Integrated modeling for the Upper Rea flood problematic

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Abstract

With increasing pressure on environmental resources such as water, the need of integrated management strategies has been identified. The principles of integrated water management (IWM) rely on sustainable development goals and focus on the harmonization of environmental, economical and social interests. In the urban context this task becomes very sensible. As a consequence of an inappropriate land use management plan, flood events can constitute major issues in cities. Today, sustainable drainage strategies (SUDS) try to replace traditional methods and seem to represent global stormwater solutions. A drainage model (STORM), an economical model (CWE) and an integrated modeling platform (CWIS) have used SUDS in order to investigate their effect on the urban flood problematic. The overall working process aimed to define an integrated water management approach. The Upper Rea catchment of Birmingham, in the United Kingdom, has been taken as a case study. Through an implemented SUDS decision process appropriate drainage units have been attributed to selected areas. The implementation of SUDS has been investigated in terms of flood decrease and economical costs. The models have been tested for their adaptability and intercompatibility. The project's results compare the effect of three different drainage strategies which contribute to the elaboration of an integrated water management plan.

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1 Introduction

The following study subscribes to the view of a Master Project carried out at the ecohydrology laboratory (ECHO) of the federal engineering school of Lausanne (EPFL) under supervision of Professor Marc Soutter and Phd student Bastien Roquier.

Water management issues deal with increasing environmental concerns, as resource pollution or flood control, which directly affects human activities. The problems encountered with water in urban agglomerations necessitate the investigation of various phenomena and the apprehension of a complex system. The close interaction between the natural environment and the constructed domain relates many different actors and stakeholders that need to be integrated in the water management system.

Common water management themes have to deal with water supply, treatment and stormwater applications. The present study focuses on the urban flooding problematic caused by stormwater sewer overflows. The Upper Rea catchment, part of Birmingham city situated in the United Kingdom, is taken as case study. The effect of several sustainable drainage strategies is investigated. An economic analysis of the resulting flood protection strategy is elaborated and a cost recovery scheme is proposed. An integrated modeling platform is then used to present the acquired results as a decision support tool.

The models used in the project are part of the European research program Switch that in collaboration with its partners is active for the resolution of urban water issues through a multidisciplinary approach and application of water integrated management practices.

1.1 Working objectives

The main objectives of the project are divided into three different goals that want to be achieved and are resumed as followed:

- **The conception of an integrated water management approach in order to deal with stormwater flood issues**. Therefore the possibility to consider hydraulic and financial challenges in order to resolve the flood problem will be researched.

- **The combined use of the drainage (Storm), the economic (CWE) model and the modeling platform (CWIS), as part of the Switch project, in order to investigate the flood problematic**. The capacity of each model's analysis towards the specific study domain will be highlighted and discussed as well as their intercompatibility potential.

- **The hydraulic and economic effects of sustainable drainage strategies are investigated for the urban study region.** The flood protection performance will be analysed and the economical characteristics will be discussed.

2 Water management

All over the world the quality of our life is directly correlated to the quality of our environment. It appears therefore crucial to maintain a viable equilibrium with of our natural resources in satisfaction with human health, economical and social development and in order to preserve ecosystems and their biodiversity. The way our environment is treated today will determine the evolution of the resources and their availability for future generations. Consequently resource management strategies appear to be a primary engineering task for many sectors of interest.

Travelling through different compartments as groundwater stock, rivers or lakes, water constitutes an essential resource, responsible for human and environmental health. The flows and the stocks of the water cycle are continuously marking the earth's topography and change a landscape's properties. All large human colonisations have followed the presence of water flows and have been subject to their changes. Water has and will therefore always play a major role for the development of mankind. While our planet has been witness of an increasingly demand of resources in the last century, the demand for good quality drinking water that presents a minimum price for household, industrial or agricultural use has risen even more.

Today complex interactions exist between the natural and the built environment. Due to higher productivity and consumption in industrial countries, constructed land has overtaken the place of natural habitats. As the size of many ecosystems has been limited in terms of population growth and specie's mobility, their status now depend on their relationships with anthropogenic activities. Moreover, as the built environment modifies the resource's cycles the risk of damage from natural extreme events increases. The effect of constructed elements on the landscape is consequently directly influencing local resources as water.

Mass flows to and from natural systems are today analysed and tried to be controlled. In this sense, resources are stocked, diverted, integrated or extracted from their surroundings. In order to maintain a healthy balance between constructed and natural environment the reciprocal interactions need to be integrated in a resource and landscaping strategy. These practices are commonly known as resource management strategies. Considering similar principles as in sustainable development, resource management strategies integrate a complete multi-domain holistic approach.

2.1 Managing the water cycle

The water cycle is locally and globally apprehended into water management plans in order to assure the resource's durability and the services provided for human future development. In this sense water life cycle assessment begins with a distribution source and is then delivered to the consumers. After the water's exploitation the resource is returned to the environment. In addition water can also pass through constructed land without direct use of the resource. Rainfall events or rivers can cause water to produce reciprocal interactions with the built environment and changes the resource's properties. The management of the water cycle can be resumed in Figure 1and is described in the following stages.

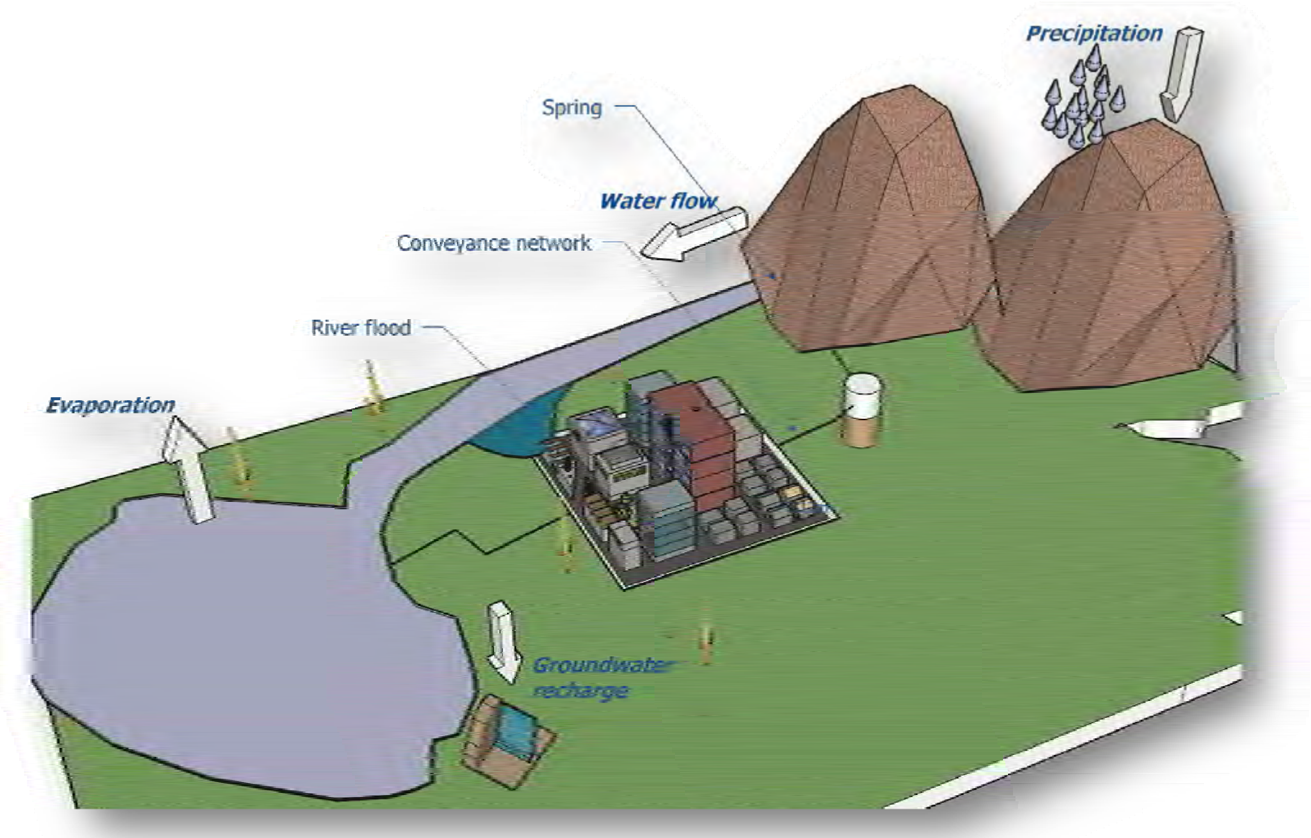

Figure 1Water cycle of an ruban catchment

- Extraction of water from different possible compounds. The type of the source can be groundwater, surface water, spring water or sea water.

- Conveyance of the resource to the consumer or the desired destination. The conveyance network can be constituted by pipe systems, open channels or different drainage systems which change the water natural course.

- Water treatment which has run through different system elements in order to restore its quality and to limit ecological pollution and human contamination risk.

- Storage of water in the system or release of the resource back to the environment. The water stock can be for various interests as for consummation, volume reduction or landscaping issues.

An important goal in management practices is to control these different stages on a long term basis in order to insure consummation demand, ecological viability and risk reduction.

2.2 Water in urban context

Water related issues become directly more complex in an urban environment. Not only the available space factor limits the potential strategies but also the number of actors involved in the water problematic grows very fast. As the density of economical and social goods is much higher than in rural areas the risk factor also becomes more important. All these characteristics enable the possible outcome of specific problems related to the urban context [38].

As described in section 2.1, the urban characteristics influence the properties and the flow behaviour of the water cycle. Therefore multiple interactions and phenomena need to be taken in account to represent the resource's flow path in cities. The major reasons why water is influenced differently in the urban environment can be resumed as followed:

The impermeable change of the soil increases the amount of runoff and transforms the hydrological properties of the subcatchment. Therefore an increasing amount of rainfall touching the ground is diverted into runoff volume and the time needed for the different flows to reach the catchments exists, also known as concentration time, is shortened.

The contact between the stormwater and the impermeable surfaces exchanges different particles. Water flows can therefore solubilises, erode and drain particles that vary from organic to metallic nature.

The water stock and flow compartments are subject to change of their natural resource balance. This can be in terms of volume, such as for groundwater compartments, or in flow characteristics as for artificial river beds.

As a result the cited effects change the water cycle's behaviour and can have consequences on the landscape, the ecological health and on human activities and goods. The possible

outcomes derived from adaptation of the water cycle are multiple. Some of the most important are listed below.

Due to higher runoff volumes and shorter concentration times an increase of the flood risk is produced. Areas which are already known to be sensible to floods can get even more dangerous and new potential risk sites can appear.

The load of organic materials or metallic particles deteriorates the water quality. Once the resource is returned to natural habitats it can damage their biological characteristics. In order to maintain a healthy environment high pollution loads need to be treated which needs an adapted sewer and waste water treatment system.

The resource's availability due to changes in the water cycle balance can become questionable. An underground water table can decrease due to inappropriate recharge or the quality of the water stock can be deteriorated until no further use of the resource can be conceivable.

Many biotopes can become endangered due to modifications of the water flow rates that control their development. Species can lose their habitats and finally disappear from the region. The ecological functions delivered from these biotic groups could have delivered an important value for ecological or anthropological life quality.

Many more causes can be the effects from urban interactions on the water cycle. New strategies are therefore needed to apprehend the urban water system and to guarantee a sustainable development of the economical, environmental and social sectors in cities.

2.3 Integrated water management

While unhandled challenges in traditional water management practices remained multiple in the urban context different techniques and strategies have been applied to approach the water problem in cities [39]. Since the recognition of the influence of urbanization on water related problems, international policies have been established. As one of the first documents citing the need for special handling of the urban water problematic the Dublin Statement (International Conference on Water and the Environment, 1992) and the Agenda 21 (UN Department for Sustainable Development, 1992) give a basis for integrated water management (IWM) principles [39]. The main themes include the handling of the water resource without damaging the environmental, economical or social sector. A new approach that integrates a catchment scale vision of the problematic becomes the starting point for

IWM applications. The major principles cited in the Dublin statement [39] [9] [10] can be resumed as followed:

Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. Management of water resources requires the linking of social and economic development with environmental protection, within the river basin or catchment area.

Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. Decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in planning and implementation

Women play a central part in the provision, management and safeguarding of water. Institutional arrangements should reflect the role of women in water provision and protection. Empowerment of women to participate in decision-making and implementation, as defined by them, needs to be addressed.

Water has an economic value in all its competing uses and should be recognized as an economic good. Access to clean water and sanitation at an affordable price is a basic right of all human beings. Failure to recognize the economic value of water in the past has led to wasteful use and environmental damage.

2.4 Water management stakeholders

IWM practices incorporate a large amount of different domains and sectors. Many different stakeholders, institutions or organisations need to be integrated into a complete water management approach. Integrated water management, a multidisciplinary task, has therefore consequences in the economical, social and environmental domains [9]. These three poles interact, change and determine the basis for water practice decisions. Figure 2 shows a schematic view of the three cited domains.

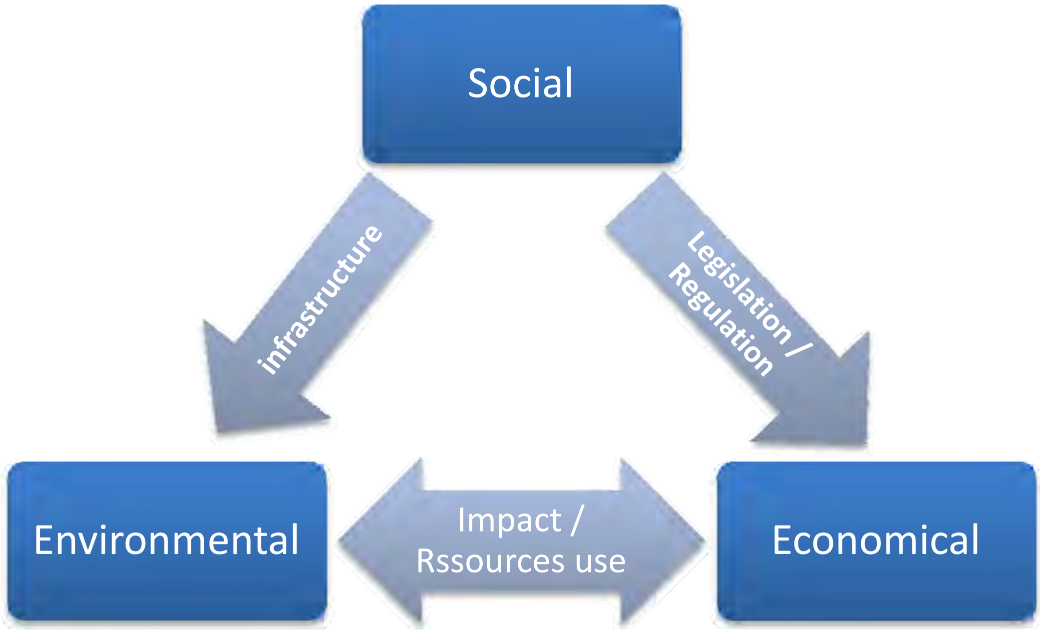

Figure 2 The three main poles in water management

The ecological domain directly reflects the health and the status of ecosystems that are in relation with the water resource element. The biotopes of concern can be of different nature as aquatic systems, soil compartments, forest or swamps. In order to keep a natural balance of these systems and to preserve biodiversity, a sufficient amount of water and a respectable quality needs to be guaranteed. In order to maintain a renewable resource the environmental concerns in water management are essential to be integrated accordingly.

The economical sectors that profit directly or indirectly from the water element are as various as the products delivered itself. Whether a specific industrial sector does account water in its production chain or not, the final service or product provided can rarely be proposed without the use of this resource. Therefore energy production, heat generation or cooling, cleaning and sanitary installations are just a small sample of industrial water applications. As main consumer of the water resource the industrial sector is at the same time the major responsible on the water cycle pollution. The economic point of view through which water is apprehended also plays an important role in the resource institutional and financial system.

Through its social importance, water management strategies try to administer the multiple relationships existing between the resource and stakeholders, actors, institutions and organizations. This spider network of dense interactions requires the identification of each interest towards the water problematic. In a general manner social influence on water management decisions can directly be noticed when analyzing cultural behavior. Therefore the implementation of hydrologic strategies or the choice of economical water taxing strategies are subject to social acceptance. Furthermore water management practices need

to incorporate risk assessment strategies when analyzing potential hazardous hydrologic events and the social aspect.

When dealing with a water management issue, the resource element itself is just a part of the whole system. The lack of integration of a domain can have undesired effects on the projects outcome or even lead to the project's failure. With the aim of including the three poles of interest water management practices exploit an enormous amount of information that's needs to be integrated in the decision making process. IWM can therefore be defined as an environmental, economic and social activity and defines a whole holistic framework approach.

2.5 Water governance plans in Europe

In European governance IWM principles have been regulated in the EC directives that have been commissioned since 1976 [24]. The nature and objectives of the directives are various, the water management concerns are mostly regulated in the Urban Wastewater Treatment Directive (91/271/EEC, 1991) [9] [10] [39].

Today the EC directives have been resumed in a new document which constitutes the basis for IWM approaches, the Water Framework Directive (WFD). Enclosing all past water EC directives, this document aims to establish a new point of view on the spatial and time scale for the urban system. Therefore water problems are formulated into a more holistic way. As a major change the River basin becomes the primary working unit for all studies. Implicating a wider investigation of the area, the water components become more detailed and understood and the different actors that are touched by the water problem need to be identified.

In order to include sustainable principles, the changes over time for several components are taken in account as well. Climate change or urban growth become direct implemented scenarios that will influence the choice of actions on the urban catchment. In order to complete the WFD observation the river basin plans will contain:

- Characterisation of the river basin's properties
- Inventory of human activities' influence on the water cycle
- Economical and financial analysis of the use and the goods provided by the resource

The major objective of the framework is to achieve an acceptable status for all European waters by 2015. The norms are defined in the WFD for natural as for human viability. Furthermore participation of the different actors of a River basin is one of the important

changes included in the WFD. The supplementary major modifications are the prevention of the pollution at source and the integration of pollution sources in management strategies. Considering a wide spread investigation for pollution control, the WFD presents the objective of considering all pollution sources in a whole management plan instead of treating each separately. The main tools through considered in the WFD are resumed in the following points [39].

- Water pricing policies and polluter pays principles
- Regulation policies in the agricultural and industrial sector as well as for individual consumers
- Planning polices controlling the urban development

Important improvements in terms of IWM principle's adoption have been presented in the WFD. However certain innovative concepts and ideals are still not formally stated as for the choice of energy saving constructions or technologies, the evaluation of the investment effects on different water treating domains or the reuse of wastewater for secondary purposes. The Bellagio statements, widely accepted as a system overview for achieving healthy urban water systems consist today in the most complete theoretical plans. Implementation of these ideals would create a water system based on recycling without the need of any external inputs.

The National policies of the European countries have integrated the WFD principles in their legislation, water management project are therefore slowly and approaching an integrated urban management vision. The urban environment's sustainability is analysed through several domains with the regulation of material flows and control of potential risk factors. Though viability of the urban system is only partially apprehended, continuous progress in the governance sector or in technological solutions are tried to be achieved. Therefore research projects try to promote newly found approaches and aim to share information on the urban problematic.

3 The Switch project

Increasing pressure from externalities as climate change, urban population growth or energy dynamics are forcing the urban system to adopt more efficient water management strategies. In order to investigate and upgrade IWM practices, the Switch project aims to regroup a number of international research facilities and to create a paradigm shift in the way water is managed in cities. As an European founded initiative, Switch regroups a cross-disciplinary team of 33 partners from 15 countries around the world. The members vary from academics, urban planners, water utilities to consultants. The group of researchers and professional actors directly apply approved strategies to real case studies for ten global cities. Through a sharing and knowledge combining processes, water related problems are tried to be resolved through a multidisciplinary approach. Lessons learned as well as results from specific on site projects are discussed and shared throughout the members.

The studies in the Switch project bring local stakeholders together and facilitate communication between them. Helping projects to include collaboration of actors from different domains, Switch actions adopt IWM practices and investigate urban water issues for a complete apprehension of the problem. The project's themes cover the whole water cycle and include stormwater management, efficient water supply and use, waste water and urban water planning, which are regrouped under different research themes. These themes are resumes as:

1. Urban water paradigm shift
2. Stormwater management
3. Efficient water supply and use
4. Waste water
5. Urban water planning
6. Governance and institutions

The Switch project is an organisation trying to offer a starting point for integrated urban water management applications. Being based on scientific knowledge it promotes strong local participation and investigates water problems in order to give enhanced understanding on the urban system functioning. Several cities have been chosen as study cases for the Switch projects. Birmingham, situated in the United Kingdom, constitutes one of these cities.

