018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

DELIVERABLE 2.1.1b: DATABASE SHOWING THREATS/UNCERTAINTIES TO STORMWATER CONTROL WHICH EXIST IN SELECTED DEMONSTRATION CITIES TOGETHER WITH THEIR PREDICTED MAJOR IMPACTS

Guidelines for the completion of a risk assessment and risk rating procedure and testing in demonstration cities

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Audience:

This Deliverable is targeted at Learning Alliance members but is also relevant to all those stakeholders with an interest in stormwater management. A methodology is proposed for the development of risk matrices which can make important contributions to stakeholder discussions of risk management strategies through consideration of social, technical and economic factors in a meaningful and transparent way.

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Purpose

The examples of threats and uncertainties in relation to stormwater management identified for selected Demonstration Cities have been utilized as a robust and transparent knowledge base for the subsequent risk management phase where stakeholders can discuss and debate whether or not identified risks are acceptable and, if not, how they can be reduced, contained or managed. The development of a SWITCH risk rating matrix, provides guidance which LAs can use to support the consistent assessment of the consequences of a particular identified threat occurring. Example descriptors are given and, although not meant to be exhaustive, do generically illustrate the types of escalating impact which could be associated with the allocation of a particular categorisation.

Background

The level of risk can be assessed by combining information generated on likelihood of occurrence with information developed on the level of consequence. One way to do this is to establish relative gradings for these parameters based on numeric values between 1 and 5. Multiplying these values together generates a ‘risk score’. The resulting overall level of risk associated with a particular threat or uncertainty can then be interpreted using an appropriate risk rating scheme. Thus combining the likelihood of occurrence with the severity of the consequences can be used as a

basis for visually illustrating the level of risk posed by each system component/aspect. This approach can then provide a useful contribution to subsequent stakeholder discussions and decision-making within the development of a risk management strategy.

Potential Impact

To contribute to the delivery of a more effective provision of urban stormwater services, which carry minimum risks and improved sustainability within the context of wider strategic, catchment-based water and land management planning.

Issues

The numeric values attributed to identified likelihoods and consequences of occurrence do not necessarily reflect a linear escalating scale of probability or severity and may follow positive or negative exponential relationships. The allocation of absolute values is susceptible to valued judgements, and the scientific appraisal of failure consequences can frequently reflect a technocratic assessment of system/component condition. However, the resulting prioritisation procedure assists the decision-making process.

Recommendations

The described methodology facilitates stakeholder engagement and hence the risk assessment procedure can thus be considered as providing the basic steps in achieving a more sustainable and integrated management decision-making tool.

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1 Introduction

1.1 Integrated Urban Stormwater Management

Despite an increasing technical knowledge and regulatory awareness of the principles of sustainable urban stormwater management, as evidenced by the plethora of national and state best practice manuals published in North America, Europe and Australia, implementation of best practice on the ground still remains uncertain and problematic (Chocat *et al.*, 2004). This technological inertia has been reinforced by impediments related to institutional, economic and socio-political uncertainties and difficulties. These factors may be much more significant than issues of technology in restraining the implementation and achievement of sustainable urban drainage targets (Ellis, 1995). It is nevertheless now clear that new approaches and attitudes are required in order to successfully address the challenge of integrated urban stormwater management (IUSM). However, in contrast to the approaches adopted for conventional and centralised sewered urban drainage systems, there can be no "one-size fits all" solution for sustainable drainage options. Neither can there be a "best solution", but rather a choice and range of feasible technical, legal, organisational and socio-financial alternatives (Starkl and Brunner, 2004). Set against a scenario of climate change and uncertain economic and socio-political futures, it is inevitable that there will be a variety of both risks and opportunities which will arise in the implementation and management of surface water drainage infrastructure. Whilst these threats and uncertainties may well have similar fundamental drivers in differing countries across the world, the nature and degree of implementation and style of management outcomes are likely to be very different in character.

In addition, it is not possible to resolve the issue of stormwater control without recognition of the interactions between diffuse rainwater-runoff, point wastewater discharges, receiving water quality and urban land management (Lawrence *et al.*, 1999). In this respect, IUSM can be defined as a structured and coherent master planning process to concurrently evaluate the opportunities to improve the management of surface water and drainage services within the context of urban landuse planning, and in ways which are consistent with wider strategic catchment and river management objectives. This requires a combination of a robust, multi-objective framework, integrating state/federal and local planning with strategic water policy and undertaken within a total catchment approach (Marsalek *et al*, 2001). This template for IUSM must also consider prevailing socio-economic conditions and institutional arrangements as well as the operating legislative framework. The priority objectives should be to avoid or minimise increased flooding and pollution, to increase use efficiency and support local environmental quality-of-life.

Objective setting, option evaluation and priority action strategies will facilitate adaptive management for sustainable urban stormwater management. The flexibility of adaptive approaches however, will be impaired if there is a lack of benchmarks and baseline information on catchment dynamics and ecosystem response. A key element in the innovative organisational framework must be the recognition of the differing regimes and impacts of storm events (Davies and McManus, 2004). Figure 1 illustrates that sustainable integrated stormwater management will need to plan for

three major categories of storm events within the hydrologic spectrum, each of which will have different impacts on the biophysical, social and economic environment.

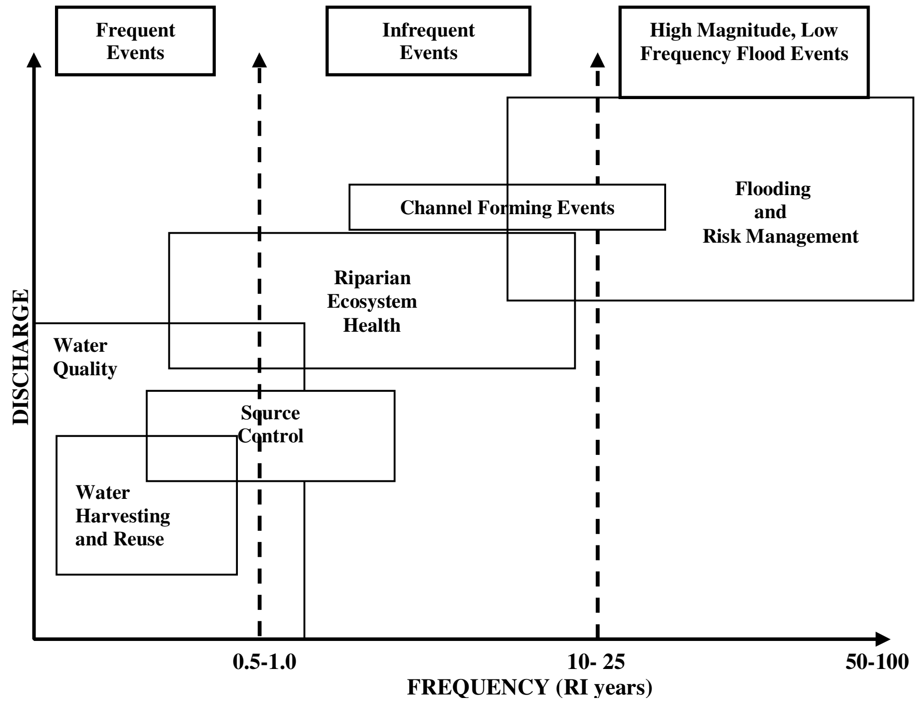


Figure 1 Stormwater Management Planning Scales and Issues.

This tri-level storm event consideration represents a significant shift from conventional planning processes such that frameworks intended to address major flood risk for example, should also consider receiving water health and ecosystem functioning, land use capacity and potential, social/community values and expectations as well as cost viability. In addition, proposed controls and management approaches should also be compatible with municipal, regional and catchment planning objectives. Specific objectives, targets and performance-based criteria will need to be set, monitored and evaluated for a variety of biophysical, ecological, social and economic parameters. The interfaces between the science of urban catchment health, ecosystem functioning, urban land planning and strategic policy decision-making will present major challenges for the new organisational structures.

An appropriate organisational framework must identify and develop relevant management objectives and targets for:

aquatic environmental values; receiving waterbody health covering both surface and groundwater, ecosystem stability, channel form

terrestrial environmental values; riparian zone, bankside vegetation, open space use etc.

social environmental values; aesthetics, recreation, local community involvement, disturbance

economic environmental values; flood damage, public health, water demand.

Each of these environmental values must be related to specific flow regime levels and to water quality effects on both short (acute) and long term (chronic) time spans. An

evaluation of these environmental values and controlling regime factors will assist in the determination of the principal waterbody stressors in order to aid the prioritisation of "hotspots" and to effectively target scarce resources. Urban water managers are now realising that there is an increasing need for management decisions which consider the risks and uncertainties about how exactly ecosystems function and the likely effectiveness of differing recovery approaches. There is also a need to relate such decisions to practical planning solutions and thus to local, regional/state and national policy as well as catchment-based intervention strategies. Increasingly the preferred sustainable approach to urban water management will be an integrated multi-disciplinary and multi-stakeholder decision process founded on an understanding of ecosystem health and urban hydrology. This approach will need to be framed within prevailing socio-political, social and organisational dimensions as well as strategic policy and legislative frameworks.

1.2 Learning Alliance (LA) Platforms

The technical problems of, and solutions for, IUSM thus require engagement with a complex array and hierarchy of administrative, legislative, political, institutional, social, economic and cultural levels and issues. A generic objective of an integrated, holistic approach is to deliver more effective provision of urban stormwater services carrying minimum risks and improved sustainability within the context of wider strategic, catchment-based water and land management planning. The focus of the innovative delivery approach within SWITCH is centred in the city-based Learning Alliances (LAs) whose work can be considered as comprising the central mechanism for affecting holistic integrated change, with its emphasis firmly based on capacity-building networks (Ellis *et al*., 2007a). The innovative aspects of SWITCH are not the development or implementation of new research tools and activities *per se*, but rather the mobilisation, integration and delivery of best practice approaches and technologies within and across different sectors of the urban water management cycle represented within the LAs.

1.2.1 The Belo Horizonte Learning Alliance Structure

The agreement to form a Learning Alliance (LA) in Belo Horizonte occurred at an opportune time, as in 2004, in anticipation of a new national environmental law, the urban water department (SUDECAP) of the Belo Horizonte municipality (PBH) coordinated the establishment of a special committee (created by a local municipal bye-law) to consider more integrated urban water and wastewater policies and to develop a masterplan for future implementation. The environmental sanitation committee (COMUSA) was therefore already committed to addressing priority policies and seeking new approaches for "*saneamento ambiental*" or integrated water resource and solid waste management and were charged with the responsibility to develop a Municipal Sanitation Plan (PMS). Figure 2 illustrates the Belo Horizonte LA structure which draws together four distinct tiers of governance and institutional organisations.

The new "*saneamento ambiental*" law promulgated at national federal level by the Brazilian Ministry of Cities (Law 11445/2007) clearly places administrative oversight of urban water services at the city council level, through which participation in, and responsibility for, integrated water and sanitation services will reside. Amongst their

functions, city councils will both develop and advise on the strategies and priorities for their municipal water and sanitation plan. This will subsume allocation of priority

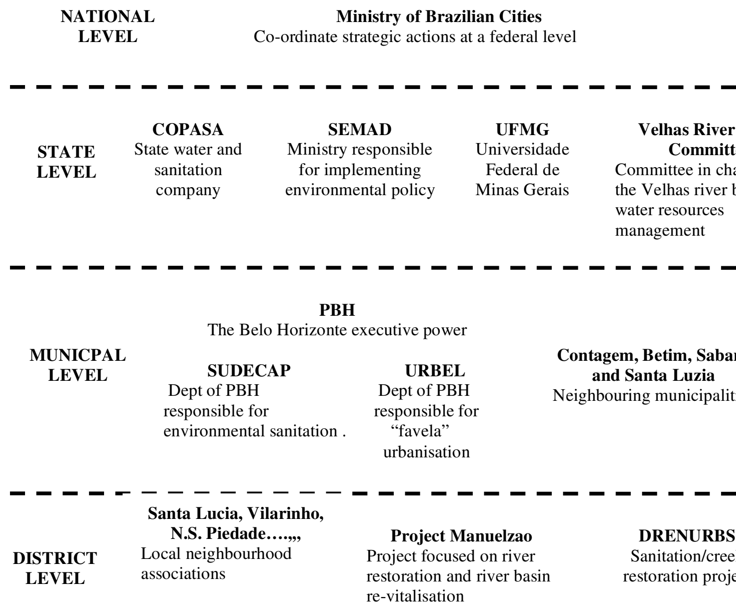


Figure 2 The Belo Horizonte LA: Connected Stakeholder Platforms.

investment, the definition of cross-subsidies and social aid as well as advise on service delegation such as might be contracted to water and wastewater companies such as COPASA. In addition, they will have to coordinate with adjacent city councils under consortium agreements and also work in association with relevant bodies such as the Health, Environment and Urban Planning Councils. The federal bill also puts in place a general political directive for public participation in services management at the local municipal level.

1.2.2 The Birmingham Learning Alliance Platform

There is a complex array of stakeholders and participants that can be identified in sustainable urban water management at the operational level within the Birmingham region as indicated in Figure 3 which shows key "actors" at regional, city and local levels. The structural arrangement shown in the figure includes both institutions which currently influence decision-making processes as well as those that might have a potential future influence. The key players and their respective roles in sustainable urban water management within the region have been described within Deliverable 6.1.2 of the SWITCH project (Green, 2007), which maps out institutional arrangements for the city. Birmingham City Council (BCC) is clearly a major player in this structural framework, although much of its policy and planning currently by-passes sustainable water management strategies and measures. The British Waterways Board (BWB), the Highways Agency and England Nature, all of whom have major interests in the aquatic and ecological development of surface waters within the region, are omitted from this framework.

The current representation in the SWITCH Birmingham Learning Alliance (LA), which is coordinated by the international developer and consulting engineering group

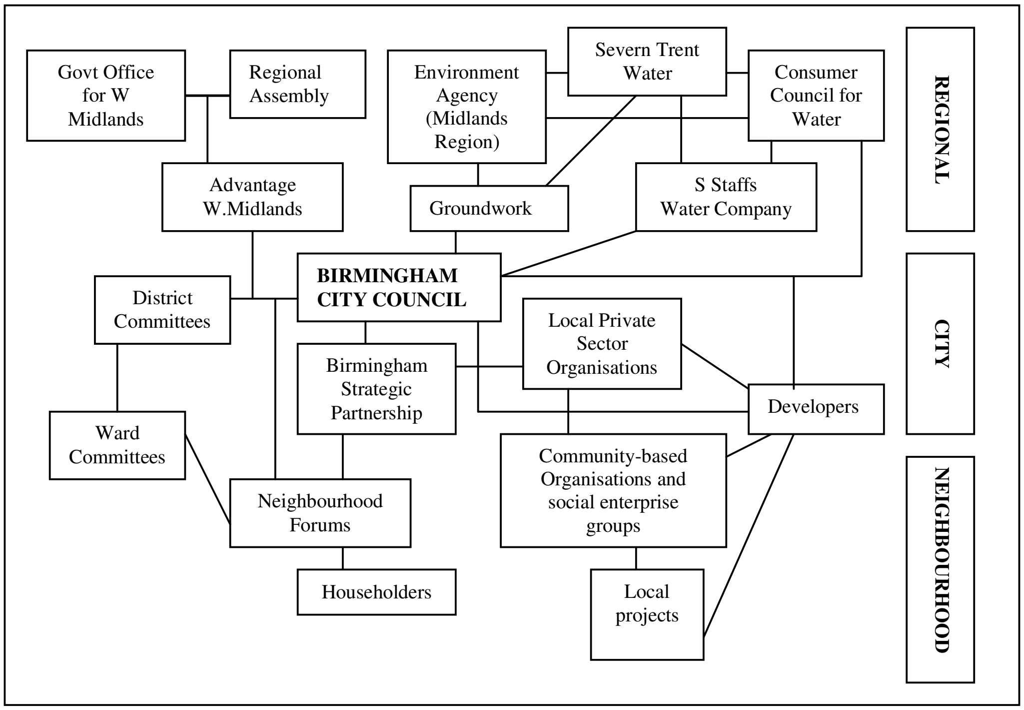


Figure 3 Key Institutional Organisations involved in Surface Water Management in the Birmingham Region.

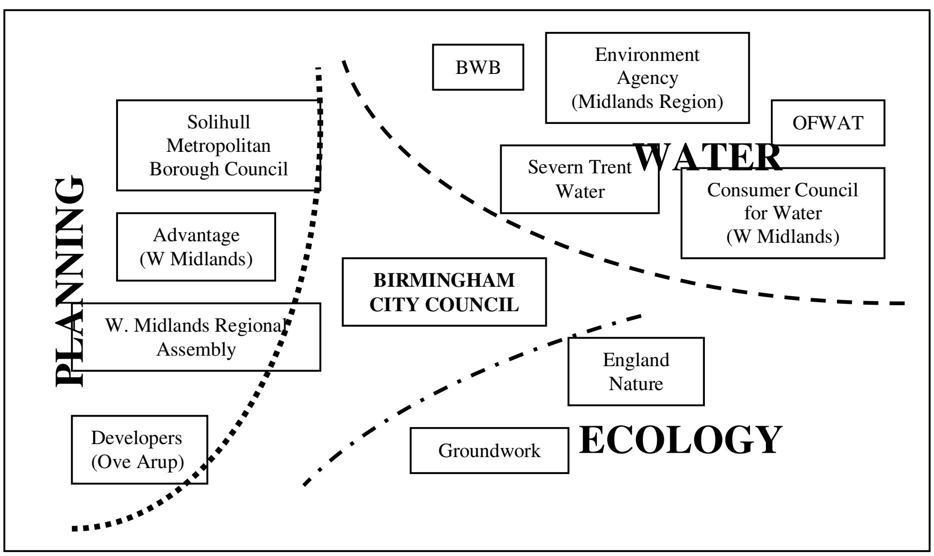


Figure 4 The Birmingham SWITCH LA.

Ove Arup & Partners based at Solihull, is a sub-set of the organisations identified in Figure 3. The LA effectively brings together principal stakeholders from the water, planning and ecological sectors (Figure 4) but whose combined interests extend well beyond those of solely urban surface water management.

1.3 Identifying Threats, Uncertainties and Risks

Each LA and demonstration city involved with Theme 2 of SWITCH and therefore having an interest in urban stormwater management was invited to undertake a detailed survey of their LA representatives to identify and quantify the principal threats and uncertainties associated with the achievement of integrated urban stormwater management (IUSM). These risks were identified within the context of both contemporary environmental, institutional, legal, and socio-political conditions as well as for the extrapolated city-of-the-future in 20 to 30 years time. The individual returns for each demonstration city are included in Section 2 of this report.

This database survey then provided the basis for the analysis of a risk assessment and the development of a risk rating procedure to evaluate the relative strengths and vulnerabilities of differing stormwater control systems and management approaches under the varying identified scenarios. Section 3 of this report develops a risk assessment template essentially based on the well-recognised "traffic light model" which delineates and justifies three levels of risk ranging from acceptable to tolerable and non-acceptable. The resulting risk scores are considered in terms of relative vulnerability and damage potential and thus a judgement on tolerability and acceptability becomes meaningful in terms of the selection of protective and mitigating measures. The basis for the structure and framework of this taxonomic approach is that developed by the International Risk Governance Council (Renn and Graham, 2005), and is also the basis for risk assessment adopted by the UK environmental regulatory agencies, the Environment Agency for England & Wales (EA) and the Scottish Environment Protection Agency (SEPA).

The city-specific threats and uncertainties are finally analysed in Section 4 in terms of the relative risks they present to urban stormwater management at both contemporary and future time horizons, with the vulnerabilities considered in terms of the relative severity and the likelihood of occurrence. This application of the risk methodology has been tested in detail for Birmingham (see Section 4.1) and Belo Horizonte (see Section 4.2). These two examples provide detail on both prevailing and expected environmental, technical, socio-economic, legislative and institutional arrangements for urban surface water drainage. The likelihood and consequences of potentially damaging events and vulnerabilities are based on the LA screening analysis which provides the justification for the risk scores recorded in the rating matrices.

2 Threats and Uncertainties in SWITCH Demonstration Cities.

2.1 Belo Horizonte: Stormwater Threats and Uncertainties (Prepared by: N Nascimento and J-R Champs).

2.1.1 Introduction

The long term threats and uncertainties associated with the urban development of Belo Horizonte (BH) are briefly discussed in terms of population growth, climate change, and the development of governance and institutional structures. This discussion is followed by a tabulated list of potential risks associated with the stormwater infrastructure and services in BH and the surrounding metropolitan area.

2.1.2 Population growth

Population growth in Belo Horizonte is virtually reaching a saturation level (Figure 5). The current average population growth rate is at 1.1 % per year (from 1990 to 2000) and nearly 95% of the municipal area is already urbanised. It is important to consider that the BH land use law still allows a considerable densification of the present urban occupation in almost all the municipal territory, with the exception of the central, very densely occupied area, and zones of restricted densification. Nevertheless, this scenario of high densification seems not to represent such a significant risk when one takes into account the mentioned present population growth rate.

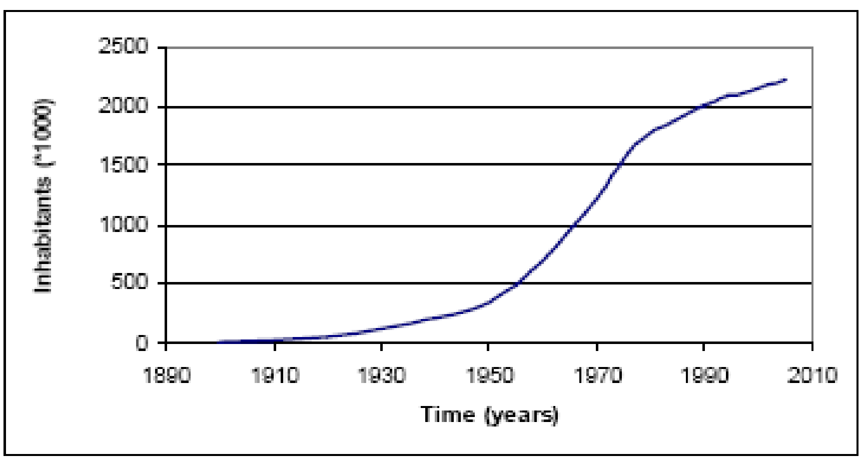


Figure 5 Population growth in Belo Horizonte.

Studies developed under the context of the Stormwater Strategic Plan have assessed the possible impacts of population growth on the percentage imperviousness taking into account densification trends at each of the 111 sub-catchments within the territorial region of BH. Figure 6 illustrates the distribution of the percentage imperviousness according to the sub-catchments for the Arrudas and the Onça rivers.

Figure 7 illustrates the percentage imperviousness increase trends for the same 111 sub-catchments.

On the basis of these data, it is possible to conclude that imperviousness within the Arrudas catchment is considerable higher than for the Onça catchment. For instance, within the Arrudas catchment 50% of the sub-catchments have a percentage imperviousness greater than 75% whereas for the Onça catchment this happens for only approximately 25% of the sub-catchments. However, the increasing trends in imperviousness, as predicted by the Stormwater Strategic Plan, are more significant for the Onça than for the Arrudas catchment, in spite of the fact that these rate increases do not exceed 20%.

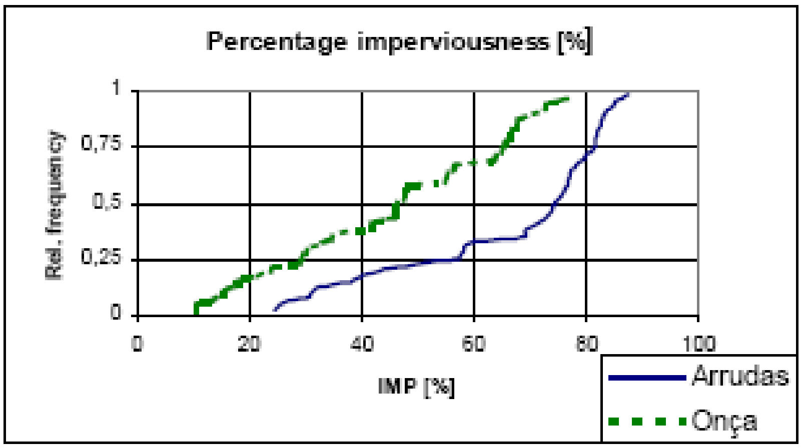


Figure 6 Percentage imperviousness distributions for the 111 sub-catchments within the Belo Horizonte region

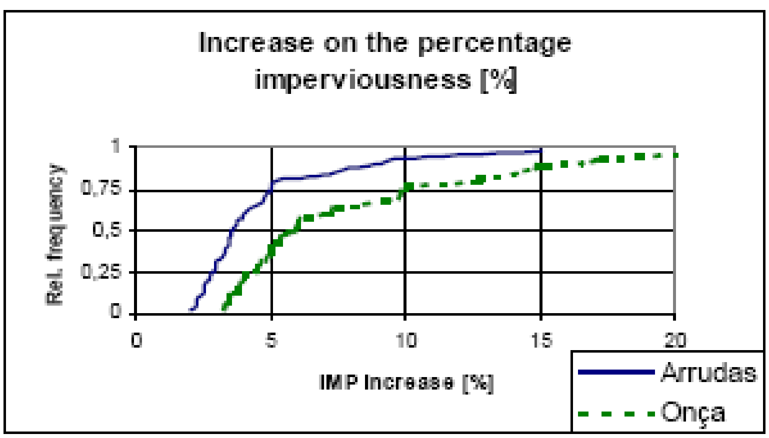


Figure 7 Trends for percentage imperviousness based on empirical distributions for the 111 sub-catchments of the Belo Horizonte region (SUDECAP, 2000)

However, pressures on water resources due to population growth as well as a variety of environmental impacts due to rapid urban expansion may be consistently expected in the metropolitan region of Belo Horizonte (RMBH), where population growth rates higher than 5% per year are still observed in certain townships (Tables 1 and 2). Part of this phenomenon is due to the attractiveness of industrial and commercial activities

as well as to the quality of public services in townships located near to Belo Horizonte. In some suburban areas the low cost of land associated, in many cases, with illegal urban developments may also partly explain this expansion process despite poor infrastructure of public services.

Table 1 Population growth in Belo Horizonte and its metropolitan region

Municipality or Region	Period- population growth rate in % per year				
	1950/60	1960/70	1970/80	1980/91	1991-2000
Belo Horizonte municipality	7.0	6.1	3.7	1.1	1.1
Total RMBH	6.2	6.1	5.0	2.5	2.4
RMBH except Belo Horizonte		6.2	7.5	4.8	3.9

Source: IBGE – Censos Demograficos, FJP/Plambel (1974) and Rigotti and Rodrigues (1994), apud www. observatoriodasmetropoles.ufri.br (visited October 2006)

Table 2 Urbanisation rate and population growth in Belo Horizonte and chosen municipalities located in its metropolitan region

Municipality	Urbanisation rate (%) of urban population in respect to total population		Population growth rate (%) per year period: 1991-2000	
	1991	2000	Total	Urban
Belo Horizonte	99.7	100.0	1.1	1.2
Betim	94.9	97.3	6.7	7.0
Contagem	93.4	99.1	2.0	2.7
Nova Lima	84.0	97.9	2.3	4.1
Ribeirao das Neves	83.4	99.4	6.2	8.3
Sabara	83.3	97.7	2.8	4.7
Vespasiano	64.5	98.4	3.8	8.7
Total RMBH	94.0	97.5	2.4	2.8

Source: IBGE – Censos Demograficos, apud www.observatoriodasmetropoles.ufri.br (visited October 2006)

Another on-going process of urban expansion is due to the increasing interest of rich people in new urban areas located in neighbouring municipalities, the so-called condominiums. The attractiveness of these new developments is explained by their low occupation density and their private security systems, not to mention that they are better endowed with green parks and leisure facilities than in the BH urban area. In spite of their low occupation density, these areas produce impacts on the environment, exert pressures on local natural resources (water, forests) and lead to a progressive privatisation of scenic landscapes and forested areas that could have different uses in the future, including public access for leisure and sport activities.

2.1.3 Climate and Climate change

Figures 8, 9, 10 and 11 illustrate the long-term mean monthly temperature, precipitation, maximum 24-hour precipitation, and relative humidity, respectively, in Belo Horizonte, assuming time series non-variability. The main climate

characteristics of the Belo Horizonte area are the relatively small thermal amplitude (in terms of mean temperatures) and a high seasonal variation of precipitation with very dry winters and wet summers.

Regionalisation studies on rainfall intensity, duration and frequency recently carried out for the BH metropolitan region (RMBH), based on precipitation data from more than 20 recording rain gauges having time series longer than 30 years, did not detect any evidence for the influence of climate change on precipitation depth or precipitation intensity for different time steps (Pinheiro and Naghettini, 1998).

