism takes in water from a natural source and eventually releases that water into another natural waterway, with additional anthropogenic consequences associated with the released water. This process is referred to as the Social Water Cycle, and is considered an "open and evolving process of water volume and quality" (Lu et al., 2016). The ultimate goal is for the post-urban or post-anthropogenic water quality to be as clean and healthy as the water that first entered the urban system. As globalization continues, it is increasingly become more important to recognize water in the decision-making processes associated with the built environment. There is an "urgent need to reverse the deterioration in quality of surface waters and protect their functionality now and for future generations" (Woods et al., 2016).

Conventional, or utilitarian, urban sewage systems are increasingly being considered outdated as it is difficult to maintain damaged and worn underground stormwater pipes. Access to these conventional systems includes tearing up streets, closing roadways to traffic, and cutting off potable water sources for periods of time, which can be expensive and disruptive (Sipes, 2010). The influence of climate change on urban regions shows that building bigger and larger pipes will not be a sustainable long-term solution toward restoring the hydrological cycle as close to nature as possible (Roy et al., 2008). Urban water management also needs to put more consideration on the capacity of their water treatment approaches in terms of storm events, redundancy, distribution, and resilience (University of Arkansas Community Design Center, 2010). According to Brown, contemporary research shows a broad range of societal values associated with urban waterways in

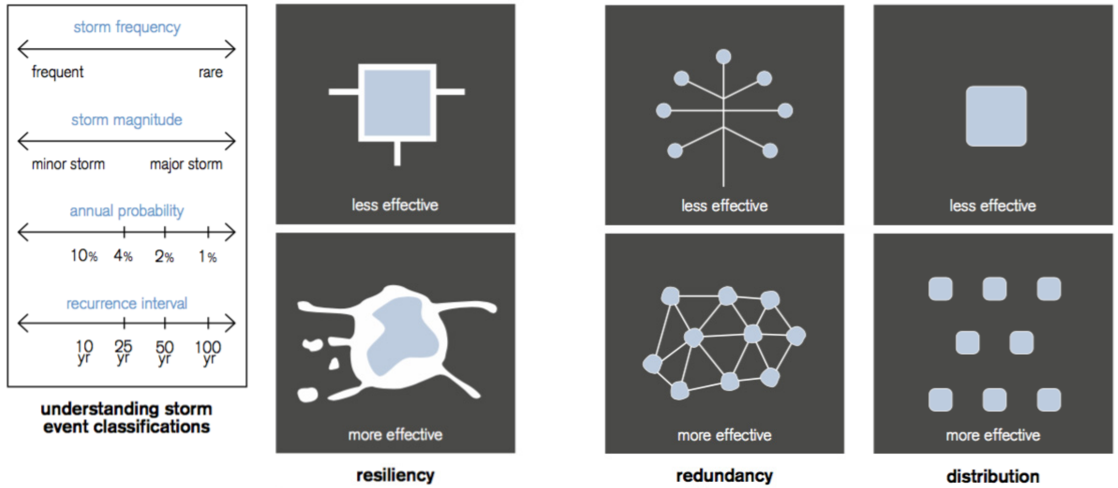


Figure 2: This series of diagrams represent the areas of consideration when dealing with water treatment including its approach toward storm event classification, resilience, reduncy and distribution (University of Arkansas Community Design Center, 2010).

relation to aesthetics, amenity, recreation, tourism, economic development, intrinsic ecological health, heritage and indigenous values (Brown et al., 2013). However, integrating and regulating these approaches into the urban fabric has proven to be highly complex and difficult to achieve, but is possible with a holistic and comprehensive planning approach.

3.4 Paradigm Shift Toward Integrated Urban Surface Water Management

In face of climate change and a growing shift toward urbanization, the adaptability of built and natural systems is a key attribute toward sustaining the built environment (Ashley et al., 2015). The proper management of large and small rainfall events is essential to flood protection, the hydrological cycle, and the ecological health of not only the aquatic environment but also all natural systems in the urban context. Modern approaches to surface water management aim to integrate water back into the landscape, in order to mimic the natural hydrological cycle (Stipes J., 2010). This infiltration approach seeks to slow down surface water runoff by providing opportunities for the water to penetrate and soak into the surface of the ground, thus directing the water "where it causes the least amount of damage and where it can be used in the most beneficial way" (Stipes J., 2010). Implementing a paradigm shift toward integrated surface water management can be most commonly considered worldwide as an approach toward best management practices (BMP). Changes toward sustainable urban surface water management solutions are "considered long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (Brown et al., 2013). This shift requires changes in the way urban water systems are planned, designed, and maintained.

The field at work is dynamic and continually changing, thus, as with other socio-economic and socio-ecological systems, surface water management also includes a high level of uncertainty and a limited capacity to control variables. According to Wong and Brown (2009), "best-practice urban water management, is widely acknowledged as complex, because it requires urban water planning to protect, maintain and enhance the 'multiple' benefits and services of the total urban water cycle that are highly valued by society." The system has the power to influence aspects of water supply, public health, heat island effect, flood protection, waterway health and protection, amenity and recreation, green space, economic vitality, and social equity, all while promoting long-term comprehensive environmental sustainability (Ferguson et al., 2013).

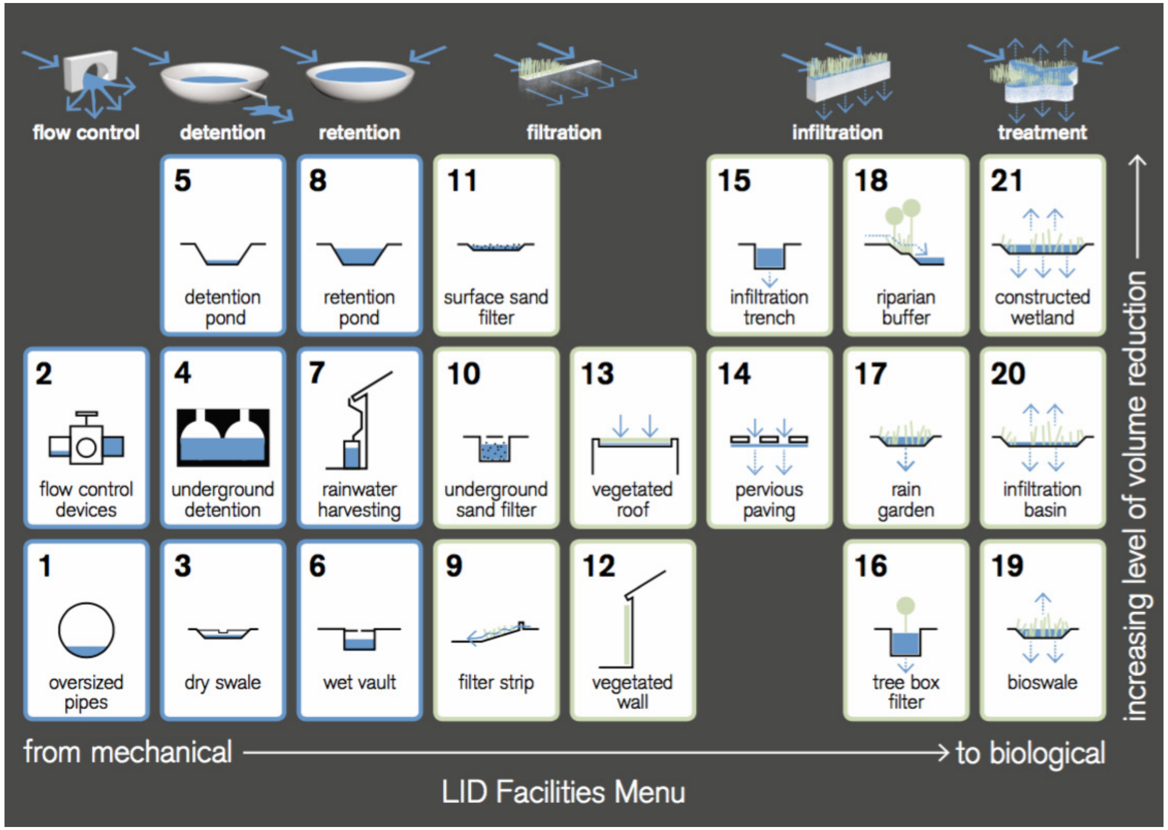


Figure 3: This diagram shows some examples of best management alternatives toward treating surface water on site, at the surface, and in a decentralized manner (University of Arkansas Community Design Center, 2010).

By controlling surface water at its source, best management practices better the quality of the surface water by filtering out and preventing pollutants from entering the natural waterways (US EPA, 2016). BMPs can consist of both structural and non-structural measures, transforming "hard engineering" into "soft engineering" (University of Arkansas Community Design Center, 2010). Countries around the world have unique and site specific approaches toward modern surface water management. The names of the approaches vary (examples will be discussed in the discussion chapter) and the specific goals and principals vary. However, the basic fundamentals of these practices remain the same worldwide. In addition to a range of practices, the tools and techniques used to manage surface water are context sensitive and should be looked at not as a centralized system but as a set of small-scale decentralized treatment facilities (Elliott & Trowsdale, 2007).

It is important to note that when dealing with an IUWM hydrological cycle, surface water is not the only factor that is to be taken into consideration. The leading concepts associated with sustainable surface water management are to collect, retain, detain, infiltrate, treat and use surface water, in order to return the water regime back to, or as close to, the natural or pre-development hydrological cycle (Ellis & Lundy, 2016).

It is essential to consider other aspects of the urban drainage system including rainwater, grey water, blackwater, the source water and wastewater associated within the three realms. The key is to look at the built and natural systems as a unified unit; the interior architectural systems should work hand in hand with the landscape elements and exterior hydrological cycle. The move towards a more IUWM system calls for stormwater, wastewater and potable water to work together as a cohesive unit rather than individually (Mitchell & Diaper, 2006).

The benefits of an integrated urban water network are countless, however, due to the nature of the topic, it is often difficult to put a monetary value to these benefits. The integrated approach has the power to reduce the consumption of potable water for non-potable water uses by redirecting gray water, collecting and harvesting rainwater and reusing surface water with local treatment features in place.

Reduction in potable water use is one aspect of the integrated approach which can most closely have a direct monetary value associated with it. According to Biachai, “integrating alternative water sources at a range of application scales into such a portfolio combining supply and demand management options can increase flexibility and adaptability of the community water system, and reduce reliance on traditional sources of drinking water” (Bichai & Ashbolt, 2016). Other benefits include flood reduction, pollution minimization, ecosystem rehabilitation, water retention and groundwater revitalization, urban landscape improvement, ecological awareness and reduction of large scale drainage investment (Brown, 2005). Many of these benefits can be characterized as ecosystem services (ES).

A disadvantage associated with IUWM networks is that probable technologies and approaches are extremely site and context specific. This means that proper analysis and understanding of the space and environment are crucial toward the successful execution of these technologies. The design and construction of traditional stormwater drainage systems was typically considered incidental or additional engineering work associated with road and building development. The water management was typically an afterthought in conventional development practices (Brown, 2005). This approach considered surface water management as a secondary or even tertiary level of importance.

The modern integrated approach to surface water management revolutionizes the disciplines and stakeholders involved in the planning and management of urban waters. This new approach calls for collaboration between engineers, architects, city planners, landscape architects and the community. The shift in responsibility is something that may be more difficult to achieve in some countries and regions more than others (Hlavinek & Zeleňáková, 2015), as it not only influences those who are responsible, but also increases the initial cost of the planning and implementation phases of a development.

Another disadvantage facing the integrated urban water management approach is the limited amount of time since it has been introduced into the fabric and language of the built environment. It was not until the late 1990's that urban stormwater was considered to be a topic worthy of discussion in the public realm (Brown, 2005). Many of the best management technologies have only been introduced and implement for about twenty years or so, and much of the technology continues to advance on a day-to-day basis. Another setback associated with this short lifespan is a lack of current regulations around the globe, which will be discussed in the following chapters.

3.5 International Approaches Toward IUWM

As stated earlier, the approach to a more integrated urban water management system varies greatly from region to region. However, as a growing field, it is critical to learn from others when applying changes in order to modernize the way surface water is managed across the world. According to Woods Bollard (2016), "reviewing methods adopted by other countries provides insight on various approaches toward more sustainable surface water management measures to most efficiently protect our natural environment, mitigate the impacts of development on natural hazards, and support future urban quality of life."

For the purpose of this thesis, integrated urban surface water measures will be looked at in three different regions: the United States of America, Australia, and the United Kingdom. These three regions are the leading players in the field of modern and innovative surface water management, whose technologies and approaches are being shared and adopted across continents. The United States refers to their integrated surface water management system as Low Impact Development (LID), whereas in Australia, they refer to it as the Water Sensitive Urban Drainage (WSUD) approach. Recently, the UK, and growingly in other EU countries, have adopted measures known as Sustainable Drainage Systems (SuDS). Not only is the practice of integrated surface water management complex, but the vast and varying vocabulary associated with it also acts as a challenge toward broadening the field and normalizing the practice. The more diverse the terminology becomes, the potential for confusion and miscommunication across professions and regions increases as well (Fletcher et al., 2015). For this reason, it is extremely important to facilitate proper communication between disciplines and between regions of the world with the use of accurate terminology and appropriate applications.

3.5.1 USA

In the United States, integrated urban surface water management practices have been implemented in accordance with the Environmental Protection Agencies (EPA) requirement for the removal of total suspended solids (TSS) in waterways. The Clean Water Act of 1972 was the first paradigm shift which paid attention to the quality of waterways and watersheds in the United States (US EPA, 2013). Starting in the 1980's, there was an increase in concern regarding the degrading effects of urbanization on watersheds (Balascio et al., 2009). In the early stages of integrated management, the practice focused mostly on centralized stormwater treatment, such as large-scale detention ponds.

Recently, it has been found that large centralized treatment facilities may be problematic as well, thus, paving the way toward non-structural and soft engineered best management practices, also known as Low Impact Development (LID) or Green Infrastructure (GI) in the States. LID is most commonly associated with urban drainage solutions specifically, whereas GI reflects more on the overall inclusion of green space hubs and corridors in order to maximize ecosystem services, of which urban drainage and the urban hydrological cycle are just examples (Fletcher et al., 2015).

The US EPA's standards regarding the total suspended solids (TSS) in waterways states that the "average annual concentration of TSS in post-construction storm-water discharges be reduced by 80%, or to values no greater than the pre-development loadings" (Balascio et al., 2009). This is based on the EPA's National Pollutant Discharge Elimination System (NPDES), which addresses water pollution by regulating point source discharge to waterways in the United States. TSS are considered the greatest cause of degradation to streams and urban watersheds as a whole. The pollutants found in addition to TSS in urban runoff include trash, chemicals, oil, grease, toxic chemicals from motor vehicles, pesticides and nutrients from gardens, viruses, bacteria, nutrients from pet waste, salts, heavy metals, and sediments (US EPA, 2016).

LID approaches are designed to detain, store, infiltrate and treat urban runoff, thus reducing the impact of urban development on the watershed. In addition to structural efforts, non-structural methods are introduced as well. Examples of non-structural methods include: alternative building and road layouts designed to minimize impermeable surfaces and maximize space for pervious soils and vegetation, compact development planning techniques, contaminant source reduction, and educational and outreach programs (Elliott & Trowsdale, 2007).

In the US, GI and LID practices are looked at on the site, neighborhood, and watershed scale. Individual states have unique criteria and regulations for addressing urban surface water management, dependent on context sensitive requirements and needs. Based on the needs of the specific state or region, ordinances are proposed in a series of categories: aquatic buffers, erosion and sediment control, open space development, stormwater control operations and maintenance, illicit discharges, post construction controls, source water protection, and miscellaneous ordinances (US EPA, 2016). These regulations are supported on local state and federal levels, depending on the criteria and context with an increase in influence through federal permits and funding (Woods et al., 2016).

3.5.2 Australia

In Australia, there has been a significant shift in the way urban water systems are planned, designed and managed. The new transition in Australian cities is to move toward a "water sensitive city" (WSC) (Ferguson et al., 2013). Increasingly, stakeholders in Australia are looking at the urban water network as a social-ecological system; one, which is dynamic and complex, requiring careful planning and attention. Water sensitive cities prioritize livability, sustainability and resilience within the context of infrastructure and urban planning (Ferguson et al., 2013). The approach toward water sensitive cities calls for best management practices, which are referred to as water sensitive urban drainage (WSUD) in Australia.

According to Wong and Brown (2009), the three pillars of a water sensitive city include: cities as water supply catchments, cities providing ecosystem services and cities comprising water sensitive communities. Unlike conventional approaches to urban surface water management, WSUD unites water infrastructure with urban planning, thus creating an adaptive and multi-functional system that is not only productive, but creates a collaboration between policy, science, practice and the community (Ferguson et al., 2013). The overarching objectives of WSUD is to provide water security, maintain public health standards, provide flood protection, waterway health and protection, allow for amenity and recreation, provide economic vitality and to demonstrate long-term sustainability while addressing multi-generational equity.

In the past 15 years, communities throughout Australia have proved how much the technology and mindset has moved toward promoting water sensitive cities and in the direction of sustainable water resource management. In recent years, there has been an ever-greater push for “fit-for-purpose” water supply design where an increase in technologies and precedent studies are pushing toward stormwater reuse in place of conventional piped potable water systems (Roy et al., 2008). According to the Australian Guidelines for Water Recycling, stormwater is defined as “‘water that runs off all urban surfaces such as roofs, pavements, car parks, roads, gardens and vegetated open spaces and is captured in constructed storages and drainage systems” (Bichai & Ashbolt, 2016). The ultimate attempt is to restore the natural water regimes while also increasing the benefits from surface water management.

3.5.3 United Kingdom

The United Kingdom underwent a series of severe floods in 2007, calling national and international attention toward a more comprehensive flood risk management plan and looking at how cities in Europe approach urban drainage systems as a whole (Ellis & Lundy, 2016). This movement resulted in the adoption of SuDS, or sustainable drainage systems, which was published in 2015. The concept of SuDS can be broken down into four surface water management categories: storage systems, infiltration systems, conveyance systems, and permeable surface with subterranean storage. In addition to the approaches, SuDS includes benefits which can be distinguished by four main categories: water quantity, water quality, amenity and biodiversity, the four main pillars of SuDS design (Woods et al., 2015).

The philosophy behind sustainable drainage systems is to maximize the benefits of surface water while minimizing negative impacts of runoff in urban areas. The starting point is to manage the water from the start, and to incorporate water management into the design process as an integral design factor. It is important to utilize surface water as a resource, treat captured rainwater at the source, manage runoff on site and on the surface, and to allow for groundwater recharge (Woods et al., 2015). These goals can be addressed by using modern surface water management technologies in order to return the water cycle back to the balanced natural, pre-urbanized, system.

The European Water Framework Directive (WFD), introduced in 2000, also encourages a shift toward sustainable urban drainage by promoting a holistic approach toward water management, with water quantity and quality in mind. The Directive pushes toward achieving “good status” of water quality for all receiving waterways in Europe by reducing pollution from point and diffuse sources (Woods et al., 2015).

Though SuDS was proposed as a tool for the UK to manage flood protection more appropriately, other EU countries have since adopted it as a guiding tool. Many countries, including Germany, are working toward the European Flood Risk Management Directive, which goes hand in hand with the EU Water Framework Directive, to address urban surface water management in a more holistic and comprehensive manner (Woods et al., 2016). Unlike in the UK, however, Germany’s approach is less focused on the quantity of runoff and flood protection, and more toward the quality of the water and its effect on the hydrological and ecological health of urban watersheds.

3.6 Cities Of The Future

Transformative cities today must be able to provide urban vitality, centrality, economy, and conditions to “ride the wave of change” for the benefit of the city (Jakob, 2010). Smart, green, eco, sustainable cities are all terms describing developments which have transformed from conventional built environments and technologies to modern innovations and examples of what it means to be urban. Recently, there has been a social-marketing shift towards promoting environmental issues as an aspect of lifestyle and daily life. This social marketing has been used to promote behavioral change through consumer peer pressure, costs, benefits and self-identity (Barr et al., 2011). Many of these eco-developments have attracted younger families living within the cycle of nature (Purvis, 2008). A majority of these young families, many with children, are creating a new social norm for younger generations where ecological sustainability and awareness of the built environment has become a fundamental aspect of daily life (Austin, 2013).

According to Pradel-Miquel (2016), “recent development in European cities has been based on the strengthening of innovation and creativity through culture-based urban renewal.” Participatory bottom-up initiatives promoting alternative lifestyles and developments have been increasing throughout Europe as countries have simultaneously been evolving socially and politically. Growingly, creative dialogue between community members and stakeholders pertaining to the development have been used not only to change the language of urban development, but also to change the approach toward a more holistic and comprehensive one (Austin, 2013). A number of case studies were visited and analyzed for the purpose of this study, all of which have received praise and attention for being innovative housing developments. The sites visited were located in Berlin, Germany and Freiburg, Germany. The following review will introduce these regions in terms of their background and approach toward sustainable urban development and green visions.

3.7 German Case Studies

Germany has been considered a top country in the forefront of environmental consciousness, green living, sustainable energy and renewable resource consumption and production. After the extensive destruction of German cities and towns during the Second World War, much of Germany was left with immense urban development obstacles, calling for the Development of Building Law of 1945 (Pahl-Weber & Henckel, 2008). Under this law, a new planning system was set into place including the new roles of federal, state and local governments in the country’s rebuilding efforts. The new components of spatial planning in Germany addressed both existing structures as well as future planning goals at all levels of spatial planning. These designated spatial planning goals include: the call for comprehensive spatial plans, green and open space, environmental protection grounds, proper water management, flood control and drainage, designated areas for natural resource extraction, agriculture and forest land designation and areas for measures to protect and develop natural environments and landscapes (Pahl-Weber & Henckel, 2008). Historical events such as the reunification of East and West Germany offered the opportunity for the renewal of infrastructure and replacement of the diminishing and war-torn built environment throughout the country (Buehler et al., 2011), allowing Germany to take a lead in innovative and green development. The review examines innovative precedent case sites in the cities of Berlin and Freiburg, Germany in terms of their IUWM and development approach.

