Strategy to Optimize Resource Management of Storm Water

Project 3a Develop Guidance for Alternative Compliance Approaches for Municipal Storm Water Permit Receiving Water Limitations and Project 3b Develop Watershed-Based Compliance and Management Guidelines and Tools

Phase I, Product 1—Draft Final Report: Quantitative Methods that Support Reasonable Assurance Analysis for California's Alternative Compliance Framework

March 30, 2018

STORMS
STORM WATER STRATEGY
CALIFORNIA WATER BOARDS

DIVISION OF WATER QUALITY

STATE WATER RESOURCES CONTROL BOARD

Prepared by Office of Water Programs | California State University, Sacramento

OWP
AT SACRAMENTO STATE

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1. Introduction and Purpose

State Water Resources Control Board (State Water Board) requirements for receiving water limitations[1] (RWLs) in municipal separate storm sewer system (MS4) permits specify that stormwater and non-storm water discharges must not cause or contribute to exceedances of water quality standards in the waters of the United States that receive those discharges. Traditional municipal stormwater permitting approaches to achieving compliance with RWLs rely on an iterative process, whereby an exceedance of a water quality standard triggers a process of best management practice (BMP) improvements. However, the iterative process was largely underutilized and ineffective in bringing MS4 discharges into compliance with RWLs. As an alternative, State Water Board Order WQ 2015-0075 directed MS4 permits going forward to incorporate a well-defined, transparent, and finite alternative path to permit compliance that allows dischargers willing to pursue significant undertakings beyond the iterative process to be deemed in compliance with the RWLs.

As a result, new alternative compliance pathways (ACPs) are being established in MS4 permits that rely on watershed management strategies that are proposed by MS4s in alternative compliance (AC) plans. These AC plans are focusing on implementing BMPs throughout a watershed and using green infrastructure approaches to achieve compliance with water quality targets. Such approaches often rely on modeling and anticipated adaptive management over extended periods of implementation to demonstrate compliance with RWLs and effluent limits, which are derived from total maximum daily loads (TMDLs) waste load allocations. There is little empirical data on the long-term efficacy of these new approaches; the uncertainty associated with data, tools, and models that are used to plan and forecast future water quality improvement raises concerns about their use in enforcing permit conditions.

The goal of this project is to improve confidence in the application of watershed management analysis tools and models as part of permit compliance actions by municipalities. To help accomplish this goal, the objective of this project is to develop technical and management guidance that local stormwater programs can use to develop alternative compliance strategies that demonstrate water quality protection and support watershed-based stormwater management. This guidance will also increase consistency among MS4 compliance strategies, improve the State Water Board's understanding of watershed tools (including data inputs and outputs, assumptions, and uncertainties), and provide MS4 programs with insights for using modeling throughout various stages of implementation of AC plans.

1.1. Reasonable Assurance Analysis Definition

Reasonable assurance analysis (RAA) is a process for communicating, often using models, the effects of future actions (and non-actions) for new stormwater BMPs, as well as the uncertainty associated with those predictions. Specifically, RAA demonstrates that the AC plan to achieve RWLs was crafted based on best available data and verifiable modeling of watershed conditions,

[1] Receiving water limitations are the water quality standards, including water quality objectives and criteria, that apply to the receiving water as expressed in the water quality control plan for the region, statewide water quality control plans that specify objectives for water bodies in the region, State Water Board policies for water quality control, and federal regulations (State Water Board Order WQ 2015-0075). RWL limitation language is common among MS4 permits in California (State Water Board 1999). Two conditions must be met in non-compliance of RWL. First, there is an exceedance of water quality standards in the receiving water and, second, the discharge causes or contributes to that exceedance.

including the effects of existing and proposed BMPs. The Bay Area Stormwater Management Agencies Association (BASMAA) provides a definition of RAA from three perspectives in its RAA guidance document:

> "From a regulatory perspective, reasonable assurance is defined as the demonstration that the implementation of control measures will, in combination with operation of existing or proposed storm drain system infrastructure and management programs, result in sufficient pollutant reductions over time to meet total maximum daily load (TMDL) wasteload allocations, water quality-based effluent limits (WQBELs), or other water quality targets specified in a municipal separate storm sewer system (MS4) permit (United States Environmental Protection Agency [US EPA], 2017). From the perspective of a stakeholder in the watershed who is focused on the improvement of water quality or restoration of a beneficial use of a waterbody, reasonable assurance is the demonstration and a commitment that specific management practices are identified with sufficient detail (and with a schedule for implementation) to establish that necessary improvements in the receiving water quality will occur. From the perspective of an MS4 Permittee, reasonable assurance is a detailed analysis of TMDL wasteload allocations (WLAs), associated permit limitations, and the extent of stormwater management actions needed to achieve TMDL WLAs and address receiving water limitations. RAAs may also assist in evaluating the financial resources needed to meet pollutant reductions based on schedules identified in the permit, TMDL, or stormwater management plan, and in preparing associated capital improvement plans." (BASMAA 2017)

The regulatory perspective is most relevant here, as it is the regulator that must decide whether an AC plan is sufficient to allow a discharger to maintain RWL compliance status by following that plan. However, the other perspectives are critical to overall success because implementation of AC plans will likely need substantial political and public support. One avenue to gaining that support for AC planning is to use the same analysis that supports RAA as part of larger integrated watershed management planning activities. RAA principally informs the development of AC plans, but models used for RAA can also usefully inform planning processes in other water management sectors, including flood control, habitat conservation, water supply, and climate action plans. In particular, the data for hydrologic flows in a well-calibrated model can be leveraged for additional applications, which helps to create holistic watershed planning processes.

1.2. Project Approach and Report Organization

The project team started by reviewing regulations, RAA guidelines, and models to inform the state-of-practice from both regulatory and technical perspectives. For further insight, experienced individuals participated in two workshops to identify RAA issues and provide insight into solutions. This report includes the work products from these efforts.

Section 2 covers the results of a review of ACP approaches compiled and compared AC MS4 permit language. The review of approaches served as a basis for the Alternative Compliance Workshop held on June 8, 2017. This workshop was attended by representatives from eight of the nine Regional Water Quality Control Boards (Regional Water Boards), and the State Water Board. The workshop identified technical needs for the quantitative analysis necessary to support RAA. These needs are summarized in Section 3. Because the primary area of technical need identified related to uncertainty, panelists at the Sources of Uncertainty Workshop held on November 30, 2017 discussed this and related topics. Section 4 lists the panelists and summarizes key topics from the workshop. Several projects were also developed based on the workshop discussion. These are presented in Appendix D. Finally, development of guidance on selecting and using analysis tools for RAA was able to draw substantially from existing work (LA-RWQCB 2014), including recent work completed after this project was initially scoped (BASMAA 2017, US EPA 2017). However, these studies were not intended to establish statewide policy regarding selection and use of RAA tools so these concepts were included in this document as guidance for future State Water Board policy development. For modelers, this report identifies data needs that will be addressed, in part, by future Strategy to Optimize Resource Management of Storm Water (STORMS) projects. For regulators, this report identifies general elements of RAA that can be considered for next-generation permits. Those elements, presented in Appendix E, are meant to support permit writers. It is recommended that policies that are developed based on these elements evolve as more experience is gained in ACPs throughout the state.

The project team included Erik Porse and Brian Currier from the Office of Water Programs (OWP) at California State University, Sacramento; Ken Schiff from Southern California Coastal Water Research Project (SCCWRP); and Elizabeth Payne and Chris Beegan from the State Water Board.

2. Review of Alternative Compliance Pathways

This section summarizes a review of alternative compliance and reasonable assurance analysis (RAA) strategies used throughout the state in MS4 permits.

2.1. Permit Review and Water Boards Survey

A survey questionnaire was distributed to management and stormwater program staff at the State Water Board and all nine Regional Water Quality Control Boards (Regional Water Boards) to gather information about current or draft MS4 permits (see Table 1). The questionnaire consisted of 36 questions focused around the seven principles for alternative compliance approaches identified in Order No. 2015-0075. See Appendix A for a copy of the questionnaire.

Table 1. Regional Water Board Permits used for Survey Responses

Region	Permit	Order No.	Adopted
1	North Coast Region	R1-2015-0030	2015
2	San Francisco Bay Region	R2-2015-0049	2015
3	City of Salinas	R3-2012-0005	2012
4	Los Angeles County	R4-2012-0175-A01	2012 (amended 2015 and 2016)
5	Central Valley Region	R5-2016-0040	2016
6	Lake Tahoe	R6T-2017-0010	2017
7	Whitewater River Region	R7-2013-0011	2013
8	Orange County	R8-2009-0030	2009
8*	Draft Orange County	Draft Order No. R8-2016-0001	(fourth draft withdrawn 2016)
9	San Diego Region	R9-2013-0001	2015

*Draft permit

2.2. Summary of Survey Responses

As identified in the survey responses, AC approaches generally fit into one of two categories: optional or prescribed AC. An optional ACP provides the regulated party a choice of how they intend to comply with RWLs: follow the traditional approach to RWL compliance or with Regional Water Board approval, develop a watershed management plan supported by empirical analysis that allows time to demonstrate compliance with RWLs. Prescriptive AC requires the regulated parties to engage in an alternative compliance pathway and, with Regional Water Board approval, develop a watershed management plan that allows time to demonstrate compliance with RWLs. Only five of the nine regions currently include an AC approach in an MS4 permit within their region, as noted in Table 2.

