SMC Non-Structural BMP Workshop Report

March 1, 2022

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SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

Technical Report 1405

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Southern California Coastal Water Research Project, Costa Mesa, CA

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INTRODUCTION

Water quality improvement plans, watershed management plans, TMDLs, municipal separate storm sewer (MS4) permits, and other water quality planning instruments across southern California ubiquitously include non-structural best management practices (NS-BMPs) as a preferred option for pollution prevention or removal. Quantitative metrics based on empirical evidence of NS-BMP pollutant removal are scarce, which leads to water quality planning based on a range of assumptions and best professional judgement. The Southern California Stormwater Monitoring Coalition (SMC) identified developing a work plan to quantify the effectiveness of prioritized NS-BMPs as a priority project in the 2019-2024 Research Agenda to begin to fill this gap in knowledge.

The approach to developing an NS-BMP effectiveness work plan includes compiling a detailed literature review from published journal papers and gray literature (e.g. local or regional agency reports) to support a workshop where SMC member agencies identified and prioritized NS-BMPs for detailed future study. The workshop was held on March 2, 2022 via Zoom, with at least 27 representatives from across SMC member agencies, plus facilitators from the Southern California Coastal Water Research Project (SCCWRP). Subsequent to the workshop, SCCWRP developed draft work plans for evaluating pollutant removal effectiveness of street sweeping and catch basin cleaning. This report documents the workshop discussion, leading to NS-BMP prioritization and work plan development. The slide deck used to conduct the workshop is provided as Appendix A.

NS-BMPs were defined loosely as programmatic activities and source controls that ultimately lead to runoff-borne pollution prevention. NS-BMPs can be physical elements such as turf replacements or rain barrels, but are distinguished from “structural BMPs” which require engineering design and permits to construct. Likewise, municipal programs that can lead to the construction of physical elements are also considered NS-BMPs themselves (e.g. rain barrel workshops). It was not considered critical to specifically define the term for the purposes of the workshop. In fact, the US Environmental Protection Agency (US EPA) no longer uses the term NS-BMP because of widely varying interpretations. The discussion was useful to generally align workshop participants with the overall project scope.

LITERATURE REVIEW TAKE-AWAYS

A detailed literature review was conducted to prepare for the workshop, with a primary focus on studies quantifying the effectiveness of NS-BMPs. The literature review revealed an overall dearth of publications that investigated pollutant removal effectiveness of NS-BMPs. The relatively few field studies that have been conducted provide little empirical evidence of NS-

BMP impact on runoff or in-stream water quality impact (runoff or in-stream). Findings of the literature review are summarized herein, and are organized into: a) public education, outreach, and participation; b) street sweeping and street cleaning; c) catch basin or inlet cleaning; and d) disconnecting impervious area. The full annotated literature review is attached as Appendix B.

Public Education, Outreach, and Participation

Substantial literature can be found on behavior change applied across many fields, but relatively few were identified specifically with regard to water quality and NS-BMPs. Direct water quality impacts from programmatic activities such as education and outreach suffer from a temporal disconnect between the occurrence of the program, when individuals exhibit altered behavior, and runoff events. Awareness is most important component in the path towards behavior change (Gray et al. 2015). Behavior or attitude change itself may not always directly translate to water quality improvement, but it can lead to public support for institutional programs or policies that do (Gray et al. 2015, Penn et al. 2014), such as plastic bag bans or the Los Angeles County Safe Clean Water Program (Measure W).

Street Sweeping and Street Cleaning

Studies that attempt to measure street sweeping or catch basin cleaning impacts at outfalls demonstrate that there are many potential confounding catchment effects (e.g., other contributing land uses) and high event-to-event variability in pollutant build-up and wash-off in natural rainfall events that make measuring in-stream impacts especially challenging. It has been estimated that ~250 samples are required to detect differences at outfalls in total suspended solids (TSS) event mean concentrations between swept and unswept catchments because of high variability in urban road runoff concentrations (Sample 2012 reported by Center for Watershed Protection 2016). A post-hoc statistical analysis compiling results amongst 15 studies failed to detect statistical differences between swept and unswept catchments, citing the high coefficients of variation for TSS, suspended sediment concentration (SSC), or chemical oxygen demand (COD) data (Kang et al. 2009, Kang et al. 2008).

Street sweeping has been shown to effectively reduce the volume of roadway debris, but not nitrogen or phosphorus in runoff (Pearson et al. 2018). Wash-water from street cleaning using a pressurized water jet contained hydrocarbons and oil & grease, but wash-water contained less contaminants than runoff measured in the same catchment (Gasperi et al. 2005). Analysis of the National Stormwater Quality Database (https://bmpdatabase.org/national-stormwater-quality-database) suggests street runoff quality should be considered independently, rather than including within “residential”, “commercial”, or other composite land uses. These data can be coupled with information on street sweeper effectiveness to estimate pollutant load reductions (Center for Watershed Protection 2016).

The most prevalent studies on street sweeping measure the characteristics of captured road debris. Lloyd et al. (2019) measured sediment-attached concentrations of heavy metals and oil & grease from 79 sampling locations around Virginia, and 27 locations for PAHs. The Center for Watershed Protection (2016) compiled data from studies across the USA, concluding that road debris has relatively consistent pollutant concentrations. Heavy metals are sediment-attached (Muhammad & Hooke 2006, Zanders 2005). Small particles contain a greater proportion of attached contaminants, but small particles are only a small fraction of the total sediment load (Zanders 2005). Sediment delivery to the receiving water must account for capture of coarse particles in the curb & gutter, and in catch basins (Center for Watershed Protection 2016). Street sweeping removed ~2200-~3100 lbs/acre/yr of TSS in Seattle. Associated cost estimates of street sweeping compared to the cost of constructing regional facilities leans strongly in favor of increasing the frequency and coverage of street sweeping for per mass of dry sediment removed (Seattle Public Utilities 2009). Caution is recommended in adopting results from older studies because street sweeper technology has evolved (Muhhamad and Hooke 2006).

Studies on sweeper technology are clear. Newer sweeper technology (vacuum and regenerative air sweepers) provide superior performance to mechanical broom sweepers (Center for Watershed Protection 2016 citing multiple studies from across the country, City of San Diego 2010-2015). Mechanical sweepers may be more effective on steeper slopes (City of San Diego 2010-2015), but are ultimately unable to capture small particles. They are not recommended for crediting pollutant removal based on compilation of multiple studies from around the country (Center for Watershed Protection 2016). The City of San Diego resolved to phase out mechanical sweepers in favor of newer technologies as vehicles in the existing fleet reached the end of their useful lives.

Collating results across studies is challenged by different pollutants measured in different studies, and using different measurement techniques (e.g., reporting pollutant extracts as mg/L or sediment-attached concentrations in mg/kg). A Center for Watershed Protection (2016) expert panel report recommended shifting to models for evaluating water quality impacts, while using empirical data used to support or calibrate loading assumptions.

Catch Basin or Inlet Cleaning

Highly variable trash and debris accumulation measured in catch basins suggests that additional data could be beneficial to informing maintenance schedules. There is not a clear link between street sweeping and catch basin sediment accumulation, but ultimately only two direct studies were identified. Street sweeping did not result in a measurable difference in catch basin accumulation, but catch basins were all less than 10% full at the time of the study (Seattle Public Utilities 2009). A Maryland study of 97 catch basins reported highly variable levels of accumulation. Fewer than half the catch basins inspected required cleaning according to their existing guidance. Self-cleaning inlets lose functionality and eventually accumulate debris. (Morgan State University and Center for Watershed Protection 2018).

Disconnecting Impervious Area

Impervious area disconnection is a promising management strategy with history of linkages to urban stream health (Epps & Hathaway 2021, Walsh et al. 2009). For example, macroinvertebrate community composition and the tissue concentrations of Cu, Pb, and Zn in 3 stream invertebrate taxa (*Cambaridae, Tipulidae, and Hydropsychidae*) found across 7 urban stream sites were correlated with watershed hydrologic connectivity (Baruch et al. 2018).

Disconnecting impervious area to allow infiltration and evapotranspiration decreases runoff rate and volume, and delays the timing off-site hydrographs at the site scale. Laboratory experiments demonstrated differences in runoff rate ratio between 0 and 25% impervious area connectivity, at the beginning of synthetic storms. No additional benefits were observed with 50% impervious area connection (Shuster et al. 2008). Variability in pollutant loads to 3 urban streams is partially attributed to effective impervious area for multiple pollutants (Epps & Hathaway 2021). Runoff reduction tests and steady-state infiltration testing was successfully used to calibrate a model that predicted substantial stormwater management from urban residential lawns (Mueller & Thompson 2009).

Impervious area disconnection can be achieved with structural or non-structural BMPs, but is not common in southern California watershed management plans.

Prioritizing NS-BMPs for Future Study

Workshop participants were provided with a list of 27 NS-BMPs to consider for prioritization for future study. Discussion yielded 3 additional ideas. After discussion to ensure all NS-BMPs were represented in the lists, an on-the-spot survey was administered using Microsoft Forms. All participants were asked to select their top 5 NS-BMPs (each respondent was allowed 5 choices in total, without prioritization). Broad classifications of NS-BMP were provided solely for the purposes of organizing an otherwise long list of NS-BMP options. The classifications were irrelevant to the survey outcomes. The individual NS-BMPs included:

- Ordinances requiring structural BMPs
- Design training to facilitate structural BMP implementation
- Contractor training to support structural BMP construction
- Maintenance training to support structural BMPs
- Inspector training to support structural BMP construction
- Facility inspections

- Catch basin/ drain inlet clean out
- Managing exposed soils
- Erosion control/slope stabilization (non stream-bank)
- Street sweeping
- Disconnecting directly connected impervious area
- Illicit discharge disconnection
- Covering outdoor stockpiles/storage/trash enclosures
- Incentives
- Turf replacement with alternative landscapes
- Conversion of spray to drip irrigation
- Vehicle washing restrictions/bans
- Targeted audience outreach
- Pick up after your pet campaigns
- Rain barrel programs
- Litter campaigns
- Adopt-a-highway
- SB 346 for copper (brake pads)
- SB 757 for lead (wheel weights)
- Zinc reduction in tires
- Pesticide/herbicide bans/restrictions
- Plastic bag bans
- Inspector training
- Incentive programs (except irrigation)
- Breaking down barriers to implementation

Twenty-seven individual responses were recorded for the survey. An example is shown in Figure 1. The full survey result is provided in Appendix C. Three practices received an equal number of votes, and were the most commonly selected NS-BMPs overall:

- Catch basin /drain inlet cleaning (12)
- Street sweeping (12)
- Targeted audience outreach (12)

Subsequent discussion identified general agreement that there have been numerous failed attempts to quantify effectiveness of targeted audience outreach including in Los Angeles County, and SMC funds are better directed elsewhere for future study. Survey respondents that did not vote for any of these options were invited to make further comment. Several subsequent votes resulted in favor of street sweeping and catch basin/inlet cleaning for further study.

Additional on-the-spot surveys were administered to develop additional information to shape the workplans. Participants were asked to rank each potential outcome from a study on NS-BMP performance in terms of how useful the information might be to their agency. All options and the full survey results from 23 participants are shown in Figure 2. Quantifying pollutant load or concentration reductions due to the NS-BMP received the most “must-have” votes.

