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Evaluating And Optimizing Sustainable Drainage Design To Maximize Multiple Benefits: Case Studies In China

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A SYSTEMATIC FRAMEWORK FOR EVALUATION OF MULTIPLE BENEFITS OF DRAINAGE DESIGN: CASE STUDY IN AUSTRALIA

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Achieving sustainability and maximising multiple benefits have become the main focus of modern infrastructure design. Drainage engineers and planners are facing an increasing challenge of justifying multiple drainage design options in real life. In order to streamline the decision making process, a multi-criteria evaluation framework has been developed. In this paper, a case study based on a typical development site in Australia is used to illustrate the usage of the evaluation framework.

INTRODUCTION

In the past, the focus of drainage design was on sizing pipes and storages in order to provide sufficient network capacity. This traditional approach, together with computer software and technical guidance, had been successful for many years (DoE/NWC, 1981). However, due to rapid population growth and urbanisation, the requirements of a "good" drainage design have also changed significantly. In addition to water management, other aspects such as environmental impacts, amenity values and carbon footprint have to be considered during the design process.

Going forward, an alternative approach using a combination of traditional (e.g., pipes and storage) and green infrastructures (e.g., ponds, swales, wetlands) is recommended. In UK, drainage systems using this sustainable approach are recognised as Sustainable Drainage Systems (SuDS) (Woods-Ballard et al., 2007). Similar (but not identical) systems are called Low Impact Development (LID) or Best Management Practices (BMPs) (USEPA, 2006) in US and Water Sensitive Urban Design (WSUD) in Australia (Brown et al., 2007). In this paper, the term sustainable drainage system is used for consistency.

The key challenge of moving from simple objectives (e.g., capacity and costs) to complicated objectives (e.g., capacity, flood risk, environment, amenity, etc.) is the difficulty to strike a balance between various objectives and to justify potential benefits and trade-offs. In order to assist decision makers, a new decision support system for drainage design has been developed (Chow et al., 2013). In this paper, a case study based on a typical development site in Australia are used to illustrate the usage of the framework.

METHODOLOGY

A systematic evaluation framework has been developed to quantify both drainage system performance and monetary measures. The technical details and configuration of the framework can be found in Chow et al (2013). Figure 1 below gives an overview of the framework structure.

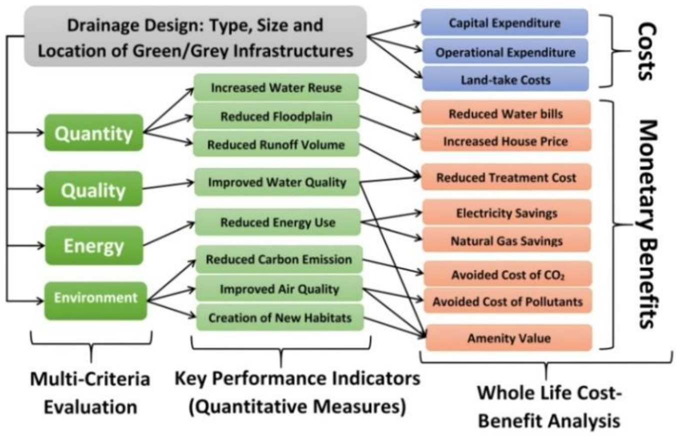

Figure 1. Overview of the systematic, multi-criteria evaluation framework (Chow et al., 2013).

SITE OF INTEREST

In order to illustrate how the framework can be applied to real-life problems, a typical development site in Yarralumla, Australia has been selected for case study. The site is highlighted in Figure 2 below and it is surrounded by developed areas. The natural runoff generally flows from South East to North West.

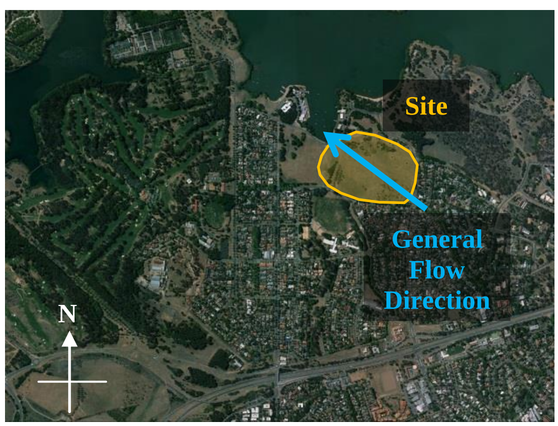

Figure 2. Selected development site for case studies in Yarralumla, Australia.

PROPOSED DRAINAGE DESIGN

One of the key philosophies of sustainable drainage design is to mimic or enhance natural flow patterns (Woods-Ballard et al., 2007). For that purpose, a design consisting of six sustainable drainage components is proposed. Runoff is controlled and allowed to flow from South East to North West, mimicking a natural runoff route. Figure 3 below shows how the proposed design is modelled using drainage design software XPDRAINAGE (XP Solutions, 2014).