Table 2. Alternative Compliance Approaches in each Regional Water Board Permit

Permit in Region	Optional Alternative Compliance	Prescribed Alternative Compliance
2		✓
4	✓	
5		✓
8	✓*	
9	✓	

* Draft permit

State Water Board Order WQ 2015-0075 (along with WQ 98-01, is a precedential order that requires municipal stormwater permits to not cause or contribute to exceedances of water quality standards in the receiving water) identifies the following seven principles to be followed in drafting RWL compliance alternatives:

1. Continue to require compliance with water quality standards in accordance with Order WQ 99-05
2. Allow compliance with TMDL requirements to constitute compliance with RWLs
3. Provide for a compliance alternative that allows permittees to achieve compliance with RWLs over a period of time as described above
4. Encourage watershed-based approaches, address multiple contaminants and incorporate TMDL requirements
5. Encourage the use of green infrastructure and the adoption of LID principles
6. Encourage the use of multi-benefit regional projects that capture, infiltrate, and reuse storm water
7. Require rigor, accountability, and transparency in identification and prioritization of issues in the watershed, in proposal and implementation of control measures, in monitoring of water quality, and in adaptive management of the program

Of those, current permits across regions consistently addressed five of the principles (1, 2, 4, 5, and 6), as shown in Table 3.

Table 3. Summary of Survey Responses to Questions about Principles 1, 2, 4, 5 & 6

Permit in Region	AC Type	1 RWL	2 TMDL	4 Multiple cont.	5 GI/LID	6 Multi-benefits
2	Prescriptive	Yes	Yes	Yes	Yes	Yes

4	Optional	Yes	Yes	Yes	Yes	Yes
5	Prescriptive	Yes	Yes	Yes	**	Yes
8*	Optional	Yes	Yes	Yes	Yes	Yes
9	Optional	Yes	Yes	Yes	Yes	Yes

*Draft permit
** Survey response was "no." However, for Principle 5 while the AC approach in the MS4 permit in Region 5 does not explicitly encourage green infrastructure (GI) or low impact development (LID), the permit language in general requires permittees to incorporate LID strategies into their Planning and Development Programs.

Two particular principles of interest from Order 2015-0075 that relate to RAA are Principles 3 and 7. Principle 3 describes how MS4 permits should incorporate an ambitious, rigorous, and transparent alternative compliance path that allows permittees appropriate time to come into compliance with RWLs without being in violation of the RWLs during full implementation of the compliance alternative. All of the AC approaches described in the survey responses require specific compliance schedules for plan development and implementation, but the schedule requirements differ among MS4 permits. MS4 permits also differed in when they deemed permittees to be in compliance or out of compliance with the permit and the RWLs. For some, permittees are considered in compliance when the regulated party applies for the ACP, as long as they are meeting all of the prescribed milestones. In other permits, permittees are not deemed in compliance until their watershed management plan is approved by the Regional Water Board. Within the AC approaches, the permits differed slightly in what was deemed non-compliance with RWLs, and what the consequences were for permittees who exceeded water quality standards and/or failed to meet milestones and deadlines. Table 4 summarizes the survey responses to questions about Principles 3 and 7.

According to Principle 7, MS4 permits require rigor, accountability, and transparency in identifying and prioritizing issues in the watershed, in proposing and implementing control measures, in monitoring of water quality, and in adaptively managing the program. Each AC plan requires some type of forecasting, modeling, and/or data analysis to identify and prioritize water quality issues. However, while some MS4 permits expect rigorous RAA, others are rather vague. None of the permits describe how the analytics will be used for adaptive management decision making.

Table 5 describes the types of required supporting documentation for each AC and RAA approach. This includes the types of quantitative analyses that are acceptable, as well as permit requirements regarding minimum data needs to perform the analysis. While modeling is required in several permits, in others less complex quantitative analyses are allowed. The minimum data requirements for each analysis are typically based on land-use and pollutant-loading data. Quality assurance and quality control checks, as well as estimates of error and performance confidence, are required for the MS4 permits in Regions 4 and 5.

These results and Tables 1–4 were described and discussed at the Alternative Compliance Workshop held on June 8, 2017. This workshop was attended by representatives from eight of the nine Regional Water Boards and the State Water Board. The summary served as the backdrop for conversations and brainstorming of needs associated with AC approaches and RAA.

Table 4. Summary of Survey Responses to Questions about Principles 3 & 7

Permit in Region	AC Type	3 Compliance Begins at	3 If Permittee is out of Compliance	7 Analysis	7 WQ Issues Prioritized	7 Adaptive Management
2	Prescriptive	Effective date of permit	Subject to enforcement and must modify BMP strategies	RAA (as defined in permit)	N/A: Priority WQ issues are prescribed in the permit	Integrated monitoring report and adaptive improvements (every 5 years)
4	Optional	Upon Notification of Intent	Must modify AC plan and are subject to traditional compliance (during modification process)	RAA (as defined in permit)	Yes: Requires/defines categorizing water body-pollutant combinations	Integrated monitoring program and adaptive management (every 2 years)
5	Prescriptive	Upon Notice of Applicability	Must modify AC plan or face enforcement of traditional compliance	RAA (as defined in permit)	Yes: Defines pollutant prioritization pathway	RAA audit every 10 years and adaptive management (Years 3 and 5)
8*	Optional	Upon filing Notice	Must modify AC plan and are subject to traditional compliance (during modification process)	Quantitative/ Modeling	Yes: Permittee to include in AC plan	Annual effectiveness assessments
9	Optional	Upon acceptance of AC plan	Subject to enforcement and must modify BMP strategies	Quantitative	Yes: Requires identifying priority WQ conditions	Integrated monitoring and assessment program and adaptive management

Table 5. Supporting Documentation for AC & RAA Approaches

Permit in Region	Quantitative Analysis Type	Details	QA/QC	Minimum Data Required	How is Uncertainty Addressed?
2	RAA: peer-reviewed models, specific to mercury and PCBs	Calculated load reduction assessment using accounting system described in permit and Integrated Monitoring Report.	—	Land-use mass yields of mercury and PCBs; RAA must establish the relationship between areal extent of GI implementation and mercury/PCBs load reductions, estimate the amount and characteristics of land area that will be treated through GI in future years, and estimate the amount of mercury/PCBs load reductions that will result from GI implementation by specific future years.	—
4	RAA; peer-reviewed models in public domain (model examples: WMMS, HSPF, SBPAT)	In some cases, it may be possible to identify a ”limiting pollutant” that can be used as the focus of the analysis—i.e., to estimate necessary pollutant reductions and to analyze the BMP scenario to achieve the required reduction—which will result in achievement of required reductions in other pollutants. Where this approach is taken, adequate justification must be provided.	Established QA/QC criteria; QA/QC checks of data	Sub-watershed data collected within last 10 years; land-use and pollutant loading data; identification of all data sets; data on BMP performance drawn from peer-reviewed sources.	Data shall be statistically analyzed to determine best estimate of performance and the confidence limits on that estimate of the pollutants to be evaluated.
5	RAA; should be mostly public domain models or comparable methods, such as trend analyses (model examples: HSPF, SWMM, SUSTAIN)	Models may use an established surrogate relationship between WQ constituents and PWQC concentrations and/or loads. RAA may evaluate multiple constituents and ultimately identify the limiting pollutant that drives the implementation strategies and activities.	Established QA/QC criteria; QA/QC checks of data	RAA must be a quantitative evaluation that relies on BMP performance data, reasonable assumptions that are clearly stated. RAA shall use available relevant data collected, including land use and pollutant loading data.	Evaluation should provide error estimate for annual average loads or other relevant targets or propose modifications to the assessment program to refine the quantification as new info is collected. Data shall be statistically analyzed to determine the best estimate of performance and the confidence limits on the estimate of the pollutants to be evaluated.
8*	Quantitative/ Modeling	Draft permit additionally requires a SWOT analysis to evaluate the non-technical merits of the plan such as likelihood of securing funding.	—	No minimum required; analysis is required to amount to a “reasonable assurance,” but there are no standards or protocols that fully define this yet.	—

9	Quantitative; no model parameters are provided, model is not required	—	—	Permittee must conduct an analysis with clearly stated assumptions that must quantitatively demonstrate goals. Analysis must “reasonably” and “quantitatively” demonstrate implementation of the WQ improvement strategies can achieve the numeric goals within the schedules.	—

3. Identifying Technical Needs for Reasonable Assurance Analysis

As noted, the first of two technical workshops assembled experts and Regional Water Board staff on June 8, 2017, for the explicit purpose of identifying technical issues for RAA. The technical issue areas generated from the workshops are described in this section. General areas identified as technical issues included model selection, input data, verification data, and model reruns during the AC timeline.

3.1. Model Selection

Currently, the various regions utilize different hydrologic and water quality models for RAA. Some are public, while others are private. Workshop participants noted that there is little rationale for model selection among regions around the state, especially in areas where the most complicated models may not be necessary or affordable. Quantitative evaluation of sensitivity, precision, and bias for various watershed models and various outcomes would inform improved guidance on model selection.

3.2. Data

Guidance is needed for both model input data and compliance verification monitoring data.

Two types of water quality model input data are of primary interest: monitoring data and BMP performance data. Other than LA-RWQCB (2014), there is little to no guidance for what constitutes acceptable input data for watershed modeling. In many cases the data used is 15 years old and may not reflect current conditions. Watershed models typically estimate performance parameters of various BMPs from the International BMP database. Performance data are compiled from around the world and may or may not represent the performance typically achieved in California. So, even if a watershed model predicts existing conditions perfectly, there may be a lack of confidence that future scenarios will achieve the forecasted volume or pollutant reductions.

In addition, the level of outfall discharge and receiving water monitoring data required to verify AC progress is inconsistent around the state, both in terms of monitoring design and level of effort. No Regional Water Board has stipulated how the monitoring data will be used or interpreted for making decisions. Monitoring design guidelines are needed, including site density and sampling frequency. One approach is to base guidelines on statistical power analysis. This requires establishing a statistical level of confidence, estimating the target effect, and estimating error at a particular site and between sites. Another possible guideline is to trigger monitoring based on the scale and location of compliance activities within the watershed.