Pollutants of interest were prioritized by survey participants as per Figure 3. Pollutants were ranked: 1. bacteria; 2. nitrogen and flow (loose tie); 3. sediment, phosphorus and trash (loose tie). There is some disconnect between the prioritized NS-BMPs of street sweeping and catch basin cleaning and the ranking of pollutants of interest. The primary intent of street sweeping and catch basin cleaning is to remove particulate road debris and trash.

Figure 1. Example output from the on-the-spot survey using Microsoft Forms to select priority NS-BMPs

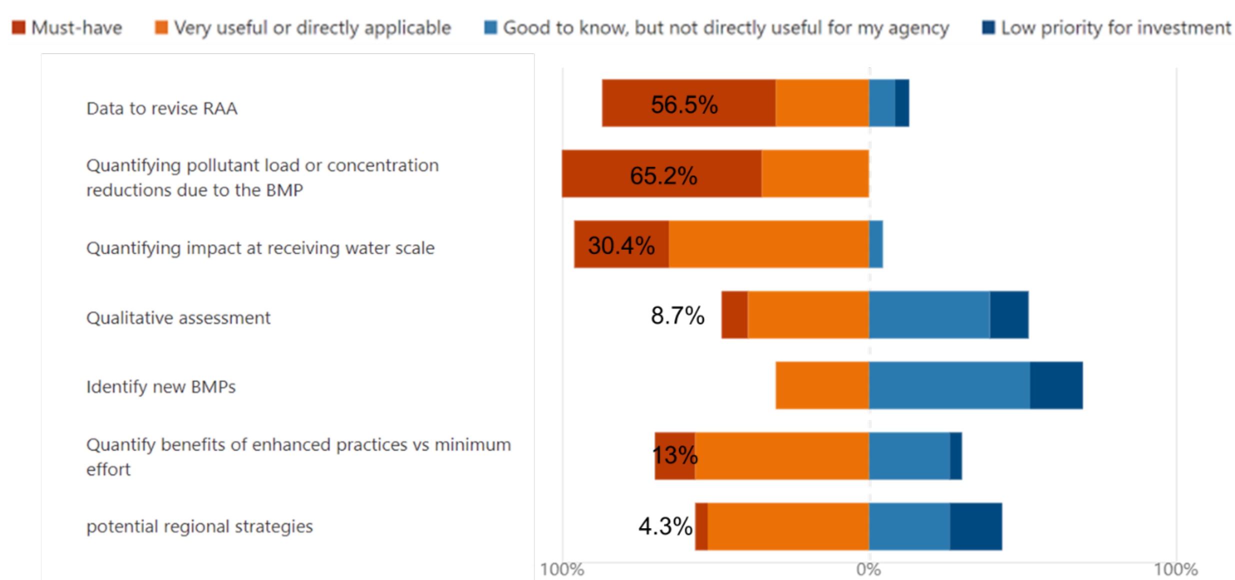

Figure 2. Types of outcomes from further study on NS-BMPs.

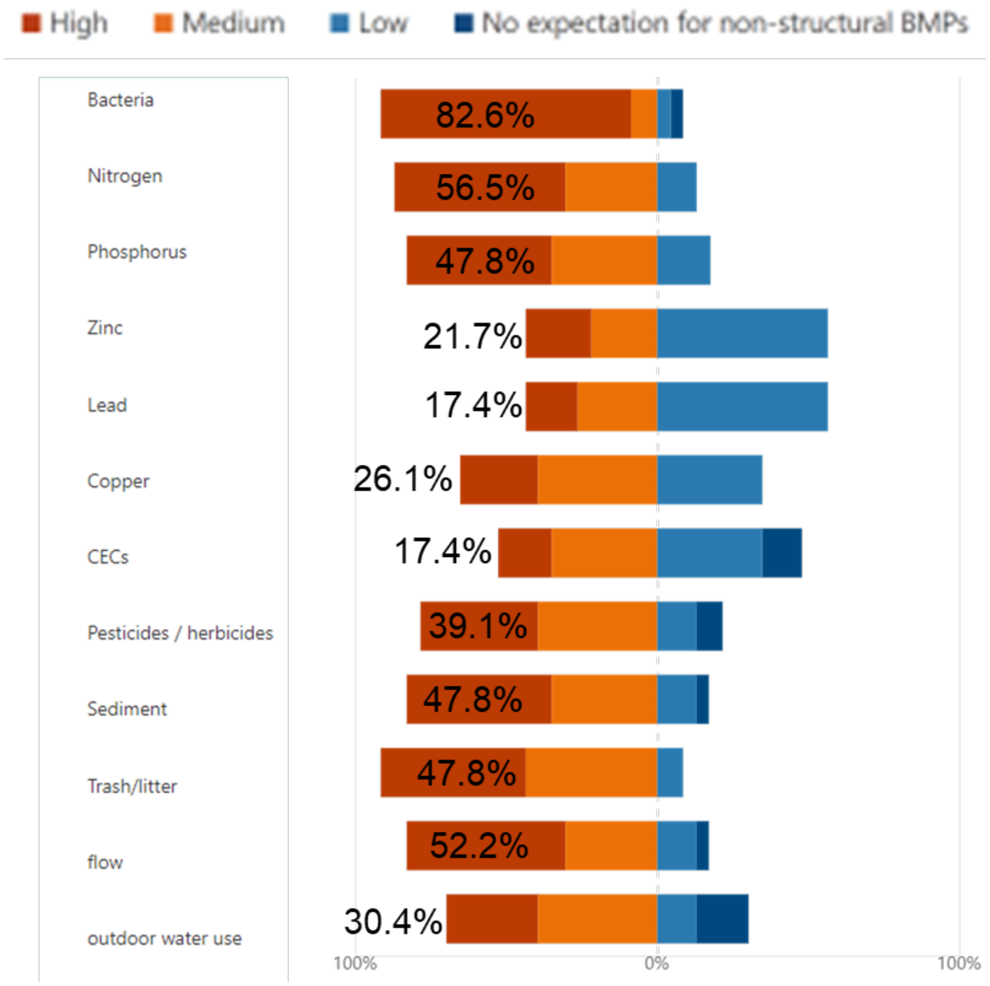

Figure 3. Pollutants of interest for further study.

NS-BMP Work Plan Development

Coupling the outcomes of the workshop prioritizations and the information gleaned from the literature review, SCCWRP developed two draft workplans for consideration for future investment by the SMC:

1. Effect of Street Sweeping on Wet Weather Pollutant Loading and Concentrations from Southern California Roadways
2. Effect of Catch Basin Cleaning on Wet and Dry Weather Pollutant Loading and Concentrations from Southern California Roadways

These draft work plans are attached as Appendix D and E.

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APPENDIX A: WORKSHOP SLIDE DECK

Southern California STORMWATER MONITORING Coalition

Developing a Workplan for Assessing the Effectiveness of Non-Structural Stormwater BMPs

Steering Committee Workshop

SCCWRP Established 1969

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03.01.2022

Agenda

Background/ setting the stage	5 min
Define "non-structural BMP"	10 min
Literature review results	20 min
Non-structural BMP practices & prioritization (+ survey)	25 min
Study design: big picture (+ survey)	25 min
Break	10 min
Develop research questions / hypotheses	20 min
Next steps	5 min

Rationale and objectives

- Non-structural stormwater BMPs are the preferred first option for pollution prevention or removal
  - In every MS4 permit and Water Quality Improvement Plan
  - Programmatic activities or source control
- Very little, if any, quantitative data on effectiveness of non-structural BMPs
- #3 Ranked project in the 2019-2024 Research Agenda
- Goal of this project is to develop a work plan for quantifying the effectiveness of non-structural BMPs
  - Use workplan as an RFP for work in 2022/23

Approach

- Conduct a literature review for state of the science
- Facilitate an SMC Workshop to prioritize non-structural BMPs for further research
- Develop the workplan for highest priority non-structural BMPs

Goals for today

1. Prioritize non-structural BMPs for detailed study
2. Establish what you want to learn from a detailed study, for example:
   - Justification for continued resources to support
   - Technical data to support WMPs or permits
   - Logistical support to help agencies implement practices efficiently and effectively

What is your definition of a non-structural BMP?

- Actions and activities intended to reduce urban runoff pollution that do not involve construction of a physical component or structure to treat runoff or reduce flow volume.
  - Dry weather flow
  - Wet weather flow

Distinction?

- MS4 permits include Minimum Control Measures that include a variety of nonstructural BMPs
- Watershed Management Plans identify additional non-structural BMPs that exceed basic permit requirements
  - Enhancement or expansion of existing programs, e.g., increased street sweeping frequency or use of superior sweeper type or expanded area
  - New initiatives

Agenda

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Literature Review

- Limited review of Watershed Management Plans & gray literature
- Focus on peer-reviewed journal articles
- Report empirical studies, mostly at field scale
- Exclude uncalibrated model studies

Spoiler alert: there's not a lot of well-documented information available.

Public Education / Outreach / Participation

- Substantial literature on behavior change applied across many fields
- Awareness is most important component in the path towards behavior change (Gray et al. 2015)
- Behavior or attitude change itself may not always directly translate to water quality improvement, but it can lead to public support for institutional programs or policies that do (Gray et al. 2015, Penn et al. 2014)
  - Measure W
  - Plastic bag bans

Street sweeping

- Does street sweeping influence water quality at outfalls?
  - Unable to detect differences in end-of-pipe samples from swept vs unswept catchments because of high variability in TSS, SSC or COD data collated across 15 studies (Kang & Stenstrom 2008, Kang et al. 2009).
  - Estimated ~250 samples are required to detect differences in TSS event mean concentrations between swept and unswept catchments because of high variability in urban road runoff concentrations (Sample 2012 reported by Center for Watershed Protection 2016)
  - Outfall samples reflect runoff from the entire catchment.

Street sweeping

- Does street sweeping influence runoff water quality?
  - Street sweeping effectively reduces volume of roadway debris, but does not reduce N or P in stormwater from 6 sampling locations (Pearson et al. 2018).
  - Wash-water from street cleaning using a pressurized water jet contained hydrocarbons and oil & grease (Gasperi et al. 2005).
  - Analysis of the National Stormwater Quality Database suggests street runoff quality should be considered uniquely, rather than including within “residential”, “commercial”, or other composite land uses. These data can be coupled with information on street sweeper effectiveness to estimate pollutant load reductions (Center for Watershed Protection 2016).

Street sweeping

- What are characteristics of captured road debris?
  - Lloyd et al. (2019) measured sediment-attached concentrations of heavy metals, PAHs, & oil & grease from 79 sampling locations around Virginia (27 locations for PAHs).
  - The Center for Watershed Protection (2016) compiled data from studies across the USA, concluding that road debris has relatively consistent pollutant concentrations.
  - Heavy metals are sediment-attached (Muhammad & Hooke 2006, Zanders 2005).
  - Small particles contain a greater proportion of attached contaminants, but small particles are only a small fraction of the total sediment load (Zanders 2005).
  - Sediment delivery to the receiving water must account for capture of coarse particles in curb & gutter, and catchbasins (Center for Watershed Protection 2016).