3.7.1 Berlin

According to the official Visit Berlin website, “Berliners love living green”. According to the site, a majority of the city follows LOHAS, a “lifestyle of health and sustainability” (Anonymous, 2016a). Since the fall of the Wall, much of the city, which currently consists of over 50% green and open space, introduced a multitude of bike paths, parks, gardens (the Guerilla Gardening Movement) and public space (Anonymous, 2016a). With a current population of approximately

3.5 million people living in Berlin, and a projected increase of 250,000 inhabitants by 2030, due to a continued shift toward living in urban cities (Thierfelder & Kabisch, 2016), it is assumed that Berlin will need about 20,000 new apartments per year to accommodate for the expected increase in population (Larondelle & Lauf, 2016).

The city's approach toward reaching this quota includes heightening existing building stocks and re-designing over-dimensioned traffic areas within the existing cities fabric, as opposed to building out and "sprawling" the city. The development plans within Berlin focus on a set of Urban Ecosystem Services (UES) including water provisioning, particulate matter removal, heat regulation, carbon sequestration and recreational areas (Larondelle & Lauf, 2016). Bolund and Humhammar (1999) first introduced the term "ecosystem services" in 1999 when trying to describe the "value and benefits that urban residents may attribute to internal ecosystems located within a city."

UES has been a topic of much interest, with many studies reviewing how cities can be held accountable for the continued benefits they receive from the local ecosystem, and how these benefits can be maximized while minimizing negative human impact accordingly. Repeatedly, imperviousness is found to be the determining factor for ecosystem services supply, with large urban parks and forests providing the most services. With a shift toward compact cities structures and infill development, there is not only an opportunity design with UES mind (Larondelle & Lauf, 2016), but to also use best management practices and urban green spaces (UGS) as a means of promoting equitable and healthy urban environments (Kabisch et al., 2014).

Berlin's city administration has acknowledged that nature conservation and the improvement of green space and public amenities is vital toward sustainable urban development and social equality. The city's Urban Landscape Strategy considers three objectives: "beautiful city", "productive landscape", and "urban nature", when new policies and projects are being considered (Thierfelder & Kabisch, 2016). The "beautiful city" theme looks at qualifying historical and current landscape architecture. The "productive landscape" urges for an ecologically motivated lifestyle, which includes urban gardening and allotment gardens. And the theme of "urban nature" focuses on experiencing nature within the city, while trying to mimic natural ecosystems in the built environment through the production and livelihood of ecosystem services (Thierfelder & Kabisch, 2016).

Since the fall of the Wall, Berlin has seen a drastic increase in green infrastructure, or low-impact development. Such innovations include but are not limited to green roofs, green facades, and permeable pavers. These tools are used to mimic the natural process of soils and vegetation to provide ecosystem services including stormwater management, urban heat island amelioration and habitat creation (Buehler et al., 2011).

German policies have called for an increase in transparency regarding stormwater services. For this reason, German households are charged for stormwater services based on an estimated amount of runoff produced by their property. This is referred to as the Individual Parcel Assessment (IPA) (Buehler et al., 2011). The implementation of the IPA system has increased citizen's awareness of how choices regarding their property and land cover influence their household wastewater - it incentivizes green infrastructure on a household level. Benefits of the IPA includes the ability to increase public awareness on humans impact on surface water management, accumulation of data on water usage and waste for more appropriate watershed planning and the ability to incentivize on-site low impact stormwater management strategies (Buehler et al., 2011).

Berlin's heat regulations address the high summer heats, which are intensified in the city, and the storage possibilities associated with solar radiation. High temperatures in cities can cause an increase in heat stress, resulting in negative effects on the energy balance of the human body due to "hot atmospheric conditions" (Larondelle & Lauf, 2016). According to Dugord (2014), "in Western societies, the combined effects of climate warming, proceeding urbanization and demographic change (e.g. population aging) increase the risk of city populations to be subject to heat related stress." The urban heat island (UHI) effect has a direct correlation with land-use patterns. The cooling effect of green spaces compared to "gray" surroundings, referred to as the park cool island (PCI), can reduce air temperatures through vegetation cover and air flow (Dugord et al., 2014).

In 1994, the city of Berlin announced the Green Space Factor Requirements and the Green Points System, an innovative set of regulations, which calculates the percentage of a development parcel that must be permeable post construction. This is a concept that is being adopted globally by other innovative green cities and communities such as the Bo01 development in Malmo, Sweden (Austin, 2013). Recently, Berlin held its first annual "Berlin Water Week," which included the Berlin Aquadays 2016 and Blue Planet Water Dialogues, introducing to the public how careful planning and management of water plays a great role in the city's character and living environment (Anonymous, 2016b). The Berlin Aquadays were uniquely centered on the topic of decentralized rain and sewage management. One of the focus areas of this conference was the gray water-recycling concept featured in the Block 6 Project, one of the sites analyzed for the purpose of this study. Due to the specific nature of this project as a gray and black wastewater treatment and urban agriculture facility, and less of a surface water management precedent, the analysis of this site will not be discussed in further detail for the purpose of thesis.

3.7.2 Freiburg

Freiburg, Germany, was heavily bombed during World War II, to the point where very little remained of the city center besides the historic Cathedral. The city was rebuilt with the intention to recreate the character of the original city. The original narrow street plan was followed, with historic stone canals running along the roadsides (Gregory, 2011). To this date, the thin canals filled with water run through the streets of Freiburg, incorporating a sense of water and surface water management into people's daily lives. A larger, more commercialized, central canal, home to the

Image 1,2,3 (top to bottom): These photos reflect the historic downtown Freiburg culture which roots from a pedestrian only old town with open canals running through the narrow streets and plazas (Photos by author).

urban myth of the granite sewer alligator, acts as the living soul of the historic city center. In the 1970's, Freiburg was the site of a revolutionary green movement when a group of environmental and anti-nuclear activists successfully protested against a government planned nuclear power plant in Whyl, 20km north of the city (Fastenrath & Braun, 2016). This compelled the local community to come up with a proposal of how the city would provide energy for the growing population of residents. The result was a long-term oriented "communal energy concept," based on energy conservation, production of renewable energy, and the development of environmentally friendly and innovative technologies (Fastenrath & Braun, 2016). The grassroots movement and local knowledge, in the college town of Freiburg, was what led the initial transition toward the green city it has become today.

Freiburg has been recognized nationally and internationally as a leading green city, especially in the areas of transportation, energy, waste and water management, land conservation and green economics (Gregory, 2011). The overall strategy for Freiburg since the mid 1970's has been to provide for the needs of the people while minimizing environmental harm and "letting nature do the work" (Gregory, 2011). In 1973, with the pressure of direct public participation, the entire city center was converted into a pedestrian zone. A more sustainable transportation network was introduced by coordinating and integrating land-use and transportation planning, integrating public transportation regionally with trams, promoting bicycling, and restricting automobile use throughout parts of the city (Buehler et al., 2011).

Recently, the ecodistricts of Vauban and Rieselfeld, two sites analyzed as part of this study as Site B and Site C respectively, were developed as two inner suburbs built around light rail line extensions of central Freiburg. Both communities include mixed residential, commercial, educational and recreational land use, within a comprehensive set of transportation options focusing on pedestrian, cycling, and public transportation amenities (Buehler et al., 2011).

Freiburg's parking policy is designed to make car use less convenient through an increased cost for parking, complex street design network, and limited parking spaces. In the district of Vauban, an individual parking space costs approximately 18,000 Euro, making it less desirable for residence to want to invest in the infrastructure or amenity (Gregory, 2011). It is important to note that the success of Freiburg's transportation system was not overnight. The changing transportation system, land-

Image 4: A photo of the car-free Bertoldsbrunnen square, in the historic Freiburg city center, with tram lines running in all directions (Photos by author).

Image 5: This photo shows how the canal system and drainage infrastructure can be used to separate public plazas and roads from semi-public/private retail and residential entrances (Photos by author).

use systems, and overall approach and image of travel behavior took almost 40 years to adopt (Buehler et al., 2011). It is behavioral changes like these that make long-term sustainable communities successful.

Freiburg as a whole consist of 5,000

hectares of forests, 600 hectares of parks, over 160 playgrounds and more than 3,800 small garden allotments. The Rieselfeld district alone consists of 240 hectares of landscape conservation and only 78 hectares of residential development as it was designed with a compact development approach (Gregory, 2011). Reiselfeld was developed with a more traditional block structure with four to five story buildings whereas Vauban consists more of a mix of architectural styles. The Vauban district also includes a mix of low-energy buildings, passive houses, and plus energy building styles. Both districts were a direct result of public participation and collaboration between community members, architects, developers and engineers, which resulted in the ambitious energy and waste efficient projects with a “learning by planning” approach (Fastenrath & Braun, 2016).

3.8 Future Opportunities

Water centric sustainable communities are the “cities of the future” (Novotny et al., 2010). Under the new and innovative urban water paradigm, the term “wastewater” will essentially become a misnomer, as it is replaced with terminology such as “used water,” “reclaimed water” and “resource recovery” (Novotny et al., 2010). In the cities of the future, there may be no need for a sewer system. Water can be dealt with in a decentralized manner, closing the loop and lengthening the cycle of the urban water cycle (Niler, 2015). In the cities of the future, buildings will not only be considered fixed structures, but living “liquid structures” as well (Niler, 2015).

Although integrated urban surface water management techniques have been growing over the past 20 years, wide scale implementation of such technologies have been limited (Brown, 2005). With an increase in public knowledge and community participation, a shift in interdisciplinary roles among the involved professions, and an increase in political and legal regulations, water centric cities can become the new norm in the built urban environment.

4.0 Methodology

4.1 Precedent Case Study Review

Part of the research for this thesis study included a series of site visits to existing integrated surface water management projects in Berlin, Germany and Freiburg, Germany. The above literature review introduced Germany, and specifically these two cities, as forerunners in the realm of sustainable and innovative development and urban systems. The two cities of Berlin and Freiburg were also selected as case studies due to their similar climate and precipitation attributes with Prague, Czech Republic. The following chart represents the similarities and differences between the annual levels of precipitation in three cities being discussed. According to the World Weather and Climate online database (2016), the average annual precipitation, including rain, hail and snow, for Freiburg, Berlin and Prague are as follows: 887 mm, 591 mm and 526.3 mm, respectively. Although Freiburg's precipitation is far greater than in Prague and Berlin, it will be noted in the following chapters how regardless of climate intensity, similar IUWM techniques can be adapted and used for the treatment of surface water based on site conditions and requirements.

The precedent case studies will discuss three developments in three German districts in terms of their integrated surface water management practices, and its influence on the urban fabric and sense of place. The first site is located in Friedrichshain, Berlin, formerly part of East Berlin, which will be known as Site A for the purpose of this study. The second neighborhood is part of the Vauban District of Freiburg, and will be referred to as Site B. And the third community analyzed is located in Rieselfeld, Freiburg, which will be addressed as Site C. These three sites were analyzed after two days of extensive analytical site visits and walk-through observations made by the author and supervisors of this thesis, in addition to online data, resources and published literature.

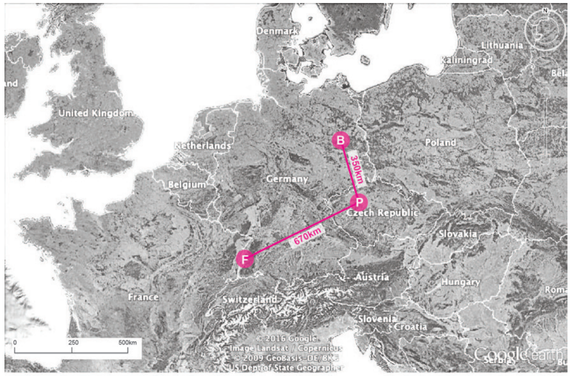


Figure 4: This diagram shows the geographical relationship between Prague (P), Berlin (B), and Freiburg (F). Freiburg is located furthest from Prague with 670km of distance between the two (Created by author, Original map data: Google Earth, 2016a).

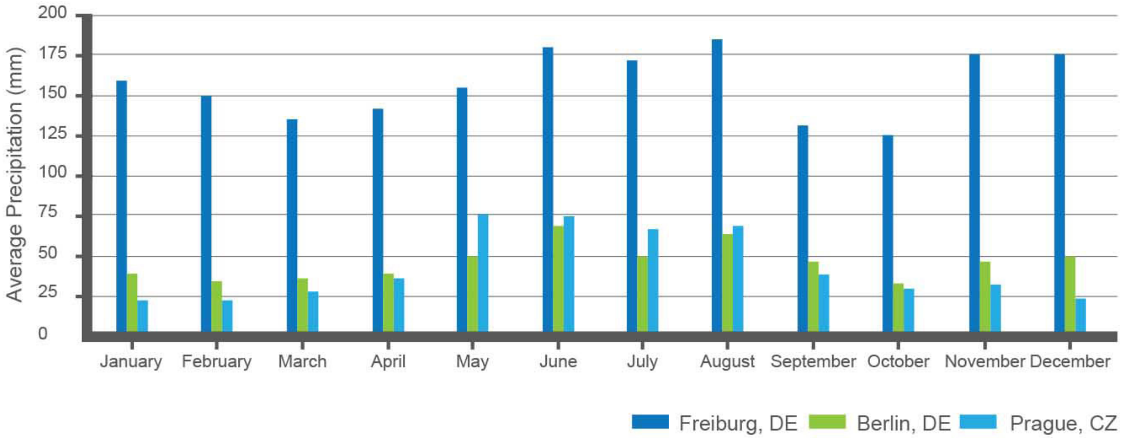


Figure 5: This graph compares the average annual precipitation (including rainfall and snow) in Freiburg, Berlin, and Prague, to show the climatic relationship between the three study areas (Created by author, Original data: World Weather and Climate, 2016).

4.1.1 Site A – Friedrichshain, Berlin

The first precedent study is located at the Southeast corner of the Friedrichshain district of Berlin. The peninsula shaped landform is surrounded by the Rummelsburger See (lake) to the North and the Spree river to the south. The developments which were analyzed are located on the North of the peninsula along the edge of the Rummelsburger See. Site A is well connected to its surrounding city with its location off of the Berlin Ostkreuz S-Bahn stop, as well as several Berlin public transport bus stops located within the vicinity.

The focus of the study at this site was the housing developments between Fischzug and Uferweg Street. The housing modules can be broken down into two groups or typologies. The first typology consisted of the newly developed housing complexes which include apartment style housing as well as single family townhomes. The apartment blocks include inner block shared green space while the town homes typically include private back gardens. The second housing typology on this site consists of block style apartment buildings, including a senior home facility, which have communal green spaces between the buildings and typically include vegetative roofs. The fabric of this urban development and the gridded street pattern is guided by green streets, allées and linear park spaces allowing for water retention and infiltration along the way. It is also important to note the importance of these developments in relation to the adjacent Rummelsburger See and the active recreational boulevard that runs along the water's edge.

The integrated surface water management of typology one primarily focuses on filtration and infiltration. The use of green roofs, open and directed roof water downpipes, lush vegetative surfaces, permeable pavers and limited impervious land cover allows for the biological filtration and infiltration of the surface water, supporting groundwater recharge and a balanced hydrological cycle.

The three to four story attached homes in the first typology of housing have downspouts attached to the roofs, collecting and directing roof water to vegetative surfaces on the ground floor. It is important to note that most of the vegetative surfaces consist of lush plantings, as opposed to

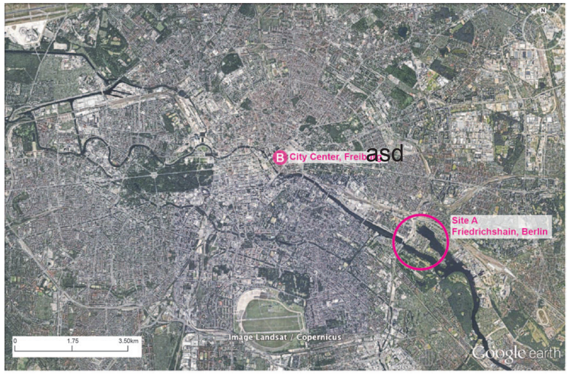


Figure 6,7 (top, center): This series of orthophotos represent the location of the precedent study Site A in relation to the center of Berlin, Germany (Created by author, Original map data: Google Earth, 2016b).

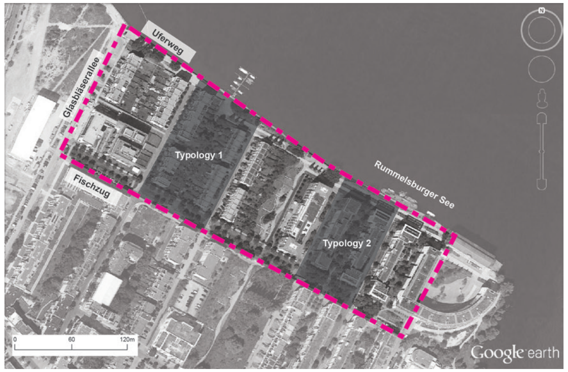
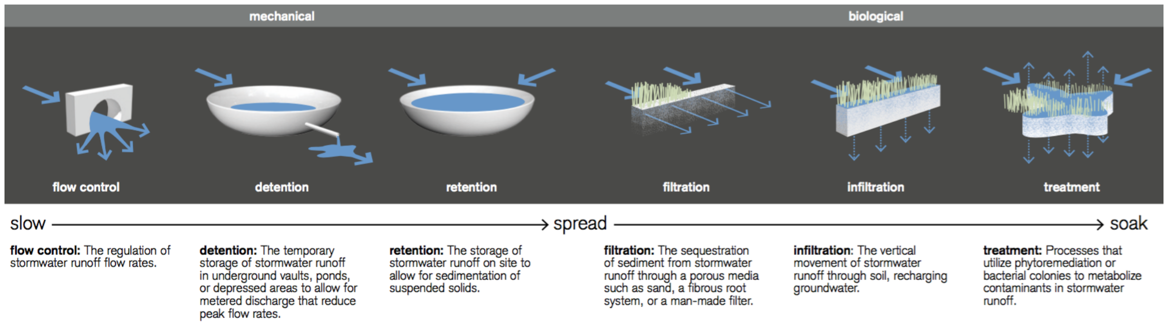


Figure 8 (bottom): This diagram highlights the study area, specifically the two typologies which will be analyzed as part of the study (Created by author, Original map data: Google Earth, 2016b).

traditional lawn front gardens. The amount of impervious surface on this development is minimized with the use of narrow 5 meter roads and semi-pervious driveways and parking areas. Some of the buildings include first floor private residential garages, while others are limited to open surface parking. In addition to the front gardens, these homes have private back yards, or gardens. Typically, these garden allotments consist of small vegetable gardens, lawn, patios and children's play features. In general, it can be said that the surface water management of this development relies heavily on surface water flow, spread and percolation, which is only possible due to the limited imperviousness seen throughout the site.

Image 6 (top): This photograph shows a front entrance garden with vegetation and permeable surfaces surrounding the open downspout. This allows water to infiltration, spread and soak on site. The photograph is labeled with the associated water management functions and associated ecosystem services produced by the entrance garden and roadway design. A variety of permeable pavers are used to differentiate between public and private, and parking versus pedestrian areas (Photo by author).

Figure 9 (bottom): The diagram to the right shows typological diagrams based on a slow, spread and soak approach toward ISWM. The diagram also differentiates the approach based on mechanical or biological system. This approach is mimicked on Site A, typology 1 as vegetation and pervious surfaces are used to slow, spread and soak the surface water on site (University of Arkansas Community Design Center, 2010).



The second housing typology located at Site A in Friedrichshain, Berlin, consists of larger four to five story apartment buildings. Some of the buildings include vegetative roofs which reduce the amount of excess water directed to the surface level, and reduce the peak discharge levels. Green roofs influence water management through the plants ability for rain water intake and evaporation and the soils ability for water retention. The prominent surface water management approach for these blocks consists of the treatment of water in the shared green space between the buildings.

The green space makes use of high and low points and changes in land form in order to create water catchment and retention areas to allow for ground infiltration over time. Not only is this space used for water management, but it is also a central amenity space, acting as a gathering space, park space, and main access point for the buildings and lower apartment units. The terraced character allows for some spaces to still be utilized by patrons even during

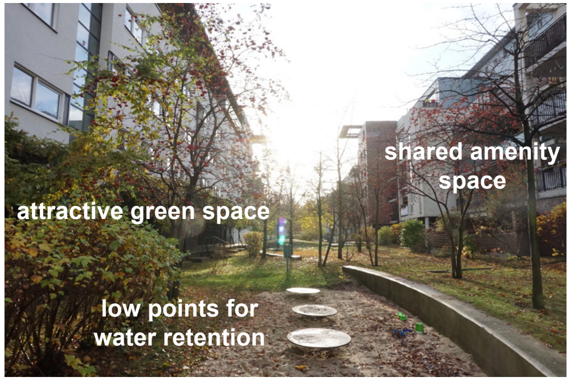


Image 7,8,9 (top, bottom left, bottom right): This series of photos shows the dual function of the central amenity space working as a water retention and infiltration zone. Concrete canals connect open roof downspouts to sand filled infiltration trenches while lower depressions are created within the landscape to treat local surface water with a spread and soak approach. Very little impervious surfaces are seen on this site (Photo by author).

or after rain events, while they are also available for water storage and overflow during larger storm events.