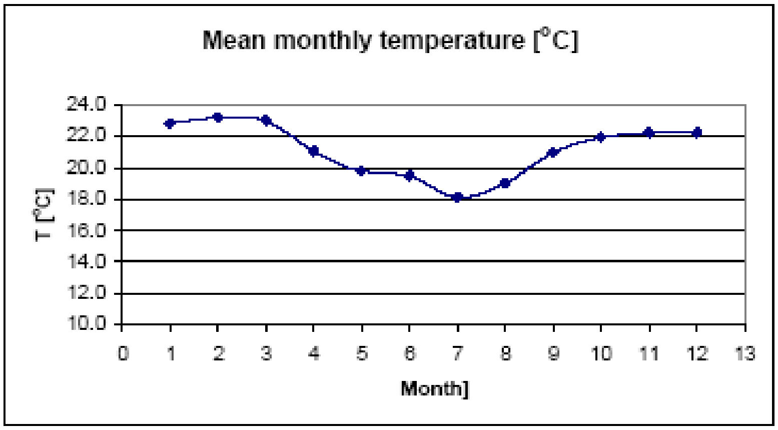


Figure 8 Mean monthly temperatures for Belo Horizonte

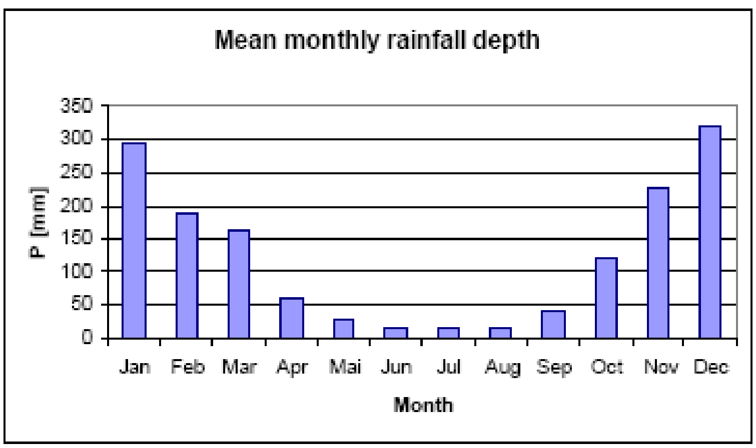


Figure 9 Mean monthly precipitation for Belo Horizonte

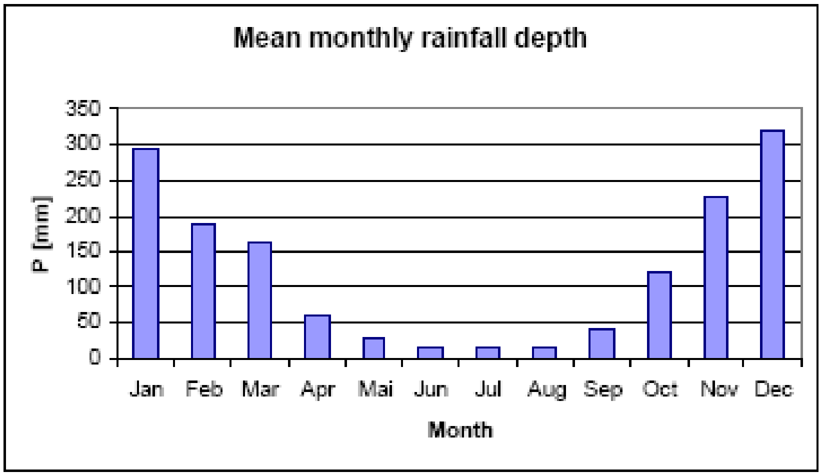


Figure 10 Maximum 24-hour precipitation for Belo Horizonte

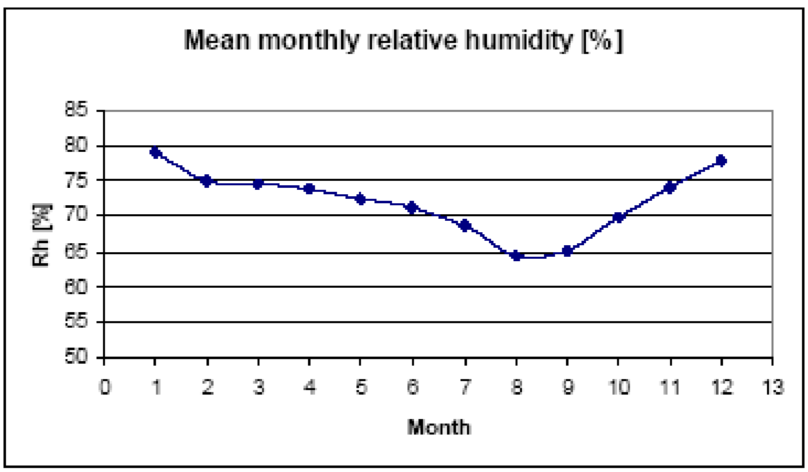


Figure 11 Average monthly relative humidity for Belo Horizonte

In contrast, increasing temperature trends can be identified, particularly in terms of mean temperatures (Figure 12). However, it has to be recognised that there can be difficulties in isolating global change effects from anthropogenic impacts at a local scale, as urban heat islands can develop due to increases in impermeable areas and changes in vegetation cover and in wind patterns. In BH, part of the increasing temperature trends, as highlighted by the 5-year moving mean, are coincident with a period of intense urbanisation from the 1970s onwards (Figure 12).

A particular concern with respect to climate change is the possible synergistic combination of global with regional changes due to local anthropogenic impacts caused, for instance, by deforestation and/or urbanisation. Studies assessing regional and local impacts of climate change are not numerous in Brazil. Nevertheless, according to Nobre *et al.* (2005), existing studies suggest that an increase of 2 to 3 C

in average temperature may lead to a reduction of trees by up to 25% in the

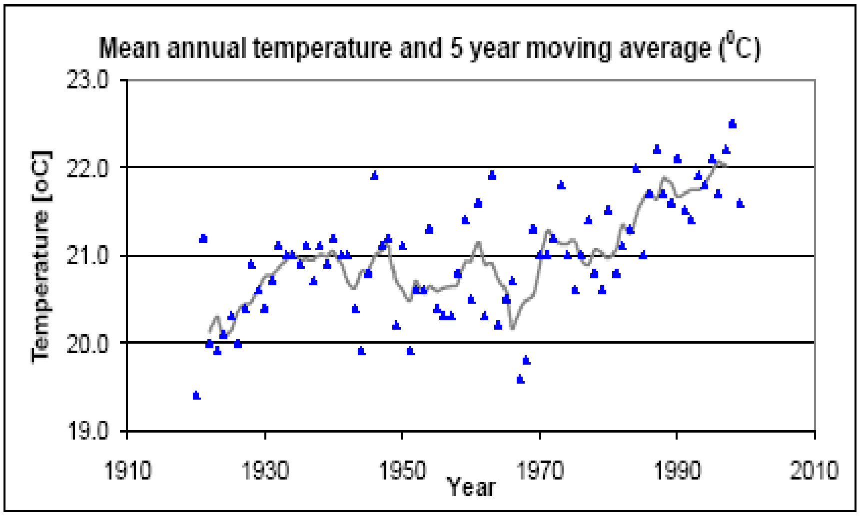


Figure 12 Mean annual temperature and 5-year moving average for Belo Horizonte

"cerrado" area (savannah) and by up to 40% in the Amazonian forest, before the end of the 21st century. These kinds of vegetation changes may, in turn, result in a warmer and drier climate, which may lead to water shortages, among other possible impacts.

The IPCC (2001) report on the possible impacts of climate change in urban areas, cited by Bigio (2003), suggests:

- Expected increases in the scale, intensity, and frequency of rainfall resulting in periodic flooding of flood prone areas and in landslides on geologically unstable slopes (areas typically occupied by low-income informal settlements).
- Sewage treatment systems and solid waste disposal areas could be affected by flooding, with possible contamination of water supply sources.
- An evolution to drier climates which compromises the replenishment of the water tables and reduces minimum flows, possibly implying a water shortage.
- Intense episodes of thermal variability which could severely strain urban systems by adding environmental health risks for more vulnerable sectors of the population, imposing extraordinary consumption of energy for heating and air conditioning, and disrupting ordinary urban activities;
- Increased possibility of fires in urban and forested areas; severe hail, and windstorm events.
- Worsening urban air pollution exacerbated by increased ground level ozone formation.
- Enhanced effects of urban heat islands due to higher overall temperatures.

Although assessments of these kinds of risks are not so far available for Belo Horizonte and its surrounding region, they are likely to happen in the future provided that forecasts on global change are confirmed.

2.1.4 Risk and Uncertainties Associated to Governance and Institutional Development

In addition to the risks mentioned above, and part of the reasons for the emergence of these risks, are institutional and governance issues. These may concern the requirements for integrated planning and management that must be developed at different territorial and institutional scales:

- territorial scale: district, city, metropolitan, river basin, state, national;
- water supply and sanitation sub-sectors: water supply, wastewater, storm water, solid waste
- sectors of the urban policy development: urban planning, urban development major projects, housing, industrial development, road system and transport

For some of the sectors, water issues are not currently included in the decision-making procedures or in the legislation. The implementation of an effective integrated urban water management system will, therefore, require considerable improvements on governance and institutional development, in order to ensure effective co-operation among different sectors of decision-making, policy formulation and management within the urban sphere as well as within the river basin sphere.

One part of the required institutional development for integrated urban water management is capacity building. IUWM implementation implies considerable changes in technical and managerial methods, including monitoring, modelling, planning, decision-making on the basis of indicators, adopting new legislation, communication, facilitating public participation, etc. These changes require well-trained professionals in new methods and techniques, which will require the training of existing staff as well as the hiring of new professionals.

Therefore, uncertainties and risks related to governance and institutional development refer mainly to concerns associated with the difficulties in implementing relevant new policies, methods and legal requirements.

2.1.5 Long-term Uncertainties and Potential Risks to Urban Surface Waters in Belo Horizonte and the RMBH

Stormwater

Risk and uncertainties	Event	Comments and explanations	Existing instruments and means to handle the risk and to mitigate impacts
Flooding	Significant changes or increases in the occurrence of floods and damage caused by floods.	Main causes: • Increases in imperviousness due to urbanisation • Lack of investments to correct the present hydraulic functioning problems which exist in the stormwater sewerage system • New developments (legal and illegal) in flood prone areas • Lack of proper maintenance • Technology update is not sufficient, persistence in using oversimplified design methods • Climate change alters storm frequency and intensity	Emergency plans exist, but there is need for further developments with respect to the prevention and mitigating action planning required to cope with these kinds of risks. Difficulties persist in handling urbanisation, particularly the spreading of informal settlements. Urban development plans and urban land use legislation do not properly consider impacts of urbanisation on water and other natural resources in an effective way.
Pollution of receiving waters by wet weather diffuse pollution	Significant changes or even increases in the wet weather diffuse pollution.	Main causes: • Increases in imperviousness due to urbanisation • Lack of proper maintenance • Technology update is not sufficient; persistence in using oversimplified design methods • Wet weather pollution not properly considered • Failures in other sanitation sectors, as in solid waste management.	High pollution of receiving waters by wastewater outflows masks effects of diffuse pollution. Difficulties persist in handling urbanisation, particularly the spreading of informal settlements. Difficulties in controlling illicit solid waste disposal on land and directly to water bodies. Urban development plans and urban land use legislation do not properly consider impacts of urbanisation on water and other natural resources in an effective way.

Persistent and chronic pollution of receiving water	Implemention of planned interceptors is postponed.	Main causes may be lack of investment for iinstalling interceptor sewers associated with high costs; political and social difficulties associated with removing informal settlements from riparian areas, thus posing problems for the building of interceptors.	The Belo Horizonte Sanitation Plan states the complete equipment of the sanitation system in 20 years.
	Persistence of illicit connections between stormwater and wastewater sewerage systems.	Main causes: • Technical difficulties in locating and reducing these kinds of connections. • Need for training and information in order to avoid new inadequate connections between the two systems. • Informal settlements (shantytowns) usually "adopt" combined sewerage systems.	
	Lack of investments to increase WWTP treatment capacity	Although of low risk, changes in policy and planning may postpone investments in treatment plants.	
	Operational failure or poor operation of WWTP leading to poor treatment performance		The Brazilian Continuous Education Programme on Water Supply and Sanitation headed by the UFMG in the Southeast Region focuses on operational capacity building. COPASA and PBH are partners of this programme. COPASA possesses high maintenance and consistent operational standards.
	WWTP not equipped to remove nutrients (nitrogen and phosphorous) and emerging polluters as endocrine-disrupting chemicals.	Emerging polluting chemicals are not usually monitored in Brazil. Awareness of the problem is not wide.	

Risks associated to the use of BMPs	Failures on flooding control and wet weather pollution abatement. Health risks, soil pollution associated to the use of BMP devices Reduced public acceptance of BMP	Main causes: • Lack of maintenance • Technology update is not sufficient • Persistence in using oversimplified design methods for source control and other BMP devices • Failures in controlling urbanisation and diffuse pollution sources (including erosion processes at the catchment scale) • Ignorance or not enough concern regarding wet weather diffuse pollution and its impacts on BMP	The Stormwater Strategic Plan includes a programme on technology update and on capacity building focusing on monitoring, modelling and new technologies, including BMPs. The BH municipality is investing in environmental education and dissemination of urban drainage new technologies for a large public awareness, including river restoration and BMP. The SWITCH project research and demonstration activities will certainly contribute to reduce the mentioned risks.
Accidents related to natural disaster	Disruption of stormwater systems due to natural hazards like flooding or landslides.		Emergency plans exist, but there is a need for further developments on prevention and mitigating action planning to cope with these kinds of risks.
Failures of system units due to lack of maintenance or ageing of infrastructure and associated equipment.	Key units (e.g.: major culvert channels) may fail due to lack of maintenance or ageing: structural rupture due to abrasion or foundation problems		Maintenance and operational standards are high and consistent. Nevertheless, a comprehensive assessment of investment needs for the modernisation of ageing systems must be performed. This particularly concerns ageing sewerage equipment where maintenance is less regular than in the case of the water supply distribution system.
Increasing costs	Increasing costs imposed by different causes see opposite).	Possible causes: • Investment for the modernisation of ageing systems • Maintenance costs • Operational costs: monitoring, modelling • Costs imposed by vandalism	It is part of the Swornmwater Strategic Plan the assessment of alternatives for funding current stormwater operational actions.

System failure induced by vandalism.	Vandalism leading to system disruption	There is concern related to the risk of vandalism against monitoring equipment (rain gauges, automatic samplers, data logger stations, etc) that will be implemented under the Swormwater Strategic Plan and the SWITCH demonstration activities.	The BH municipality is investing in environmental education and dissemination of urban drainage new technologies for a large public audience. This may include information on equipment installed in the catchments and its role, possibly contributing to vandalism reduction.

2.2 Birmingham: Stormwater Threats and Uncertainties (*Prepared by: P. Sharp and J B Ellis)*

2.2.1 Introduction

Urban flooding and diffuse pollution is a complex phenomena as it results from multiple sources, involves a variety of flow and process mechanics and occurs in restricted topographical situations. In addition there is a complex interaction of flood events ranging from peri-urban fringe, pluvial, fluvial and sewer flooding with a more restricted risk from groundwater flooding. Both flooding and pollution control are also complex because they involve a variety of stakeholders drawn from government, public and riparian organisations having shared and frequently unclear responsibilities and powers for surface water drainage. According to Defra (2007), around 2.1 million domestic and commercial properties in England are at risk of urban pluvial flooding corresponding to some 4 – 5 M people. This number is only likely to increase with pressures from climate change, urban creep and increased urban development. The UK central government Foresight Future Flooding report (Evans *et al*., 2004) predicted that costs of future urban flooding could rise to anything between £1 – 10 billion per annum by the 2080s if improved actions are not taken now to reduce the risks.

2.2.2 The Birmingham Area

Birmingham represents the largest local municipal authority in the UK with a total population of nearly 1M in 2005 (and with 5M in the greater metropolitan area), being the second largest city in the UK and having an annual residential growth rate exceeding 1.6% since 2001. Residential and commercial space has grown substantially (+10%) since 2000, especially in terms of city centre office stock and with the implementation of the city centre masterplan.

There is a history of flooding throughout the early part of the 20th century within the Birmingham city area of the River Rea catchment as a result of intense rainfall events leading to flash flooding (Humphries, 1928). The topography of the upper Rea catchment possesses "ravine-line" valleys along its southern boundaries with the Lickey and Clent hills, which rapidly feed surface water into the main river during rainfall events. The historical extension of impermeable surfaces associated with the growth of early industry in the lower Rea valley exacerbated these natural runoff effects to cause severe and frequent flooding and pollution in the lower river reaches within the central city area.

Tanning and textile industries developed along the Digbeth and Deritend section of the river Rea flood plain during the late 16th century with a further development of cloth, paper and metal-working industries in the late 17th and early 18th centuries. The River Rea is now almost totally hidden from sight as it enters the city at Highgate and is locked into a heavily engineered channel through the city centre. The heavily urbanised nature of the river means that baseflows are depleted in dry weather conditions but there are rapid responses and the potential for flash flooding associated with sewered runoff during wet weather events. The amount of previously unregulated industry has also left a legacy of contaminated land and poor groundwater quality which in turn can be detected in contaminated river bed sediments.

The lower river sections were severely channelised during the 1890s industrial period to prevent flooding of local factories and warehouses. However, further major flooding re-occurred in 1927 and further straightening and culverting was undertaken in the 1930s which involved lowering the river bed by up to 2m. This has resulted in a deep 6–8m brick-lined channel through the central city area but has prevented any further serious flooding incidents since that time. The river was classified by the Environment Agency (EA) as a "main" river in 2005 with all direct flood defence and water quality responsibilities passing to the regulatory agency under permissive powers.

Thus the Rea channel, like most of Birmingham's rivers, has become neglected with poor water quality, increased flows from extension of the impermeable area and culverting works. Aquatic habitats have been lost with the river ecology having deteriorated to near sterile conditions in some sections and with the general amenity value of the river corridor being at a minimum. According to Birmingham City Council (BCC) and Severn Trent Water (SWT) flood registers, in the period between 1998 and 2000, over 525 separate flooding incidents were recorded in 46 areas of the metropolitan region involving 12 flood events. The STW flood register currently identifies 14 locations "at flood risk" and their Drainage Area Programme (DAP) Needs report identified a further 10 key flood locations within the Rea catchment.

Although some improvements in recent years have occurred, water quantity and quality present major problems within the Rea catchment principally associated with:

CSO and SWO outfalls during wet weather giving rise to rapid increases in flow rates and volumes

storm flushing of diffuse pollution into the receiving water causing a loss of oxygen and poor BOD levels leading to a suppressed ecology

poor ecological biodiversity with contaminated bed sediment

fly-tipping of domestic and commercial waste

a river system which is largely inaccessible and is of poor amenity value to the local community

rising groundwater levels bringing up contaminants that have previously been contained within the unsaturated zone.

wildlife habitats in the river sections and banksides that have been badly damaged.

increasing development pressures on bankside locations which need managing in a sustainable way for both river ecology and community needs

a lack of historic regard for the control and management of diffuse urban runoff and unclear lines and authority boundaries of responsibility.

2.2.3 Stormwater Risks and Uncertainties for the River Rea Catchment, Birmingham

Risk and uncertainties	**Event**	**Comments and explanations**	**Existing instruments and means to handle the risk and to mitigate impacts**
Flooding	Significant changes or increases in the occurrence of floods and damage caused by floods.	Main causes: Increases in imperviousness due to urbanisation Lack of investments to correct the present hydraulic functioning problems which exist in the stormwater sewerage system New developments in flood prone/plain areas Lack of proper maintenance Technology update is not sufficient, persistence in using oversimplified design methods Climate change alters storm frequency and intensity	Management of stormwater in the City of Birmingham is split. The Water Company (Severn Trent Water) is responsible for drainage of properties (domestic and business/commercial). The City Corporation is responsible for land drainage and “non-river” water courses and urban streets. The Highways Agency is responsible for draining national highways. This is however devolved under an agreement to the City Highways Department and is financed by the central government though this Agency agreement. The Environment Agency has overall responsibility to manage “main rivers” and for the overall protection of surface and ground water bodies. Planning Policy Statement (PPS25) requirements will now prevent further new inappropriate development in flood prone (zones) areas.

			Formation of Birmingham Action Group in respect of flood management
Pollution of receiving waters by wet weather induced pollution	Significant ecological degradation of water bodies due to diffuse pollution entering via stormwater drainage system or over-land flow.	Main causes: Increases in run-off from higher levels of imperviousness due to urbanisation Lack of correct maintenance of existing stormwater/drainage infrastructure. Historic assets and oversimplified design methods Rainfall induced pollution pathways not properly considered/understood Failures in other sanitation sectors, such as in solid waste management/land use/street cleaning, etc. Inappropriate land use within the catchment Upstream CSO spillages	Pollution effects upon receiving water courses/bodies from combined sewer overflows (CSO's). These now being eliminated or upgraded (EA consented) under WFD/Asset Management Plan 4 (AMP4) as Environmental Objective of EA/OFWAT as "point-source" pollution. Divided responsibilities for urban stormwater managements need to be addressed to solve "diffuse pollution" effects on water body quality. Water Framework Directive (WFD) addressing this currently.
Pollution of receiving waters due to groundwater contamination (from former land use contaminated land)	Movements of groundwater mobilizing historic land-use contamination and entering the surface water (receiving) bodies and affecting water quality. Urban and suburban considerations.	Main cause: Pathway and receptor mechanisms not properly understood. Rising groundwater in urban areas Incomplete assessment of contaminated areas from former land-uses. Polluting effects from modern chemicals/materials and synergistic effects.	Research programme looking at groundwater – surface water interaction and natural remediation methods. Planning Policy Strategy documents for new urban development planning. WFD implementation.

Poor ecological status	Suppressed biological diversity and scores	Main cause: Severely canalised, lined channels with many culverted sections Fast flowing, fluctuating flow regime Low flood retention times Low nutrient levels Elevated BOD and low DO levels especially during and after wet weather flows Sewage fungus Contaminated bed sediment	Gradual reduction and elimination of CSO spillages under both WFD and AMP4 programmes; improved BOD/DO levels Gradual reduction in illicit cross-connections under STW future sewer upgrading and rehabilitation programmes WFD to address "issue of "good ecological status"; but Rivers Rea and Tame likely to seek derogation as heavily modified water bodies (HMWBs)
Surface water management	Divided, semi-autonomous distribution of powers and responsibilities for surface water drainage and non-point discharges	Main causes: Historical separation of duties/powers for surface water drainage and control operations Lack of resources and commitment for control of diffuse urban runoff Priority for control and management of point discharges and CSO spillages	UK central government review of current distribution of responsibilities and powers for surface water management. Recommendations for single authority power and responsibility under Pitt Review following July 2007 floods New planning process and decision-making requiring local area planning for drainage infrastructure
Urban development planning	Historical lack of regard for urban flood plain development leading to increased risks of flooding and pollution events	Main causes: Increased housing densities both outside and within urban flood plain Increased imperviousness and runoff potential Increased pollution levels from diffuse urban runoff Reduction in infiltration and evaporation capacities; shift in	New UK planning process and decision-making frameworks Future requirement for SWMP under local, regional and national (WFD) regulations Enhanced and strengthened planning powers under PPS25 (Development and Flood Risk) guidelines to control urban development

		water balance Lack of overall stormwater management planning (SWMP)	Enhanced and improved stakeholder consultative process Future Local/Regional Liaison Groups for flood management and emergency response
BMP/SUDS Implementation	Difficulties of introducing and implementing source/site control measures and in necessary legislation for sustainable long term O&M	Main causes: Lack of and uncertainties with technical knowledge on BMP design and performance Issues under "right-to-connect" for non-sewered BMP discharges Historical definition of "sewer" and exclusion of BMP structures Issues of BMP adoption and funding in relation to long term O&M requirements Issues of exceedance flows during extreme event flows	Central government (and OFWAT) review of existing legislation relating to "sewer" designation and right-to-connect" Establishment of National SUDS Forum and Working Parties Publication of Codes of Practice for BMP adoption and O&M agreements Publication and increasing awareness of codes of practice and design guidance.

2.3 Hamburg: Threats and Uncertainties (Prepared by H Langenbach, J Eckart and W Holste)

2.3.1 Introduction

The threats and uncertainties to the further development of decentralised water management in Hamburg (looking 30 – 50 years into the future) have to be answered in co-operation with the relevant participants of the Hamburg learning alliance. The following interim comments on the future of water management serve as a basis for further discussion. The main drivers and their effects on water management are described together with a focus on the demands of storm water management and how this will develop in the future in Hamburg. To cover the different possibilities a series of different scenarios have been developed.

2.3.2 Climate change

The worldwide climate change has impacts on the local water cycle in Hamburg. The projections for Hamburg based on current regional model calculations within the time frame of 2071-2100 [Spiegel Online, 2007; Die Welt, 2006] are:

In Hamburg (and the whole of North Germany) an average warming of between 1.8 and 3.5°C is expected. For the average amount of precipitation several possible scenarios have been discussed. One scenario forecasts no significant changes of the average rainfall. Another scenario predicts a reduction of 20% of the amount of precipitation in the summer and no changes in the winter. The last scenario forecasts a shift of the average amount of precipitation from summer to winter. However all scenarios forecast an increasing number of storm events. So the danger of fluvial flooding in Hamburg will increase. Otherwise, in summer there is the danger of low water levels in the rivers (Elbe, Alster, Bille etc.) with negative impacts on water quality.

The average wind velocity in Hamburg will decline, but the number of extreme events (strong gales) will increase. In combination with the expected rise of sea level the danger of storm tides caused by the North Sea will increase.

2.3.3 Urban development

The term 'urban development' combines several drivers including population growth, settlement area, sealed up area etc. The interactions between the different elements are not autonomous and might be influenced by the decisions of urban planning and water management. Therefore the scenarios have to include future planning decisions. The following scenarios could describe possible future urban development:

Hamburg continues to have a growing population and therefore despite the converse endeavours of the municipality, the existing trend of increasing settlement areas (and with it’s sealed areas) continues. Because of the increasing competition for the limited settlement area, the land available for decentralized storm water management is restricted. Therefore several new development areas will develop storm water sewers instead of concepts of decentralized storm water management. Also in existing residential and commercial areas no additional solutions of decentralized storm water management will be realized. The resulting increased storm water runoff into the sewerage system increases the likelihood of fluvial flooding or negative impacts on the water quality of surface waters in Hamburg.

Other scenarios predict, in medium term, a stable population in Hamburg (as in the rest of Germany). Under this situation, future inner city development could lead to decreases in sealed areas and the development of additional green space in existing settlements. In new development areas as well as in existing settlements areas, decentralized storm water management concepts will be feasible. The natural water cycle can be enhanced and the problems caused by storm water runoff could be reduced.

2.3.4 Socio-economic demands

The socio-economic demands of further development contain several aspects:

An important pre-condition for the realisation of new concepts of storm water management is the acceptance of the inhabitants. Up to now the inhabitants of Hamburg have exhibited assume indifference to storm water management. The extensive introduction of these concepts throughout Hamburg could result in increasing danger of rejection by the inhabitants. In particular, technical oriented measures which do not offer the possibility of multifunctional use and which reduce the useable public and private space are likely to produce the danger of conflicts with inhabitants. Otherwise, well designed and integrated storm water management concepts could make considerable contributions.

Because of the narrow public finances of the municipality of Hamburg (HEINZ, 2006) the financial commitment for the realisation, operating and maintenance of storm water management systems will be delegated to private investors and land owners. When the control for the realisation, operating and maintenance is carried out by the municipality of Hamburg or other competent organisations (e.g. water associations) no problems are expected. Otherwise there is the danger that because of a lack of interest, finances and knowledge of private operators the function and performance of storm water management solutions are affected. Consequences could be local disturbances (e.g. flooding caused by inoperative measures) as well as general problems (e.g. preference of conventional sewerage system by the inhabitants).

2.4 Emscher Region: Stormwater Risks and Uncertainties (Prepared by H Sieker)

2.4.1 Tabulated list of stormwater risks and uncertainties

Risk and uncertainties	Event	Comments and explanations	Existing instruments and means to handle the risk and to mitigate impacts
Flooding	Significant changes or increases in the occurrence of floods and damage caused by floods.	Main causes: Depression of ground due to former mining activities Increases in imperviousness Lack of investments in the past to correct the hydraulic functioning problems which exist in the stormwater sewerage system Climate change alters storm frequency and intensity	Emscher Master Plan - Management of stormwater in the cities in the Emscher region. The Emschergenossenschaft (a cooperative) with responsibility for the main sewers, treatment plants and the water courses. The municipalities (the cooperative has 19 member cities) are responsible for drainage of public land and urban streets. The water authorities have overall responsibility for the protection of surface and ground water bodies.
Groundwater table	Rise of the groundwater table causing basement flooding and damage of building foundation	Main causes: Depression of ground due to former mining activities Rehabilitation (sealing) of (combined) sewer system, loss of drainage function Increased stormwater infiltration	Groundwater models developed by the Emschergenossenschaft to forecast the effect of sewer rehabilitation and stormwater infiltration Construction of "Infiltration-Drainage-Systems", a combination of swale infiltration and trench drainage systems to manage stormwater runoff and high groundwater tables.

Base flow	Low baseflow in rivers and creeks	Main causes: Reduced groundwater renewal due to surface sealing and stormwater drainage Large combined sewer parallel to the main rivers	Rainfall-runoff models developed by the Emschergenossenschaft to forecast the effects stormwater management.
Pollution of receiving waters by wet weather induced pollution	Pollution of water bodies due to stromwater emissions (direct discharges in separate systems and combined sewer overflows).	Main causes: Missing stormwater treatment Too much rainwater in (combined) sewer system Rainfall induced pollution pathways not properly considered/understo-od Failures in other sanitation sectors, such as in solid waste management/land use/street cleaning, etc.	Federal ordinance for stormwater systems (obligatory in Northrhine-Westphalia) Guideline for CSOs by the German Water Association (DWA A128, under revise) Emscher Master Plan Management plans following the Water Framework Directive (WFD)
Hydraulic stress	Morphological degradation of water bodies and drift of organisms (macrozoobenthos)	Main causes: Stormwater discharge without retention	Guideline BWK M3 which limits the one-year-discharge in relation to the pre-development state. Verification by rainfall-runoff models Proposed measures: disconnection, retention ponds and soil filter.
Pollution of receiving waters due to groundwater contamination (from former land use contaminated land)	Movements of groundwater mobilizing historic land-use contamination and entering the surface water (receiving) bodies and affecting water quality.	Main causes: Rising groundwater in urban areas Incomplete assessment of contaminated areas from former land-uses. Polluting effects from modern chemicals/materials synergists. Extremely high cost for rehabilitation	Groundwater models WFD implementation.

2.5 Accra: Risks and Uncertainties Affecting Urban Waters (prepared by Olufunke Cofie)

2.5.1 Drinking Water

Risk and uncertainties	Event	Comments and explanations	Existing instruments and means to handle the risk and to mitigate impacts
Water quality degradation	Inflow of wastewater at loose joints especially during low pressures	Some distribution networks are laid inside drains and are also close to sewers.	
	Network is old and damaged in some places. Rusted pipes and other supply appurtenances	The networks have not been serviced for a long time.	Currently metal pipes are being replaced with plastic pipes with eventual cessation in the use of metal pipes
	Contamination of Densu river through the dumping of waste by inhabitants along the course of the river	There is a major commercial activity at Nsawam and the traders as well as the community have dumped waste into the river.	
	Punctured and burst pipes introducing contaminants into the water supply.	Some distribution pipes connecting households are laid haphazardly across roads and streets and within drainage networks.	
	Toxic algal blooms in reservoirs due to catchment environmental degradation.	Higher risks for less protected catchments	.
	Operational failures	Low risk considering high operational standards	
	High level of emergent pathogen occurrences in water supply sources due to environmental disruption	High health impacts in the case of pathogens which are difficult to remove by conventional treatment processes (e.g.: *Cryptosporidium,Giardia*) and viruses.	