Street sweeping

- Does sweeper technology matter?
  - Newer sweeper technology (vacuum and regenerative air sweepers) provide superior performance to mechanical broom sweepers (Center for Watershed Protection 2016 citing multiple studies from across the country).
  - Mechanical broom sweepers unable to capture small particles. Technology not recommended for crediting pollutant removal based on compilation of multiple studies from around the country (Center for Watershed Protection 2016).
  - Older studies of street sweeping may no longer be applicable (Muhammad & Hooke 2006).

Catch basin / inlet cleaning

A study of 97 inlets across Maryland highways (Center for Watershed Protection 2019) revealed:

- Accumulation in catch basins is variable.
- Different densities of materials (vegetation vs trash vs sediment) makes it difficult to compare relative accumulation.
- Fewer than half of catch basins inspected required cleaning, operationally defined as when the pipe or chamber was > 25% full.
- Materials begin to accumulate once pipes in self-cleaning inlets become clogged.
- Seasonality of materials' accumulation provides opportunities to optimize maintenance scheduling that may yield increase in load reductions

Disconnected impervious area

- Effective impervious area a.k.a. directly connected impervious area is an indicator of urban stream health (Epps & Hathaway 2021, Walsh et al. 2009)
  - Macroinvertebrate community composition and the tissue concentrations of Cu, Pb, and Zn in 3 stream invertebrate taxa (Cambaridae, Tipulidae, and Hydropsychidae) found across 7 urban stream sites were correlated with watershed hydrologic connectivity (Baruch et al. 2018)
- Disconnecting impervious area to allow infiltration and evapotranspiration decreases runoff rate and volume, and delays the timing off-site hydrographs at the site scale.
  - Laboratory experiments demonstrated differences in runoff rate ratio between 0 and 25% impervious area connectivity, at the beginning of synthetic storms. No additional benefits were observed with 50% impervious area connection (Shuster et al. 2008).
  - Variability in pollutant loads to 3 urban streams is partially attributed to effective impervious area for multiple pollutants (Epps & Hathaway 2021).
  - Runoff reduction tests and steady-state infiltration testing was successfully used to calibrate a model that predicted substantial stormwater management from urban residential lawns (Mueller & Thompson 2009).

Literature review take-aways

- Relatively little empirical evidence of non-structural BMP impact on water quality (runoff or in-stream).
  - Many potential confounding catchment effects and high event-to-event variability in pollutant build-up and wash-off make measuring in-stream impacts especially challenging. Center for Watershed Protection (2016) expert panel report observes shift to models for evaluating water quality impacts, while empirical data used to support/ calibrate loading assumptions.
  - There is a temporal disconnect between the occurrence of education/ outreach, when individuals exhibit altered behavior, and runoff events.
- Majority of information is about street sweeping, with more studies about pollutants attached to road debris.
  - Challenge to collate results, as different pollutants measured, using different techniques (e.g., extracts reported as mg/L vs sediment-attached mg/kg).
  - Center for Watershed Protection (2016) expert panel report provides comprehensive review and consolidation.
- Impervious area disconnection is a promising management strategy with history of linkages to urban stream health.
  - Can be achieved with structural or non-structural BMPs.
  - Not common in WMPs.

Current study: Mitigating Dry Weather Runoff (SCCWRP & County of San Diego)

Main objective: Measure effectiveness of turf replacement & conversion of spray to drip irrigation to minimize dry weather runoff.

Agenda

Background/ setting the stage	5 min
Define "non-structural BMP"	10 min
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Break	10 min
Develop research questions / hypotheses	20 min
Next steps	5 min

Potential practices to study

Terminology is intended only to broadly organize specific non-structural BMPs that are broken out in subsequent slides.

Broad Category of Non-structural BMP
Planning and development
Pollution prevention
Dry weather runoff reduction
Public education/ outreach/ participation
Source control

Planning and development BMPs

BMP	Targeted outcome
Ordinances requiring LID BMPs	trigger structural BMP implementation
Training to facilitate structural BMPs	support structural BMP implementation
design	
contractors/construction	
maintenance	
Grant applications	obtain external funding for structural BMPs

Pollution prevention BMPs

BMP	Targeted outcome
Facility inspections (enforcement)	
industrial facilities	
commercial facilities	ensure functioning BMPs
other private property	
MS4 (pipes, culverts, catchbasins)	
Catch basin/ drain inlet clean out	prevent pollutant mobilization
Managing exposed soils	prevent pollutant mobilization
Erosion control/slope stabilization (non stream-bank)	prevent pollutant mobilization
Illicit discharge disconnection	eliminate non-runoff discharges

Pollution prevention BMPs

BMP	Targeted outcome
Street sweeping	prevent pollutant mobilization
private property (parking lots, private streets)	
public streets	
highways	
sweeper technology (mechanical, vacuum, regenerative)	
frequency	
Disconnecting directly connected impervious area	prevent pollutant mobilization
Downspout disconnection	
Covering outdoor stockpiles/ storage/ trash enclosures	prevent pollutant mobilization

Practices

Terminology is intended only to broadly organize specific non-structural BMPs that are broken out in subsequent slides.

Broad Category of Non-structural BMP
Planning and development
Pollution prevention
Dry weather runoff reduction
Public education/ outreach/ participation
Source control

Dry weather runoff reduction BMPs

BMP	Targeted outcome
Irrigation reduction	Limit dry weather flow
incentives	
turf replacement with alternative landscapes	
spray conversion to drip irrigation	
Vehicle washing bans/restrictions	

Public education / outreach / participation BMPs

BMP	Targeted outcome
targeted audience outreach	encourage behavior change or garner public support
pick up after your pet campaigns	decrease bacteria
rain barrel programs	reduce pollutant mobilization from residential land use
litter campaigns	reduce trash
adopt-a-highway	reduce trash

Source control BMPs

BMP	Targeted outcome
SB 346 for copper (brake pads)	eliminate major copper source
SB 757 for lead (wheel weights)	eliminate major lead source
zinc reduction in tires (initiative by Dept of Toxic Substances)	eliminate major zinc source
pesticide/herbicide bans/restrictions	eliminate sources
plastic bag bans	reduce plastic source

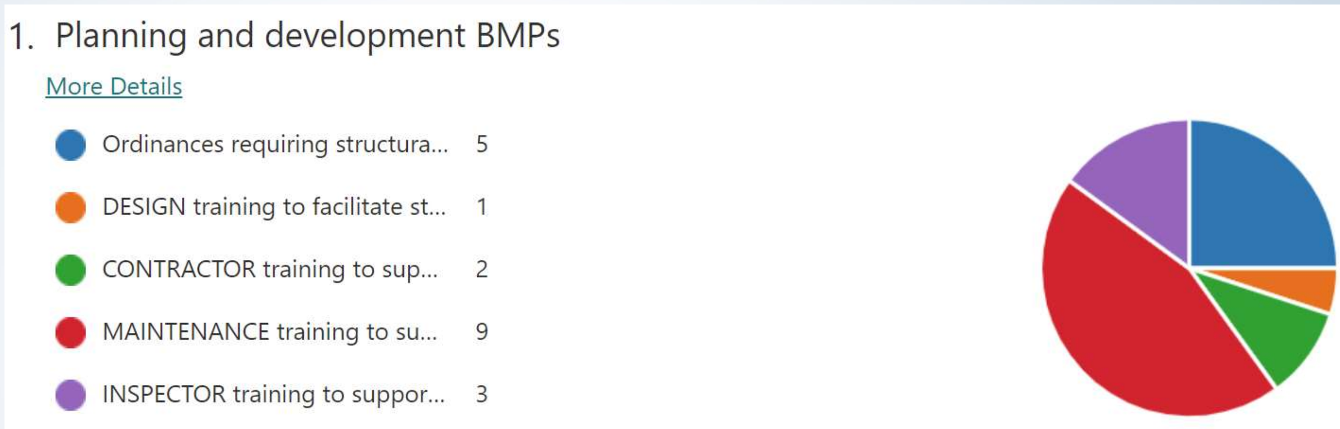
Survey: https://forms.office.com/r/piLQHNMMmk

-prioritize non-structural BMPs for developing study plans

Survey = 10 min

Survey Results: Non-structural BMP Practice Prioritization (27 responses)

Participants asked to select top 5 BMPs across all categories (each respondent to submit 5 total choices)



Survey Results: Non-structural BMP Practice Prioritization (27 responses)

3. Dry weather runoff reduction

More Details

incentives	11
turf replacement with alternati...	8
conversion of spray to drip irri...	1
vehicle washing restrictions/b...	2

4. Public education/outreach/participation

More Details

targeted audience outreach	12
pick up after your pet campai...	1
rain barrel programs	5
litter campaigns	6
adopt-a-highway	2

Survey Results: Non-structural BMP Practice Prioritization (27 responses)

5. Source control

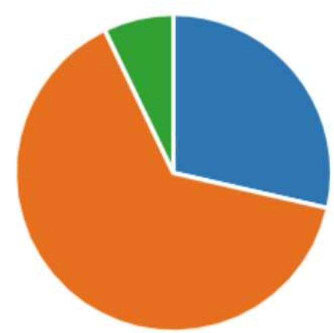
More Details

SB 346 for copper (brake pads)	3
SB 757 for lead (wheel weights)	0
zinc reduction in tires	3
pesticide/herbicide bans/restri...	5
plastic bag bans	4

6. New ideas

More Details

inspector training	4
incentive programs (except irri...	9
breaking down barriers to imp...	1



Agenda

Background/ setting the stage	5 min
Define "non-structural BMP"	10 min
Literature review results	15 min
Non-structural BMP practices & prioritization (+ survey)	25 min
Study design: big picture (+ survey)	25 min
Break	15 min
Develop research questions / hypotheses	20 min
Next steps	5 min

Potential outcomes of detailed study

How does your agency envision using the information generated by project outcomes?

Outcome	Opportunities	Challenges
Data to validate or revise RAA components	Integrate with TMDLs	Different data structures across models, e.g. % reduction vs. redefining source loads or hydrology.
Quantifying pollutant load reductions from BMP itself	• Enables cost-benefit (e.g. $/lb phosphorus removed) • Integrate with TMDLs	Ability to transfer to a range of models?
Quantifying impact to receiving water	Holy grail	Different physical or temporal scales e.g., effects of street sweeping may not be measurable at receiving water scale with current tools; public education targeting behavior change not likely to effect storm event loads in near-term.

Potential outcomes of detailed study

How does your agency envision using the information generated by project outcomes?

Outcome	Opportunities	Challenges
Qualitative assessment	Foster public support	Not quantitative
Identify new BMPs	Expand management options	May not be in existing permits or WMPs
Quantifying the benefits of enhanced practices vs. minimum effort	Support WMPs	Does the differential matter?

Water district turf replacement programs require stormwater features

Before

After

Priority pollutants?