Small cement canals guide water from the downspouts to sand filled infiltration trenches, while the remaining space is used to treat surface water flow. Children's play areas filled with sand are also used for water infiltration during rain events in addition to their amenity use.

The main street, Fischzug, acts as a central spine for the peninsula, with a series of bus stops along the road. In addition to the roads function for vehicular circulation, there are also two large vegetative swales running parallel to the roadway. These green strips include lawn, trees, and sand pedestrian paths at the high points. These areas as called "gartenhydrants" as seen on signs at the site, translating to water garden from the original German meaning. The use of

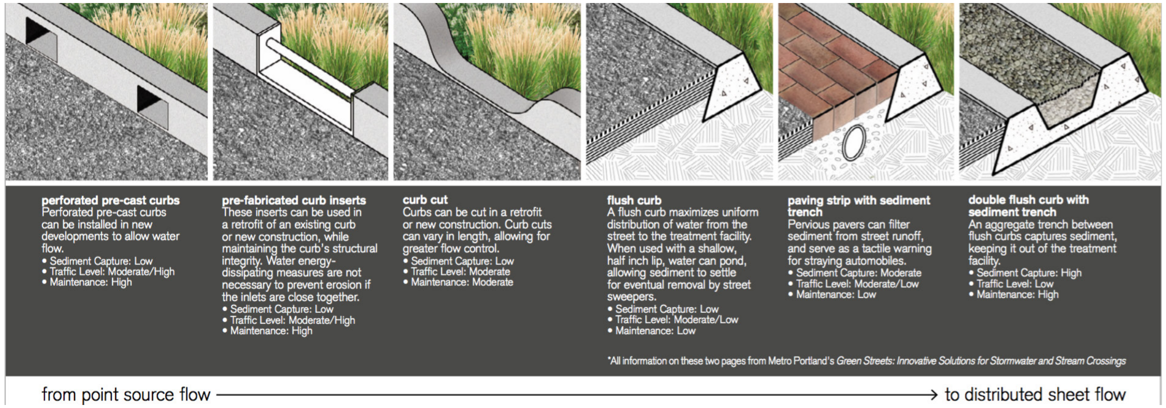


Figure 10 (top): The diagram shows curb alternatives allowing surface water runoff to enter retention and detention basins along roadways instead of following conventional curb and gutter drainage systems (University of Arkansas Community Design Center, 2010).

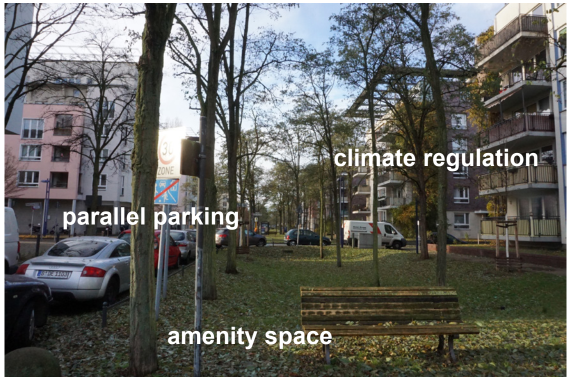


Image 10, 11, 12, 13 (center left, center right, lower left, lower right): These series of photos show the roadside as an amenity space and functional network with a curb cut and concrete swale system used to direct water into vegetative retention areas (Photo by author).

curb cuts along the road allow for rainwater and surface water to sheet flow into the designated detention areas. Fischzug is wider and allows for on street parking, unlike the narrow residential roads located in typology one and two of this study.

The pedestrian boulevard, Uferweg, located along the Rummelsburger See has minimal impervious surface and is designed to reduce the amount of point source polluted runoff into the river. Along the typology one housing, sand surface cover is used to allow for additional infiltration of surface water. A vegetative swale directly along the water's edge is used to capture any excess runoff which may approach the water's edge, preventing it from directly entering the river. Along the typology two housing, a change in ground elevation is used to help ensure that the water from the development will be treated within the inner open space of the buildings, limiting the risk of runoff from directly entering the water body. Along the boulevard, there are two paths between green strips. The condition of this space is not well maintained at this time, thus not functioning to the best of its abilities or potential as an amenity and water treatment facility.

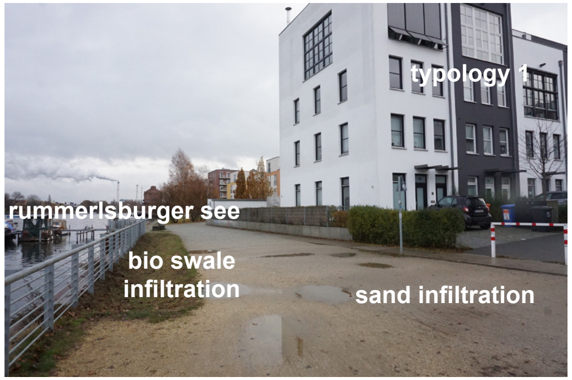


Image 14: The area between typology 1 and the Rummelsburger See consists of sand and gravel paving and a vegetative retention strip running parallel to the water's edge to reduce the amount of point source pollution from surface water runoff.

Image 15: The ground floor of typology 2 is raised higher than the Uterweg pathway creating a bowl like effect with the central open space to make sure all water associated with the building plot is treated on site. The public amenity space along Uterweg includes some vegetation and impervious paving, thus could be redesigned to incorporate more effective surface water management approaches.

Figure 11: This diagram summarizes the general water management schemes on Site A as also represented with photographs and descriptions (Created by author, Original map data: Google Earth, 2016b).

4.1.2 Site B – Vauban, Freiburg

Vauban, located in South Freiburg, near the Black Forest border, is a sustainable development constructed in 2000. In the 1930's, Vauban was home to a French military base. After the second world war, the district grew with hippies and squatters, who took over the original war barracks and eventually transformed them into co-housing districts.

Today, Vauban has become a "sustainable model district," home to Rolf Disch's first Passivhaus development, a 59 unit Solar Settlement part of the International Solar Energy Society and countless low impact development housing complexes (Gregory R., 2011). The analysis of Vauban focuses on a series of housing blocks located in South Vauban between Vaubanalle and the Dorfbach stream. The site is connected to the greater Freiburg city via the extensive light rail/tram and bus network with three stops located in the district along Vaubanalle: P.-Modersohn-Platz, Freiburg, Vauban Mitte, and Innsbrucker Straße. The comprehensive public transportation network, in addition to a purposefully limited road network and a high cost for parking (approximately 18,000 euro) have created a precedent setting pedestrian and cyclist friendly district.

The integrated surface water management approach for Site B is one of flow control, transport, detention and infiltration. This is very similar to the slow, spread, and soak LID approach which is used in more modern North American urban housing developments.

The blocks which this analysis focuses on not only treat the water on site, but the runoff water is directed in two directions. To the North, the surface water is captured in a series of vegetative swales running parallel to the light rail line. To the south, the surface water runoff is treated with dense vegetation, before becoming runoff as sheet flow into the local stream network. It is important to note the importance of the dense vegetation seen in Vauban. Conventional residential lawn space has been transformed into dense, vegetative networks, providing the possibility for evapotranspiration, local habitat and micro-ecosystems for flora and fauna. This method of bio-engineered

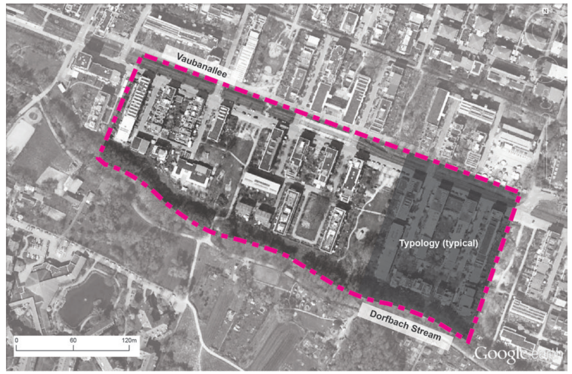


Figure 12,13 (top , center): This series of orthophotos represent the location of the precedent study Site B in relation to the historic town of Freiburg, Germany and Site C, Riselfeld, which is also located on the outskirts of Freiburg (Created by author, Original map data: Google Earth, 2016c).

Figure 14 (bottom): This diagram highlights the study area of Vauban and has highlighted a typological block which will be analyzed in further detail (Created by author, Original map data: Google Earth, 2016c).

solutions allows for a regenerative and nutrient rich environment that is ultimately able to hold and infiltrate a great deal of surface and underground water.

In addition to vegetative roofs, which a majority of the buildings at this site have, there are a series of open downspouts directing excess rainwater from the roof into shallow canals between housing parcels. The canals or swales are typically made of pavers and are well integrated into both the entrance gardens of the residences and the road network. These canals either lead into vegetative areas, or are connected to a greater canal network following the road layout, directing all the captured surface water into a series of swales along Vaubanalle.

The success of the swale network is that the water flow is gravity fed through a hierarchical system of site sensitive designed infrastructure. The entrances to residential units are typically higher than the elevation of the road, allowing for an approximate 2% slope from the finished floor elevation of the building to the roadside, thus allowing for easy and subtle water flow. The road itself is also sloped with the lower end meeting the main street, Vaubanalle.

The narrow roads within the blocks of this site are seen less as a road and more of

Figure 15: The above diagrams represent a North American approach to LID urbanism which replaces conventional urbanism (left) consisting of a “drain, direct, dispatch, approach by treating water on site and at the surface with an integrated LID (right) “slow, spread, soak” approach, as applied in the Vauban District (University of Arkansas Community Design Center, 2010).

Figure 16: Traditional industrialized monoculture lawns require high amounts of maintenance and offer little back to the environment and local ecosystem in terms of habitat creation, biodiversity, or surface water management. The revolutionized lawn, as seen in the residential plots of Vauban adapt the vegetation to local climate and are used to mitigate stormwater runoff, while also reducing traditional lawn irrigation and management costs (University of Arkansas Community Design Center, 2010).

Image 16,17: These photos show examples of a low impact lawn as seen through out Site B in Vauban (Photo by author).

a communal amenity and open space. In addition to the circulation aspect and the water management layer of the streets, the human scale street section is a space for gathering and play, with benches and children's play equipment found throughout. Vauban changes the role of streets from strictly utilitarian to functional and social.

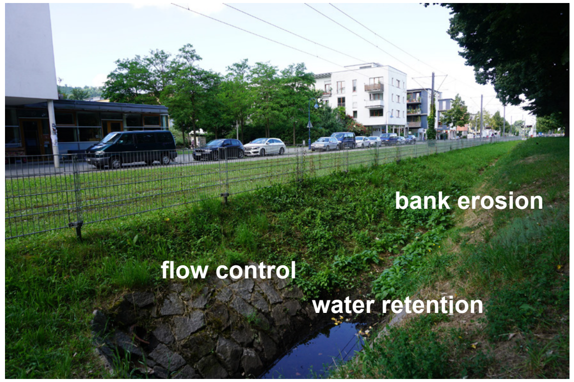
In addition to the open space allotted by entryways and streetscape, and private back yards for first floor residents, the neighborhood is designed to incorporate a series of parks separating the residential

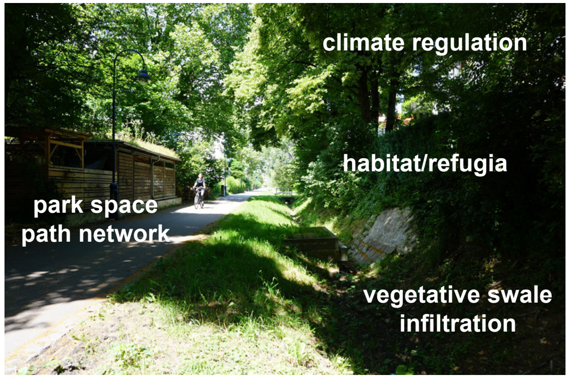
Image 18 (top): This photo represents the typical streetscape in Site B. Narrow swales direct water from rooftops to larger swales which direct water to a series of larger retention swales. The lush vegetative streetscapes and minimal impervious surfaces allow for water infiltration and evapotranspiration in addition to providing other ecosystem services such as climate regulation, habitat creation, and heat island stress reduction (Photo by author).

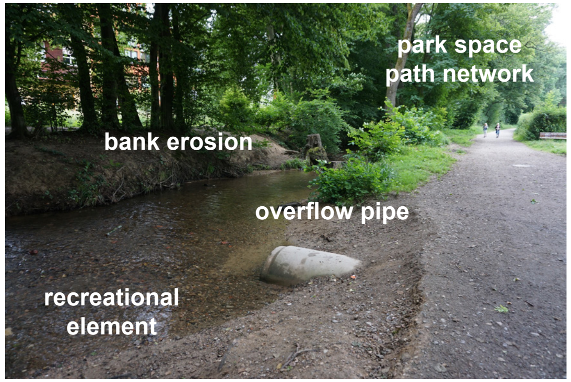
Image 19 (left): Strict regulation on parking, narrow roads, and a high cost for pricing allow Site B to be primarily designed for pedestrians and cyclists. The elimination of on street parking creates a human scale which has been lost in conventional and traditional neighborhood streetscapes (Photo by author).

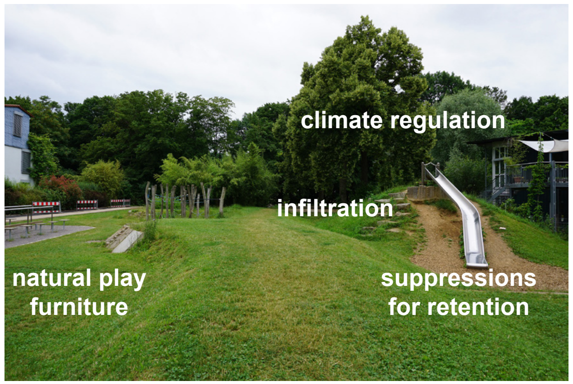
Image 20 (right): The center line of the road is at a higher elevation, thus allowing water to enter the parallel swales, however the ability for water to flow into the drains and eventually join the vegetative swales parallel to Vaubanalle is possible due to the 2-5% slope of the road from the end of the street to the beginning (Photo by author).

buildings. These park spaces, with nature-play themes and play features, have limited impervious surfaces and are utilized for surface water infiltration in addition to their function as park space. The parks integrate direct access from Northern Vauban to the Dorfbach stream and the associated greenway, The greenway acts as a type of riparian buffer for the Dorfbach stream, while also incorporating public amenities such as pervoius gravel walking and biking paths.









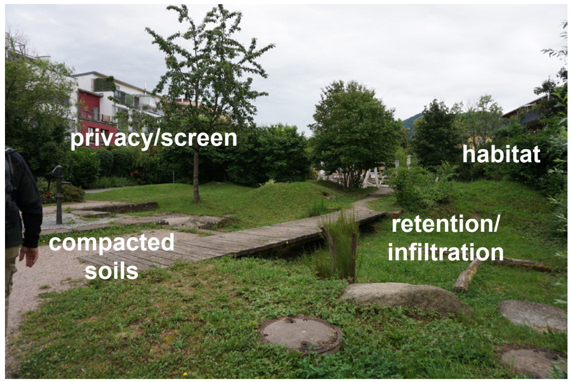


Image 21,22 (top): These photos show the condition of the series of vegetative swales running parallel to the Vaubanalle tram line. The water runoff north of the housing blocks is directed to these series of swales for water retained and infiltration. During larger storm events, the excess water is directed to the Dorfbach Stream to the West of our study site (Photo by author).

Image 23,24 (center): The surface water south of the housing blocks is led to a vegetative swale running parallel to the Dorfbach stream. This swale treats the surfacewater runoff and allows it ample time for infiltration. In the case of larger storm events, the swale directs overflow directly into the stream behind. The stream has lost some of its original riparian buffer due to recreational use (Photo by author).

Image 25,26 (bottom): Between the typological housing blocks there are several park spaces with various natural playscape elements. The parks make use of topography to create spaces for water retention and infiltration. There is minimal impervious surface however the soil is extremely compacted due to heavy use thus surface water infiltration is limited on site (Photo by author).

Figure 17: This diagram summarizes the general water management schemes on Site B as also represented with photographs and descriptions (Created by author, Original map data: Google Earth, 2016c).

4.1.3 Site C – Rieselfeld, Freiburg

The Rieselfeld district, located in Western Freiburg, is a larger district with more diverse housing developments. The most common housing typology consists of “eastern-block” style housing estates, which were rebuilt in the 1980’s after a war torn Freiburg (Purvis A., 2008). The site which the analysis focuses on within Rieselfeld is less dense than in Vauban (Site B)and consists of three or four story shared housing developments with a uniformed aesthetic. The housing blocks and road structure are centered around a central park space with a network of recreational paths stemming out of the open space (Purvis A., 2008).

Though Site C is less dense than the Vauban development, the Rieselfeld development is still considered a conservation development with 240 hectares of the property designated as landscape conservation and only 78 hectares allotted and developed as residential development (Gregory R., 2011). Just as with Site B, Riselfeld is also connected to the greater Freiburg transportation network with a series of bus and light rail stops: Freiburg Geschw.-Scholl-Platz, Maria-von-Rudloff-Platz, and Bollerstaudenstraße. However, due to a more extensive and user friendly road network, the presence of private vehicular transportation and on street parking is much greater compared to Vauban and central Freiburg.

At first glance, Rieselfeld does not appear as green and innovative as Site A and Site B. Due to the older nature of the buildings and infrastructure, compared to the other sites, Rieselfeld may come across as a more conventional development in terms of innovative design and sustainability criteria. The key attribute in terms of the sites integrated surface water management is highlighted within the green space network, hidden beneath dense vegetation.

The surface water management approach at Site C is a combination of hard and soft engineering. Typically, surface water

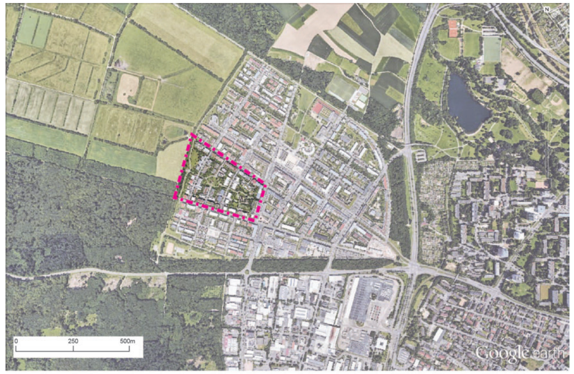


Figure 18,19 (top, center): This series of orthophotos represent the location of the precedent study Site C in relation to the historic town of Freiburg, Germany and Site B, Vauban, which is also located on the outskirts of Freiburg. Rieselfeld was developed with a conservation development approach, with 68% of the district maintained as landscape conservation. The edge of the conserved landscape can be seen to the West of the study area, with the Bollerstraudenweg stream acting as an active border (Created by author, Original map data: Google Earth, 2016c).

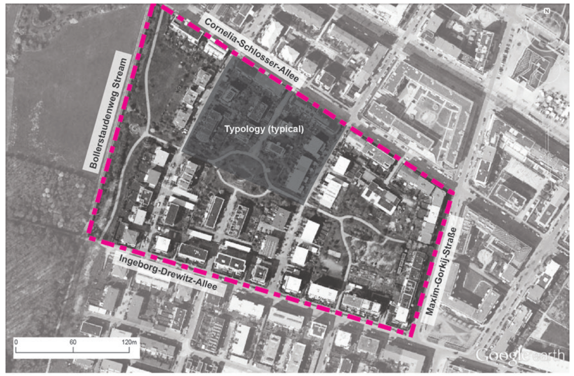


Figure 20 (right): This diagram shows the limits of the study area of Vauban and has highlighted a typological block which will be analyzed in further detail. Unlike Sites A and B, the study area of site C is uniquely developed compared to its surrounding built environment (Created by author, Original map data: Google Earth, 2016c).

is directed off of the roadways and to an underground pipe network. However, unlike conventional urban drainage which would transport the polluted surface water runoff to a treatment facility off site, the development in Site C transports the water into a series of vegetative and landscape retention and infiltration swales and ponds. These living systems allow for the polluted surface water to be treated by biological filtration, and infiltrated back into the local groundwater system over time.

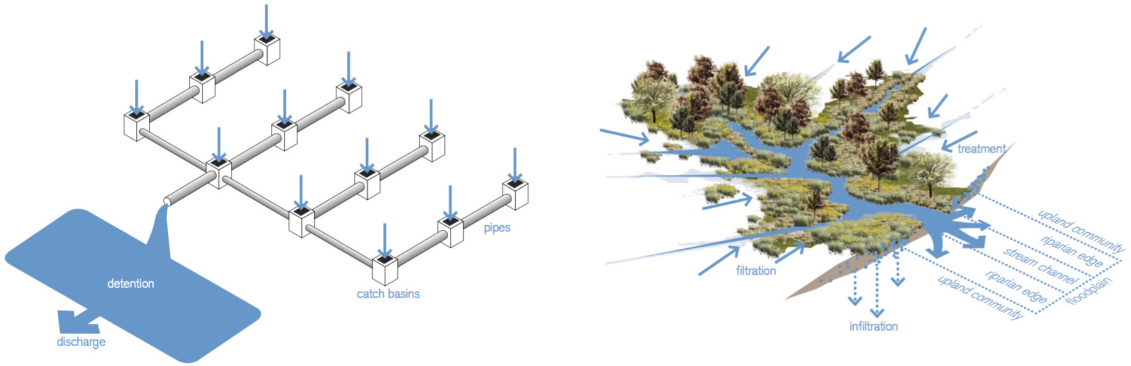


Figure 22: These diagrams depict a typical approach to conventional urban drainage compared to a LID soft-engineering alternative, which is also used at Site C. Conventional surface water management, also known as "end of pipe" infrastructure focuses on catchment, direction and dispatch of the polluted water to another site. Low impact management on the other hand is considered more as a "watershed approach" with the use of the slow, spread and soak concept. The low impact approach attempts to mimic the natural hydrological cycle on site with soft engineering techniques (University of Arkansas Community Design Center, 2010).