4 The upper Rea catchment

The upper Rea catchment is part of the urban agglomeration of Birmingham. This city and metropolitan borough is situated in the West Midlands county of England. As second most populated metropolis in the United Kingdom the city of Birmingham represented the country's powerhouse of the industrial revolution. Today Although Birmingham's industrial importance has declined it has developed into a national commercial center catching the interest of many international business investments [14].

Located southwest from Birmingham's city center, the upper Rea catchment envelopes an area of approximately 1,800 ha and is occupied by a population of roughly 70,000 people [8]. The region derives its name from the river Rea that takes its source from the Wasely and Lickey hills situated North West of the catchment. Travelling its first kilometers through the catchment, the river's path has a declination of 70 m in the region representing a moderate gradient. Passing through dense populated areas the Rea river is mostly canalized all along its way. Having several tributaries as the Callow Brook, Hanging Lane Brook, Turves Green Brook, Griffins Brook and Bourn Brook the small river played an important role in the development of the region. The Rea's flow passage begins at the North West edge of the catchment passes through the Upper Rea catchment near the former Rover works at Longbridge, then flows through a tunnel under the A38 highway and continues to the Eastern edge of the region. The general flow pathway of the Rea river therefore crosses the catchment from the Western to the Eastern side and reaches at its end the Tame. The river Rea has played a vital part in the development of the city.

The land use in the catchment varies from urban and open urban development to public open space and parkland, urban fringe, industrial premises, major road and rail infrastructure and the River Rea and its tributaries. Major constructions have changed the soil properties in the last decades as the expansion of the Great park commercial center and the development of the Longbridge industrial zone. Being at the limit of Birmingham's rural background, the upper Rea's land properties range from high asphalted impervious surfaces faces to more pervious natural spaces.

The catchment's topography is generally represented by a gentle almost flat profile in the center and ravine like valleys in the South. The geological characteristics defined for the area are presenting a poor permeable soil. As the principle soil type Mudstone consists of a mixture of clays and sand. Depending on the proportion of sand the water infiltration potential is rather low. Contrariwise to the rest of Birmingham's region the upper Rea catchment didn't register any problems with groundwater level elevation. The soil's poor permeability limits any surface contamination with the underground water stock.

The upper Rea region is subject to intense rainfall events which can cause flash flooding [8]. As particular phenomena the catchment is subject to very different rainfall records than the rest of the Birmingham city area. Flood events have been registered since the beginning of the 20th century in the region. The latest most important flooding episodes have causes severe damage on infrastructures and deteriorated the life quality of the indigenous population.

The flooding events are situated at different areas of the catchment and are the consequence of different phenomena [6]. The flood system behavior of the upper Rea catchment is complex and varies from peri-urban runoff flooding to river and sewer overflow. Records of the flood events are registered by the water distribution company Severn Trent and the local municipality administration, Birmingham city council. The water problematic is in hand of different stakeholders which causes misunderstanding and unclear responsibilities in order to resolve the flooding issues.

4.1 The flooding mechanism

The historic records identify several sources that contribute to the production of flood events in the region [8] [11]. The main zones that have been identified with flood risks are shown in Figure 3.

Figure 3 Upper Rea flood risk zones

Different reasons are the cause of water exceedance in the subcatchment. These can be separated according to the origin of the floods and are listed as followed:

- Pluvial
- Fluvial
- Sewer
- Peri-urban runoff

Pluvial flooding is mostly due to urban impermeabilisation of the ground and linked to parcel presenting a low topographic gradient or featuring a depression of the landscape.

Fluvial flooding records have increased with the change of the river's bed and pathway. Receiving direct runoff inflows from impervious surfaces the different rivers are also subject to sewer overflows from the urban system. The combined sewer overflow control structures and direct draining from the sewers have an important effect on the river's water level and flow rate. Complicated interactions with the rivers and the sewer system continuously cause one element to overcharge the other.

The sewer network is composed by a foul, a storm and a combined sewer system. In the Upper Rea catchment mostly all the water distribution and the waste water system are privatized infrastructures and belongs to Severn Trent Water limited (STW). Contrariwise, local private sewers are managing the water flows for different parcels. The radius of the different parts of the canalizations are dimensioned for a 30 year period return event. Flooding events recorded by STW show at the same time quality and quantity problems relating to sewer flooding. The main events are located principally near to the industrial area of Longbridge and near to the commercial zone of the Great park. As described for the river problem, the risk of sewer's overcharging depends on the hydraulic behavior of the river.

Peri-urban runoff flood is caused due to the clay proportion in the upper Rea catchment's soil and the hilly topography in the Southern part of the region. Water therefore runs from the peri-urban zone to the constructed land and then ponds on the surface.

Due to the lack of consideration of overflow paths, of the combined effect of the river and the sewer and the rapid impermeable development of various areas the stormwater problematic increases. The catchment is therefore in need for a better land use management plan.

4.2 Flood responsibilities and policies

The water related issues in Birmingham are regulated by public and private instances. Several actors and organizations are involved in the water system that integrates many stakeholders with different administrational actions. The split of the tasks and the share of responsibilities in the water domain stays quite unclear. In fact, the organizational path that needs to be followed in order to resolve a certain problem is regulated by different institutions. Furthermore the elaboration of a certain project often lacks in a holistic view due to data sharing and communication problems between the organizations [8].

The main stakeholders involved in water related issues in the Upper Rea catchment can be resumed by six organizations [10]. These are the Birmingham city council (BCC) as the local authorities, Severn Trent Water Limited (SWT) as the main water provider and waste water treatment company, the environmental agency (EA) as the governmental institution, the highway authorizes responsible for all urban roads, the environmental department for flood and rural affairs and local drainage boards constituted by consultants and professionals experts for a specific project. Table 1resumes these actors with their respective functions and responsibilities.

Table 1Flood actors and organizations of the Upper Rea catchment

ORGANISATION	RESPONSIBILITIES	LEGISLATION
Local Authorities (BCC)	Drainage, flood alleviation and regulation of non-river watercourses. Control and regulation of land development strategies.	• Public Health Ac 1961 • Drainage Act 1991 • National land use guidelines
Highway Authorities	Responsibility to keep urban roads free from flooding and to control highway runoff.	• Highways Act 190 • Land Drainage Acts 1991, 1994
Internal Drainage Boards	Not for profit supervisory duties over flood defense and drainage projects.	• Land Drainage Acts 1976, 1991 and 1994
Water Companies (SWT)	Responsibility for providing and maintaining a public sewerage system including sewers carrying surface water from impermeable building areas.	• Water Industry Act 1991 and 1999
Environmental agency (EA)	Aims to protect and enhance the environment and make positive contributions towards sustainable development. Responsible for operation, maintenance and improvement of flood defenses and 24 hour flood warning service with emergency response.	• Environment Act 1995
Department for Environment, Food and Rural Affairs (Defra)	Sets central government policy (and transposed EU legislation) and provides strategic directions.	• Water act 2003

The roles of the organizations towards the local population and the different links among them are schematically represented in Figure 4 Flood responsibility share of the Upper Rea cathmentFigure 4.

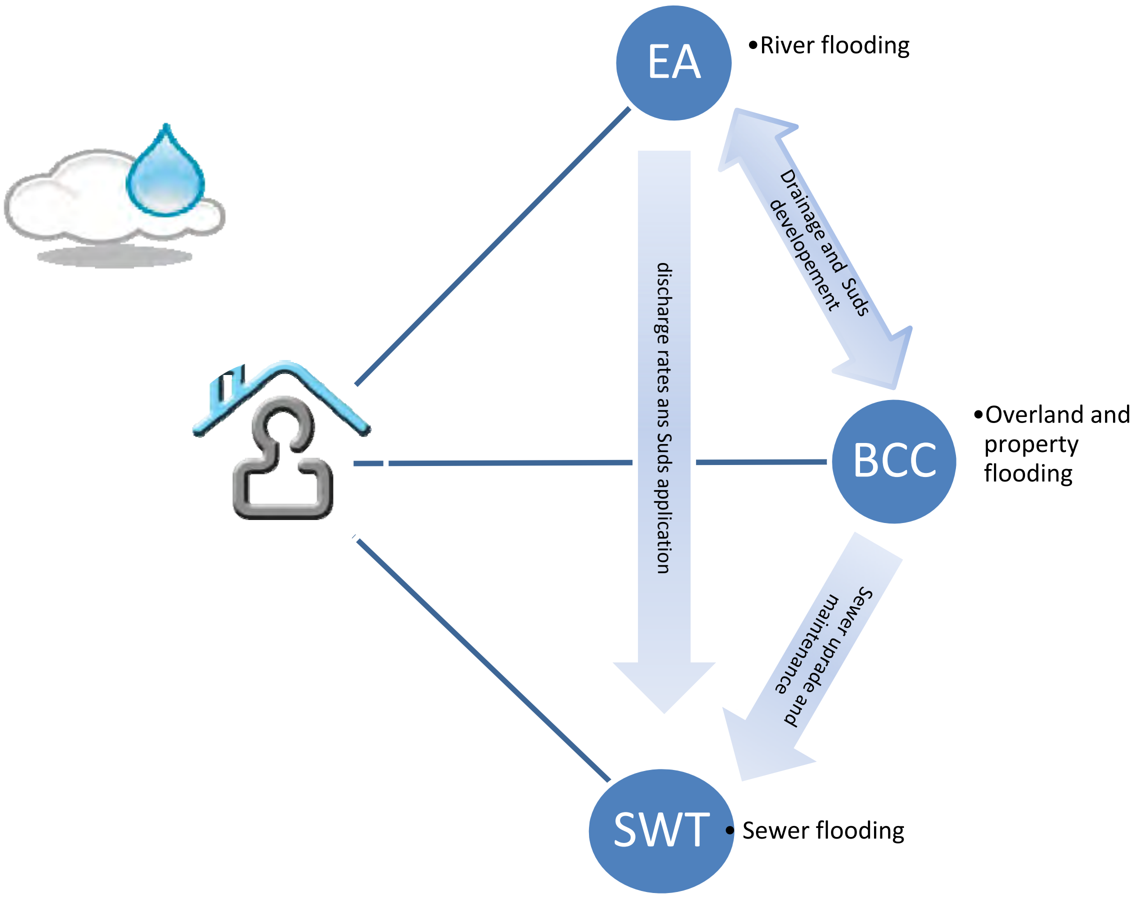

Figure 4 Flood responsibility share of the Upper Rea cathment

However the roles of each organization are defined, local population is still unclear with the question: “Who is responsible for what once a flood has occurred?” [8]. Residents from the Upper Rea catchment are very unclear on this point and many projects are still lacking of a suitable coordination in order to follow the national edited guidelines.

4.3 Policies and flood regulation laws

Under the European directives and the WFD, the UK is regulated by different policies in order to manage the flood problems [10][18]. The major documents that regulate the water organizations are cited in Table 1. As a non exhaustive list of water legislation documents the most important papers relevant to the water problematic in Birmingham are described [14] [23].

The water act 2003 is the base of the water legislation in the UK. It precise the roles of the different stakeholders and contains the resource management plans.

The water industry act 1991/1999 and Resources act 1991 detail the general duties and functions of the stakeholders [18]. These documents are the direct application of the Water act 2003.

The governmental program “Making space for water” serves to define visions and future objectives that want to be attained by the UK. The program edited by the Defra fixes guidelines for local management plans and sets constrains for building regulations, water use and many other sectors that can have influence on the resource.

There have been noted major gaps in the legislation in order to deal sufficiently with the flood problems. For example pluvial floods responsibility is not defined in the legislation. In a general aspect, the legislation doesn’t oblige active prevention behavior from water companies which leads to only reactive measures and management plans. The executive force of the governmental programs is also very limited. The implementation of sustainable drainage systems as well as their maintenance isn’t defined as a necessity in management plans. The weakness and the missing of certain important elements in the national legislation induces a general passive behavior in flood protection programs and limits the application of long term sustainable land use strategies.

4.4 Longbridge and Great park

The upper Rea catchment is composed of different activity sectors. Two of them appear particularly interesting when water problems are analyzed. The first is the former industrial sector of the car plant MG Rover the Longbridge area. The second is constituted by a large commercial center situated near to the Great park area. Through the relatively important surface of these two zones, the characteristics of their land use and the onsite flood events observed, it appears interesting to investigate their influence on the flood behavior of the catchment [7].

The Longbridge area has most recently been exploited by the car manufacturer MG Rover. The Longbridge industry became shut done and some parts of the older sections of the site were demolished after MG Rover fell into foreign administration in 2005. Under new administration the car company, now called MG Motors UK Ltd has proclaimed full activity again in the same area. In order to become a productive plant the area has needed a rehabilitation of the infrastructures and a reorganization of the site. The Longbridge construction site represents the biggest regeneration scheme in the West Midlands and one of the largest in England. Over 140 hectares are subject to this project which aims to reactivate the local economy. As a good opportunity to integrate the zone to the

Birmingham's land use and drainage plan the BCC has therefore subscribed the zone's development to an area action plan. This program includes different objectives as the creation of over 10'000 jobs, the construction of households for the workers, the growth of Birmingham life quality with the establishment of a commercial center and the sustainable development of communities, buildings and green spaces. The implementation of SUDS strategies has been considered which represents a strong opportunity for the region to decrease the flood risk.

The Great park area includes some large commercial surfaces, office parcels, residential plots and natural open spaces. The area is crossed by the great park at its Western end and touches the Frankley balancing pond at its Eastern end. Subject to important development in the last decade the Great park area contains parkland, a cinema and bowling alley, a health centre, restaurants, a hotel and a supermarket. The complex formed in the area represents one of the largest mixed use development sites in the UK.

5 Urban water management tools

Through increasing pressure on the urban system the need for an integrated management approach grows. In order to apply IWM principles the framework of the water cycle in cities needs to be apprehended. As already discussed, the multiple water pathways and interactions in an urban environment form a complicated stormwater system. In order to better understand and to describe each step of the water cycle, the overall functioning needs to be split into various stages. A possible approach is to divide the water flow pathway dependently on the structural or natural element it runs through. The main elements can be identified as the followed [9].

- Water supply network
- Waste water network
- Surface runoff
- Waste water treatment
- Natural surface water elements
- River
- Lake
- Groundwater

Each of these elements has specific hydraulic properties, different reactions that can change the amount, the quality or the flow rate of water and communicates with the other compartments. Together these compartments form the water system of an urban environment.

In order to maintain a healthy status of the urban population, to insure an adapted development of the natural environment and to guarantee the quality and the amount of the aquatic resource the urban water system's behavior needs to be investigated. The use of models that reproduce specific aspects of the water system can lead to predictions of risks, help to monitor flows or identify financial needs [32]. Possible applications are multiple and can help management practices to detect leaks, to check accordance with financial policies or represent the urban water system's behavior in a whole.

The procedure of modeling water and wastewater flows, sewer pressure charges, water quality aspects and economical strategies represents a challenging exercise. For hydraulic models for example not only the flow behavior needs to be translated but also the stochastic aspects of input and output frequencies. The model's methodology and structure differs for each type of investigation.

However the simulation of the water cycle in cities combines a various number of complicated responses, models try to reproduce them with simplifications. For stormwater modeling this procedure can be roughly translated by three main reactions that consist in a stock, in a solute transport and a flow action. The three main purposes of modeling the water urban framework can be resumed by these points:

- Dimensioning infrastructures for long term operations and lifetime
- Adaptation of hydraulic facilities to guarantee management guidelines and accordance to official norms
- Investigation and definition of possible economic scenarios that can have effect on the future state of the urban system
- Identification and analysis of the urban water problematic

The implementation of IWM strategies is strongly simplified by the use and the apprehension of different models. Meeting different needs and applicable at different stages of a decision procedure, models common devices in water management practices. Used in the scientific domain, in political sectors or in economical analysis they constitute today an indispensable instrument. Employed to meet planning, designing or operation objectives the type of models can be as various as their applications.

As in IWM many disciplines play a central role to define the total system. Not only a unique model will be able to resolve all the water management issues. In order to obtain a holistic vision of the water problematic different models can be used to analyze a specific topic. In addition a modeling framework platform can be used to regroup the different models in order to form and integrated water management tool. The following sections are presenting the models and the integration platform used during the project.

5.1 Information Systems (IS), Integrated Modeling Frameworks (IMF) and Decision Support Systems (DSS)

Common applications that deal with the handling and the organization of information sets can fall under the definition of information systems (IS), integrated modeling frameworks (IMF) and decision support systems (DSS). The following part gives a brief description of their principles [26] [27] [28] [32].

IWM practices are subject to an enormous amount of information coming from different domains of activity and present in diverse formats. An information system (IS) can be described as an integration system of a various amount of information that can be

represented, stored or processed. An essential task in IS is the creation of views that allows to represent the desired information. This can be done by the intermediate of different graphical representation facilities.

An important aspect of IS is their ability to store information on a central data base and the possibility of processing it in order to produce the desired presentation of the records. It therefore directly serves as a storage communication tool that is able to share and translate solutions among stakeholders.

A difficult part in the work procedure of an information system is the definition of the term information itself. Beynon-Davies defines the functioning of an information system as "a system which main task consists in the manipulation of signs". The main activity highlighted is therefore the processing of the information itself. But why does is it seem to be so important to transform the information? It is in fact not a question of changing the original data but a matter of dealing with its nature.

The data collection can for instance be used to create overviews of the state or the functioning of a system, to establish an investigation tool for operations, or to create a financial flow diagram. A widely used form of IS in environmental applications are geographical information systems. In a broader sense, information systems are used to manage the desired information for communication purposes.

Integrated modelling frameworks (IMF) can be described as an interface for the integration of various models. The main objectives of these applications are the reuse of existing components in order to facilitate the integration of models dealing with various kinds of disciplines. IMF works with the infrastructure of the models and manages the information exchange between them. An Integrated management framework can therefore be decomposed into a set of software libraries, classes or components which can be reused to assemble and deliver an integrated assessment tool.

Decision support systems (DSS) consist in powerful water management tools. DSS are designed to enable comparison and investigation of different strategies or situations in order to help the analysis for decision makers. A DSS can be described as an interactive software-based system that can include ISs and modeling tools enabling users to compile a project's information from a combination of data. DSS helps decision makers in the solution of unstructured problems by extracting, summarizing and displaying the desired information.

An important effort has been done in the last years in order to regroup the functionalities of these different applications. A resulting program has been developed in the Switch research network and can be use as an information decision support platform.

5.1.1City Water Information System (CWIS)

CWIS can be described as a generic decision support system as it enables the possibility to compare a large variety of decision factors that can influence the adoption of a final choice. Partly an information system, partially a decision support application, CWIS incorporates the functionalities of an IMF and can be described as an integrated management tool. It therefore enables the storage, the representation and the integration of models in a same program. A specific characteristic of CWIS is the way it manages the information in the system. Consequently it integrates data accordingly a defined formal structure of knowledge also called ontology [28]. The language therefore constructed is based on an architecture that distinguishes the elements according the type and the level [26][27]. Once the information is present in the data base it forms a network of objects that can be linked.

The need for a more generic approach to incorporate and to manage data with various formats has produced the elaboration of CWIS. This program uses the principles of an IS with the advantage of incorporating all kind of different information. The module integrates the possibility to present elements in 5 different program views that are illustrated in Figure 5.

