CATCHMENT-SCALE STORMWATER QUALITY IMPROVEMENT STRATEGIES: WHAT TO DO? WHERE? AND HOW MUCH WILL IT COST?

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ABSTRACT

Regional councils in New Zealand are facing increasing pressure to address an array of contaminants and improve urban stormwater quality and reduce impacts on rivers and beaches. Contaminants like bacteria, metals and nutrients are pervasive and often exceed regulatory limits in a substantial percentage of samples collected from urban stormwater outfalls. To address these contaminants, catchment-scale stormwater quality improvement strategies are needed, as directed by the National Policy Statement for Freshwater Management. This paper presents the process and findings from multiple next-generation, quantitative stormwater quality planning efforts by municipalities along the West Coast of the United States including southern California and Washington state. The outputs from linked models to simulate baseline catchment conditions and the effectiveness of stormwater control measures are a key element of stormwater planning. The presented modelling approaches emphasize process-based models that are open source and public domain (LSPC, HSPF and SUSTAIN). The cost-optimization modelling provides a pathway toward developing high-efficiency stormwater quality programs and supporting development of more reasonable implementation schedules. Web-based tracking systems, which are also open domain, can facilitate a "hands on" environment for the public to understanding model outputs. During the implementation phase, web-based systems can also support tracking and demonstrating progress toward defined schedules and milestones. Combined, these tools can transform stormwater programs from relying on qualitative, anecdotal data to adopting quantitative analyses that allow for targeted, efficient and transparent programs with multiple benefits for the public. The National Policy Statement for Freshwater Management provides an impetus and opportunity for regional councils to adopt stormwater quality improvement programs that provide substantial benefits to both ecosystems and communities.

KEYWORDS

stormwater, water quality, contaminant, catchment, modelling

PRESENTER PROFILE

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1 INTRODUCTION

Regional councils are facing increasing pressure to address an array of contaminants and improve urban stormwater quality and reduce impacts on rivers and beaches. Contaminants like bacteria, metals and nutrients are pervasive and often exceed regulatory limits in a substantial percentage of samples collected from urban stormwater outfalls (http://www.bmpdatabase.org/). To address these contaminants, catchment-scale stormwater quality improvement strategies are needed, as directed by the National Policy Statement for Freshwater Management (2014).

This paper presents the process and findings from multiple next-generation, quantitative stormwater quality planning efforts by municipalities along the West Coast of the United States including southern California and Washington state. The outputs from linked models to simulate baseline catchment conditions and the effectiveness of stormwater control measures are a key element of stormwater planning. The presented modelling approaches emphasize process-based models that are open source and public domain (LSPC, HSPF and SUSTAIN). The cost-optimization modelling provides a pathway toward developing high-efficiency stormwater quality programs and supporting development of more reasonable implementation schedules. Web-based tracking systems, which are also open domain, can facilitate a "hands on" environment for the public to understanding model outputs. During the implementation phase, web-based systems can also support tracking and demonstrating progress toward defined schedules and milestones.

2 COMPONENTS OF CATCHMENT SCALE STORMWATER QUALITY PLANNING

When reviewing the approaches used along the West Coast of the U.S., a quantitative framework for catchment-scale stormwater quality planning consists of three components, as follows:

1. **Process-based modelling system** with linked components to simulate baseline catchment hydrology/water quality and the effectiveness of stormwater control measures. Process-based catchment models include Loading Simulation Program – C++ (LSPC) and Hydrologic Simulation Program – Fortran (HSPF). The preferred process-based model for simulating the performance of stormwater control measures in terms of flow, concentration and load reduction is the System for Urban Stormwater Treatment Analysis and Integration (SUSTAIN). All of these models are public domain, peer-reviewed and free for download. See **Figure 1**.

2. **Scenario builder or viewer** to allow the stormwater agency and stakeholders to review modelling outputs and weigh the related outcomes including costs versus benefits; green versus gray infrastructure; centralized versus distributed approaches; and more. Web-based approaches for the viewer allow the stakeholders to easily access and use the viewer, while also simplifying updates and distribution of the most recent modelling results. See **Figure 2**.

3. **Implementation tracking system** that allows agencies and stakeholders to upload stormwater control measures completed to date and evaluate the cumulative performance of implemented measures. Web-based approaches allow project information to be presented in a user-friendly frontend while the backend stores project information and handles performance calculations. Performance calculations can be conducted through an array of performance curves based on pre-run simulations (e.g., using SUSTAIN) or through "modelling on the fly" where the user inputs are converted into modelling input files and the results are

harvested from output files in real-time. See **Figure 3** for an example "dashboard".