The water treatment retention areas in Site C are well integrated into the neighborhood's public park space and recreational path network. Underground pipes and connections cutting below pedestrian paths and amenity spaces carry the surface water from one designated retention space to another, thus slowing down the water, allowing it to spread across the landscape and ultimately soak or infiltrate into the ground.

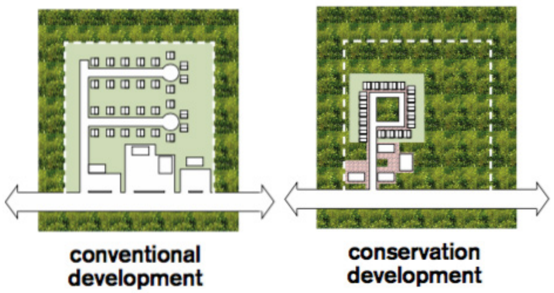


Figure 21: The diagrams above show the difference between conventional development and conservation development, a planning method used during the planning and reconstruction of Rieselfeld (University of Arkansas Community Design Center, 2010).

The topography of the site allows the water management and piping system to be guided by gravity and natural flow. The housing plots and road network are set slightly higher than the open park space. Once the surface water enters the drains along roadways and intersections, the water is then gravity fed to the vegetative treatment amenities. The ultimate goal of this integrated approach is to reintroduce the natural hydrological cycle into urban landscapes and developments.

As seen in Sites A and B, Site C also makes use of vegetative green roofs to minimize the amount of surface water needing to be managed. In instances where green roofs are not available, open down pipes are connected to the roof gutter system which directs the flow of water through front entrance gardens and eventually to roadside drains. Though this system is not as prominent as seen in Site B, it is still a key element in Rieselfeld's integrated water management network.

The focus of this study are will be put on the decentralized biological treatment network that is woven into the fabric of this community development.

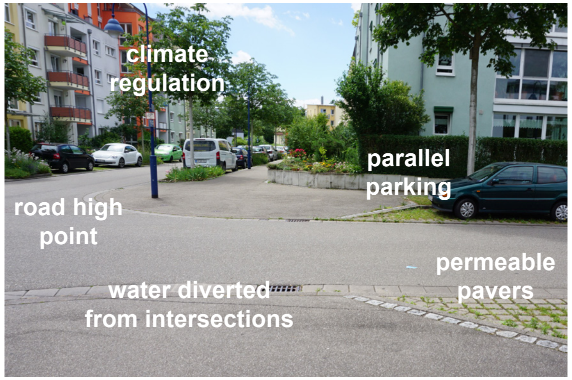
Image 27 (top left): This photo of Cornelia-Schlosser-Allee shows the street scape with planting beds, infiltration strips, and street trees available for climate regulation, heat mitigation, and water management. Unique to this site is the allocated electric car parking which is highlighted in green. The parallel parking is differentiated with permeable pavers and separated by the road with drainage outlets at the low point (Photo by author).

Image 28 (top right): Central to the surface water management practice in Site C is to divert surface water away from intersections. An elevated crown road design allows for surface water to sheet flow to the edges of intersections (Photo by author).

Image 29,30 (center): These photos reflect the narrow residential streets which approach the park space in the center of our study site. As seen in Site B, these narrow streets are seen less as roads and more as amenity spaces or extension of homes. Lush vegetation captures and treats roof water directed from open downspouts. The slope of the road and higher finished floor elevations (FFE) allows for the surface water to flow more easily into catchment drains at the end of the road (Photo by author).

Image 31 (bottom left): The drain network is designed to make a clear separation between public roadways and private entrances. The simple use of distinct permeable pavers along the axis of the drains is a unifying element through out the roads and housing blocks seen in Site C (Photo by author).

Image 32 (bottom right): Just as with Site A and B, many homes in Site C make use of open downspouts to treat rain water vegetatively. The level of vegetation and ability to allow for infiltration varies from parcel to parcel. It is also important to note the importance of vegetative roofs and its influence on minimizing the amount of surface water on the ground (Photo by author).

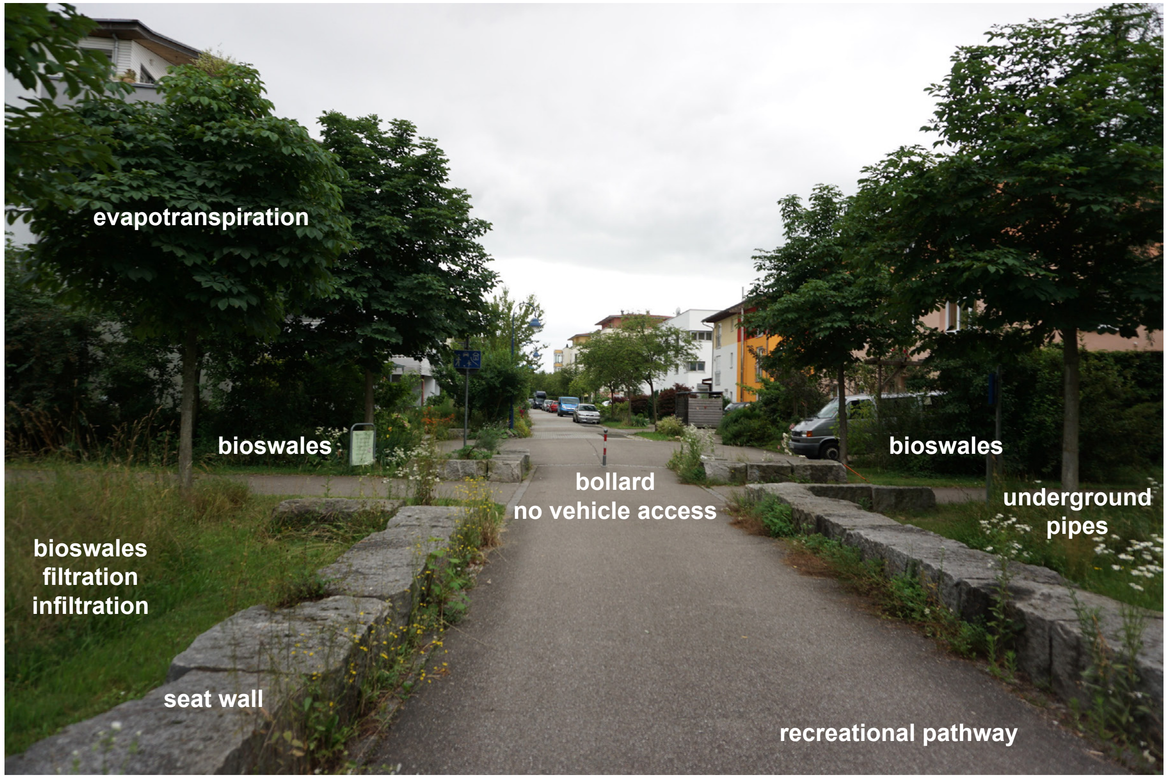


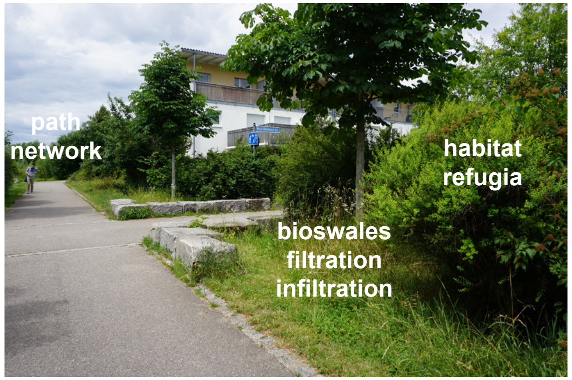
The open space and recreational path network run parallel to the open water network which flows through the site, creating an extremely lush and "nature-like" feeling to the park space. The pipe outlets leading the surface water from one section of the site to the next are hidden amidst dense vegetation, creating a seamless network between the two systems. Though the look and feel of the space seems very natural and organic, it is still a very highly engineered water management network. The limitation of such an approach is the vast amount of space which is needed for treatment and open space amenities.

Image 33 (top): This photo represents the relationship between the housing blocks and the park space. The park space is cut off to vehicular traffic with bollards, limiting car circulation from north to south of the study site, promoting alternative transportation such as walking or cycling. The series of bioswales and retention areas begins at the edge of the park where the water from the roadways enters the treatment zones (Photo by author).

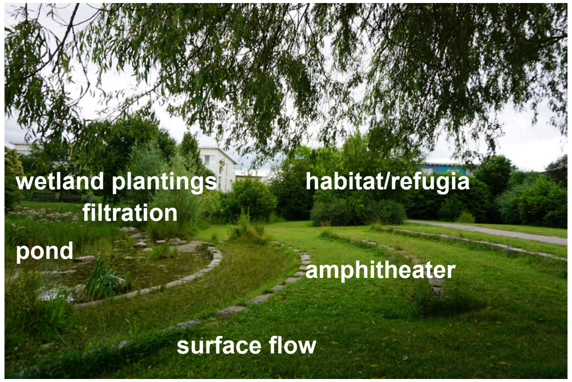
Image 34 (bottom left): The network of paths through out the site remain elevated, as the swales and vegetation are sunken into the landscape. This change is topography is used to allow for water collection and retention through out the area, with the exception of designated open park space at surface level (Photo by author).

Image 35 (bottom right): Concrete pipes transport water from one section of the park to another, eventually leading the non-infiltrated or transpired water to the Bollerstaudenweg Stream at the edge of the study site (Photo by author).





In addition to the water conveyance network, there is also a playground and pond located in the center of the park space. The pond is used as surface water retention as well as recreational amphitheater space. Site C is a project which exemplifies the multifaceted benefits of integrated surface water management in housing developments. The benefits of this approach go well beyond water management and into a realm of ecosystem services and socio-economic benefits associated with having an extensive park and open space in a densely populated neighborhood. Examples of such services and benefits include habitat creation, increase in property values due to landscape and water amenities, as well as a higher quality of life with greater access to outdoor open space.



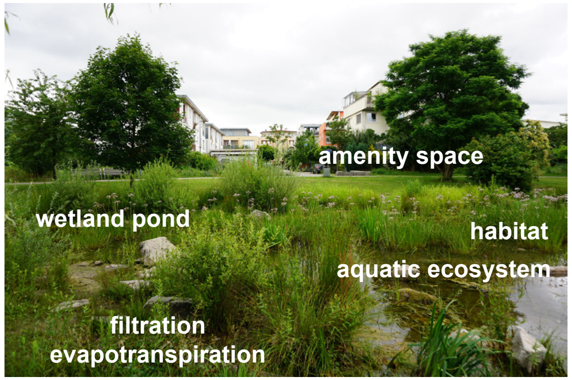


Image 36,37 (top): The central pond and wetland provide countless ecosystem services including a park and water feature (Photo by author).

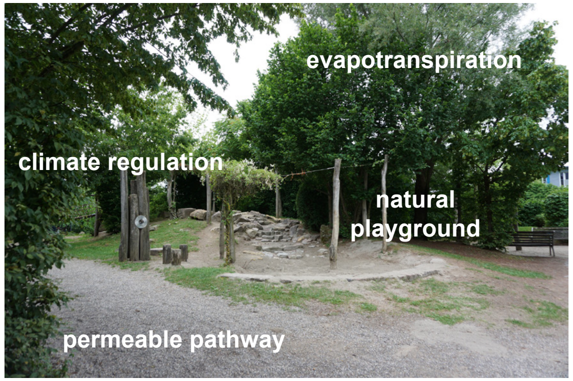


Image 38 (center left): Several nature playgrounds are located through out pockets of the park space amidst lush vegetation and water catchment areas (Photo by author).

Image 39 (center right): Pathways run through out the park, and are typically running parallel to the water management network. The sense of water is always present at the site (Photo by author).

Image 40,41 (bottom): The park offers open views to the conserved land to the north of the study area. An extreme change in elevation separates the park and the Bollerstaudenweg Stream below (Photo by author).

Figure 23: This diagram summarizes the general water management schemes on Site C as also represented with photographs and descriptions (Created by author, Original map data: Google Earth, 2016c).

4.1.4 Peak Discharge Study

As discussed in the literature review and previous chapters, one of the most important characteristics of a development influencing surface water quantity and quality is the amount of imperviousness on the site. Impervious surfaces are a leading cause of non-point source (NPS) pollution as the surface water comes in contact with numerous surfaces, all of which contain unique pollutants (EPA, 2016b). Through the use of conservation development, high density housing, stricter road networks and green infrastructure, the amount of impervious surface can greatly be reduced.

The following diagrams calculate the amount of peak runoff produced in a typological block of the 3 precedent studies. Peak discharge events typically result in the most polluted and intense runoff episodes. The results found will be neutralized based on 1-hectare of land in the three sites analyzed. The rational equation for peak discharge of runoff used is Q=ciA where 'c' is a calculated runoff coefficient, 'i' is the rainfall intensity and 'A' is the area that is being calculated. The calculated runoff coefficient is based on ground cover, land use and associated pollutants. The runoff is associated with a standardized value (Petschek P., 2016). The calculation is solved based on varying land covers as differentiated and vectorized by orthophotos of the sites.

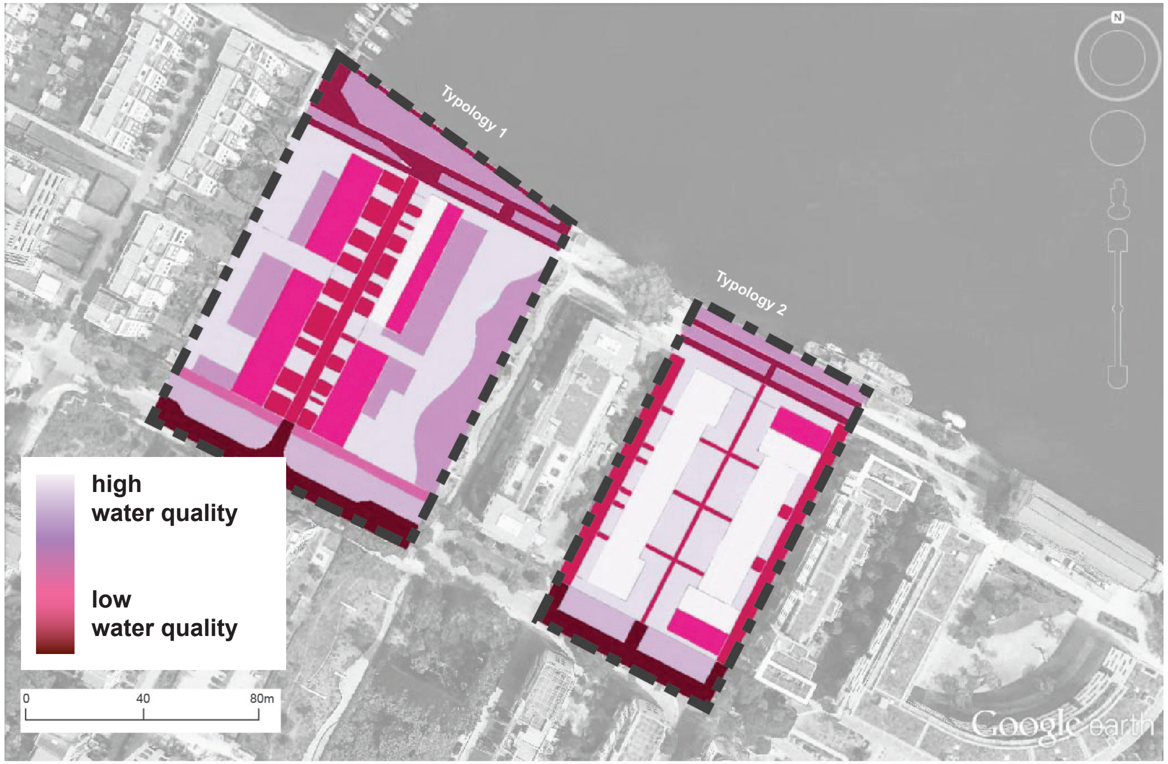


Figure 24: Two typologies were analyzed as part of the Site A study area. As seen in the figure, typology 1 consists of larger areas with lower water quality attributes compared to typology 2 (Created by author, Original map data: Google Earth, 2016b).

The lower the peak discharge the better, as it shows that the surface water is treated on site using LID and IUWM techniques and less polluted water is entering the central sewage system and receiving water bodies. When more water is treated on site, a greater amount is re-introduced into the local groundwater table, thus replenishing and balancing the natural hydrological cycle. The practice of stabilizing and replenishing the groundwater is important in terms of future flood protection and mitigation. The threat of severe flash floods is increased when the groundwater table is not balanced. If the groundwater is able to be replenished, it will increase the holding capacity of water during larger rain events.

The diagrams completed for the runoff study are based on ground cover and are reflective of the quality of water when exposed to that surface. The lighter colors represent less of a negative effect on water quality, while the darker hues infer that the water is susceptible to more pollution resulting in lower quality surface water runoff.

For example, there is a difference between the pollutants which come in contact with rain water on conventional roofs compared to green roofs. Conventional flat roofs made of concrete may contain the following pollutants: heavy metals, polycyclic aromatic hydrocarbons (PAHs), microbes, pathogens, and pesticides. Depending on the location of the roofs and its relation to vehicular traffic, some pollutants such as PAH's may be more evident. In addition to the pollutants, conventional roofs do little to nothing to mimic the natural or pre-development water cycle. On the contrary, green roofs help to reduce the speed of water by giving it time to infiltrate and evaporate into the atmosphere.

Similar to roofs, traditional asphalt roads also host a high variety of pollutants. Examples of these include: total suspended solids, polycyclic aromatic hydrocarbons (PAHs), phosphorous, nitrogen, motor oil,

Figure 25 (top right): This figure represents the imperviousness and water quality at Site B. A typical typological block on this site is approximately 4ha (Created by author, Original map data: Google Earth, 2016b).

Figure 26: The table to the right represents the surfaces seen on the three sites and provides the runoff coefficient (c) that is associated with the ground cover (Created by author, Original data: Petschek P., 2016)

Graphic	Surface Cover	'I' Rainfall Intensity (l/s)	'C' Runoff Coefficent
	Natural Water	0.03	0
	Greenroof	0.03	0.7
	Vegetation	0.03	0.1
	Swale	0.03	0.2
	Lawn	0.03	0.4
	Gravel/Sand	0.03	0.2
	Roof	0.03	1.0
	Permeable Paver	0.03	0.6
	Paver	0.03	0.6
	Road	0.03	1.0

copper, and micro-organisms. Many of these pollutant are considered as chronic pollutants meaning their continuous presence and accumulation has greater and more sever negative effects over time on things such as receiving water bodies. More pervious or permeable pavements and vegetative land covers greatly reduce the quantity of such pollutants by using vegetation as a mitigating factor.

Figure 27 (top right): This figure represents the imperviousness and water quality seen at Site C in Riselfeld, Freiburg. The primary use of green roofs on buildings in this study site greatly reduce the amount of impermeable hardscape on the site (Created by author, Original map data: Google Earth, 2016c).

Figure 28: The following table represents the data gathered for the peak runoff evaluation. The areas of land cover were found by vectorizing orthophoto images and calculating areas of surface cover. The areas were then used in the rational Q=ciA equation using the runoff coefficient and rainfall intensity data provided in Figure 26. The result of peak runoff based on individual land cover was added to represent the total peak discharge for the site. Due to an inconsistency in site size, the result was neutralized based on a 1 hectare area, to allow for a more appropriate comparison between the sites (Created by author).

Graphic	Surface Cover	Site A1 'A' Area (m²)	Site A1 'Q' Solution	Site A2 'A' Area (m²)	Site A2 'Q' Solution	Site B 'A' Area (m²)	Site B 'Q' Solution	Site C 'A' Area (m²)	Site C 'Q' Solution
	Natural Water	0	0	0	0	995	0	258	0
	Greenroof	310	6.51	2220	46.62	2300	48.3	3654	76.734
	Vegetation	3943	11.829	2977	8.931	14185	42.555	6192	18.576
	Swale	960	5.76	477	2.862	3011	18.066	0	0
	Lawn	3355	40.26	630	7.56	6022	72.264	2933	35.196
	Gravel/Sand	348	2.088	0	0	191	1.146	0	0
	Roof	1849	55.47	354	10.62	5592	167.76	1496	44.88
	Permeable Paver	1240	22.32	1288	23.184	5254	94.572	3829	68.922
	Paver	921	16.578	352	6.336	0	0	476	8.568
	Road	893	26.79	616	18.48	2022	60.66	1325	39.75
	Total Area (m²)	13819	13819	8914	8914	39572	38577	20163	19905
	Total Q (l/s/m²)	-	187.605	-	124.593	-	505.323	-	292.626
	Total Area (ha)	1.3819	1.3819	0.8914	0.8914	3.9572	3.8577	2.0163	1.9905
	Total Q (l/s/ha)	-	135.75874	-	139.772268	-	130.99075	-	147.0113

4.2 Prague Project Introduction

The project site selected for this Master Thesis is located in Černý Most, Prague in the Czech Republic. The task is to propose a series of typologies associated with retrofitting existing surface water management networks in urban housing estates. The site of Černý Most was selected as a typical example of such housing developments in the Czech Republic, known as Panelák housing estates in Czech, and in neighboring post-communist European countries. The schematic proposals will incorporate BMP and SUDS solutions into the existing built environment in order to transform the current site with conventional drainage into an integrated surface water management network. Though the task is to primarily address surface water management, the schematic typologies will also address other aspects of the built environment such as circulation, habitat and socio-economic elements.