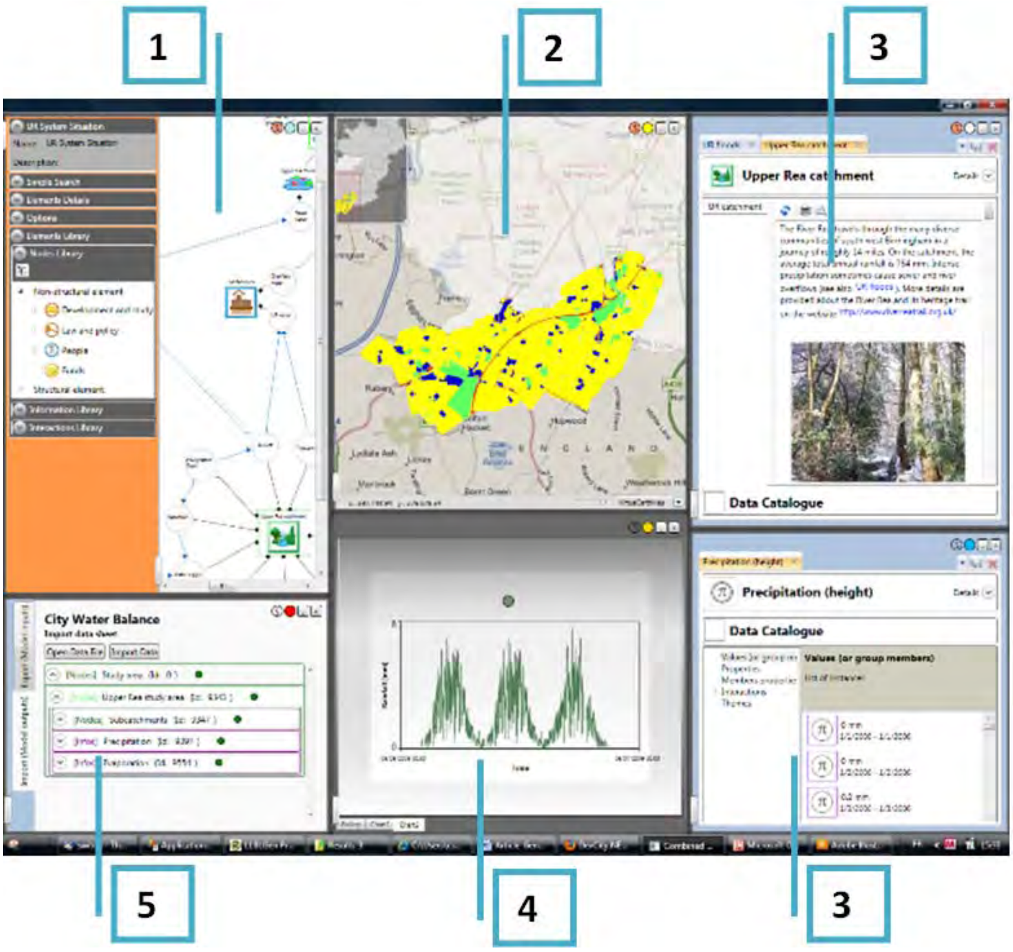

Figure 5 CWIS views

1) The system view enables to represent all information regarding their class equivalent in the ontological classification in the data base
2) The graphical view enables to represent all spatial data in a GIS module
3) The data and report view can represent all literary and non structural records
4) The chart view enables to represent all kind of time series or indicators
5) The data exchange view enables to have a look on the data exchange procedure in order to couple a model

Possible information that can be gathered in any management practices are widely distributed among formats that they can reveal. In order to illustrate this explanation with an example lets analyze the information gathered during a project that deals with the construction of bridge. A whole number of inputs need to be considered and a possible list with the possible formats of the information is detailed below.

Table 2 Bridge construction documents with various formats

Information	Document
Construction site	Map
Dimensions	Excel sheet
Stackeholders	Table
Law and policies	Pdf

All the information in Table 2 has a different format that varies from numeric values to String or graphical illustrations. The main task of an information system is to be able to apprehend and represent the data appropriately. The representation of the data itself is therefore directly subject to the effective possibilities to show structural or non structural information. Spatial information in CWIS is therefore represented by a geographical module. Tables or descriptions can be represented through indicators or text scripts.

With the help of CWIS it is possible to represent a certain problematic and to include all elements that seem relevant to understand the system's behavior. The system view is particularly interesting as it enables the representation of spatial and non spatial elements on a same arrangement and relates the created objects by relationships. In order to illustrate this principle let's take the case of the upper Rea catchment and analyze the flood situation in a general perspective.

The system view of the Upper Rea catchment contains the main actors and components that play an important role for the flood situation. A common way to represent such cases is the construction of a problem tree. In consequence Appendix D shows the flood problematic

centered above direct and indirect causes than can contribute to the development or the increase of floods. The flood consequences are represented above the flood object. Interactions and dependencies between different processes are also put in evidence. Figure 6 illustrates a piece of the problem three.

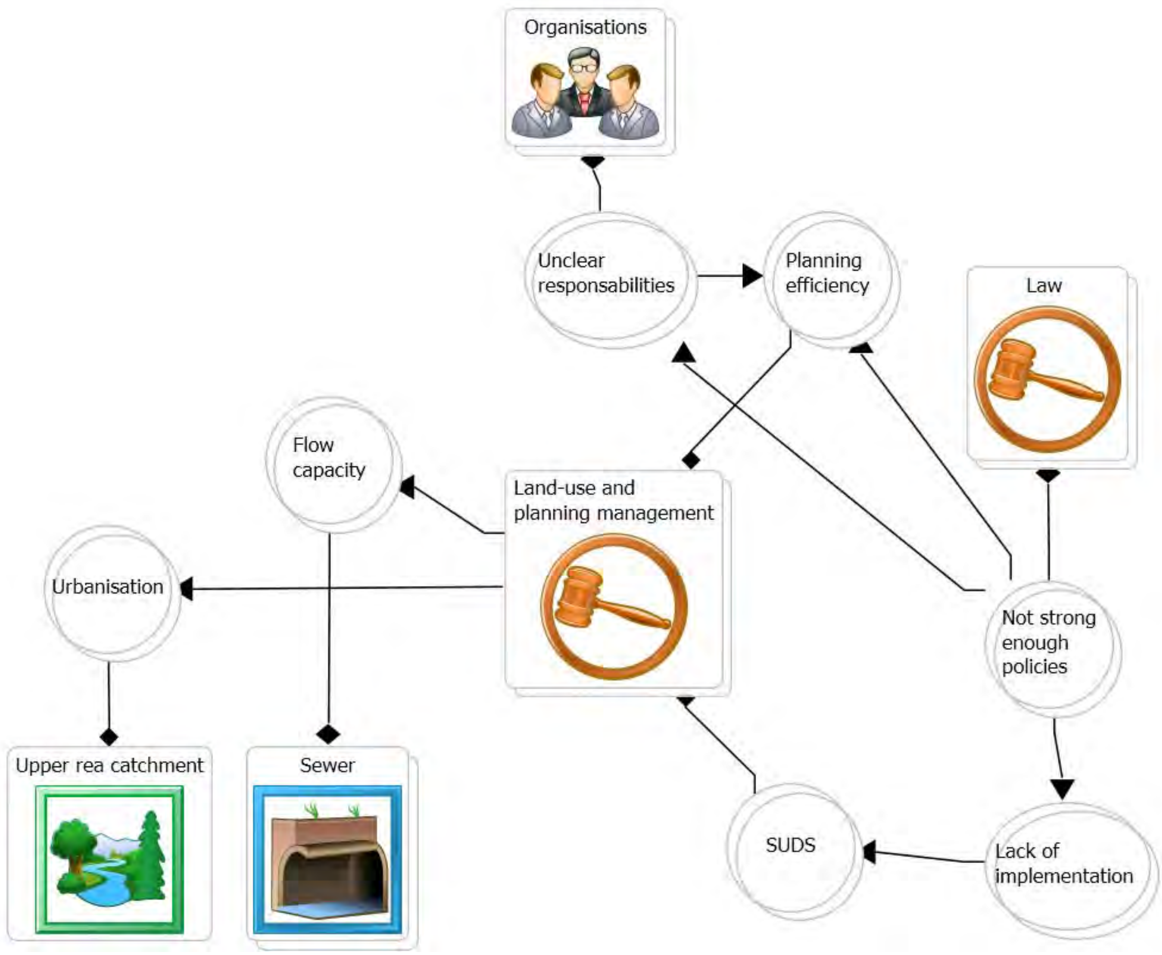

Figure 6 Part of the Upper Rea problem three

A first overview of the different objects and their relationships can highlight existing problems. For instance, the planning efficiency of stormwater strategies can be limited by unclear responsibilities among local organizations. This problem can be increased by the lack of strong policies which can also limit the implementation of SUDS. Furthermore Figure 6 can help to take precautions on processes that can have important relationships as it is the case between the land use management and the urbanization property of the catchment and the flow capacity of the sewers which act as direct causes of flood events.

5.2 Economical urban model and strategies

The adoption of integrated water management strategies can be described as a change in the manner the water system is apprehended. This development is also commonly rephrased in the water sector as a shift in the water paradigm [20] [201]. Some major modifications that exist between the way the resource element has been approaches before and is managed today are resumed in Table 3.

Table 3 Traditional and new management approaches

Before	Today
Stormwater is a nuisance Convey stormwater away from urban areas as rapidly as possible	***Stormwater is a resource*** Harvest stormwater as a water supply, and infiltrate or retain it to support urban aquifers, waterways, and vegetation
Build to demand It is necessary to build more capacity as demand increases	***Manage demand*** Demand management opportunities are real and increasing. Take advantage of all cost-effective options before increasing infrastructure capacity

In developed countries water has always been treated as a social good that needs to be supplied. As an undeniable fact, water is necessary for human health and should be accessible to everyone [4]. The presence of this resource contributes to increase the quality of life and is also the vector of a region's development. When the economical growth is measured, the water element can therefore be linked to the financial profits. It is therefore possible to assign an economical value to the water element [4] [35] [36] [21].

Another important change that has been introduced to the new paradigm involves the water element itself. As already discussed, water can have a value as an economic good as well as a social good. Many past projects in water management have failed due to the lack of consideration of these two values. Therefore, in order to insure access to safe fresh water and to extract the maximum benefits from water resources, an economical water approach had to be integrated in IWM practices [4] [22]. Dealing with water as an economic good is indispensable for logical decision making on water price allocation. In consequence water stakeholders need to be regrouped in a controlled competitive water sector in order to

increase efficiency of the water use, distribution and treatment. The management of water, as an economic good can be translated as the procedure of the resource element's allocation for competitive uses in order to maximize social benefits [22].

The water demand as well as the water charges in the water system have risen exponentially due to higher consumption and the amplification of externalities, such as stormwater damages. The total expenses of water management projects have therefore become very important. The resulting costs have generated important deficits for the water service's stakeholders in the private and the public sector. A solution needed to be found in order to maintain a sustainable economical water system.

Following the IWM principles that have been stated in the WFD, the main objectives in economic management practices is the full cost recovery among the total water system [21]. The full cost of a water project can be resumed as containing calculated costs and estimated costs. On the one hand the capital costs, operation and maintenance costs represent the components that are usually well known and that can be fixed precisely. Whereas on the other hand more variable elements are expressed, as for example environmental externality costs, for which the prediction is more difficult. In many economic projects it is the integration of this less predictable part that causes financial plans to turn out incomplete. If the recovery options are implemented correctly all financial charges that have been assigned are regained on a long term basis. In order to put this procedure in place IWM economical tools and strategies exist, the main economical instruments can be resumed as [21][4] [25]:

- Taxes
- Subsidies
- Prices

The price the people pay for water is the main income for water projects and therefore constitutes an essential and sensible instrument. Water tariffs are the result of the pricing allocation and can be roughly defined as all charges that have some direct relation to the provision of the water service. The way the tariffs are constructed is directly influencing the water use of the consumers respectfully to a classical offer demand scheme.

Subsidies also called eco-investments or eco-taxation when they are related to environmental resources are not very appreciated the neo-economic sectors. In water management subsidies represent a direct financial provision from a governmental institution to financially help water providers to keep the end user's price low and competitive or to encourage consumers to adopt a certain water strategy. The critics in subsidies are directly related to the need of investment from the public to private or semi private sectors. In other words, if public provisions have to be pumped in the water system then external financial aids are necessary to keep the water system viable. The total charges can't therefore be

assumed by the pricing tariffs. The cost recovery scheme becomes therefore dependent on external financial help. In consequence, water subsidies should never be used to support the private sector in order to keep a competitive and efficient economical water sector. They are well adapted to promote social equity, growth, employment and to encourage certain water management strategies.

As described above the externalities in water charges can become very important if the system is subject to changes. These can take various forms as it can be the case for land use modifications, resource scarcity or environmental risk factors. A common example of water taxation is the pollution tax that is adopted to control water pollution and the protection of ecosystems. Based on the principle of polluter pays, the tax is proportional to the amount and the quality of the released water into the environment. The tax is directly impounded to the water consumer that pays dependently on its environmental impact. The general principle of the taxing system mostly remains the same as it represents a public imposed charge that serves to guide the consumer's behaviors. However the objectives of different taxing strategies can differ depending on the desired outcome as for example the decrease of water consumption or the limitation of surface impervious development.

All the three cost recovery tools can have different consequences on the pricing strategy which constitutes the vital issue for the recovery of full costs. When the water pricing system is defined in order that the charges are equal to the marginal costs of providing the water services, the resource will be allocated the in most efficient way [22].

5.2.1CWE

The program CWE developed by the NTUA is based on the development and comparison of different cost recovery strategies. Using the described economic instruments, it represents a modeling tool that can be used to implement financial strategies. The model incorporates water supply, waste water treatment, supplementary water saving strategies and enables the integration of storm water infrastructures.

Considering the overall costs in the water system, CWE enables to distribute and to recover the total charges by attributing a pricing scheme on the consumers. This scheme can be adapted for different household incomes, the imposition of fixed charges, the annual cost growth and for the expected development of the urban region.

The results of CWE can directly be exported as an Excel workbook and can be visualized as costs, tariff schemes or recovery percentage during the studied period of time. Figure 7 shows the CWE model's interface.

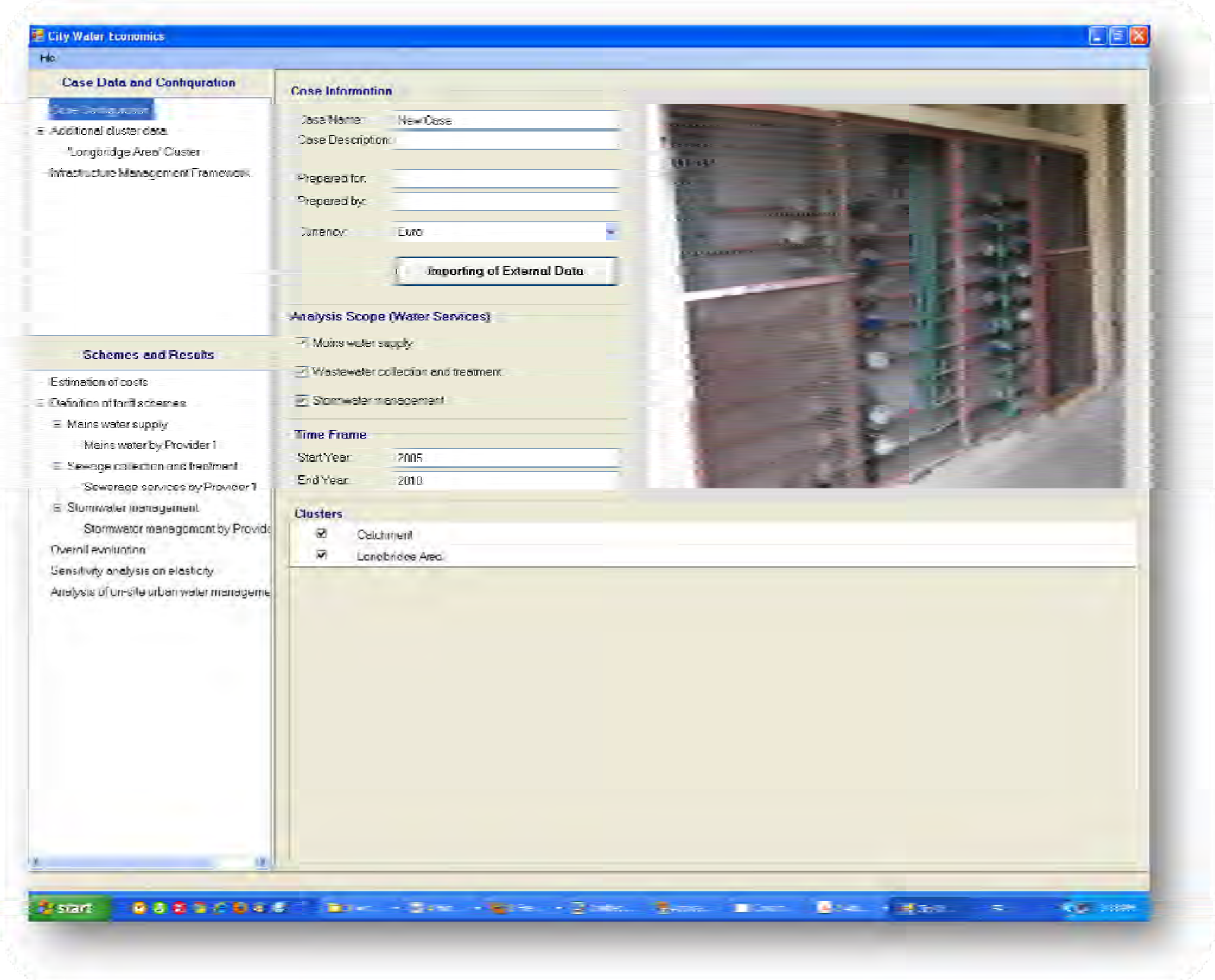

Figure 7 CWE interface

5.3 Urban drainage and flood

As origin of the water cycle, precipitation is the main vector for water spatial distribution [9]. All water systems are dependent on this highly variable parameter that can form different kind of processes according to where it takes place. In cities precipitation is subject to a change in the proportion infiltration/runoff as many areas are impermeable. The excess surface water resulting may therefore slowly infiltrate over time, evaporate, pond until it has reached a certain height, accumulate in depressions and run through the urban environment according to the topography and structural obstacles. All these courses of action can change the water balance in cities, creating water stocks, drain routes, infiltration zones and feed the water system compartments. In IWM practices the resulting complex flow network is controlled through constructional measures and urban land use strategies.

Urban surface water process also known as runoff constitutes a very difficult water process to predict in urban areas. The drain routes are directly influenced by the surface's elevation profile but also by the urban constructed landscape. As a result rainfall will always be drained following the steepest possible channels. In order to estimate the flow path it appears necessary to have a detailed land model with the latest land use changes. The other three important parameters of the drainage process are the rainfall amount, the flow rate and the time needed for the runoff to reach the system's outlet [13] [34].

The amount of stormwater depends on the size of the subcatchment that contributes to the drainage channel and to the proportion of impermeable surface. The sum of all water that drains to the same subcatchment can be expressed in volume units.

From the moment a rain droplet touches the ground until the time needed to reach the subcatchment's outlet the flow rate depends on the urban landscape. The runoff velocity can therefore be influenced by the dimensions of the drainage channel or by the encountered obstacles. The stormwater flow rate is expresses in terms of volume over time.

The moment at which all the subcatchment's runoff contributes to the outlet's discharge is defined as the time of concentration and depends on the flow velocities and the retention periods of the runoff volume. The concentration time can be expressed in time units.

In consequence, in order to predict a catchment's drainage behavior these three parameters have to be investigated. A large amount of information and a good knowledge of the catchment's surface are therefore needed.

With heavy rainfall or an increase in the impermeable surface proportion, the capacity of the drainage network can be exceeded. This means that the runoff generated, overcharges the natural flow paths or the constructed drainage channels which are unable to evacuate the total amount of stormwater. When this overload becomes important enough, the water level rises and the so called floods are formed. This can occur where ditches, drainage channels, culverts or sewers capacities are exceeded.

Not only the amount of drainage water but also the runoff velocity can limit the flow to pass through the subcatchment. As different drainage channels can have reciprocal interactions the important flow rate in one channel can and produce localized floods in the other. In order to illustrate this principle, lets take the example of the combined flood event of a main street and the sewer system below. The street and the sewer system act as separate drainage channels with the gully structures serving as connections. While the sewer system receives runoff from upstream and from the streets inflows to the gullies, the road directly drains the direct surface rainfall. Two possible flood events can occur. The sewer system can get overcharged and overflow into the streets by intermediate of the gullies. The second

flood event can occur due to water ponding on the streets and limited the throttle capacity of the gullies. In both events flooding occurred due to the amount and the important flow rate.

With the aim of understanding and reproducing the runoff behavior in urban environments it is important to integrate all drainage elements into the final model. The hydraulic behavior and the dimensions of the system's key drainage infrastructures are needed to get appropriate results. Furthermore their interactions need to be described for rainfall events with different magnitudes and durations.

5.3.1Storm

The storm drainage model enables the prediction of stormwater runoff and calculates the respectfully flow rates. Presenting a routing model, the urban domain is decomposed into subcatchments that contribute individually to the catchment's runoff production. The generated runoff at each subcatchment is routed through the use of a reservoir based method. It is an object-oriented programming device written in Microsoft Visual C++[34]. The distribution of the flows is spatially calculated on a one dimensional approach and can be investigated for each hydraulic element that can be implemented in the model. Storm uses a continuous long term simulation in order to verify the effect of different rainfall events on the system. Suitable to control the dimensioning of different infrastructures it includes a surface runoff model as well as a sewer model. It therefore enables the simulation of flows over impervious and pervious areas, through channel and pipe networks and through storages. Furthermore it is able to investigate the behavior of the catchment response to the rainfall events as a function of time and at several locations throughout the catchment.