3.3. Recalibrating and Rerunning Models

It was recognized that uncertainty can decrease as more data is collected throughout the implementation timeline. However, current requirements, if any, to recalibrate and rerun watershed models are arbitrary or based on permit terms rather than actual changes (infrastructure improvements or new BMPs) in the watershed. Further, the analysis tools used for initial RAA may not be appropriate for later stages of verification.

4. Identifying Areas of Uncertainty

The second of two technical workshops assembled experts and Regional Water Board staff on November 30, 2017. This workshop focused on identifying and dealing with uncertainty in RAA. In particular, the second workshop was designed to identify the most critical technical needs for addressing the focus areas identified in the Alternative Compliance Workshop held on June 8, 2017. The workshop charge is provided in Appendix B.

A panel of municipal managers, modeling experts, and regulators was convened to represent the cross-section of expertise typical of BMP planning, design, and modeling. During the morning session, participants identified areas of technical uncertainty. During the afternoon session, participants organized those areas into common themes and then discussed potentially beneficial projects that the State Water Board might pursue.

The panelists were invited based on experience in modeling, RAA guidance, nongovernmental organizations (NGOs), permittees, and BMP data. The panelists were:

- Brandon Steets (Geosyntec)
- Chad Helmle (TetraTech)
- Chris Minton (Larry Walker Associates)
- Dave Smith (US Environmental Protection Agency)
- Drew Kleis (City of San Diego)
- Eric Strecker (Geosyntec)
- Ian Wren (San Francisco Baykeeper)
- Jing Wu (San Francisco Estuary Institute)
- Nicole Beck (2ndNature)
- Sean Bothwell (California Coastkeeper Alliance)
- Shelly Luce (Heal the Bay)
- Steven Carter (Paradigm Environmental)
- TJ Moon (Los Angeles County)
- Tom Mumley (San Francisco Bay Regional Water Board)
- Renee Purdy (Los Angeles Regional Water Board)

Study team members present were workshop facilitator Ken Schiff of SCCWRP; Erik Porse and Brian Currier of OWP; Dominic Roques of the Central Coast Regional Water Board; and Beth Payne, Chris Beegan, and Annalisa Kihara of STORMS. Other interested parties observed.

4.1. Sources of Technical Uncertainty

Panelists discussed how, at each step of the process, sources of uncertainty exist, including:

- Knowledge of drivers of impairment
- Interpreting existing water quality standards
- Waste load allocations
- Translating waste loads into units that are appropriate for dry and wet weather urban runoff
- Selection of design storms

- Achievable time frames for implementing plans and achieving improvements
- Land use and associated runoff and loading estimates
- Locations of primary source load areas
- Precipitation and hydrology
- Differences in the source, fate, and transport among pollutants, including how surrogates relate to regulated pollutants
- Estimates of BMP effectiveness and performance
- Location of BMPs in relation to contaminant sources
- Inherent uncertainties in modeling approaches
- Use of the outputs to generate plans of viable resolution and detail

Additional sources of uncertainty concern the ability to implement BMPs, including funding and financial planning and support among voters and elected officials.

Workshop participants agreed that there are many challenging factors involved in implementing TMDLs and MS4 permits, but no one factor contributed overwhelmingly to the uncertainty identified. However, most of the discussion was based on the collective experience of data mining and modeling. Few had performed quantitative analyses of uncertainty on many of the factors identified. So, even though modelling was an easily identified source of uncertainty, it is likely no more significant than other factors that play a role in the uncertainty in the process.

It was noted that uncertainty is a matter of fact at any point along an ACP timeline, and RAA guidelines should increase confidence in analysis outcomes given the realities of limited resources, lack of data, and impediments to implementation. However, the challenge of increasing confidence in outcomes applies to municipal acceptance. Panelists noted the need for increased confidence among audiences other than regulators, including political leaders and the voting public who will be asked to support future water projects. Some panelists were concerned that communicating too much information can confuse non-technical audiences and actually lower confidence. The outcome of the discussion was that, as a process, RAA can promote greater transparency in the understanding of current conditions, desired conditions, and the change needed to achieve desired conditions.

Panelists also identified that it is inappropriate to merely perform a sensitivity analysis using best and worst case scenarios from the available data. This does not consider the likelihood that the extremes of each input factor would occur at the same time. As a result, the more inputs (data) added to the model, the more the results of a sensitivity analysis can diverge. Wide ranges in possible results do not necessarily communicate how likely those divergent outcomes really are. The calculated result and associated ranges of outcomes can exceed a target level of confidence (statistically speaking). Uncertainty analysis should be constructed to properly account for relationships between explanatory factors that influence model results.

Another observation affecting initial tolerance of uncertainty is that as data is collected throughout the ACP timeline, uncertainty will be reduced. Greater uncertainty should be expected earlier in the process. Some panelists felt that this was a reason for caution in communicating uncertainty early in the process. Just because initial uncertainty is high, ultimate RWL compliance is more certain where a robust adaptive management process is in place.

Panelists also discussed how some pollutants, such as bacteria and trash, are not well supported by existing modeling approaches and data availability. This presents a regulatory challenge when ACP permit language requires all TMDL pollutants to be assessed at the onset of the ACP timeline. With bacteria, issues such as indicator organisms, regrowth within receiving waters, and heterogeneous distribution of human sources (e.g., discrete occurrences of leaking infrastructure) all make the task of modeling bacteria extremely challenging. With trash, issues such as generation locations and pathways to receiving waters present unique challenges. Options for customizing ACP using RAA for challenging constituents are discussed in Section 5.2.

Panelists also discussed uncertainties in setting TMDLs, but this issue was tabled as outside the scope of this project. Other critical issues mentioned, but also outside the scope of this project, include cost uncertainty, finance plans, and political support.

4.2. Improving RAA

Panelists were asked two summarizing questions:

1) What have we learned so far and what would we do differently (if we could start over)?
2) How can we improve?

One concern is the substantial number of assumptions required to translate some permit requirements into quantifiable outcomes that can be assessed by a model. For instance, utilization of dry and wet weather waste load allocations in urban watershed planning requires a number of key decisions (e.g., design storm) and assumptions that can vary by pollutant and watershed. Without clear regulatory guidance for these assumptions, along with a collective understanding of their necessity and implications, transparency in the RAA process may be reduced.

Additionally, the two questions above spurred insights from panelists regarding the interpretation and use of models for RAA:

- Modeling is highly useful in identifying broad programmatic needs and gaining agency and political support, but project siting requirements respond to many real-world factors including but not limited to feasibility, land ownership, and existing infrastructure
- Feedback in the process is important and models can and should be revisited over time as part of adaptive management processes
- Users should understand tradeoffs in model sensitivity and the benefits of focusing on a few key model parameters such as metals, bacteria, and hydrologic flows
- The proper scale and scope of a modeling program is not clear (for example, should it be phased, focusing first on monitoring locations close to new BMPs, then later move to trends in receiving waters?)
- Regulatory agencies need experts that are savvy to review model inputs
- Lack of appropriate models for hard-to-assess contaminants, such as bacteria, increase uncertainty, so new modeling approaches may be needed for these contaminants
- Standardizing data sets and processes can increase confidence that regulators perceive based on familiarity of methods overtime, but standardizing methods and data can also propagate errors over space and time

4.3. Common Themes

In the second half of the workshop, panelists grouped the issues raised in the prior sessions into six overarching themes:

1. Model sensitivity and critical data needs
2. Uncertainty guidance for estimation and communication

3. Optimizing evaluations and assessments
4. Process mapping for development of an ACP
5. Increasing confidence in decision-making
6. Addressing planning tools that are outside the modeling process

The first three themes aligned with the STORMS RAA project and were discussed in more detail. The next three themes addressed issues outside of RAA, but within a larger ACP perspective. While these themes do not align with the scope of the current STORMS project, they are nonetheless important considerations for future projects and policy development. The results of brainstorming related to all six themes are presented in Appendix C.

4.4. Future Considerations for Planning and Implementing STORMS Projects

Reoccurring themes of uncertainty and transparency highlighted the need to develop a list of universal elements of RAA. Proposed elements are presented in Appendix E. Panelists generally agreed that reducing uncertainty would benefit more from improved data rather than improved models. Consequently the project team developed two projects that can be implemented immediately to improve data quality and one that addresses a comparison of sensitivity among models. An example scope of work for each project is provided in Appendix D.

5. Review of Models for Reasonable Assurance Analysis

Given this backdrop of issues regarding the implementation of RAA and associated uncertainties noted by practitioners with significant experience in RAA models in California, this section of the report comprehensively describes the role of modeling and modeling approaches for RAA. It surveys common types of models, identifies assumptions and limitations of various models, and assesses rationale for using various models. The section identifies issues that regulations should consider in providing specific guidance on what modeling approaches to use in RAA.

The discussion that follows covers key themes. First, the section reviews general modeling approaches used in planning and managing urban stormwater. Second, it characterizes existing models, including core models generalizable to any municipality and region-specific models used by municipalities in California for RAA. Third, it discusses how models align with planning and verification stages of stormwater permits, and how this relates to milestones of the RAA process. Fourth, it describes how uncertainty is typically characterized in stormwater models. Fifth, it outlines key questions that municipalities should consider when developing a model for RAA, which can best align modeling outcomes with analysis needs. Finally, it notes potential projects that could improve confidence in stormwater models used in RAA, drawing on the contributions of workshop participants. The section builds on previous reports published by the Los Angeles Regional Water Quality Board, USEPA Region 9, BASMAA, and private consultants with experience in developing stormwater models for California municipalities. These are referenced throughout (US EPA 2017; BASMAA 2017; Geosyntec Consultants 2013; LA-RWQCB 2014).