4.3 Current Czech Approach Toward Urban Drainage

Climate change and a rapid rate of growing urbanization have become key factors in a progressive drive toward implementing integrated surface water management into the Czech landscape and urban fabric. An increase in extreme flood events over recent years has resulted in the overflow of local sewage systems, and ultimately resulted in the degradation of receiving water ways due to direct outflow. Polluted urban surface water outflow has changed the water quality, biodiversity, mitigation cost and quality of life in Czech's natural water bodies (Stransky D. et al., 2011). In 2012, 82.5% of Czech Republic's total population lived in buildings connected to centralized sewerage systems. As urbanization increases, the number of people dependent on the system annually has been increasing, resulting in the extensive expansion of sewerage networks and wastewater treatment facilities in the country (Ministry of Agriculture of the Czech Republic, 2012).

Historically, the Czech Republic has been limited to combined sewer systems and has not been exposed to decentralized water management approaches. Recently, separate sewage systems have begun to be implemented in the outskirts of larger municipalities (Stransky D. et al., 2011). Compared to more progressive countries, the Czech Republic has had a delay in the implementation of more modern water management approaches and technologies due to its international isolation during the second half of the 20th century (Stransky D. et al., 2011). Though this political era has passed, there is still a large paradigm shift waiting to be had in terms of the built environment and sustainability. An increased interest in water management has only become evident in recent years after several severe flood episodes. Until then, urban drainage lacked awareness in the public eye, and was only considered an afterthought for city engineers. A lack of political will to implement and encourage sustainable principles and technical standards still holds as an issue compared to neighboring countries like Germany.

Until 1989, professions such as engineers had limited access to international research and development and were thus confined to conventional and conservative urban drainage practices (Stransky D. et al., 2011). The approach toward urban drainage and water management has only recently begun to expand into a field of its own. In 2007, the first specialist group on Urban Drainage for the Czech Water Association (SGUD) was established (Stransky D. et al., 2011). This group began incorporating the EU Water Framework Directive into the Czech built environment and put great attention on urban drainage and water management across the country.

Today, under the Water Act and Building Act of 2010, new development projects must address managing surface water on site. Many developers have nonetheless been able limit the implementation of these principles through certain loopholes within the legal system. The fact that the Czech Republic does not have national technical standards for design and construction of low impact technologies creates a gray area in terms of requirements and regulations. Most commonly German regulations and standards are being used in the Czech Republic, however the enforcement of such standards is not possible as of yet (Stransky D. et al., 2011).

Under the Water Act and Building Act, existing developments are entitled to economic breaks on stormwater fees if alternative solutions are used to decentralize the water management. With that said, there are currently no clear or standardized national guidelines to quantify these changes (Stransky D. et al., 2011). It is clear that a paradigm shift toward sustainable water management requires a change in perception at all levels of stakeholders and for all professions involved in the built environment. It is thus extremely important to educate not only professionals but also community members, policy makers and decision makers to explain the role and importance of sustainable urban water management.

4.4 Černý Most Analysis

Černý Most is located in the North East of Prague in Prague 14. The housing estates date back to the 1970's and 1980's with typical Soviet style pre-fabricated concrete block housing apartments. The site is located along the Prague Metro Line B (yellow line) off of the Rajská Zahrada station. The following station, Černý Most, is more closely associated with a large Ikea and shopping center, Centrum Černý Most, than the housing estates. With that said, the project site will be referred to as the Černý Most housing estate.

According to the Prague Institute of Planning and Development (IPR) (2016a), one third of Prague residents reside in panel block housing typical of what is seen at Černý Most. IPR and the city of Prague have begun to look at the Černý Most housing estate as a prototype for revitalizing traditional housing estates dating back to the 70's and 80's. The revitalization is said to focus on "public spaces, increasing the economic potential of the area, expanding the range of leisure activities and reviving civic life" (IPR, 2016a).

According to the Mayor of Prague 14, Radek Vondra, "we cannot view housing estates as appendages from a previous era, but must

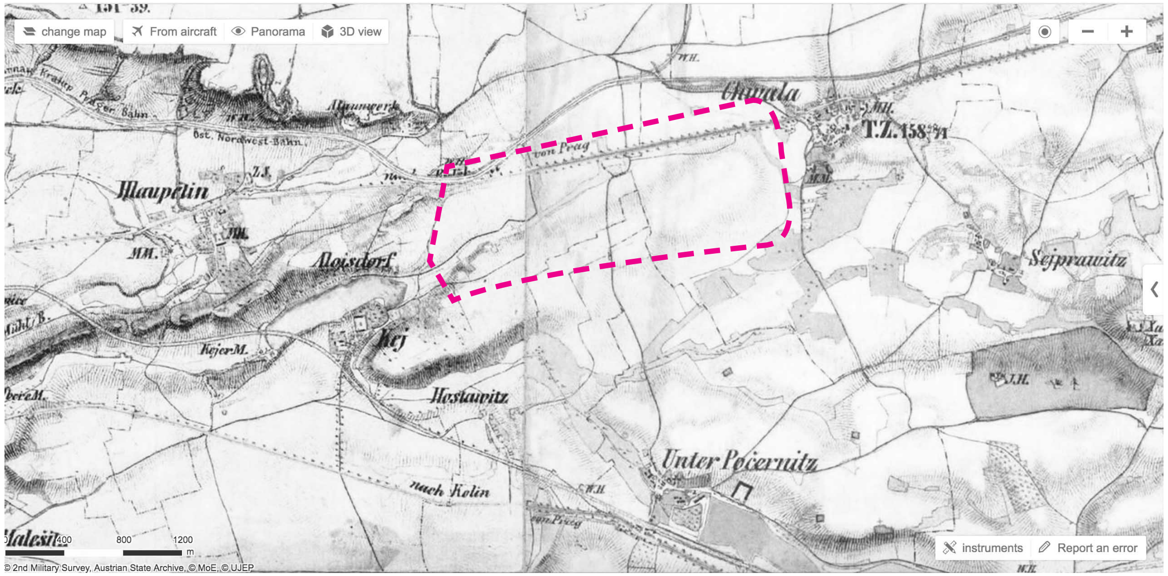


Figure 29: This 19th century military map, dated 1987, shows the former land of Černý Most as farmland with no evidence of extensive development or residential parcels (Mapy CZ, 2017).

see them as locations that have their own specific charm and offer their own unique opportunities” (IPR, 2016a). The current status of the Černý Most development lacks maintenance, a sense of place and a connection to the surrounding landscape and environment.

The current state of the Černý Most housing estate is one that is typical of this housing typology after over 25 years. As time goes on, developments such as these begin to be neglected and forgotten. The sense of community fades, and the residents lose the connection between their home and self identity. These effects are even more extreme is cases such as communist-era developments where a sense of community may never have even existed.

More and more, housing estates on the outskirts of large cities, as seen here, are becoming night time communities where locals commute between their home and the city on a daily basis. The dependency on vehicles, regardless of the metro and

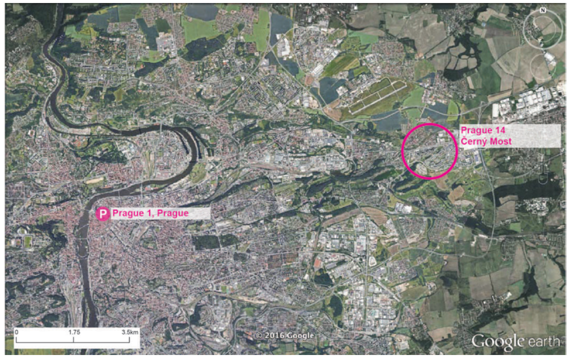


Figure 30: Černý Most in relation to Prague’s city center (Created by author, Original map data: Google Earth, 2016d).

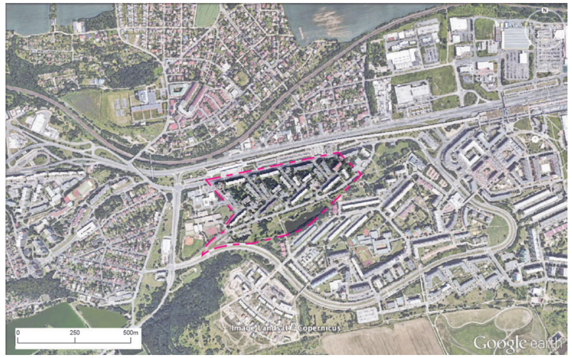


Figure 31: Černý Most housing estate in context to the surrounding Prague 14 neighborhood (Created by author, Original map data: Google Earth, 2016d).

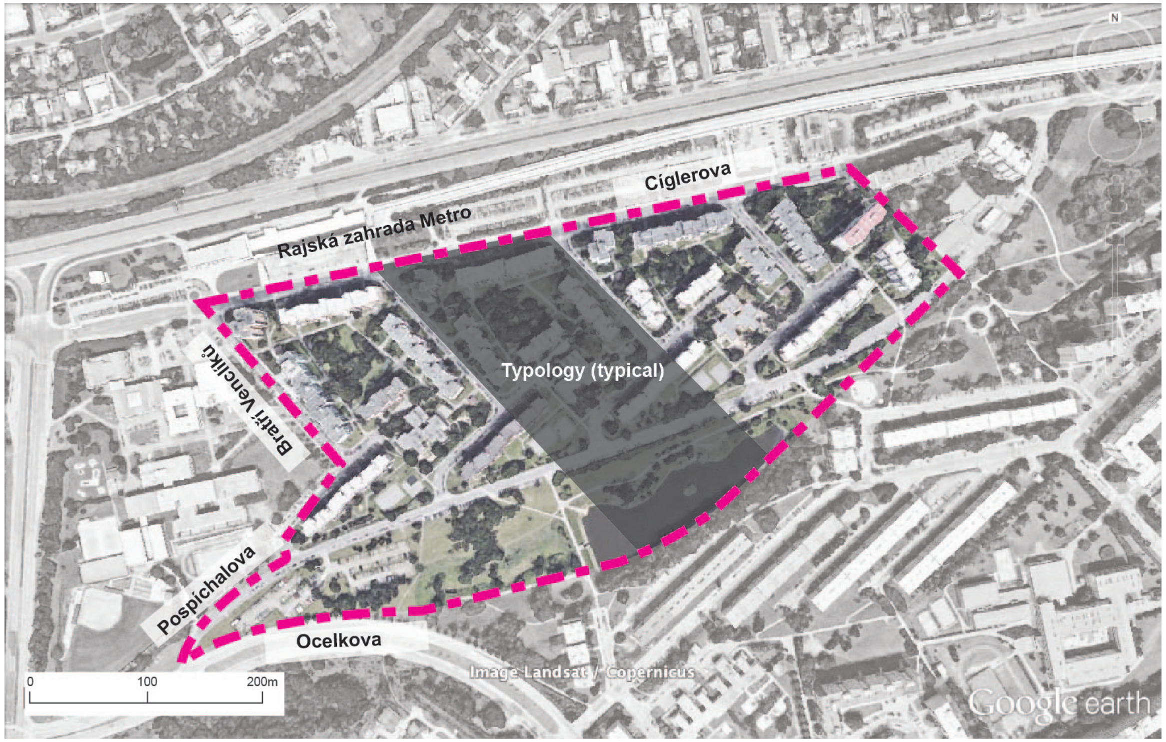


Figure 32: This diagram highlights the study area for the Černý Most housing estate project. The study will focus on the typical housing block typologies North of the pond and public open space. The study and proposals will integrate the housing blocks with the open space network and will reintroduce inner road patterns, while connecting back to the greater existing road network (Created by author, Original map data: Google Earth, 2016d).

bus connection to the city center, is evident in Černý Most as with most housing estates of this type.

The current land cover at the Černý Most housing estate consists of pre-fabricated concrete block housing structures with flat conventional roofs. The expansive and confusing road network is built from asphalt and is surrounded by asphalt sidewalks and pathways. The vegetation on the site primarily consists of conventional lawn with occasional shrubs and hedges to provide privacy for first floor residential units. There is very little evidence of biodiversity or noteworthy habitat based on the existing plantings on site. The vegetation near the man-made pond becomes more wild and less maintained compared to the landscape surrounding the buildings, but is limited by the steep topography.

As with the three German precedent studies, Černý Most was evaluated based on the surfaces on site as well as the quantity and quality of peak discharge runoff. Based on the current condition at Černý Most, the peak runoff for 1 hectare of land based on a typical typological block was calculated using the rational Q=ciA equation. The study was evaluated once with a result of 172 liters per second per hectare of runoff.

Compared to Sites A, B and C, the current

Image 42: A typical photo of the lawn surface cover in the central green space areas within the housing blocks. Some areas also include evergreen shrubs and hedges but open lawn and scattered trees are typical of this development (Photo by author).

Image 43: Vast open lawn makes up the south part of the study area, adjacent to the pond. As seen in the photo, some shrubs are used to separate the parking along Pospíchalova street and the open space (Photo by author).

Image 44: In the case of Černý Most, the roads, sidewalks and secondary paths are all made of asphalt material. For this reason, all asphalt areas area calculated as ‘roads’, with a runoff coefficient of 1.0, in the peak discharge calculation (Photo by author).

Image 45: A single gravel path is seen running along the artificial pond. This area is the only evidence of non-asphalt pedestrian surface cover (Photo by author).

land cover in Černý Most resulted in the highest amount of peak discharge runoff. The site with the least runoff based on the study of the typologies was Site B, Vauban, with 127 l/s/h. This can be attributed to the sites minimal road surface, the extensive use of permeable and semi-permeable ground covers and the presence of dense vegetative ground cover.

Initially, the calculated result for Černý Most was not as high as anticipated. One factor to consider is that during first evaluation, the existing water bodies were included as part

Figure 33: This diagram represents the land cover at Černý Most based on a typical typological block. The diagram shows land cover in terms of the water quality upon interaction with said land cover. This study allows for the estimated calculation of peak discharge runoff on the site. A similar study was done with the precedent Sites A, B and C. (Created by author, Original map data: Google Earth, 2016d).

Figure 34: The table represents the results of the rational peak discharge equation. Areas of land cover were calculated based on the vectorization of an orthophoto, as seen above in Figure 33, and were assessed based on the runoff coefficient of the land cover (Created by author, Original data: Petschek P., 2016).

Graphic	Surface Cover	'I' Rainfall Intensity (l/s)	'C' Runoff Coefficent	Typology Area (m²)	Typology 'Q' Solution	A1 'Q' Solution	A2 'Q' Solution	B 'Q' Solution	C 'Q' Solution
	Natural Water	0.03	0	6835	0	0	0	0	0
	Greenroof	0.03	0.7	0	0	6.51	46.62	48.3	76.734
	Vegetation	0.03	0.1	1090	3.27	11.829	8.931	42.555	18.576
	Swale	0.03	0.2	0	0	5.76	2.862	18.066	0
	Lawn	0.03	0.4	16620	199.44	40.26	7.56	72.264	35.196
	Gravel/Sand	0.03	0.2	330	1.98	2.088	0	1.146	0
	Roof	0.03	1.0	6359	190.77	55.47	10.62	167.76	44.88
	Permeable Paver	0.03	0.6	0	0	22.32	23.184	94.572	68.922
	Paver	0.03	0.6	0	0	16.578	6.336	0	8.568
	Road	0.03	1.0	11179	335.37	26.79	18.48	60.66	39.75
	Total Area (m²)			42413	35578	13819	8914	38577	19905
	Total Q (l/s/m²)				730.83	187.605	124.593	505.323	292.626
	Total Area (ha)			4.2413	3.5578	1.3819	0.8914	3.8577	1.9905
	Total Q (l/s/ha)				205.416268	135.75874	139.77227	130.99075	147.0113

of the study area, however, the water bodies were not included in the peak discharge calculation as they do not have a value. The area of the water body is much greater in Černý Most, thus it may have skewed the average runoff value had the water body not been included in the total typological area.

For this reason, the rational equation was re-evaluated after removing the area of water bodies from the total area of the typologies that were being analyzed. The results showed that Černý Most produced 205 l/sh, which was a much more anticipated result. Consequently, the calculation for Vauban (Site B) also increased with the removal of the stream area, resulting in 130 l/sh, but still stands as the lowest runoff producing

Image 46-51: This series of photos represents the inner facing courtyard spaces between the housing blocks of Černý Most. The topography here is quite extreme with up to 6 meters change in elevation from the point closest to Cíglerova street to the lower border street. The open space is typically raised and at times inaccessible with fences. Other than a few benches, there is little to no programed activity for these central areas. From site observations, it can be noted that the surface water management in this area primarily consists of sheet flow to the nearest drain outlet, typically on the pathway at lower elevations. The open space consists mostly of conventional lawn and scattered tree plantings, offering minimal surface water mitigation function. The connections to this open space are obstructed due to excessive parking lots at the entrances. The parking zones break the clear connection and axis between the courtyards and the surrounding site (Photos by author).

site amongst the precedent studies.

The Černý Most housing estate is located along a more than average steep terrain. Per the existing topography, in the case that there were no engineered water management features, the surface water would naturally sheet flow into the two artificial ponds at the south of the study site. The housing blocks and associated path and road networks are positioned along a downhill land form.

The steep character of the site tapers off at the edge of the open public space to the south, however the steep edge of the ponds creates an inaccessible amenity.

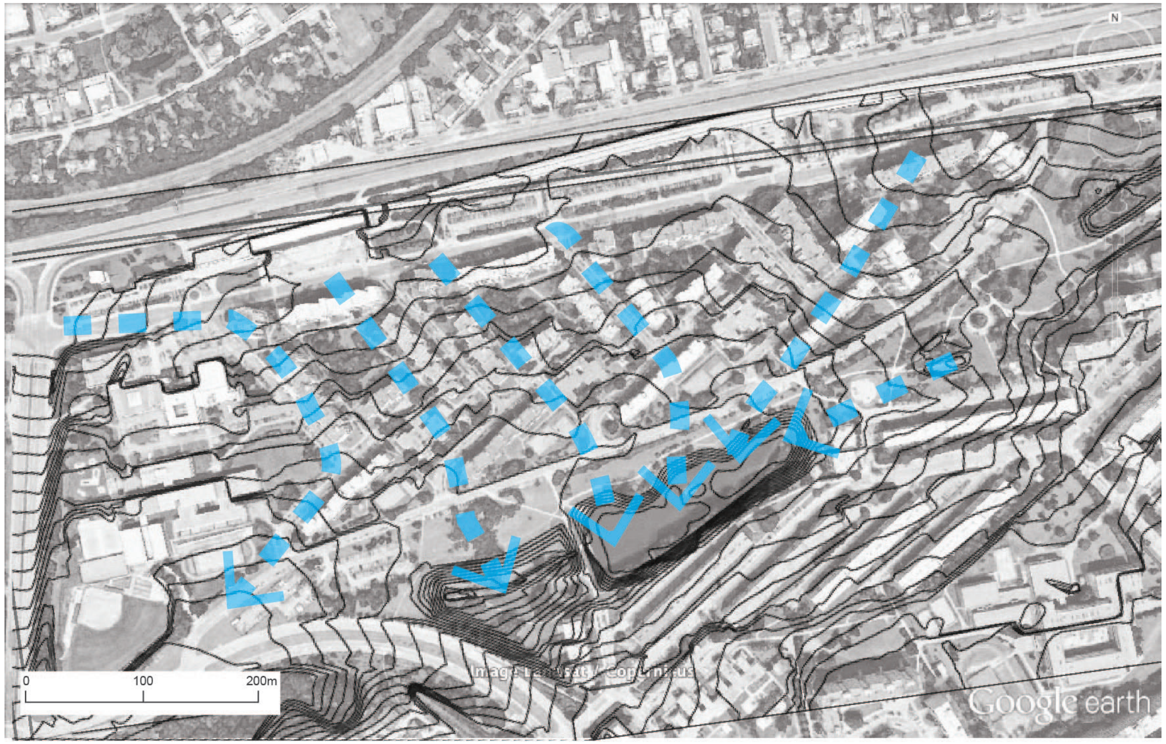


Figure 35: This diagram represents the existing topography at the site, with 1 meter contour lines. The diagram helps visualize the steep character of the site and what would be the natural surface water flow without any engineered interventions (Created by author, Original map data: Google Earth, 2016d, Utility data: IPR, 2017).

Image 52 (left): This image represents the extreme and untraversable landform along the edge of the pond, limiting access for residents as well as local species. Creating a more gradual transition to the waters edge would allow for a more ecological and stabilized bank by providing the opportunity to create a wetland type of ecosystem. The current embankment offers little water management function, and has an increased risk for erosion during intense rainfall episodes (Photo by author).

Image 53 (right): This image shows the change in elevation within the housing block's inner courtyard. It highlights the change in topography along the main axis, the pathway, as well as between the buildings and the public open space in front of it. This situation creates a channel like effect along the paved pathways which carry surface water through the site at high speeds with no opportunity for local treatment on site (Photo by author).

Redesigning the steep embankment could provide a more site sensitive design that would provide services for residents as well as the environment.

The current surface water management practice at Černý Most follows conventional urban drainage typologies. All rain water collected from the expansive roof network is piped and taken underground, where it is

Image 54-55 (top): These images show the pond as a local amenity. Typically, water features such as this can add to real estate value and quality of space. Ponds also tend to give a sense of character to a neighborhood. Several seating areas are existing, inviting people to enjoy the scenery, however, the space is underutilized as an amenity. A narrow gravel path runs along the north of the pond with several benches along the way. The benches have been found empty during site visits to the site and the paths have only been seen used for the purpose of walking dogs (Photos by author).

Image 56-57 (center) : Despite the steep topographical character of the site, there are a few underutilized open flat areas as well. The open space is separated from the housing estates to the North by Pospíchalova street. The wide street, along with the unregulated parking zone to the South of it, encourages high speed driving and acts as a hard border and barrier separating the housing blocks and the open space network (Photos by author).