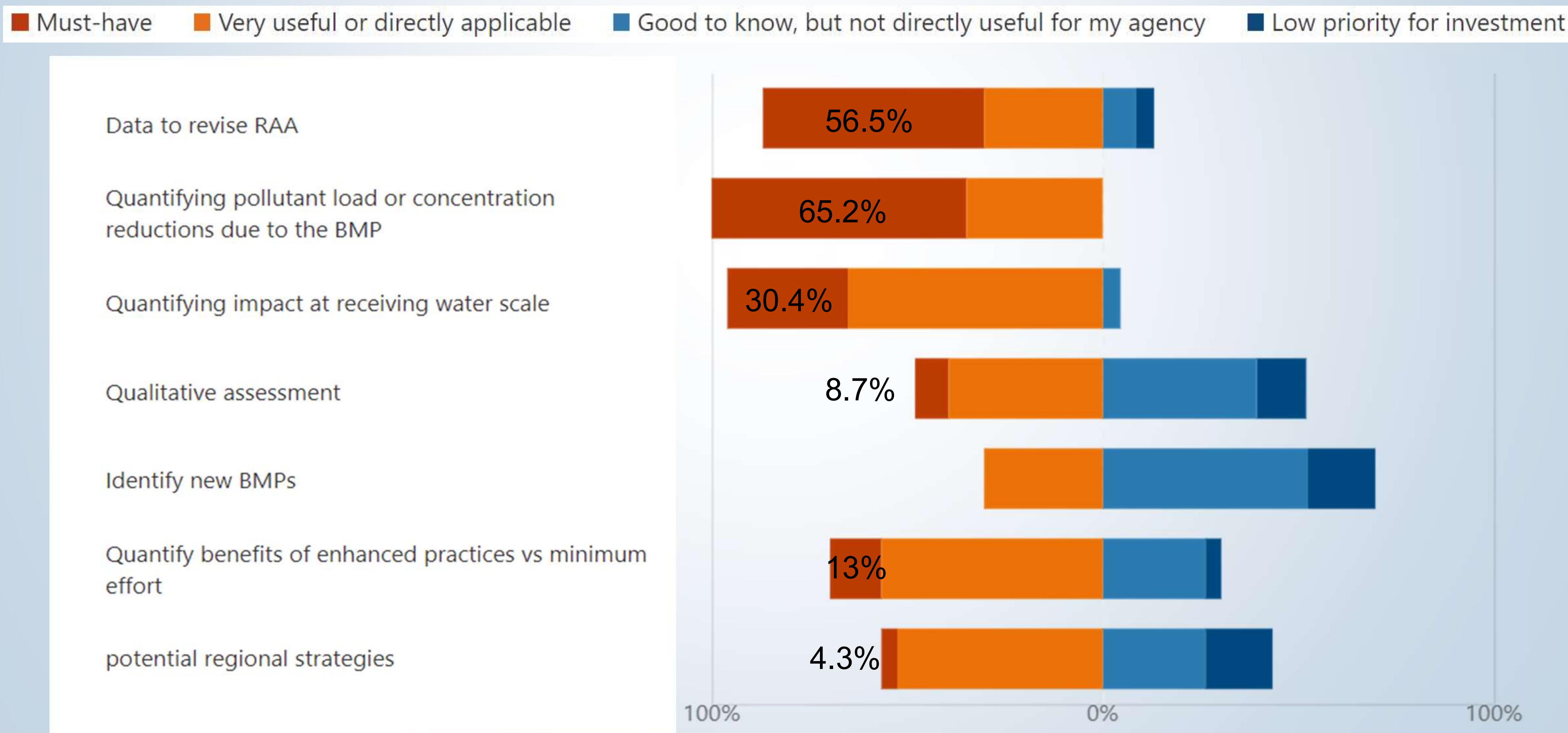
- Bacteria
- Nutrients
  - Nitrogen
  - Phosphorus
- Heavy metals
  - Zinc
  - Lead
  - Copper
- Sediment
- CECs
- Pesticides / herbicides
- Trash / litter

Survey: https://forms.office.com/r/sZ3rdZSN5S

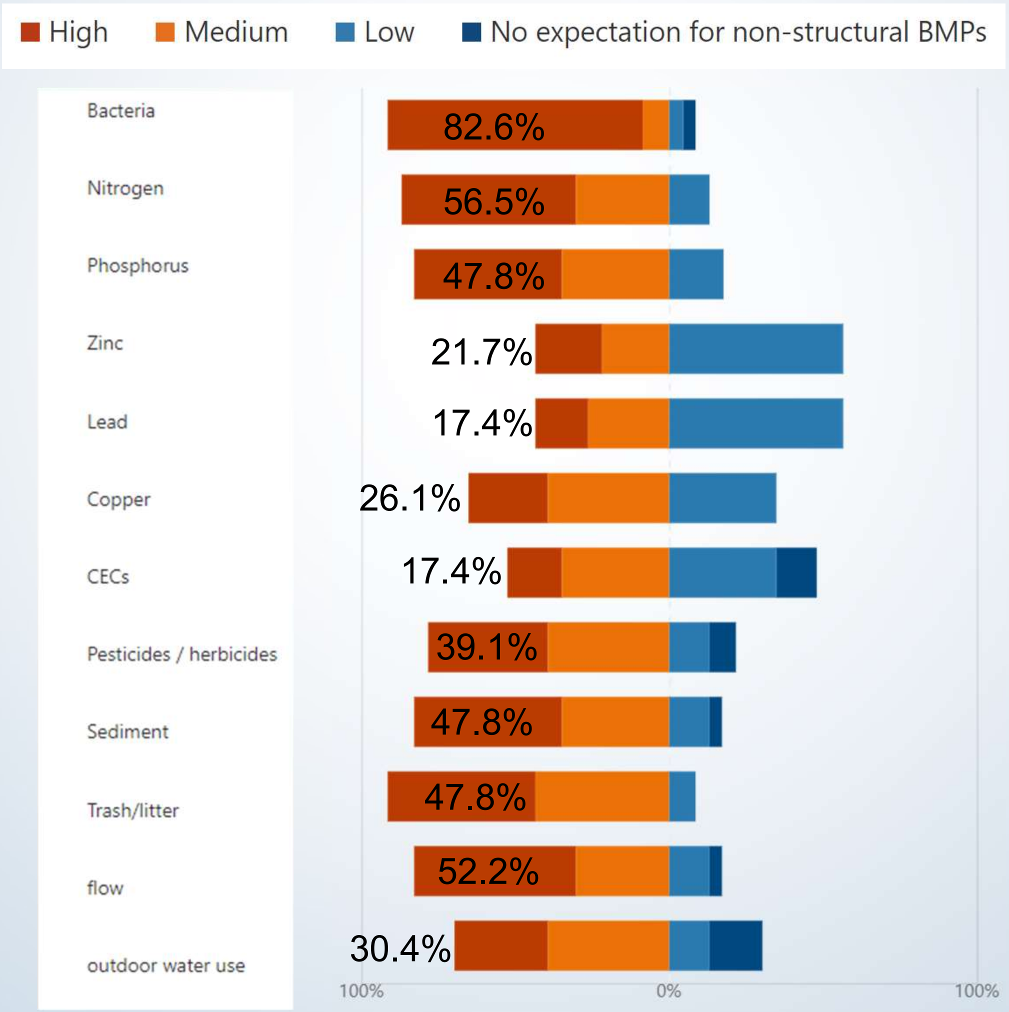
- rank potential outcomes
- rank pollutant types

Survey + break = 10-min

Survey Results: Potential Outcomes of Study (23 responses)



Survey Results: Priority Parameters to Measure (23 responses)



Agenda

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Break	10 min
Develop research questions / hypotheses	20 min
Next steps	5 min

Survey results

Develop research questions/ hypotheses

- Priority practices are:
  - Catch basin /drain inlet cleaning (12)
  - Street sweeping (12)
  - Targeted audience outreach (12)
  - Dry weather incentives (11)
  - Training for structural BMP maintenance (9)
  - Other incentives (9)

- Priority pollutants are
  1. bacteria
  2. nitrogen
  3. flow
  4. sediment
  5. trash
  6. flow

  (2–3 tied; 4–6 tied)

- Data types are ranked
  1. Quantifying pollutant load reductions from BMP itself
  2. Data to validate or revise RAA components
  3. Quantifying impact to receiving water
  4. Quantifying enhanced vs minimum effort
  5. Qualitative assessment
  6. Regional strategies
  7. Identify new BMPs

Agenda

Background/ setting the stage	5 min
Define "non-structural BMP"	10 min
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Develop research questions / hypotheses	20 min
Next steps	5 min

Approach

- ✓ Conduct a literature review for state of the science
- ✓ Facilitate an SMC Workshop to prioritize non-structural BMPs for further research
- ➨ Develop the workplan for highest priority non-structural BMPs

Next steps

Task	Due date
Draft workplan for RFP	May 10
Comments from Steering Committee	May 24
Final project workplan for RFP	June 14

Appendix B: Annotated Literature Review

Appendix B

Annotated Literature Review of Non-Structural Best Management Practices

Introduction

The annotated literature review herein focuses on documenting studies that link the implementation of a non-structural best management practice to urban runoff or in-stream water quality impacts, if/where feasible. The literature was sourced from published journal papers and limited gray literature (i.e., reports conducted by municipal or regional agencies found online). Empirical studies conducted at field scale were prioritized for review. Uncalibrated model studies were excluded.

Studies are organized categorically as

Within each category, studies are reviewed in reverse chronological order. This may be particularly relevant for street sweeping studies, since street sweeper technology has changed.

Public Education / Outreach / Participation

Gray, S.S., Brown, C., Haimann, R., Quinn, A. (2015). Non-Structural Best Management Practice Pollutant Load Reduction Estimation Method. WEFTEC2015, Chicago, IL, Sept. 26-30.

Study objective

Quantify the pollutant loading reduction that may arise from outreach and education to be applied to TMDL wasteload allocations in five San Diego watersheds.

Methods

- Best professional judgement based on literature review, practical experience, and stakeholder input.
- A framework was developed for calculating the effect of behavior change based on the literature review, which included studies on public perceptions and behavioral change and several Center for Watershed Protection studies (including analogies between qualitative non-structural BMP recommendations and quantitative structural BMP assessments).
  - The framework adjusts factors depending on scope of education and outreach program, assigns high-medium-low- or no pollutant removal potential, and the extent to which each BMP has the potential to control a polluting behavior.
  - The pollutant removal potential for each non-structural BMP was considered for specific pollutants, for example, pet waste programs were assumed to influence only bacteria and nutrients.

Main Findings

- The framework was applied to 80 nonstructural BMPs under consideration for the City of San Diego's Water Quality Improvement Plans for five watersheds.
- Public education and outreach primarily promotes problem awareness, which is the largest component in the path towards behavior change, after "intention" to undertake a behavior. Problem awareness is attributed to a potential for 18% behavior change.
- The framework represents a quasi-subjective assessment derived from mostly reasonable assumptions and a process described that results in quantitative values.
- The authors specifically call-out a need for direct measurement.

Limitations

- Considered water chemistry only, excluding physical or biological benefits of nonstructural BMPs.
- The heavy influence of professional judgement suggests that a qualitative or categorical approach for ranking pollutant removal may have been more appropriate, recognizing that the objective was to develop quantitative outcomes for use in wasteload allocations.
- A list of assumptions and limitations are provided.

Other Comments

- Substantial literature exists on behavior change applied across many different fields.
- Behavior or attitude change itself may not always directly translate to water quality improvement, but can lead to support for institutional programs or policies that do.