These components are further described in subsections below.

2.1 BASELINE HYDROLOGY AND WATER QUALITY MODEL

Baseline hydrology and water quality models are the foundation of stormwater quality planning. Projects along the West Coast of the U.S. have included detailed hydrology and water quality calibrations for each stormwater plan, as follows:

- **Water quality calibration:** the water quality calibration process leverages two primary monitoring datasets: (1) small-scale, land use-specific water quality monitoring data collected locally and (2) large-scale receiving water monitoring data collected by routine monitoring by stormwater programs.

- **Hydrology calibration:** streamflow gages were used for the hydrology calibration.

The model calibration is conducted across numerous catchment, and outputs are generated to demonstrate the calibrated modelling system is able to accurately predict flows and contaminant concentrations in each catchment. As shown in **Figure 4,** the calibration process often includes analysis from upstream to downstream gages, or from areas with homogenous land use to mixed land use. Also, uncertainty in boundary condition data is considered during the calibration process.

2.2 SIMULATE PERFORMANCE OF STORMWATER CONTROL MEASURES

Once the model is set up to accurately simulate baseline hydrology and water quality conditions, the required contaminant reductions to achieve regulatory limits (numeric attribute states in the NPSFM) can be been estimated. Then, the next stage of stormwater quality planning involves identifying the optimal combination of stormwater projects ("control measures") to achieve the regulatory limits (numeric attribute states). The representation of control measures in the model is an important element, as it provides the link between future catchment activities, model-predicted water quality improvement, and, ultimately, attainment of water quality standards (numeric attribute states).