Image 58-59 (bottom): There is an existing children's play ground SE of the project site. There are also two asphalt paved open spaces within the housing estate. One of these areas acts as a football field and outdoor fitness facility for residents while the other is an underutilized open paved space (Photos by author).

mixed with surface water runoff collected by the drain network on the ground floor. All of the surface water on the site is led into drain outlets located along the asphalt roadways and pathways. The unique topography on the site allows for all surface water to sheet flow toward drains located at low points (typically paved areas). With the exception of some dense vegetative areas on raised surfaces in the courtyard areas, much of the site consists of conventional lawn land cover and impervious pavement, adding to the high speed and low quality of the surface water runoff. The sewage pipes then carry the collected wastewater off site to the central water treatment plant. In the case of a systems overflow, the CSO will release the rainwater directly to the Kyjský pond and associated Rokytka river.

It is important to note that none of the collected rain water from the study area of focus area reaches the two existing ponds on the site. Currently, the only surface water management function of the ponds comes from a single rain water drainage outlet with piped rain water collected from the southern housing estate.

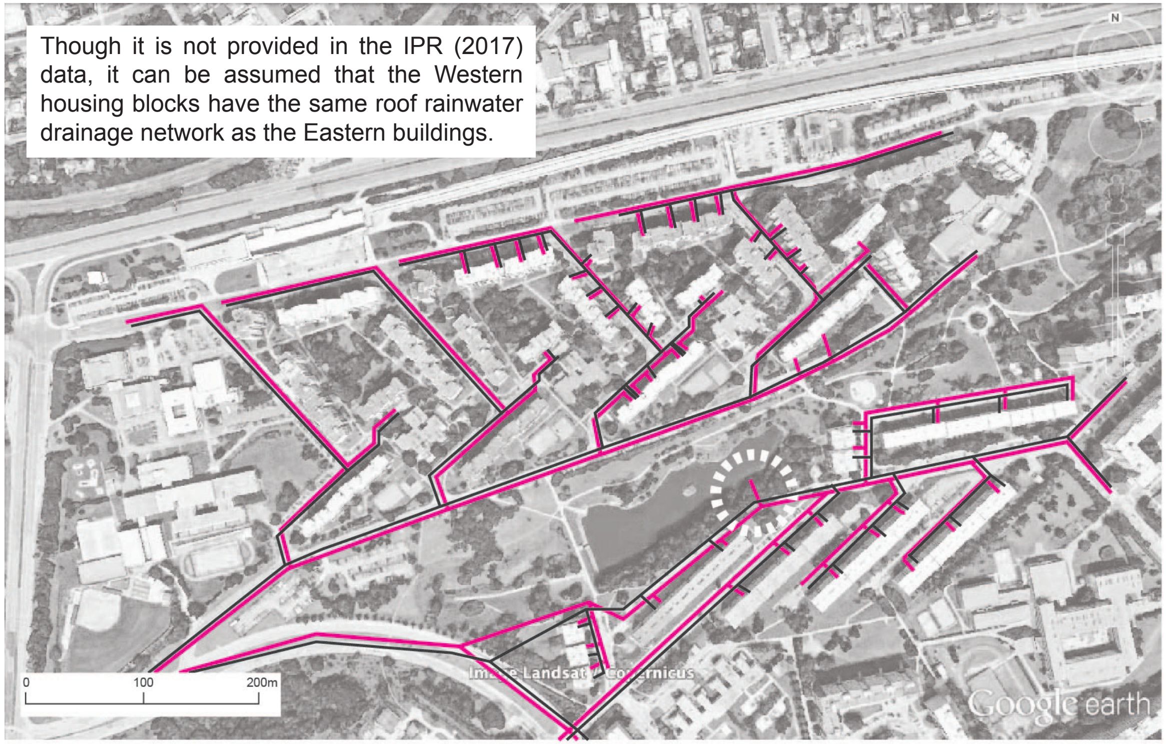


Figure 36: This diagram represents the existing underground wastewater sewage and rain water sewage utility network at Černý Most. The pink lines represent the rain water sewage pipes and the gray lines represent the sewage network (Created by author, Original map data: Google Earth, 2016d, Utility data: IPR, 2017).

Image 60-61: These images show the typical road network and drainage system in the housing estate. Drain outlets are located at the low points of road sections, where they collect the water associated with that catchment area. The underground utilities run along the road networks and carry the sewage and rainwater off site (Photos by author).

5.0 Results

The following chapter will introduce the proposed typological solutions for the surface water management of the Černý Most housing estate.

5.1 Černý Most Proposal

The previous chapter reviewed the existing condition of the Černý Most housing estate in context to Prague, the character of the place, and the current surface water management situation. The result of this thesis will be a proposal transforming the existing conventional urban drainage into an integrated system. The suggestions made will be reflective of the analysis put together from the three German precedent case studies (from the methodology chapter) as well as the knowledge gained from the literature review chapter of this thesis.

The proposal will include two schematic plans for Černý Most. The plans will introduce typological solutions toward integrated surface water management which can be applied to similar housing estates both in Prague and elsewhere. The schematic plans will be supported with sections and reference images portraying the adapted integrated surface water management system.

As discussed in the literature review and previous chapters, integrated urban water management system are most successful when they are inclusive of both interior architectural systems as well as landscape systems. Integrated water management addresses all forms of water including potable water, wastewater, gray water, black water, rainwater, surface water, stormwater and groundwater.

However, due to limited resources and scope constraints of the thesis, the proposals for the purpose of this study will focus on exterior surface water management on the ground level only. The integration of surface water on the site will stand alone from the existing interior architectural water systems in place at the housing estate.

It is important to note that additional green infrastructure such as green roofs, structural water harvesting solutions, and the recycling of certain wastewater would support and benefit the proposed water management and urban drainage solutions. As noted with the precedent studies, green roofs have a direct influence on the quality and quantity of surface water. However, due to limited data pertaining to the existing structures on site, the Černý Most proposals will not include structural solutions as part of the surface water design typologies.

The main difference between the following two schematic proposals is that one proposal includes the existing Pospíchalova street and the other reorganizes the road and circulation network to minimize the effects of impervious surfaces on surface water. The difference in the proposals also results in a more expansive green space network to the South of the block houses in the second schematic proposal. The plans will be introduced first with a diagram representing the flow of water, and second with a diagram representing the surface covers and their integral role in the management of surface water.

The proposals will also be supported with associated sections. The sections and all calculations pertaining to the proposals will be based on the typical typology that was highlighted in the analysis phase of the project.

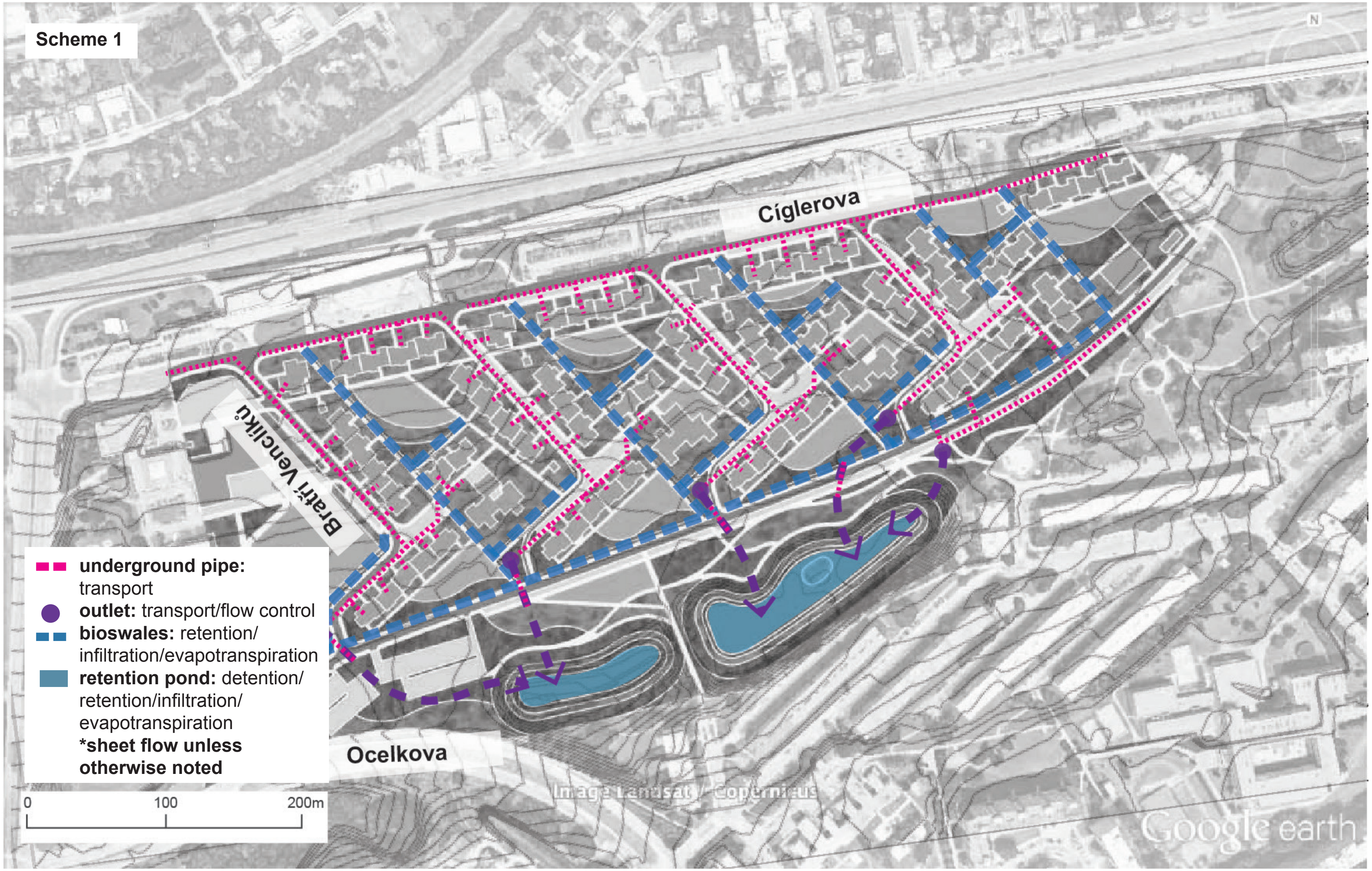


Figure 37 (Appendix 10.0 Page I): The first scheme shows the water movement for the proposed integrated surface water management plan for the Černý Most housing estate. This scheme includes the existing Pospíchalova street. The diagram designates the flow of water both below ground and above ground (Created by author, Original map data: Google Earth, 2016d).

Due to high building heights, varying between 6 to 12 stories, and steep slopes located through out the site, the roof rainwater as well as the surface water along the housing estate roads will remain in underground pipes. The building heights do not allow for downpipes to be opened directly to ground level vegetation (as seen in the case studies) due to the high velocity of water movement in the piped system that would cause erosion and disruption to environment upon release. The steep slopes along the roads within the housing blocks also limit the ability for water to be 'daylighted' due to a risk of erosion and flooding. The term 'daylighted' is most commonly used when referring to a piped stream or waterway which has been uncovered and brought back to the ground surface. This term is being used in the context of this study to refer to the release and exposure of piped water to the surface level as surface water.

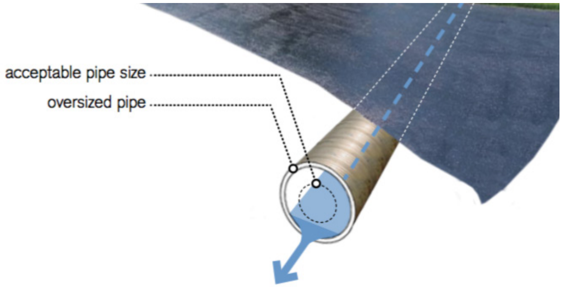


Figure 38: This diagram shows the physical difference between conventional pipes and oversized pipes. (University of Arkansas Community Design Center, 2010).

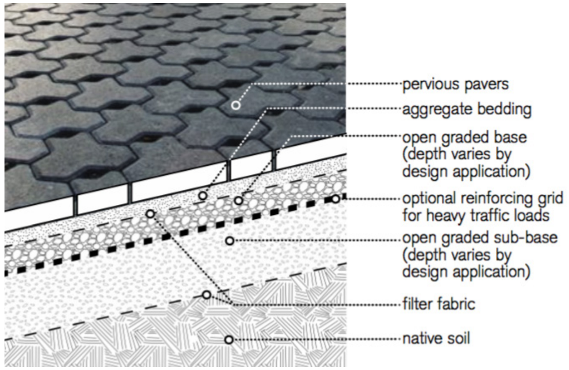


Figure 39: This diagram shows a typical example of permeable pavement technologies and the layers involved which allow it to function successfully (University of Arkansas Community Design Center, 2010).

Both proposal schemes aim to eliminate the underground pipes wherever feasible. Per the proposals, approximately 800 meters of existing underground stormwater drainage infrastructure will be removed by 'daylighting' or releasing the captured water on site in swales and vegetative filter strips or infiltration basins. On roads with reasonable slopes, the surface water will be directed to pervious pavers with curb cuts guiding the surface flow into vegetative zones designed for retention and infiltration.

The existing pipes can be integrated into flow control technologies that would release captured water at a more reasonable and 'natural' rate. Examples of these devices include flow splitters and level spreaders.

In place of conventionally sized pipes, the pipes directing the underground collected water can be specified as oversized pipes. Oversized pipes allow for better flow control by reducing problematic backwater effects when releasing water into a vegetative treatment area during greater rainfall events.

Though the road pattern has been kept the same as what is existing in the first proposal, the road widths and slopes have changed for the proposal. When possible, on one way roads, the roads have been limited to one lane. The existing imperviously paved parking lanes have been transformed into angled parking strips (either 45 degree, or 60 degree based on context) with permeable pavers. These parking strips also include curb cuts when feasible to allow for surface water to flow into filter strips or infiltration basins.

The once asphalt paved sidewalks and pathways have also been transformed into paths made of permeable pavers in the areas surrounding the block houses, and sand and gravel paths in the southern open space zone. The existing utilitarian sized pathways have also been resized to vary between 1m and 2.5m widths to limit the amount of infrastructure while also keeping feasibility and the comfort of residents in mind.

The following is a description of a typical courtyard cross-section as shown below:

A: A typical one way road section includes 60 degree angled on-street parking to allow for maximum parking spaces. The one lane road is paved whereas the parking zone and sidewalks are made of permeable pavers to allow for filtration of large sediments and surface water infiltration. The road continues to follow the conventional surface water drain network, which is connected to the roof drains of the surrounding buildings as well (diagrammatically shown in pink). The areas in front of the buildings are vegetative and act as filter strips as they manage the sheet flow surface water from rain events.

B: Filter strips treat the surface water sheet flow around the concrete and impervious buildings. Though the roof rain water is directed off of the immediate site by way of underground pipes, the vegetation provided by the filter strips allow for infiltration of surface water and sheet flow around the buildings. A vegetative bioswale, represented in Images 43 and 545, runs along a main path connecting the North part of the site to the South side. The bioswale is used more as a conveyance tool carrying surface water into larger infiltration basins.

C: This vegetative area acts as a mix between a rain garden and infiltration basin with undulating land form allowing for water retention and infiltration as well as groundwater recharge. This area would encourage high ecological biodiversity and a habitat source for native flora and fauna as it would mimic a natural wetland in function.

D: This area consists of filter strip plantings

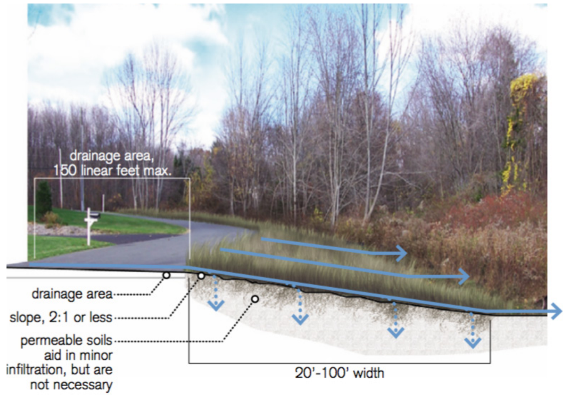


Figure 41: This diagram shows an example of a filter strip and its associated functions and design requirements (University of Arkansas Community Design Center, 2010).

and meadow-like vegetation. The planting scheme is less dense than the infiltration basins and offers more flexibility in terms of use and management. A primary function of filter strips is to slow the speed of runoff and allow for infiltration and evapotranspiration.

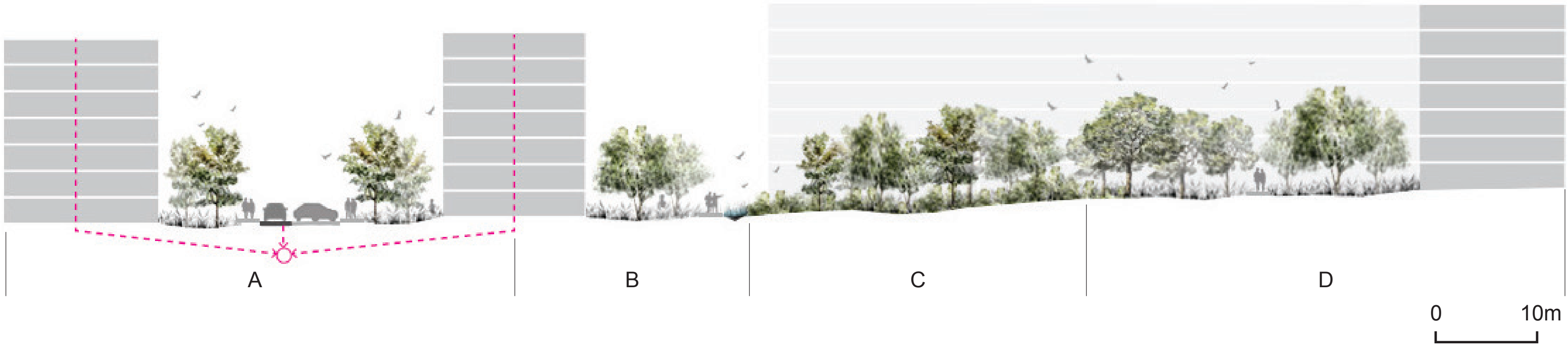


Figure 40 (Appendix 10.0 Page V): This section cuts through the central courtyard space between the Northern block houses. The section is cut from West to East and includes a typical road cross section (Created by author).

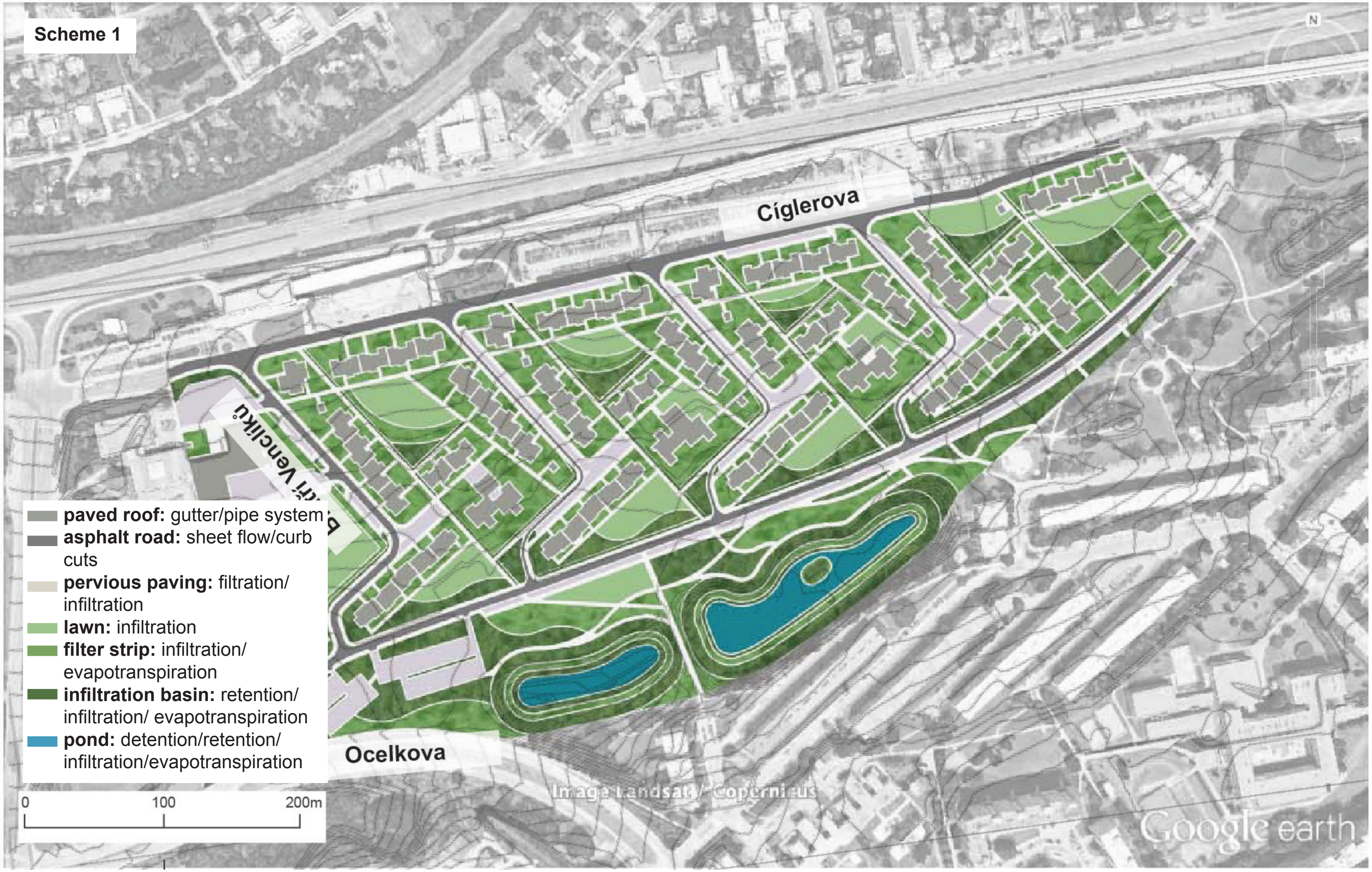


Figure 42 (Appendix 10.0 Page II): This concept plan designates the surface cover for the first schematic proposal in terms of surface water management. The plan represents the difference between areas made of filter strips and infiltration basins. Both typologies offer vegetative water management, however the infiltration basins are limited in terms of human interaction and use due to temporary inundation and wetland vegetation (Created by author, Original map data: Google Earth, 2016d).