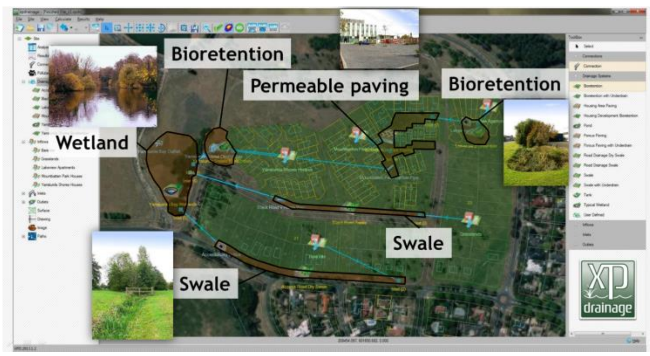

Figure 3. A drainage design modelled in XPDRAINAGE.

EVALUATION PART I – DRAINAGE SYSTEM PERFORMANCE

Using the evaluation framework, the design is evaluated numerically. For example, in Figure 4 below, annual runoff reduction and added amenity value, are shown and compared. According to the results, permeable paving (left, light blue) is effective in reducing runoff but it does not add amenity value (absent from right). On the other hand, the swale components (left, pink and brown) are not as effective as permeable paving in runoff reduction. Yet, they can contribute to added amenity value.

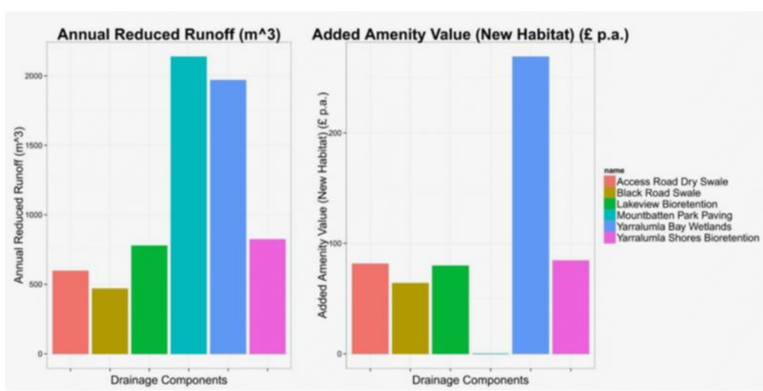

Figure 4. Evaluation of multiple benefits.

EVALUATION PART II – CAPITAL AND OPERATIONAL EXPENDITURE

The other important aspect of a drainage design is its costs. In Figure 5 below, the operational and capital expenditure (annualised) incurred by individual drainage components are shown and compared. The capital expenditure (e.g., materials and construction) of permeable paving (light blue) is significantly higher than others. Yet, cost is only one of the factors in the overall consideration. By comparing costs and other performance measures (as discussed in last section), decision makers can have a better understanding of the big picture instead of a narrowed view based on specific measures.

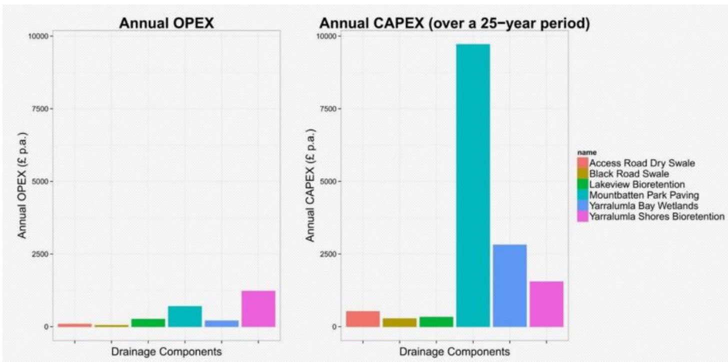

Figure 5. Evaluation of monetary measures.

COMPARING DIFFERENT DESIGN APPROACHES

In previous sections, drainage components within the same design are evaluated individually. Yet, in reality, it is more important to compare the overall performance of a design instead of individual components. Therefore, in this section, a comparison between two different designs is shown. We modified the original design (as discussed above) and replaced some sustainable drainage components with storage tanks. In order to carry out a like-for-like comparison, the storage tanks were sized to minimise the difference in the outflow of both designs. Yet, it is inevitable that the hydraulic behaviours are fundamentally different. The modified design with storage tanks is considered a more traditional approach. The model is shown in Figure 6 below.