5.1. Model Utility

Increasingly, stormwater management relies on coupling analysis with models to support planning needs and verification requirements. Such assessments, which are core components of RAA in support of permit compliance actions, take many forms. Aligning appropriate analytical and modeling approaches with management needs can be challenging.

To understand current systems operations and plan future systems to meet goals, managers can undertake performance assessments (sometimes termed empirical approaches), mathematical modeling, and watershed characterizations (Jefferson et al. 2017). Performance assessments evaluate the effectiveness of existing installations by analyzing collected data, which can be specific to a single installation or include data points across a watershed. Mathematical modeling uses data and assumptions to create numerical representations of physical processes involved in precipitation and runoff. These models can help understand current and future performance of stormwater infrastructure. Finally, watershed characterizations identify geographic boundaries of areas for prioritizing the use of various stormwater measures, based on a number of descriptive and quantitative factors. For instance, priority areas for new stormwater measures can be identified and mapped based on key factors such as topography, soils, land use type, land values, or other spatially-explicit characteristics.

In developing and using these tools for stormwater management, it is important to distinguish between planning and verification. Planning studies can use a variety of quantitative modeling and ranking procedures to help size infrastructure improvements, assess the scale of implementations necessary to meet water quality goals, or prioritize geographic locations for new infrastructure. Planning occurs early in the RAA process or at key milestones of adaptive management. Verification examines the performance of existing or newly installed infrastructure using collected data. Verification can occur for specific BMPs or at broader geographic scales across a watershed. RAA supports both planning and verification efforts that are part of municipal actions to meet permit requirements.

Modeling and quantitative assessments that comprise RAA are actions that constitute compliance with municipal stormwater permits through ACPs. Quantitative procedures that meet the needs of milestones throughout ACP must consider the frequency at which RAA models will be used during the life of municipal stormwater projects. For instance, if a quantitative tool such as a model is to be used for multiple RAA studies that support iterative and adaptive stormwater planning over a decade or longer, the model should be devised to be flexible and provide the necessary information required for planning across a lifetime of ACP activities.

These broad considerations shape the sorts of tools that municipalities would use in support of RAA. But model development is also subject to resource or data limitations. Stormwater modeling and performance assessments can require significant time, money, and expertise to undertake. Permits differ across regions and the specifics of a permit can influence the best alignment of existing data and models, information needs as part of permit compliance, and resources within municipalities.

5.2. Characterizing and Comparing Models

Computer-based watershed models use mathematical relationships to simulate aspects of stormwater system performance, with the goal of modeling water flows and water quality as accurately as possible (Nix 1994). Such models support the creation of scientific knowledge and address decision-making needs. Models can generate improved understanding of watershed processes, compare opportunities and tradeoffs between management options, assess the effects of water allocation schemes, and identify relationships between landscape characteristics, climate patterns, and downstream water quality measurements, to name a few applications.

Computer-based urban stormwater models were first developed in the 1970s with initial software such as the Stormwater Management Model Level I, STORM, and the Hydrologic Simulation Program-Fortran in C (Heaney, Nix, and Huber 1976; HEC 1977; Johanson, Imhoff, and Davis 1976). Numerous existing sources have documented the many available urban stormwater models that have been developed (Nix 1991; Nix 1994; Zoppou 2001; Obropta and Kardos 2007; Elliott and Trowsdale 2007).

Mathematical stormwater models can generally be classified according to several categories, which are not fully exclusive and overlap:

- Models classified as deterministic or stochastic characterize how the models simulate processes affecting runoff and incorporate uncertainty. Deterministic models use specified inputs to yield exact outputs based on mathematical relationships. They simulate hydrologic and hydraulic processes. Stochastic models similarly use mathematical formulas to relate rainfall and runoff processes, but rather than stipulating outputs directly from inputs, stochastic models relate processes to each other through statistical relationships of one or more variables, derived from analysis of observations. Because observed relationships in runoff and correlating parameters (climate, rainfall, land cover, etc.) are “noisy,” equations derived from statistical observations include estimates of the degree of uncertainty associated with the model and procedures used to identify the best fitting relationship. An example of a stochastic urban runoff model is an Ordinary Least Squares (OLS) linear regression that details a buildup-washoff relationship, with contaminant concentrations at a downstream discharge point explained by variables such as antecedent (preceding) dry days and volume of runoff. While deterministic models attribute direct cause and effect, stochastic models demonstrate correlations (not causation) and incorporate inherent randomness. Stochastic models often have coarser geographic resolution (lumped). Additionally, as they are derived from observed data, stochastic models are best used for planning rather than verification purposes. They help yield informed assessments of effective management options rather than simulating outcomes (Tasker and Driver 1988). For both deterministic and stochastic models, the intent of the modeling procedure is to inform planning by relating watershed characteristics, climate, soil, geology, and precipitation with downstream water quality and quantity measurements. The extent to which models can support verification and evaluation is a function of their underlying design assumptions.

- Whether the geographic resolution of the model does or does not differentiate specific watershed areas in the study region determines if the model is distributed or lumped. Distributed models represent watersheds as more than one distinct sub-region of specified geographic boundaries, where runoff is estimated according to parameters unique to that geographic area. The sub-regions are all connected through a prescribed network for routing water flows, which simulates how water moves through the larger watershed and denotes the relative locations of sub-regions. Alternatively, lumped models treat a study zone as a single region. Predictive inputs and resultant outputs are correlated, but lumped models lack more specific geographic resolution. Distributed models tend to be more data intensive but offer greater flexibility for planning and verification purposes.
- Event-based or continuous models specify whether the models use particular design storms, such as the 85th percentile rainfall event, or a continuous hydrologic record in modeling runoff processes. Event-based models focus on particular design storms, such as the 85th percentile storm used in many stormwater planning procedures in California, to simulate rainfall and associated runoff for that particular event. Alternatively, continuous models simulate flows over time, using a time record over a given period of interest with sufficient hydrologic data. Continuous models tend to be more data intensive, but offer greater flexibility for planning and verification purposes.

In practice, almost all stormwater models are hybrids, containing features of multiple classification types. Most are spatially distributed and must define how interconnected parts of the watershed interact, including how all of the contributing data interconnects and relates. Aligning planning and verification needs with available data and expertise dictates the selection of watershed-scale modeling tools appropriate to support stormwater infrastructure assessments (US EPA 2017). Many robust models capable of supporting stormwater planning processes in California are continuous and distributed, or at least pseudo-continuous and pseudo-distributed (Nix 1994). This does not mean that, for instance, aspects of uncertainty are absent from deterministic models. Moreover, some regions with limited data or established modeling procedures look to more straightforward modeling approaches that rely on less complex empirical methods (Blackwell, Steets, and Schal 2015).

In addition to the above categories, the Los Angeles Regional Water Quality Control Board, as part of its assessment of models useful for RAA, categorized stormwater models as distinctly capable of simulating: 1) land and watershed processes, 2) receiving water processes, 3) BMP performance (through process-based and empirically-based methods), and 4) integrated stormwater and BMP processes that are tailored to a specific region. These categorizations group models in a way relevant for regional board procedures, especially in the task of linking model outcomes with regulatory metrics and planning needs. Models could fall into several of the categories. In addition, integrating BMP processes often involves the inclusion of sub-modules (LA-RWQCB 2013).

5.3. Developing Stormwater Models for RAA

Creating a model to simulate rainfall and runoff in urban watersheds as part of RAA is a multi-step process. First, the modeler must characterize baseline conditions in the urban watershed, representing existing infrastructure, land use distributions, land cover, and other characteristics. Through typical procedures for model development, parameters are calibrated to observed data using a chosen time period that should include wet- and dry-weather events. Model performance is then evaluated using a longer record of time. Performance characteristics are assessed by comparing model and historic volume, flow, and contaminant concentrations. Through either continuous simulation over time or specific precipitation events of interest, the modeled period would include wet- and dry-weather conditions capable of addressing how permits address these events.

With a calibrated model established, it becomes possible for modelers to assess how various actions, including land use changes, new BMPs and infrastructure improvements, or even municipal actions such as street sweeping (depending on the model), would affect water quality outcomes. Some integrated modeling frameworks support optimization of potential actions based on cost or performance factors (see Section 5.4). For all models, the difference between historic values and outputs (assuming a well-calibrated modeling procedure developed according to guidelines) provides the assurance that municipal managers and regulators need to know that future new infrastructure, undertaken based on results of the RAA, will ultimately achieve water quality outcomes specified in municipal permits.

Some existing documents, such as the watershed plans developed as part of Enhanced Watershed Management Programs (EWMPs) in Los Angeles, summarize the necessary steps to develop calibrated and useful models (LA-RWQCB 2014). Two key factors, data inputs for the model and requirements for model outputs, ultimately shape how a model is constructed.