Through a graphical working interface which can include geographical background shapes Storm can implement different elements characterized and dimensioned with specific property tabs. The collections of possible included elements can be resumed accordingly to their drainage behavior and their hierarchy in the runoff process. Storm therefore distinguishes three main elements that can be represented spatially in the urban drainage system

- Surfaces
- Routing elements
- Drainage elements

The surface elements are the receivers of the rainfall and constitute therefore the direct producers of runoff. Dependently on the permeable properties a surface can be allocated to

a permeable or impermeable surface. The runoff behavior can be expressed through the runoff coefficient and different losses. The amount of runoff produced from the surface is directly proportional to the size of the area. Each surface is part of a subcatchment which has supplementary properties defined as the evaporation or the height of the groundwater for this region.

The routing elements constitute the drainage channels serving as links between the surface, the drainage elements or other routing components. In consequence different type of pipe networks systems can be implemented as sewers with storage capacities or multiple branchings. The hydraulically behavior of the link elements are directly calculated in Storm depending on their dimensions and their flow properties. These elements can play the role of transport components and define the limiting flow rates in the system.

The drainage elements are infrastructures that receive a certain inflow, act as reservoirs and infiltration devices and distribute the runoff to downstream elements. Their influence on the runoff is directly proportional on the nature of the drainage structure and on its dimensions. As in IWM, Storm differentiates between centralized drainage systems and decentralized drainage systems also known as sustainable drainage systems (SUDS). These centralized and SUDS strategies are represented in Storm through different alternatives. With the possibility of linking the drainage elements to all kind of other elements the drainage functioning of an urban system can be reproduced for many possible configurations. Figure 8 shows an implemented drainage scenario.

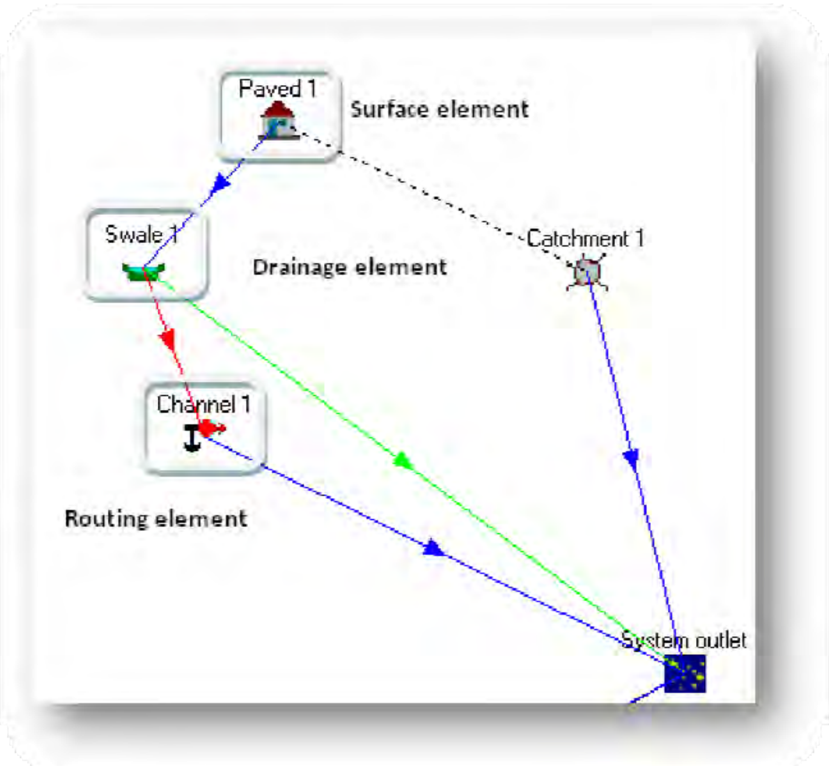

Figure 8 Storm model scenario with the model basic elements

The results of the long term simulation in Storm are presented in Microsoft Access format which can also be viewed in Excel. The calculation investigates the water runoff process in the constructed system for a desired time step and gives results for each elements assigned. For important time series and in order to filter the final outputs it is possible to define the desired end results. In consequence Storm gives the flood volume and the flood duration for the respectfully rainfall event.

5.4 Linkage between the models

In order to demonstrate the possibility to use the Switch applications jointly with the intention of investigating the project's problematic it seemed interesting to incorporate the cited models into a unique interface. As an already existing feature in CWIS the model connectivity application has been adapted to launch the CWE. The connectivity has not been performed for Strom as the construction of the desired urban drainage model passed through an objective oriented approach and couldn't be performed with by the input/output formatting approach in CWIS. The linkage between CIWS and CWE has been performed by PhD student and master project supervisor Bastien Roquier.

6 Sustainable urban drainage strategies (SUDS)

As described in 5.2, IWM practices have brought a change in the water paradigm. This is also the case for the drainage strategies chosen in order to prevent or to decrease a certain urban water related issue. The force of change rose from the manner the traditional approach used to manage stormwater [30] [40]. Consequently it has always been the aim to collect stormwater in order to dispose or to channelize it somewhere else through underground pipe systems conveying the water away as quickly as possible, either into some other part of the catchment or into the natural environment. New concerns appeared with this approach as the discharge of stormwater damaged the related areas in term of quantity and quality. As a result the change of natural flow characteristics and the contribution of urban washed pollutants leaded to important problems throughout the urban-rural agglomeration. Furthermore with the increase of rainfall intensity, traditional methods had to continuously adapt the structural dimensions. Instead of shifting the problem from one place to another, water management practices therefore identified the need for a more efficient way to deal with stormwater.

Through the adoption of the Agenda 21 principles the traditional stormwater management approach has been revealed to be incomplete [39][40]. In order to meet long term drainage objectives strategies had to approach the stormwater issue on a wider spatial and time scale. Sustainable urban drainage strategies (SUDS) have been developed with sustainable principles in order to reduce urban water risks and to preserve the environmental health. Working on a three dimensional sustainability scheme SUDS strategies are applied in order to meet quantity, quality and amenity and biodiversity preserving objectives. Figure 9 shows the main objectives that SUDS try to fulfill by presenting benefits in all three categories.

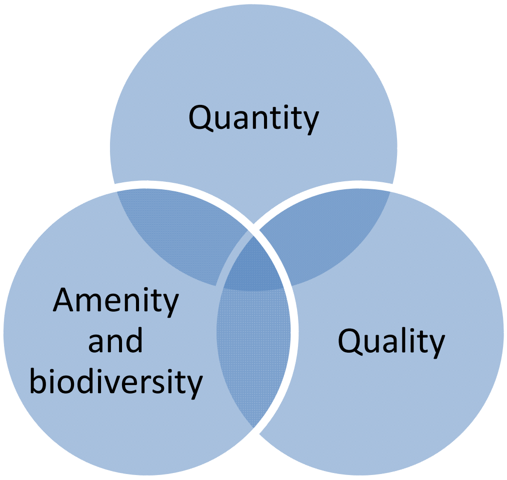

Figure 9 SUDS application objectives

As main difference between conventional drainage strategies and sustainable strategies, SUDS present decentralized systems acting locally on runoff sources and incorporating a water treatment chain. In consequence each SUDS unit is connected to relative small runoff volumes which pass through a filtering or biodegrading process. With an effective control of the stormwater volume at its source large stormwater control infrastructures can therefore be minimized.

SUDS are considered as cost-effective easy-to-manage solutions that can decrease runoff flow rates, reduce the runoff volume and apply a first treatment to stormwater [40]. Acting as reservoirs, infiltration devices and reducing the catchment's retention time, SUDS are hydraulic solutions for the urban system. It is therefore possible to use SUDS as flood control devices, water resource and ecosystem protections systems and to enlarge biodiversity through creation of new natural habitats in the urban environment. The SUDS strategies investigated through this project are listed and described in the following points.

6.1 Swale

Swales are open, shallow channels covered with grass or other vegetation [40]. The general form of swales is trapezoidal with draining side slopes and a filtering bottom. The hydraulic behaviour can contribute to flood attenuation by storing, conveying and infiltrating the water into the ground. Swale can slow down flows and treat pollutants by uptake from the vegetation or underground infiltration and can replace conventional drainage systems as curbs, gutters and storm sewer systems. Swales are typically used beside roads and parking lots and should be used for rather small catchment in order to reduce the flow velocity and the corresponding erosion risk. Figure 10 shows a possible swale infrastructure.

Figure 10 Swale

Source : 2009 Thomas Engineering SA

6.2 Trench

Infiltration trench are long, shallow excavations filled with a rapid filtering media as rock or rubble [40]. The reservoir volume of trench can temporarily store the stormwater received. Gravitational filtering occurs while the water percolates to the bottom of the Trench. The stored water can then infiltrate side wise and from the bottom. Trenches therefore reduces the runoff rates and volumes, remove sediments and can help to preserve the natural water balance. Trenches are used with underlying permeable soils where the groundwater can be vulnerable to pollution. Due to the high clogging risk and the low biodegradation behavior trenches should not be incorporated in a drainage treatment train. Figure 11 shows a possible trench infrastructure.

Figure 11 Infiltration trench

Source : Washington County Maryland

6.3 Porous pavement

Pervious pavement represents an overlying pedestrian and vehicle pavement that infiltrates the stormwater into an underlying temporary storage compartment [40]. The water can then percolate in to the ground, can be stored and can be canalized to further drainage infrastructures. Porous pavements can constitute shallow reservoir for quite large areas and can act as sedimentation devices. As pervious pavements can support heavy overlying loads they are typically used for paved areas as car parks. Figure 12 shows a possible porous pavement.

Figure 12 Pourous pavement

Source : Minnehaha Creek Watershed District

6.4 Greenroof

Greenroofs represent a multi layer drainage system applied on roofs [40]. The upper layer consists of a vegetation surface of various kinds of plants. Depending on the size of the plants the greenroof contains an underlying subsurface that contains a specific substrate. The roof is protected through a drainage and a protection cover. As the rainfall percolates into the system the water can be temporarily stored, absorbed, evaporated and treated through a various kind of processes. Greenroofs therefore decrease the runoff volume and peak flows and canalize the rainfall to further drainage systems. Used on flat and gentle slope roofs, the greenroof can be applied for large small to large areas. Beside the hydraulic control greenroofs have also beneficial effects on the air quality and the building's isolation. Figure 13 shows a possible greenroof.

Figure 13 Greenroof

Source : Green building elements

6.5 Pond

A detention or retention pond represents a large excavated piece of land used to store water volumes [40]. Ponds are designed to support aquatic or swamp sideline vegetation and can act as a storage unit, biological treatment device and can create new habitats. The retention time of the water in the pond helps to increase the sedimentation and the biodegradation processes and allows important volumes to evaporate. Infiltration can happens at the sides and at the bottom of the pond that can be connected to a throttled overflow output. Ponds need to be implemented on unconstructed areas and can receive important runoff volumes from adjacent parcels. When designed right ponds can enhance the local wildlife, the biodiversity and the aesthetic of the urban landscape. Figure 14 shows a possible pond.

Figure 14 Pond

Source : Wikipedia

6.6 Multicriteria analysis

As decentralized drainage systems are slowly replacing the traditional centralized systems in urban management plans, the questions remains which sustainable strategy should be used. Furthermore many traditional methods are still very effective and can be equipped with a more sustainable end of pipe treatment system. The rehabilitation of existing stormwater control infrastructure and the implementation of sustainable drainage strategies can relate to a large choice of SUDS options.

The drainage infrastructures have specific hydraulic characteristics, present different treatment methods and require an adapted place to be realized. Despite the technical constraints, local communities may more easily accept one or the other drainage option. Finally the cost factor can play an important role for the preference of a certain SUDS strategy. As in many management problems there is not only a unique possible solution.

When the decision maker of a stormwater project is confronted with a situation that requires to choose among several options that are related to different parameters, the decisional step becomes a multicriteria problem. Therefore the choice of a certain strategy represents the non linear response of its effect on various numbers of urban parameters that have been designated in order to fulfill certain prefixed objectives. The use of a

multicriteria approach enables the comparison of different options and allows simultaneous evaluation of a vast number of criteria, including those that may indicate the success and the failure of a particular process [3]. This decisional tool may highlight the existents of possible conflicts between multiple objectives and can indicate the obligation to consider a compromise among them in order to meet the desired outcome.

A multicriteria analysis can produce a more comprehensible resume of the situation and reveals itself as a strong communicational instrument that explains decision among different stakeholders [3]. When the criteria are formulated adequately to the problem considered, the decision making process with a multicriteria approach enables to reveal the optimal solution.

In order to illustrate this concept let's take the example in section 5.1.1 of the construction of a bridge. A possible problem that could exist during this project would be the choice of the size of the bridge. The collection of criteria that could be kept for the decision making process, could be the social acceptance, the cost factor, and the mobility factor. The size of the bridge would affect the criteria in the following three possible points:

1. The bigger the bridge, the more traffic could pass and the mobility of local transports would be enhanced.
2. The bigger the bridge, the more cars would pass through the local neighborhood which would decrease the social acceptance of the project
3. The bigger the bridge, the more the project would need financial needs and the more the cost factor could lead to the project failure.

The multicriteria approach revealed the existence of different parameters that can be important for the choice of the bridge's size. It showed that point 1 is contradictory to point 2 and 3, a compromise is therefore needed in order to harmonize the acceptance for all the three criteria. The project responsible is then charged to fix the priorities depending on the working objectives.

6.6.1SUDS decision matrix

Following the multicriteria approach, it is important to identify the project's appropriate criteria and to evaluate the desired choices according to the chosen goals. A common possibility to represent the possible choices and their effect on the criteria is the construction of a decision matrix. This decisional tool consists in a quantitative technique that gives the performance of all possible choice relatively to the investigated objectives represented by criteria. A basic decision matrix construction consists of establishing a set of criteria that are subdivided in indicators, which each give the score of the examined choice. In order to obtain the rank for the desired criteria the scores of the indicators are summed

up. In order to evaluate the total rank of the choice for all criteria, a weighting procedure of the scores can be performed. This allows the project responsible to fix the priority objectives that have to be met.

The decision matrix built for the choice of the SUDS strategy works accordingly to the cited principles. The basic structure of the matrix has been inspired and adapted from an existing decision matrix constructed by the Daywater decision tool [33] [34]. The resulting scores of the SUDS strategies for each indicator have been extracted and adapted from the SUDS manual [40] [29]. In this report the efficiency of the drainage units have been qualified accordingly to three categories, high, medium and low. This classification has been translated into a quantitative score as described in Table 4.

Table 4 SUDS decision matrix scores

SUDS manual classification	Project's ranking
High	3 if a high indicator value is advantageous 1 if a high indicator value is disadvantageous
Medium	2
Low	1 if a low indicator value is disadvantageous 3 if a low indicator value is advantageous

The specific scores for each indicator can therefore be used to compare the SUDS strategies. The comparison permits to rank the SUDS with a final score and enables to highlight their result per indicator. The resulting rank determines which SUDS are performing better for a chosen weighting, the improvements though have to be taken relative in magnitude. In consequence units that may have scores that are not very different should be considered as equally good. Nevertheless the establishment of final ranks can be used to give a first overview of the sud's capacity to meet the project's objectives. Figure 15 shows the matrix.

Criteria	Indicators	Greenroof	Porous pavement	Swale	Infiltration trench	Detention ponds	Weighting indicators(%)	Weighting criteria(%)
Hydraulic control	*Runoff volume reduction*	3	3	2	3	1	5	**30**
	Runoff flow rate control 1/2 year event	3	3	3	3	3	5	
	Runoff flow rate control 1/30 year event	3	3	3	3	3	5	
	Runoff flow rate control 1/100 year event	1	1	3	1	3	15	
Water quality	*Total suspended solids*	1	3	3	3	2	10	**20**
	Heavy metals removal	1	3	2	3	3	5	
	Nutrient removal	1	3	2	3	1	1	
	Bacteria removal	1	3	2	2	1	2	
	Capacity to treat fine suspended solids and dissolved pollutants	3	3	3	3	1	2	
Response of system to climate change	*System reliability and durability*	2	3	3	2	3	20	**20**
Social and economic factors	*Maintenance*	1	2	3	3	3	5	**20**
	Costs	1	2	3	3	3	10	
	Community acceptability	3	2	2	2	3	3	
	Habitat creation potential	3	1	2	1	2	2	
Risk of failure and Urban planning	*Adoption Status*	2	2	3	2	1	5	**10**
	Building development issues and stormwater regulations	2	1	2	2	1	5	
Tot scores		369	428	402	426	303	100	**100**

Figure 15 SUDS decision matrix

The working objectives wished to be fulfilled are represented through the five following criteria containing each specific indicators. The weighting factors have been assigned in order to highlight the overall optimal solution for the project's effect.

- Hydraulic control

The flood protection and prevention parameters for the SUDS strategies have been evaluated through the capability of each strategy to reduce the total runoff volume and to response to different storm events. As the score for the 5 and 30 year return period were generally equal for all the SUDS units and in order to increase the difference among the total score, the 100 year return period has received the highest weighting.

- Water quality

The water quality indicators reveal the efficiency of each SUDS unit for particles sedimentation and biodegradation. As the water treatments of the SUDS are dissimilar, the indicator's scores show large differences in the treatment efficiency. The two most important aspects in stormwater quality are the total amount of suspended solids and the

heavy metal removal. The weighting procedure has therefore be attributed in order to reduce the clogging risk of the drainage infrastructures and to decrease the environmental heavy metal contamination as these elements are very difficult to treat or to remove once a area has been contaminated.

- Response to climate change

The evaluation of each SUDS to climate change is described by an indicator reflecting the potential to accept increasing stormwater volumes and more frequent rainfall events. The resulting score testifies the SUDS capacity to accept more water and to stay functional on a long term basis.

- Social and economic factors

These indicators are synonym of the financial costs of the SUDS, the maintenance effort, the potential of the SUDS to be accepted by local population and the possible creation of new environmental habitats. As in many management projects the cost factor plays an important role with an accordingly weighing factor attributed.

- Urban planning

In this criterion the political will as well as the national and international directives are represented. Therefore specific SUDS are more easily chosen if the management policies contribute to its implementation.

The weighting process of each indicator constitutes a sensible task as it influences the final scores and the relative ranking. In order to obtain results that are consistent with the desired drainage results the weights have to be changed in dependence to the specific problematic. In consequence in Figure 15 the flood control criterion has the highest weighting as the control of stormwater constitutes the primary objective of the implemented SUDS for the Upper Rea case study. The matrix indicates that porous pavements are the best alternatives for the investigated SUDS. Infiltration trenches seem to be the second best solution. As the difference between the first and the second best alternative is very little, both solution have to be considered as equally good.

The matrix can easily be adapted for other drainage issues by adapting changing the weights. Therefore an area with important pollution due stormwater contamination could use the matrix with increased weights for the water quality criterion. All combinations of weights are therefore possible. It is essential though to control that the sum of the criteria weight's are equal to a hundred.

Having defined the general properties of each drainage strategy and their response to the selected criteria, the intrinsic characteristics of each subcatchment had to be investigated.

Therefore, in order to permit the implementation of SUDS for a certain area, the drainage strategy still needs to be compatible with local constraints. The specific surface, the permeability of the soil and the land use function have been selected from the SUDS manual as limiting factors for the SUDS implementation. The Figure 16 shows the applicability of the drainage strategies regarding the site properties and the site land use characteristics.

Figure 16 SUDS site constraints

6.6.2SUDS choice

The final choice of the drainage strategy implemented has been taken using a multicriteria approach with the decision matrix and the site constrains. In order to summarize the decision procedure the Figure 17 shows the five different stages that have been followed.