Penn, J., Hu, W., Cox, L, Kozloff, L. (2014). Resident and Tourist Preferences for Stormwater Management Strategies in Oahu, Hawaii. *Ocean & Coastal Management* 98(2014) 79-85. http://dx.doi.org/10.1016/j.ocecoaman.2014.06.002

Study objective

Measure residents' and tourists' preferences and willingness to pay for different approaches to stormwater management in Hawaii.

Methods

- Choice experiment (survey) that included broad categories of non-structural BMPs, structural BMPs, warnings & advisories, water quality testing, and education. Some examples of what activities fall under each category were given in the survey. Information on stormwater pollution and its connection to beach recreation were also provided to participants. Willingness to pay was presented as a household wastewater fee for residents, and an airport transit fee for tourists.
- A limited cost-benefit analysis of augmenting water quality strategies was conducted. The costs were determined through consultation with individuals in the local government. Benefits were based on willingness to pay by respondents, rather than water quality improvement potential.

Main Findings

- Residents and tourists rank water quality testing and education as 1 & 2, respectively.
- The survey results indicate value of information sharing to garner and maintain public support because the authors acknowledge that structural and non-structural BMPs are more effective for water quality improvement.

Limitations

- Very limited detail on cost-benefit analysis.

Other Comments

N/A

Kaplowitz, M. and Lupi, F. (2012) Stakeholder Preferences for Best Management Practices for Non-Point Source Pollution and Stormwater Control. *Landscape and Urban Planning*, 104 (2012) 364-372. doi:10.1016/j.landurbplan.2011.11.013

Study objective

Measure residents' preferences for a variety of mostly structural BMPs, and identify BMP combinations likely to be supported by local stakeholders in a Michigan watershed.

Methods

- Choice experiment (survey) amongst six types of BMPs, applied to specific landscape zones. Only the "streambank" landscape included nonstructural BMPs of streambank naturalization and /or rip rap armoring. The remaining BMPs included dry basins, wet ponds, wetlands, and filter strips for uploadn and lowland areas.
- All BMPs were assumed equally effective for water quality treatment.

Main Findings

Streambank naturalization was preferred by far by residents over rip rap.

Limitations

All BMPs were assumed to provide equal water quality treatment.

Other Comments

- An extensive literature review provided on the topic of engaging the public or stakeholders in decision-making, and how to measure stakeholder preferences for BMPs.
- The literature seems to be plentiful on how to influence and measure behavior change.

May, C.W. and Horner, R.R. (2004). The Limitations of Mitigation-Based Stormwater Management in the Pacific Northwest and the Potential of a Conservation Strategy based on Low-Impact Development Principles. 9th International Conference on Urban Drainage, Portland, Oregon September 8-13, 2002.

Study objective

Discussion paper on conservation practices as non-structural BMPs.

Methods

Undocumented discussion paper based on authors' professional experience.

Main Findings

- The paper presents limited data on the index of biological integrity via citations (not new work).
- Retention of native forest & wetland cover, minimizing impervious surfaces, and wide continuous riparian buffers are important practices for maintaining / protecting biological integrity in streams in the Pacific Northwest.

Limitations

- No data nor discussion on water chemistry.
- The existing level of development in southern California renders the discussion of limited practical value for most SMC member agencies.

Other Comments

N/A

Keller, Brant D. (1999). Griffin, Georgia's Stormwater Utility "A Non-Structural Best Management Practice (BMP)". Proceedings of the 1999 Georgia Water Resources Conference, Athens, Georgia, March 30-31, 1999.

Study objective

Describe the successful creation of a stormwater utility in City of Griffin, GA, to ensure funding for future stormwater improvements, in anticipation of NPDES Phase II.

Methods

The process to develop the utility including preparation (identifying the city's infrastructure needs with respect to stormwater), concept development (feasibility study), detailed analysis (policy and financial analysis), data and systems implementation (logistics of calculating charges, invoicing and receiving payments), and public information and education (supporting implementation).

Main Findings

Forward-looking paper outlining what the utility will accomplish at a high level.

Limitations

The paper is about funding the utility, not measuring water quality benefits.

Other Comments

N/A

Street Sweeping

Lloyd, L.N., Fitch, G.M., Singh, T.S., and Smith, J.A. (2019). Characterization of Environmental Pollutants in Sediment Collected During Street Sweeping Operations to Evaluate its Potential for Reuse. *Journal of Environmental Engineering* 145(2): 04018141.
https://doi.org/10.1061/(ASCE)EE.1943-7870.0001493

Study objective

Measuring sediment-attached concentrations of heavy metals, PAHs, and oil & grease in road-deposited sediments to consider alternatives for reuse or limitations on disposal.

Methods

- 79 sampling locations throughout Virginia, organized by ADT and land cover in the catchment. Only samples from the higher ADT locations were sieved for pollutant attachment according to particle size. PAH analysis was conducted for samples from 27 locations.
- Vacuumed road sediment during dry weather after at least 2 antecedent dry days. The vacuum was a 5-gal, 4.5 hp wet/dry vacuum with removal efficiency claimed equivalent to a regenerative air sweeper.
- Samples analyzed for metals, PAHs, and O&G.

Main Findings

- Concise tables of average heavy metals concentrations and PAHs from this and other studies.
- ADT cannot be used as predictor of heavy metals, PAHs, or O&G concentrations.
- Land use in a catchment is not a consistent predictor of heavy metals or PAHs, but is reasonable for O&G.
- Increasing concentrations with decreasing particle size were measured for heavy metals and PAHs.

Limitations

- The sampling method may not capture all particles < 75 um.
- Runoff concentrations were not measured.

Other Comments

- Largest sampling effort for a single study noted amongst the literature.
- Tables summarizing this and previous study outcomes are well presented if/when sediment-attached pollutant concentrations are of interest.

Pearson, B.J., Chen, J. and Beeson, R.C. (2018). Evaluation of Storm Water Surface Runoff and Road Debris as Sources of Water Pollution. *Water Air Soil Pollution* (2018) 229:194.
https://doi.org/10.1007/s11270-018-3793-2

Study objective

1. Quantify road debris as a source of nitrogen (N) and phosphorus (P)
2. Quantify N and P in stormwater
3. Determine if street sweeping influences N and P in stormwater

Methods

- 6 sampling locations amongst three community types in Florida: 3 new (< 10 yrs) residential, 2 established (> 10 yrs) residential, and 1 established mixed-use commercial/high density residential
- Monthly street sweeping occurred on one side of a street using a Pelican, Elgin sweeper. Sampling of road debris was also performed monthly using a hand-held vacuum along a one-meter segment of swept and unswept sides of the street.
- First-flush samples collected from 36 catch basins on swept and unswept sides of the same street. Rainfall samples were collected once in each location. Multiple storm events were collected from each location.
- Samples were analyzed suite of nitrogen and phosphorus forms.

Main Findings

- Street sweeping effectively reduced the volume of roadway debris, but did not find that it reduced nitrogen or phosphorus in stormwater.
- There was no significant differences between swept and unswept runoff samples collected at catch basin inlets, nor when samples were grouped by community type.
- The mean and standard deviation runoff concentrations from each of the six communities monitored is presented in tabular form. Swept and unswept runoff data are pooled. Ranges amongst the six communities monitored are:
    - $1.23 \text{ mg/L} \leq \text{TKN} \leq 3.69 \text{ mg/L}$
    - $0.19 \text{ mg/L} \leq NO_x \leq 1.00 \text{ mg/L}$
    - $0.40 \text{ mg/L} \leq \text{TP} \leq 0.93 \text{ mg/L}$
    - $0.16 \text{ mg/L} \leq \text{Ortho-P} \leq 0.61 \text{ mg/L}$

Limitations

- Whether areas other than the roadway contributed runoff to the catch basins was not reported.
- The timing of sample collection with respect to street sweeping was not reported.
- The leaching potential of sediment-attached nitrogen and phosphorus should be measured to associate effectiveness of street sweeping with the potential to reduce pollutant loads.
- Differences were not found between mean precipitation and runoff concentrations, except for two ortho-phosphorus from two communities. It is considered unusual that nutrient concentrations in precipitation would not differ from urban runoff at a catchment scale.

Other Comments

The literature review presents many citations on the concentrations of contaminants attached to road debris.

Schueler, T., Giese, E., Hanson, J., Wood, D. (2016). Recommendations of the Expert Panel to Define Removal Rates for Street and Storm Drain Cleaning Practices. Report to the Center for Watershed Protection.

Study objective

An expert panel developed recommendations for consideration by the Chesapeake Bay Program on how sediment and nutrient removal credits are calculated for street and storm drain cleaning based on a combination of the most recent 10 yrs' publications and modeling with WinSLAMM.

Methods

- The expert panel reviewed new research conducted over the previous ten years on (a) nutrient and sediment loading from streets, roads and highways (b) the particle size distribution and nutrient, carbon and toxic enrichment of urban street dirt and sweeper waste, and (c) ten recent research studies that evaluated the effect of different street sweeping scenarios on different street types across the USA.
- A modeling approach using WinSLAMM was adopted to derive sediment and nutrient reduction rates for street sweeping, given the absence of studies with empirical evidence supporting measurable differences between water quality from swept and unswept streets. WinSLAMM was selected in part because it has been calibrated using empirical data on street solid build-up and wash-off.

Main Findings

- Road runoff has moderately higher nitrogen concentrations than other forms of impervious cover.
- The accumulation rate, particle size distribution and pollutant content of street solids follows a relatively consistent and uniform pattern across the USA. These relationships provided an empirical basis for modeling how solids are transported from the street to the storm drain.
- Street cleaning may be an "excellent" strategy to reduce the toxic inputs from urban portions of the Chesapeake Bay watershed, given the high level of toxic contaminants found in both street solids and sweeper wastes.
- The water quality impact associated with street cleaning will always be modest, even when it occurs frequently. Mechanical broom sweepers have little or no water quality benefit. Advanced sweeping technologies, however, show much higher sediment reduction potential.
- Street parking and other operating factors can sharply reduce sweeper pick-up efficiency.
- The adjacent tree canopy influences the organic and nutrient loads on the street on a seasonal basis, but the management implications for this phenomenon are unclear.
- The ten sweeper studies 2006-2016 have produced a lot of quantitative data on the sediments and nutrients that are picked up by sweepers, but none were able to measure a detectable water quality change within storm drains that can be attributed to upland street cleaning. One key reason is the high variability that often occurs in street runoff can outweigh a measurable signal due to street cleaning. To date, researchers have been unable to collect enough paired stormwater samples to detect a statistically significant difference due to treatment. Consequently, most researchers now rely on simulation or mass balance models to quantify the impact of street cleaning.

- A spreadsheet tools was developed to consolidate results for removal rates for different street cleaning practices (primarily technology type and cleaning frequency). Additional credits were developed for catch basin cleaning.

Limitations

No new data collected.

Other Comments

The panel also recommended a long term research strategy to provide managers with the better data to improve the effectiveness of future street and storm drain cleaning programs.