5.3.1. Data Needs

Stormwater and watershed models are often data intensive. Simulated processes in a watershed model include overland flow, groundwater recharge and infiltration, interflow, evaporation and evapotranspiration, in-stream sediment transfer, bacteria and organic matter growth, and chemical and biological transformations. Simulating these requires data inputs for:

- Topography and geography, including land use, land cover, slope, and watershed boundaries
- Surface water flows based on stream locations, flow volumes and velocities, and in-stream depths
- Urban runoff processes including runoff outfall locations, discharges, and pollutant concentrations
- Soil data such as hydrologic soil groups
- Climate and atmospheric processes, such as historic and predicted precipitation or estimates of evaporation and evapotranspiration

Table 6: Data requirements for watershed modeling in support of stormwater planning and RAA permit processes (adapted from LA-RWQCB 2013)

Data Requirements for Urban Stormwater and Watershed Models	
Geography and Topography	**Climate**
Imagery and satellite data Topography (digital elevation models) Land use and land cover	Precipitation Evaporation and evapotranspiration

Stream and channel network Drainage areas and outfalls	
Soil and Geology	**Hydrology**
Soil groups Distribution and composition of soils Sub-surface geology Groundwater basins Average slope Vegetative cover of soil	In-stream flows In-stream depth (wetted depth or profile) Water storage infrastructure
Water Quality	**Jurisdictions**
Point source locations Non-point source characterizations Contaminant discharges characteristics (flow and duration) Contaminant concentrations	Water utility boundaries Municipal boundaries Watershed planning areas

Hydrologic and water quality data are important in calibrating a model to meet performance criteria. The resolution, or level of detail, for data can vary in both space and time. For spatial resolution, data for precipitation records, discharge volumes, and pollutant loads would be associated with a specific site or a corresponding sub-watershed area. More data points attributable to specific boundaries creates a model with greater spatial resolution. For temporal (time) resolution, higher-detail models would simulate flows at minutes, hours, days, and weeks over time. Stormwater flows, and the models that simulate them, are very sensitive to daily and hourly precipitation and runoff effects, making greater temporal resolution important for simulating runoff volumes and flow rates known to significantly affect pollutant loading and hydromodification effects.

The scale for implementing Stormwater Control Measures (SCMs) or BMPs—terms that are often used interchangeably—influences the temporal resolution of models. For instance, modeling distributed BMPs with high geographic resolution for a small area requires a model with much higher temporal resolution, as small BMPs can quickly become inundated during a large rainfall event and create localized flooding. Alternatively, modeling a region at a larger geographic scale, where runoff flows into a large receiving water body, may be successfully completed at a daily or coarser time step, depending upon the desired outcome metrics from the model. Similarly, a BMP designed to capture, infiltrate, and discharge water over the course of several days may be appropriately modeled at a daily time step.

At whatever temporal or spatial resolution, the performance of a model is assessed through its capacity to match observed data. In general, for continuous simulation models, good modeling practices will identify a set of data for developing and calibrating the model parameters. This could be, for example, a year of runoff and pollutant loading data that incorporates hydrologic events of many types (large storms and dry periods). Calibrated model performance is then assessed in its capacity to simulate observed data from another, often larger, time period. Similar calibration and validation data sets would be used in developing many types of models, the validity of each subject to expert judgement.

In California, guidelines exist for the sensitivity or tolerance allowable in acceptable RAA models. The Los Angeles Regional Water Quality Board, as part of developing RAA and Alternative Compliance Pathways guidelines in LA County, outlined criteria for evaluating model performance. In creating a model, key parameters, such as runoff ratios infiltration, and evaporation, are iteratively refined to improve model results in comparison to field data. Documented materials provide detailed guidance on input parameters (hydrology, water quality, and sediment inputs; BMP performance inputs; and event mean concentrations by land use) along with appropriate ranges for assessing model sensitivity that are used to evaluate performance (LA-RWQCB 2014).

5.3.2. Permit Compliance

Once available data has been assembled and the scope of the modeling project understood, modelers have the data necessary for calibration and validation. But, importantly, the scope of the model must also consider the ultimate needs for model outputs as part of planning and ACP milestones. Without aligning model outputs with permit compliance requirements, models may not fully address municipal planning needs.

Some watershed planning regions in the U.S., as well as many metropolitan areas of California, have developed (or are developing) large scale models of stormwater and watershed processes, including both water flow and quality, as part of RAA. Several recent models have been developed specifically in support of municipal planning that demonstrates compliance with MS4 permits through ACPs that use RAA with watershed-scale modeling to inform planning and infrastructure improvement needs (US EPA 2017; BASMAA 2017; State Water Board 2015). This is a notable change from past procedures. In particular, models are developed to meet performance specifications that provide regulators assurance that, if projects are implemented at the scale identified by modeling, municipalities will remain in compliance with regional stormwater permits. During the period of model development and analysis through RAA, permittees are in compliance by demonstrating that they are developing (or have developed) an analysis with sufficient rigor that is appropriately aligned to the assessment needs of the watershed.

A particular challenge, then, in developing RAA models is to ensure their usefulness for permit compliance and regional planning now and in the future. This involves correctly scoping the spatial and temporal resolution of the model, securing necessary model inputs from existing or newly collected data, and ensuring that model outputs can be interpreted for permit compliance metrics. The stormwater models used in RAA to date have adapted existing tools and methods to address these needs in various ways. The sections below describe considerations in aligning models with outcomes, as well as the suite of core and tailored modeling tools used in RAA in California.

In developing models, a critical consideration is identifying a well-aligned modeling approach, whereby model outputs usefully estimate metrics for evaluating permit compliance. Several models used for RAA in California additionally include a method to prioritize decisions, and even locations, of necessary stormwater infrastructure improvements. For instance, models that simulate the functions of various BMPs and associated reductions in pollutant loads are commonly integrated. In principle, tools may provide outputs at one or more levels of detail:

- High-level performance targets that quantify a total amount of runoff reduction or needed investment that communities in a watershed must commit to meet permit compliance through an ACP
- Comparison of BMP types and sizes to help evaluate the costs and performance of BMP options that support permit compliance actions by simulating the operations and costs of collection

devices within a module as part of a larger watershed model or through BMP-specific comparisons and calculations not included in the watershed model
- Siting guidance for BMPs, such as general matching of BMP types with geographic characteristics for land use, existing infrastructure, runoff characteristics, and upstream watersheds to help managers match BMPs with sites without providing specific guidance for locating a BMP within the watershed
- Actual BMP locations that identify ideal sites and types of BMPs for meeting ACP, though models usually inform the data gap rather than pinpoint sites and BMP types.

Thus, models help quantify, with some degree of uncertainty, desirable outcomes of such actions at multiple scales. Reductions in discharge volumes and pollutant loads, estimated increases in water supply and groundwater recharge, potential reductions in hydromodification effects, and quantified reductions in greenhouse gas emissions are all useful results that contribute to ACP compliance planning and multi-benefit stormwater management.

For RAA efforts to date, some existing guidance specifies the types of outputs necessary for demonstrating reasonable assurance in modeling outcomes (LA-RWQCB 2014). In the Los Angeles region, for instance, outputs are to be listed as tables and figures. Tables specify outputs for current pollutant loadings in a sub-watershed, load reduction estimates for dry and wet weather conditions, surface runoff volumes, and absolute and percent reductions in runoff volume. Figures denote pollutant reductions from modeled BMPs over time according to continuous simulation results as well as flow hydrographs and pollutographs at compliance points. Either figures or tables are allowable to summarize modeled results of BMP performance, including load reduction and distributions of storage capacity across events.

In translating this detailed guidance to other parts of the state, if RAA outputs do not have the spatial or temporal resolution similar to continuous simulation models, then the guidelines noted for LA will not be entirely applicable. But even within that guidance, a survey of the suggested BMP performance metrics for permittees illustrates the complexity of performing calculations. For instance, guidance is offered for assessing BMP performance from both process-based and empirically-based simulations of BMPs. This is a typical delineation for modeling approaches that use scientific knowledge. Units span from inches per hour for infiltration rates to percent removal for suspended solids or concentrations (per 100 milliliters) of various contaminants based on confidence intervals associated with field data.

Other examples additionally illustrate challenges in interpreting model outputs in terms of permit requirements. For instance, in the San Francisco Bay Area, one mercury regulation specifies an objective of 0.2 milligrams of mercury per kilogram of fish tissue. Translating this value to match a model output is not achievable through current tools. Instead, scientific knowledge and assumptions are necessary to estimate a total mercury loading value for the region and required load reduction. Polychlorinated biphenyls (PCBs) are another contaminant in the region where load reduction targets must be derived and then assessed across the permittees in the watershed.

Some challenges are not in the interpretation of model outputs, but in actually generating results of value. As noted by the workshop panelists, several contaminants of concern are difficult to incorporate into RAA modeling or may not even be easily incorporated into continuous simulation watershed models. Bacteria, trash, and pesticides all require unique treatment in models.

With current modeling approaches, a single RAA model may not effectively represent all the processes needed for the variety of TMDLs that exist in a municipality. In particular, issues such as surrogate representation, fate and transport, and heterogeneous distribution all make the task of modeling extremely challenging. This, in turn, affects how a model informs the determination to use BMPs as part of an AC plan. Contaminants such as trash or bacteria may require separate investigations and monitoring that compliment RAA modeling as part of an AC plan. An ACP that, at the outset, emphasizes source characterization in lieu of RAA modeling could provide regulators with a higher level of assurance that permit compliance will ultimately be met.

For smaller municipalities in California, regulatory assurance is more likely to come from analysis that uses mixed methods, but does not primarily rely on a large and comprehensive continuous simulation modeling approach—especially at early milestones.