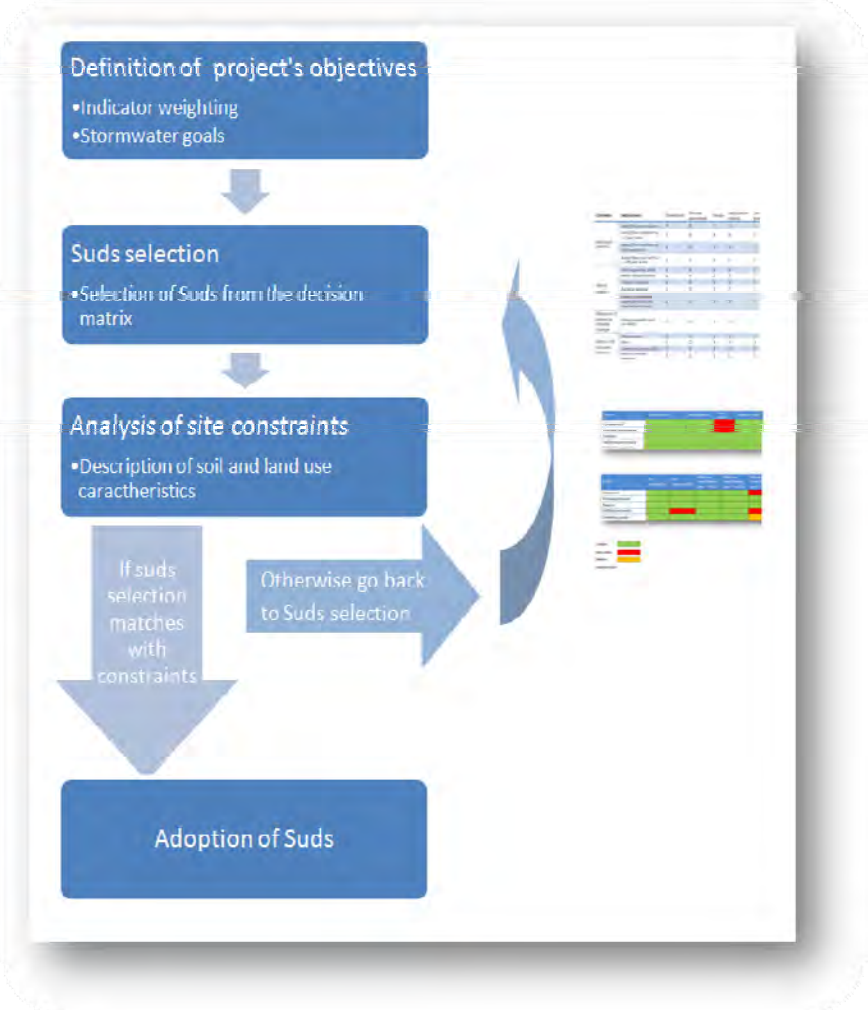

Figure 17 SUDS decision process

7 Model implementation and results

7.1 Storm implementation

As cited in section 5.3.1, Storm makes use of subcatchments which can be divided into surfaces with different characteristics. The data needed for the drainage model for the upper Rea region has been imported from an external life cycle analysis tool. The format of the received information presents a custom made definition of the region properties. The catchment is therefore subdivided into clusters which can be described as parcels that have similar land use properties. Each cluster belongs to a predefined unitblock class representing the identifier for a certain land use type. For instance, a commercial shopping center situated in a residential area can be geographically delimitated from the neighboring parcels by analyzing the topology of the zone. A corresponding cluster could therefore be formed by the shopping center building and the parking area around it. The formed cluster could then be grouped around a unitblock type, for example retail. Following the cited approach a whole catchment can be subdivided into a large number of clusters belonging to unitblock types. The clusters that have been identified for the studied area are shown in Figure 18.

Figure 18 Implemented clusters in Storm

Under a closer look of the received information it has been noted that a portion of the studied area has not been digitalized in the input files. This has notably been the case for the great park region. New clusters have been constructed for this area following the input files strategy. In addition a lack of details appeared in order to transpose the cluster structure into a drainage subcatchment model. The Longbridge region consisted in one unique large cluster which appeared to be inconsistent in order to estimate the effective stormwater contribution to the sewer system. Therefore the results from the Defra study have been integrated in the cluster construction of the Longbridge zone [7]. However the detailed partitioning into subcatchments from the Defra report could only be vaguely interpreted. The main information gathered though, was the fact that only the west-northern part of the Longbridge area contributed to the sewer system. Three new clusters have consequently been digitalized for the Longbridge region.

The input files received contain the permeable characteristics for each unitblock type by giving the proportion of roof, paved, and asphalted area. These proportion have been used to calculate the respectfully surfaces that have been incorporated into the storm modeling structure. Therefore depending on the initial unitblock type each cluster has been transformed into a roof, a paved and an asphalted surface.

The sewer system has also been extracted from the collected data and has been split into several parts, relatively to the changes of pipe diameter and the upstream contribution network.

The studied upper catchment area without any drainage strategies implanted will be expressed as the initial reference state and consists of 23 contributing surfaces and 11 sewer sections. Figure 19 shows the reference state implemented in Storm.

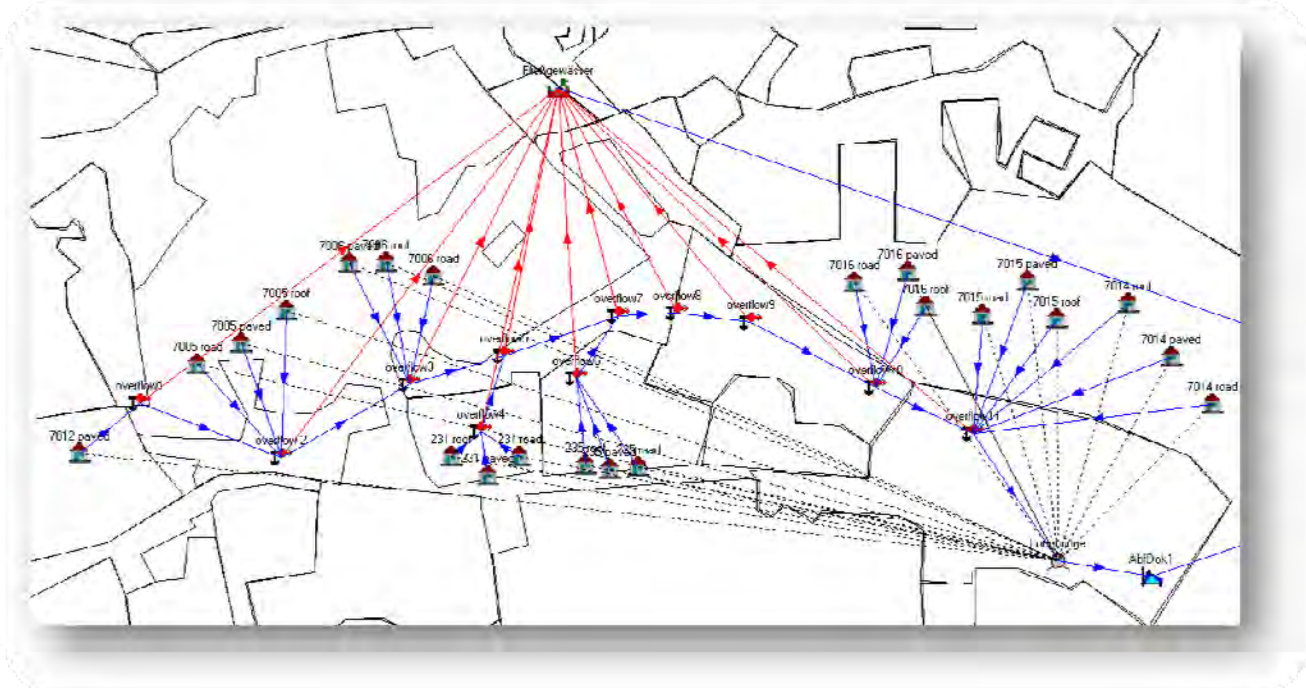

Figure 19 Storm reference state

The stormwater flow destinations are represented by the blue colored arrows and the sewer overflow destinations during flood event are represented by the red arrows. As can be noted all surfaces drain to the sewer system which in case of flooding, overflows into an artificial river. This last element has only been added in order to investigate the magnitude of the flood events.

7.2 Reference state calibration

In order to compare the results from the initial reference state the flooding events have been compared with the results presented in the Defra report [6]. In the governmental investigations a sewer model has been used to estimate the floods at different nodes of the pipe network. The flood investigation highlights the worst case events of rainfall return events of 5, 30 and 100 years for maximum rainfall duration of 8 hours. The magnitude and the location of the flood events are presented in Appendix A, B and C. Figure 20 shows the approximate flooding over the studied sewer system.

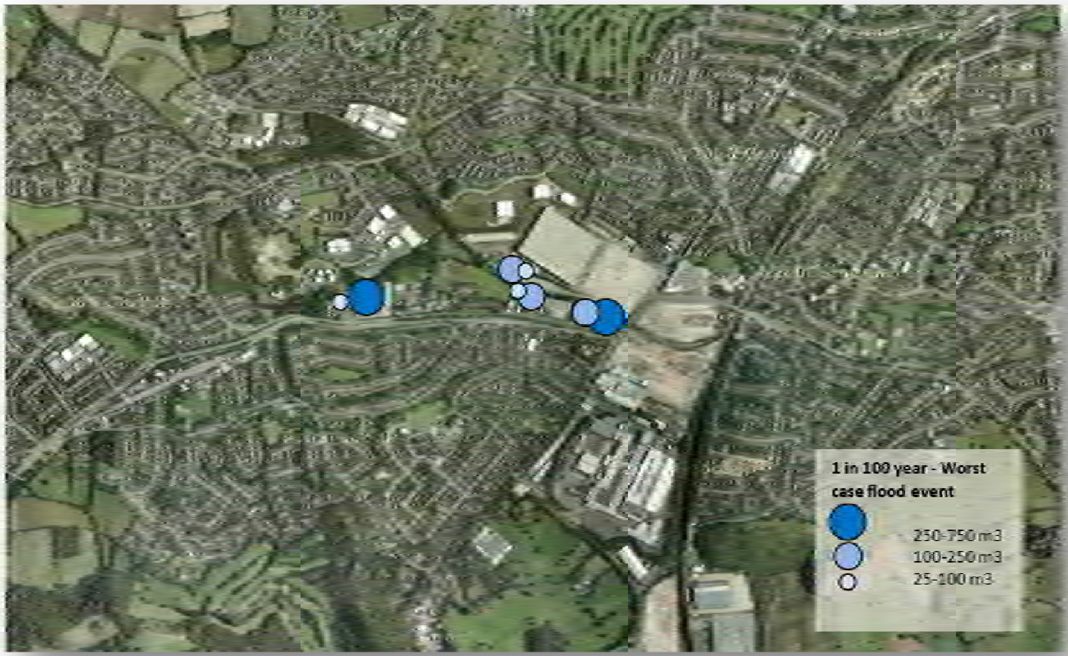

Figure 20 Defra report estimated sewer flooding for a 1 in 100 year event

A first comparison of the results from the Defra report and the storm drainage results show that the implemented drainage model predicts flood events at similar locations [6]. Therefore the major flooding events have been found near to the commercial surfaces of cluster 213 and 235 and at the outflow from the Longbridge industrial site. Through a second investigation the storm results appear much higher than the magnitude calculate by Defra. Table 5 summarizes the overflow volumes of the models for the two principle flood nodes. The drainage model overestimated the flood magnitude for flood zone 6 and flood zone 7.

Table 5 Predicted sewer flood events from the Defra model and the initial reference state in Storm

Models	Flood volume zone 7 (m^3)	Flood volume zone 6 (m^3)
Defra sewer model	1161	606
Storm initial reference state	7896	1263

The difference between the two models in respect to the flood magnitudes has therefore been investigated and different reasons appeared to constitute potential causes. Three main hypotheses have been identified in order to explain this incoherence.

The first explanation comes from the way the cluster properties have been defined in the input files. The proportion of impermeable surface has therefore been attributed for each

unitblock type through a rough estimation produced through a spatial identification of these zones with Google Earth. As the life cycle analysis tool doesn't need more specific detailed information of the different parcels, this approach is sufficient for the desired water cycle analysis. In consequence the use of the input files surface proportions in Storm can lead to some imprecision.

The second hypothesis concerns the surface allocation of the Longbridge site. The drainage destinations of the industrial zone have remained very approximate through the information presented in the Defra report. In that sense the exact area draining into the combined sewer system from the Longbridge site remained unknown. In addition the industrial area drains partially to a private sewer system which doesn't discharge into the combined model network. These characteristics have complicated a precise identification of the drainage surfaces.

The third possible explanation results from the difference appearing between the two drainage models. Therefore the Defra model is applying a model rain with a maximum duration of 8 hours. As a more complete and realistic approach the Storm drainage model is using a continuous simulation as it works with rainfall records. The Defra model doesn't account for subsequent rainfall event that can happen over different days. In that manner the drainage system's anterior state is not included in the flood analysis. An underestimation in term of flood frequencies and magnitude can therefore influence the results.

The three hypotheses have been considered for the initial drainage reference state in storm. In consequence the possibility of overestimation of the surface impermeability has been stated for all clusters. For the Longbridge site the magnitude of the disparity between the flood results from the Defra report suggested that the surface draining to the combined sewer had to be much less than estimated. The third hypothesis suggested that due to the difference in the simulation process of the two models the comparison of the flood events had to be taken with precautions. Consequently the floods volumes calculated from the two models can be compared with a certain accounted discrepancy.

The resulting modifications of the initial reference state that rely on the approved hypothesis are listed as followed

- The impermeable surfaces from the cluster have been deceased of 30%
- The Longbridge area has been diminished of 70%

With these modifications the location of the flooding event for the corrected reference state in Storm still matched the ones of the Defra model and the flood volumes appeared much closer for all return rainfall events. Table 6 shows the new results predicted at the flood zone 6 and 7.

Table 6 Predicted sewer flooding from the Defra model and the corrected reference state in Storm

Models	Flood volume zone 7 (m^3)	Flood volume zone 6 (m^3)
Defra sewer model	1161	606
Storm corrected reference state	937	759

The modified initial reference state has been adopted for the further drainage system investigation.

7.3 Drainage strategies

Through the SUDS decision approach the drainage strategies have been defined and implemented in Storm. In order to compare different possible alternatives the projects objectives have been adapted. This gave 3 different scenarios that are represented as in the following points. All SUDS infrastructures have been dimensioned accordingly to the UK standards of a 30 year return event [40].

- Strategy 1 No infiltration

As the soil characteristics reveal a low infiltration potential the use of infiltration strategies has been excluded. Therefore all drainage strategies are based on retention and conveyance of the stormwater flows.

- Strategy 2 Infiltration

The possibility of infiltration devices has been accepted for clusters that are near to unconstructed natural areas. Therefore a certain part of the runoff is canalized by a SUDS conveyance infrastructure to an infiltration unit placed on the natural area. The infiltration devices may therefore produce an overflow volume but the risk of the flood event is decreased through the lack of possible damaged caused on the natural cluster. In order to respect the water quality the runoff produced from the asphalted area is not permitted to be infiltrate directly. In consequence for the paved and the road area at least two treatment chains are necessary prior infiltration.

- Strategy 3 wetland pond

In order to decrease the amount of implemented SUDS for the Longbridge industrial site and the respectfully costs a retention pond has been constructed north of the zone. The pond is placed on an unoccupied natural area and receives all the stormwater runoff from the cluster. The reservoir structure is attached to the sewer network by the construction of a new link, sewer node 12. In order to guarantee the water quality, the treatment chains are necessary and have implemented by the conveyance through swales, the sedimentation, filtration and the biodegradation of the reservoir pond which is constructed as a wetland.

7.4 Storm drainage results

Figure 21 shows cluster 231 and 235 with the implemented strategy 1.

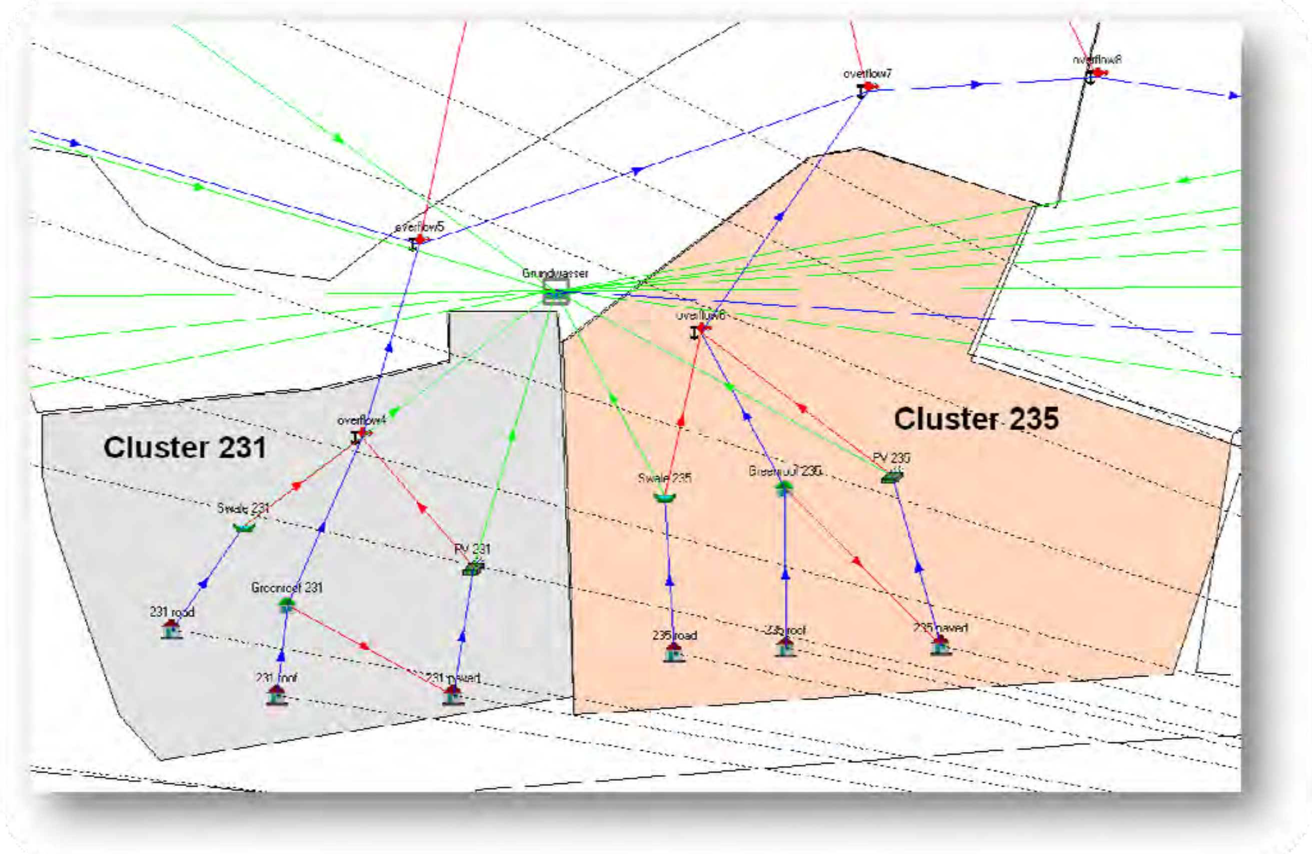

Figure 21 Drainage strategy 1 implemented in Storm

Therefore following the multicriteria analysis described in Figure 17 the impermeable surfaces of the entire study area have been connected to a SUDS unit as presented in Table 7.

Table 7 Impermeable surfaces and their corresponding drainage unit for strategy 1 in Storm

Impermeable surface	SUDS	Commentary
Roof	Greenroof	If roof is flat
Paved	Pervious pavement	-
Road area	Swale	Both sides of the road

For drainage strategy 2, in addition to the suds implementation in strategy 1, an infiltration unit has added as described in Table 8.