The following is a description of a typical axial section as shown below:

A: The existing road, Ciglerova, which runs parallel to the Rajská Zahrada metro station is kept in place. This road contains a main segment of the underground pipe network, which is connected to the Northern most row of block houses.

B: This segment represents the beginning of the bioswale network. The section is cut through the low point of the swale, however hints at the land form and vegetative treatment facilities in the background as well.

C: The central courtyard includes designated open lawn space for recreation and amenity use, as well as both filter strip planting and designated infiltration areas. The thick vegetation of the infiltration basins makes that area non accessible as a recreation space but still provides other ecosystem services including habitat creation, climate regulation, air quality management, an attractive landscape amenity, and increased property values.

D: This segment represents the underground piped drainage network which is kept in place. Until this point, both schemes follow the same patterns, however, this section will be continued by two separate sections representing the two proposed schemes. It is important to note the change in elevation which occurs along this section cut. The steep nature of the site allows for the gravity flow of surface water to the Southern region of the site via the bioswale.

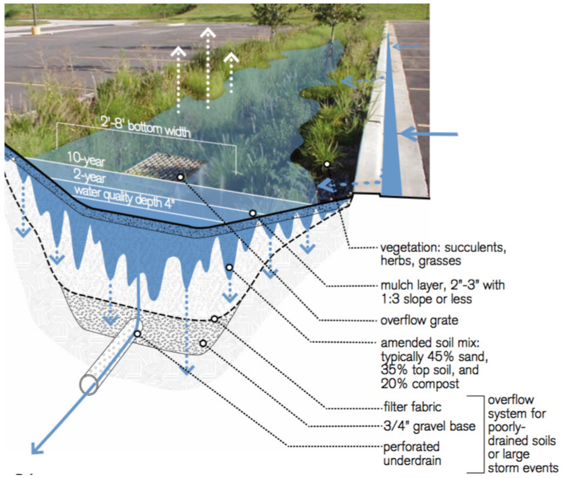


Figure 44: This diagram shows an example of a vegetative bioswale. Though bioswales allow for retention, infiltration and evapotranspiration, their main function is to transport surface water at a lower velocity and quantity than on a hard surface (University of Arkansas Community Design Center, 2010).

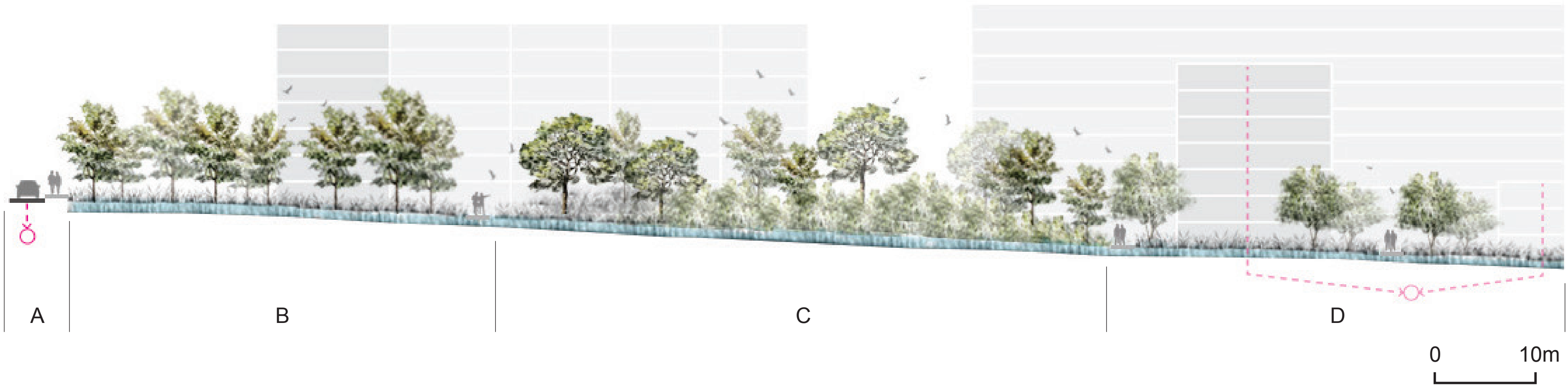


Figure 43 (Appendix 10.0 Page V): This section cuts through the central courtyard space between the Northern buildings. The section is cut from North through South along the vegetative bioswale. This axis is an integral part of this proposal, guiding both pedestrian movement as well as water flow through the site (Created by author).

The following is a description of a typical section as shown below:

A: A continuation of the bioswale which runs through the Northern park of the housing estate site, as seen in Figure 41.

B: This section is maintained as pedestrian only and acts as a main link between the Northern housing blocks and the open green space to the South of the project site. This section also represents the last of the housing blocks connected to the existing underground drainage system. The drainage network releases the collected water into an adjacent infiltration basin (not seen in the section cut).

C: This segment is a representation of the existing Pospíchalova street. The current scheme is altered with the addition of angled parking spaces on semi-permeable surfaces. The road and the parking zones are connected to the adjacent infiltration basin in segment D through curb cuts. The street scape should be sloped (min. 2% slope) in order to allow water to sheet flow into the vegetative treatment areas.

D: This segment of the section represents the vegetative infiltration basins which can also be found in the courtyard section. In other areas of the site, this area may vary between usable open lawn, filter strips, and infiltration basins as seen here, all of which can provide unique amenity functions and ecosystem services.

E: The existing topography on site shows a steep slope between the open space and the pond. The steepness of the existing slope creates unfavorable conditions which can lead to soil erosion, a loss of habitat and ecosystem functions. The proposed schemes calls for a more gradual slope allowing for water sheet flow at lower speeds, and more favorable living conditions for native and local flora and fauna. The proposal integrates the pond into the surface water management network, as the ultimate end point and retention pond for the water which was collected and treated uphill.

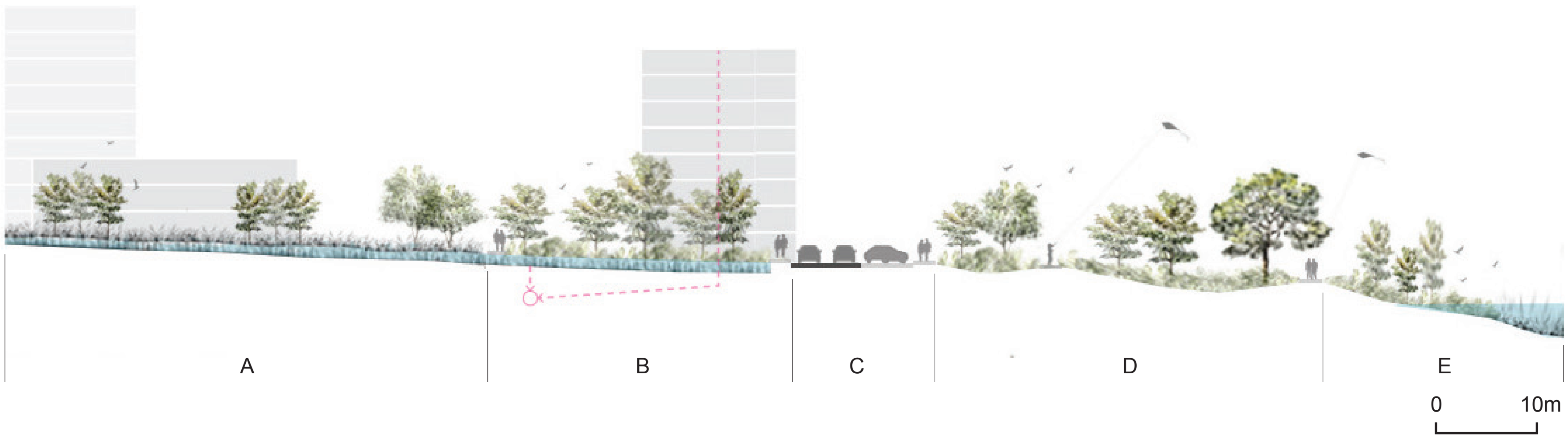


Figure 45 (Appendix 10.0 Page V): This section is a continuation of the previous section (figure 44), along the main proposed axis running from North to South. The section represents scheme one which includes the existing two way road, Pospíchalova (Created by author).

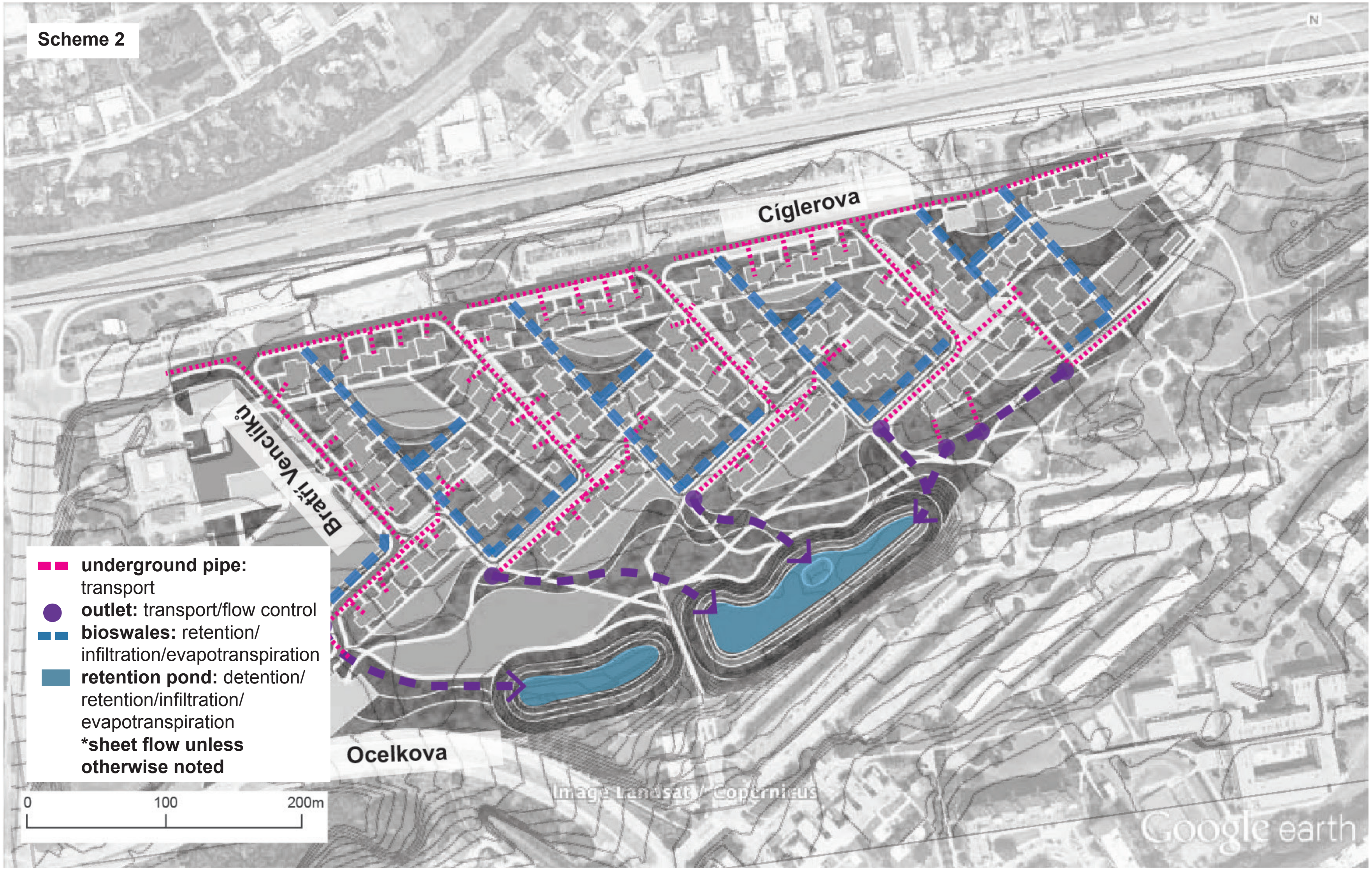


Figure 46 (Appendix 10.0 Page III): The second scheme shows the proposed integrated surface water management plan for the Černý Most housing estate with the removal of Pospíchalova street. The proposal reorganizes the vehicular circulation on site with looping 1-way roads. The diagram designates the flow of water both below ground and on ground level (Created by author, Original map data: Google Earth, 2016d).

The main difference between the first proposal and the second proposal is the road network. As seen in the Freiburg precedent study, specifically in Site C, Vauban, a limited road network results in many beneficial attributes in a development. Limited road networks reduce the amount of impermeable surfaces which influence both the quantity and quality of the surface water.

A limited road network also increases the available space for the creation of amenities for public use. By removing Pospíchalova street, there is a greater area in the Southern part of the site designated for green open space. This space provides a variety of ecosystem services as well as usable park space for residents.

The greater open space also creates a slight difference regarding where the water is directed to and treated in terms of infiltration basins. Though the location has changed, the general schema in terms of water management remains the same as the first proposal.

In addition to eliminating a main road, on street parking spaces have also been removed. For this reason, three schematic parking garages have been introduced to replace the eliminated parking spaces. One problematic aspect of the current housing estate that was noted during the analysis

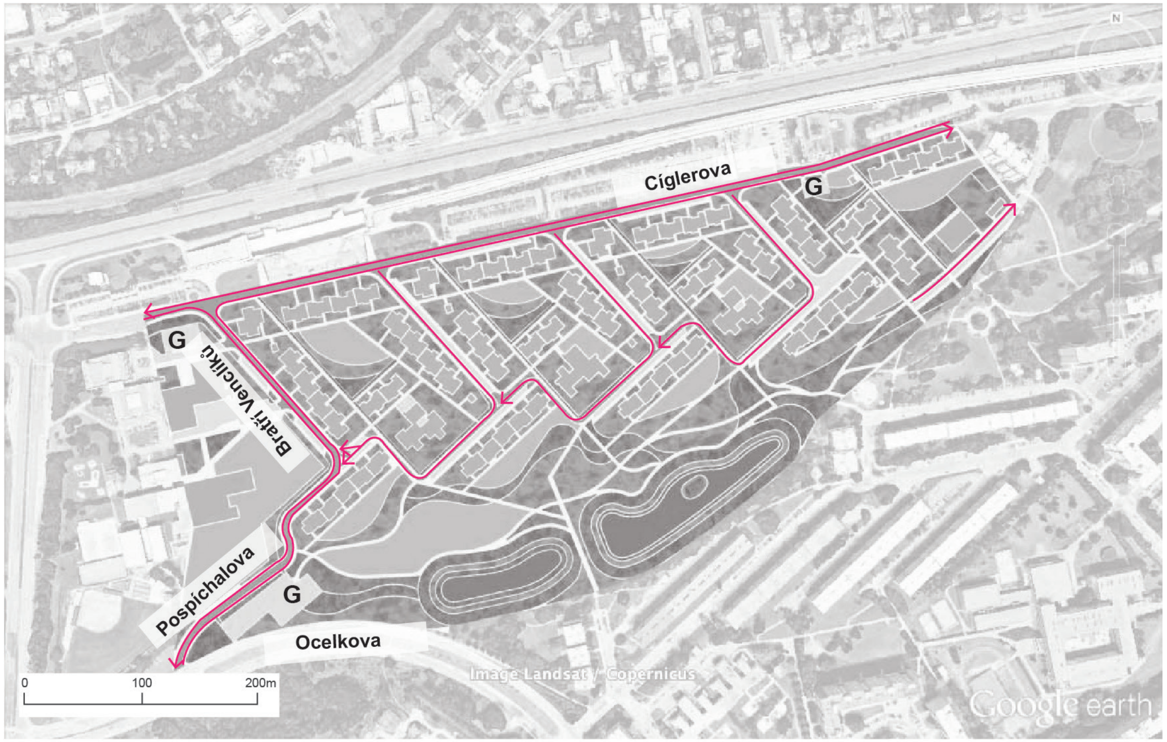


Figure 47: The diagram represents the new proposed road network for the Černý Most housing estate. The new scheme minimizes the amount of impervious surfaces on the site and designates proposed areas for new parking garages, designated by a 'G'. The proposed parking garages would include vegetative green roofs to minimize the impact of surface water quantity and quality (Created by author, Original map data: Google Earth, 2016d).

was the unorganized and invasive on street parking taking place. With the alteration of the road and parking networks, this proposal aims to address and regulate the current parking issues.

The narrow street typology and change in paving material is also used to introduce a more human scale to the site. The influence of the up to 12 story housing blocks and the current strong asphalt paving create an unfriendly and unapproachable streetscape environment that this proposal also aims to address.

Figure 48 (Appendix 10.0 Page IV): This concept plan designates the surface cover for the second schematic proposal in terms of surface water management. The filter strips and infiltration basins both act as vegetative water management and open space however the infiltration basins are limited in terms of human interaction and use due to the requirements of the infrastructure (Created by author, Original map data: Google Earth, 2016d).

The systematic movement of water from paved areas, semi-permeable surfaces, lawn, filter strips, infiltration basins and ultimately the retention pond has been designed based on the existing topography of the site. The patterns of water movement are key elements in the proposed typologies introduced for this project.

Lawn is used primary to reduce the speed of surface water flow compared to the paved and impervious surfaces. Though planting strips allow for infiltration and evapotranspiration (dependent on the vegetation) they are most vital in filtering the surface water and capturing larger insoluble pollution and sediments.

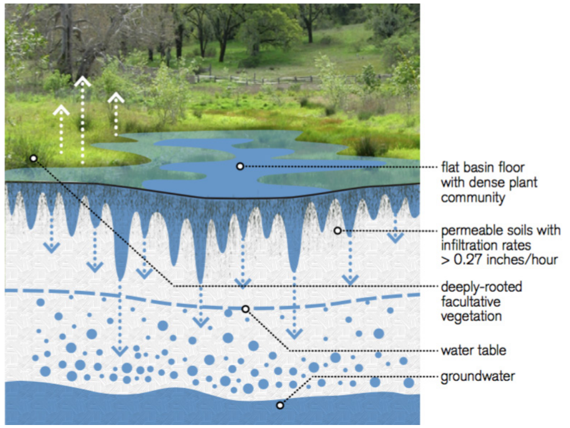


Figure 49: This diagram represents the function of infiltration basins. They have the ability to infiltrate and recharge the local ground water by mimicking the pre-development hydrological cycle (University of Arkansas Community Design Center, 2010).

The infiltration basins act as the end-of-the-pipe infrastructure in the surface water management system before the water ultimately enters the receiving water bodies, the two retention ponds at the Southern end of the site. Meadow and wetland like vegetation and depressions temporarily detain and infiltrate surface water, however, infiltration basins do not hold water for long periods of time. Vegetation typical of infiltration basins are native species that have phytoremediation capacities in order to uptake and treat the water.

An important aspect of integrated surface water management and the use of low impact infrastructure such as infiltration basins is the soil quality. As the purpose of the study was to propose typological solutions for typical housing estates, it is important to note that specific attention was not paid to the condition of the soil at the project site in Černý Most. In the case that the project was proposing site sensitive and specific solutions, it would be imperative to know the type and quality of the soil on site, and to make decisions accordingly as proper soil is vital to the proper function and long term management of BMP solutions.

Retention ponds are typically located at the lowest point of a development or site. Černý Most currently has one pond and one overflow retention area, however, based on the analysis it is seen that these ponds are separate from the existing surface water management on the site. The proposed typologies change that by integrating the ponds into the water management network. The now two ponds act as retention ponds, meaning they will hold water for long periods of time and will be fed via surface water runoff from the higher elevations. Typically, this would not be a healthy or sustainable system, however the water that will be considered ‘runoff’ will have already been treated by several measures including permeable pavers, swales, filter strips and infiltration trenches. The retention ponds will provide other ecosystem services including aquatic ecosystems, biological water treatment, and amenity space which can increase property values.

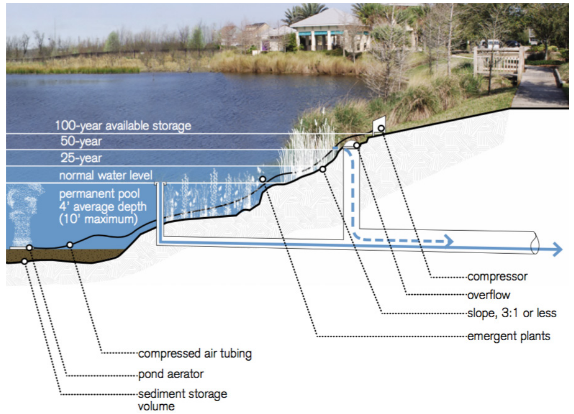


Figure 50: This diagram shows the basic design requirements for retention ponds (University of Arkansas Community Design Center, 2010).