Water shortage	Flow reduction during dry seasons due to climatic change and farming activities along the banks of the Densu river	Water supply rationing and risk of search by the population for alternative unsafe water source Farming along the banks of the river have exposed it to the direct impact of the sun leading to excessive evaporation and the drying-up of the river.	Communities along the banks of the river are educated to desist from farming along the banks of the river. Water resources management law and environmental protection laws have been enacted but there are difficulties in enforcing them.
	Limited production by GWCL	Low capacity of treatment plants which cannot treat sufficient water to meet the required demand of the city	
Conflicts related to the use of water and other natural resources	Difficulties in ensuring protection of water resources and risk of water shortage or water quality degradation due to conflicting interests at the river basin scale.	Agricultural activities (including irrigation), mining and other commercial activities are common in all the catchments where the water sources are located. e. g. there is a major commercial activity at Nsawam where the Densu river crosses the Accra – Kumasi road. The Akuapem South district found it difficult to evict traders along the banks of the river. Urbanisation exists in some of the catchments.	Water resources management law and environmental protection law have been enacted to handle conflicts of water as well as other natural resources use (land, forest, etc) but there are difficulties in enforcing them. The difficulties with regard to urbanisation persist, particularly the spreading of informal settlements along the river catchment
Accidents related to natural disaster	Disruption of water supply systems due to natural hazards such as flooding, fires or landslides.		Institutions such as the National Disaster Management Organization have been established to assist during natural disasters but there is the need for further developments on prevention and mitigation planning to cope with these kinds of risks.
Failures of individual operating units due to lack of maintenance or	Pumping units, major pipelines, and other appurtenances may fail due to lack of maintenance or	The pumping units, pipelines and other appurtenances have not being replaced for a long time. Leakages are	Poor maintenance standard by the GWCL due to financial constraints, however there are a

ageing of the infrastructure and associated equipment. Leakage of water.	ageing. Leakage of water within the drinking water distribution system is still high.	rampant because of illegal connection on the distribution network.	few renovations at treatment plants and some of the pipes have been replaced. Nevertheless, a comprehensive assessment on investment needs for the modernisation of ageing systems must be performed.
Contamination or system failure induced by conflict between inhabitants of communities hosting treatment plants and the management of such plants .	Vandalism on properties at the Weija treatment plant by the Weija communities and other surrounding towns	The main cause being that the Weija dam is on their land and do not get adequate supply from GWCL. Again, parts of Weija township are not connected to the distribution network of GWCL	
Increasing costs	Increasing costs imposed by different causes (see opposite).	Possible causes: Water resources pollution leading to higher treatment costs Investment for the modernisation of ageing systems Low cost recovery Energy costs	

2.5.2 Wastewater

Risk and uncertainties	Event	Comments and explanations	Existing instruments and means to handle the risk and to mitigate impacts
Persistent and chronic pollution of receiving water	There are no interceptors. Lack of adequate functioning waste water treatment plants	Main causes may be lack of investment for installing interceptor sewers associated with high costs; political and social difficulties associated with removing informal settlements from riparian areas thus posing problems for the building of interceptors. Most of the treatment plants are not functioning at all and wastewater is discharged untreated into water bodies.	.
	Lack of investments to increase WWTP (wastewater treatment plants) capacity	Financial support from the Municipal Authority has not been forthcoming. The three treatment plants in the Accra metropolis are presently broken down	
	Operational failure or poor operation of WWTP leading to poor treatment performance	Main causes: Poor operational qualifications; Technical problems such as lack of spare parts Poor management	The government rehabilitated one of the broken down treatment plants. The Municipal Assembly have in their plans to rehabilitate the treatment plants and if possible seek financial assistance from international donors, NGO's, and other private organization to build a bigger treatment plant.

	WWTP not equipped to remove nutrients (nitrogen and phosphorous) and emerging pollutants such as endocrine-disrupting chemicals.	Emerging polluting chemicals are not usually monitored in Accra. Awareness of the problem is not wide.	
Accidents related to natural disaster	Disruption of wastewater systems due to natural hazards like flooding or landslides.	Accra has been experiencing perennial flooding over the years.	
Failures of operating units due to lack of maintenance or ageing of infrastructure and associated equipment.	The treatment plants at Teshie, Achimota and Lavender Hill near the Korle Lagoon are not operating due to lack of maintenance or ageing.		Maintenance and operational standards are low due to financial constraints, institutional problems and poor management The Accra sewerage system is in very deplorable state. Concerns have been raised about the system. Blocked and leaking sewers have been rehabilitated.
Increasing costs	Increasing costs imposed by different causes (see opposite).	Possible causes: High operational cost because workers have to be supplied with sanitary products and safety equipment. Energy costs	
Uncertainties relating to final sludge disposal	Untreated sludge from public toilets, domestic house is discharged into the sea or ocean.	The treatment plants are not working properly and the sea or ocean appears to be the only alternative place to dispose off the sludge.	

2.5.3 Stormwater

Risk and uncertainties	Event	Comments and explanations	Existing instruments and means to handle the risk and to mitigate impacts
Flooding	Significant changes or increases in the occurrence of floods and damage caused by floods.	Main causes: Increases in imperviousness due to urbanisation Drains of inadequate capacity Siltation of drains reducing their capacities Poor solid waste management Lack of investments to correct the present hydraulic functioning problems which exist in the stormwater sewerage system New developments (legal and illegal) in flood prone areas Lack of proper maintenance Climate change alters storm frequency and intensity	Difficulties persist in handling urbanisation, particularly the spreading of informal settlements. Urban development plans and urban land use legislation do not properly consider impacts of urbanisation on water and other natural resources in an effective way. There have been few demolition exercises in flood prone areas to deter people from developing in such areas. The Municipal Assembly organized clean-up activities to desilt drains.
Pollution of receiving waters by wet weather diffuse pollution	Significant changes or even increases in the wet weather diffuse pollution. Wastewater (grey water and black water) are discharged into storm water drains. Solid waste is dumped into storm water drains.	Main causes: Increases in imperviousness due to urbanisation Failure in wastewater management. Slum communities do not have toilet facilities and they use the	High pollution of receiving waters by wastewater outflows masks effects of diffuse pollution. Difficulties persist in handling urbanisation, particularly the spreading of informal settlements. Difficulties in controlling illicit solid waste disposal on land

		drains as place of convenience. Lack of proper maintenance Wet weather pollution not properly considered Failures in other sanitation sectors, as in solid waste management.	and directly to water bodies. Urban development plans and urban land use legislation do not properly consider impacts of urbanisation on water and other natural resources in an effective way.

Persistent and chronic pollution of receiving water	There has not been planned implementation of interceptors.	Main causes may be lack of investment for installing interceptor sewers associated with high costs; political and social difficulties associated with removing informal settlements from riparian areas, thus posing problems for the building of interceptors.	Stormwater flow into receiving water bodies untreated. The municipal Assembly are planning on how to minimize the risk of polluting such water bodies
	Persistence of illicit connections between stormwater and wastewater sewerage systems.	Main causes: The sewerage system at some parts has broken down and therefore flows into the stormwater system. .	
	Lack of investments to increase WWTP capacity	Financial support from the Municipal Authority has not been forthcoming. The three treatment plants in the Accra metropolis are broken down.	
	Operational failure or poor operation of WWTP leading to poor treatment performance	The sewers in Accra are not functioning properly and therefore uncommon to see	
	WWTP not equipped to remove nutrients (nitrogen and phosphorous) and emerging polluters as endocrine-disrupting chemicals.	Emerging polluting chemicals are not usually monitored in Accra Awareness of the problem is not wide.	

Risks associated to the use of Best Management Practices (BMP's)	Failures on flooding control Health risks, soil pollution associated to the use of BMP devices Reduced public acceptance of BMP	Main causes: Lack of maintenance Technology update is not sufficient Persistence in using oversimplified design methods for source control and other BMP devices Conservative nature of the people Failures in controlling urbanisation and diffuse pollution sources (including erosion processes at the catchment scale) Ignorance or not enough concern regarding wet weather diffuse pollution and its impacts on BMP	There are strategic plans by the government to manage storm water in order to reduce the effects of flooding. The Municipal Assembly is investing in environmental education and dissemination of urban drainage new technologies for a large public awareness, including river restoration and BMP. The SWITCH project research and demonstration activities will certainly contribute to reduce the mentioned risks. Other advocacy groups such as Friends of the Earth and Water Bodies are helping in this direction.
Accidents related to natural disaster	Disruption of stormwater systems due to natural hazards like flooding or landslides.	Flooding is rampant in Accra because of drains of inadequate capacity, siltation of drains, illegal development in flood prone areas, etc.	Government is expanding the drainage system in Accra. Also providing new drainage facilities.
Failures of system units due to lack of maintenance or ageing of infrastructure and associated equipment.	Key units (e.g.: major culvert channels) may fail due to lack of maintenance or ageing: structural rupture due to abrasion or foundation problems.	The drainage systems have been turned into refuse dumps and are choked with solid waste.	Maintenance and operational standards are low. The government is now upgrading the drainage system in Accra. The Municipal Assembly in their quarterly clean-up activities desilt blocked drains..
Increasing costs	Increasing costs imposed by different causes see opposite).	Possible causes: Investment for the modernisation of ageing systems Maintenance costs Operational costs:	The Municipal Assembly sought assistance from private entities to help in cash and kind in carrying out the clean-up activities,

		desilting of blocked drains. Costs imposed by vandalism	maintenance, etc.
System failure induced by vandalism.	Vandalism leading to system disruption	Some people blocked the drains with sand as means to drive across the drain. Some people also store the perforated metal slabs on drains	

3 A Risk Assessment Template Framework (Prepared by J B Ellis and L Scholes)

3.1 Introduction

It is clear from the specific threats and uncertainties to stormwater control identified by Learning Alliance (LA) representatives in Accra, Belo Horizonte, Birmingham and Hamburg (the SWITCH demonstration cities which contributed information to the first part of this Deliverable) and the Emscher region, that there are a wide range of factors which may result in "system failure". These identified factors encompass a range of engineering, scientific, environmental, hydrological, social, planning and financial aspects of stormwater control.

System failure within this context generally refers to a particular component or aspect either not performing or having the outcome which was intended. However, system failure can also be interpreted in a broader sense as the progressive development and identification of defects and deficiencies (or threats) rather than a single catastrophic failure, although both types of system failure might occur in relation to, for example, an identified uncertainty such as the impacts of climate change. Threats can therefore be regarded as events, processes, properties, activities or actions that can lead to or exploit a vulnerability (weakness or hazard), such that they can undermine the performance integrity of a stormwater management asset, system component or strategy.

3.2 Risk Assessment

Clearly the threats and uncertainties identified within each city need to be further assessed (either quantitatively or qualitatively) in order to enable risks to the current stormwater control systems (the 'identified body' requiring protection within this Task) to be identified, prioritised and managed within any stormwater design or strategic policy approach. This risk assessment process can be achieved by:

- Identifying modes of system failure (i.e. threats and uncertainties)
- Assessing the consequences (severity) of such a failure occurring
- Assessing the likelihood or probability of an identified failure occurring (i.e. the relative vulnerability to failure)

Both the latter two assessment stages (i.e. the 2nd and 3rd bullet points set out above) are typically applied to an information or data set using an appropriate relative scale e.g. 1 to 5, where the numeric values have been pre-defined to represent either a comparatively escalating severity of consequence or likelihood of occurrence (see Figure 13). Such a risk assessment approach is well recognised and accepted (e.g. CRAMM, 2003; DEFRA, 2004; USDA, 2003; Renn and Graham, 2005) and has the advantage that it enables the overall assessment procedure to be more objective as well as allowing aspects to be handled that are not strictly governed by explicit numeric engineering or environmental criteria.

In terms of UK practice, the risk assessment approach is consistent with current flood risk guidance (DETR, 2001) and the Environment Agency of England and Wales (EA) accreditation checklist for the evaluation of sustainable drainage systems. In

these terms, the risk assessment approach essentially represents a technical appraisal exercise based on identification of critical failure processes and a technical evaluation of the failure likelihood associated with these processes in both time and space. Although the use of technical or quantitative data is preferred, this approach recognises that neither the impact nor the likelihood of an identified event occurring can always be readily quantified, if at all. Hence, this methodology also supports the use of more qualitative data and the use of ‘expert judgement’ which, in the absence of field or literature data, is recognised as a pragmatic approach to managing the need to make decisions in the face of uncertainty.

3.3 Risk Rating

The risk assessment methodology described above utilises a generic hazard and operability (HAZOP) type approach to identify causes and effects of system failure in combination with data/information available on the likelihood of an identified risk occurring. Once this information has been compiled, it can then be used to prioritise the identified risks, effectively developing a ranked order of risks based on a combination of the severity of a particular risk occurring together with its likelihood of occurrence. A common approach to the combination of these two sets of data is the development of a matrix which enables both sets of data to be viewed simultaneously in a format which readily supports the application of an initial approach to risk rating such as that developed by the Environment Agency for England and Wales (EA, undated) based on an initial 5 point scale, with subsequent combined values categorised as low, medium or high in relation to scores of 1-5, 6-10 and 12-25, respectively (see Figure 13).

		Severity of consequence				
		Insignificant (1)	Minor (2)	Significant (3)	Damaging (4)	Critical (5)
Likelihood of occurrence	Very Low (1)	1	2	3	4	5
	Low (2)	2	4	6	8	10
	Medium (3)	3	6	9	12	15
	High (4)	4	8	12	16	20
	Very High (5)	5	10	15	20	25

Interpretation of overall risk: High = 12-25 (red), Medium = 6-11 (yellow), Low = 1-5 (green)

Figure 13 Matrix Used to Evaluate the Level of Risk

This type of 3-level interpretation of risk scores is commonly described as a ‘traffic light’ approach, with the colours red, yellow and green being used to support users in differentiating between risk levels. The development of a risk assessment matrix, and the subsequent risk rating procedure, can thus provide a framework to facilitate decision-making processes based on an initial technical risk assessment, and it is the development of such a matrix for the demonstration cities participating in this task which is the aim of this current deliverable. This matrix will then be used to inform LA discussions related to the development of risk management strategies, as described in Section 3.4 below.

3.4 Risk Management

One objective of the risk assessment and risk ranking phases is to provide a robust and transparent knowledge base for the subsequent risk management phase where stakeholders can discuss and debate whether or not identified risks are acceptable and, if not, how they can be reduced, contained or managed.

Figure 14 illustrates this overall risk management process which, following the description of the system under consideration, proceeds from the identification of threats and uncertainties to the determination of risk levels and then to management decisions regarding implementation. The methodology is essentially based on identifying the vulnerability (threats/weaknesses) of system components and assessing the frequency and consequences of likely failure with a focus on “high-level” stormwater aspects and issues.

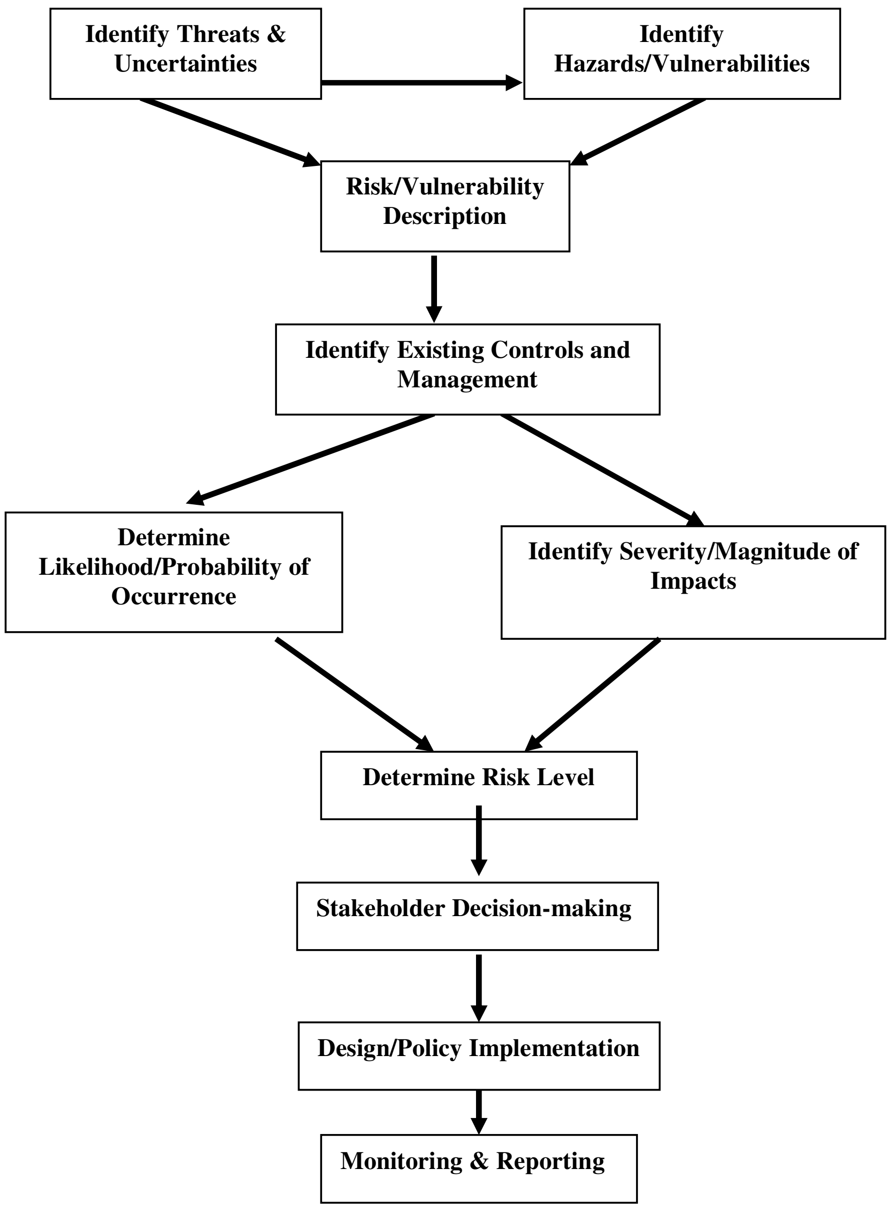


Figure 14 Risk Assessment Process Flow Chart

3.5 Guidelines to Completing a Risk Assessment

To ensure clarity, it is essential that, in completing each stage of the risk assessment and ranking procedure, hazards are unambiguously and precisely identified and that classifications of impacts and frequency of occurrence are supported by brief statements justifying the allocation of one value in comparison to another. This process may be to some extent iterative, with the threats and uncertainties originally identified by LAs requiring refinement to more precisely identify a particular aspect of an identified threat which is being considered. For example, the threat of 'increased frequency of storms' could require further refinement if both the increased frequency of increased intensity storms and the increased frequency of storms having no change in intensity were of interest.

3.6 Assessing the Consequences of a System Failure Occurring

In assessing the potential impact of an identified failure occurring, the answer is sought to the question "what will happen if the system or system component fails to act/serve as intended?" A pre-requisite to answering this question is a knowledge or statement of the expected level of performance which may be clear and unambiguous for some aspects of the stormwater management system, e.g. a swale designed to protect a highway from flooding by a storm event of up to a 30 year return period, and the consequences of such a failure can be estimated in terms of the costs (direct and indirect) incurred as a result of sub-flooding, if appropriate. The failure of a wetland to achieve a specified pollutant removal level e.g. annual average concentration (mg/l) per annum target, can similarly be quantified in terms of the costs required to increase the retention capacity combined, perhaps, with the costs of correcting downstream damage or the enhanced treatment required to re-establish receiving water standards. In other cases, the performance objective may be more ambiguous e.g. in providing an amenity function for a particular stormwater control device it may only be possible to express values in relative terms e.g. allocations of high, medium or low values. However, a grading level for the consequences of system failure can be constructed which can support classifications based on either absolute or relative estimations.

In relation to the development of a SWITCH risk rating matrix, Table 3 provides guidance which LAs can use to support the consistent assessment of the consequences of a particular identified threat occurring. Example descriptors given in Table 3 in relation to a particular level of consequence are not meant to be exhaustive, but to generically illustrate the types of escalating impact which could be associated with the allocation of a particular categorisation. The numeric values given to each consequence grading are not necessarily intended to reflect a linear escalating scale of consequence or severity, such that a value of 4 is twice as severe as that allocated a value of 2. The numeric scaling may be linear but could also be applied in either a positive or negative exponential manner. Users should be aware of the general relationship between the numeric values being allocated to specific gradings and be prepared to justify the scaling used.

Table 3 Guide to Assessing the Level of Consequence of an Identified Threat/Uncertainty Occurring with the SWITCH Stormwater Matrix

Level of consequence (Grading)	Example descriptors for relative grading	Numeric value associated with grading level
Very high consequence	Critical: complete system compromise; unacceptable under any circumstances; catastrophic; loss of life; extreme cost	5
High consequence	Damaging: Substantial failure to meet regulatory requirement; substantial impact such as flooding of properties; temporary loss; considerable cost	4
Medium consequence	Significant: moderate impact; potential to cause political, administrative and/or financial strain or pressure; tangible damage	3
Low consequence	Minor: minimum impact; some additional costs/efforts required	2
Very low consequence	Insignificant: negligible or no impact felt	1

3.7 Assessing the Likelihood of an Identified Failure Occurring

In assessing the likelihood of an identified failure occurring, the answer is sought to the question "how often is this particular feature or component likely to fail?" As with the guidance outlined above (assessing the consequence of a failure occurring), a pre-requisite to assessing the likelihood of a failure to occur is knowledge of the expected or targeted level of performance of the stormwater management system or component. This question might be answered from available published data, historic evidence, expert judgement or modelling etc. For example, hydrologic modelling of a swale designed to contain the 1: 30 year runoff event would be expected to fail each year with a probability of 0.033. This might then be graded as being of low significance as it clearly meets the desired criteria or standard of protection. However, if the channel only achieves in practice a 5 year level of protection, then the probability of failure in any one year rises to a 1:5 frequency (or a probability level of 0.20) and this might then be regarded as being of at least medium significance. In the absence of data, predictive models or where there is a large degree of associated uncertainty, the use of expert judgment is recommended as a pragmatic approach.

With regard to the SWITCH stormwater control risk rating matrix, Table 4 provides guidance which LAs can use to support the consistent assessment of the likelihood of a particular identified threat or failure occurring. As in Section 3.6 above, the generic example descriptions given in Table 4 only describe how a range of 'likelihood of occurrence' data might be comparatively graded. As with the scaling ratio applied for consequence, the numeric values assigned to the gradings for 'likelihood of occurrence' can be linear or non-linear in distribution.

Table 4 Guide to Identifying the Likelihood of Occurrence of an Identified Threat/Uncertainty with the SWITCH Stormwater Matrix

Likelihood of occurrence (Grading)	Possible descriptors for relative grading	Numeric value associated with grading level
Very high probability	Almost certain to fail to meet required criteria during anticipated design life; failure during every wet weather event	5
High probability	High likelihood to fail to meet required standards; frequently fails during storm events	4
Medium probability	May not meet required standards	3
Low probability	Normally meet required standards throughout design life	2
Very low probability	Unlikely to fail during lifespan	1

3.8 Risk Rating

The level of risk can be assessed by combining information generated on likelihood of occurrence (Table 4) with information developed on the level of consequence (Table 3). One way to do this is to convert the relative gradings assigned following the guidance given in Sections 3.1 and 3.2 and converting these allocations into numeric values 1 to 5 as shown in Tables 3 and 4. Multiplying these values together generates a 'risk score'. The resulting overall level of risk associated with a particular threat or uncertainty can then be interpreted using a risk rating scheme such as that developed by the EA and shown in Figure 13. Thus combining the likelihood of occurrence with the severity of the consequences can be used as a basis for visually illustrating the level of risk posed by each system component/aspect. This approach can then provide a useful contribution to subsequent stakeholder discussions and decision-making within the development of a risk management strategy.

A risk rating approach, such as that outlined above, is essentially concerned with the prioritisation of risk failure and as a procedure to support subsequent management policy and control strategies; the process of weighing policy alternatives in consultation with interested stakeholders and in the selection of appropriate and acceptable prevention and control options. Figure 15 illustrates the use of probability of occurrence (Y-axis) and consequence (X-axis) for characterising management categories of risk in terms of tolerable and acceptable risk levels. An acceptable level refers to risk levels which are deemed so low that any mitigation measures are considered unnecessary. Tolerable levels refer to risks which require mitigation but which are deemed to be beneficial and reasonable.

However, even where absolute values can be assigned to derive the matrix scores, the methodological approach is still susceptible to valued judgements, and the scientific appraisal of failure consequences can frequently reflect a technocratic assessment of system/component condition. Accepting this caveat, the final prioritisation procedure does allow the methodology to be opened up to much wider decision-making groups and has the advantage of facilitating stakeholder engagement. The risk assessment procedure can thus be considered as providing the basic steps in achieving a more sustainable and integrated management decision-making tool.

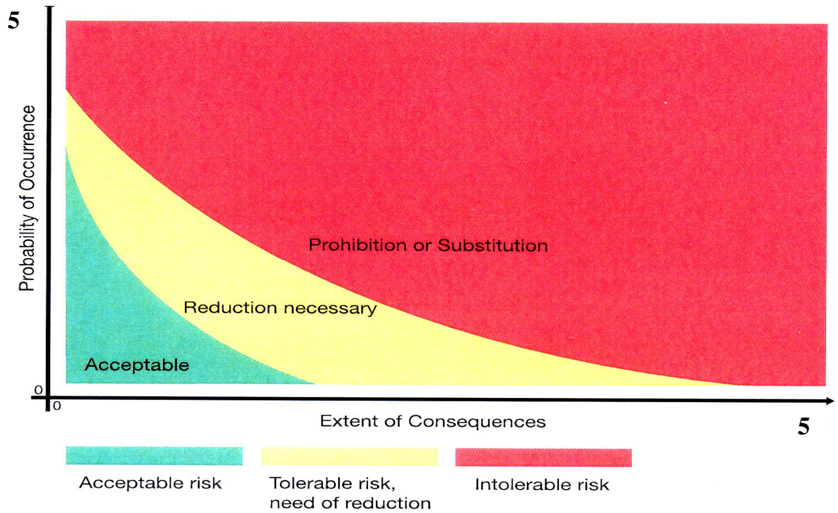


Figure 15 Risk Characterisation Approach

As discussed in Section 3.2, given that many of the uncertainty criteria or component aspects will not be readily quantified in comparable or absolute terms, the risk assessment procedure may often essentially be an exercise in the use of expert judgement. Confirming the results of risk assessment can be very difficult, particularly where cause-effect relationships are hard to establish or where they might be unstable or difficult to understand. Thus although providing a "standardised" methodological procedure, the accuracy and objectivity of the numbers appearing in the prioritisation matrix are somewhat spurious. A sensitivity analysis should therefore be performed to examine the variability in risk outcomes arising from variations in stakeholder preferences and priorities which can then be used to test the robustness and reproducibility of the procedure.

Risk assessment will always present challenges of complexity, uncertainty and ambiguity and for successful risk management it is important that the implications of these challenges are made transparent during the methodological phases. A further issue arises from risk levels/impacts which are deemed by the analysis to be "acceptable" but for which no risk reduction or mitigation measures are considered. For uncertain and ambiguous risk problems, a "discourse-based" stakeholder strategy can be deemed to be an appropriate approach to create tolerance and mutual understanding and acceptance of conflicting views and values. Such discourse will also facilitate and support risk communication to underpin and rationalise the risk assessment decisions. However, it is also recognised that in the final analysis, this approach might be unable to do anything about the identified risks, which would then need to be addressed in some other way.

A final issue of the risk appraisal methodology relates to the assessment of organisational capacities in relation to stormwater management. Paquet (2001) has suggested that it is useful to distinguish between assets, skills and capabilities when considering institutional capabilities. Assets form the social capital for risk management in the form of knowledge bases and structural conditions for effective management. Skills refer to the quality of institution and staff performance in exploring, predicting and dealing with emerging risks. Capabilities describe the

institutional framework necessary to translate assets and skills into successful strategic policy.

It is also recognised that many issues within risk assessment are dynamic and that as change takes place, the level of e.g. vulnerability will also change with impacts on subsequent risk assessment calculations. In this respect, a less simplistic (though harder to apply) approach to risk assessment could be:

RISK = Pb *(1 – Pe) * C

where Pb = likelihood/probability of a hazard occurring (or vulnerability to a hazard)
Pe = system effectiveness/efficiency
(1 – Pe) = the "success" of hazard or vulnerability
C = the consequence or impact of an "asset" loss

Through the use of the "1-Pe" term, this equation subsumes a consideration of the sensitivity or susceptibility of the threat in terms of the effectiveness of the resistance to the threat as well as the potential vulnerability. An alternative basic risk formulation, which more specifically evaluates the effectiveness of resisting or mitigating measures, is expressed as follows:

RISK = (Vulnerability x Threat x Impact) / Mitigating Measures

3.9 Case Study Example Using Information from Belo Horizonte

As set out in Section 3.2, the process of risk assessment involves thee stages, each of which are discussed below within the context of their application to develop a SWITCH stormwater control risk matrix:

3.9.1 Identification of modes of city-specific threats/uncertainties to stormwater control and their impact

This part of the process has already been completed by representative of the LAs within Accra, Belo Horizonte, Birmingham and Hamburg as well as the Emscher region with a view to both current threats and those which may be of concern within the 'City of the Future' (i.e. in 25- 30 years time). These reports are given in Sections 2.1 to 2.5 above and are also available on the SWITCH website. As an example, three of the threats to the stormwater management system identified by the Belo Horizonte LA are listed within the first column of Table 5.

3.9.2 Assessing the level of consequence of an identified event occurring

The second column in Table 5, entitled 'level of consequence', is subdivided in to 4 sub-columns. Using the guidance set out in Table 3, the level of consequence for each identified threat has been graded, together with a brief explanatory note summarising why a particular grade was applied, both in relation to current conditions (defined as 'within the next 5 years') and within the 'City of the future' (defined as within the next 25-30 years). Such gradings can be developed and applied on the basis of prior knowledge of the system, expert opinion, literature and/or field data and questionnaire analysis.

3.9.3 Identifying the likelihood of events occurring

Using the guidance set out in Table 4, the likelihood of identified threats taking place in relation to the two specified time frames (i.e. within the next 5 years (current conditions) and in the 'City of the Future' (a time scale of 25-30 years time)) have been graded, and this information has been entered within the sub-columns of column 3 of Table 5. Grading values can be generated using a prior working knowledge of the system, expert judgement, literature and/or field data and questionnaire analysis etc.