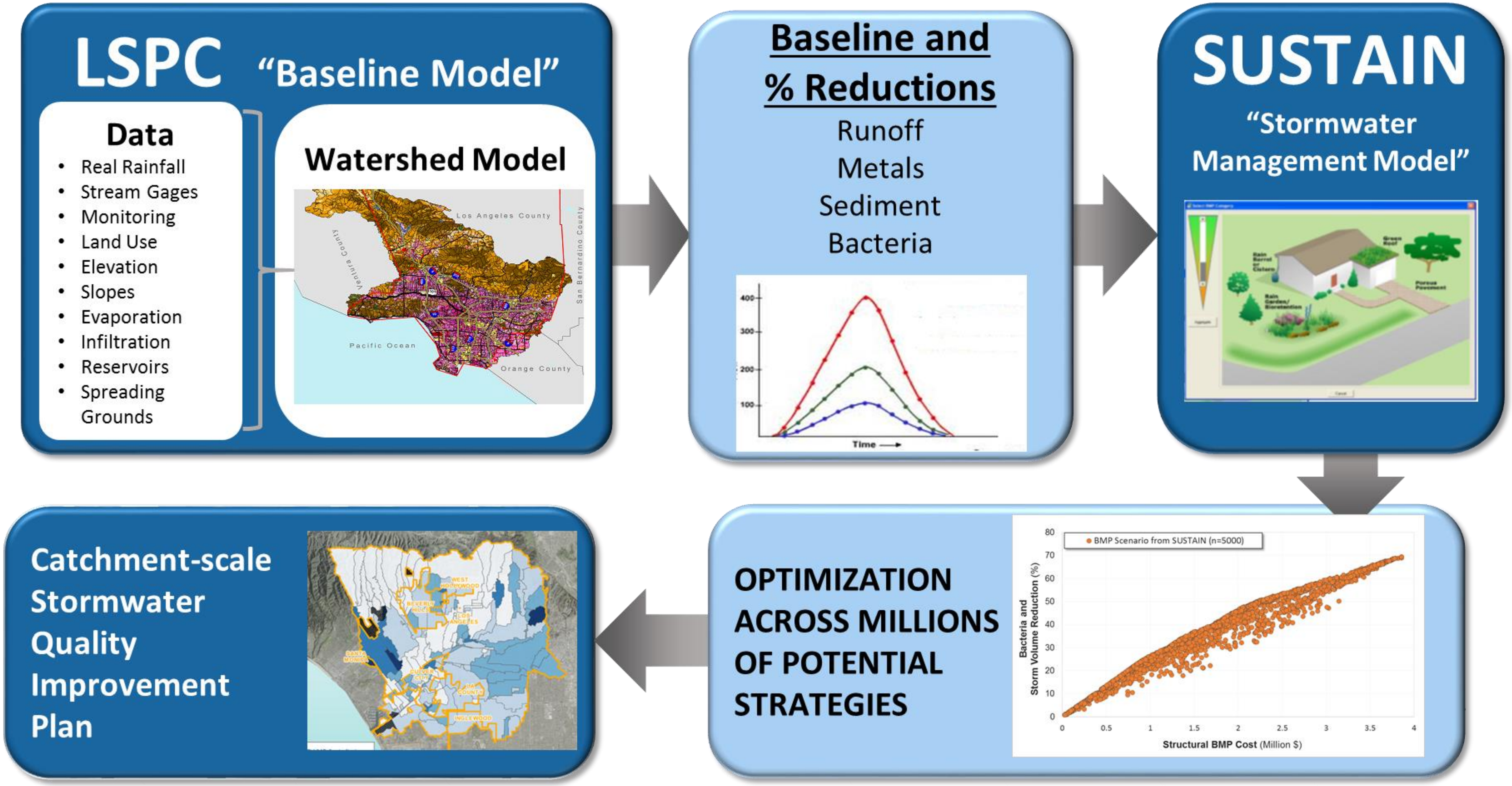

Figure 1. Illustration of Process-based Modelling System to Support Development of Catchment-scale Stormwater Quality Plans