5.4. Stormwater Modeling in California

Generally, stormwater and urban watershed modeling approaches for RAA in California include one or more of the following procedures:

- Simulating watershed flows of overland runoff, evaporation and evapotranspiration, infiltration, and other key biophysical and chemical processes, which all support quantifying pollutant loading in receiving waters
- Evaluating the BMPs simulated by models that are either physically-based where BMP processes are mathematically represented, or empirical where BMP processes are derived from past performance and codified through tools such as statistical analysis and regression
- Prioritizing decisions to identify the scale, location, and potential combinations of BMPs that, if implemented as part of a watershed-level program, could meet receiving water goals over the long-term

Models developed as part of RAA and permit compliance actions must offer capabilities for rainfall and runoff processes, which can estimate the extent of BMPs and new infrastructure required in a watershed for meeting water quality goals. While simulating watershed processes is an essential task for a model, evaluating BMPs and prioritizing decisions may not be included in RAA models. But whatever the capabilities of a model, as noted previously, matching the scope of model outputs with relevant jurisdictions included in municipal stormwater permits can be challenging. As the EPA describes it:

> “While traditional approaches to watershed plans tend to use a holistic approach that considers all point and nonpoint sources that are hydrologically connected (USEPA 2008), the permit-driven approach aims to isolate, quantify, and manage pollutant sources that originate from within the MS4 permit boundary. In some cases, there may be more than one municipal jurisdiction that is addressed by a permit that collectively drain and comingle within a receiving water. Furthermore, areas addressed by separate NPDES permits, federal land, or state-owned land subject to other management that fall within the delineated hydrologic boundaries should also be considered and, in some circumstances, removed from the designated planning area.” (US EPA 2017)

The more robust examples of municipal stormwater models to date continuously simulate flows (surface and groundwater) and pollutant discharges to receiving waters of interest, including potential engineering infrastructure to mitigate the effects of intensive land use and urbanization. These generally consider three categories of pollutants (single or in combination):

- Pollutants identified as subject to TMDL limitations
- Pollutants included on the 303(d) list
- Pollutants with noted exceedances in receiving waters specific to permits

As part of the STORMS project examining RAA, workshop participants discussed the challenges they have encountered in aligning model outcomes with identified permit compliance metrics in California. Model developers noted the need for regulatory clarity on some contaminants, especially when permit compliance guidelines are not in units directly calculable from existing models. Specifically, the workshop attendees noted that RAA guidance should:

- Describe how numeric targets are set and translated to desired model conditions
- Define critical conditions in terms of water quality statistics (average, max, percentiles) and consistency over periods of time versus specificity at a particular point of comparison

The models must be flexible in helping meet multiple goals for TMDLs, RWLs, and other water quality measures.

In performing RAA to date, modelers have made assumptions to help align model results with permit procedures, and worked with Regional Water Board personnel to determine best practices for doing this in a given region. When guidance is lacking, many assumptions are necessary to translate permit requirements into quantifiable outcomes capable of assessment through a model. Conditions for identifying appropriate wet and dry weather periods that can determine waste load allocations, variation in modeling procedures among pollutants, or qualitative source control measures for contaminants, such as bacteria, are among some of the assumptions required to match model outputs with permit metrics.

Generalized stormwater models, along with specific models developed for use in California watersheds (i.e., both core models and watershed-specific models) are summarized below. The summary draws on existing documentation that was developed to describe the capabilities of core models and integrative modeling frameworks (LA-RWQCB 2014; US EPA 2017; BASMAA 2017). Additional existing sources detail the many models that have been developed over decades in support of urban stormwater planning (Zoppou 2001; Nix 1991; Nix 1994; Elliott and Trowsdale 2007).

5.4.1. Core Numerical Simulation Models

Several core models of hydrologic processes are used directly for RAA or are incorporated into integrative modeling frameworks. These are capable of continuous simulation based on inputs derived from observations, statistical analysis of observations, and national parameters. These include:

- Stormwater Management Model (SWMM)—First developed by the US Environmental Protection Agency (US EPA), SWMM is now on its fifth iteration. SWMM is tailored to urban stormwater management and simulates overland and pipe flow, and performs water flow and pollutant loading calculations. It also has associated modules for simulating various BMPs. SWMM can be used as a standalone desktop platform, but it has also been incorporated into numerous commercial and open-source software platforms.
- Loading Simulation Module in C++ (LSPC)—LSPC is a watershed modeling system that incorporates an underlying model, the Hydrological Simulation Program-Fortran, to simulate water quality and quantity in watersheds. LSPC can perform calculations for pollutant and nutrient loading, and it provides continuous simulation capabilities for modeling surface, sub-surface, and climate processes. LSPC and HSPF are underlying models for Los Angeles County's Watershed Management Modeling System, which is open source and has been used in analyses to optimize existing stormwater capture basins and understand future water supply management options in the LA Basin (County of Los Angeles 2009).

- Soil and Water Assessment Tool (SWAT)—SWAT was developed by the US Department of Agriculture and Texas A&M to simulate water quantity and quality processes for small watersheds and river systems. It is widely used for these purposes, but in the context of urban and watershed runoff management, must be coupled with other models that provide additional capacities for modeling BMPs or performing prioritization.
- CE-QUAL-ICM—This model simulates water quality in surface water bodies. Developed by the US Army Corps of Engineers, CE-QUAL-ICM simulates biogeochemical cycles such as carbon, nitrogen, phosphorus, and oxygen within water bodies, along with physical characteristics including salinity, temperature, and solids.

5.4.2. Integrative Modeling Software

Several software products integrate the core models previously mentioned to provide flexible platforms that can be applied to many problems. Examples of popular models include:

- EPA SUSTAIN—The SUSTAIN model was developed by US EPA to support watershed-scale stormwater planning and optimization. SUSTAIN combines SWMM and HSPF to simulate flow, pollutant loading, and sediment loading, as well as BMP processes. It also incorporates capacity for multi-objective optimization across cost, locations, and receiving water quality using an evolutionary algorithm. EPA SUSTAIN was developed to be incorporated into ArcGIS. It was first released in 2013 but is no longer being supported (US EPA 2009).
- GreenPlanIT—GreenPlanIT was developed by the SFEI to support regional urban stormwater planning with BMPs and green infrastructure. It has been used in communities throughout the San Francisco Bay Area, but can be applied to any municipal region. Similar to SUSTAIN, GreenPlanIT uses SWMM and an evolutionary algorithm to simulate the effects of BMPs on downstream water quality and identify cost-effective priority actions using multi-objective optimization. It also supports site-level planning and project tracking to assist utilities in implementing long-term infrastructure plans. Because it uses SWMM for core hydrology and pollutant loading calculations, GreenPlanIT is tailored to urban areas.
- Watershed Management Optimization Support Tool (WMOST)—Researchers developed WMOST for the US EPA to support watershed-scale planning and decision-making. WMOST is capable of simulating entire watershed-scale processes, including both urban hydrology and engineering operations such as wastewater treatment, as well as environmental processes including precipitation and groundwater recharge. WMOST incorporates SWMM, SWAT, and HSPF for simulating water quality and quantity, along with potential BMPs. It was released in 2013.
- WinSLAMM—First developed in the 1970s, WinSLAMM models the stormwater runoff volumes and contaminant loading from rainfall events. WinSLAMM also models common BMPs, including unique representations of some non-structural measures such as street sweeping. WinSLAMM incorporates uncertainty in results by quantifying residual error and using Monte Carlo Analysis.
- MIKE-URBAN—Produced and maintained by DHI, the MIKE suite of software provides tools for hydrologic and hydraulic modeling, including flood planning, watershed management, and urban stormwater. MIKE-URBAN supports one-dimensional and two-dimensional modeling for urban stormwater management, flood planning, and water quality using SWMM. It also supports demand planning and analysis using the EPANET software for modeling water distribution networks. MIKE-URBAN includes a custom interface with GIS and is commercially available.
- PC-SWMM—Developed by CHI, Inc., PC-SWMM is an urban stormwater planning model that combines SWMM and custom software with a GIS interface, adding additional capacity for

creating runoff and routing networks modeled by SWMM. PC-SWMM is a commercially-available product.

5.4.3. Region-Specific Models in California

Regional models for California watersheds have been built and calibrated to simulate watershed processes for specific regions and have constituted stormwater permit compliance during early stages of ACP. Existing models used for RAA in California incorporate one or more core models to perform hydrology and water quality calculations, calibrated to local conditions. They include core hydrology sub-models, GIS, and other software to perform continuity calculations (preserving flow and pollutants) across watersheds of interest addressed by a permit. Some examples of relevant models include:

- Watershed Management Modeling System (WMMS)—WMMS was developed by LA County and consultants to support watershed planning and stormwater permit compliance. It uses LSPC and a geospatial interface (MapWindow*)* to perform continuous water quality and quantity simulations for a 25-year time horizon and optimize locations for potential BMPs. WMMS has supported multiple water planning processes in LA, including permit compliance, re-optimization of existing LA County stormwater infrastructure, infrastructure investments needs, and countywide water planning goals for future water supply portfolios (LACDPW 2013).
- Structural BMP Prioritization and Analysis Tool (SBPAT)—SBPAT was developed by Geosyntec to support watershed planning and permit compliance for the City of Los Angeles. It provides similar functionality and output support as WMMS and has been used for multiple applications in Los Angeles, San Diego, and other coastal areas. It uses SWMM and draws on the International BMP database for empirical parameters to support BMP planning (Geosyntec Consultants 2013).
- Tool to Estimate Load Reductions (TELR)—TELR is a model for estimating water quality benefits and expected volume and load reductions from implemented BMPs. Developed by 2ndNature, it is currently used in numerous municipalities in California. It was created as a simplified but still spatially-explicit model for stormwater planning, which can be utilized in understanding geographic differences in stormwater runoff that informs planning for target volume reductions.

5.4.4. Modeling Best Management Practices and Low Impact Development

A host of models, spreadsheet tools, and worksheets are available to support the design of BMPs to meet performance requirements. The US EPA, for instance, compiled a list of BMP and green infrastructure modeling tools, which can be used in planning and performance assessments (USEPA 2018). Several of the previously discussed integrated modeling platforms used for RAA in California incorporate capabilities for simulating BMPs.

Most BMP modeling tools are useful in designing devices to meet volume and flow reduction targets. Few tools explicitly model treatment processes within BMPs that influence the performance of devices for removing constituents. Variability of influent characteristics, including size and concentration of constituents, makes mechanistic modeling of BMP treatment processes extremely challenging. Instead, most assessments of BMP performance, either as a single device or as part of a larger watershed, use straightforward metrics of percent removal for various constituents. The likelihood of performance can be estimated from distributions of performance from submitted data to the International BMP database and local sources.