Table 8 Infiltration facility added to suds units for strategy 2 in Storm

SUDS	Infiltration facility	Commentary
Greenroof	-	-
Pervious pavement	Infiltration trench	Two treatment chain
Swale	Infiltration trench	Two treatment chain

Figure 22 shows the implementation of strategy for cluster 231 and 235

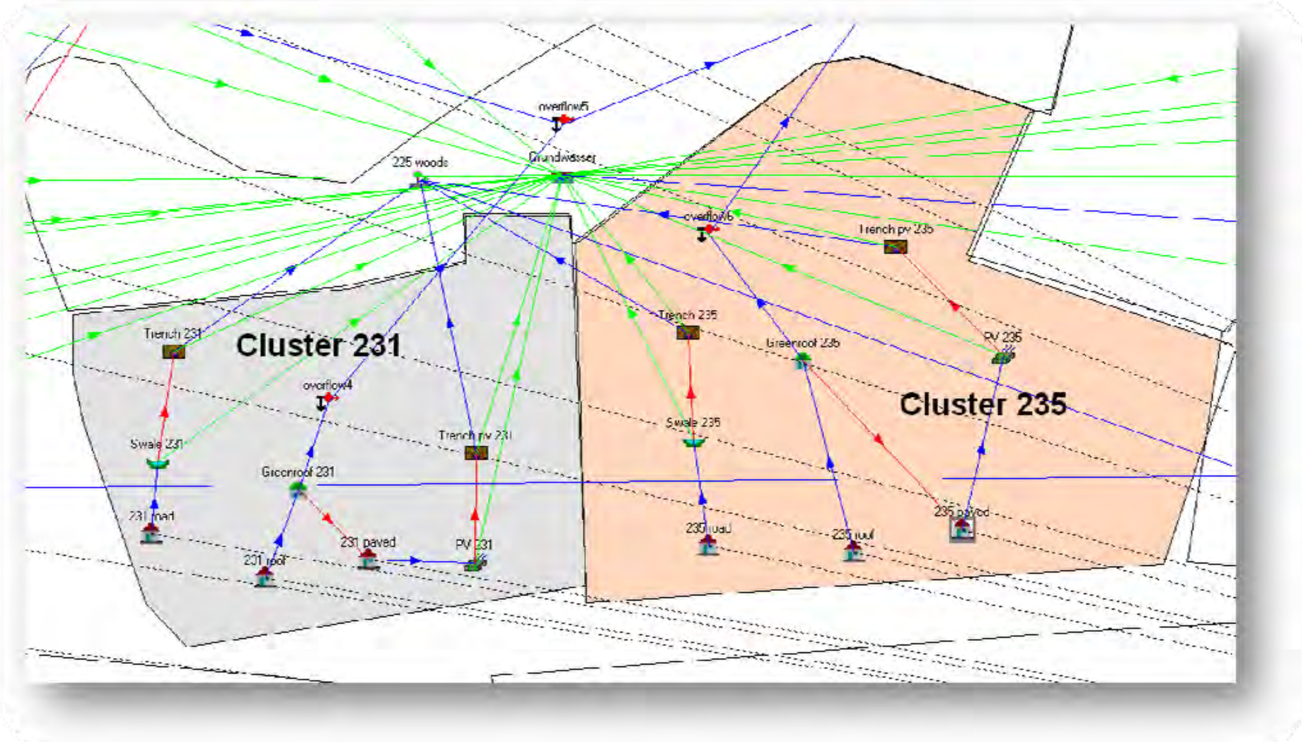

Figure 22 Drainage strategy 2 implemented in Storm

Strategy 3 retakes the SUDS implementation of strategy 1 for clusters 7012, 7005, 7006, 231 and 235. A pond is constructed near to the Longbridge industrial zone. For clusters 7014, 7015 and 7016 all the stormwater drains to the pond through swale channels. Figure 23 shows the constructed pond north of the Longbridge clusters.

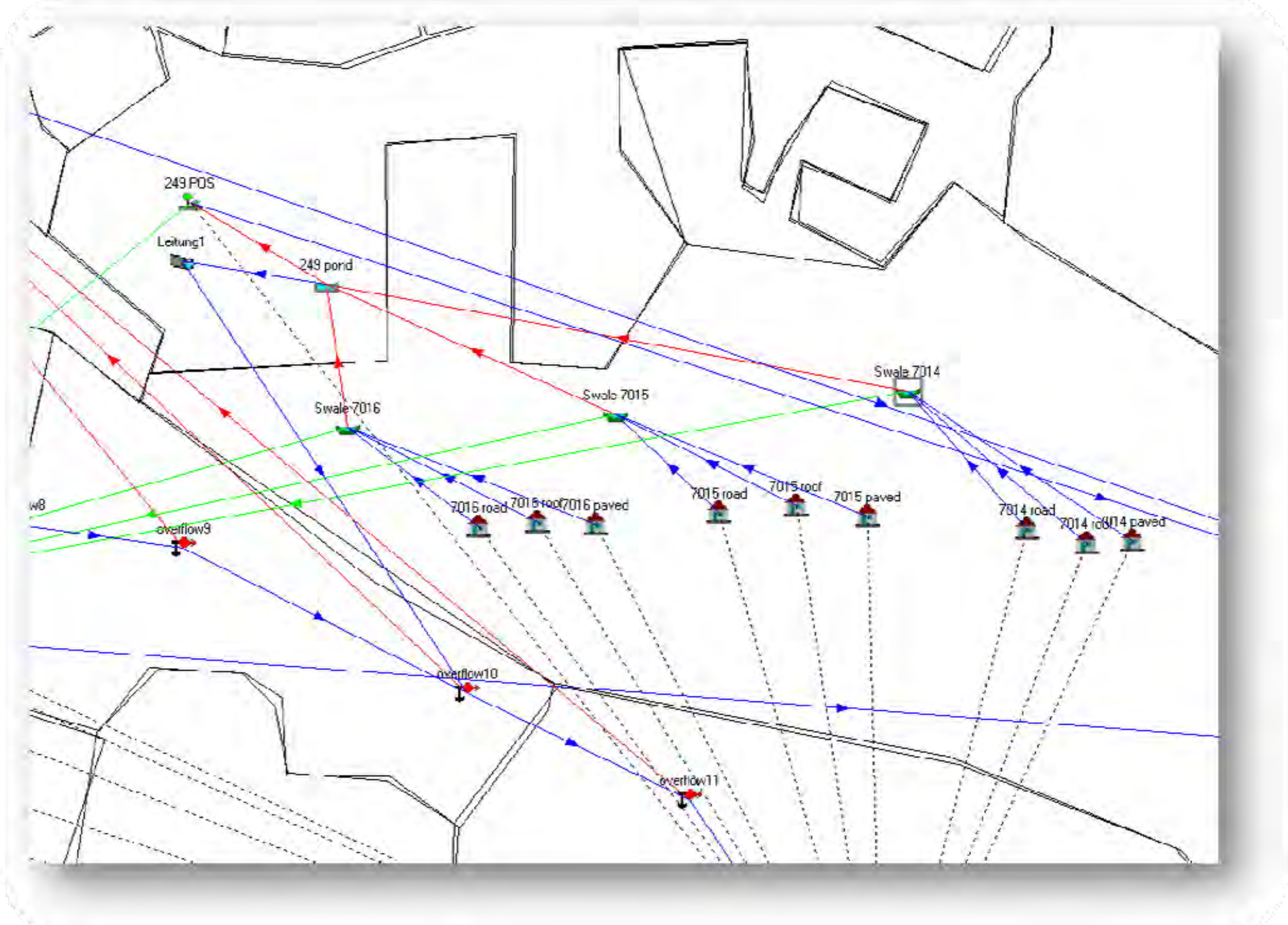

Figure 23 Drainage strategy 3 implemented in Storm

The flood predictions have been investigated over the total period of precipitation events which covers 38 years of hourly rainfall records. The strategies gave different flood predictions that can be compared in Table 9, Table 10 and Table 11.

Table 9 Strategy 1 flood predictions for zone 6 and 7

Drainage strategy 1	Flood zone 6	Flood zone 7
Average flood volume (m^3)	88	335
Maximum flood volume (m^3)	474	335

Table 10 Strategy 2 flood predictions for zone 6 and 7

Drainage strategy 2	Flood zone 6	Flood zone 7
Average flood volume (m^3)	108	285
Maximum flood volume (m^3)	323	285

Table 11 Strategy 3 flood predictions for zone 6 and 7

Drainage strategy 3	Flood zone 6	Flood zone 7
Average flood volume (m^3)	88	0
Maximum flood volume (m^3)	474	0

In consequence with strategy 1 the flood events have been deceased for all the different nodes in the sewer system.

The strategy 2 decreases still a bit more the sewer flood risk for maximum floods but create possible flood locations on the natural zones. The volume of flooding can reach which could reach the neighboring commercial zones. Therefore the average flood volume has slightly increased in respect to strategy1. The difference is essentially due to the impermeable characteristics of the catchment's soil that limit the infiltration possibilities of the SUDS. In consequence as the water infiltrates very slowly, the infiltration trenches fill very quickly and stay full over a longer period. Consecutive small rainfall events can therefore cause the infiltration devices to get s overcharged more frequently and can then produce important flood events.

The strategy 3 shows that for a reservoir volume of no flood event is cause due to the stormwater from the Longbridge site. The pond itself doesn't cause an overflow either and all the water penetrated the soil through infiltration or is evaporated.

7.5 CWE implementation

The economical analysis applied on the upper Rea catchment has been performed in order to assess the stormwater strategies applied with Storm. The financial study is divided in two parts, implementing the stormwater scenarios in CWE and using the economical tools defined in section 5.2. In the first step the model calculates the costs of each drainage scenario. A financial proposal of the overall stormwater plan of the Upper Rea region is then suggested in accordance to a full cost recovery scheme with the incentive of SUDS use.

In order to estimate the cost of the defined drainage scenarios the financial characteristics of the SUDS units have been extracted from the SUDS Manual investigations. Therefore each drainage infrastructure has a financial cost defined in capital cost and maintenance cost. The price of construction and usage of a SUDS unit has been calculated for the specified dimensions in Storm and over a chosen study period of 30 years. This time interval corresponds to the mean life time for the implemented SUDS units. Appendix E gives the detailed costs for each drainage scenario. The cost characteristics have been calculated over time in CWE and are illustrated by strategy in Figure 24.

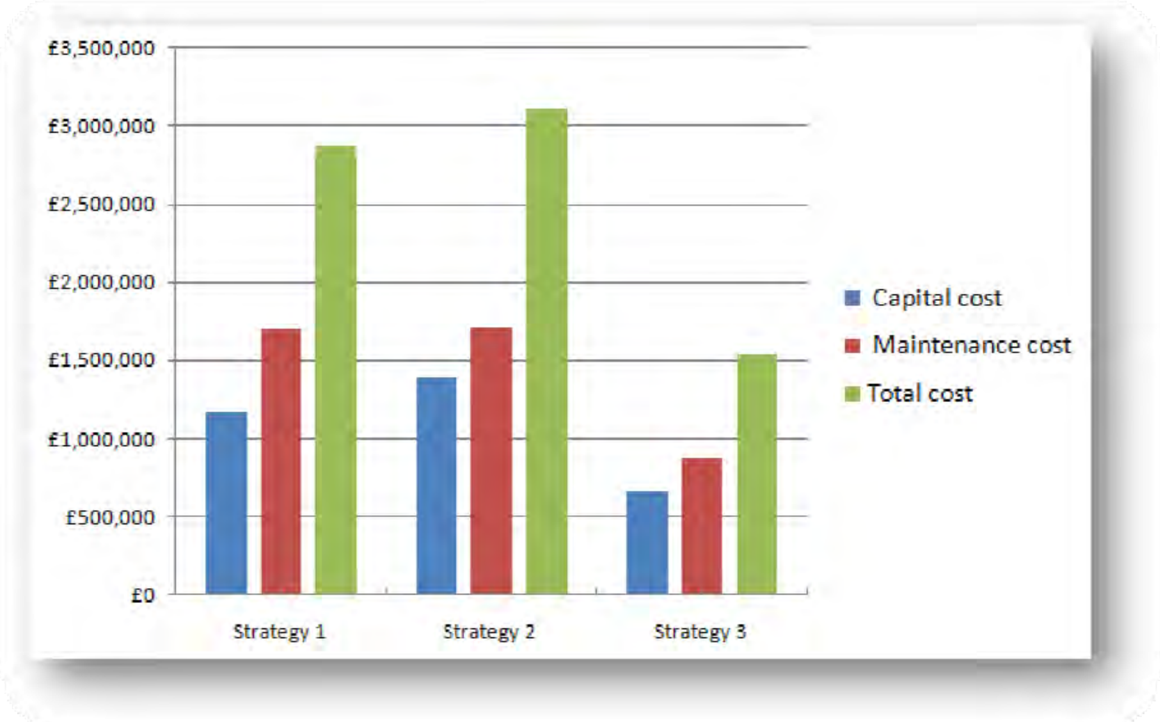

Figure 24 Drainage strategie's costs over the 30 year study period

The capital cost have been divided for the total study period and attributed for each year. Defining the annual cost growth of 3%, the total cost over the expected lifetime of 30 years is represented in table.

7.5.1Cost benefit analysis

Through the financial analysis the total costs of the drainage scenarios have been given. The economical study can be completed by comparing the amount of money that needs to be investigated by scenario with the flood protection obtained. This evaluation inscribes itself in a classical cost benefit analysis.

The decrease of the flooding achieved with the implementation of each drainage scenario can be defined as the main benefit produced. In consequence the attenuation can be measured in different ways as for example the average floods volume decrease, the number of floods occurring during the model period or the limitation of the maximum volume of floods. Despite which benefit is chosen the result for the drainage scenarios respect the same rank order. Attributing a related cost to each scenario it is possible to present the comparison with the desired flood reduction parameter. Figure 25 shows the decrease of maximum flood volume in respect to the financial aspect of the 3 strategy.

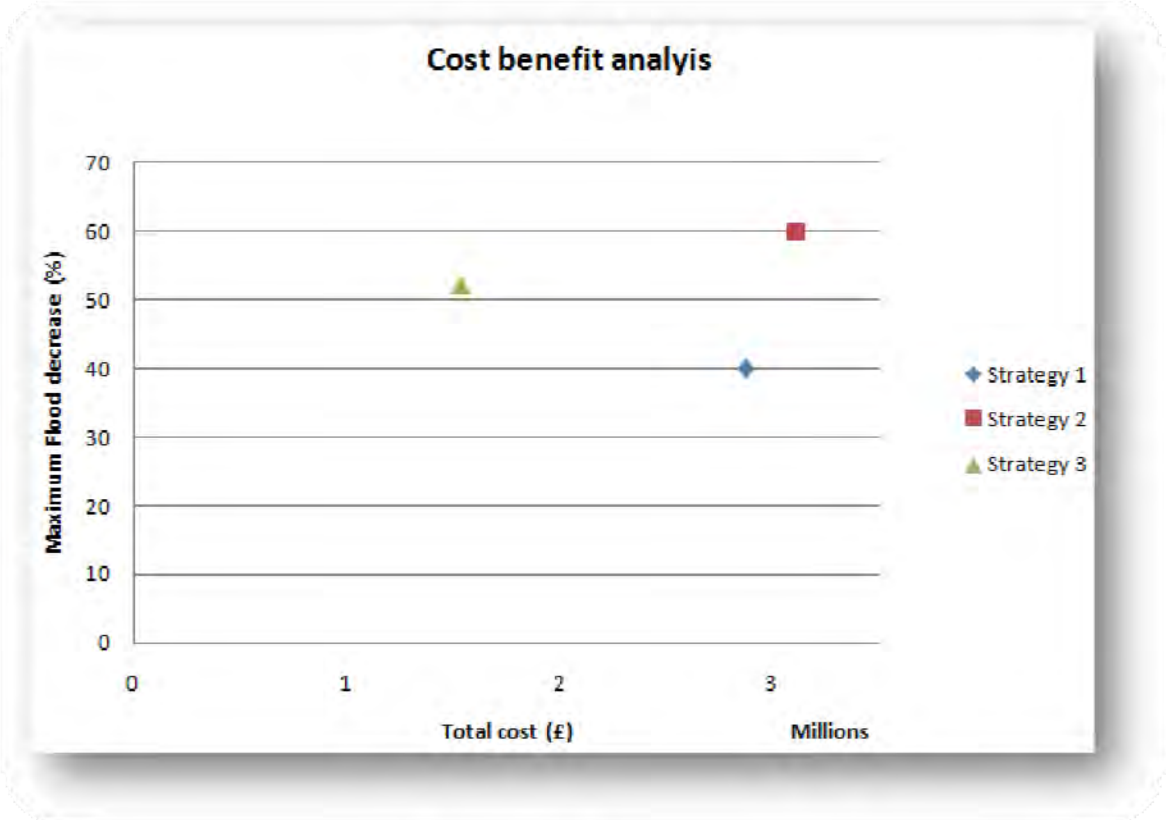

Figure 25 Cost benefit analysis for the drainage strategies

The analysis of the results shows clearly that strategy 1 delivers the smallest benefit for the most important cost. In Figure 25 it is therefore possible to see that strategy 1 is far away from the possible best solution and that the difference in benefit between strategy 2 and 3 is translated higher costs. The question of choosing strategy 2 or 3 as the optimal solution can therefore be influenced on the desired objectives serving as constraints. However the establishment of a cost/benefit ratio represented in Table 12 completes the graphical illustration. As strategy 3 has the smallest ratio it is therefore chosen as the optimal drainage strategy.

Table 12 Cost benefit ratio

Drainage strategies	Cost benefit ratio

Strategy 1	71848
Strategy 2	51808
Strategy 3	29543

7.5.2Stormwater tax plan

Through the WDF directives the UK has integrated the will of SUDS implementation in its on national directives as in the PPSS5 [15] [10]. The applications of these guidelines remain though pretty unfulfilled. In consequence stormwater drainage strategies often lack in their cost recovery scheme and produce large investments supported from the local municipalities. In addition the use of SUDS remained very sporadic. Following the WFD principles and with the aim of proposing a cost recovery scheme for the Upper Rea catchment financial plan has been elaborated.

In order to cover the cost of the drainage scenario the total investment is redistributed to the households as a stormwater tax. This strategy is already largely adopted in Europe and has demonstrated positive effect in cost recovery schemes as for Example in Germany of in Sweden [5]. A general stormwater tax of 1 pound per m2 of impermeable surface has then been added in order to integrate the additional drainage infrastructure expenses for the entire catchment. The resulting expenses are represented in Table 13 for each residential unitblock type.

Table 13 Stormwater tax per type of residential unitblock

Unitblock	Type	Stormwater tax (£)
5	Residential – Detached small garden	243
7	Residential – Flats	237
1	Residential – Terraced Small Garden	236
2	Residential – Terraced Large Garden	215
6	Residential – Detached large garden	212
8	Residential – Home	210
3	Residential – Semi-detached small garden	181
4	Residential – Semi-detached large garden	156

As the amount of tax can grow rapidly for larger properties than residential areas the stormwater tax should be adapted for the commercial and industrial zones. Retaking the

same tax imposition for areas smaller than 100 m2 the increase of tax for surface above 100 m2 can be adapted with a lower gradient, Furthermore as SUDS strategies become very costly when covering large surfaces, the tax gradient can be lowered again reaching surfaces bigger than 1'000 m2.

As a defined objective in the UK nation drainage guidelines the propagation of SUDS can be achieved through financial motivation. Retaining this strategy a possible decrease of the stormwater tax is then proposed to the consumer if he implements a sustainable drainage unit on the area of its property. The tax can therefore be lowered 1 pound per m2 of impermeable surface controlled by a SUDS unit. As mentioned for the tax imposition scheme, the gradient of the tax decrease can be lowered when the surface is getting important.

An example of a tax decrease scheme for the implementation of SUDS on impermeable surfaces belonging to a residential area of unitblock type 5 is given in Figure 26.

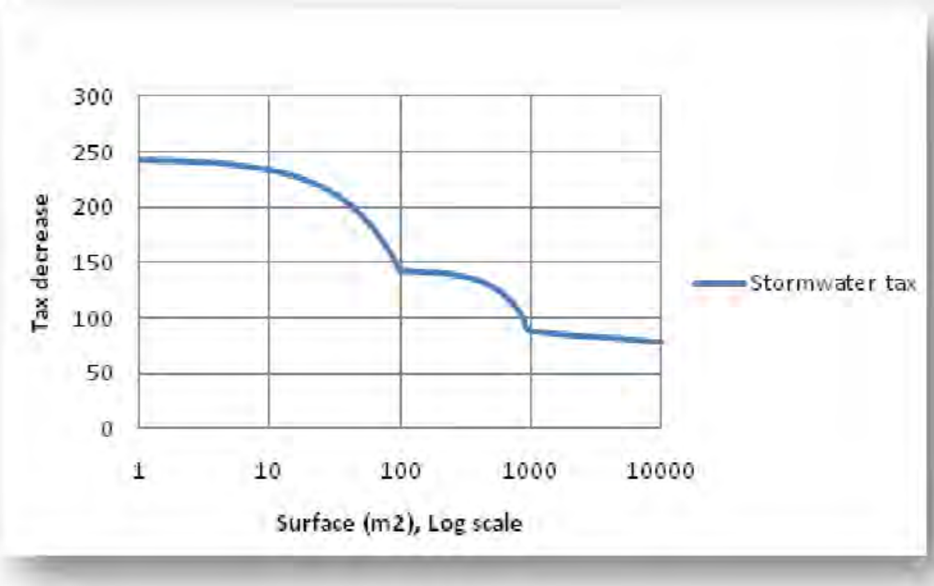

Figure 26 Example of a tax decrease scheme

Through the important overall financial investment of SUDS the total expense of a consumer implementing a drainage strategy would still be more important than just to pay the stormwater tax. In order to satisfy the financial interest in the implementation of SUDS an additional decrease of the tax has to be accorded. As a common governmental instrument of economical motivation the use of subsidies can enhance the exploit of a product and induce a change in behavior. Following the national UK guidelines the implementation of SUDS can therefore be enhanced with an appropriate financial help in form of subsidy. Introducing this financial tool into the stormwater tax scheme, the final consumer's cost can be lowered. Figure 27 shows the user's tax end cost with and without the implementation of SUDS and

the amount of subsidies necessary to cover the user's charges with the implementation of a greenroof or a porous pavement.