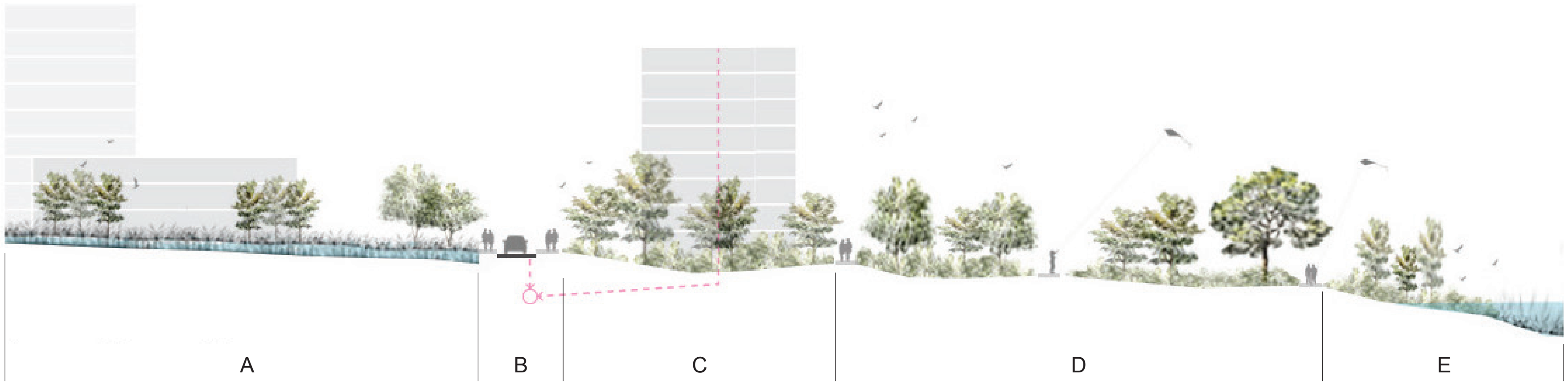


Figure 51 (Appendix 10.0 Page V): This section is the continuation of the section cut (Figure 43) along the main proposed axis running from North to South. The section represents the solutions from the second scheme proposal (Created by author).

The following is a description of the typical section as shown above:

A: A continuation of the bioswale which runs through the Northern park of the housing estate site.

B: This section represents the proposed one way road that loops around the block. This new road pattern minimizes the amount of impervious surface while keeping the site well connected.

C: This infiltration basin is used to treat the surface water flow. A similar basin past the section cut is used to retain and treat the water outflow from the underground pipe network. The swales are connected to treatment areas via oversized pipes when necessary (ex. road and path crossings).

D: This segment is a continuation of the open space. In other areas of the site, this area may vary between usable open lawn, filter strips, and infiltration basins as seen here, all of which can provide unique amenity and ecosystem services.

E: As with scheme one, the existing topography has been transformed into a more gradual slope allowing for water sheet flow at lower speeds, and more favorable living conditions for native and local flora and fauna and other ecosystem services. The retention pond is integrated into the surface water management proposal.

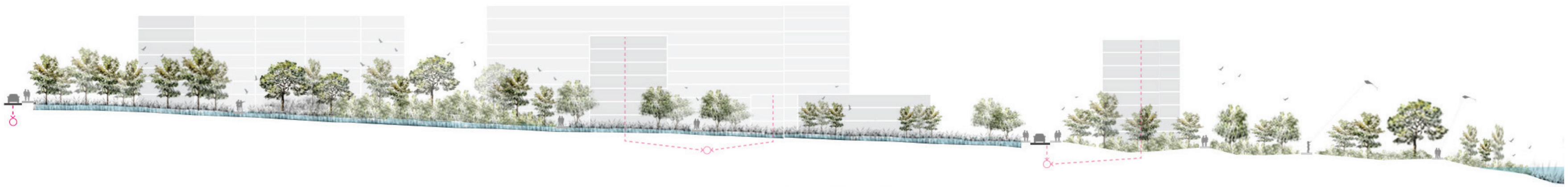


Figure 52 (Appendix 10.0 Page V): The full section cut of scheme two cutting from Ciglerova Street to the retention pond through the proposed main axis. The section depicts a 16m change in elevation over a 300m stretch of land (Created by author).

As with the precedent studies, the two schematic proposals were evaluated based on the quantity and quality of the site's runoff. Both options were evaluated based on the rational equation Q=ciA to quantify the amount of peak runoff discharged during a storm event.

The results were compared to the existing conditions at Černý Most in the table below. The proposed integrated surface water management plan in the second scheme produced 95l/s/ha less than the current state of runoff in the housing estate, decreasing the amount of runoff by approximately half the amount.

As mentioned earlier, structural changes to existing buildings were omitted from the proposal due to a lack of data and information. With this said, it is possible to show the effect green roofs would have on the calculated peak runoff. If all conventional roofs in the study area were transformed into green roofs, the total peak runoff per hectare would be reduced by 66 l/s/ha.

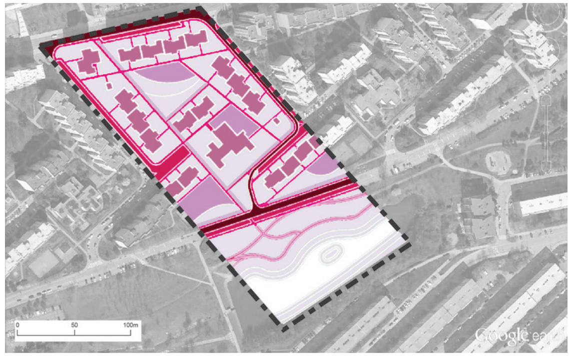


Figure 53: This diagram represents the quality of surface water based on the land cover of the first schematic proposal. The water quality is based on the water's interaction with land cover for a typical typological block in the housing estate. This study estimates that the peak discharge runoff on the site is 120 l/s/ha (Created by author, Original map data: Google Earth, 2016d).

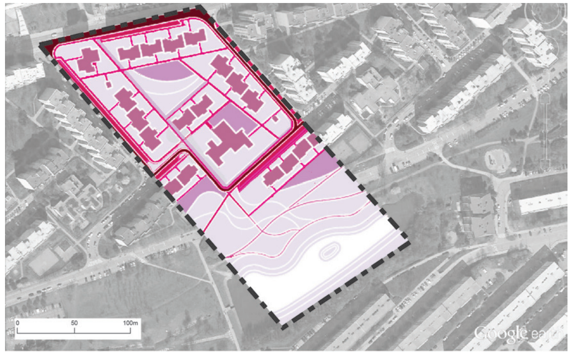


Figure 54: This diagram represents the second schematic proposal, with alternative road and open space networks. The calculated peak discharge runoff on the site is 110 l/s/ha², producing almost half of the runoff developed at the existing site (currently calculated at 205 l/s/ha) (Created by author, Original map data: Google Earth, 2016d).

Figure 55: The table represents the calculations for the rational peak discharge equation. Areas of land cover were calculated based on the vectorization of orthophotos and were assessed based on the runoff coefficient of said land cover. The table compares the results of the existing condition at Černý Most with the two proposals (Created by author, Original data: Petschek P., 2016).

Graphic	Surface Cover	'I' Rainfall Intensity (l/s)	'C' Runoff Coefficent	Existing Area (m²)	Existing 'Q' Solution	Scheme 1 Area (m²)	Scheme 1 'Q' Solution	Scheme 2 Area (m²)	Scheme 2 'Q' Solution
	Natural Water	0.03	0	6835	0	3250	0	3250	0
	Greenroof	0.03	0.7	0	0	0	0	0	0
	Vegetation	0.03	0.1	1090	3.27	19867	59.601	22205	66.615
	Swale	0.03	0.2	0	0	950	5.7	620	3.72
	Lawn	0.03	0.4	16620	199.44	2906	34.872	2780	33.36
	Gravel/Sand	0.03	0.2	330	1.98	640	3.84	815	4.89
	Roof	0.03	1.0	6359	190.77	6309	189.27	6309	189.27
	Permeable Paver	0.03	0.6	0	0	6390	115.02	4941	88.938
	Paver	0.03	0.6	0	0	0	0	0	0
	Road	0.03	1.0	11179	335.37	2101	63.03	1493	44.79
	Total Area (m²)			42413	35578	42413	39163	42413	39163
	Total Q (l/s/m²)				730.83		471.333		431.583
	Total Area (ha)			4.2413	3.5578	4.2413	3.9163	4.2413	3.9163
	Total Q (l/s/ha)				205.416268		120.35161		110.20172

6.0 Discussion

The results produced for this thesis propose typological solutions toward transforming a conventional surface water drainage system into an integrated and low impact surface water management network. Though the proposal focuses on the management of surface water, the concepts and attributes introduced have the capacity to offer more to the development than just water management.

As noted during the evaluation of the three German precedent studies, developments with integrated and innovative surface water management networks are seen as more desirable and positive living environments. When describing these sites, words such as eco, green, resilient, innovative, and sustainable are used.

According to Austin (2016), although it is difficult to realize, high dwelling density provides ecosystem benefits that can contribute to the sustainability of the city and region. As seen in Riselfeld, Site C, newer developments are using planning approaches such as conversational development to build high density residential zones on smaller footprints. Housing estates like Černý Most inhabit large densities of residents. The potential to transform these unappealing and undesired sleeping blocks into environmentally sensitive and promising living communities has the power to change the living conditions for large quantities of people.

Based on the analysis of the precedent studies and the schematic proposals for Černý Most, a study can be done to evaluate the amount of green space available per resident per hectare of land. Based on the previous chapters and the analysis of the site, the following estimations can be made to represent the number of residents per one hectare of land on the site:

Site A Berlin (typology 1)	85 residents/ha
Site A (typology 2)	500 residents/ha
Site B Vauban	150 residents/ha
Site C Riselfeld	175 residents/ha
Černý Most Proposal	700 residents/ha

Contingent on the typological data collected for the peak runoff study, the amount of open space in each study area was calculated by combining the vegetative and lawn areas in the typological sections. The total area of green space was then divided per one hectare of land.

The results of the percent of green space in one hectare of land are as follows:

Site A Berlin (typology 1)	52%
Site A (typology 2)	40%
Site B Vauban	52%
Site C Riselfeld	45%
Černý Most Proposal	51%

The following values represent the amount of green space per resident in 1 typical hectare of land:

Site A Berlin (typology 1)	$62 m^2$
Site A (typology 2)	$8 m^2$
Site B Vauban	$35 m^2$
Site C Riselfeld	$25 m^2$
Černý Most Proposal	$7 m^2$

It is important to note the varying building uses and capacities between the analyzed sites. Based on the housing types, the 6-12 story block-housing typologies found in Černý Most can most closely be compared to the high density apartment buildings found in the second typology in Berlin. On the contrary, the first typology in Berlin was based on single family town-house units with a much lower residential density, resulting in a very different green space ratio.

In addition to the proposal's influence on accessible open space for residents, addressing surface water management has a wide range of attributes and ecosystem services that are typically not associated with a proposal as technical and functional as water management.

Image 62-63: These images compare the typical housing styles and density between the Černý Most housing estate (top) and Berlin's typology 2 site (Photos by author).

A look specifically at the Vauban, Freiburg (Site B) analysis, shows the influence the amenities and design for surface water have on the quality of life for residents, as well as the environmental benefits it provides. The minimized and restricted road network and human scale materials in addition to the roadside vegetation have transformed streets from its original utilitarian function to a usable and interactive park space. The roads in this case study have become an extension of the home, and a common space among all residents, thus promoting an open and inclusive neighborhood dynamic and culture.

The limited road network also reduces the amount of impervious land cover. As discussed in previous chapters, roads are not only considered negative in terms of the quantity of runoff produced, but also because of the harmful pollutants associated with roadways and its influence on the quality of surface water runoff.

The lush vegetation surrounding the buildings of Vauban both on the ground level and roof have created an ecological oasis filled with refugia and habitat for a vast variety of flora and fauna. The evidence of gardens and urban agriculture in the private and common spaces adds to the resident's environmental consciousness and stewardship of the environment. The constant visual connection to water, whether through the extensive swale and bio-swale network or the Dorfbach stream have transformed the way children interact with the natural element, therefore influencing the way they value it as a resource.

As Purvis (2008) states, the residents of Vauban "live with the cycle of nature," creating a new social and cultural paradigm.

Image 64: The Černý Most proposal calls for filter strip plantings to treat surface water runoff and provide countless other ecosystem services as seen in the Vauban case study (Photo by author).

Image 65: Visible and accessible bioswale networks along pathways and roadways in Vauban are proposed for the Černý Most site as well (Photo by author).

A few kilometers away in the Riselfeld neighborhood (Site C), an extensive open space network directed by vegetative bioswales and infiltration basins allows for plentiful recreation and leisure activities. The gravity fed surface water drainage network reduces the amount of hard infrastructure and engineering on the site and replaces it with soft solutions and proper land management.

What is important to note regarding the soft

Image 66: Recreational paths running through infiltration basins connected by underground oversized pipes in Riselfeld are part of the solutions proposed for the open space in Černý Most (Photo by author).

Image 67: Wetland ecosystems as seen in the Riselfeld pond are also proposed for the infiltration basins and two retention ponds in the Černý Most proposal (Photo by author).

engineering practices seen in Rieselfeld, and proposed for the Černý Most housing estate, is the maintenance associated with low impact green infrastructure. Unlike hard engineering solutions, soft solutions are living, breathing and growing. Maintenance for integrated surface water management systems can vary from regular to annual in terms of intensity. Regular maintenance my include irrigation and maintenance of vegetation, keeping piped networks clean and removing sediments from retention areas. More extensive maintenance may include large soil amendments after a certain period of time or annual filtration infrastructure maintenance.

The quality and state of the soil in LID systems is vital toward ensuring a functional and successful system. As mentioned in the Results chapter, the typological solutions proposed for this study were done so independent of the existing soil type and quality on the Černý Most site. In the case that this project was more site specific rather than exemplary, more attention would have to have been made in terms of the existing geological and hydrological conditions. Without proper knowledge of existing natural conditions, proposed best management practices may not function to the best of their abilities.

The importance of irrigation is another key factor in the urban water network. In well integrated systems, infrastructure such as roof water harvesting and grey water recycling could be incorporated into the on site irrigation network. Had the scope of the proposal included built and interior architectural water systems, concepts such as green roofs, water harvesting and local water treatment would have not only worked hand in hand with the proposed surface water management network, but would have benefited the quantity and quality of the urban drainage network as an integrated system.

The vegetative courtyard spaces seen in the Berlin case study (Site A) offers respite from summer heat waves with dense vegetation creating a microclimate for not only the courtyard but the interior facing apartment buildings. According to Larondelle (2016), the top 5 urban ecosystem services (UES) accounted for in Berlin are: (1) water provisioning, (2) particulate matter removal, (3) heat regulation, (4) carbon sequestration and (5) recreational areas. All 5 urban ecosystem services are fully provided for within the confines of the study area and the analyzed courtyard space. The exemption of roads within the courtyard space, as also seen in the Černý Most proposals, allows for an open and vegetative green space which can provide surface water management, heat regulation, carbon sequestration, and the removal and reduction of particulate matter due to the reduction of potential pollutants (such as vehicles).

In addition to environmental services provided, the study area offers recreation by providing a common space for residents to gather and connect. The notion of re-introducing neighbors after an era of separation is something that is needed and relevant based on the past and still somewhat current housing culture in the Czech Republic.

The Černý Most proposals have been based on bits and pieces of the analyzed precedent studies. Innovative design elements and surface water management solutions have been applied to the housing estate in Černý Most respective to the sites physical, socio-economic, and socio-political aspects.

Image 68: Communal courtyard spaces including play spaces, seating, and grilling areas as seen in the Berlin case study are encouraged when trying to reintroduce Černý Most residents to the outdoors and to each other (Photo by author).

As discussed in the literature review chapter, learning from others is crucial. "Reviewing the methods adopted by other countries provides us with an opportunity to explore how we can use more sustainable surface water management measures to most efficiently protect our natural environment, mitigate the impacts of development on natural hazards, and support future urban quality of life" (Ashley et al., 2015).

The current political and social climate of the Czech Republic is not as open to innovative design solutions, as compared to countries such as Germany, the UK, the US, Australia and even China. Countries and regions have been creating and implementing planning systems to replace the conventional methods that are still commonly followed in countries such as the Czech Republic. Innovative design approaches such as Garden Cities, New Urbanism, Landscape Urbanism, Smart Growth, and Sponge Cities, just to name a few, have come and gone or are still developing to better the field and face of sustainable urban development across the world.

Countries such as the US and UK have created initiatives to promote and implement sustainable development, hoping to transform and improve the built environment not only for humans but for the environment as well. Rating systems such as Building Research Establishment Environmental Assessment Method (BREEM) (UK), Leadership in Energy and Environmental Design (LEED) (USA), the Living Building Challenge (USA), and Green Building (EU) are all in place to educate, promote, and influence sustainable, resilient and regenerative development. Programs such as these can be found all over the world, specific to individual countries and regions, however the Czech Republic has remained fairly independent and slow to catch onto this movement.

As discussed in the introduction to the project chapter, there has been a call for a paradigm shift in how development is approached in terms of regulations, the role of professions, and stakeholders knowledge and participation in the Czech Republic. These changes do not occur overnight, however, studies such as this thesis and other projects and proposals both in education, theory and the built environment advocate for a positive paradigm shift. Integrated urban water management transforms the roles of disciplines and stakeholders and encourages an approach primarily addressing water quality. The result of this approach act as a driving force in achieving other aspects of sustainable developments.

7.0 Conclusion

In the 2015 Study of Housing in the Czech Republic, The Czech Ministry of Regional Development (2015) published that 47.5% of Czechs occupy dwellings in multi-dwelling buildings. The Prague Institute of Planning and Development (IPR) (2016a) states that one third of Prague residents reside in panel block housing, typical of what is seen at Černý Most. These housing estates, or 'sídliště' in Czech, are central not only to the population's daily lives but also their cultural perspectives and views on housing and community structures.

Housing estates, like Černý Most, located near attractive cities such as Prague have proven to still be desired as places to live due to their relatively low cost and manageable commute to a city, but not specifically for their high quality of life and positive lifestyle. According to the Prague Institute of Planning (2015), the population of the collective Černý Most housing estate was 23,263 in 2014. The population is estimated to rise to 24,667 by the year 2020.

By retrofitting existing communities and adapting them to meet international housing and community development standards, there is an opportunity to revamp the quality of life in these districts. By focusing on a relative and important aspect of a development, such as water management and drainage, planners, architects, engineers, and stakeholders have the opportunity to address other aspects of development related to making a community resilient, healthy, and sustainable. This thesis has primarily aimed to approach surface water management while also incorporating other beneficial aspects of integrated development into the proposal or reasoning behind it.

After in depth analysis' of several innovative case studies of developments with integrated surface water management networks in place, and an analysis and review of the conventional urban drainage patterns in place in the Černý Most housing estate, appropriate schematic proposals were made to transform a conventionally designed site into an innovate and precedent setting one. Solutions proven to work in the German case studies and in literature were applied to the site in the Czech Republic to show the adaptability and feasibility of low impact infrastructure.

The ultimate aim of this master thesis was not to propose a fully site sensitive project limited to the Černý Most housing estate, but to offer possible schematic solutions for addressing surface water in a more integrated manner. The proposals integrating surface water management into existing housing estates were to show the ability to adapt not only Černý Most but other sites as well - to influence and have an impact on the districts in which 3.5 million Czechs call home, and elsewhere in Europe and around the globe (IPR 2016a).

The Prague Institute of Planning has already begun looking at existing housing estates around the city in terms of sites for revitalization and resilience plans. However, the approaches thus far have centered around resident's needs and desires such as, community gardens, better access to public transport, safer streets and good parking (IPR, 2016b). This thesis aims is to help convince and influence planners, architects, engineers, developers and stakeholders to view surface water management not only as a solution to urban drainage, but to use integrated systems as a leading factor in community revitalization projects guiding other design solutions.

The intention of this master thesis and project proposal was to provide examples both of existing precedent studies proven to have sustainable surface water management practices in place and examples of proposed typologies which can help promote a paradigm shift in how urban drainage and community development is perceived and approached in the Czech Republic and abroad.

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9.0 Abbreviations

BMP: Best Management Practices

BREEM: Building Research Establishment Environmental Assessment Method

CSO: Combined Sewer Overflow

EIA: Effective Impervious Area

ES: Ecosystem Services

EU: European Union

FFE: Finished Floor Elevation

GI: Green Infrastructure

IPA: Individual Parcel Assessment

IPR: Prague Institute of Planning and Development

IUWM: Integrated Urban Water Management

ISWM: Integrated Surface Water Management

LEED: Leadership in Energy and Environmental Design

LID: Low Impact Development

LOHAS: Lifestyle of Health and Sustainability

MGMT: Management

NPDES: National Pollutant Discharge Elimination System

NPS: Non-point Source (pollution)

PAHs: polycyclic aromatic hydrocarbons

PCI: Park Cool Island

SGUD: Czech Water Association Group for Urban Drainage

SuDS: Sustainable Drainage Systems

TSS: Total Suspended Solids

UES: Urban Ecosystem Services

UGS: Urban Green Space

UHI: Urban Heat Island

US EPA: United States Environmental Protection Agency

USS: Urban Stream Syndrome

WFD: Water Framework Directive

WSC: Water Sensitive City

WSUD: Water Sensitive Urban Design

10.0 Appendix Drawings

The appendix includes 5 A3 drawings from the proposals as discussed in the Results chapter of the thesis.

The drawings include the following:

I Scheme 1 Water Movement Diagram

II Scheme 1 Surface Cover Plan

III Scheme 2 Water Movement Diagram

IV Scheme 2 Surface Cover Plan

V Typical Sections Through:
Road and Courtyard
Axis - Scheme 1
Axis - Scheme 2