3.9.4 Calculation of risk scores, risk rating and interpretation of risk levels

Having completed the above sections, the numeric values allocated to the two data sets (level of consequence and likelihood of occurrence) within each identified timeframe may be multiplied together to give a single numeric value termed the 'risk score' (see sub-columns of the final column of Table 5).

These risk scores can be converted into a level of risk by, for example, using the EA's evaluation of the level of risk approach set out in Figure 13. Using these allocations, the level of risk identified within Belo Horizonte are graded as high, medium or low, with these allocations entered in the final column of the risk matrix after each risk score (Table 5).

Having completed the risk assessment and rating stages outlined above, the developed risk matrices can form an important contribution to stakeholder discussion of risk management strategies supporting the incorporation of social, technical and economic factors in a meaningful and transparent way.

Table 5 SWITCH Stormwater Risk Matrix for Selected Threats Identified within Belo Horizonte

Identified threat	Level of consequence				Likelihood of occurrence				Risk score	
	Within the next 5 yrs	Score	In 25 -30 yrs time	Score	Within the next 5 yrs	Score	In 25 -30 yrs time	Score	Within the next 5 yrs	In 25 -30 yrs time
Increase in occurrence of flooding	Very high; area prone to floods resulting in loss of life	5	On-going work to relocate families from high-risk areas	2	Medium: increases predicted but degree of certainty unclear	3	High: major increases predicted (but level of certainty)	4	15 Level of risk = high	8 Level of risk = medium
Increases in wet weather diffuse pollution	High; river water used for washing and recreation	4	Low; planned enhancement of drainage systems will reduce e.g. CSOs	2	Low; activities within catchment may change	2	Medium; whilst reduction in CSOs etc are predicted, increases in personal earnings may result in increased car ownership	3	8 Level of risk = medium	6 Level of risk = medium
Operational failure of WWTP	Medium; initial damage but skilled workers available	3	Planned improvements in technology reduce the impact of failures	2	Planned SWM investments may not be fully implemented within next 5 yrs	4	SWM current focus of investment so future performance anticipated to be high	2	12 Level of risk = high	4 Level of risk = low

4 Examples of Risk Assessment and Rating for Demonstration Cities

4.1 Birmingham and the Eastside Development Area (Prepared by J B Ellis and B Shutes)

4.1.1 The Development Area

The Eastside development area represents a major urban regeneration initiative within Birmingham city centre and covers an area of 170 hectares with 17 separate development land parcels. It is located in the heart of the city centre lying immediately to the east of the central business district. The location within the UK of the Eastside development area and the associated River Rea catchment are identified in Appendix 1. Figure 16 shows the boundaries of the proposed Eastside development area in more detail with the River Rea running in a north easterly direction to join the River Tame near Junction 6 on the M6 motorway. The river has a number of culverted and bridged sections and also passes beneath the Warwick & Birmingham Canal and as indicated in Figure 17 lies in a flood plain having fairly steep side slopes to the north west and south east. The side slopes and flood plain have been extensively built over with the prevailing historical land use as shown in Figure 18 being industrial/commercial premises, offices, warehouses, loading yards as well as service and access roads. The intense built-up nature of the development area is visible from the Google Earth satellite photograph in Figure 19 although much of the development has become derelict over time. The intensity of the built-up area means that there is a high impermeable surface area contributing to surface water runoff with very short times of concentration and the Rea channel has been subject to severe flooding incidents in the historic past. Figure 20 illustrates the surface water drainage which discharges either directly to the Rea or enters the combined sewer system.

The Eastside initiative intends to promote a new city quarter based on the themes of learning, technology and industrial heritage. In addition, it will accommodate 3500 new dwellings as well as a range of business premises, a city park and other public open spaces. Figure 21 shows the proposed developments within the area with the major City Park shown in dark green lying to the north of the Curzon Park/Gateway developments above the east-west railway line out of Birmingham New Street station. The figure also shows both the main surface water (blue) and foul water (red) sewer systems within the development area. In the southern section of Eastside lying below the railway line, the separate surface water sewers are principally directed to outfalls into the River Rea as confirmed in Figure 20.

4.1.2 The River Rea

4.1.2.1 Surface Drainage and River Regime

Figure 16 shows the location of the open and culverted sections of the River Rea within the Digbeth and Nechelles districts of the Eastside development area. The river here lies in a deep 5 m x 12 m wide brick-lined channel, flowing at a low gradient of less than 1:400 and under dry weather flow conditions the surface water occupies some 5 – 7 m of the cross-section leaving exposed marginal, brick-lined side berms. Large sections of the channel are culverted and/or bridged prior to its

downstream confluence with the River Tame at the M6 Gravelly Hill (Junction 6) interchange.

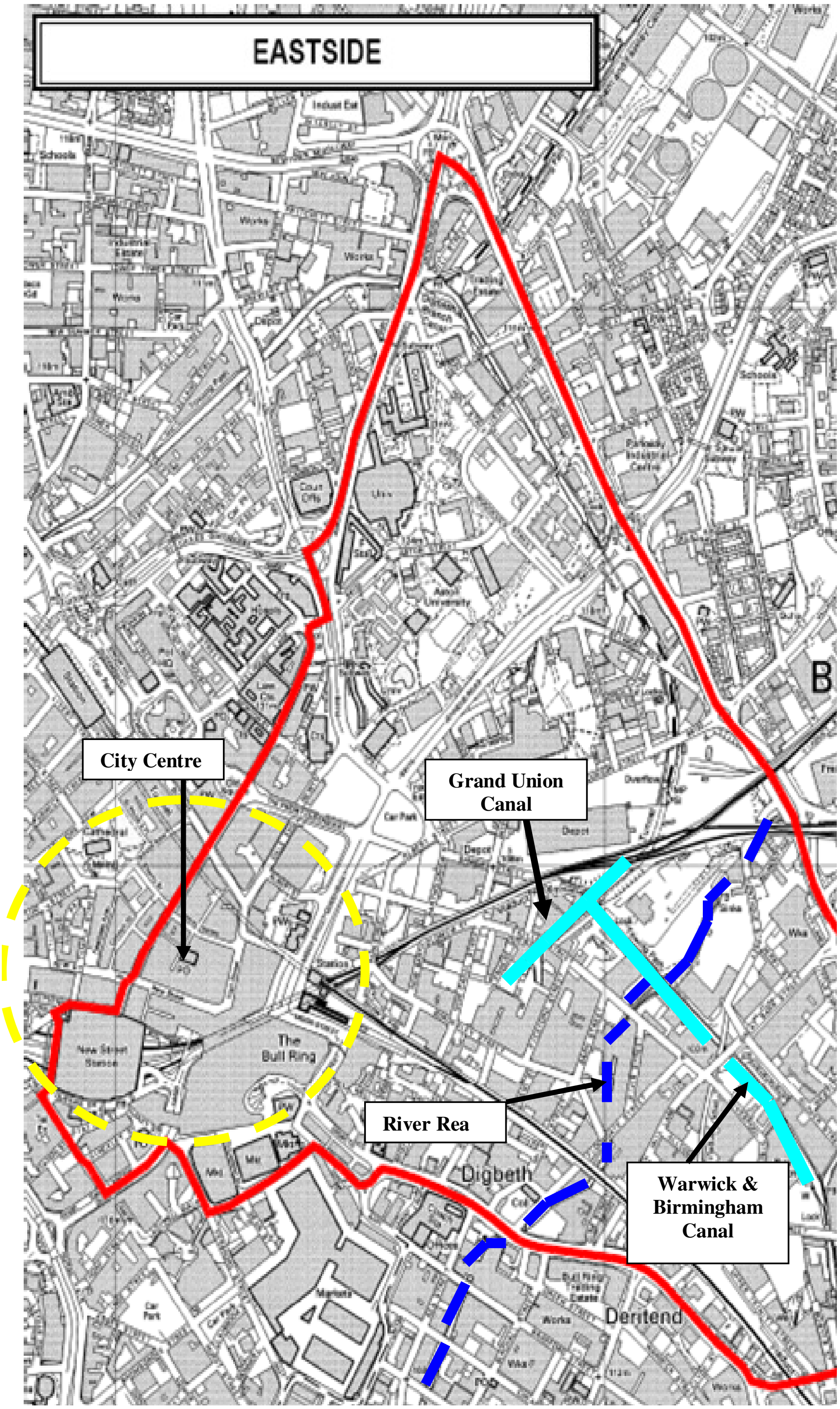


Figure 16 The Eastside Development Area

The numbers on the figure refer to the photographs of the river taken at various points in the Eastside area, all of which emphasise the nature of the heavily engineered channel. The arrows associated with the numbers indicate the direction

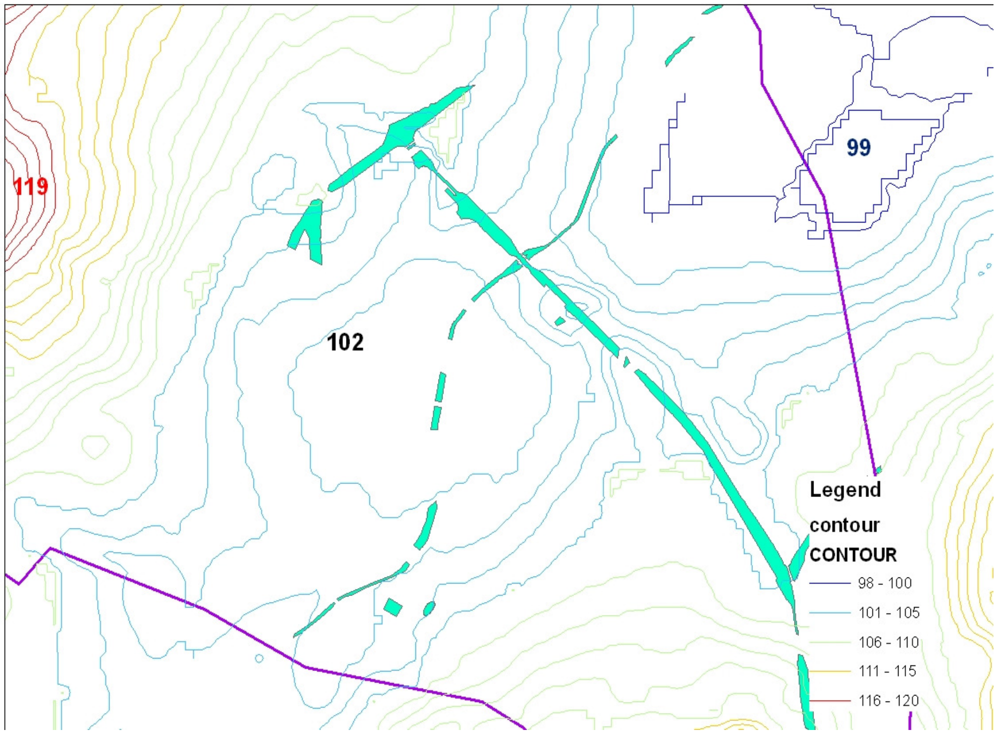


Figure 17 The topography of the Rea Channel and Flood Plain.

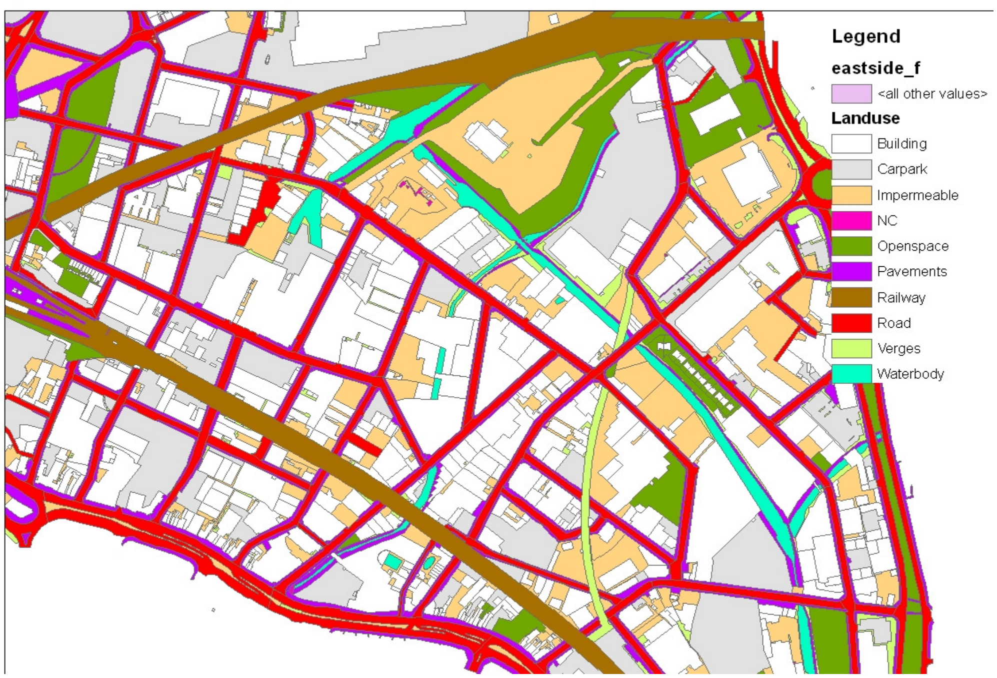


Figure 18 Historic urban land uses within Eastside.

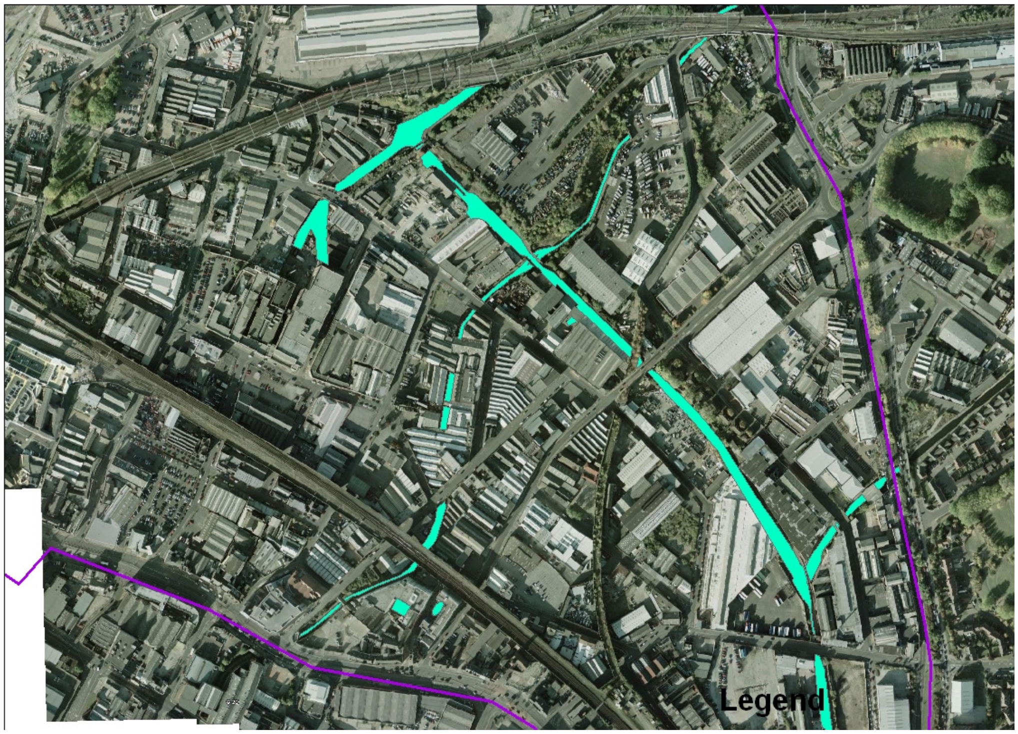


Figure 19 The intensely built-up nature of the Lower Rea Valley.

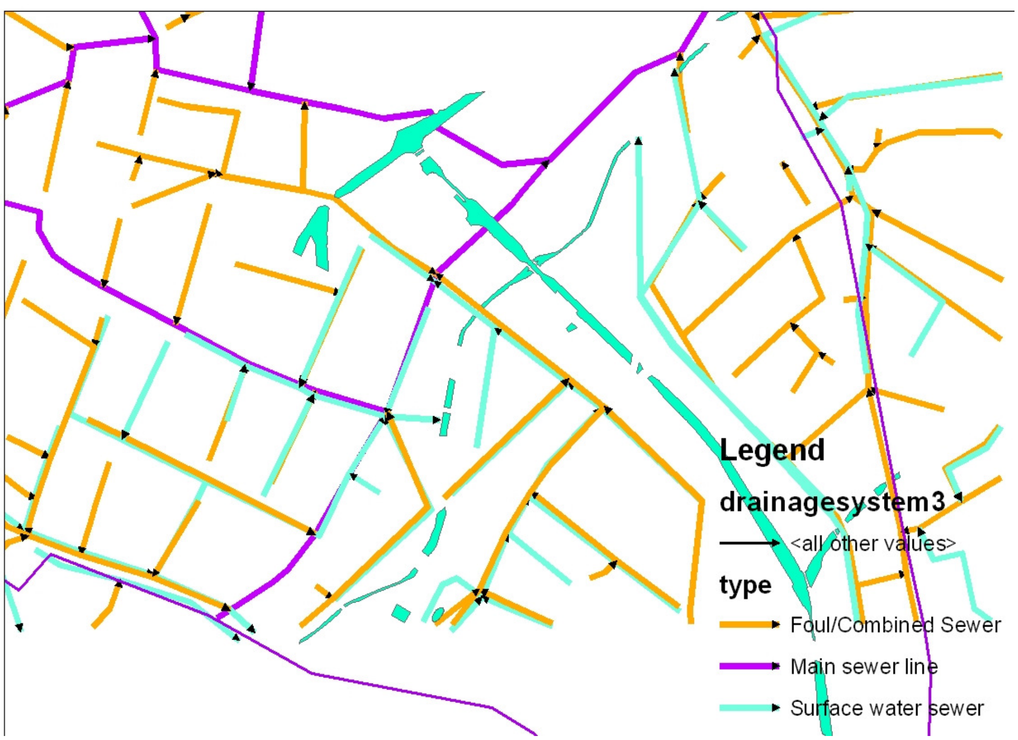


Figure 20 The drainage system within the Lower Rea Valley.

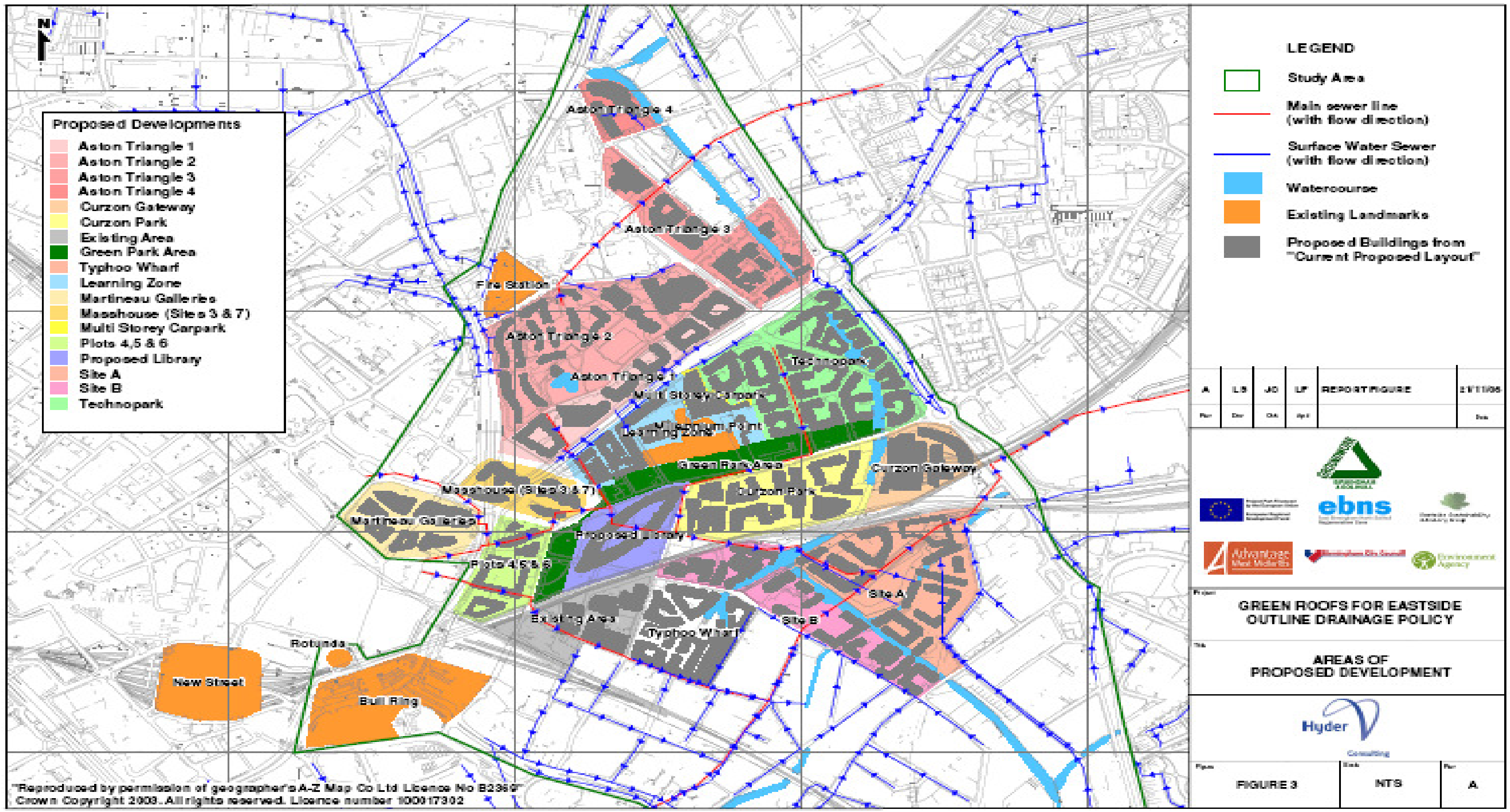


Figure 21 The Eastside Development Area and sewer drainage. (From: Hyder Consulting, 2003)

(upstream or downstream) in which the photographs were taken. The channelisation was originally implemented in the south eastern Digbeth area during the 1890s following serious flooding in 1852, with further culverting downstream occurring in the 1930s following substantial further flooding. The photographs clearly exhibit the over-designed form of the urban channel within this Eastside development area which has resulted in no recorded incidents of flooding since the construction of the final 1930s engineering works. This would therefore suggest that there is currently minimal risk of out-of-channel flooding.

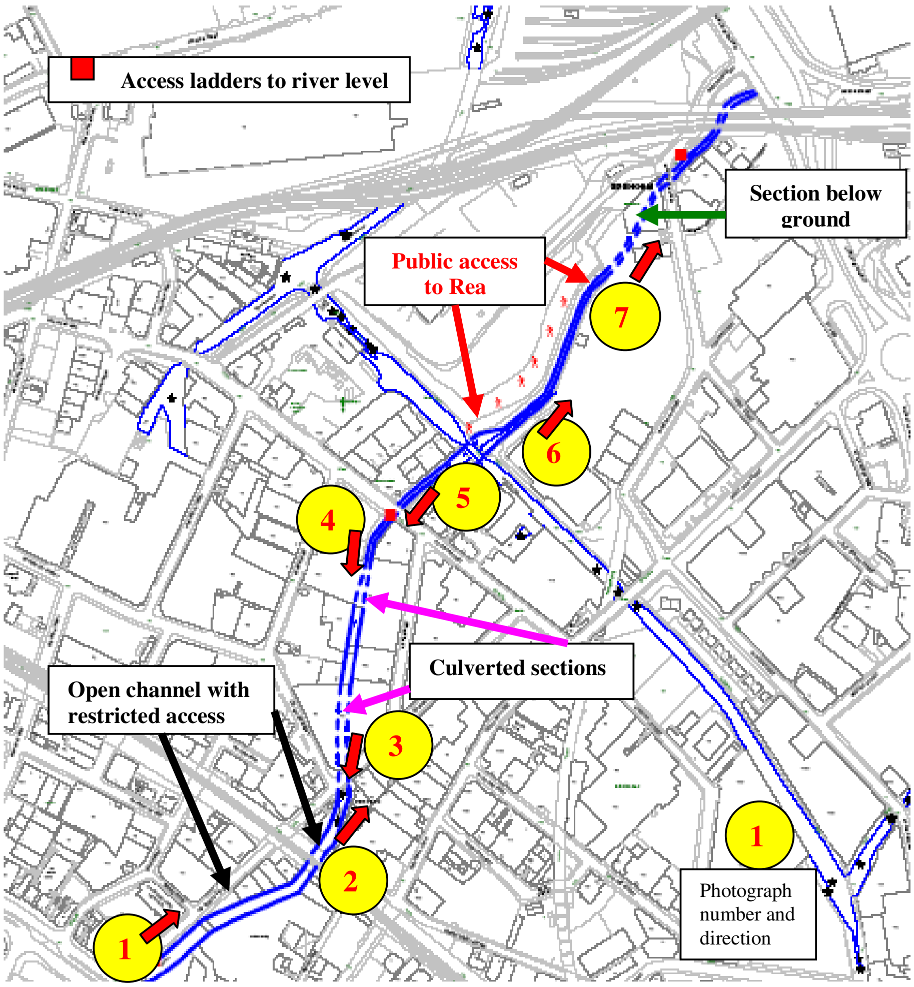


Figure 22 The River Rea in the Eastside Development Area

The Hyder Consulting (2003) report for Birmingham City Council notes that the channel is designed to contain a 1:80 flooding return event, but other personal communication (Chatterton, 2008) has suggested that the channel may be capable of providing a level of protection exceeding the 1:100 RI event. This higher service level may reflect the effect of adjoining building and roadside walls which extend the design height of the channel wall and thus provide additional flood protection. The level of existing flood risk is therefore much less than indicated by the official Environment Agency (EA) flood risk maps, which would suggest that some sections of the river would be subject to significant flooding at return periods less than 1:80

(Figure 23). The channel is also shown as lying within Flood Zone 2 in the BCC Supplementary Planning Document (SPD), *The Birmingham Plan* (Dutton, 2007).

Photograph 1 Rea Channel at the junction of Deritend High Street and Floodgate Street.

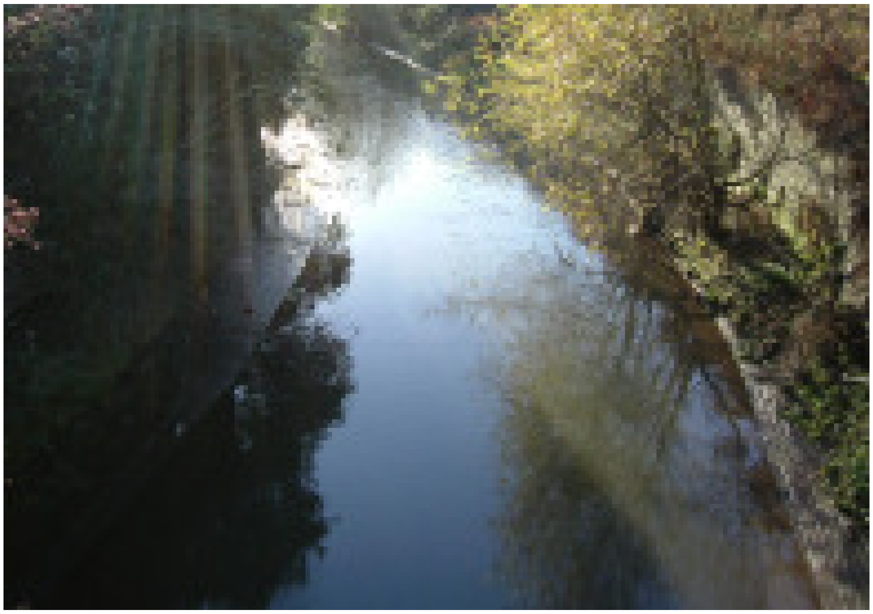
Photograph 2 The Rea channel near Floodgate Street railway viaduct.


Photograph 3 The Rea channel at river level in Deritend looking upstream towards the railway viaduct.

Photograph 4 River Rea viewed at access ladder near Fazely Street

Photograph 5 45m Culvert taking River Rea under Fazeley Street

Photograph 6 The Rea channel at Canal Junction



Photograph 7 River Rea at end of walkway above Canal Junction.

The nearest EA gauging station is approximately 2 km upstream at Calthorpe Park where the contributing and totally urbanised catchment area is 74.3 km^2 (see Appendix 2). Given the extensive impermeable surfaces associated with this urbanisation, the lag time between rainfall and peak flow is short producing a typical flashy response to storm events with a steep rising limb occurring on the storm hydrograph. As indicated in Figure 24, during wet weather flows, the rising limb can increase very rapidly with the event of 26/27 January 2002 increasing from 2 m^3/s to over 50 m^3/s within the space of 60 minutes. As indicated from the Calthorpe Park gauging data shown in Appendix 1, the average mean daily flow is 0.8 m^3/s although peak mean daily flows can reach 5 m^3/s. The EA Hiflows-UK website indicates that there have been a number of measured flows in excess of 30 m^3/s and the largest single flow noted in the Hyder Consulting report (2003) is 67 m^3/s as observed on 28 September 1998. During the 2000 and 2007 floods the river flow reached near capacity being close to the top of the culverted sections shown in photographs 4 and 5. Flow volume for this near bankfull capacity within the over-deepened Eastside Rea channel has been estimated as being 124 m^3/s (Coyne, 2008).

4.1.2.2 Surface Drainage and Flood Risk

The strategic sewer river modelling (SSRM) hydraulic analysis, based on InfoWorks CS conducted on the River Rea as part of the Defra Integrated Urban Drainage (IUD) Birmingham pilot study, calculated predicted peak flows and volumes for different return period storms (Smith, 2007). Figure 40 shows determined peak flow source contributions for a 1:100 RI, 120 minute duration storm event from this analysis. From a predicted peak flow of 21.9 m^3/sec, nearly half (10.6 m^3/sec) was derived from CSO spillages to the river. These were of particular importance at the start of storm events as a first-flush phenomenon. The runoff contribution from rural tributaries, as indicated in the figure, is relatively small.