Some stormwater models—including HSPF, WinSLAMM, and SWMM—include modules for simulating BMP performance, but limits exist on what such modeling can demonstrate. Volume and flow reduction targets for devices can be met using modeling that helps tailor BMP sizes, but removal efficiencies and other treatment processes within the “black box” are much harder to manipulate. Thus, RAA can help determine the types and sizes of BMPs to include, as well as how many total units to install. Secondary decisions, such as where to place BMPs or how to improve performance of a particular device, are more difficult.

Modeling BMP performance as part of RAA and ACP must also consider implementation milestones. As noted previously, early ACP milestones will most successfully measure performance of individual BMPs rather than identify improvements at the watershed scale. Statistical analysis of performance data, derived from samples of influent and effluent constituent concentrations, is the most likely method for assessment. Such assessments test if a BMP is performing as expected. Later at ACP milestones, however, performance assessments or RAA would assess effects at larger geographic scales, potentially at the watershed-scale. To include installed BMPs as part of this watershed-scale assessment, watershed models capable of simulating BMP processes would be required.

5.5. Incorporating Uncertainty in Models

In any analysis with modeling, both stochastic and deterministic, uncertainty exists in results. As noted by workshop participants, uncertainty in urban stormwater models can result from many sources of random variability in hydrologic and environmental processes, challenges in translating real-world conditions into a model with inherent simplifications, and uncertainty associated with specific parameters (Zoppou 2001).

5.5.1. Sources of Uncertainty

Sources of uncertainty have been grouped into categories (Montalto, Behr, and Yu 2012; Behr and Montalto 2008; Sample et al. 2003; Gold et al. 2015; US EPA 2007):

- Variable costs across BMPs and management alternatives, which can have wide ranges
- Variable performance of traditional and new stormwater infrastructure
- Human factors such as the installation rate of new on-site infrastructure by property owners, behavior for certain activities related to contaminants such as littering, and maintenance of BMPs on private property
- Modeling simplifications
- Analysis assumptions that simplify or make judgements about environmental conditions that influence runoff, such as build-up and washoff rates or land cover

Urban stormwater models have incorporated a variety of procedures to characterize uncertainty. First, sensitivity analyses can quantify parameters that, when changed, have the greatest effect on outcomes. Sensitivity analysis is typically used in model calibration but can also provide insights into actual model outcomes for a verified model if assumptions or new data offer additional details for parameter ranges. It has been used in RAA efforts in Los Angeles. Second, input parameters that are generally included in models as a single value representing a mean of observed data could also include variance that provides confidence intervals for the output distributions. A sensitivity analysis based on ranges of input parameters simulates this procedure following model development, but incorporating stochastic variables into actual model calculations is more difficult. Finally, Monte Carlo techniques can be used to generate a large number of outcome scenarios from many (typically thousands) of model runs with randomly sampled input parameters. The output estimate distributions of output variables can give an indication of the relative likelihood of real-world outcomes given reasonable assumptions of quantified system uncertainties (Zoppou 2001).

5.5.2. Stochastic Modeling Examples

While RAA models to date have addressed uncertainty, purely stochastic approaches to stormwater modeling, such as regression or more complex mathematical procedures, have not been emphasized for RAA in California. Examples of stormwater modeling with stochastic approaches do exist in the state. For instance, in the Dominguez Channel watershed of LA County, a regression equation was used to predict pollutant loading to downstream locations based on a set of parameters that included pollutant concentrations, deposition rates, assumptions of decay (decay functions) before being washed off of hard surfaces, storm durations, and dry days prior to a rainfall event (Wang et al. 2011). The many parameters were ultimately lumped into a few factors and the performance of several regression models was compared using typical statistical tests.

Stochastic modeling has also assessed relationships in stormwater loading to Southern California coastal areas. For instance, researchers at the Scripps Oceanography Laboratory and SCCWRP used statistical analysis to understand contaminant discharge plumes from ocean outflows, including assessing the risks posed by stormwater runoff to key coastal habitat areas (Rogowski et al. 2015).

Beyond municipal watershed planning, the California Department of Transportation (Caltrans) funds significant work for monitoring and managing stormwater as part of its permit compliance activities. Associated studies used empirical assessments of observed data, sometimes with regression, to assist in sizing BMPs, to understand relationships between highway traffic levels and resultant pollutant washoff, and to predict first flush characteristics (Kayhanian et al. 2003; Kim et al. 2005; Lee et al. 2004).

In summary, statistical analysis and many types of stochastic models have been used to understand likely contributing factors for stormwater runoff. The variety of models and the many scales at which they can be implemented, including analyzing outflows from a single outfall up to lumped watershed models, mean that many have not necessarily made it into peer-reviewed publications or surveys of comprehensive modeling techniques that are most appropriate for guiding policy. But the relative lack of purely stochastic models for RAA may not hold true of future ACPs, especially as small- and medium-sized communities throughout the state are increasingly required to undertake RAA for permit compliance. For such modeling, performance assessments can use established statistical techniques to assess the confidence of regression models, or more complex statistical procedures, to guide modelers and regulators.

5.6. Beyond Modeling: Watershed Classification Approaches

In additional to hydrologic modeling, other approaches have been developed to inform watershed-level planning related to stormwater and hydromodification goals. Such approaches have long roots in landscape planning and analysis. For instance, in a 1969 seminal analysis, Ian McHarg characterized relationships between landscape characteristics and function, using typologies to classify regions and understand what land use planning and mitigation actions could be taken to responsibly grow cities while preserving natural systems (McHarg 1969). In the 1970s, the U.S. Geological Survey developed the first nationwide classification system for land use and land cover, which serves as a basis today for methods to categorize land area based on the function and cover of the land surface in that zone (Anderson et al. 1976).

Extending this approach to stormwater planning can assist in categorizing the boundaries of watershed zones that relate to assumed or measured characteristics of runoff (Huang and Ferng 1990). For this task, multiple data sets (layers of surface, sub-surface, and climate characteristics) must be collected and integrated to understand the effects that processes have on stormwater runoff outcomes. In this view, natural hydrologic processes that are influenced by many factors—slope, geology, land cover, and others—are altered by urbanization and the documented effects of increasing the velocity and volume of runoff from precipitation (Leopold 1968).

In California, such approaches for categorizing watersheds have been applied for stormwater planning and hydromodification mitigation as part of recent permit compliance processes. For instance, in the Central Coast of California, researchers developed a framework for identifying watershed management zones and associated strategies based on a broader collection of characteristics (Booth et al. 2012). The method first created physical landscape zones (PLZs) based on topography and geologic characteristics. Then, within each of these PLZs, key watershed processes were identified, including:

- Overland flow
- Infiltration and groundwater recharge
- Groundwater interflow
- Evaporation and evapotranspiration
- Sediment transport and organic matter delivery
- Chemical and biological processes and transformations

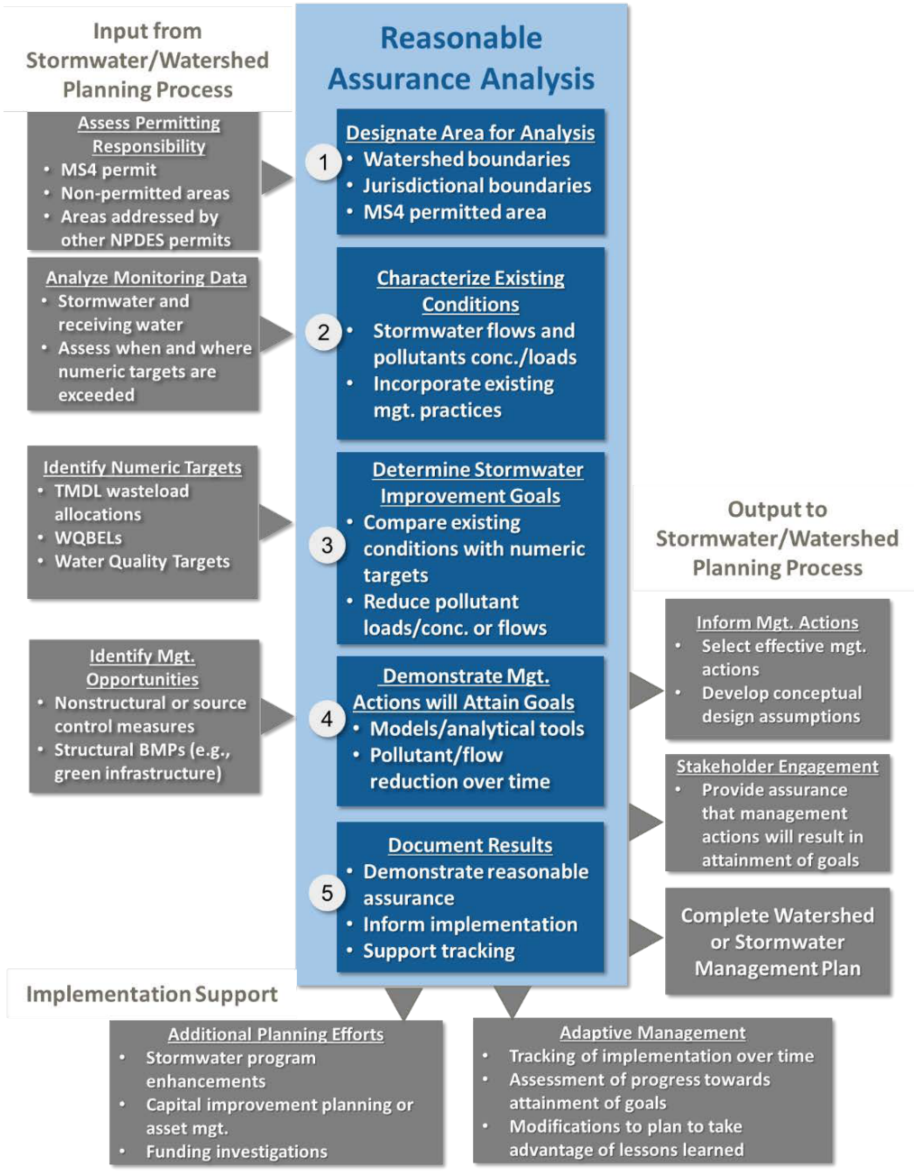
The geology, slope, land cover, and level of urbanization all affect which of these processes are dominant in an identified watershed management zone. Additionally, zones were organized according to the type of receiving water body they contribute to, including surface streams, lakes, rivers, wetlands, and groundwater basins. The combination of understanding surface and sub-surface characteristics, associated watershed processes, and ultimate downstream receiving waters helps inform what types of BMPs and control measures are most appropriate. The method is detailed and requires significant knowledge, but does offer a “snapshot” approach that is not reliant on the high-resolution temporal data that typically feeds watershed models.