Depending on the stormwater planning objectives the amount of total subsidies accorded can be adapted. Therefore Figure 27 shows a significant decrease for surfaces smaller than 100 m2 as can be noted by looking at the consumers' cost with SUDS.

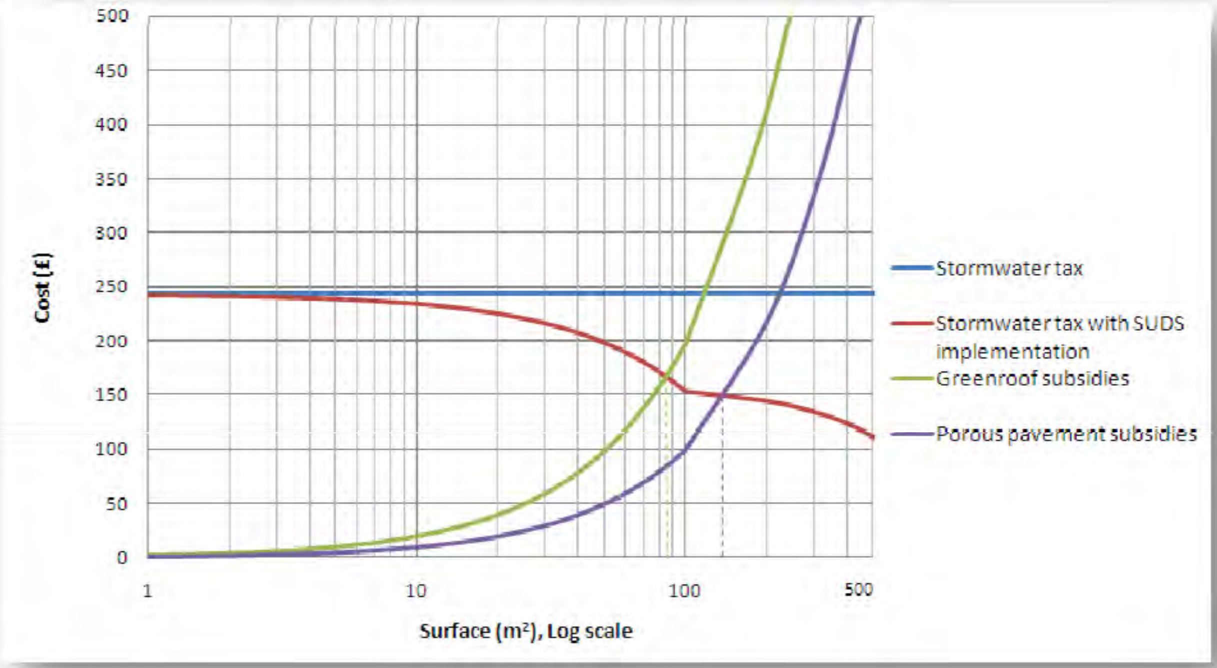

Figure 27 Stormwater costs with SUDS subsidies

As the surfaces are getting more important the gradient of the end user's cost can be adapted as can be noted by the inflexion of the stormwater tax with SUDS at 100 m2. The evolution of the needed subsidies to keep the end user's SUDS cost low depends also on the implemented drainage strategy. Greenroof accorded subsidies are therefore more important than for porous pavement. Figure 27 also reveals the moment at which the amounts of subsidies are getting more important than the actual stormwater tax perceived. Therefore users that implement greenroofs are getting costly for the planning authorities when the implemented surface overcomes the 85 m2 as well as for porous pavement alternative after 140 m2.

In consequence depending on the desired political objectives a relative amount of subsidy can be spend in order to equip the study area with SUDS. The investment accorded can therefore improve the realization of national guidelines, limit the size of impermeable runoff area and serve as a stormwater prevention system.

7.6 CWIS implementation

Applied as a decision support system CWIs enables the possibility to compare and to represent a project's details and to create a global overview of the investigated strategies. Having synthesized the major aspects of a problematic and the possible solutions CWIs can be used to link the gathered information to the identified project's elements and to illustrate the effect on the problematic. The multi view representation has been used in CWIS in order to represent the results achieved with Storm and CWE.

In a first step the model results and the project's element have been stored into the information system's data base. Then in respect to the CWIS's ontology nodes, information and relationships have been attributed to produce the functional views. In consequence the finalized decision illustration has been created in form of a system view that contains the project's problematic and gives the results of the drainage and the economical model. Figure 28 shows the produces view.

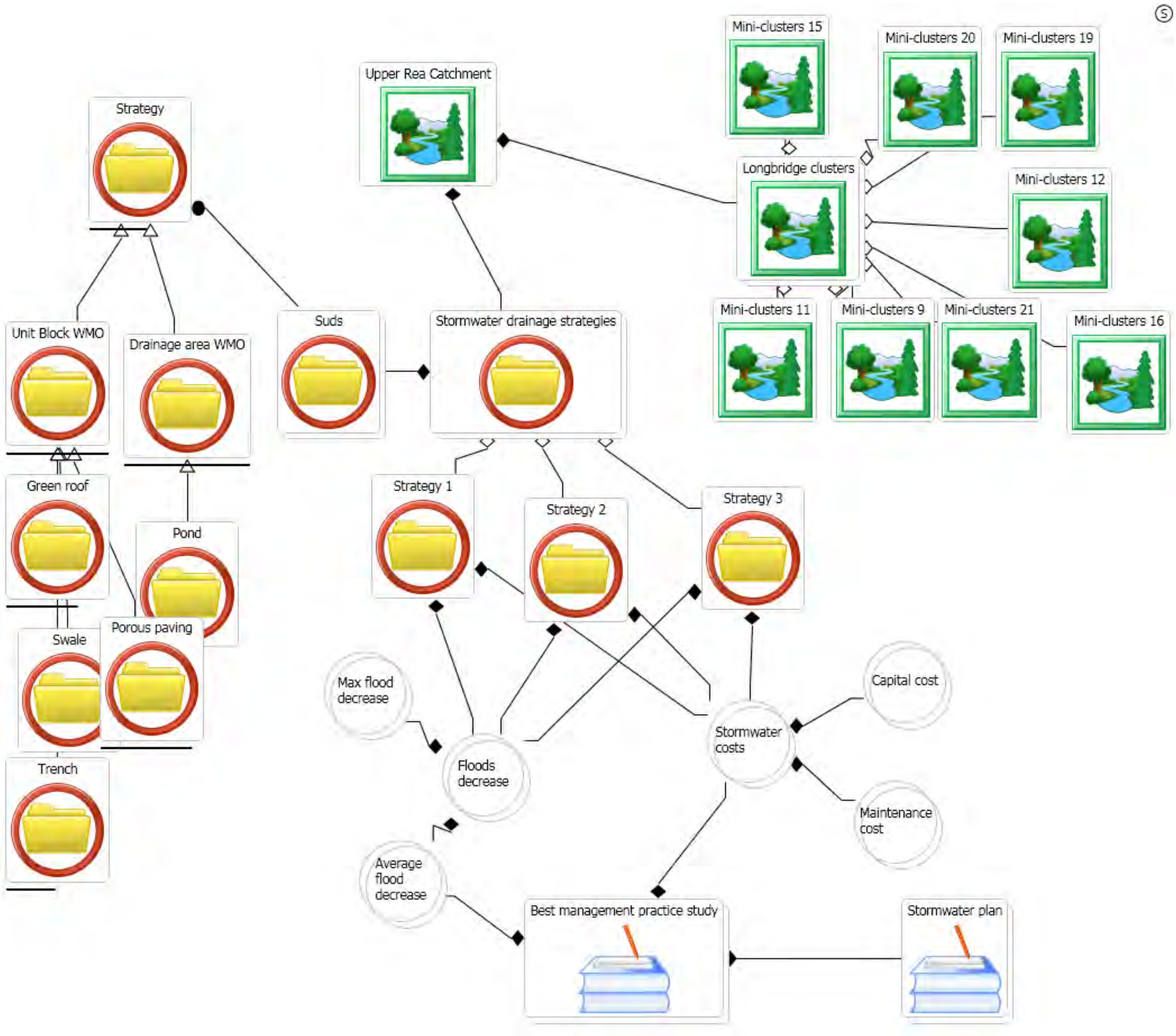

Figure 28 CWIS system view of the Upper Rea flood study

Through the synchronization possibility of the different views in CWIs it is then possible to attach the desired data on the created objects. The finalized scheme includes therefore the description of the Upper Rea flood problematic, gives an spatial overview of the investigated areas, resumes the drainage strategies and the results investigates, characterizes the SUDS units, gives the economical assessment results and shows the indicators used in the combined cost benefit analysis.

For a decision maker it is therefore possible to investigate the different informations attached to the objects. Depending on the projects interest it is therefore possible to navigate through the upper Rea flood drainage strategies. For example if the SUDS units want to be investigated then it is possible to select desired class in order to obtain further information. Therefore Figure 29 shows the linking between the greenroof class and its description.

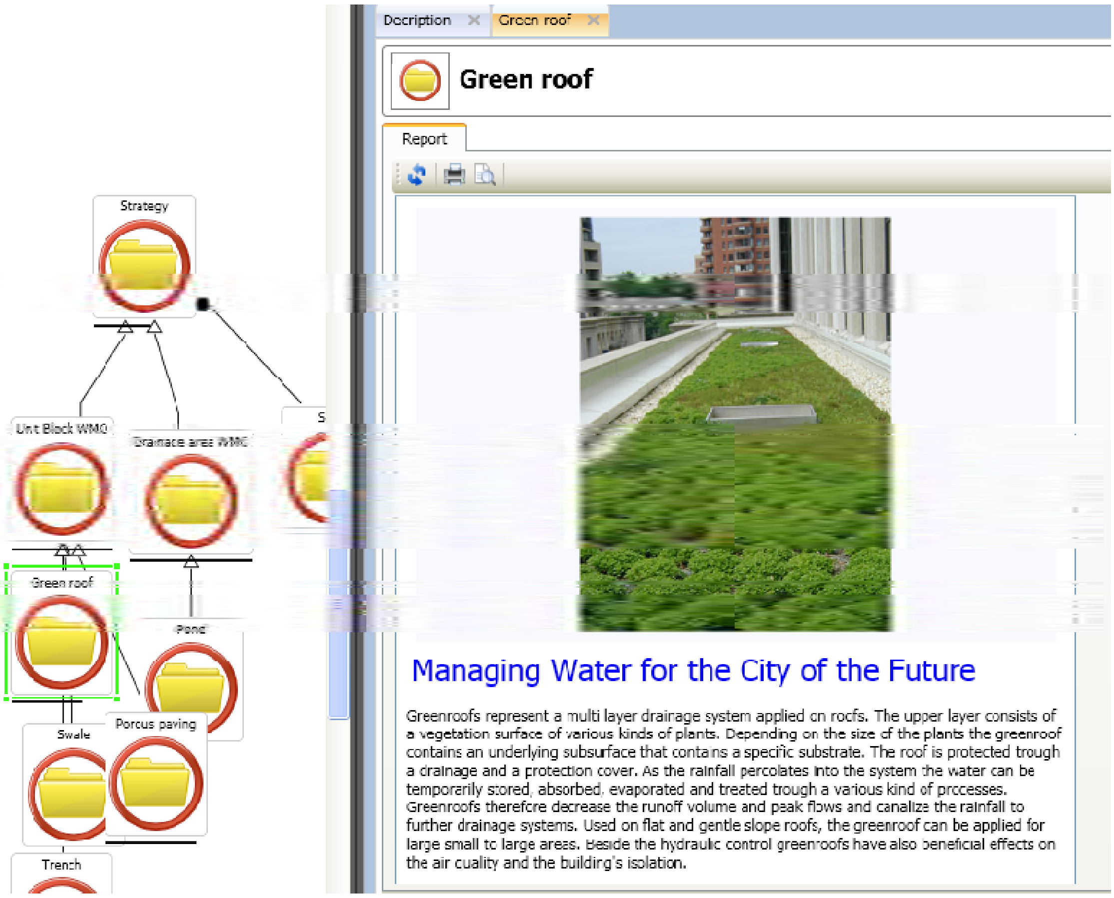

Figure 29 Greenroof description attached to the greenroof class

If for example the decision maker is more interested in the comparison of the drainage strategies in terms of flood control than these values can also be visualized by selecting the corresponding objects in the system view. Figure 30 shows the decrease of maximum floods for the implemented drainage strategies.

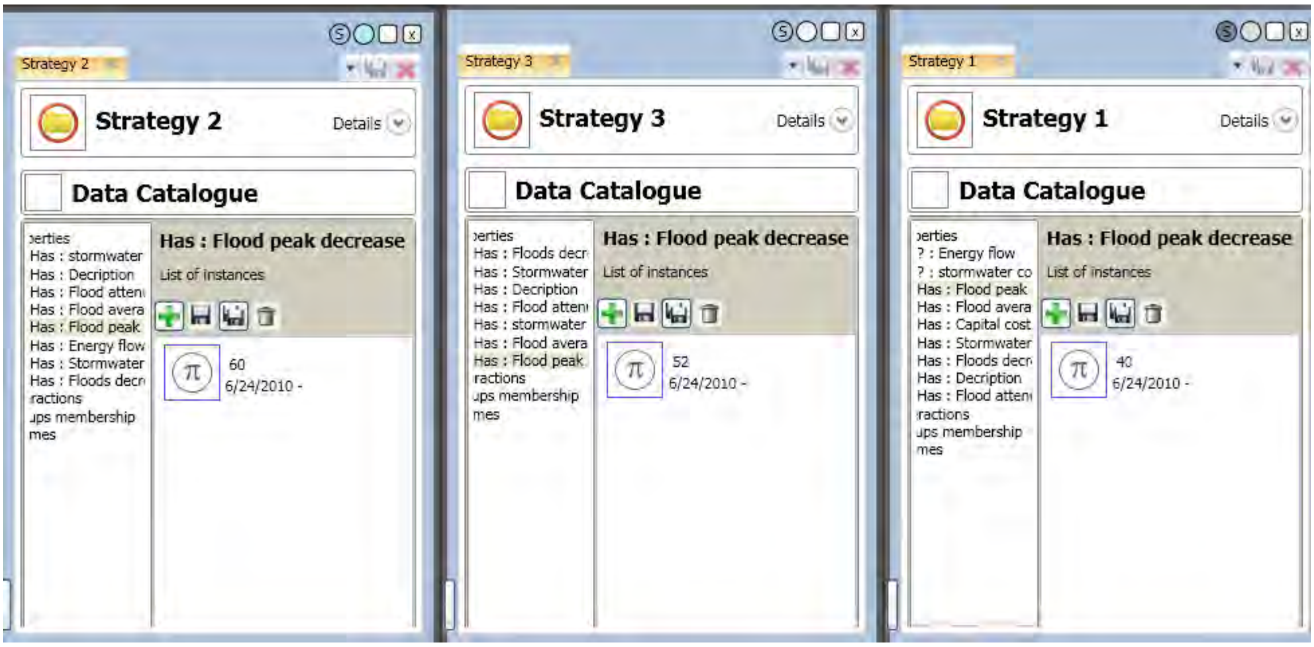

Figure 30 Comparison of the flood decrease of the drainage strategies

The decisional approach can then be guided through the consultation of the gathered information that is attached to the created objects in the system view. With the implemented problematic and the multi view presentation it is therefore possible receive a brief overview of a project's situation, to communicate and to describe the solutions in order to guide the decision making step.

8 Discussion

8.1 Model capacity

The models used in order to investigate the flood problematic of the Upper Rea catchment have been used separately to analyze the specific domains. During the project's work different aspects of the model's behavior towards the researched objectives have been identified as strength and weaknesses. With the aim of giving an overall critical appreciation of the results presented it appears important to describe the problems accoutered and the uncertainties related to the presented solutions. In consequence the adaptability and the sensibility of the models have been described.

8.1.1Storm

As a robust drainage model Storm has been used to investigate the flow characteristics of the Longbridge zone. Two aspects appeared important during the model's implementation. The first is related to the construction of the surfaces and the definition of their drainage parameters. Following the avalaible data the area has therefore been subdivided into three categories of impermeable surfaces, each one containing specific runoff values accordingly to the nature of the impermeable layer. Losses during the runoff process and temporary reservoirs are included as arbitrary constant parameters for each surface. The rainfall therefore falls on the surfaces, produces a certain runoff amount respectfully to the related surface and the runoff parameters and reaches the outflow following the routing model equations.

As the runoff parameters and the flow behavior are constant for an entire surface the produced stormwater amount and flow dynamics can only be interpreted as approximations. This proposition can be neglected for very homogene zones as for example a flat asphalted landscape. On the contrary for more heterogenic surfaces, which is usually more often the case, small depressions or multilayer obstacles can increase the difference between the measured and the calculated runoff values with Storm. While the error stays tolerable when analyzing small zones the difference can lead to wrong results with the increase of the study surface.

This feature highlights an important point to take in account prior to the drainage area's implementation in Storm. Therefore the spatial scale represents an essential working constraint. In consequence, Storm can be used without troubles for the implementation of

little drainage areas as for example the stormwater modeling of a unique house or for a small residential block. Every distinct object as roofs, walkways or curbs can be included in the drainage model. For larger areas the same approach demands an important knowledge of the site, the flow dynamics and represents a work intensive process. When the spatial resolution is decreased and the distinct objects are not implemented then the model's results become less precise.

The second important aspect encountered in Storm is related to the first in term of spatial resolution and represents the amount and the type of information that is available for the drainage zone construction. As describes in section 7.1 the data from the Longbridge zone came directly from an external life cycle tool. Through the available information the hypothesis of the relation cluster-subcatchment has been adopted. Furthermore the surfaces created in Storm represent an extrapolation of three type of objects contained in the clusters. Through the rough estimated data avalaible, the size of each surface is also very approximate. In consequence the drainage model implemented in Strom is subject to these estimations and had to be adapted with respect to verifications detailed in section 7.2.

The sewer system has been constructed with the information extracted from the received input files where the dimensions have directly been given from the Severn Trent company. In consequence a good correspondence between the existing and the implement sewer system can be denoted. A more difficult task was the estimation of the surface's inflow locations and the surface's effective contribution to the sewer flow. As it has been stated as hypothesis for the Longbridge industrial zone some proportion of the total runoff from the surfaces can have a different destination than the sewer system. While it is impossible in Storm to investigate the flow destinations only a more thorough study of the landscape with help of a DTM could lead to more precise information.

Through the limiting factors described the total area of Longbridge the drainage model with Storm has produced overall acceptable results. Through the verification with the Defra model the predicted flood locations and flood volumes have been verified. While the amount of information was limited, the implementation in Storm would have been very time consuming for the apprehension of further spatial details. Storm therefore constitutes a useful drainage model for large areas if only poor information is available, the runoff destinations are well known and if the precision of the final results can be accepted with a certain margin of tolerance. While this was the case for the current project, future investigations should be considering this fact.

8.1.2CWE

The total potential of CWE analysis options hasn't been exploited during the stormwater study. As described in section 7.5, the current working objectives focused on the cost calculation of the drainage strategies. More detailed investigations could analyze as well the water supply and water treatment cost in order to produce a entire cost recovery scheme for the urban environment. Nevertheless the introduction of further costs has not been the aim of the economical appraisal and wouldn't have changed the proposed final stormwater recovery scheme. Therefore only the stormwater cost options module in CWE is discussed in the following points.

The main input parameter for the stormwater cost calculations for CWE necessitates the knowledge of the capital costs and the maintenance costs during the study period. This information can be gathered easily from literature as it has been the case for the costs extracted fro the SUDS manual. A further possibility available in CWE permits to include variable costs over time enabling the simulation of changing water flows. This option demands the knowledge of runoff amounts and destinations along the drainage systems. Besides the cost per volume unit has to be included which constitutes a more complicated factor to estimate and that usually has to be evaluated for each drainage unit separately. This last complication reveals an important point that controls the investigation possibilities in CWE. As in Storm the amount of information needed to exploit the entire CWE functionality is considerable. In consequence not only prices need to be gathered from local water services but also the overall water system needs to be quantified in term of flow volumes.