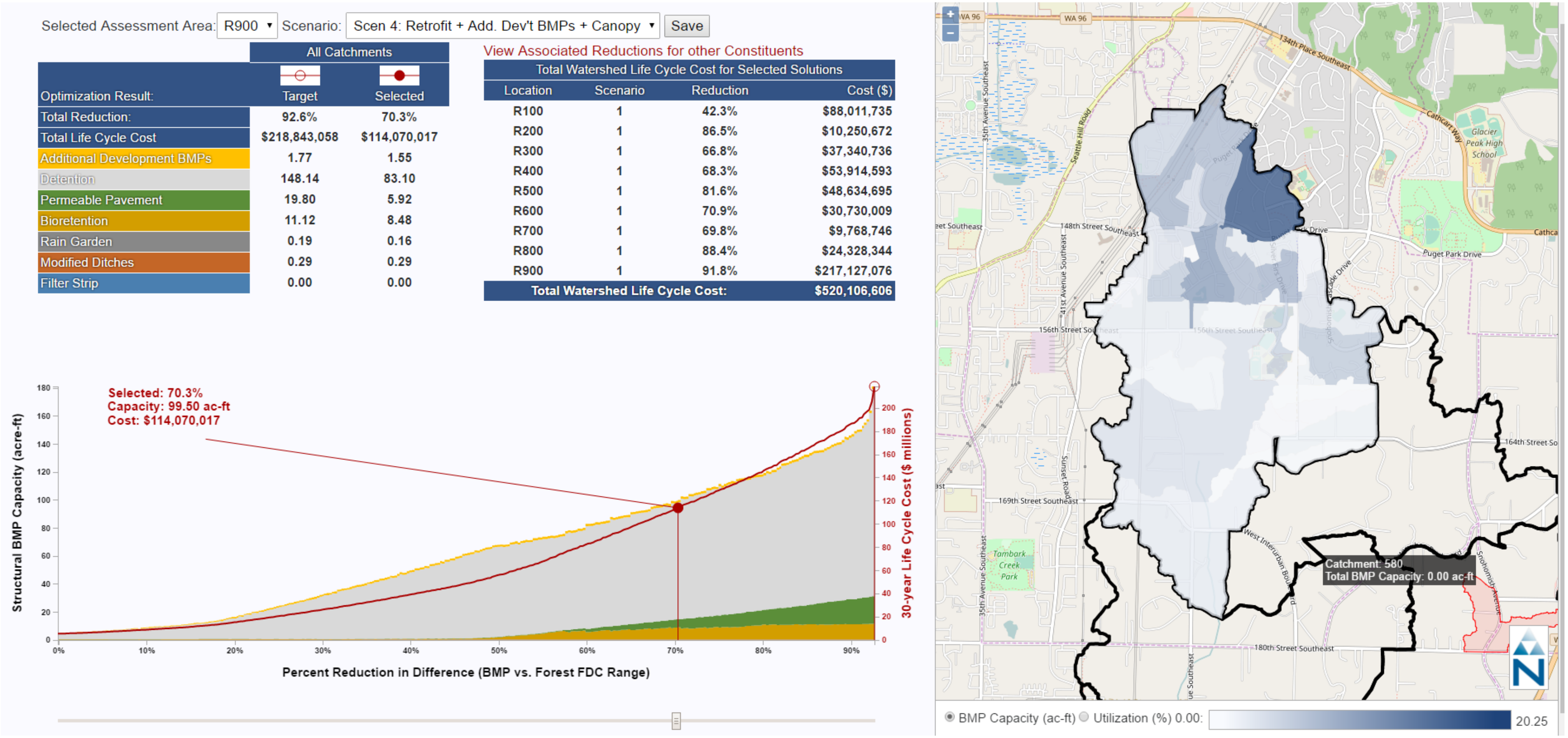

Figure 2. Example Web-based Scenario Builder/Viewer with User Entries at Top of Screen, Modelling Outputs at Bottom of Screen and GIS-based Viewer on Right