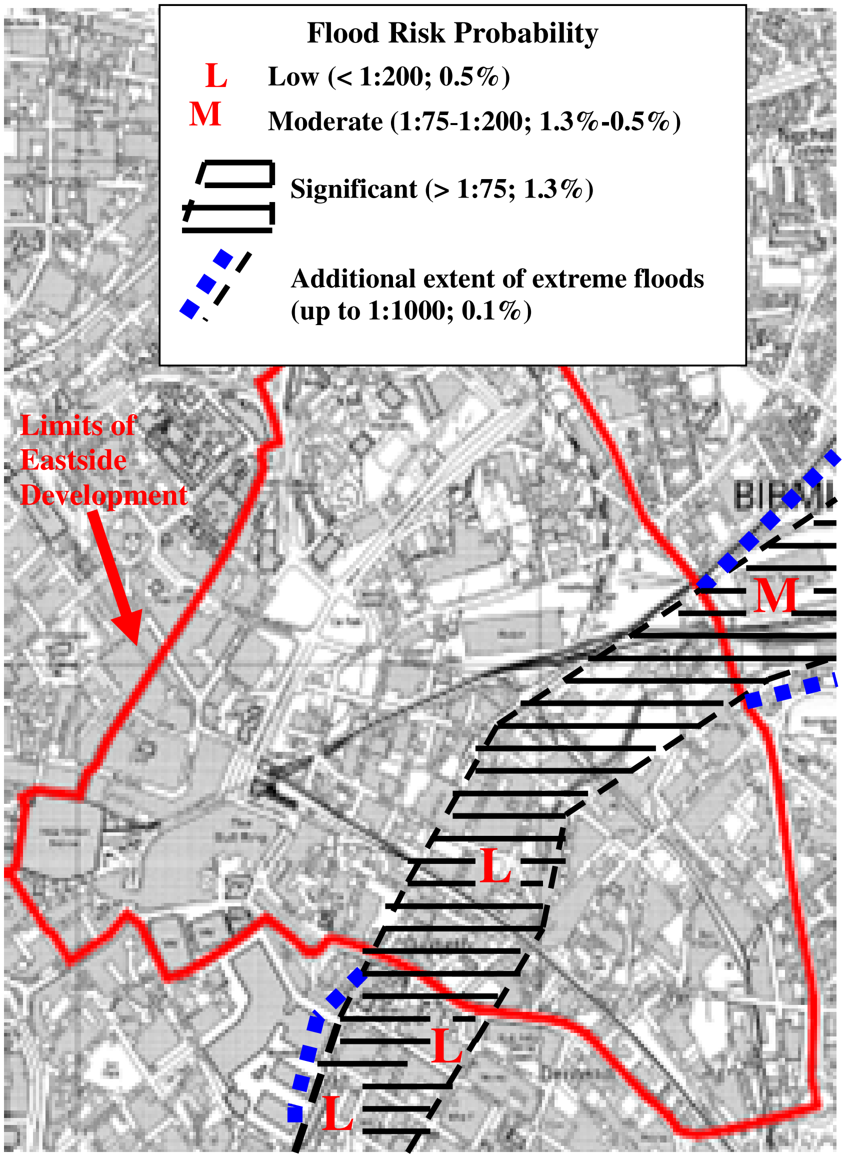


Figure 23 EA flood probability for the River Rea in Eastside (From: Ellis *et al*., 2007b)

Whilst the SSRM modelling under the IUD Pilot Study did not extend as far down as the Eastside section of the River Rea, the analysis did identify a number of surface water outfalls (SWOs) and emergency overflows (EOs) which became submerged during high flow periods in the main channel. Such storm induced blockages during extreme events could lead to surcharging of the incoming surface water sewer pipes (typically being less than 525 mm diameter), and which have a more restricted hydraulic design capacity which is typically in the range of 1:25 to 1:30 RI. The Pitt Review (2008) of the June 2007 flooding in the UK indicated that nearly two-thirds of the urban flooding was due to pluvial surface water drainage and this conclusion is confirmed by the data shown in Figure 25 where by far the largest contribution to peak flows on the River Rea derives from SWOs.

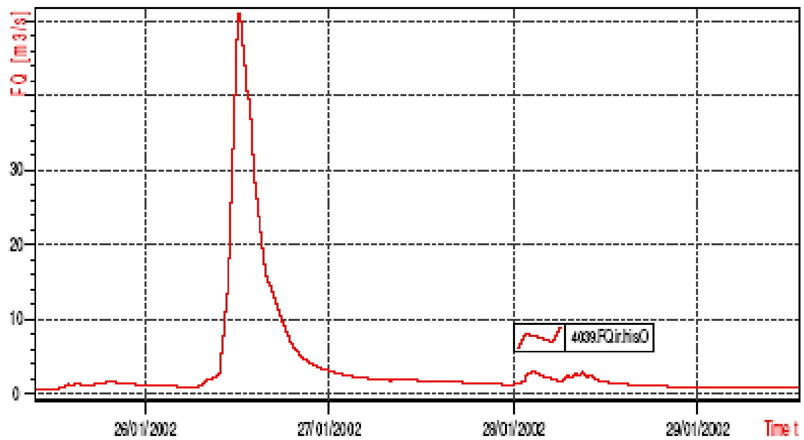


Figure 24 Storm event hydrograph for River Rea at Calthorpe Park.

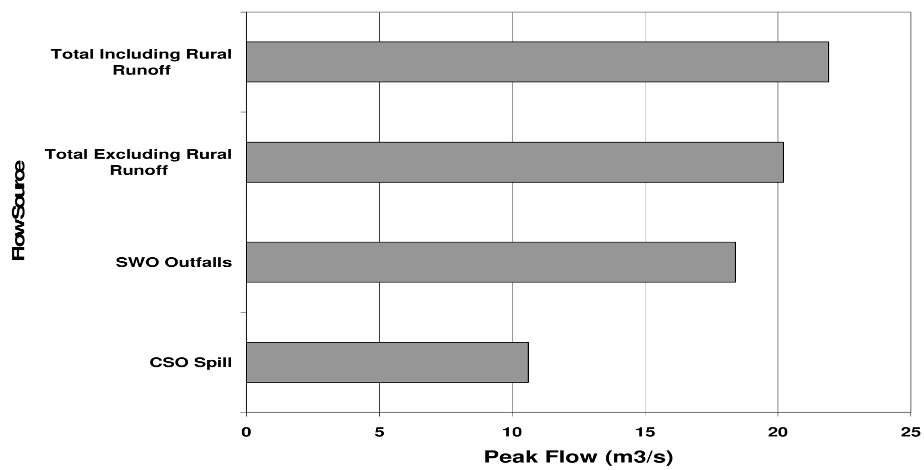


Figure 25 River Rea peak flow contributions for a M100-120 extreme storm event (After: Smith, 2007)

Table 6 UK Rainfall Data for 1:30 RI

Duration (hrs)	Rainfall Total for 1:30 RI (mm)	Highest Recorded UK Rainfall Depths (mm)	Birmingham Region 2007 (mm)
0.5	25	80	
1.0	30	92	
2.0	36	193	
6.0	49		
12.0	59		>75
24.0	70	279 (1879)	>70

The Pitt Review also drew attention to the inadequate hydraulic capacity associated with the 1:30 design for separate surface water sewer pipes which is the standard level of protection for both internal and external flooding. Table 6 shows duration and depths of rainfall equating to a 1:30 design storm event, as calculated from the CEH *Flood Estimation Handbook*, which clearly indicates that the summer 2007 intensities would inevitably exceed the surface water pipe design capacities. In the June 2007 storm event, central England recorded a total rainfall depth of 364 mm compared with a previous 30 year average of 154 mm. Warwickshire recorded 208 mm which is 4.5 times the monthly average. Rainfall intensities exceeding 6–8 mm/hour were

sustained for extensive periods of time and followed previous rainfall events which had already thoroughly wetted the ground surface and thus generated very short lag times leading to extensive areas of standing water on streets and car parks.

The data seriously question whether the 1:30 design for surface water sewers provides a sufficient level of protection against extreme events and in the light of the circumstances of increased runoff due to future climate change and urban creep. Traditional sewer models and standard surface water drainage design are not well suited to 1:100 extreme return period analysis, yet it is precisely these extreme events that stakeholders are interested in. Current SSRM modelling does not take into consideration that extreme events may route overland (which creates the flood risk) flowing direct into the local watercourse. In addition, within the Rea Main Drainage Asset Plan (DAP), there is very limited, if any, verification of the surface water sewer systems. Most modelling analyses are also based on a specific stated return period such as 1:30 or 1:100, yet other factors such as antecedent wetness, areal reduction factors and storm duration can all have a significant impact on the results. Figure 26 taken from a Hyder Consulting report for Groundwork Birmingham and Solihull (2007) would suggest that events exceeding the 1:5 RI are likely to lead to surcharging of the Eastside surface water drainage system.

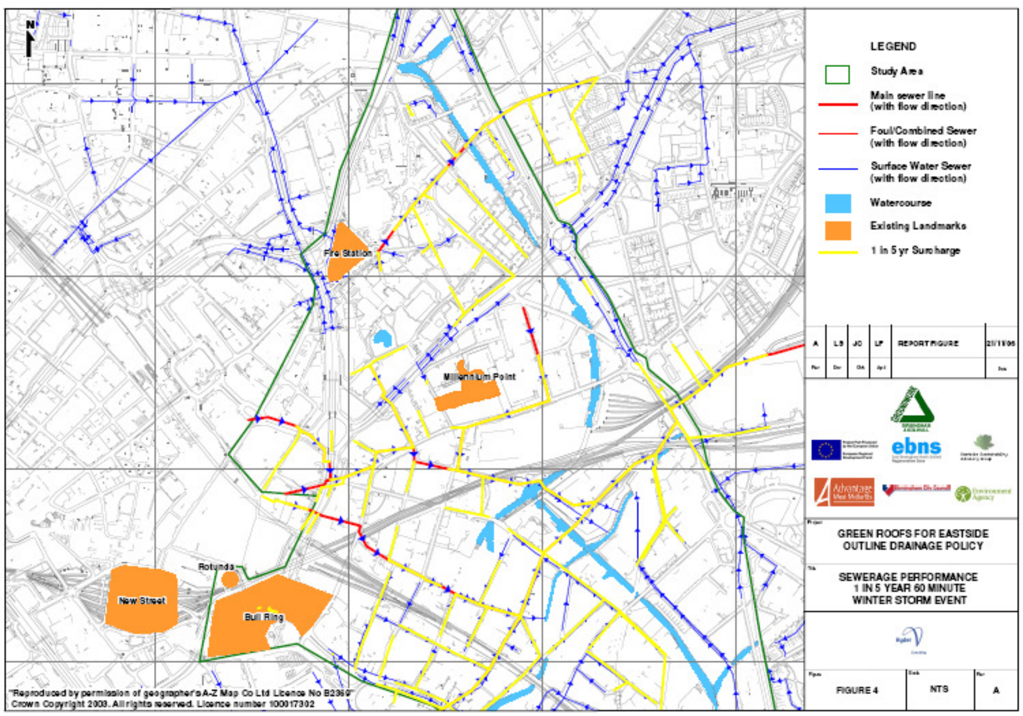


Figure 26 Surface water sewer surcharging during extreme storm events (From: Groundwater Birmingham & Solihull, 2007)

The Defra Integrated Urban Drainage (IUD) Pilot Study for the Upper River Rea (Birmingham City Council, 2008) identified such flooding risks to the river corridor arising from extreme events. For the 1:100 event, up to 14% of sewer nodes were predicted to flood with extensive surcharging and consequent out-of-sewer flooding. Under these extreme exceedance conditions, widespread overland flow routing across impermeable urban surfaces would occur with worst case flood volumes being greater than 500 m^3. The contribution of the road network to act as part of the drainage network under extreme exceedance flow conditions is implicitly recognised by this

screening procedure. Even relatively minor features of the urban landscape, such as kerb heights and property threshold levels, can significantly affect the localised flood risk.

However, such overland routing and depths need to be thoroughly ground-truthed to be satisfactorily included in any hydraulic analysis. However, there are no reported incidents of any significant flooding occurring within the Eastside area and this questions whether the sewer surcharging identified in Figure 26 is an artifact of the modelling parameters and working assumptions. Given that the hydraulic design is for pipe sizes to convey the 1:25–1:30 storm event, it is difficult to understand how such extreme sewer surcharging could result from a storm with only a 1:5 return period. Certainly from BCC field and highway information, it would appear that the modelling substantially overemphasises the current level of pluvial flood risk for the Eastside area. The surface water sewer surcharging could be related to the filling-up of the main trunk sewer system which collects extensive wastewater flows from west, southwest and central Birmingham. The shallower parts (> 3m deep) of this combined sewer network close to the River Rea, are assumed within the SWT DAP model to connect to the surface water network (as well as to the canal system and the River Rea itself). Thus during high return period events, there appears to be evidence for contemporary surcharging of the surface water system from the deeper wastewater sewer system.

The Birmingham LA has undertaken on behalf of BCC, a preliminary review of the likelihood of surface water sewer surcharging following development of the individual Eastside development parcels (Coyne *et al.*, 2008). The sewer modelling takes a critical flood threshold associated with the 1:30 RI event and a 26 mm/hour rainfall intensity, together with an 80% unrestricted runoff flow rate from assumed 90% impermeable sites. Under these modelling conditions it was found that six of the development parcels would be probably liable to surcharging, with flows exceeding the maximum pipe diameter capacities. This risk analysis implies that the River Rea (and canal network) not only would be subject to increased exceedance flows but also to lowered water quality as a result of such flush spillages.

Surface flooding and overland flow routing during extreme events would be exacerbated by blocked (or partially blocked) roadside gullies which are normally designed to handle 1:1–1:5 storm rainfall events. The council is responsible for cleaning gullies on adopted roads and they would normally be cleaned and jetted once per year (or twice to three times per year in the central business district), although it is not known whether this frequency is generally achieved. During very extreme storm events such as the summer 2007 storms, the highly turbulent surface flows may well have been capable of flushing out any blockages, but clearly gullies do have the potential for exacerbating pluvial flooding depths. However, it is also highly likely that during extreme storm events surface runoff frequently by-passes the highway drains as the gully grating becomes blinded by litter and urban debris. By-pass flows and surface flooding may thus not be the result of any gully chamber blockage, but reflect the rapid blinding of the road surface gully gratings during the onset of storm flow conditions.

A better knowledge of 2-D overland flow and exceedance flows during extreme events would greatly improve the understanding of the urban pluvial flood risk and

help to mitigate future impacts. Whether this is a practical possibility at a regional catchment scale and incorporated into future stormwater management plans (SWMPs) is open to question. However, considerable preliminary investigations of extreme surface water flooding based on 2D overland routing of blanket extreme rainfall coupled with ground-truthing, is being undertaken to generate potential flood hazard maps rather than risk maps (Hankin *et al*., 2008). Such screening approaches however, may be more suitable for strategic flood risk assessments (SFRAs) and catchment management plans (CMPs) and restricted to the more vulnerable flood risk areas due to the onerous data and modelling requirements.

4.1.2.3 Flood Risk Assessment

The IUD Pilot Study (Smith, 2007) also analysed the impact of future climate change and urban creep on river flows and levels as well as the outcome of increasing all sewers by one standard pipe size i.e the 525 mm diameter pipe being increased to 600 mm. The results of this hydraulic analysis, with climate change and urban creep scenarios being assumed as being 20% and 25% respectively, are shown in Figure 27. Irrespective of the differing storm durations considered, peak river flows increase as a result of both climate change and urban creep, with the impact of climate

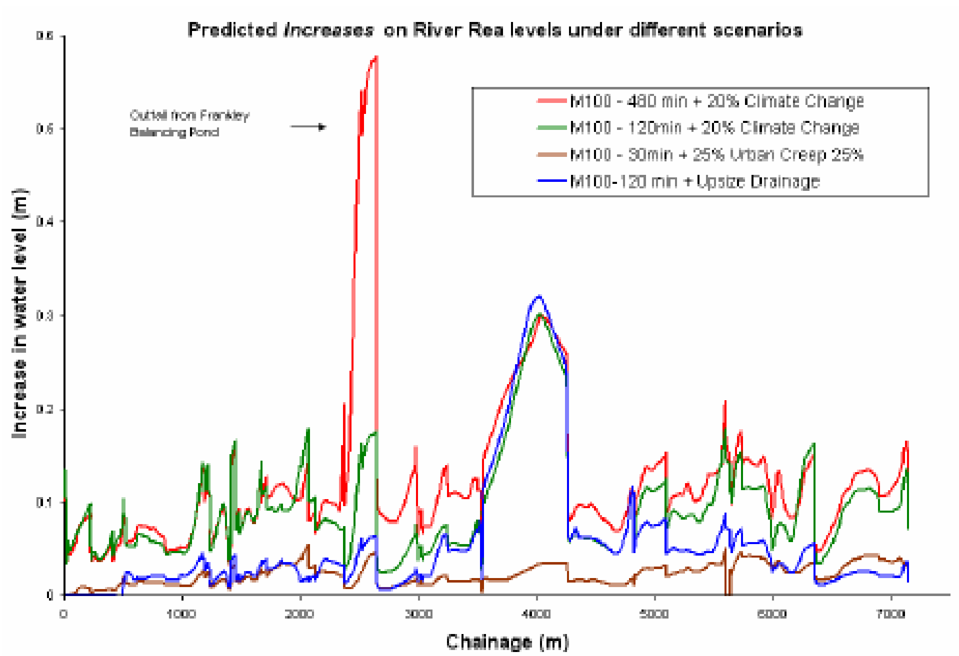


Figure 27 Predicted increases of River Rea flow level under different future modelling scenarios (From: Smith, 2007)

change (at a 20% scenario) being greater than the increase for urban creep (under 25% scenario). The most significant difference noted in the hydraulic analysis was in predicted flood volume, when a 20% increase in rainfall intensities from climate change is predicted to increase the total volume of sewer flooding by up to 63%. The analysis also suggested that the extent of predicted river flooding downstream increased with both climate change and urban creep, thus the impact in the Eastside river corridor is likely to be even greater. The impact of upsizing sewers would clearly result in a significant increase in the total peak spill volumes to the river (Figure 27) but given the rehabilitation costs and implications for the sewer network operation, such upsizing is very unlikely to be a cost-effective way of resolving the

pluvial flooding problem. A recent draft statement of principles for the sustainable development of the River Rea (Coyne, 2008), notes that the current level of protection for the channel within Eastside is for a 1:100 RI including a 20% allowance for climate change. This is roughly equivalent to a peak flow volume of 124 m^3/s which is very close to the overbank flooding situation and certainly would make public access to the channel and adjacent corridor unsafe during, and immediately after, such high flow periods.

The likelihood and impacts of future flood risk in the Eastside Rea corridor, particularly given the scale and type of proposed new developments are therefore most probably higher than currently experienced. Given the current low likelihood of flood risk, these future scenarios may only increase the risk to marginal levels. However, the scale and intensity of proposed land use changes (and the locked-in land and property values), that will result from future development, could mean that the likely consequences and damage impacts might well be significant even at the margin.

Future development must seek to minimise the impervious area as much as possible and introduce source control drainage wherever feasible to ensure that future risks are also minimised. Such action is embodied in the Birmingham City Council *Policy Statement on Flood and Coastal Defence* in Section 3.12 which accepts the precept of PPS25 to "include measures for ensuring sustainable urban drainage systems to control surface water runoff". The potential benefits of SUDS drainage for future developments in the urban area are also acknowledged in Section 6.7.1 (Flooding) of the June 2006 Birmingham City Council *Climate Change Strategy Consultation Draft* document with flood risk matrices being required for large scale developments over 1 hectare. Groundwater levels in the Eastside area generally vary between 3 to 7 m below ground level (according to borehole data for the Curzon Gateway site), which would theoretically enable the full range of SUDS infiltration devices to be strategically employed in addition to attenuation and storage. However, given the prolonged industrial heritage and the nature of the brownfield site, there might be risks of leachate mobilisation of contaminants lying "dormant" within the unsaturated zone.

The preferred surface water drainage approaches of BCC would be to encourage green roofs and retention tanks to achieve stormwater attenuation, with temporary diversions of extreme flows to local storage points. It may be that there will be only very limited opportunities for alternative SUDS options such as swales, filter strips, infiltration devices and surface storage/attenuation basins. The introduction of "hard" SUDS such as permeable paving, poses difficulties in heavily urbanised areas such as Birmingham city centre where surfacing is subject to constant disturbance from utilities e.g. cabling, piping, service access etc. There are difficulties of ensuring restoration of sub-base, bedding and pavoir re-laying as well as potential for blockage and ponding. A pragmatic and open-minded approach is required to ensure an appropriate mix of conventional and alternative drainage options are implemented.

4.1.2.4 River Water Quality and Ecology

The EA conducts water quality monitoring within the River Rea along the 5.2 km reach between Cannon Hill and Saltley Viaduct that starts south of the Eastside area and finishes to the north. A further 2.3 km reach from Saltley Viaduct to the confluence with the River Tame is also regularly monitored and included in the EA

water quality dataset. The river quality objective (RQO) target for the Cannon Hill to Saltley Viaduct reach is RE4 and this was achieved over the period 2004–2006 although it should be noted that this classification reflects only a fair to poor chemical status. For the period 2002–2005, there was marginal compliance, and prior to that in 1999–2003, significant failure was recorded. Table 7 shows the EA data for the most recent period (2004–2006) for which the river was compliant. For the preceding 2002–2005 period, the average BOD levels were 4.03 mg/l, which were only marginally compliant. Thus the river quality based on chemical parameters (DO, BOD and ammonia i.e. General Quality Assessment, GQA gradings) was Grade D in the 2004–2006 period having being previously Grade E during the 1999–2005 period. The higher BOD and ammonia levels noted in the early surveys might reflect the impact of CSO spillages on receiving water quality as well as the effect of disturbed sediment oxygen demands. In addition, the persistent flushing of surface

Table 7 River Rea water quality 2004–2006: Cannon Hill to Saltley Viaduct

	Average	**Standard deviation**	**95th-ile**	**90th-ile**	**10th-ile**	**No. of samples**
BOD (mg/l)	4.82	2.12		6.57		34
Ammonia (mgN/l)	0.366	0,186		0.514		34
Un-ionised ammonia (mgN/l)	0.01	0.0043	0.0107			34
DO (%sat)	95	15.47			80.5	34
pH	7.9	0.33	7.49			34
Hardness Mg/l $CaCO_3$)	232					34
Dissolved Copper (g/l)	95.14	6.21	12.1			34
Total Zinc (g/l)	193.42	112.51	332.04			34

pollutants through the separate sewer system provides a continuous accumulative innoculum to the receiving waterbody. Given the high flow contributions from surface water outfalls noted in Figure 25 and the elevated unit area pollutant loadings associated with intensive urban land use activities (Ellis and Mitchell, 2006), the high risks to water quality are likely to continue into the future. Even if there were a 100% reduction in urban runoff, it is not likely that this would result in any substantial enhancement in the chemical grading as the contribution of surface water to total BOD loads is relatively small compared to that derived from CSO spillages. Thus future programmes of measures (PoMs) need to address the fundamental issue of upstream CSO spillages and encourage a widespread adoption of SUDS drainage for surface water runoff in the headstream sub-catchments.

The five-yearly biological survey (based on macroinvertebrates) is not available for the Cannon Hill to Saltley Viaduct reach, but for the downstream Northfield to Cannon Hill reach it had improved to Class D in the 2006 survey compared to Class E in the 2000 survey. Thus the river is classified as having a “poor” biological status with an ecological quality index (EQI) score of 0.56 in terms of average score per taxon (ASPT) based on the BMWP biological diversity scoring system. An EQI value of less than 1.0 would indicate that the observed biological score is less than the predicted score and would therefore imply a depressed biodiversity. This is not a

surprising outcome given the heavily engineered nature of the river channel which would be virtually ecologically sterile in some sections.

The EU WFD Article 5 preliminary risk assessment for the Greater Birmingham region shows that much of the lower Rea and the adjoining River Tame are designated as being "at risk" or "probably at risk" in terms of water quality (Ellis *et al*., 2007c). The 2007 UK risk assessment submission made in accordance with WFD Article 5 indicates that between 40%-60% of surface waters in the Birmingham region are intending to seek designation as "heavily modified and artificial waterbodies" (HMWBs). The lower Rea channel reaches are quite likely to receive such designation and seek some derogation from the WFD ecological criteria within the first river basin management plans (RBMPs). However, even assuming a successful outcome from SWMPs and PoMs, given the inherited engineered nature of the Eastside Rea channel, it is difficult to expect any significant future biological improvements. The brick-lined, fast-flowing river channel, combined with an endemic flashy regime, all predicate against substantial ecological improvements. There may well be some localised opportunities for sediment dredging and reedbed planting as at the aqueduct cross-over location of the Rea with the Warwick & Birmingham Canal (Photograph 6), but such opportunities remain fairly limited. Therefore the risks to long term water quality and receiving water ecology are likely to remain quite high into the foreseeable future.

A recent biodiversity survey of the Eastside area (Donovan *et al*., 2005) showed that the industrial heritage of the district has created various ecological habitats, particularly along transport and canal/river corridors, some of which contain rare and protected species e.g. black redstarts and bats. The report places emphasis on the retention of habitats immediately adjacent to the River Rea corridor and the Grand Union and Warwick & Birmingham Canals through optimisation of the development design layout and establishment of green/brown roofs as well as continuance of existing critical "bare" and "dead" ground. Such provisions would maximise the "green point" score per hectare in terms of local Biological Action Plan (BAP) targets. However, it might be difficult to obtain appropriate agreement and funding of all developers to provide leasing adjacent to river and canal corridors for landscaping and ecological improvements. BCC must also be seen to be adopting an "even-handed" approach to developers and not be considered as giving differing advice or additional requirements to individual developers. The Water Framework Directive (WFD) will require even heavily modified water bodies (HMWBs) such as the Rea to be improved to a base standard and an "acceptable" level of ecological potential even if initial derogation is sought and achieved, although what this base level will be is still uncertain. Measures to improve channel and bank habitat with daylighting of culverted sections where possible and the introduction of wetland habitats along or near river reaches would give increased opportunities for ecological connectivity and help join up the existing fragmented habitat patches.

4.1.2.5 Surface Water Drainage Responsibilities and Adoption

Risks and Barriers to Current IUD Management

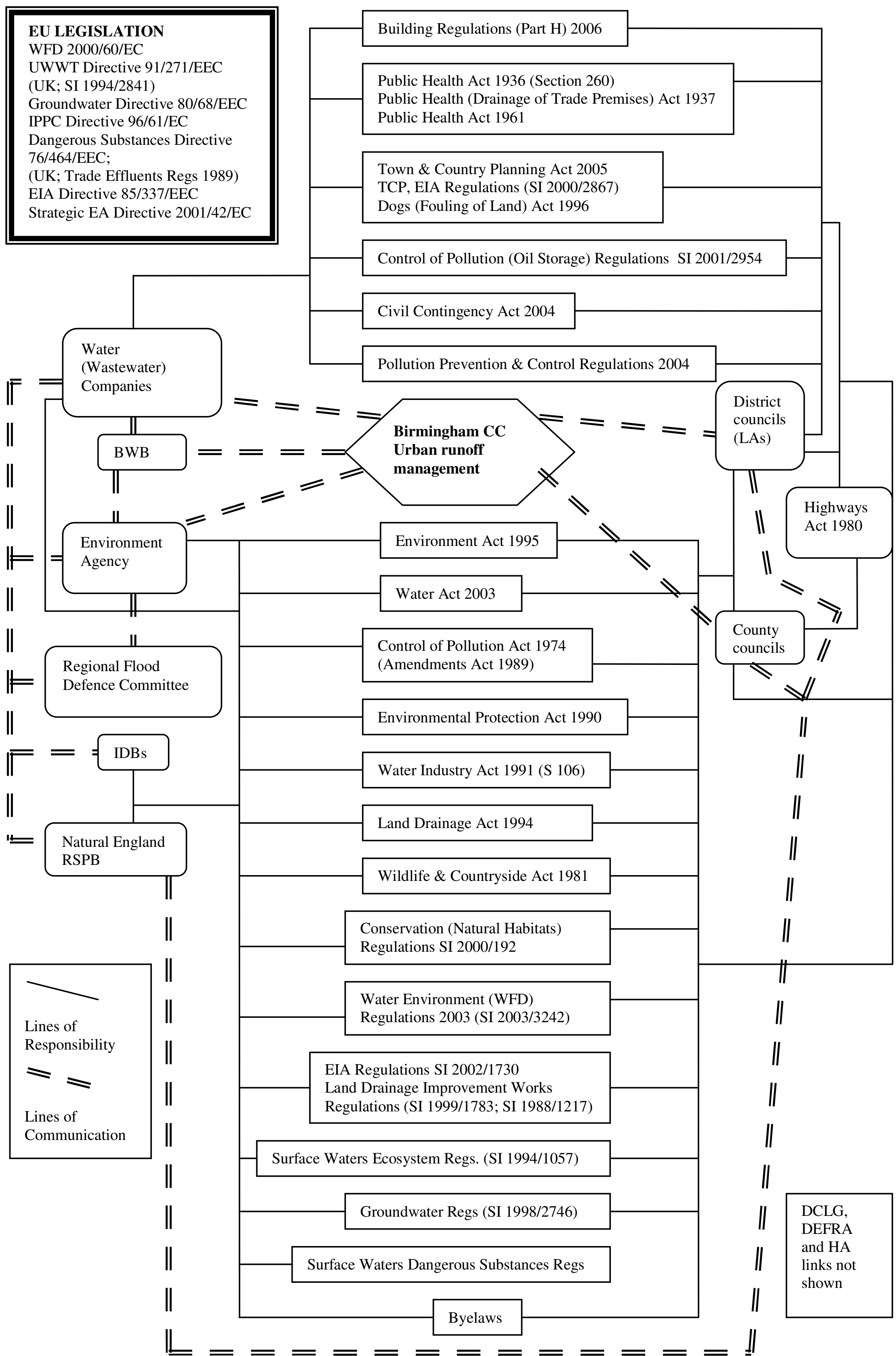
The background to, and current structure of, the legislative, regulatory and planning framework for urban surface water drainage in relation to the position and responsibilities of Birmingham City Council has been outlined in a previous SWITCH document (Ellis *et al*., 2007c). Figure 28 illustrates this generic framework which

emphasises the complexity and fragmentation of both the legislative and agency responsibilities which serve as a barrier to integrated urban drainage (IUD) management and meaningful stakeholder consultation. The more specific identification of delivery responsibilities within this framework, and the difficulties of achieving a fully integrated approach to urban runoff drainage for the Rea catchment, have been explored in the context of the Defra IUD Pilot Study (Birmingham City Council, 2008).