Serving as great asset for the elaboration of detailed cost scheme this CWE's characteristic can be less profitable when less data can be accessed and a rough analyze is sufficient.
As CWE uses similar spatial division as CWB the program enables to calculate the cost per unitblock or per household. In consequence the partitioning of the urban region is very important to determine the price distribution. This can become problematic for large commercial or industrial areas as they are accounted as a unique identity per cluster in CWE. The prices that large impermeable zones will have to pay can therefore become excessive. As it is implemented for the households the price scheme for industrial and commercial areas should integrate the financial possibilities of the different establishments.

The stormwater cost recovery scheme in CWE is based on the calculation of the total costs and is then calculated as pricing strategies. This analysis is very useful for determining the economical feasibility of drainage strategy implementation. While this approach can be used for already planned or already established drainage strategies the questions remains on how to quantify the lack of protection and how to promote certain drainage strategies. As in the present project, many locations sensible to flood events still need adapted drainage systems.

Though the cost estimation of lacking drainage systems is difficult to calculate estimation based on the financial damage of previous flood events could give an approximate magnitude. As implemented during the project the subsidy option can be applied for the promotion of SUDS. In consequence these two essential IWM issues are interesting aspects that need to be included in a complete economical assessment of an urban environment.

8.1.3CWIS

The representation possibilities in CWIS have been illustrated with the different views. The system view enables to describe the catchment's elements and shows the outcome of the implanted drainage strategies. As a strong decision tool the CWIS model is well adapted to communicate the solutions of the stormwater investigations. Consequently the project's outcomes can be shown respectfully to the desired objectives. A large spectrum of various types of results has been presented and the flood problematic of the Upper Rea catchment has been documented.

As a representation program the stormwater problematic has been synthesized and the drainage solutions have been compared. The creation of the resulting views appears therefore as an important asset for a management project. Nevertheless, further working options could be implemented in CWIS in order to deal with flood issues.

During the investigation of the catchment's drainage behavior and the SUDS implementation it would therefore appear very interesting to include different queries for the GIS module. A valuable asset would therefore be the automatic scan of the studies area properties to choice an appropriate implementation site for drainage strategies. Another possibility would be to overlap a DEM on the catchment's map and to include flow route algorithms in order to determine the stormwater runoff paths. In consequence a large variety of subsequent analyzing methods could be included in CWIS which would increase the already strong potential of the model.

8.2 Model intercompatibility

A significant phase during the project's work was the transfer of the data from one model to the other. While this step has been done manually CWIS incorporates the possibility to launch direct applications from its interface. This possibility has been implemented for CWE but couldn't be done for Storm as the input data structure was not compatible. As models developed in the SWITCH European project the interconnectivity of the different programs

constitutes an important benefit. In consequence the ability of symbiotic exploitation of the models has been described.

While CWE and CWIS can be used as simultaneous applications as the input structure follows the same type of format, Storm adopted a more visual implementation. In consequence the drainage elements in Storm that have to be created manually with the visual interface cannot be constructed through an input file. As this option is missing in Storm cannot be launched with an application on CWIS. This lack of implementation unfortunately increases the overall work of the flood investigation for the Upper Rea catchment. Nevertheless the data format of CWB can be translated into Storm drainage elements.

With the aim of analyzing flood issues all three models can be described as complementary offering valuable tools to investigate the problematic. Therefore the drainage strategies can be implemented, the respectfully cost estimated and the overall scheme represented and described. Through the manner Storm manages its inputs the model offers the smallest potential of compatibility with the other two. In consequence it appears more interesting to include supplementary stormwater related algorithms into CWIS or to develop a more compatible drainage model.

8.3 SUDS decision process

The construction of the decision matrix allowed allocating appropriate SUDS strategy to the different types of impermeable surfaces. Through important site constraints the final choice of SUDS evocated a unique possibility of each surface removing any ambiguity. In accordance with the stormwater objectives the selection of SUDS has produced three different strategies.

The SUDS adoption methodology can therefore be applied for all types of drainage sites as the constraints can be modified and developed. The variety of investigated SUDS can also be changed for alternative strategies if the behavior of the new drainage units towards the indicators is investigated and the results quantified in accordance with the projects classification.

In order to estimate the robustness of the SUDS selection process the methodology still has to be examined for other scenarios. In consequence a sensibility analysis could be performed by varying the weighting factor in the SUDS decision matrix. Due to the project's time limitation this step still needs to be completed.

The presented SUDS selection process in Figure 17 can be generalized for the overall project's approach. In accordance with integrated water management principles the

implementation and investigation of the models results can be represented as the overall working steps in Figure 17. The drainage model's results would therefore feed the input parameters of the economical model. If the solutions obtained with the economical appraisal are acceptable then the overall stormwater strategy is accepted. Otherwise it is necessary to go back to the implementation of the drainage model and to change the drainage objectives in order to meet the financial goals. Having defined an iterative management decision process the interests of various stakeholders as well as the problem's objectives can be achieved through an optimization procedure.

8.4 Flood investigation results

The accuracy of the results obtained with the different models has already been described above. Taking into account the uncertainties related to the results obtained different conclusions can be drawn for practical implementations.

The transformation of clusters into subcatchment constitutes a general rough approximation. Even though the proportion of impermeable area had to be adapted for subcatchments, the difference in flood prediction between Strom and the Defra model remained relatively small. Furthermore the flood locations corresponded directly between the two models. It is therefore interesting to note that the subcatchment hypothesis appeared acceptable for the drainage areas investigated. As the clusters have been constructed by unitblock identification of the Upper Rea catchment this land use splitting approach could reduce the amount of information needed in order to produce runoff estimations. However this possibility has only shown to be appropriate for small areas that have a unique outflow destination and should still be tested for other regions.

The implementation of SUDS showed direct improvements to decrease the flood events. Therefore the decrease in the average flood volumes showed the potential of SUDS to control small return event. In addition larger flood could also be preventing as has shown the decrease in the maximum flood volumes. Nevertheless the amount needed of SUDS per subcatchment in order to obtain these results is very important. Consequently SUDS are well adapted for urban drainage areas as long as the contributory stormwater surfaces are not getting to big. Otherwise supplementary stormwater options should be evaluated as the implementation of centralized drainage systems or land use restructuration. In addition the type of SUDS that are implemented in respect to the soil properties and land use characteristics has to be investigated for each new study zone.

Another important conclusion can be taken by comparing the different drainage strategies. The implementation of a centralized drainage system as for example a pond can therefore be very effective. This result suggests that during the exploration of drainage strategies all

possibilities should be included as standard centralized methods. In order to increase the sustainability of these drainage units it is possible to convert or to include them with a SUDS treatment chain.

During the cost evaluation of each strategy the high costs of the SUDS units have been confirmed. Again, the inclusion of the pond or the right choice of SUDS can drastically decrease the total cost. The investigated SUDS units should therefore be implemented for small areas in order not to exceed in dimensions.

The implementation of a stormwater recovery scheme in urban environment showed that for large agglomeration the tax system wouldn't generate a disproportionate cost for the end consumer. The choice to accord different tax schemes for different kind of residential areas depending on the proportion of impermeable surfaces can be considered as an applicable strategy in order to promote the implementation of SUDS. It appears therefore important to introduce stormwater into future cost recovery plans.

As cited in section 7.5.2 the decrease of the stormwater tax has to be adapted for larger areas and can directly reflect planning objectives. As in the presented example by Figure 27, the decrease of little surfaces can be considered as the proprietary goal in order to keep the subsidies low. On the other hand the decrease of larger impermeable surfaces can be promoted by adapting the gradient of the decrease of tax. For this strategy the tax decrease would appear insignificant for areas smaller than 100 m2 and would then grow as the SUDS implanted surfaces are getting important. The gradient of the decrease of stormwater tax therefore be adapted according the local authorities stormwater planning strategy.

As the amount of subsidies can grow very fast when the SUDS implanted surfaces are increasing the cost for local authorities can become quickly very important. As mentioned in section 7.5.2, the moment at which the subsidy overcomes the income from the stormwater tax national investments are necessary to cover the financial balance sheet from local authorities. As can be seen in Figure 27 the choice of SUDS can modify the amount of accorded subsidy but as the implemented surface is getting bigger the relative financial difference between two types of sustainable drainage strategies becomes irrelevant. Local budgets have therefore to be evaluated in order to adopt an affordable subsidy scheme.

9 Conclusion

The need for integrated water management strategies has become increasingly important in the last decades. While flood events will constitute a growing issue, the problematic of the relationship between water and the urban environment demands planning strategies to adopt a holistic approach. Therefore all three poles of integrated water management principles need to be integrated in order to improve a projects success. In stormwater development plans hydraulic and economic analysis need to be compared to meet planning objectives and to satisfy actors and stakeholders interests.

An integrated water management approach has been performed for the flood problematic of the Upper Rea catchment. Therefore different sustainable drainage strategies have been investigated with the aim to find a sustainable flood protection plan. An economical appraisal of the stormwater protection infrastructures has been achieved and a cost recovery scheme has been proposed. Finally an integrated modelling platform has been used to apprehend all the results and to synthesise and to communicate the solutions.

The combined analysis of the hydraulic aspects and the financial characteristics of the drainage strategies has been possible and confirmed the importance of taking into account these two aspects. Therefore the implementation of appropriate drainage strategies showed that the flood risk could be decreased for the region. The choice of the drainage infrastructures played in important role for the total long term investments as the cost factor varied accordingly. The comparison between the final cost and the benefit generated from the drainage strategy enabled to highlight the most effective alternative. While the proposition of a stormwater tax scheme has been performed with the aim of defying a cost recovery scheme it has furthermore demonstrated the possibility of using subsidies in order to promote national stormwater guidelines. The project's working stages enabled therefore to contribute to an integrated water management plan

In correspondence with the project's objectives the aim of the overall flood investigation focused as well on the possibility to use the described models together to apprehend the flood problematic of the Upper Rea catchment. The drainage model therefore highlighted the importance of the information's spatial resolution and demonstrated the possible effect on flooding for different strategies. The economical model enabled to present the important financial differences between several drainage strategies and showed that a cost recovery scheme can be proposed for stormwater issues. The integrated modelling platform has been used to implement synthesized views of the project's strategies and outcomes serving as a communicational tool.

The intercompatibility of the models showed that the economic model can be linked with the integrated modelling platform. The drainage model's data had to be handled manually. The results from each model could be transposed from one to the other. Despite the integration difficulties due to the lack of the drainage model's compatibility the models can be described as complementary with the aim of flood investigations.

The implementation of sustainable drainage strategies showed that significant stormwater protection affects that can be obtained. The choice of the drainage infrastructures can be adapted in respect to local constraints and to the general drainage objectives. A decision matrix with a drainage decision process has been established. An important characteristic in the dimensioning of sustainable drainage strategies has been revealed through the economic analysis and puts in emphasis the important cost of these drainage units. It has therefore been noted that sustainable drainage strategies become inappropriate for large areas.

The importance to include centralized drainage systems during the comparison of the drainage strategies has been confirmed. Therefore the optimal drainage strategy for the studied area represents a combination between traditional and sustainable stormwater applications. Even though the implementation possibilities have still to be verified in accordance with local organizations and stakeholders an overview of sustainable drainage strategies has been given.

Additional investigations have to be undertaken in order to verify the onsite implementation possibility of the presented strategies. In respect with the project's objectives the current results can help future studies to deal with integrated water management flood issues in terms of guidelines. Therefore the importance of considering hydraulic, financial and communicational tools in an urban water project has been demonstrated.

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Appendix A Defra model's sewer flood prediction of the Longbridge and the Great park zone

Flood Risk Zone	Node References	Worst Case 30, 120 and 480 min duration storms			Sum of Flood Volume in Flood Cluster			Possible Consequence
		1 in 5 year Predicted Flood Vol (m3)	1 in 30 year Predicted Flood Vol (m3)	1 in 100 year Predicted Flood Vol (m3)	1 in 5 year Predicted Flood Vol (m3)	1 in 30 year Predicted Flood Vol (m3)	1 in 100 year Predicted Flood Vol (m3)	
Zone 5	SO98771701	40.8	166.2	267.1	41	220	456	Residential Highway
	SO98771702	0	1.3	3.8				
	SO98771801	0	35.6	82.8				
	SO98771802	0	16.6	102.4				
Zone 6	Area Leisure	21	109.2	201.8	44	482	1128	Commercial
	C13	0	0	3.9				
	GP_Area AWFP	0	14.5	139.7				
	GP_Area LC1a	9.7	53.5	99.7				
	GP_Cinema Area 1	0	38.6	117.7				
	GP_Cinema Area 2	0	68.2	164.3				
	GP_Unknown	0	0	11.1				
	Safeway Stores	13.6	198	389.6				
Zone 7	Longbridge MH19	0	14.3	80.8	35	455	1161	Industrial Highway Railway
	SP00771701	0	31.3	86				
	SP00771803	0	34.8	107				
	SP00772702	0	11.4	40.4				
	SP00772703	0	18.5	56.6				
	SP00772801	0	44.5	173				
	SP00773601	0	46.1	110.6				
	SP00776501	4	68.6	161.2				
	SP00777501	0	0.3	14.4				
	SP00778505	30.7	185.3	330.5				

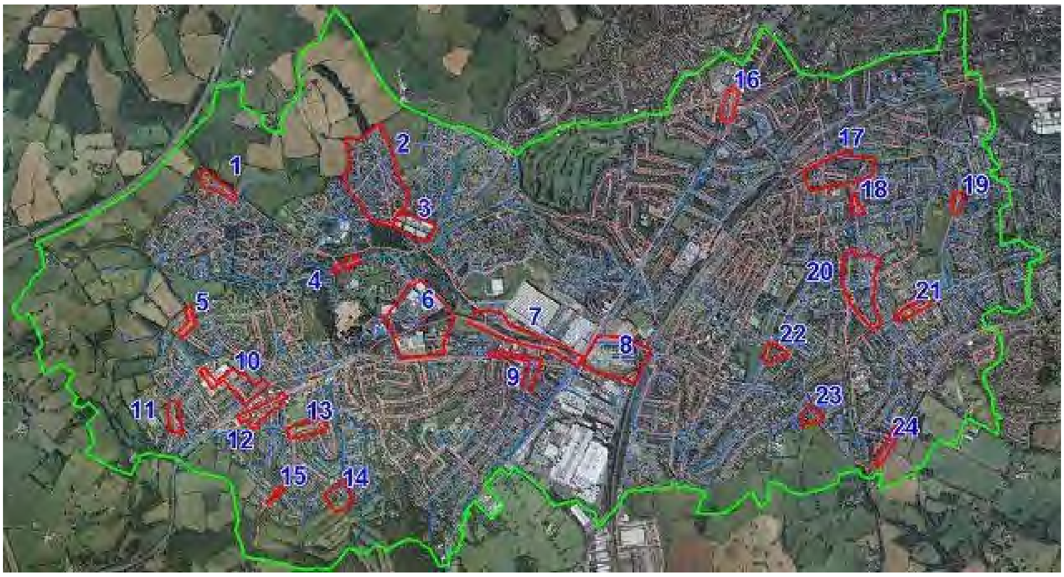
Appendix B Storm model's sewer flood predictions of the Longbridge and the Great park zone

Initial reference state		
Sewer	**Average flood(m3)**	**Peak flood (m3)**
overflow6	574.3391101	1263.774519
overflow10	292.4064768	1862.173457
overflow11	270.8457301	6033.913031

Corrected reference state		
Sewer	**Average flood(m3)**	**Max flood(m3)**
overflow 6	140.3314729	759.2474569
overflow 10	0	0
overflow 11	477.610817	937.5540246

Strategy 1		
Sewer	**Average flood(m3)**	**Max flood(m3)**
overflow 6	88.00136915	474.9719706
overflow 10	0	0
overflow 11	335.413587	335.413587
Strategy 2		
Sewer	**Average flood(m3)**	**Max flood(m3)**
Trench 231 road	6.504085519	6.504085519
Trench 231 pv	108.5446316	323.6877375
overflow 10	0	0
overflow 11	285.5718288	285.5718288
Strategy 3		
Sewer	**Average flood(m3)**	**Max flood(m3)**
overflow 6	88.00136915	474.9719706
overflow 10	0	0
overflow 11	0	0

Appendix C Location and volumes of the predicted sewer flooding of the Defra model



Appendix D Problem three Upper Rea

Appendix E SUDS capital and maintenance cost in UK pounds

Strategy 1			
SUDS	**Capital cost (year)**	**Maintenance cost (year)**	**Maintenance cost (month)**
7012 PV	4750.2	15.834	1.3195
7005 swale	1392.395	13.92395	1.160329167
7005 pv	7844.8944	26.149648	2.179137333
7006 swale	1409.94	14.0994	1.17495
7006 pv	7962.7968	26.542656	2.211888
231 swale	4341.84	43.4184	3.6182
231 roof	168815.141	6339.9336	528.3278
231 pv	44955.8928	149.852976	12.487748
235 swale	6540.91	65.4091	5.450758333
235 roof	258990.2055	9726.5014	810.5417833
235 pv	42442.9152	141.476384	11.78969867
7016 swale	6237.135	62.37135	5.1976125
7016 roof	179764.089	6751.126594	562.5938828
7016 pv	61864.86915	206.2162305	17.18468588
7015 swale	6898.397143	68.98397143	5.748664286
7015 roof	199535.9649	7493.668875	624.4724063
7015 pv	68669.2566	228.897522	19.0747935
7014 swale	2631.917143	26.31917143	2.193264286
7014 roof	71967.32401	2702.767375	225.2306146
7014 pv	24767.1774	82.557258	6.8797715

Strategy 2			
SUDS	**Capital cost (year)**	**Maintenance cost (year)**	**Maintenance cost (month)**
7012 PV	4750.2	15.834	1.3195
7005 swale	1392.395	13.92395	1.160329167
7005 pv	7844.8944	26.149648	2.179137333
7006 swale	1409.94	14.0994	1.17495
7006 pv	7962.7968	26.542656	2.211888
231 swale	4341.84	43.4184	3.6182
231 roof	168815.141	6339.9336	528.3278
231 pv	44955.8928	149.852976	12.487748
235 swale	6540.91	65.4091	5.450758333
235 roof	258990.2055	9726.5014	810.5417833
235 pv	42442.9152	141.476384	11.78969867
7016 swale	6237.135	62.37135	5.1976125
7016 roof	179764.089	6751.126594	562.5938828
7016 pv	61864.86915	206.2162305	17.18468588
7015 swale	6898.397143	68.98397143	5.748664286
7015 roof	199535.9649	7493.668875	624.4724063
7015 pv	68669.2566	228.897522	19.0747935
7014 swale	2631.917143	26.31917143	2.193264286
7014 roof	71967.32401	2702.767375	225.2306146
7014 pv	24767.1774	82.557258	6.8797715
7012 trench pv	1741.74	4.2224	0.351866667
7005 trench r	1348.341225	3.268706	0.272392167
7005 trench pv	2876.46128	6.973239467	0.581103289
7006 trench r	1368.6057	3.317832	0.276486
7006 trench pv	2919.69216	7.0780416	0.5898368
231 trench road	4754.9502	11.527152	0.960596
231 trench pv	16483.82736	39.9607936	3.330066133
231 trench road	7294.87605	17.684548	1.473712333
231 trench pv	15562.40224	37.72703573	3.143919644

Strategy 3			
SUDS	**Capital costs (year)**	**Maintenance costs (year)**	**Maintenance costs (month)**
7012 PV	4750.2	15.834	1.3195
7005 swale	1392.395	13.92395	1.160329167
7005 pv	7844.8944	26.149648	2.179137333
7006 swale	1409.94	14.0994	1.17495
7006 pv	7962.7968	26.542656	2.211888
231 swale	4341.84	43.4184	3.6182
231 roof	168815.141	6339.9336	528.3278
231 pv	44955.8928	149.852976	12.487748
235 swale	6540.91	65.4091	5.450758333
235 roof	258990.2055	9726.5014	810.5417833
235 pv	42442.9152	141.476384	11.78969867
7016 swale	8000	80	6.666666667
7015 swale	12000	120	10
7014 swale	16000	160	13.33333333
7012 trench pv	1741.74	4.2224	0.351866667
7005 trench r	1348.341225	3.268706	0.272392167
7005 trench pv	2876.46128	6.973239467	0.581103289
7006 trench r	1368.6057	3.317832	0.276486
7006 trench pv	2919.69216	7.0780416	0.5898368
231 trench road	4754.9502	11.527152	0.960596
231 trench pv	16483.82736	39.9607936	3.330066133
231 trench road	7294.87605	17.684548	1.473712333
231 trench pv	15562.40224	37.72703573	3.143919644
239 pond	25830.72695	430.5121159	35.87600966