Urban drainage design and climate change adaptation decision making

Since the middle of the 19th century urban drainage has been a vital infrastructure in cities. Traditionally, urban drainage has been used as a convenient cleaning mechanism for public hygiene and an efficient conveyance facility to tackle floods for life and assets protection. From the early 20th century, the design objectives of urban drainage systems also include elements such as environmental protection and amenity values. Among the objectives, flood protection has received much attention in recent years as a result of increasing flood hazards and risks due to climate change impacts. Although mitigation steps have been taken in attempts to reduce global warming, adaptation is highly advocated to supplement mitigation to cope with the unavoidable adverse impacts of flooding on vulnerable assets. The emphasis of this PhD thesis is flood protection in the context of pluvial flooding by investigating new principles and approaches for assessment of urban drainage adaptation measures under climate change impacts. The thesis describes a new framework for design and analysis of urban drainage that accurately assesses hazards and vulnerabilities of urban areas and quantifies the present and future risks based on projections of climate change and city development. Furthermore, this framework can be utilized to identify cost-effective measures that can reduce the overall flood risk to an acceptable level considering both costs and benefits of adaptation. The framework is mainly based on a utilitarian approach that studies urban drainage adaptation solutions from a socio-economic point of view. The methodologies involve the state-of-the-art flood inundation modelling, risk assessment tools, socio-economic analysis tools, city planning, and uncertainty analysis. The thesis has explored several limitations of the current design practice of urban drainage. To further supplement and develop the common practice, a systemic and integrated framework is proposed by incorporating three research areas: (i) risk-based economic approaches for assessment of climate adaptation design, (ii) uncertainty analysis of climate adaptation assessment and (iii) reframing the assessment approaches by incorporating additional benefits and costs of adaptation alternatives. To strategically provide a functional performance of urban drainage systems, a risk-based economic approach is developed to take into account the impacts of all probable floods in terms of their probabilities and consequences (e.g. extents of floods, costing of damage). It is found that this approach contributes to a better understanding of the contributions of different return periods/flood events to the overall risk under both current and future climatic conditions and therefore can be used as guidance for further adaptation actions (e.g. formulation of an appropriate service level). Furthermore, the risk-based economic approach enables an assessment and comparison of the expected benefits (due to saved flood damage) and corresponding costs of different adaptation measures. This gives more detailed insights into the pros and cons of different adaptation options, thus helping to optimize the efficiency and performance of urban drainage adaptation design. The thesis investigates impacts of uncertainties associated with not only the hydrological conditions (e.g. design intensities, climate change impacts), but also the present and future vulnerability conditions (e.g. impacts on assets). This enables a complete assessment of effects of various uncertainties in the climate change assessment process. Furthermore, in the study, two types of uncertainties are distinguished: 1) the overall uncertainty of an individual adaptation scenario, which may influence the choice of action; and 2) the marginal uncertainty between adaptation alternatives in order for a direct comparison of their efficiency once a decision of action is taken. Based on assessments of the two types of uncertainties, it is found that although climate change adaptation assessment is often associated with large uncertainties, it is still possible to identify robust adaptation options based on calculated marginal uncertainties. This is because that the uncertainties related to costing of floods and magnitude of climate impacts will be levelled out when comparing adaptation alternatives. In addition, a sensitivity analysis is also incorporated in the framework to assess the relative contribution of inherent uncertainties in the assessment. This allows an identification of critical/important uncertainties that matter for decision making and also provides a guide for further efforts to improve decision making in relation to climate change adaptation. Traditionally, assessment of climate change adaptation is based on conventional engineering solutions, meaning that only response impacts in the context of hydrological extremes are considered while the added intangible values (e.g. recreational amenities due to a nice blue-green neighbourhood) of adaptation options are often ignored or underestimated. In order to facilitate the development and implementation of water sensitive urban design concepts climate change adaptation tools must take into account the additional benefits of using these concepts. This thesis develops a reframed design framework to account for such intangible goods/values of adaptation options. This serves as a valuable basis for evaluating the benefits of provision of positive environmental values and the preservation of water resources. It is found that neglecting intangible values in climate adaptation assessment can easily bias the decision making; the reframed approach hence provide an important tool for assessment of additional benefits and costs of such innovative solutions. The thesis points towards an integrated framework for urban drainage adaptation design considering climate change effects and adaptation benefits and costs. The case studies show how the proposed framework can be utilized to manage the anticipated climate change risks in a cost-effective way under different circumstances. The introduced framework provides an important supplement or replacement of current design practices under influence of climate change.