The Defra IUD study concluded that the complex organisational arrangements lack clarity and lead to inefficient and piecemeal investment decisions leaving the urban area less able to cope with the flooding and pollution risks associated with future climate change and urban creep. Since withdrawal in 1974 from local authorities of responsibility for public infrastructure, BCC has only held "permissive powers" in respect of surface water drainage, although the city council has recently secured a service agency contract from EA for O&M responsibility of the designated "mains" River Rea receiving channel through the city. All surface water sewers and their outfalls within the BCC area are the statutory responsibility of Severn Trent Water (STW), although BCC does hold responsibility for maintenance of flap valves/gates for some surface water sewers discharging to the Rea channel. There is however, some lack of clarity over direct responsibility of various open surface water channels/ditches under private ownership. There are numerous small dimension pipes and associated outfalls from historic (and sometimes derelict) commercial/industrial premises and storage/service yards etc., which drain surface water into the Rea. These would have been recognised pre-2000 as critical ordinary water courses (COWS), but currently lie in administrative/regulatory "limbo".

Figure 29 highlights the variety of stakeholders involved in the urban drainage decision-making processes in the Rea catchment and some of the issues which require multi-stakeholder consultation and interactive participation. The tenuous and sometimes ineffective lines of communication between the various stakeholders and the unclear boundaries of overlapping responsibilities can only be addressed through amendments to legislation, institutional and planning arrangements, some of which are being currently reviewed at central government level (Defra, 2008).

Figure 28 Generic framework for urban surface water management (From Ellis *et al*., 2007b)



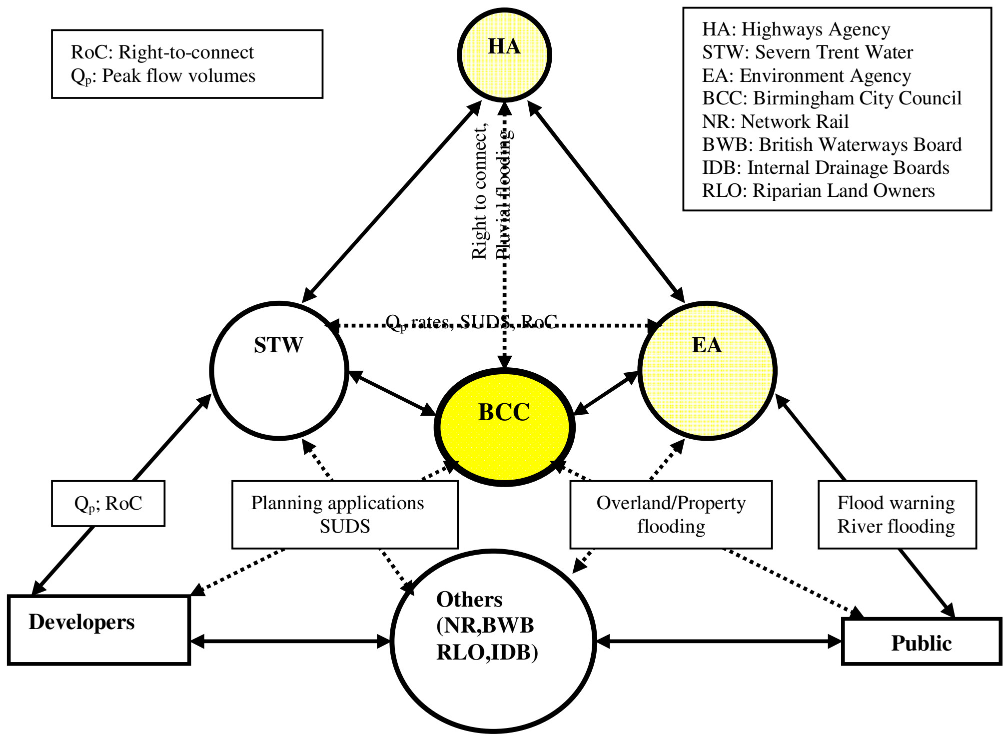


Figure 29 Stakeholders in surface water drainage (After: BCC, 2008)

Surface water flooding control has evolved organically and there is a history of cooperation and joint action between BCC, STW and EA in dealing reactively with emergency events. However, under existing legislative and regulatory frameworks, the boundaries of responsibility and leadership lack clarity which gives rise to clear risks in achieving fully effective and efficient surface water drainage management.

Figure 30 illustrates the principal barriers and difficulties to achieving an integrated stakeholder consultation process for strategic urban drainage management. There is currently little basis for the structured and systematic adoption and management of surface water facilities within an urban catchment. The various stakeholder organisations and agencies have differing incentives, accountabilities and investment planning horizons, with responsibility for urban pluvial flooding lacking both strategic direction and legislative clarity. There are clear tensions between the need for promoting urban growth initiatives and the realisation of capital receipts against the need for effective sustainable drainage and the minimisation of surface flooding risk.

Currently, large scale development proposals such as Eastside are dealt with on a “piecemeal” basis with drainage essentially addressed at the site/local level with little if any consideration of the accumulative effect of development streaming on the wider long term, strategic catchment level impacts. The streaming of Eastside proposals over a 5 to 10 year period also causes difficulties in ensuring a progressive, consistent and integrated policy for the differing spatial and temporal development elements.

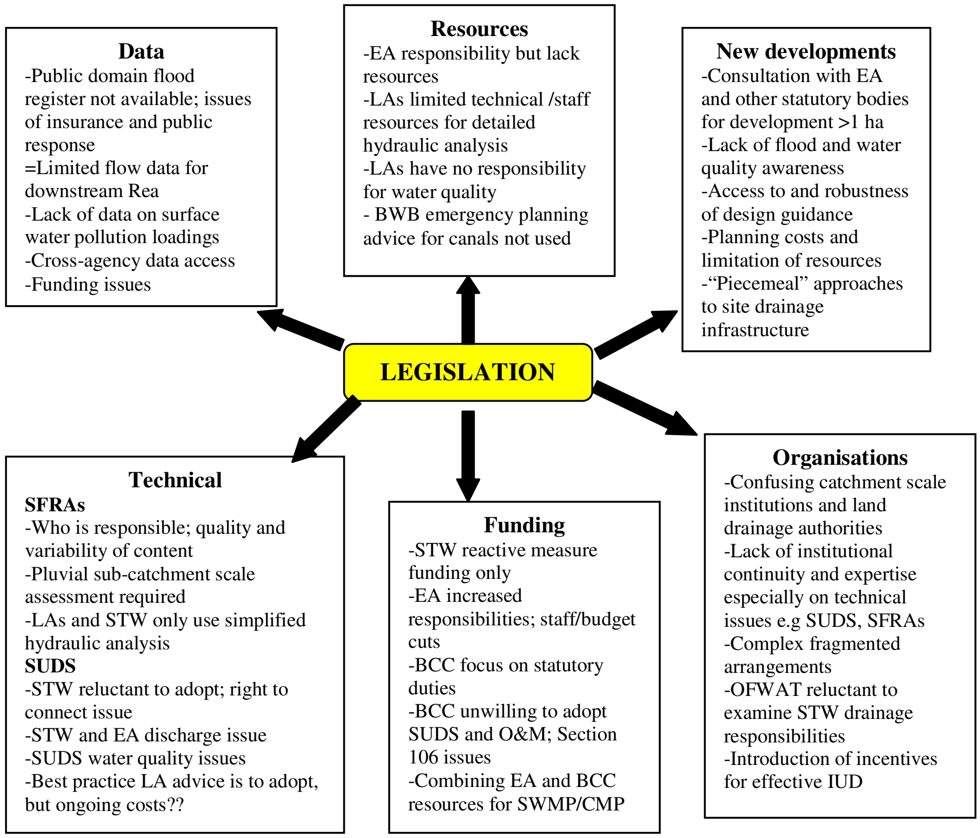


Figure 30 Barriers to stakeholder IUD within the Rea Catchment (After: Birmingham City Council, 2008)

City Park is being developed separately from Eastside and there is no overall holistic masterplan for integrating the Park within the surrounding individual development parcels. This reduces the opportunities for introducing an integrated surface water drainage programme. It is intended for example, to supply two of the three park areas in the proposed City Park from either potable water or pumped groundwater rather than seeking to re-use stormwater. An attenuation basin could supply all water features in the Park, but it could be difficult to obtain agreement, funding or long term maintenance for this solution. It has been suggested that up to three ornamental attenuation ponds might be created within the Eastside City Park and these could be supplied by water pumped from the River Rea. To some extent this would support the development of a "green corridor" as well as help improve the riverside biodiversity potential. Consultation and advice is nevertheless, typically uncoordinated until the final planning submission stage is reached (and the EA risk assessment matrix completed), by which time modifications and alterations to infrastructure can become difficult and costly. There are further issues related to the discharge of excess water and the need to treat stored water that the public might come into contact with or might ingest. BWB would also require a full treatment including oil interceptors and detention storage prior to any discharge of surface waters into their canal system.

It has also been alleged that there is no overall strategic delivery vehicle for the Eastside development area with supplementary planning guidance falling between administrative departments. Development has pushed up land prices and is occurring in an uncoordinated fashion which could result in an incoherent and unsustainable growth pattern. Outside its canals, Birmingham has very little surface water which can be considered as being crucial amenity assets for future cities. The deliberate development of waterside locations could offer considerable opportunities and benefits for both business and residents.

Future IUD Management and Risks

The introduction of a new planning framework for England & Wales together with the introduction of PPS25 "*Development and Flood Risk*" is achieving a major breakthrough in the planning decision-making process and urban infrastructure provision. The former planning system as adopted formally by BCC in October 2005 is outlined in a previous SWITCH Deliverable report (Ellis *et al*., 2007c), with the Local Development Framework (LDF) incorporating a revised Local Development Plan (LDP) which recognises the need for water minimisation techniques. Section 3.71 of the BCC LDP states that the "*full potential of sustainable drainage systems (SUDS) must always be reviewed before any rainwater runoff is diverted into sewers or stormwater drains*". Section 3.73 also states that "*where feasible, surface runoff and contaminated water should be treated through the use of natural features*" with extreme exceedance flows requiring attenuation facilities. The new planning framework allows flood risk and urban water quality management to be addressed at regional, area or local levels, although there are still issues remaining over catchment-level planning and the overall integration of site, local, and sub-catchment drainage.

PPS25 also gave the EA a statutory consultee role to all significant future development proposals, although neither Severn Trent Water nor the Internal Drainage Boards are currently statutory consultees in the planning process. The practice guide consultation paper to PPS25 does provide advice on the practical implementation of strategic PPS25 policy in terms of flood risk assessment and the management of surface water (DCLG, 2007). Based on this, the EA has developed (March 2007) detailed standing advice for development and flood risk assessment which gives considerable guidance on the need for and type of flood risk assessment that will be required for developments falling into Flood Zones 2 and 3, as well as for development exceeding 1 ha or lying adjacent to a main river. This flood risk standing advice, available on the EA website, clearly states that the "*first option for managing surface water should be according to sustainable drainage system (SUDS) principles*" for drainage of sites exceeding 1 hectare.

The new planning structure and the formal methodological and consultation procedure for flood risk assessment is already improving the decision-making process with developers encouraged to undertake pre-application enquiries with the EA, STW and LAs covering flood risk, water quality, biodiversity, pollution control, land contamination and water resources. For development sites falling within Flood Zones 2 and 3, the EA will also provide advice to local authority planning departments on flood risk at the planning application stage either directly, or on low risk development through their Standing Advice website. The emergence of 2D modelling capabilities for hazard assessment of extreme event exceedance flows and their overland routing within urban areas provides further technical support to the decision-making process

and these have been trialled in the Defra River Brent IUD pilot project. Such detailed screening approaches which allow multiple sources (exceedance flow, sewer surcharging, out-of-channel spillage etc.,) and pathways to be considered simultaneously, are moving modelling procedures towards integrated solutions (HR Wallingford, 2004). In addition, recent storm scale modelling (SSM) advances by the Meteorological Office will enable earlier and more accurate prediction of localised extreme rainfall events which will further facilitate future risk assessment procedures. However, the basic problem in such integrated modelling approaches is in obtaining sufficient data to be confident that the outcomes provide a true representation of the hydraulics of the system under extreme conditions.

The most recent Defra (2008) consultation document on surface water drainage has outlined proposals for Surface Water Management Plans (SWMPs) and SUDS responsibilities which could designate local authorities as the lead agency in the delivery and management of effective urban surface water drainage. However, a proliferation of plans will not on their own result in an integrated solution, even if delivered through cooperative action. In particular, SWMPs can either be read as being a required component of CMPs or as a required component of SFRAs, where the EA has responsibility for the former and the LA for the latter. The SWMPs will also need to be related to the River Basin Management Plans (RBMPs) being prepared by the EA. It is clear that the lines of powers and responsibilities, particularly at the boundaries will need to be carefully clarified together with the supporting income streams to underpin these responsibilities and their ongoing delivery and maintenance. The Defra (2008) surface water consultation document links the development of SWMPs with the new requirements of PPS25, which would further favour future responsibility to lie with the LAs.

The establishment and implementation of a formal joint liaison group for flood management (with BCC, STW, EA, BWB, HA and other stakeholders) for SWMP purposes would provide a major step towards the achievement of holistic, integrated surface water management. The experience of such Flood Liaison Action Groups (FLAGs) in Scotland, and the experience gained under the Defra IUD Upper Rea pilot project and led by Birmingham City Council, would indicate that such integrated and coordinated approaches can be effective. A Birmingham Strategic Partnership (BSP) stakeholder group already exists in relation to neighbourhood renewal but has had no involvement in sustainable urban water management initiatives and does not include either the EA or SWT in its membership. The Eastside Development Team formed within the Planning & Regeneration Service of the BCC directorate, is intended to provide an overall coordinated management of strategic sustainable development but has no specific remit relating to surface water drainage infrastructure.

However, there will be a need for changes in current legislation and regulation policy for sustainable urban drainage to be achieved in an effective and efficient manner. This includes a revision of the "right-to-connect" and of Section 106 adoption and costing arrangements as well as a review of the distribution of responsibilities to clarify statutory duties and their boundaries for action One reason for the reluctance of wastewater undertakers such as STW to be involved with SUDS lies in their denial that they act as a land drainage authority, asserting that their responsibility is limited to receiving (and treating) those effluents which are contained within sewers.

In the context of Eastside, BWB is also clearly a major stakeholder in surface water drainage and their agreement would be required before development could drain directly into a canal. It is clear that surface water management has to be considered in the wider framework of integrated water resource management rather than considered in isolation. However, integration tends to pull towards a large geographical and catchment scale, whilst stakeholder engagement and democratic accountability tends to pull in the opposite direction. It is also the case that sustainable integrated drainage without inclusion of the water quality dimension is unachievable. The Defra (2008) surface water consultation document says very little about water quality and there is certainly no thought of yielding responsibility for this dimension of the urban aquatic environment to the local authority. Irrespective of this, BCC has, and will continue to give, water quality advice on urban surface water runoff where appropriate based on their working experience in addition to that provided by the EA and STW.

If LAs are to be the responsible bodies for surface water drainage management, their resources and capabilities to do the job will need to be ensured. This will require a secure revenue stream, so the obvious logic would be to introduce a specific charge for surface water runoff; removing that element from the "bundle" of charges under the existing sewer charge-including one for highway drainage. It is therefore appropriate to suggest that surface water drainage and highway drainage should be de-coupled from the general wastewater charge and surface water levies charged by the local authority on the basis of the runoff load or some surrogate thereof such as the impermeable area. In the short term, a large proportion of the revenue raised might well need to be paid out to contracting groups such as STW, BWB, IDBs etc., to cover their costs of using the existing infrastructure to drain the area. There would need to be sufficient headroom on the charge level so that incentives could be offered for water minimisation techniques.

4.1.2.6 The SWITCH Stormwater Risk Matrix for Threats and Uncertainties for the River Rea at Birmingham Eastside.

Table 8 provides a risk assessment matrix for the identified threats and uncertainties associated with urban surface water management for the River Rea within the Birmingham Eastside area. The matrix parameters and scores have been developed based on the information given in the preceding sections of this report and on stakeholder interviews. The rating scores are given for both prevailing conditions anticipated over the next five years as well as extrapolated for the city-of-the-future in 25 – 30 years time. The colours allocated to the final summed score values are those shown in Figure 13 and 15, where green is equated with "acceptable risk", yellow as "tolerable risk" and red as "unacceptable risk" levels respectively.

Table 8 Risk Matrix for Stormwater Threats/Uncertainties for Birmingham Eastside

Identified threat	Likelihood of Occurrence		Level of Consequence		Likelihood of Occurrence		Level of Consequence		Risk score	
	Within the next 5 years	**Score**	**Within the next 5 years**	**Score**	**In 25-30 yrs time**	**Score**	**In 25-30 yrs time**	**Score**	**Within the next 5 yrs**	**In 25-30 yrs time**
Increased flooding	Surcharging of surface water sewers from combined system during extreme (>1:10RI) wet weather events Increased and more frequent summer storm intensities Backing-up of surface water outfalls/drains by river flooding Increased likelihood of pluvial surface water flooding with exceedance flows Ageing sewer infrastructure; insufficient hydraulic capacity No record of surface flooding for Eastside area and July 2007 floods (>1:80-60 RI) did not seriously impact on the surface water drainage system. High level of service protection (>M75-60 event) provided by deep, culverted Rea channel Urban creep and re-development extending impermeable surface area.	**3**	Flood risk consequences are currently minimal given channelled depth of the Rea and extent of urban dereliction within the Eastside floodplain area. Flood nuisance to local traffic and pedestrian movement Routing of overland exceedance flows (storms >1:30RI) along street and gutter pathways Blockage and damage to surface water outfall flaps Blockage of gullies and surface drains	**1/2**	Introduction of upstream flood controls will help to reduce flood occurrence Works on flood control employing upstream detention basins; control target stated as 50-yr return period. Reduction in CSO spillages from rehabilitation and repair drainage asset planning (DAP) programmes Increased likelihood of flood potential with climate change, urban creep and ageing sewer infrastructure	**2**	Reduction in frequency and volume of CSO spillages Dwellings relocated from high-risk areas; increased flood resilient building Increased land and property values following development	**2**	**3 - 6** Level of risk: low to medium	**4** Level of risk: low

Table 8 (cont.)

Identified threat	Likelihood of Occurrence		Level of Consequence		Likelihood of Occurrence		Level of Consequence		Risk score	
	Within the next 5 years	**Score**	**Within the next 5 years**	**Score**	**In 25-30 yrs time**	**Score**	**In 25-30 yrs time**	**Score**	**Within the next 5 yrs**	**In 25-30 yrs time**
Persistent pollution of receiving waters	Very high, due to lack of interceptors, cross connections and CSO/SWO outfalls; no provision for sewer separation in AMP4 Untreated separate surface water flows from impermeable surfaces associated with all wet weather events. Surcharging from combined to surface water sewers during extreme (>1:10) storm events Fly tipping, debris and litter	**4/5**	Consistently poor surface water with high HCs, HMs etc. associated with extensive impermeable areas on commercial, retail and industrial land uses Poor quality due to lack of interceptors, presence of illicit cross connections and CSO/SWO outfalls/spillages High BOD and low DO especially during/after wet weather (strong first-flush); marginal GQA compliance Contaminated bed sediments; micro-pollutants, oils etc. Unsightly aesthetic channel appearance due to litter, debris etc. Degradation of river banks ; strongly engineered watercourse Poor quality groundwater leakage from historical industrial heritage; lack of strategy for groundwater management	**5**	Planned improvements in the sewer system: construction of interceptors and reduction in cross connections and CSOs. Target of eliminating all cross connections not totally feasible. WFD implementation but probably derogation under HMWB status; likely to suppress urgency for quality improvements Climate change resulting in more frequent and polluting SWO flush discharges Upstream source SUDS controls	**3/4**	Reduced BOD and improved DO as a result of planned improvements under AMP4/5in the sewer system and reduction in CSO frequency: construction of interceptors and reduction in cross connections etc. Improved aquatic quality and habitat resulting from implementation of national diffuse pollution control programmes (Defra, OFWAT etc) Achievement of Higher GQA quality status (~ Grade 2/3). Research work on hyperoic zone interaction and natural groundwater remediation.	**3/4**	**20 - 25** Level of risk: high	**9 - 16** Level of risk: medium to high (but low confidence in rating)

Endemic poor receiving water ecology	Urbanisation resulting in continued poor ecological status and biodiversity values; continuous innoculum of pollutants and poor water quality Strongly engineered, canalised, brick-lined channel with many culverts, piers etc Restricted, fast-flowing with strongly fluctuating regime CSO spillage results in algal and sewage fungus dominance Continued poor bed sediment quality restricting benthic feeders	**5**	Continued suppressed ecological status and extremely low biodiversity scores and ASPT values Brick construction and lining to channel results in sterile habitat conditions During high storm event periods persistent washout of vegetation from channel Low food retention times and poor nutrient status High pollutant loadings with sewage fungus present Contaminated bed sediment prevents re-colonisation	**5**	Reduction in CSO spillages and upstream SUDS controls providing opportunities for improved water quality and biological diversity Improved BOD and DO levels and reduction in toxic micropollutants Improved channel habitats and river restoration schemes Contaminated sediment still very likely to be present	**4**	Limited improvements and overall change to channel form and flow regime. Restricted channel and bank environment. Marginal habitat improvements from Eastside development works and possible WFD Programmes of Measures (PoMs) BWB improvements to adjacent canal waters Pressure to achieve (or move towards) "good ecological status" (GES) after 2015 likely to lead to improvements	**3/4**	**25** Level of risk: very high	**12 - 16** Level of risk: High (but some uncertainty in rating)
Surface Water Management	Weak, uncoordinated surface water management and organisational arrangements Lack of integration between source, site and catchment scale management Issues of coordination and consultation between drainage and planning	**4**	Uncoordinated, divided and semi-autonomous distribution of powers and responsibilities for surface water drainage and urban diffuse runoff Lack of resources and commitment for control of diffuse urban runoff Priority given to control and management of point discharges	**4**	UK central government (Defra) review of powers and responsibilities for surface water drainage Formation of single authority power for surface water drainage and integrated management as recommended under the Pitt review No forward planning of canal system to support	**2/3**	Consequences of future management failure for surface water control remain relatively high in terms of pollution and flood potential Formation of Birmingham Flood Action Group following highlighting of surface water management issues during Defra IUD Pilot project for Upper River Rea	**3**	**16** Level of risk: high	**6 - 9** Level of risk: medium to low (with some uncertainty and lack of confidence in rating)

	Issues over “right-to-connect” with wastewater companies and with highways drainage Issues over Section 106 adoption of surface water SUDS facilities Separation of responsibilities and powers for flooding and water quality Multiple stakeholders working to varying time scales and budgets Lack of coherent SWMPs Some limited liaison group action for upper Rea		Historical separation of duties for surface water drainage, control and O&M operations Lack of leadership for surface water control and management		sustainable development Review by OFWAT of “right-to-connect” and of definition of “sewer” Code of Practice for agreement and adoption of SUDS facilities under national Working Party Formation of Regional and Local Flood Action Groups Development and implementation of Stormwater Management Plans (SWMPs) under WFD and new planning requirements Consideration of surface water infrastructure under Local Development Framework planning Uncertain potential for coordination of flow and quality issues for surface water drainage Uncertain compatibility between SWMPs, CMPs and LDF plans Uncertainty over funding and operational arrangements for any new (and central) designation of surface water management authority		Pitt Report of July 2007 pluvial floods highlighted consequences resulting from lack of coordination and separation of responsibilities			

Urban Landuse Planning	Little integration or consideration of surface water drainage and diffuse runoff in traditional urban land use planning Lack of planning consultation on surface water drainage Erratic liason between local authority planning and EA, STW, BWB and other stakeholders on surface water issues in development planning Increasing housing densities for new developments; time pressures on development approvals Little planning control on urban creep No formal stakeholder consultative process or framework Lack of integrated SWMPs at either site or regional levels	**4**	Continued flood and pollution potential as well as poor ecological status of receiving waterbodies due to lack of coordination between planning process and surface water flows and water quality/ecology issues Continued untreated and uncontrolled SWO outfall discharges due to limited planning controls on diffuse discharges from impermeable surfaces Limited stakeholder consultation so lack of public awareness and participation in decision-making process on surface water drainage Deleterious impacts of development on urban water balance Testing of PPS25 (*Development & Flood Risk*) guidelines still in infancy so limited and uncertain impact on urban land use planning and drainage infrastructure	**4**	New UK planning process and decision-making frameworks. Strategic drainage planning and green infrastructure planning for eastside lacks coherent integrated approach Future requirement for SWMPs under local, regional and national (WFD) regulations likely to strengthen communication and integration Strengthened and enhanced planning powers under PPS25 (*Development & Flood Risk*) guidelines for surface water drainage on new developments Improved and enhanced stakeholder consultation on drainage infrastructure Future local and regional liason groups for flood management and emergency response Joint working groups (BCC/ Eastside Team/AWM etc) to implement leadership and joint decision-making Uncertainty over coordination of flood and water quality management and target	**2/3**	Continued lack of coordination and integration of surface water drainage and the planning process expected to remain uncertain leaving pollution, ecology and flood problems If present structural and planning arrangements continued, impacts of climate change, urban creep, increasing housing densities likely to be severe.	**3/4**	**16** Level of risk: high	**6 – 12** Level of risk: medium to high (but with some uncertainty in rating)

					setting Uncertainty over integration between site, regional and catchment level planning					
BMP/SUDS Implementation	Lack of awareness, knowledge and experience of SUDS design and implementation requirements; uncertain design parameters Failures may occur due to uncertainties not allowed for in the design process or for land use changes, Diffuse wet weather pollution not properly taken into account. Failures in maintenance. Lack of coordination between SUDS and minimisation of heat island effects Business-as-usual approach fails to maximise sustainable drainage opportunities	**4**	Low levels of source and SUDS controls for diffuse surface water flows and pollution whose levels remain high with consequent receiving waterbody impacts including potential threats to public health Continued on-site difficulties with urban runoff from impermeable surfaces; issue of exceedance flow routing Low levels of secondary re-use and continued strain on urban water resources Continued uncertainty and doubts over SUDS performance	**4**	Growing concern over wet weather diffuse pollution issues. Improvements on O&M requirements are likely to occur. Planned monitoring system may contribute to better maintenance and the development of improved design criteria. High groundwater levels prevent deep infiltration/recharge and soakaways	**2**	Possibilities of failure in operation and maintenance may result in increasing health risk and soil pollution risk. Possibility of a reducing public acceptance of BMPs/SUDS if poor performance or failure	**3**	**16** Level of risk: high to medium	**6** Level of risk: medium to low

4.2 Belo Horizonte and the Engenho Noguera Creek Catchment (Prepared by: N Nascimento)

4.2.1 Urban Waters in Belo Horizonte

Belo Horizonte (BH) is the capital of the State of Minas Gerais, which in economic terms (gross product) is third among the 26 Brazilian states. The city lies at 20° South latitude and 44° West longitude (Figure 31) and has an altitude of 750 to 1,300 m. It is located in a mountainous region of tropical soils that originated from the decomposition of metamorphic rock. Tropical highland weather predominates in this area, with an average yearly rainfall of 1,500 mm and an average yearly temperature of 21 C. The rainy season lasts from October to March, when 90% of the total yearly rainfall occurs. The highest monthly average rainfall (315mm) takes place in December. Typical rainfall intensities are also relatively high (e.g. 200 mm/h in the case of a 10-year return period event with 5 minutes duration; 70 mm/h for the 50-year return period and 1h duration event). Mean relative humidity reaches 50% during winter and 75% in summer.

Figure 31 Location map of Belo Horizonte (Nascimento *et al*, 1999a)

BH has 2,227,400 inhabitants with a population density of 6,900 inhabitants/km^2. It is a planned city, built in 1898 to become the capital of the state; the total area of the municipality is 330 km^2. The overall metropolitan area (RMBH; Belo Horizonte Metropolitan Area) consists of 33 distinct municipalities with an area of 9,179 km^2 and a total of 3,900,000 inhabitants.

Belo Horizonte drains to two main catchments (the Arrudas creek and the Onca creek catchments), each representing about 50% of the total municipal area (Figure 32). Parts of these catchments are located in neighbouring municipalities: Contagem, upstream of Belo Horizonte, and Sabará and Santa Luzia, downstream of Belo Horizonte. There are no main rivers in the municipal territory, although the Arrudas and the Onça are direct tributaries of the Velhas River, which has a total drainage area

of about 40,000 km^2. This, in turn, is a tributary of the Sao Francisco River, the longest river within Brazil with a drainage area of approximately 600,000 km^2.