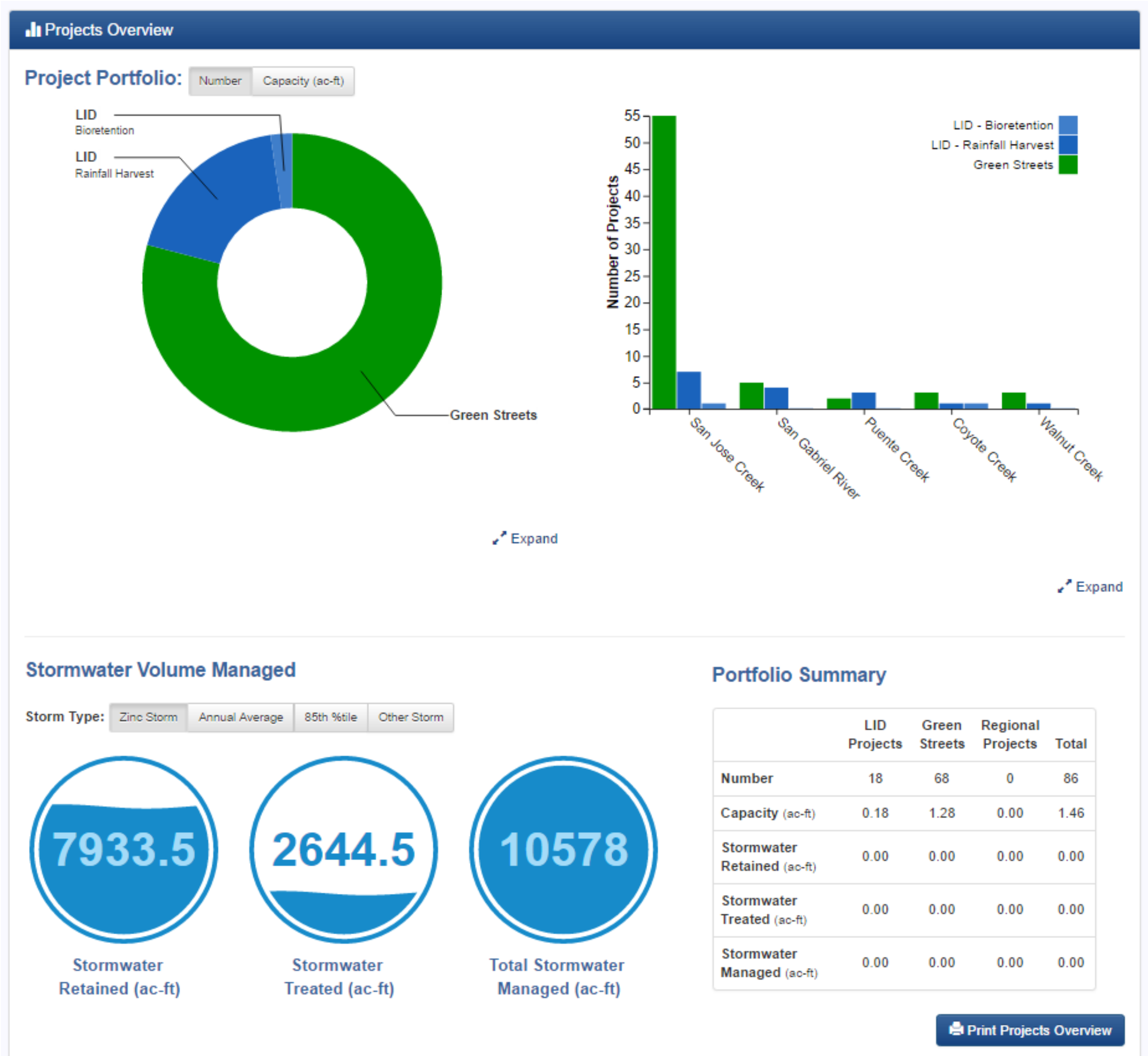

Figure 3. Example Dashboard from a Web-based Tracking System for Stormwater Control Measures

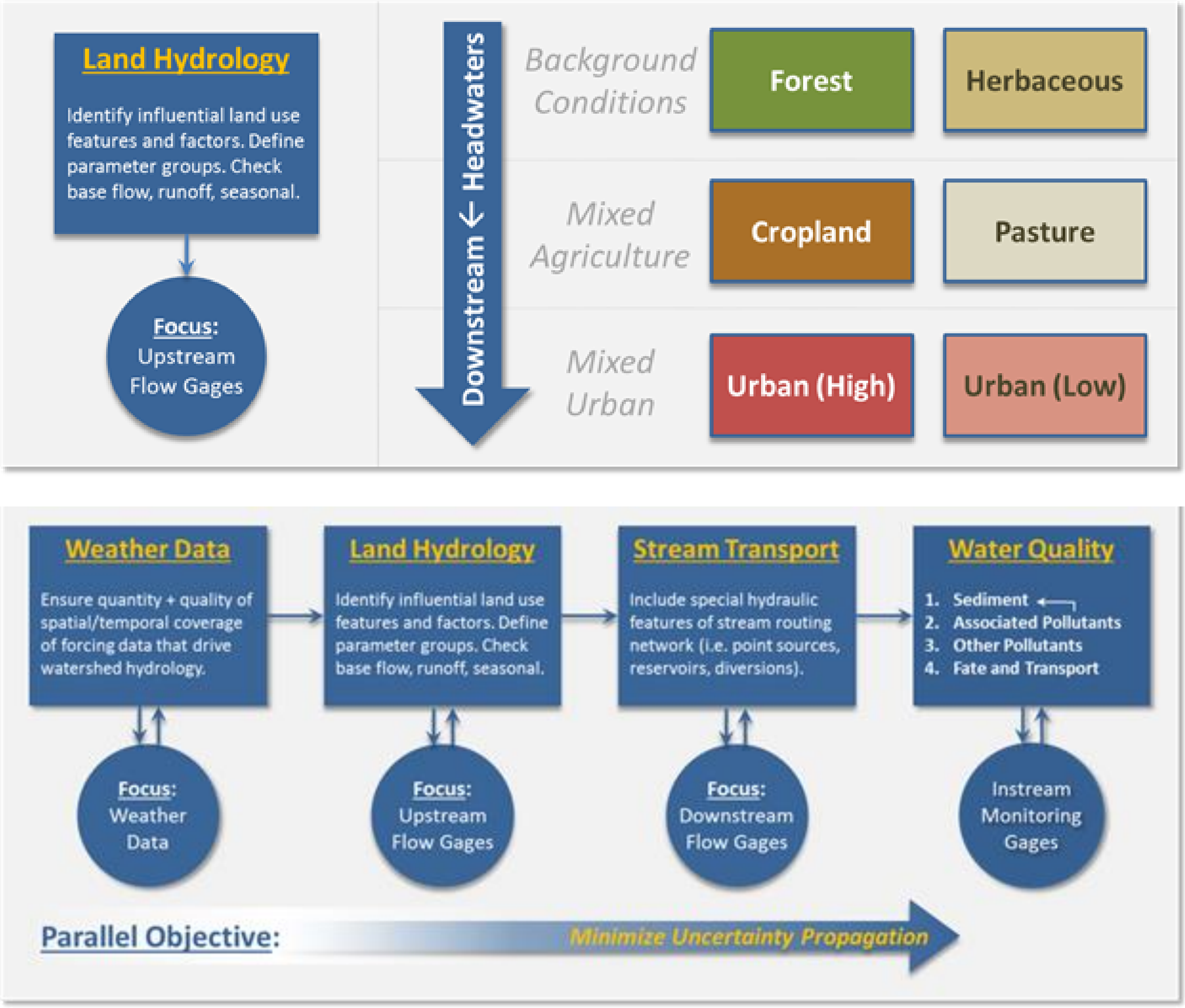

Figure 4. Illustration of Baseline Calibration Process Considering Land Use (top) **and Uncertainty of Boundary Condition Data** (bottom)