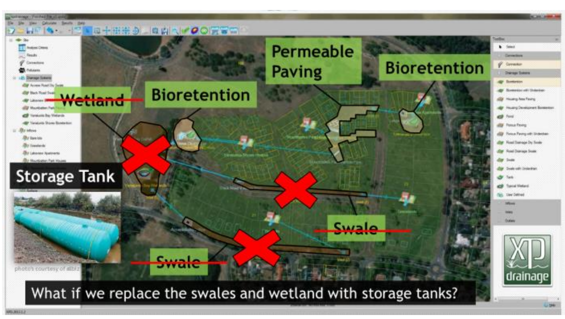

Figure 6. Modifying original design to include storage tanks.

For illustration and comparison purpose, we name the original design as “sustainable” and the modified design as (more) “traditional”. The evaluation framework was then applied to both designs. The results are shown in Figure 7 below.

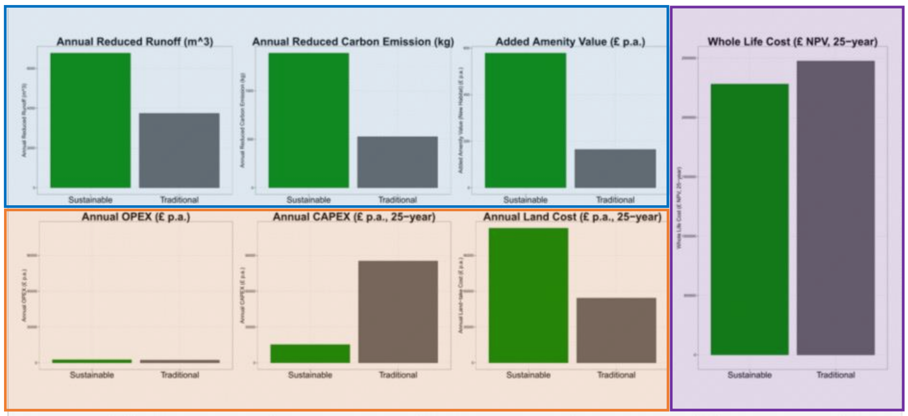

Figure 7. Comparison of two drainage designs.

First, multiple benefits expected from each design are compared (blue area, top left). The sustainable design offers more benefits, in terms of runoff reduction, reduced carbon emission and added amenity value, than the traditional design. This is explainable as we replaced three sustainable drainage components (two swales and one wetland) with storage tanks which do not offer additional benefits.

Next, the economics of both designs are compared (orange area, bottom left). The operational costs for both designs do not differ much. Yet, the capital expenditure for the modified design is significantly higher than the original design. This is due to the materials and construction costs incurred by the inclusion of three storage tanks. Considering just the operational and capital costs alone, one might agree that the sustainable approach is better. However, when the value of the land is added to the mix, the picture becomes slightly different. As the selected site is located in a sub-urban area of Australia, the land value is considerably lower than in crowded city centres like Sydney, London, Shanghai, etc. The sustainable design, despite being a lot cheaper than the modified design to construct, occupies more surface area due to the use of sustainable components. This evaluation framework gives a straight-forward, effective way to compare all costs.

Finally, by summing up all monetary measures (both long-term cost and benefits) and applying a discount rate, a whole life cost comparison can be made (purple area, right). Over a 25-year period, the sustainable drainage is expected to be cheaper in this case study. In reality, it is up to the users of the framework to decide the length of period for the whole life cost calculation.

Although this comparison example is basic and only shows some of the performance measures, it illustrates how the evaluation framework can help decision makers to compare different design options with numbers and charts effectively. This tool is important as, in reality, decision makers might need to consider multiple drainage designs at the same time. It is important to streamline the workflow and keep the comparison consistent.

CONCLUSION

As the focus of drainage design shifted from ensuring sufficient network capacity to maximising multiple benefits, new decision support tools are needed to assist decision making process. This paper presents a systematic evaluation framework for drainage design that has been developed for this purpose.

A case study based on a typical development site in Australia is used to illustrate the usage of the framework. First, drainage components within a proposed design are evaluated individually. The purpose is to explain some of the fundamental components of the framework. After that, two different drainage designs, each evaluated as a complete system, are used to show the importance of having such evaluation framework.

As decision makers face the challenge of having multiple drainage design options in real life, it is important to have an effective and consistent evaluation routine. By using a systematic evaluation framework, the potential benefits of different drainage designs can be evaluated consistently and communicated effectively. This will help streamline the drainage design workflow and provide evidence-based decision support through the design cycle.

Beyond evaluation, an optimisation engine has also been developed to link with the evaluation framework. The optimisation engine and case studies can be found in a related paper (Chow et al., 2014). The work carried out so far enables one to narrow down specific areas of interests and future development. Further work is required to better understand the relationships between benefits and the uncertainty of underlying performance measures.

ACKNOWLEDGEMENT

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