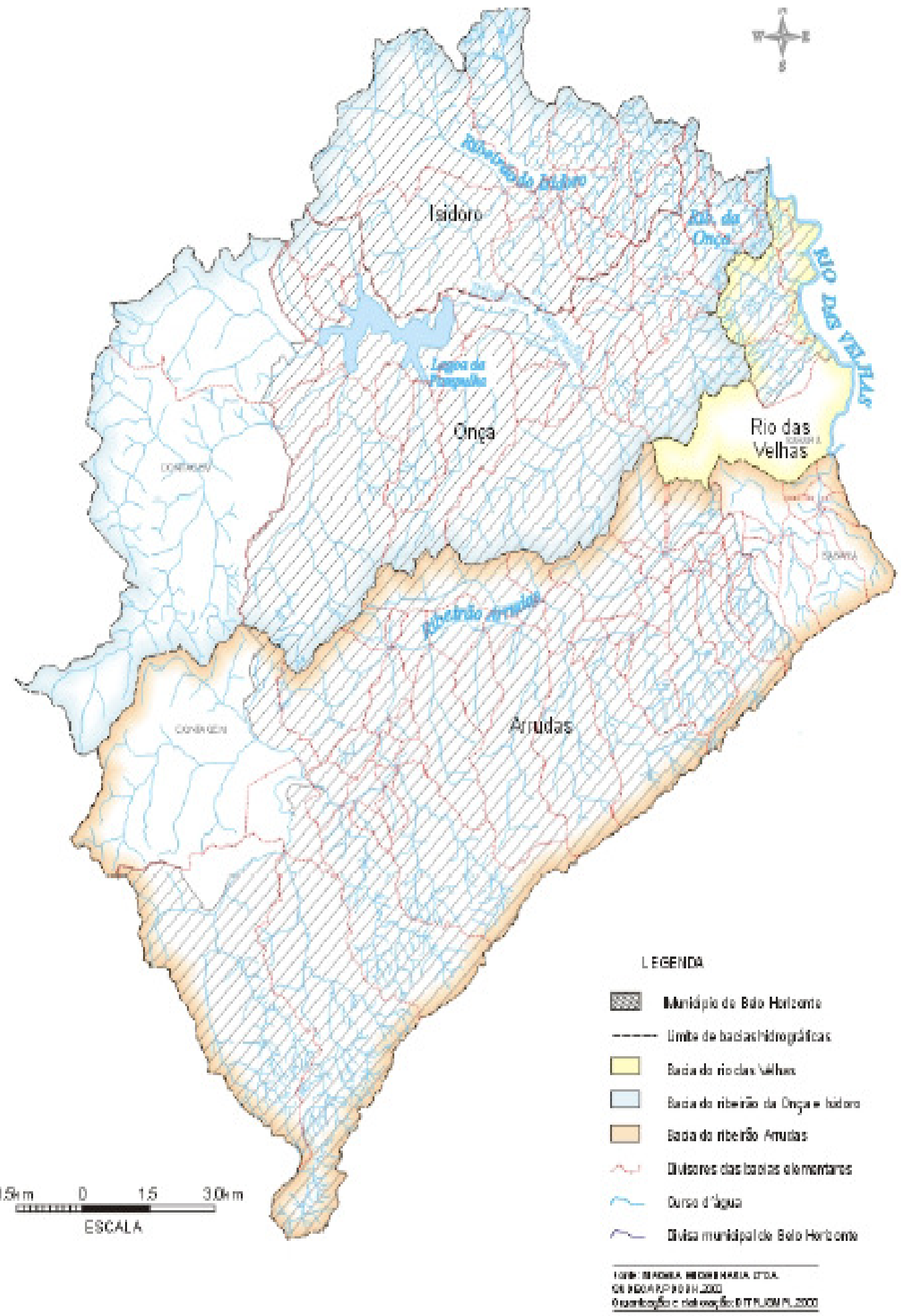


Figure 32 Arrudas and Onça Creek catchments and the Belo Horizonte municipality borders

In Belo Horizonte as well as throughout the BH metropolitan area, a separated sewerage system has been adopted, although illicit inter-connections between the

wastewater and stormwater networks prevail, resulting in heavily polluted receiving bodies in the urban area and in the Velhas River downstream of the city. Another source of water pollution by wastewater is related to the lack of interceptor pipelines (Figure 33) as part of the main sewerage system. Therefore, improvements to urban creeks, detention ponds, wetlands, and to the Velhas River water quality will require important investments in wastewater interception. Alternatively, a new approach, which may combine the existing end-of-pipe WWTP with decentralised treatment facilities, may be adopted.

Figure 33 Pollution of receiving bodies by wastewater due to lack of sewer interceptors

Another point under evaluation by the BH municipality is the possibility of keeping combined systems in certain areas where in fact this approach has already been informally adopted e.g. in many of the shantytowns. Embracing such an approach will require improvements to those existing systems in order to eliminate continuous outflows to receiving waters (Figure 34) and to employ modern solutions for the reduction of CSOs e.g. retention structures.

In Brazil, as required under the federal legislation, water supply and sanitation are public services which are under municipal responsibility. In BH, COPASA, a state company, provides these services through a concessionary agreement. Since its creation in the 1960s till the end of the 1990s, COPASA, like all the other Brazilian state water utilities, had been in charge of planning, operation, control and regulation of the BH water supply and the wastewater systems. Recently, the BH municipality decided to recover its role in water supply and sanitation planning and regulation; a new policy that has led to modifications in the municipal legislation for the sector (e.g.: Municipal law 8260/2001 stating the municipal policy on water supply and sanitation) as well as on the concession rules (e.g.: the Cooperation Agreement between COPASA and the BH municipality, from November 2002, for the provision of drinking water and sanitation). As an outcome of these political changes, the municipality has become a shareowner in the COPASA state utility (Municipal law 8754/2004).

Figure 34 Creeks heavily polluted by wastewater and solid waste

Further to the concession contract amendments, other instruments and institutional improvements were set up by the BH municipality in order to allow the development and implementation of a comprehensive municipal policy for drinking water and sanitation:

• The Municipal "Saneamento" Committee (COMUSA): composed of municipal staff and stakeholder representatives, having as its main purpose the development of a water resources management policy for the municipality ("saneamento" means, in Portuguese, drinking water + wastewater + stormwater + solid waste);

• The Municipal "Saneamento" Fund: having the purpose of contributing to financial actions on water supply and sanitation within BH (Decree 11289/2003);

• The Water Supply and Sanitation Strategic Plan; and

• The Municipal Conferences on “Saneamento”: an instrument of intense public participation on the decisions related to the water supply and sanitation policy.

Stormwater management has been entirely under the responsibility of the BH municipality since the city foundation. Traditional stormwater systems prevail in the city, although experiences with detention ponds have existed since the 1950s. There is a 4,300 km network of roads all equipped with gutters, inlets etc. The municipal database on the drainage infrastructure has details on 64,000 inlets (gullies), 11,500 manholes, 1,100 outflow structures (outfalls), and almost 770 km of stormwater sewers. There are some 700 km of perennial creeks in the municipal area. Parts of these creeks have been lined to the extent of nearly 200 km, most of them as culverted concrete channels (Figures 35 and 36).

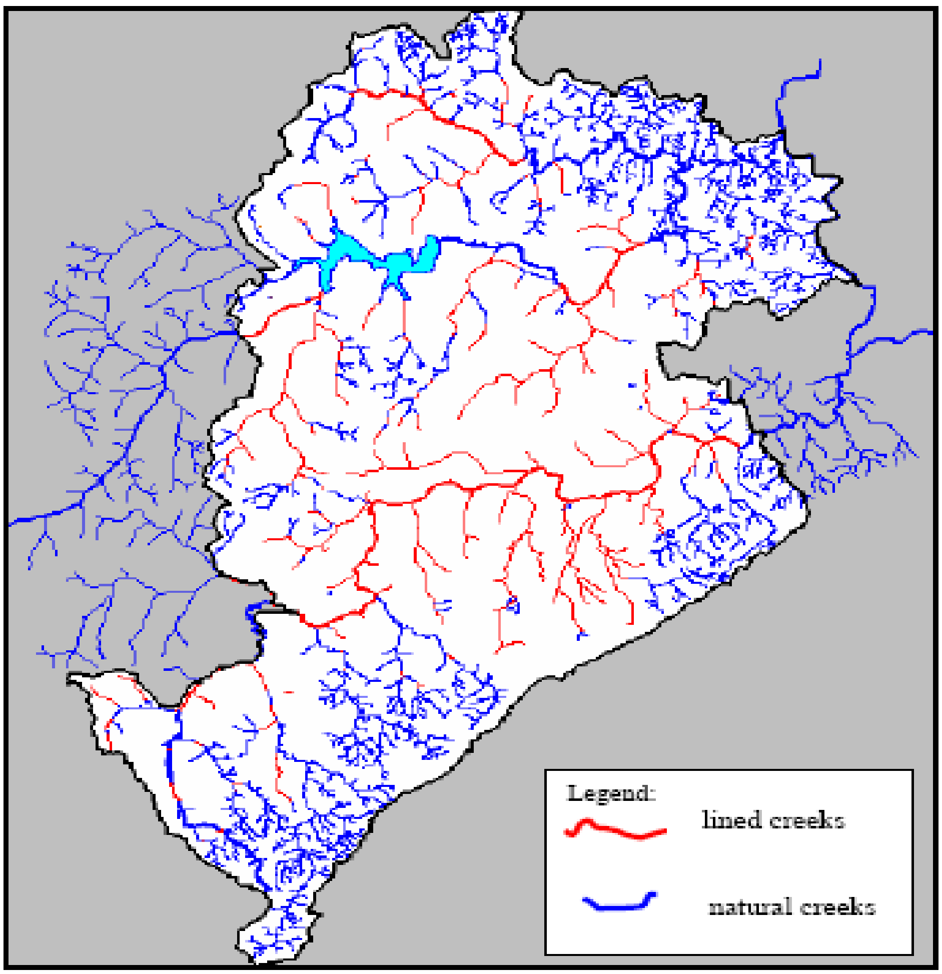


Figure 35 The hydrography of Belo Horizonte distinguishing between lined and natural creeks.

Figure 36 First lining works on the Arrudas Creek during the 1920s.

The creek lining policy, which prevailed up to the 1990s, was mainly justified by the following rationale:

• Lining is required to increase the flow velocity and the channel conveyance, reducing the flood risk;
• Lining facilitates the incorporation of interceptor pipelines and the so called 'sanitary roads';
• Lining makes the maintenance of the creek easier;
• Health risks due to direct human contact with polluted waters may be reduced by creek lining;
• Inhabitants of riparian zones usually ask for creeks to be lined.

However, using concrete box culverts as a "solution" to aesthetic, odour, garbage and water-borne disease problems related to heavily polluted streams demonstrates an oversimplified approach to stormwater management. The apparent simplicity of stormwater management, as perceived during most of the last century, led to the use of very simple design methods for storm water systems. Synthetic models were used which did not require observed data to calibrate parameters (e.g. rational method and synthetic unit hydrograph). Since observed data were not considered necessary for stormwater management, the BH municipality did not invest in monitoring stream discharges or water quality parameters. One of the consequences of this approach is high uncertainty in hydrologic design. A similar oversimplification also prevailed in hydraulic design. Complex flow conditions, including the effects of stream confluences, flow transitions or unsteady flows, were infrequently considered and model simulations of these conditions were infrequently carried out. Only uniform flow conditions were regularly considered in the design of channel structures, which usually resulted in underestimations of flood risk and flood effects.

The intense urban growth during the 1970s (Figure 37) combined with inequalities in the distribution of income has led to huge impacts on water quality in receiving bodies and an increase of flood risk (Figure 38).This is mainly due to the impacts of new urban developments causing an increase of imperviousness and also to the occupation of flood prone areas. Most frequently, flood prone areas are occupied by poor people precisely because the land is less valued and inappropriate for legitimate construction (Figure 39).

Water pollution by wastewater discharges and diffuse pollution inputs, including solid waste and the products of severe erosion processes have caused the degradation of water quality in streams and the reduction of conveyance capacities of sewers and channels due to sediment deposits (Figure 40). Detention basins have also been heavily impacted (Nascimento *et al.*, 1999b). An example is the Pampulha detention basin (PDB), part of one of the city's most important urban complexes.

A close correlation has been observed between the population growth and the number of flood events in Belo Horizonte (Figure 41) and Figure 42 illustrates the spatial distribution of flood occurrences in the BH territorial region.

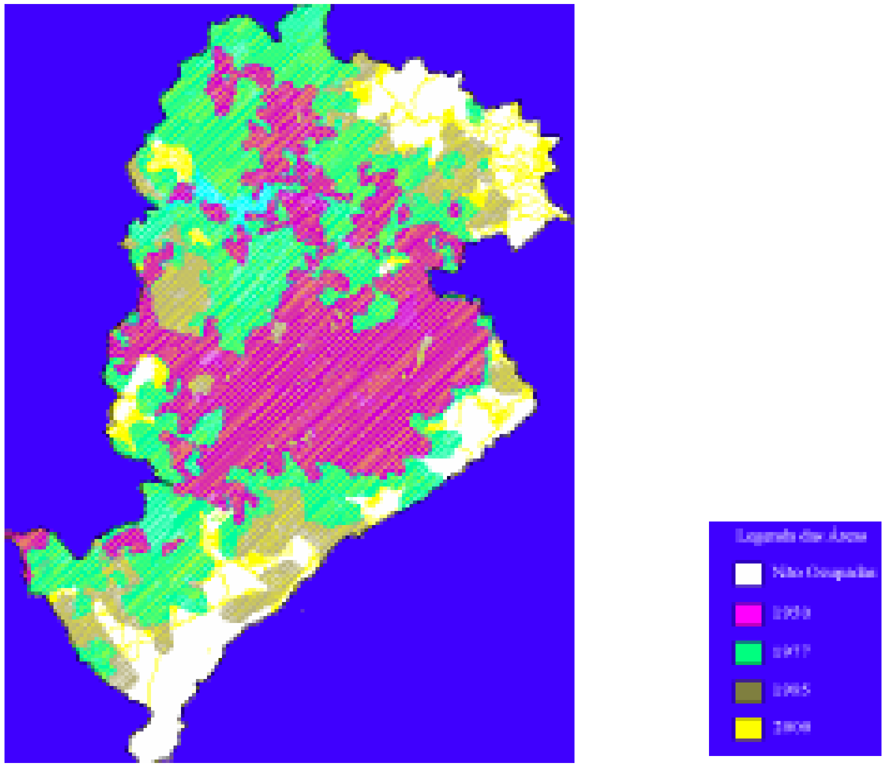


Figure 37 Urban development within Belo Horizonte, 1950 – 2000.

Figure 38 A flood event in the Arrudas flood plain area.

Figure 39 Occupation of flood prone areas by low-income urban development

Figure 40 Sediment and solid waste trapped in lined and culverted channels.

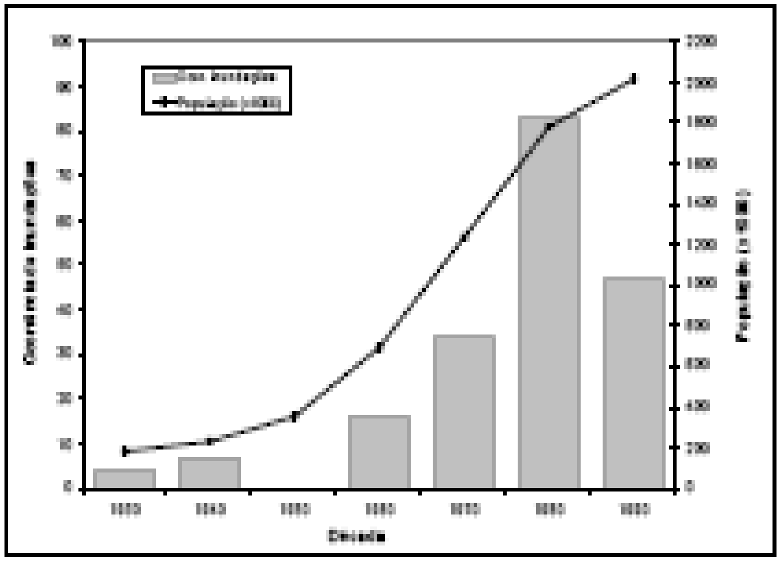


Figure 41 Population growth (dotted line) and number of flood occurrences (bars) during the period 1930 to 1990 (Champs, Aroeria and Nascimento, 2005)

With the implementation of the municipal Storm Water Strategic Plan (SWSP) combined with the Water Supply and Sanitation Strategic Plan (WSSSP) the formal stormwater and sanitation policies have recently changed. As an example, an ongoing programme, DRENURBS aims to retain the remaining natural creeks in the urban and suburban areas. This programme is supported and partially funded by the BID (Inter-American Development Bank – IDB). The SWSP includes the building of some 40 new detention basins in the urban area, with a main purpose of flood control. There are still relatively few concerns related to stormwater diffuse pollution although the problem obviously exists. This is mainly because pollution of water bodies by wastewater is intense enough to mask the effects of diffuse pollution on water quality.

As part of the SWSP the BH municipality has already implemented the following actions:

- A survey programme on land use and on stormwater existing infrastructure, assessing the physical characteristics of all the existing system components;
- A stormwater maintenance programme focusing on the present BH storm water infrastructure, involving structural renovation of drains, culverts, lined channels, natural channels, etc;
- The implementation of a GIS and a database system gathering data about the storm water system. This GIS is compatible with the previous and more general municipal GIS which contains a huge database about BH including layers on land use, road system, public buildings, health care system, etc.

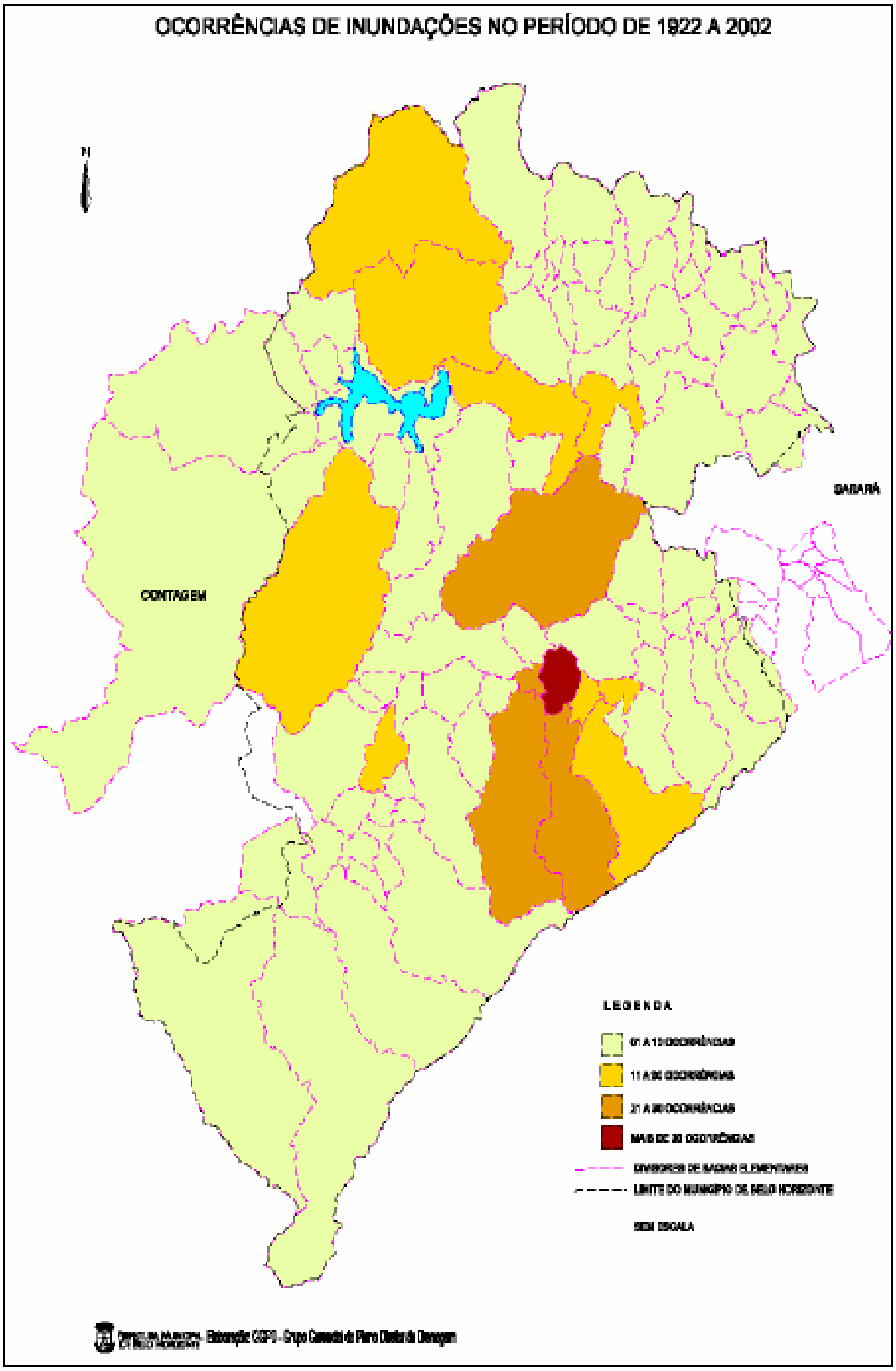


Figure 42Number of reported flood occurrences in the period 1922-2002
Colour scale: yellow stands for less then 10 occurrences; red for more than 30 occurrences

Presently, the on-going Stormwater Strategic Plan and the Water Supply and Sanitation Strategic Plan focus on the following programmes:

a) the DRENURBS programme: creek restoration in the urban area, which involves not only the restoration of polluted creeks but complete sanitation, risk management (risk of flooding, risk to public health …), and a housing programme addressed at people living in risk prone areas (improvement of housing conditions, removing people from flood risk areas);

b) the stormwater monitoring programme: establishing and operating a rainfall, discharge and water quality measurement network to allow the identification of BH stormwater problems at the present time and to contribute to the future evaluation of the efficiency of control measures implemented according to the stormwater plan. This DRENURBS programme will also contribute to impact assessment of urbanisation on water resources and to the statement of land use regulatory measures aiming at the mitigation of these impacts.

c) the rainfall-runoff and hydraulic modelling programme: data generated by the monitoring programme will feed models that will be employed to diagnose the functioning of the storm water system to devise the main causes of system operational problems and to simulate different control measure scenarios. The first phase of this programme started in 2006. In this phase, modelling will be performed prior to the monitoring programme, using data from the existing rainfall measurement network and from detailed surveys on land use and on the stormwater sewerage system characteristics, already concluded. Modelling results from this phase will be useful in devising actions to deal with critical and urgent problems and in designing the monitoring network.

d) the research and technological development programme: the main programme goal is the development of stormwater management technologies to solve the principal stormwater problems. Although the final scope of the programme has not yet been concluded, the following themes will certainly be part of it:

- physical modelling of specific hydraulic structures, like gutters, culvert entrances and confluences with the purpose of efficiency evaluation under particular conditions that prevail in BH (steep channels, high flow velocities, frequent changes in water flow regimes, …) and design criteria statements;
- evaluation of the volume of solid waste transported by the storm water system during storms and assessment of the waste typology (this is a common problem in many Brazilian towns, due to failures in solid waste management);
- experimental investigation through pilot experiments of the efficiency of source control devices (BMPs, infiltration trenches, pervious pavements, detention facilities,…) in terms of runoff and pollution abatement, maintenance requirements, building and operational costs, design criteria statement, etc. Although there is important literature available on this subject, local particularities need to be considered (e.g. rainfall intensity, sediments and solid waste, public acceptance, maintenance requirements, costs …).
- Assessment of the benefits of flood control measures by an economic evaluation of direct and indirect flood damages.

e) the institutional and managerial development programme: this programme aims to provide a statement of legal, economic, institutional and managerial measures in order to improve storm water management in the BH municipality.

For the development of these programmes, the BID is contributing with 60% of the required funds and the BH municipality provides the remaining 40%. In BH, about 360,300 inhabitants live in shanty towns, poorly urbanized areas, mainly located on the hills around the legal urban area or in flood prone areas. These areas are subjected to frequent landslides or flooding during the intense rain events which typically occur in summer. The BH municipality has developed a successful risk management programme concerning landslides and floods, which has reduced injuries, deaths and damage. It consists essentially of preventive measures such as removing people from risk areas to safer locations and the development of emergency plans based on a network of small local risk management centres equipped with rescue teams (health professionals, engineers etc…) and appropriate equipment. Nevertheless, further progress is needed with regard to more preventive measures, urban development planning, and of course long term measures focusing on the social and economic inclusion of people living in shanty towns.

4.2.2 The Engenho Nogueira Creek Catchment

The Engenho Nogueira creek extends a distance of 2.6 km and drains a catchment area of 6.0 km². It is a tributary to the Pampulha stream which flows to the Onça stream, one of the main watercourses within the BH municipal area. Figure 43 shows the location of the Engenho Nogueira creek catchment (ENCC) within the Belo Horizonte (BH) municipal area. The catchment area is inhabited by 19,500 people, representing about 1% of the BH total population. Its population density is much lower than that of the BH total area, being 3,250 inhabitants/km^2 compared to 6,900 inhabitants/km^2 (Figure 44). This is, in part, explained by the fact that the catchment is partially occupied by Pampulha Airport, by the Federal University of Minas Gerais central campus and by one of the Brazilian Army quarters in BH.

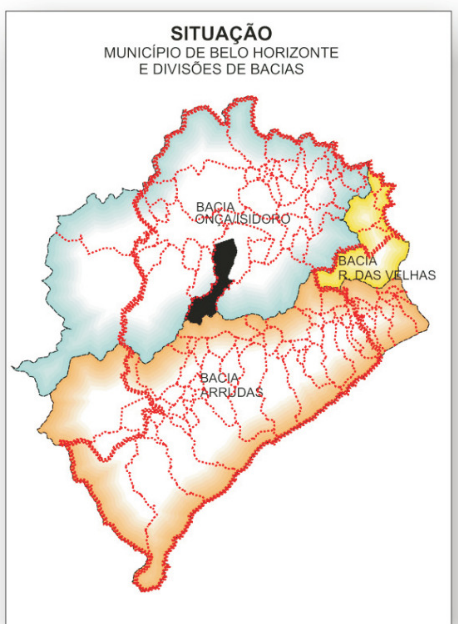


Figure 43 Location of the Engenho Nogueira Creek catchment within the BH Municipal Region (source: PBH, 2005)

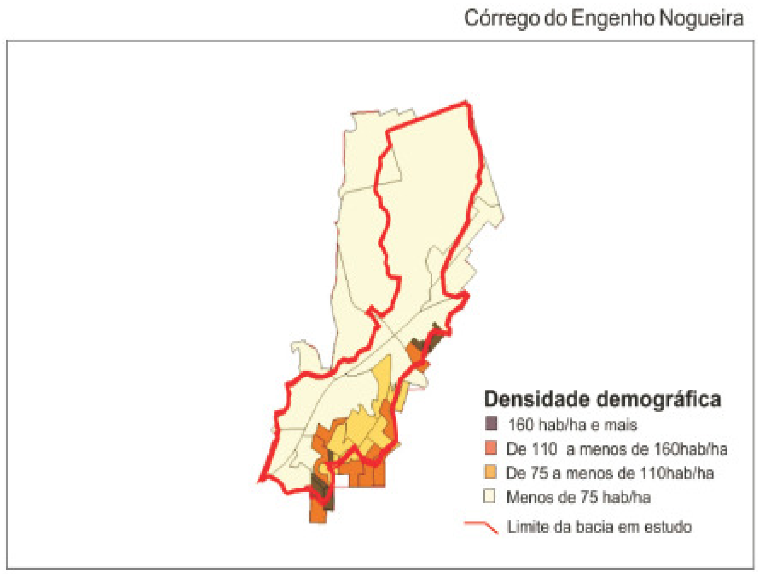


Figure 44 Population density distribution at the ENCC (source: PBH, 2005)

Three main roads cross the Engenho Nogueira creek catchment including a road ring connecting the urban area to the Brazilian highway network. Commercial and industrial areas are located along these roads and in the neighbourhood of the airport (malls, warehouses, parking lots …). The residential areas mainly occupy the hills in the upstream catchment as shown in Figure 44.

The ENCC is one of the 6 catchments selected by the BH municipality as priorities for the first phase of the DRENURBS programme. The main focus of this programme is on creek restoration in the urban area, a target that involves not only the restoration of creeks hugely impacted by the urbanisation process, in itself, but also complete sanitation, risk management (risk of flooding, risk to public health …), and a housing programme addressed at people living in risk prone areas (improvement of housing conditions, removing people from flood prone areas).

In the context of the DRENURBS programme, an environmental diagnosis of the ENCC was carried out by the municipality in 2002 (DRENURBS, 2002), in order to identify the main environmental problems in the area and the main needs of the catchment inhabitants in terms of sanitation, housing and risk control. The DRENURBS diagnosis assessment is also part of a Municipal Environmental Sanitation Strategic Plan (PMS, being its acronym in Portuguese, (PBH, 2004)). This assessment concerned all the Onça and Arrudas stream catchments, the two main watercourses of the municipal area and resulted in alternatives for integrated urban water management as well as for related public policies, such as housing, creation of green areas, improvements on the road and public transport systems and so on. The studies also addressed questions concerning technical, economical, environmental and social viability and feasibility of the different alternatives, as well as the environmental and socioeconomic impacts of the planned actions at two different scales: that of the selected catchments by the DRENURBS programme, and that of the Arrudas and Onça stream catchments that would result from the actions planned in each DRENURBS catchment.

For its first phase, the DRENURBS programme defined, among others, the following actions:

- Creek restoration on a total extension of 26 km;
- The construction of 5 detention basins;
- The setting up of green corridors, parks and squares, totalising 36 ha of additional green area;
- The construction of new sewer systems (30 km) and interceptor pipelines (31 km);
- The relocation of 1,365 dwellings from flood prone areas.

In the particular case of the ENCC, the DRENURBS diagnosis could identify problems as follows:

- frequent floods along the main watercourse;
- urban erosion problems near to the creek sources;
- water pollution mainly due to the dumping of solid wastes and wastewater directly into the watercourses.

Regarding the contamination of the catchment water bodies by wastewater, the main sources of pollution were identified as cross connections between the wastewater and the stormwater sewer systems as well as the lack of interceptor pipelines to properly deliver the collected wastewater to the WWTP. Figure 45 shows a typical section of the Engenho Nogueira creek reach in present conditions.

As part of the PMS and DRENURBS diagnosis studies, the locations of the main environmental problems within this catchment area were identified as illustrated by the catchment diagnosis map (Figure 46) (PBH, 2004).

Figure 45 A reach of the Engenho Nogueira creek (source: PBH, 2005)

Flood impacts in the ENCC are particularly important, with huge consequences to residents in the area, to academic activities at the UFMG central campus (which is frequently flooded), to important road links (as previously mentioned), and to Pampulha airport (which is also located in the Engenho Nogueira flood prone area).

Figures 47 and 48 illustrate results of hydraulic simulations of the Engenho Nogueira creek reach that crosses the UFMG central campus, performed with the model HEC-RAS (HEC, 1998). These are simulations of estimated 2-year and 10-year return period maximum discharges flowing in the channel reach. They essentially point out that overflows may occur even for events of very low return periods (T = 2 years). Furthermore, the simulation issues allow the visualisation of frequent changes in flow conditions, from subcritical to supercritical flow states, and vice-versa, mainly due to specific characteristics in the channel reach (e.g.: abrupt lateral restrictions, abrupt vertical transitions, slope changes …), which may contribute to increasing the risk of floods in the area.

The broad intervention plan to the ENCC was preliminarily defined according to the application of the general DRENURBS principles of restoring streams as near as possible to their natural conditions, ensuring complete sanitation and water pollution abatement as well as reducing flood risk. An outstanding public involvement in the decision-making process on the kind of interventions and actions to be implemented will be established focussing on the development of a detailed project for this area.