The three main categories of stormwater control measures include low-impact development (referred to as "low impact design" or "water sensitive design" in New Zealand), green streets, and regional projects, as defined below:

- **Low-Impact Development (LID):** these are distributed devices that capture, infiltrate, and/or treat runoff at the parcel, normally less than 5 tributary hectares. Common LID practices include bioretention, permeable pavement, and other infiltration projects that prevent runoff from leaving a parcel. Since the vast majority (nearly 70 percent) of runoff from the developed portion of the catchment is generated from impervious areas on parcels, LID is a natural choice as a key improvement strategy to treat runoff from parcel-based impervious areas. LID can be viewed as the "first line of defense" due to the fact that the water is treated on-site before it runs off from the parcel and travels downstream.

- **Green Streets:** these are distributed devices that are typically implemented as linear bioretention/ biofiltration installed parallel to roadways. These systems receive runoff from the gutter via curb cuts or curb extensions (sometimes called bump outs) and infiltrate it through native or engineered soil media. Permeable pavement can also be implemented in tandem or as a standalone practice, such as in parking lanes of roads. Green streets have been demonstrated to provide "complete streets" benefits in addition to stormwater management, including pedestrian safety and traffic calming, street tree canopy and heat island effect mitigation, increased property values, and even reduced crime rates (LINK)

- **Regional projects:** regional projects are centralized facilities located near the downstream ends of large drainage areas (typically treating tens or hundreds of hectares). Regional projects receive large volumes of runoff from extensive upstream areas and can provide a cost-effective mechanism for infiltration and pollutant reduction. Runoff is typically diverted to regional projects after it has already entered storm drains. Regional projects are key to recharging groundwater supplies and offsetting demand for potable water. Routing offsite runoff to public parcels (versus treating surface runoff near its source, as with green streets and LID) often allows regional projects to be placed in cost-effective locations.

The cost optimization modelling used to select the most cost-effective catchment-scale strategies considers three primary elements:

- **Opportunity** – Where can the control measures be located and how many can be accommodated?

- **System Configuration** – How is the runoff routed to and through the control measures and what is the maximum size of each control measure based on specified design constraints?

- **Cost Functions** – What is the relationship between control measure volume/footprint/design elements and costs? For example, the capital cost of regional projects in southern California are approximately $0.5-1.0 million $USD per acre-foot of storage (1 ac-ft = 0.12 ha-m).

Stormwater quality improvement strategies can be based on the most cost-effective scenarios (after evaluating millions of options), while incorporating the input from the decision-makers and stakeholders and considering the needs and opportunities within the communities. **Figure 5** shows an example illustration where the size of control measures dictates the volume of stormwater that can be captured and treated.