City of San Diego. (2010-2015). Street Sweeping Pilot Study. Phase I – V. Individual reports accessible online: https://www.sandiego.gov/stormwater/pilot-projects/streetsweeping

Study Objective

The City of San Diego undertook a 5-phase pilot study to

Method

Main Findings

- **Frequency of sweeping**: Increased sweeping frequency using vacuum-assisted sweepers provided a linear increase in debris removal benefit. That is, additional sweeping with the vacuum-assisted sweeper resulted in similar debris removal rates at both the once-per-week and twice-per-week sweeping frequencies. Mechanical sweepers were less effective at debris removal on a weight-of-debris-removed-per-mile-swept basis when sweeping was conducted twice per week as opposed to the standard once-per-week frequency.
- **Sweeper types:** Vacuum-assisted sweepers are generally more effective than the regenerative air and mechanical sweepers at removing debris and especially fine particulates. Site-specific variations in roadway surface condition, roadway grade, and presence of a curb and gutter may have limiting impacts on vacuum-assisted machine performance. Vacuum-assisted sweeper performance declines on sloped streets.
- **Median sweeping:** Initial median sweeping event collected three to five times more debris than subsequent three-week-interval sweeping events. This suggests that a significant buildup of roadway debris occurs within and adjacent to median areas. The results also indicate that debris collected from median areas is similar in pollutant concentrations to the curb and gutter areas on the shoulder edge of the roadway surface.
- **Speed efficiency** study indicate that the operational speed of mechanical street sweepers has little impact on the weight of debris collected in the field.

Limitations

Other Comments

Seattle Public Utilities and Herrera Environmental Consultants. (2009) Seattle Street Sweeping Pilot Study. Accessed online 05.30.2022:
https://www.worldsweeper.com/Street/Studies/Seattle2009/SPU2009Study.pdf

Study Objective

Evaluate whether street sweeping can significantly reduce the mass of pollutants discharged to area receiving water bodies while reducing the frequency of catch basin cleaning.

Methods

- Mass balance approach measuring debris remaining on streets after sweeping (street debris), debris removed by the sweeper (sweeper waste), debris accumulated in catch basins (catch basin sediment), and thus estimating debris exported off site via urban runoff (mass balance result).
- Street sweeping conducted bi-weekly (alternate side of the street sweeping means half of each street is swept weekly). Sweeping was suspended in control sites for the duration of the study. Sweeping was conducted by a regenerative air sweeper at ~5-7 mph.
- Field measurements conducted approximately every 4 weeks.
  - Street debris collected using an industrial vacuum on swept and unswept sides of the street 1-2 days prior to street sweeping.
  - Sweeper waste stored in dumpsters unique to each location, and weighed on an industrial scale after dewatering. Materials > 2 mm removed and tracked separately.
  - Sediment accumulation in 12 catch basins was determined by measuring down from the rim of the maintenance hole to the surface of the sediment.
  - Debris samples from each component composited quarterly for analysis.

Main Findings

- Street sweeping did not result in a measurable difference in catch basin accumulation, but catch basins were all less than 10% full at the time of the study.
- Street sweeping removed ~2200-3100 lb/acre/yr.
- Median monthly street debris yield at swept sites was 48-90% less than control (unswept) sites.
- The mass balance indicates street sweeping can reduce the amount of pollutants discharged to receiving waters.
- Cost estimates of street sweeping vs. cost of constructing regional facilities leans strongly in favor of increasing the frequency and coverage of street sweeping for per kilogram of dry sediment removed.

Limitations

Runoff water quality was not measured specifically citing previous studies that struggled to produce a measurable difference, and the estimated effort required according to a statistical power analysis.

Other Comments

N/A

Kang, J-H., Debats, S., and Stenstrom, M.K. (2009). Storm-Water Management Using Street Sweeping. *Journal of Environmental Engineering,* 135(7):479-489 https://doi.org/10.1061/(ASCE)0733-9372(2009)135:7(479)

Kang, J-H. and Stenstrom, M.K. (2008). Evaluation of Street Sweeping Effectiveness as a Stormwater Management Practice Using Statistical Power Analysis. *Water Science & Technology,* 57 (9): 1309–1315. https://doi.org/10.2166/wst.2008.270

Study objective

Use previously published data to determine if there is a statistical difference in outfall water quality between swept and unswept catchments.

Methods

- Conducted a post-hoc statistical power analysis of previously published data. The null hypothesis tested was *street sweeping does not cause reduction in EMCs at outfalls.*
- The investigation included 15 outfall EMC data sets for total suspended solids (TSS), suspended sediment concentration (SSC) or chemical oxygen demand (COD) in 13 locations from 4 previous street sweeping studies (NURP 1983; Austin, TX 1995; Boston & Milwaukee 2002). The original analysis of data from Austin, TX did find statistically significant differences in TSS at $\alpha = 0.01$.
- Compared end of pipe samples from swept and unswept catchments (either paired catchments or before-and-after samples)
- Treatments also considered type of street sweeper (mechanical broom vs vacuum assisted).

Main Findings

- No differences were detected between swept and unswept observations with statistical power.
- Results were attributed to a high coefficient of variation in the underlying data and overall small sample set.

Limitations

The newest data set considered is 20 yrs old.

Other Comments

- "…numerous studies to evaluate sweeping efficiencies, little evidence has been documented that street sweeping directly improves storm-water quality"
- Extensive literature review on the motivation for street sweeping and the debate over effectiveness, including a summary table of studies published 1972-2005, with main findings.

Muhammad, N. and Hooke, A.M. (2006). Diffuse Pollution in Oxford (Ohio, USA) Watershed and Performance of 'Street Sweeping' as a 'Best Management Practice' (BMP). *Journal of Water and Health,* 4 (3): 357–364. https://doi.org/10.2166/wh.2006.020b

Study objective

Measure outfall concentrations & street sweeper (sediment-attached) concentrations.

Methods

- Wet weather samples collected from 3 outfalls (representing residential, commercial, and high-traffic zones) in a single watershed in Ohio. 14 outfall sampling events; 3 grab samples collected at each outfall and composited.
- Street sweeping performed weekly. 4 street sweep sediment sampling events collected from the dump area of the sweepers
- Runoff and collected road debris were analyzed for total coliform, fecal coliform, fecal streptococci, heavy metals, BOD, COD, total and volatile solids.

Main Findings

- Outfalls showed the highest fecal indicators from the residential area and in spring. The outcome was hypothesized as due to lower vegetation cover. Swept debris contained high concentrations of indicator organisms, suggesting street sweeping was a useful preventative measure from pollutants entering surface waters.
- Heavy metals are predominantly sediment-attached (by far). Street sweeps showed significant accumulation, and thus an important removal mechanism. Outfall concentrations were considered low overall.
- BOD/COD and TS/VS data were less rigorously analyzed. The authors concluded that non-degradable organic matter was dominant in outfalls.

Limitations

- The fraction of each catchment that is roadway was not presented.
- Most explanations are hypotheses, e.g. more pets in residential zones, effects of colder or warmer temperatures.
- Lack of replication brings to question transferability of results (3 outfalls sampled, each with a different land use, albeit with 14 sampling events at each)
- A subjective interpretation of effectiveness of street sweeping is offered. Comparisons were not made against water quality standards or other benchmarks. A control catchment was not monitored.

Other Comments

Older studies of street sweeping may no longer be applicable as sweeper technology has evolved.

Street Cleaning

Gasperi, J., Rocher, V., Moilleron, R., Chebbo, G. (2005). Hydrocarbon Loads from Street Cleaning Practices: Comparison with Dry and Wet Weather Flows in a Parisian Combined Sewer System. *Polycyclic Aromatic Compounds*, 25:169-191, 2005.
https://doi.org/10.1080/10406630590930734

Study objective

Quantify street washing as a dry weather pollutant source.

Methods

- Evaluated water quality of wash water when using a pressurized water jet street cleaning procedure. All wash water was collected in a catch basin.
- 3 sampling campaigns occurred at two mixed use sites (high density residential with some commercial) in Paris, France.
- Samples were analyzed for a range of dissolved and particulate PAHs, *n*-alkanes, and unresolved complex mixture hydrocarbons (UCM).

Main Findings

- Street washing flushes more PAHs into the storm sewer compared to wet weather runoff events; however, it is less efficient in removing *n*-alkanes and UCM, based on comparison to previous studies at similar locations.
- Street washing did not fully remove available PAHs, but is considered a significant source of dry-weather PAHs.

Limitations

N/A

Other Comments

Street washing is not a relevant practice for southern California.

Catch Basin / Inlet Cleaning

Two reports in the Street Sweeping section (Center for Watershed Protection 2016, Seattle Public Utilities 2009) also include limited assessment of catch basin /inlet cleaning. The information is not repeated here.

Morgan State University and Center for Watershed Protection (2018). What's in Your Storm Drain Inlet? A Study to Characterize the Loads from Inlet Cleaning. Accessed online 02/28/2022 https://www.cwp.org/whats-in-your-storm-drain-inlet-a-study-to-characterize-the-loads-from-inlet-cleaning/

Study Objectives

Quantify the amount of nitrogen, phosphorus and sediment loads associated with material removed from catch basin inlets.

Methods

- 97 inlets were cleaned using a Vactor Truck 2100 Series over eleven sampling events on Maryland highways.

Main Findings

- Accumulation in catch basins is variable. Overall, the average composition of sediment, organic material and trash was 67%, 31%, and 4%, respectively (based on dry weight).
- Different densities of materials (vegetation vs trash vs sediment) makes it difficult to compare relative accumulation.
- Fewer than half of catch basins inspected required cleaning, operationally defined as when the pipe or chamber was > 25% full.
- Materials begin to accumulate once pipes in self-cleaning inlets become clogged.
- Seasonality of materials' accumulation provides opportunities to optimize maintenance scheduling that may yield increase in load reductions.
- Approximately 5 lbs of trash is removed each time an inlet is cleaned.

Limitations

The full project report was not accessible. Information here is pulled from the online summary.

Other Comments

N/A

Disconnected Impervious Area

Since Impervious Area Disconnection is uncommon in southern California water quality improvement plans and watershed management plans, only main findings from these studies are presented.

Epps, T. H. P. D. and J. M. P. D. Hathaway (2021). Inter-Event Water Quality Variability and Intra-Event Pollutant Dynamics in Context of Effective Impervious Area. *Journal of Sustainable Water in the Built Environment* 7 DOI: 10.1061/JSWBAY.0000953.

Main Findings

Effective impervious area a.k.a. directly connected impervious area is an indicator of urban stream health

- Disconnecting impervious area to allow infiltration and evapotranspiration decreases runoff rate and volume, and delays the timing off-site hydrographs at the site scale.
- Variability in pollutant loads to 3 urban streams is partially attributed to effective impervious area for multiple pollutants

Baruch, E. M., K. A. Voss, J. R. Blaszczak, J. Delesantro, D. L. Urban and E. S. Bernhardt (2018). Not all pavements lead to streams: variation in impervious surface connectivity affects urban stream ecosystems. *Freshwater Science* 37(3): 673-684.

Main Findings

Macroinvertebrate community composition and the tissue concentrations of Cu, Pb, and Zn in 3 stream invertebrate taxa (*Cambaridae, Tipulidae, and Hydropsychidae*) found across 7 urban stream sites were correlated with watershed hydrologic connectivity

Mueller, G. D. and A. M. Thompson (2009). The Ability of Urban Residential Lawns to Disconnect Impervious Area from Municipal Sewer Systems. *Journal of the American Water Resources Association* 45(5).