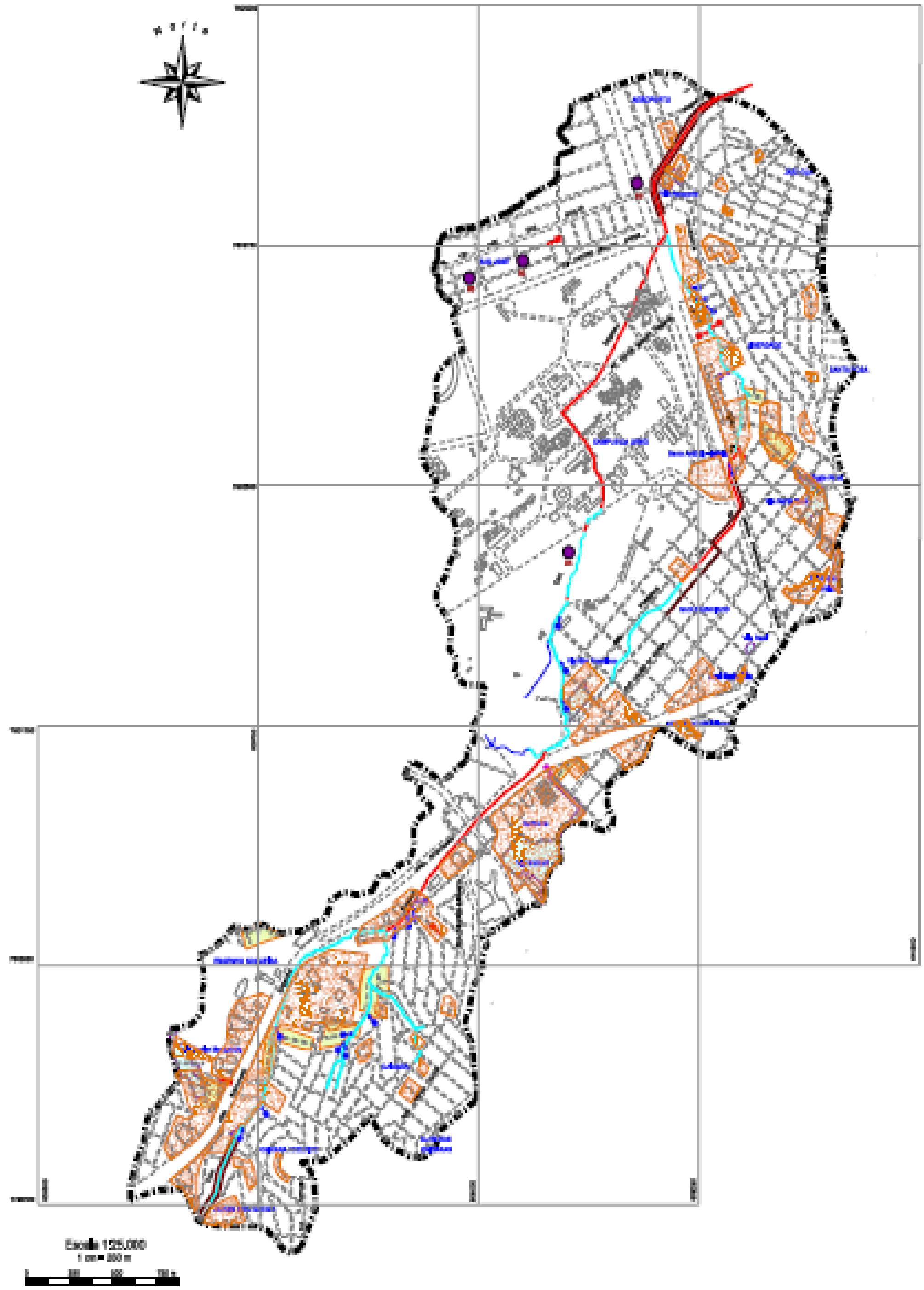


Figure 46 The Engenho Nogueira Creek catchment diagnosis map[1] (PBH, 2004)

[1] See the map key on the next page

Catchment borders

Lined creek

Non-lined creek (creek at natural state)

Creek not registered in the municipality data base (creek not surveyed)

Interceptor pipeline (wastewater)

Outflows of the sewer system to creeks, registered by COPASA* (wastewater)

Outflows of the sewer system to creeks, unknown by COPASA (wastewater)

Cross connections (from wastewater to stormwater systems), registered by COPASA

Cross connections (from wastewater to stormwater systems), unknown by COPASA

Registered floods (just one in 1980-1989 reference period)

Registered flood (more than one in the 1980-1989 reference period)

Slum areas

Areas without garbage collection service

Areas without sewer systems

Areas equipped with sewer and drainage systems and counting on garbage collection services

COPASA is the water utility in charge of drinking water and wastewater collection and disposal in Belo Horizonte

Figure 46 continued: Key for the ENCC diagnosis map

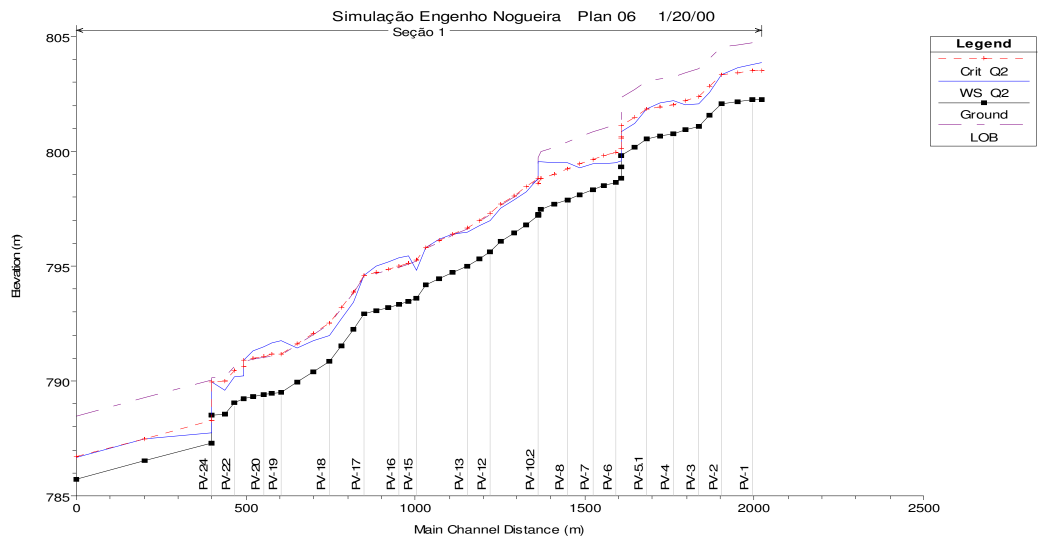


Figure 47 Engenho Nogueira creek longitudinal profile - UFMG campus reach with the water surface for the 2-y return period peak discharge

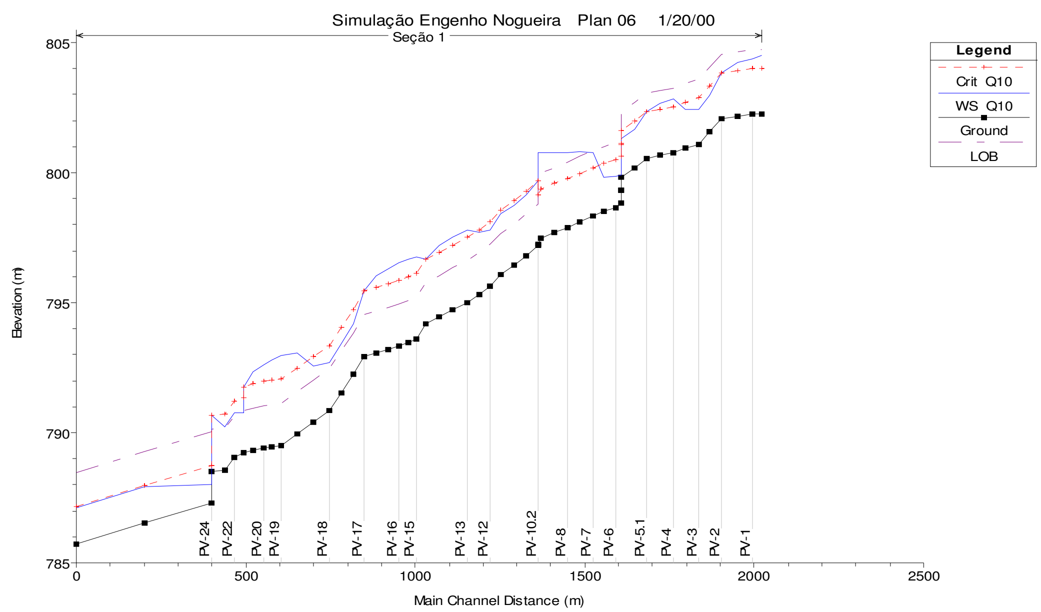


Figure 48 Engenho Nogueira creek longitudinal profile - UFMG campus reach with the water surface for the 10-y return period peak discharge

So far the interventions planned in the preliminary proposal phase are as follows:

- creek recovery, including river bed protection;
- 100% of the population covered with a sewer system, including interceptor pipelines;
- construction of two detention basins, mainly focussing on flood control purposes;
- treatment of erosion problems throughout the catchment area;
- improvements to the local road system;

- transfer of people from the flood prone areas to new houses built in the same catchment.

The flood control target is that the stormwater management system should contain the 50-year return period flood event. Water pollution control is focussed on the elimination of non-treated wastewater permanent outflows to receiving waters by the construction of interceptor pipelines, connection of remaining unconnected dwellings to the sewer system and elimination of cross connections, with a target fixed on collecting 100% of the sewage produced in the area. No specific targets are fixed in terms of reducing wet weather diffuse pollution. Notwithstanding this, some actions will contribute to the abatement of this kind of pollution as, for instance, measures focussing on erosion control in the catchment area and river banks, as well as improvements on garbage collection and road cleaning. The WWTP receiving the wastewater collected in this area is the Onça WWTP, a plant of secondary treatment capacity. The works will start in 2009 with a foreseen duration of 2 years and with estimated costs reaching R$ 28.4 millions (1 Euro = 2.60 Reais). Figure 49 maps a the planned preliminary main interventions.

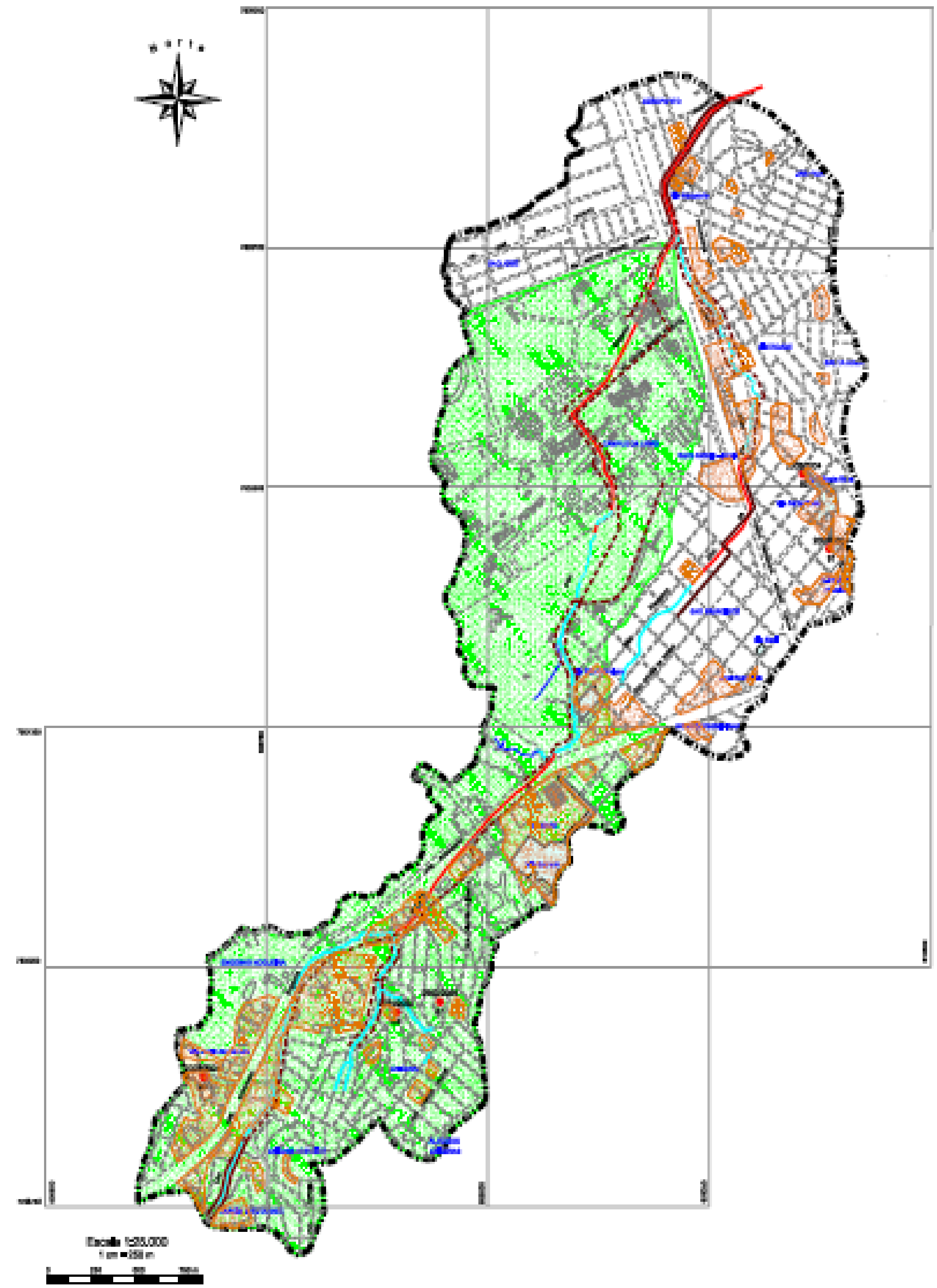


Figure 49 The Engenho Nogueira Creek catchment preliminary intervention plan[2] (PBH, 2004)

[2] See the map key in the next page

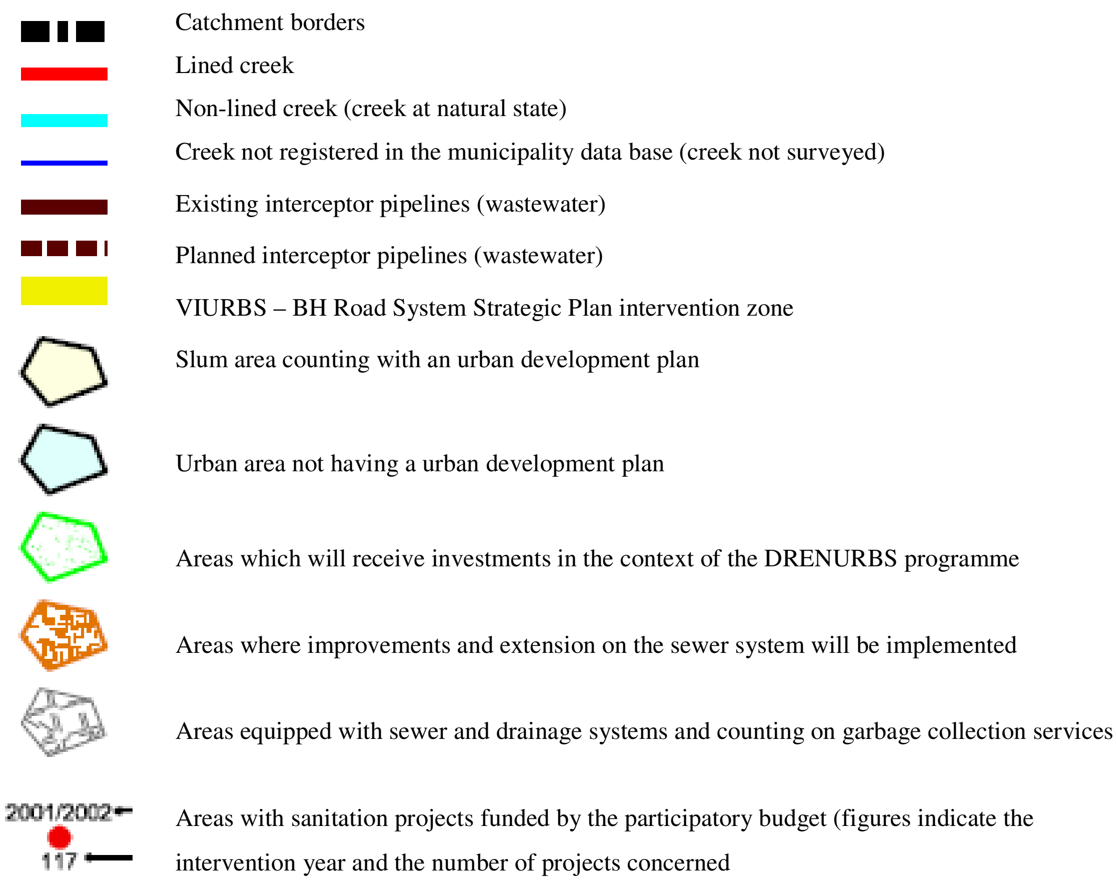


Figure 49 continued: Key for the ENCC map

4.2.3 The ISA Risk Indicator

The ISA is an indicator developed for the first edition of the Environmental Sanitation Plan (PMS) as an instrument to contribute to the decision-making process of stating priorities of actions and investments planned in the context of the PMS. For the first PMS edition concerning the 2004-2007 period, the ISA was calculated for each one of the 98 so-called elementary catchments of the municipal area. The elementary catchments are the smallest territorial units for urban planning in the municipal area. These territorial units are in accordance with the concept of adopting the river basin (catchments, in the case of Belo Horizonte) as the unit of analysis and planning and management. From now on, at intervals of four years the PMS will be updated and the ISA will be recalculated, allowing the assessment of the effectiveness of actions done in the previous period as well as the update of priorities for the next four years. Therefore, the ISA can also be seen as a tool for measuring the PMS effectiveness. Since the ISA factor has here been used as one of the information sources for the construction of the ENCC risk matrix, its derivation is explained in the following sub-sections.

4.2.3.1 The ISA Internal Risk Indicators

The ISA indicator consiste of 5 internal indicators as described in the following paragraphs.

The drinking water indicator **(*Iab*).** Considering that the water supply system (dinking water) connects to 99.7% of all BH inhabitants, this indicator is made equal to 1 for all the elementary catchments.

The wastewater indicator **(*Ies*);** This indicator is composed of two other indicators: the wastewater collection indicator and the wastewater interceptor indicator. The wastewater collection indicator (*Ice*) relates the number of inhabitants connected to the wastewater sewer system to the total inhabitants of the catchment area. The wastewater interceptor indicator (*Iie*) is calculated as the rate of the interceptor pipeline length existing in the area to the total interceptor pipeline length in the area, including the existing and the planned interceptors. The wastewater indicator (*Ies*) is then calculated by the following equation:

$$Ies = 0.65Ice + 0.35Iie \quad (1)$$

In the *Ies* equation, collection of wastewater (*Ice*) has a higher weight than the wastewater interception (*Iie*), which is justified by a higher priority ascribed by the municipality to removing wastewater from the household area in order to reduce the risk of direct contact to polluted waters.

The solid waste indicator (*Icl*); The solid waste indicator (*Icl*) relates the number of inhabitants who benefit by a garbage collection service to the total inhabitants in the catchment area.

The urban drainage indicator (*Idr*); The urban drainage indicator (*Idr*) is calculated on the base of flood events reported in all the municipal area covering the period from 1980 to 1999, according to the expression:

$$Idr = 1 - \frac{ev}{Ev} \quad (2)$$

where:
ev: number of flood events in the catchment area;
Ev: number of flood events in all the municipal area.

This is a much too simple approach for assessing urban drainage and stormwater management. It does not take into account the flood characteristics (flooded area, flood depth and duration), the flood impacts, and the vulnerability of the area to floods, as well as the local hydrologic risk of flooding (flood frequency). But it is consistent with data available at the time of the PMS first edition. A new indicator for urban drainage is under development taking into account the main issues of the recently concluded hydrologic and hydraulic modelling of the complete urban drainage system in the municipal area.

The control of vector indicator (*Icv*); This indicator takes into account a recent outbreak of dengue fever faced by different Brazilian cities, including Belo Horizonte. The dengue transmission process is closely related to lack of urban drainage and solid waste management. Furthermore, data available about the extent of this disease in Belo Horizonte are detailed and reliable.

To calculate the control of vector indicator (*Icv*), it is necessary to obtain, for each catchment area, the dengue indicator, by first calculating the distance of the number of dengue occurrences in the catchment area in respect to the number of occurrences in the municipal area:

$$A_f(\%) = \left(\frac{LDO_{1000}}{MDO_{1000}} - 1 \right) 100 \qquad (3)$$

where:

A_f: distance of the number of dengue occurrences in the catchment area in respect to the number of occurrences in the municipal area;

LDO_{1000}: number of dengue reported occurrences in the catchment area, per 1000 inhabitants;

MDO_{1000}: number of dengue reported occurrences in the municipal area, per 1000 inhabitants.

The *Idg* (dengue indicator), is made equal to 0 (zero) for the catchment with the highest A_f: and takes the value of 1 (one) for the catchment with the lowest A_f:. To the other catchments, the *Idg* takes a value in between 0 and 1. The *Icv* is made equal to the *Idg*.

4.2.3.2 The ISA derivation

The ISA indicator is calculated by adopting multiplying or weighting factors for the five indicators previously described according to the following equation:

$$ISA = 0.05Iab + 0.45Ies + 0.35Icl + 0.05Idr + 0.1Icv \qquad (4)$$

The multiplying factor for *Iab* is much lower than the other multiplying factors due to the fact that water supply connects almost 100% of all the BH inhabitants. In the case of *Idr*, the multiplying factor is kept low because data available on floods do not allow the conception of a representative and reliable indicator. A new indicator for urban drainage and stormwater management is under development and will be proposed by the beginning of 2009. The ISA can assume values in the interval of 0 to 1; the lower the value the poorer the catchment condition is in terms of environmental sanitation. Therefore, catchments having lower ISA values will be better placed for receiving investments in environmental sanitation infrastructure and service improvements.

4.2.3.3 The ISA for the ENCC

Table 9 lists the values assumed by the ISA internal indicators and the ISA itself for the ENCC and also average figures for all the 98 BH elementary catchments.

Table 9 ISA for the Engenho Nogueira Creek Catchment (PBH, 2004)

Area	ISA internal indicators							ISA
	Iab	***Ies***	***Ice***	***Iie***	***Icl***	***Idr***	***Icv***	
ENCC	1.0	0.6	0.78	0.26	0.97	0.98	0.33	0.74
BH average	1.0	0.77	0.86	0.59	0.95	0.99	0.61	0.95

Based on the ISA value of 0.74, the ENCC was positioned 22nd in the priority list in relation to the 98 elementary catchments in the BH municipality. Nevertheless, other criteria are also considered in the decision-making process, including:

- catchment population density;
- the urban development plan which exists for the catchment;
- other municipal programmes which place the area as a priority;
- the participatory budget defined interventions for the catchment area;
- the catchment counts on funds already approved for some of the planned interventions;
- funds for some of the planned interventions are under negotiation.

Combining the ISA with the other decision-making criteria, the ENCC was selected as one of the 6 priority areas for the DRENURBS programme first phase implementation.

4.2.3.4 The SWITCH Stormwater Risk Matrix for Threats for the Engenho Nogueira Creek Catchment (ENCC)

Table 10 presents the SWITCH risk matrix for identified threats within the Engenho Nogueira creek catchment, developed on the basis of general risks and threats assessed to Belo Horizonte (Nascimento *et al*, 2006) and the basic information existing about the ENCC previously described in this report.

Table 10 Engenho Nogueira Creek catchment Risk Matrix for selected threats according to the SWITCH methodology.

Identified threat	Level of consequence				Likelihood of occurrence				Risk score	
	Within the next 5 years	Score	In 25-30 yrs time	Score	Within the next 5 years	Score	In 25-30 yrs time	Score	Within the next 5 yrs	In 25-30 yrs time
Increase in occurrence of flooding	Very high, area prone to floods (reference return period of 2 yrs), resulting in high direct and indirect losses, including risk for human life	5	Works on flood control employing detention basins; control target stated in 50-yr return period. Dwellings relocated from high-risk areas.	2	Very high, area prone to floods (reference return period of 2 yrs)	5	Works on flood control targeted on containing the 50-yr return period event. Land use in the catchment is likely to result in increasing impervious area. Possible changes on storm characteristics due to climate change not included in stormwater design criteria. Detention basin failures due to poor operation and maintenance.	3	25 Level of risk: high	6 Level of risk: medium
Increase in wet weather diffuse pollution	High, creek is tributary to rivers used for water supply, fishing, washing and recreation	4	Medium. Planned enhancement of drainage system takes into account only part of pollution sources: improving urban erosion control and solid waste management.	3	Very high; increases in imperviousness due to urbanisation; wet weather pollution not properly considered; failures in other sanitation sectors, as in solid waste	5	Medium. Increases in personal earnings may result in increased car ownership. Increases in imperviousness due to urbanisation. Growing concern about wet weather	3	20 Level of risk: high	9 Level of risk: medium

					management		diffuse pollution. Improvements on stormwater management likely to occur.			

Table 10 (cont.)

Identified threat	Level of consequence				Likelihood of occurrence				Risk score	
	Within the next 5 years	Score	In 25-30 yrs time	Score	Within the next 5 years	Score	In 25-30 yrs time	Score	Within the next 5 yrs	In 25-30 yrs time
Persistent pollution of receiving waters associated to the sewer system	Very high due to lack of interceptors and cross connections. Creek is tributary to rivers used for water supply, fishing, washing and recreation.	5	Low. Planned improvements in the sewer system: construction of interceptors and reduction on cross connections.	2	Very high, due to lack of interceptors and cross connections.	5	Low. Planned improvements in the sewer system: construction of interceptors and reduction on cross connections. Target of eliminating cross connections not feasible.	2	25 Level of risk: high	4 Level of risk: low
Operational failure of WWTP	Medium: due to the lack of interceptors, most of the generated sewerage does not reach the WWTP.	3	Low: Planned improvements in treatment capacity and technology reduce the impact of failures.	2	High. WWTP works under its nominal capacity due to the lack of interceptors.	4	Low: Target of improving sewerage collection to 100% efficiency. Planned improvements on WWTP capacity and technology.	2	12 Level of risk: high	4 Level of risk: low
Risks associated to the use of BMPs	Low: health risks, risks of soil pollution will be low considering proper	2	Medium: possibilities of failure in operation and maintenance may result in increasing health risk and soil	3	Medium: Failures may occur due to uncertainties not accounted during the design process, land use changes, wet weather pollution	3	Low: Growing concern on wet weather diffuse pollution issues. Improvements on maintenance are likely to occur.	2	6 Level of risk: medium	6 Level of risk: medium

	maintenance.		pollution risk. Possibility of reducing public acceptance of BMPs		not properly taken into account. Failures in maintenance.		Planned monitoring system may contribute to better maintenance and the development of improved design criteria.			

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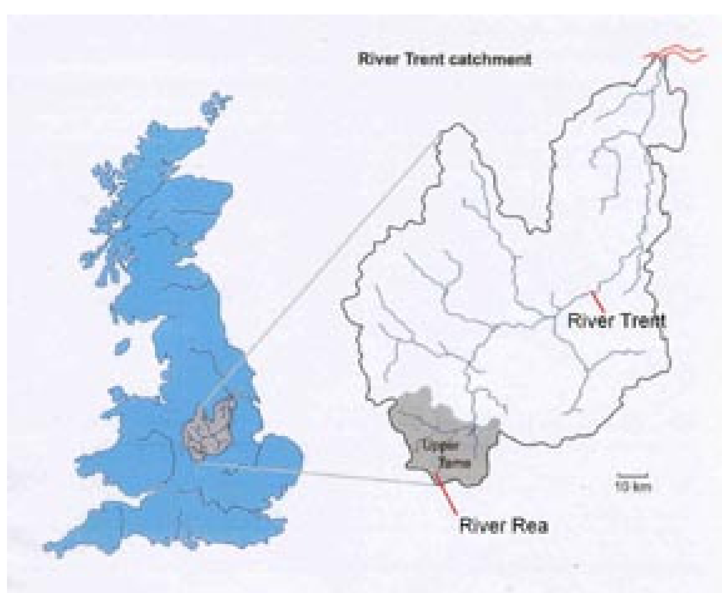
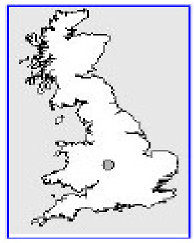
APPENDIX 1. The Rea Catchment

The Rea Catchment and Birmingham Districts.



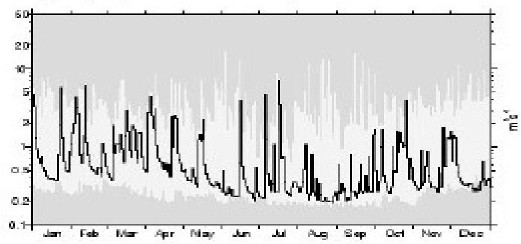
APPENDIX 2. EA Summary for Calthorpe Park Gauging Station. NRFA Reference 28039.

Grid Reference:	42 (SP) 071 847
Operator:	EA
Local number:	4039
Catchment Area:	74.0 km^2
Level of Station:	104.2 mOD
Max. Altitude:	291.0 mOD
Mean flow:	0.80 m^3s^{-1}
95% exceedance (Q95):	0.241 m^3s^{-1}
10% exceedance (Q10):	1.559 m^3s^{-1}
61-90 Av. Ann. Rainfall:	781 mm

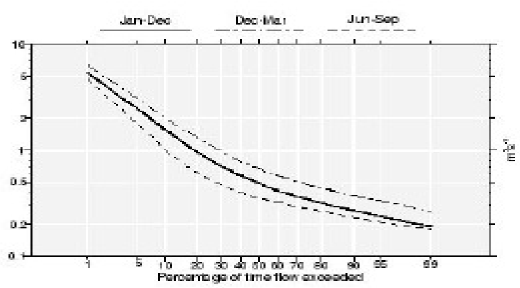


Sample Hydrograph of Gauged Daily Flows

Max. and min. daily mean flows from 1967 to 2001 excluding those for the featured year (2001; mean flow: 0.76 m^3s^{-1})



Flow Duration Curve for Gauged Daily Flows



Station Description

Crump profile weir, 3.66m wide, with flanking broad-crested weirs set in a formalised, roughly rectangular channel. Model rated. High flow gauged off nearby footbridge, but hazardous owing to high velocities. Prone to u/s siltation.

Significant imports modify flow regime.

Catchment Description

Almost totally urbanised catchment overlying clay except in the headwaters in the Lickey Hills. Very responsive, used for flood forecasting.

Factors Affecting Runoff

- Runoff increased by effluent returns.

River Flow and Catchment Rainfall on the National River Flow Archive

Gauged Daily Flows (gdf): 1967 to 2001
Monthly Catchment Rainfall (rnf): 1967 to 2001

Datatype	1960s	1970s	1980s	1990s	2000s
gdf					
rnf					