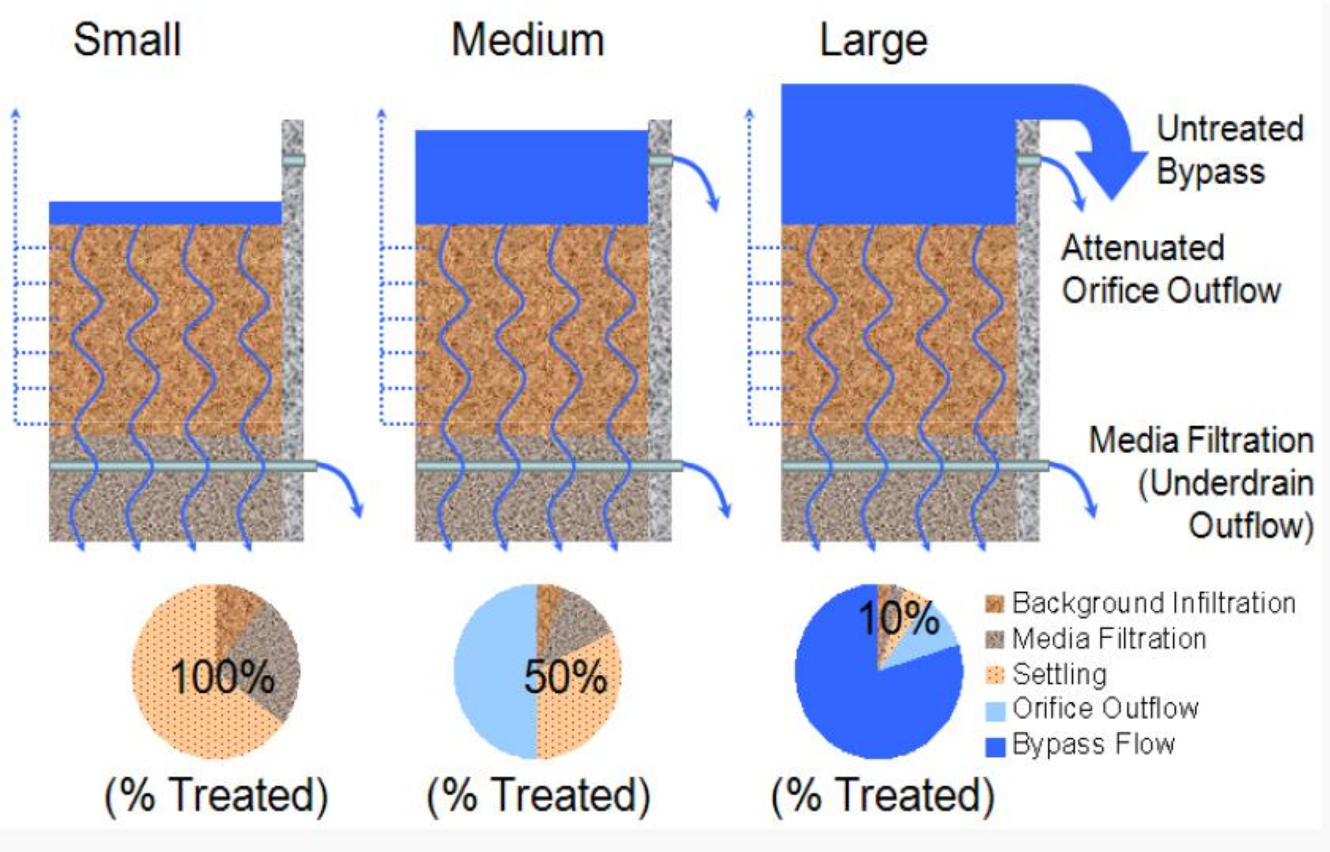

Figure 5. Illustration of the Importance of Storm Size for the Effectiveness of Capture and Treatment, which is Considered during Optimization for each Stormwater Project

2.3 EVALUATE DIFFERENT APPROACHES FOR THE STRATEGY

The process-based modelling described above inherently evaluates millions of options for improving stormwater quality, based on different increments of cost and size of the control measures within the menu. At the same time, based on stakeholder input, additional "layers" of scenarios can be generated each with its own optimization. Example of alternatives that might be evaluated include the following:

- Limiting the extent of green versus gray infrastructure in the menu (e.g., excluding green streets or green roofs as an option)
- Adjusting the storm size (e.g., targeting a 2mm storm versus 5mm storm)
- Adjusting the target for water quality attainment (e.g., choosing Numeric Attribute State A instead of Numeric Attribute State C from the NPSFM)

It can be challenging for decision makers/stakeholders to wade through these many layers of modelling outputs – especially if they are presented within appendices to technical documents. Instead, web-based scenario viewers, as shown in **Figure 2**, are efficient tools to engage interested parties and allow them to consider the different options and the corresponding implication on cost, water quality, etc.

2.4 TRACK IMPLEMENTATION AND QUANTIFY PROGRESS

Adopted stormwater quality improvement plans often have a schedule for implementation. Shown in **Figure 6** is an example 20-year implementation schedule for a large catchment in Los Angeles County, California. During the implementation phase, it is important for agencies and the public to be able to track progress toward defined milestones. Web-based systems have been developed to allow users to:

- Upload projects and see them on a map;
- Track the number and type of projects that have been built;
- Quantify the cumulative performance of implemented projects for stormwater capture and treatment;
- Compare cumulative project performance to milestones/goals defined in the system; and
- Generate reports for compliance / annual reporting.