5.7. Aligning Model Selection with Analysis Objectives and Resource Availability

As noted, RAA has tended to use one of a core group of models to simulate watershed processes, tailored to regional specifics. Most models, especially models with continuous simulation over time, have significant data requirements and take time and effort to develop. To date, Regional Water Boards have devised varying standards and guidelines for implementing RAA as part of alternative compliance options. In some basins, the use of RAA with modeling for long-term watershed infrastructure planning is required. In others, it is an option along with traditional compliance pathways. Before prescribing particular RAA requirements on specific regions/MS4s, critical questions on application, resources, and desired outcomes should be considered. The following discussion presents factors that influence RAA approaches.

RAA with quantitative assessments is typically first conducted at the outset of developing a plan for an ACP (Figure 1). To date, the results of RAA models have helped build consensus for long-term infrastructure needs across government agencies and regional stakeholders, as well as inform long-term capital planning processes. Many of the models have also been employed for other purposes, including applications beyond stormwater planning and permitting. Finally, most conceptions of ACPs include guidelines for conducting a subsequent RAA at key milestones in permit compliance, such as 2, 5, or 10 years from the effective date of the permit.

Figure 1: Reasonable Assurance Analysis as part of stormwater planning for permit compliance (source: EPA 2017). Note: The diagram focuses on using RAA in the early stages of an Alternative Compliance Pathway.



Models have generally not been used for siting projects for several reasons. First, the process of identifying exact locations for projects is subject to many factors external to model workings, including other existing infrastructure and upgrade needs, financing, interest and advocacy, and site requirements. Second, once new BMP installations are operating, the capacity for post-installation monitoring to capture predicted improvements in flow and contaminant loads relates to the scale and scope of implementations. In the early stages of compliance, water quality improvements from a limited number of implementations may not be detected at watershed scales due to the many other drivers of water quality. Finally, when watershed and stormwater runoff models become useful for other regional water planning applications, the stormwater or flood control agencies that created them may not directly realize subsequent benefits from these additional applications. Without coordinated planning and open-source publishing of watershed and stormwater planning models, they may sit on the shelf between RAA milestones. On the other hand, if stormwater utilities coordinate with other municipal partners, aspects of the modeling tools developed for RAA, including calibrated hydrologic rainfall and runoff calculations or integrated land use data, can support other planning and research applications, helping justify investments in the modeling exercise.

Mapping potential RAA models to permit compliance requirements can provide guidance for understanding how to align appropriate models with analysis outcomes (LA-RWQCB 2013). Yet, like the classification of models themselves, there are not clearly delineated guidelines for linking types of models with planning needs. In available guidance to date, US EPA (2017) outlined detailed considerations for selecting models, including regulatory guidelines; practical considerations for data availability, cost, and expertise; and analytical capabilities for incorporating BMPs, identifying modeling resolutions, and other needs.

Some additional or corresponding critical factors that can help align analysis requirements with models include:

- Modeling cities or larger watersheds—Some models are tailored for simulating urban hydrology and hydraulics, but do not do well simulating larger watershed processes. Others are the opposite. Aligning the project region with models is important.
- Types of BMPs to incorporate—As noted in US EPA (2017), certain models do better at modeling LID and BMPs, including even having custom-developed modules for processes in various types of BMPs, such as swales or dry wells.
- Planning or verification—Most models, along with watershed classification methods, are useful for planning, helping to identify and prioritize contaminants of concern and estimate the scale of necessary new BMPs in a watershed. For verification, however, stochastic models that lump explanatory parameters often are not useful. Such models correlate existing conditions, which may not remain true after new infrastructure improvements or compliance actions.
- High-level targets or siting guidance—Models with greater geographic and temporal resolution that incorporate a variety of storm event magnitudes (modeled as either over a time record or as multiple storms) can best support siting and sizing guidelines for BMPs. For higher-level targets, models could identify a preferred mix of BMPs for watershed areas based on cost and performance metrics without identifying specific sites. For siting guidance, a high-detail model could help identify optimal BMP locations in a watershed towards meeting goals. Generally, lumped models with coarse spatial resolution have limited utility for siting BMPs in a watershed.
- Outcomes to measure—As noted in US EPA (2017), matching permit requirements and modeled outcomes are important considerations in selecting models. Reasonable assurance may apply to either RWLs, measured as concentrations of pollutants, or loads measured at discharge points. This varies by permit. TMDLs may apply in some areas that do not have specific requirements for MS4 permits, which can influence the geographic scale of modeling. Aligning a model with the desired model target requires expert judgement to understand capabilities.
- Stage of compliance plan—The details of aligning RAA results with measurable field parameters influences the compliance and monitoring process. Early in an RAA, watershed models can outline high-level planning targets and the types of BMPs that best address contaminants of concern. This is essentially the process of organizing information in support of analysis. Monitoring for improvements during subsequent stages of ACPs, after some number of BMPs are installed, requires comparisons to expectations. In early years, water quality improvements would most likely be measurable at the site scale, close to a discharge point of a BMP. Prudent monitoring

would test that installed BMPs are operating as expected. Later in ACP stages, after perhaps a decade or more when municipalities have built out many more BMPs, field monitoring and subsequent modeling can look for expected improvements. Thus, early in ACP, site-specific models can be most helpful for verification and monitoring, while in later stages updated watershed models may provide insights.

- Model performance requirements—Some ACPs, such as in the Los Angeles region, outline specific model performance requirements, including periods for validation and calibration, tolerances for modeling specific contaminants, and statistical tests for flows. These requirements most closely align with distributed continuous simulation models. Thus, as regional water boards and permittees identify available data and assess necessary model outcomes that correspond with permit requirements, ensuring that model performance can be validated with reasonable assurance requires either knowing the type of model to be used or selecting a model that can meet given performance criteria.
- Available resources—As in all analysis, available resources, including data, expertise, and funds, must be considered in selecting a model. In the absence of data or funds, a robust continuous simulation model may not be feasible. In cases of developing more straightforward models, however, simplifications should be communicated transparently, including limitations of using computationally-intensive approaches.

Generally, models that use continuous simulation, are spatially-distributed at a high geographic resolution, and incorporate some capacity for understanding the certainty associated with the results are most robust and will likely meet the ACP requirements for reasonable assurance.

But, these models are also more expensive, time-consuming, and data-intensive. Requiring detailed models for a watershed with limited existing data would not provide near-term analytical solutions given the time required to gather field data and the limited number of storms that occur in most watersheds throughout California.

As an alternative, stochastic approaches may be less intensive to assemble. They can also be more flexible in dealing with mismatched temporal and spatial resolutions of underlying data. Smaller communities may look to these models to deal with limited data or lack of resources for large-scale modeling efforts.

This also has tradeoffs. Stochastic models that identify relationships between contributing factors and stormwater runoff are useful in planning, but typically not useful for later verification needs. For instance, the underlying statistical relationships in a regression model would not necessarily hold true after BMP implementations. Regression models derived from statistical relationships are only known to have good fit for the observed conditions. They may still perform well, but only after further evaluation.

Thus, a challenge for any municipality that uses a purely stochastic approach for RAA would be watershed-scale assessments for verification at later RAA milestones. These municipalities may need to undertake new modeling efforts capable of absorbing observed performance data to continue planning activities. Regional Water Boards should consider likely future regulatory actions when assessing and approving the use of models and tools for RAA. Regulators at the state level, similarly, should factor in the likely trajectory of regulatory mandates when providing guidance on model development, required outcomes, and assumptions for municipal expenditures on planning across the diverse municipalities of California.

6. Conclusions

Effective RAA requires knowledge of the full regulatory process, facilitated by clear lines of communication among regulators, municipalities, and modelers. Alternative Compliance Plans must describe how quantitative analysis supports development of stormwater actions by a municipality over long time frames. The analysis should be devised to utilize the best available sources of data that respond to clear regulatory guidance with expectations for RAA results. Discussing and communicating the many types of uncertainty that exist throughout the process, not just in the development of models, is critical to assessing monitoring outcomes and opportunities for adaptive management. Model results must usefully support municipal plans for building new stormwater infrastructure, connecting ACPs to the many other local decision-making processes that ultimately influence how and where cities spend money.

The findings from the surveys, workshops, model reviews, and uncertainty analysis enables identification of important elements of RAA, which State and Regional Water Boards can use for guiding RAA processes. To assist in assembling statewide policy guidance, Appendix E presents the elements of RAA that can be considered as benchmarks in policy-setting actions.

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