Main Findings

Runoff reduction tests and steady-state infiltration testing was successfully used to calibrate a model that predicted substantial stormwater management from urban residential lawns

Walsh, C. J., T. D. Fletcher and A. R. Ladson (2009) Retention Capacity: A Metric to Link Stream Ecology and Storm-Water Management. *Journal of Hydrologic Engineering* 14, 399-406 DOI: 10.1061/(ASCE)1084-0699(2009)14:4(399).

Main Findings

Effective impervious area a.k.a. directly connected impervious area is an indicator of urban stream health.

Shuster, W. D., E. Pappas and Y. Zhang (2008) Laboratory-Scale Simulation of Runoff Response from Pervious-Impervious Systems. *Journal of Hydrologic Engineering* 13, 886-893 DOI: 10.1061/(ASCE)1084-0699(2008)13:9(886).

Main Findings

Differences measured in runoff rate ratio between 0 and 25% impervious area connectivity, at the beginning of synthetic storms during laboratory experiments.

No additional benefits were observed with 50% impervious area connection

APPENDIX C: NS-BMP PRIORITIZATION FULL SURVEY RESULTS

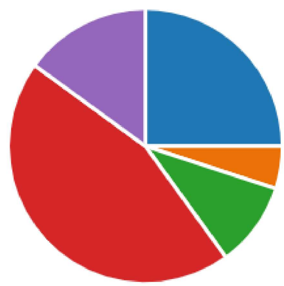
Forms(https://www.office.com/launch/forms?auth=2&from=FormsDomain) ?

Non-structural BMP Prioritization

27	02:45	Active
Responses	Average time to complete	Status

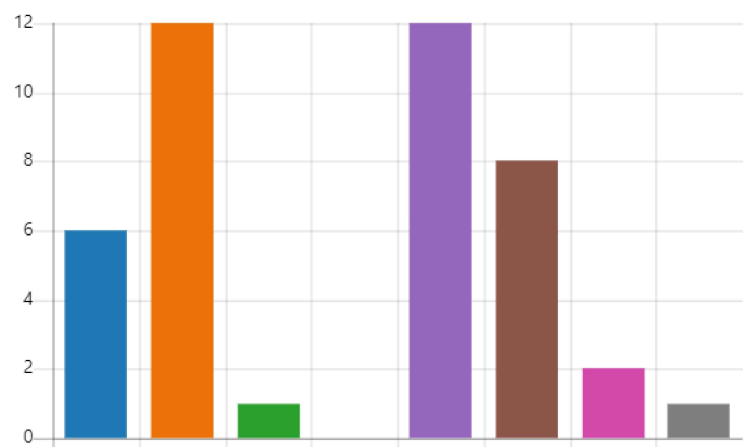
1. Planning and development BMPs

Ordinances requiring structur...	5
DESIGN training to facilitate st...	1
CONTRACTOR training to sup...	2
MAINTENANCE training to su...	9
INSPECTOR training to suppor...	3



2. Pollution prevention BMPs

Facility inspections	6
Catch basin/ drain inlet clean ...	12
Managing exposed soils	1
Erosion control/slope stabiliza...	0
Street sweeping	12
Disconnecting directly connec...	8
Illicit discharge disconnection	2
Covering outdoor stockpiles/s...	1



3. Dry weather runoff reduction

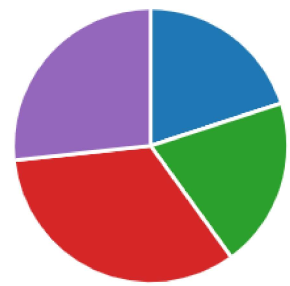
incentives	11
turf replacement with alternati...	8
conversion of spray to drip irri...	1
vehicle washing restrictions/b...	2

4. Public education/outreach/participation

targeted audience outreach	12
pick up after your pet campai...	1
rain barrel programs	5
litter campaigns	6
adopt-a-highway	2

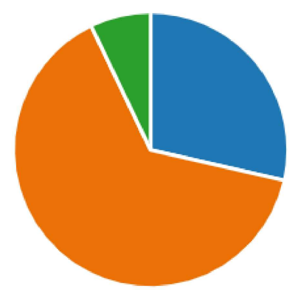
5. Source control

SB 346 for copper (brake pads)	3
SB 757 for lead (wheel weights)	0
zinc reduction in tires	3
pesticide/herbicide bans/restri...	5
plastic bag bans	4



6. New ideas

inspector training	4
incentive programs (except irri...	9
breaking down barriers to imp...	1



APPENDIX D: EFFECT OF STREET SWEEPING ON WET WEATHER POLLUTANT LOADING AND CONCENTRATIONS FROM SOUTHERN CALIFORNIA ROADWAYS

Appendix D

SCOPE OF WORK

Effect of Street Sweeping on Wet Weather Pollutant Loading and Concentrations from Southern California Roadways

The primary goal of this Scope of Work (SOW) is to quantify the positive impact of street sweeping on pollutant loading and concentrations from roadways. In its most basic form, this compares wet weather runoff from swept and unswept road surfaces. The literature clearly shows many factors are at play including climate, road use, road surface type, surrounding land use, sweeping frequency (citations here). However, little of this work has been conducted in southern California. Southern California may be unique in the literature studies with its infrequent rainfall, which can lead to extended pollutant build-up between storms. Moreover, southern California has some of the most intense road use in the nation.

This SOW details seven tasks. Initial tasks are designed to help define and refine the study design and workplan. Later tasks will implement the sampling and analysis. The general approach to this project will test swept vs unswept road surfaces across a variety of potential influencing factors (Table 1). The exact factors to be tested will depend on member agency prioritization and level of effort. Simulated storm events over isolated segments of roadways are proposed as the main means for data collection, to reduce the influence of confounding effects (natural rainfall variability, runoff from other parts of the catchment, etc.) noted in previously published field studies. Outfall monitoring is excluded because of the confounding effects of runoff from other land-uses across the catchments.

Table 1. List of potential influencing factors to be tested in this study

Factor	Variables
Climate	Rain fall volume Rainfall intensity Rainfall duration
Road Use	Average Daily Traffic Number of lanes Light duty vs heavy duty vehicles Road classification*: interstate, arterials, collectors, local roads
Road surface	Material of construction Age
Sweeper frequency	Static frequency Time since rainfall

*https://safety.fhwa.dot.gov/speedmgt/data_facts/docs/rd_func_class_1_42.pdf

Task 1. Establish Technical Working Group

A Technical Working Group (TWG) of SMC member agencies will be established at the beginning of the project. The charge to the TWG will be to: a) review, improve, and approve the study design created at the initiation of the study (Task 2), b) assist the study team in identifying and accessing study sites, c) review interim results during simulated and natural rainfall events to refine and improve the study design, and d) review and approve final oral and written reports. The TWG will be facilitated by the Project Study Team, but ultimately reports to the Steering Committee.

Product: List of TWG members

Task 2. Create Final Workplan

This project is a factorial design with many potential factors (Table 1). At a minimum, swept vs unswept road surfaces will be tested. Other factors may include, but are not limited to, vehicle use, surrounding land use, road surface, frequency of sweeping, storm size and/or intensity, amongst others. Sweeper type is not considered a factor to be tested since the literature is clear that regenerative or vacuum-assisted sweepers provide far superior performance compared to mechanical sweepers, in terms of the mass of street debris captured. Critically, the larger number of factors desired to be tested increases the number of sampling events exponentially, then multiplied by the number of replicates. Thus, this task will require weighing priority factors vs available resources for sampling.

In addition to study design, the TWG will approve the Study Team's recommendations for pollutant analytes to be measured. Street sweeping reduces pollutants in runoff by physically removing debris and particulate road deposits, typically with greater success for particles greater than ~75 μm. Removal of other pollutants therefore depends on sediment-attachment, which may also depend on specific combinations of pollutant type and particle size (e.g., heavy metals have been shown to preferentially adhere to smaller particle fractions).

In addition to rainfall and flow, the Study Team will measure total suspended solids and total trace metals, at a minimum, in runoff from swept and unswept catchments. Other analytes to be considered include dissolved trace metals, polynuclear aromatic hydrocarbons (PAHs), total nitrogen, total phosphorus, toxicity, microbiology, grain size of suspended particulates, at a minimum. The Workplan shall also defined quality assurance and quality control limits for field sampling and laboratory analysis.

TWG will determine the number of simulated and natural rainfall events to be sampled, depending on member agency priorities and level of effort. The TWG should also determine the target intensity (or range of intensities) of simulated rainfall, and the characteristics of natural rainfall events eligible for sampling should. Logistics of the rainfall simulator may influence the range of intensities for testing.

Product: Workplan approved by the TWG and Steering Committee

Task 3. Select and Set Up Sampling Sites

The first step for implementing the Workplan is to identify sites for sampling. SMC members will be needed to find sites with the right combination of factors to be tested (Task 1), street sweeping controls, enable traffic control, access to catch basins and right of way access to sample public easements.

Product: list of sampling sites with documentation

Task 4. Simulated Rainfall Events

At least three sampling events are suggested to be conducted using simulated rainfall directed over isolated roadway segments. Simulated rainfall is used to: a) remove variability due to differences in rainfall complicating comparisons between site-events, b) confirm storm characteristics such as rainfall volume or intensity, 3) control for antecedent rainfall, 4) control for catchment area, and 5) ensure timely completion of the study.

Constant rainfall intensity will be applied during each simulated rainfall to simplify flow measurement and sample compositing, according to the rate(s) determined by the TWG in Task 2. Each simulated rainfall event shall be documented with multiple measuring devices for rainfall across the test area, whether swept or unswept. The test area is limited to the road surface to ensure the best opportunity for measuring effects. The runoff volume for each simulated event will be documented using either flow sensors or total volume capture. All measurement devices shall be calibrated prior to sampling.

Simulated rainfall samples will include water collected from the rainfall simulator prior to impacting the street surface, and street runoff samples after being rained upon. All samples will be composited across the entire storm. Subsamples will be collected from the composite according to methods used by the SMC (SMC Chemistry Guidance Manual 2xxx).

Samples will be analyzed for the analytes listed in the Workplan from Task 2.

Product: Sampling summary memo

Task 5. Natural Rainfall Events

A limited number of natural rainfall events will be collected from both swept and unswept road surfaces at the street-scale as a means to validate the results collected from the simulated rainfall site-event factors. Natural rainfall samples should be collected in as similar a fashion as possible to the simulated rainfall events, with the exception that samples shall be flow-weighted for compositing.

Product: Sampling summary memo

Task 6. Data Analysis

Upon completion of the simulated and natural rainfall events, data management should be conducted to ensure the project data are complete, qualified where necessary, and fully documented with metadata.

Data analysis shall first focus on the comparison of factors designed in the Workplan. This shall be conducted in three steps: a) data characterization using plots or tables of average concentration per factor(s), b) multiple comparisons among factors using ANOVA or equivalent non-parametric test, as appropriate, to define statistically significant differences between factors, and c) multivariate modeling to assess if factors can be used to predict concentrations. Multiple comparisons will define if street sweeping reduces concentrations and/or loads of pollutants. Multivariate modeling will allow SMC members to define where, when, and how often street sweeping can be optimally utilized to reduce concentrations and/or loads of pollutants.