As can be seen in **Figure 3** (bottom left hand panel), the performance of projects depends on the storm being evaluated. For example, projects capture much more stormwater during a "wet year" when compared to a "dry year". Performance calculations can be handled in the backend of the system through a series of performance curves based on pre-run simulations (e.g., using SUSTAIN) or through "modelling on the fly" where the user inputs are converted into modelling input files and the results are harvested from output files in real-time.

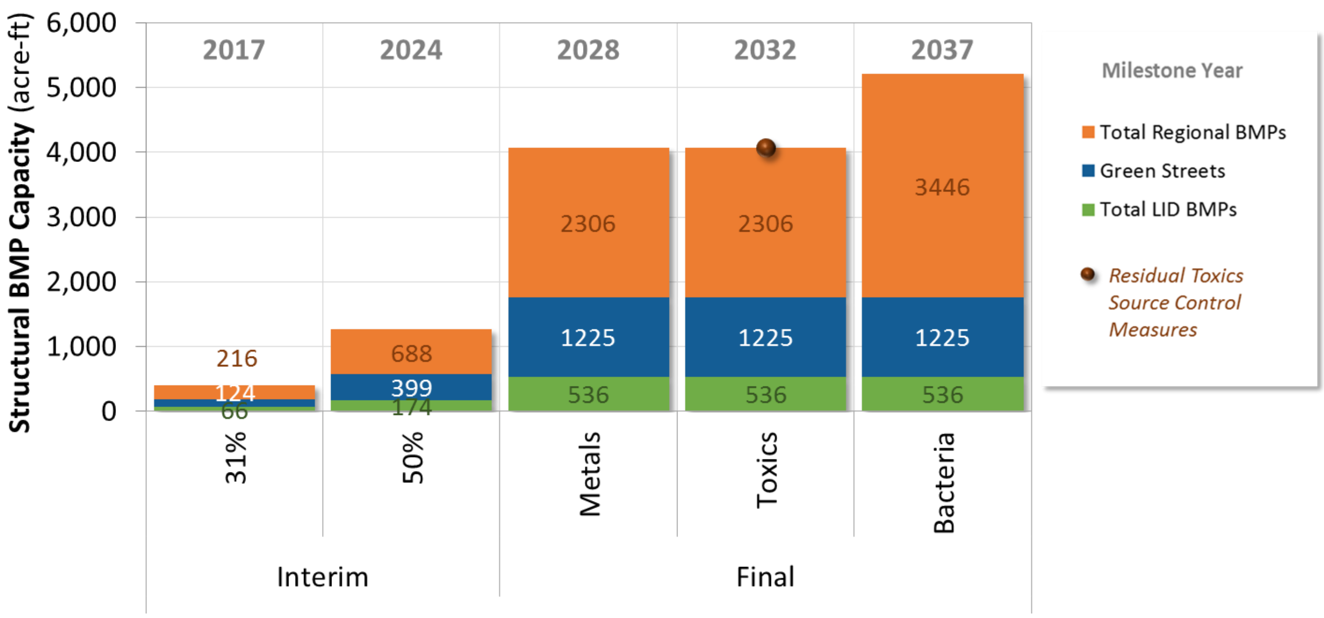

Figure 6. Example 20-year Implementation Schedule as Defined by a Stormwater Quality Improvement Plan (1 ac-ft = 0.12 ha-m)

3 CONCLUSIONS

Recent advancements in modelling and web-based systems have greatly improved the ability of regional councils to develop reliable, efficient stormwater quality improvement plans. These plans can be presented to the public for a variety of scenarios that demonstrate potential costs and benefits. For example, while the public may desire low contaminant levels during large storm events (e.g., 10mm), those benefits come at a cost; after seeing the costs to size projects to capture larger storms, the public may choose more reasonable sized storms (5mm) as the basis for stormwater quality improvement planning. Through web-based tools the public is given an opportunity to understand the modelling outputs in a "hands on" environment. Web-based systems also facilitate flexibility and accountability for regional councils to track and demonstrate progress toward agreed-upon schedules. Combined, these tools can transform stormwater programs from relying on qualitative, anecdotal data to adopting quantitative analyses that allow for targeted, efficient and transparent programs with multiple benefits for the public. The National Policy Statement for Freshwater Management provides an impetus and opportunity for regional councils to adopt stormwater quality improvement programs that provide substantial benefits to both ecosystems and communities.

4 REFERENCES

National Policy Statement for Freshwater Management, 2014. Issued by Notice in gazette on 4 July 2014. newzealand.govt.nz