Product: Oral presentation of study results to the TWG and Steering Committee.

Task 7. Reporting

A final report will be prepared by the Study Team describing the goals of the study and study question(s), methods used to answer the question(s), answers to the study questions (from Task 6), and a discussion describing the final conclusions and limitations from the study. All raw data and meta data from Task 6 will also be submitted.

Product: Draft and Final Report reviewed and approved by the TWG and Steering Committee

Schedule

TASK	PRODUCT	DEADLINE (months from project start
1) Technical Working Group	List of TWG members	1
2) Create Final Workplan	Workplan	3
3) Set Up Sampling Sites	list of sampling sites	6
4) Simulated Rainfall Events	Sampling summary memo	12
5) Natural Rainfall Events	Sampling summary memo	18
6) Data Analysis	Oral presentation to TWG	24
7) Reporting	Draft and Final Report	30

Appendix E: Effect of Catch Basin Cleaning on Wet and Dry Weather Pollutant Loading and Concentrations from Southern California Roadways

Appendix E

SCOPE OF WORK

Effect of Catch Basin Cleaning on Wet and Dry Weather Pollutant Loading and Concentrations from Southern California Roadways

The primary goal of this Scope of Work (SOW) is to quantify the positive impact of cleaning catch basin inserts or traps on reducing trash and sediment delivered to the municipal separate storm sewer system (MS4). This SOW focuses on two types of catch basin inserts that require maintenance: a) catch basin inserts for trash which are generally made of perforated metal or screens, and b) catch basin inserts that include a textile cloth that captures both trash and sediment. There is scant peer-reviewed literature on the performance of either type of catch basin inserts, particularly in southern California, and even less on the necessary maintenance of these devices.

This SOW takes two different approaches for the two different types of catch basin inserts. The first task focuses on catch basin inserts for trash capture. This task samples both dry weather and wet weather using automated image analysis to define how quickly the catch basin inserts "fill up". The ultimate goal is to estimate the amount of time until cleaning maintenance is required to ensure on-going functionality of the trash capture device.

The second task focuses on the catch basin insert for sediment. This task samples only wet weather because the overwhelming majority of sediment is transported through the MS4 during storm events. This task measures the mass of sediment in the catch basin insert following a storm, and compares this mass to the flow and sediment mass leaving the catch basin. The ultimate goal is to compare the sediment mass captured to the total mass entering the catch basin, yielding a measure of pollutant removal efficiency and effective loading to the MS4. A secondary goal is to determine how often maintenance (sediment and trash clean out) is required.

Each task requires a number of sub-tasks, detailed below. Initial tasks are designed to help define and refine the study design and workplan. Later tasks will implement the sampling and analysis.

TASK 1. ESTABLISH TECHNICAL WORKING GROUP

A Technical Working Group (TWG) of SMC member agencies will be established at the beginning of the project. The charge to the TWG will be to: a) review, improve, and approve the study design created at the initiation of the study (task 2), b) assist the study team in identifying and accessing study sites, c) review interim results to refine and improve the study design, and 4) review and approve final oral and written reports. The TWG will be facilitated by the Project Study Team, but ultimately reports to the Steering Committee.

Product: List of TWG members

TASK 2. CATCH BASIN INSERTS FOR TRASH

Task 2.1. Select and Set Up Sampling Sites

The first step for implementing this study is to identify sites for sampling. SMC members will be needed to find sites with the ability to sample based on traffic control, right of way access to sample public easements, and accessibility of the inside of the catch basin. Sites with existing trash generation rates are preferred. Sites requiring confined space entry accommodations are less desirable.

Either form of catch basin insert are eligible for monitoring. Very high variability of trash and debris capture is anticipated between sites, based on a literature review, therefore at least five replicate sites for each type of insert (perforated screen or textile) should be monitored. Additional sites can be accommodated. Additional sites will be mandatory, plus additional replicates, if quantifying the factors affecting trash generation is desired, such as land use, catchment size, or dry weather flows, amongst others.

Each site will be equipped with a camera or image sensor, power source, data logger, flow sensor (for the catch basin outlet), and a data transmission device (i.e., cellular modem).

Site operation shall include frequent monitoring equipment maintenance and troubleshooting (e.g., replacing batteries, cleaning camera lenses, etc.).

Product: list of sampling sites with photo documentation

Task 2.2. Sampling for trash

Each catch basin insert will be cleaned of all trash prior to initiating the monitoring program.

A camera will be positioned at each site to capture images of the insert on a daily basis for up to one year. The images should be transmitted via remote access to computers at the contractor's office. Images should also be downloadable in the field if modem communication is lost between the camera and the contractor's office.

Rainfall data shall be obtained from the nearest publicly available rain gauge to estimate the hydrologic load each catch basin, and to differentiate between dry and wet weather debris accumulation.

Automated image analysis will be developed for quantifying the level of trash in the catch basin insert.

When trash accumulates to the level triggering maintenance as recommended by each insert's vendor, the SMC member shall clean all of the trash from the catch basin insert. The volume and mass of trash and debris removed shall be documented.

Product: quarterly progress reports for sampling.

Task 2.3. Data storage and analysis

The contractor shall maintain the images, image analysis, and supporting metadata in a project specific database.

Data analysis can take many forms, but the primary data analysis will be a trash accumulation curve (mass or volume) for dry weather and a second for wet weather, including average number of days until cleaning is required.

Data analysis shall first focus on the comparison of factors designed in the Workplan (i.e., factors identified in Task 2.1). This shall be conducted in three steps: a) data characterization using plots or tables of average concentration per factor(s), b) multiple comparisons among factors using ANOVA or appropriate non-parametric test to define statistically significant differences between factors, and c) multivariate modeling to assess if factors can be used to predict concentrations. Multiple comparisons will define if catch basin cleaning reduces concentrations and/or loads of pollutants delivered to the MS4. Multivariate modeling will allow SMC members to define where, when, and how often catch basin cleaning can be optimally utilized to reduce concentrations and/or loads of pollutants.

Product: presentation to the Technical Working Group and Steering Committee

Task 2.4. Draft and final report

The contractor shall write a draft report, draft final report, and final report documenting the study methods, results, and summarizing the study findings. The draft report will be reviewed by the Technical Working Group. Once approved by the Technical Working Group, the draft final report will be sent to the Steering Committee for review. The contractor shall respond to comments and the final report will be approved by the Steering Committee.

The final report will be posted on the SMC web site after final approval.

The final database will be given to the contract manager.

Product: draft report, draft final report, final report, project database.

TASK 3. CATCH BASIN INSERTS FOR SEDIMENT

Task 3.1. Select and Set Up Sampling Sites

The first step for implementing this study is to identify sites for sampling. SMC members will be needed to find sites with the ability to sample based on traffic control, right of way access to sample public easements, and accessibility of the interior of the catch basin. Sites with existing trash generation rates are preferred. Sites requiring confined space entry accommodations are less desirable.

Textile or bag type catch basin inserts are eligible for monitoring. Very high variability of trash and debris capture is anticipated between sites, based on a literature review, therefore at least five replicate sites should be monitored. Additional sites can be accommodated. Additional sites will be mandatory, plus additional replicates, if quantifying the factors affecting trash generation is desired, such as land use, catchment size, or dry weather flows, amongst others.

Each site will be equipped with an automated flow compositing samplers at the outlet to the catch basin. No inlet sampling is necessary. Flow sensors and peristaltic pumps must be calibrated at site set-up and prior to each storm. Data transmission devices (i.e., cellular modem) are recommended but not required.

The catch basin insert sampling shall quantify the total mass of sediment captured by the catch basin insert. This type of sampling is rare in the literature and multiple options can be utilized based on site configuration. Two of the more straightforward approaches include total weight of the insert (i.e., a scale) or subsampling from different locations within the insert for sediment density and multiplying by estimated volume.

Product: list of sampling sites. Standard Operating Procedure for sampling and field logistics

Task 3.2. Sampling and analysis for sediment

All catch basins and inserts will be cleaned of all sediment and debris prior to initiating the monitoring program.

Wet weather flow weighted composite samples from the catch basin exit shall be collected during every sampleable storm during the wet season, not to exceed 10 storm events per site. All wet weather flow weighted composite samples will be delivered to the laboratory analysis.

Total sediment mass from the catch basin insert shall be quantified following every site-event sampled for wet weather flow composite samples, as defined in subtask 3.1. A minimum of six representative and depth integrated sediment subsamples from the catch basin insert shall be collected and homogenized for laboratory analysis.

Wet weather flow-weighted composite samples and the composited sediment from the catch basin insert shall be analyzed for a suite of parameters. Since urban drainage systems are generally considered to retain particles > 2 mm in the curb and gutter and catch basins, some analyses require sieve separation to quantify pollutant loads that might otherwise be expected to migrate through the MS4. Pollutant analysis is suggested at a minimum:

- Wet (as-collected) and dry mass of total sediment captured in the insert.
- Full particle size distribution of sediment captured in the insert.

Additional optional analysis for the wet weather flow weighted composite samples and/or the contaminants attached to the < 2 mm particles captured by the inserts can be added including:

- Trace metals
- Nutrients
- PAHs
- Pesticides
- Microplastics

- Other constituents of emerging concern

Product: Storm sampling summary memos within three days of every sampled event.

Task 3.3. Data storage and analysis

The contractor shall maintain the site descriptions, rainfall and flow data, flow compositing information, chemical analysis, and supporting metadata in a project specific database.

Data analysis can take many forms, but there are two primary data analyses to be conducted including: 1) a comparison of sediment mass in the catch basin insert versus the total mass of sediment discharged during the storm event, and 2) a sediment accumulation curve in the catch basin insert for wet and dry weather discharges, including the average number of storms until cleaning is required. Additional statistical analyses may be required to examine effects of individual factors as identified in Task 3.1 of the Workplan.

Product: presentation to the Technical Working Group

Task 3.4. Draft and final report

The contractor shall write a draft report, draft final report, and final report documenting the study methods, results, and summarizing the study findings. The draft report will be reviewed by the Technical Working Group. One approved by the Technical Working Group, the draft final report will be sent to the Steering Committee for review. The contractor shall respond to comments and the final report will be approved by the Steering Committee.

The final report will be posted on the SMC web site after approval.

The final database will be given to the contract manager.

Product: draft report, draft final report, final report, project database.

SCHEDULE

TASK	PRODUCT	DEADLINE (months from project start
1. Technical Working Group	List of TWG members	1
2.1 Set Up Sampling Sites	list of sampling sites	3
2.2 Sampling for Trash	quarterly progress reports for sampling	18
2.3 Data Storage and Analysis	TWG presentation	24
2.4 Draft and Final Report	draft report, draft final report, final report, project database	30
3.1 Set Up Sampling Sites	list of sampling sites, SOPs	3
3.2 Sampling and analysis for sediment	Storm sampling summary memos	18
3.3 Data Storage and Analysis	TWG presentation	24
3.4 Draft and Final Report	draft report, draft final report, final report, project database	30