The stormwater monitoring coalition: Stormwater research needs in southern California

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ABSTRACT - In response to growing concerns about the adequacy of existing stormwater monitoring approaches, all of the Phase I municipal stormwater NPDES lead permittees and all of the NPDES regulatory agencies in southern California recently formed the Stormwater Monitoring Coalition (SMC). This coalition is based on a common understanding that existing scientific knowledge and technical tools are not fully adequate to assist with necessary stormwater management. The SMC goal is to improve the basic knowledge and tools for creating effective monitoring and assessing efficient management techniques through collaborative, regional research. The SMC's first action was to develop a research agenda to guide their efforts. They convened a panel of both local and nationally recognized experts to identify and prioritize possible research topics and then develop project descriptions for the highest priority project ideas. The projects identified by the research panel fell into one of three broad categories including developing a stormwater monitoring infrastructure, understanding fundamental stormwater mechanisms and processes, and assessing receiving water impacts. Building a monitoring infrastructure consisted of four projects designed to improve comparability and enhance integration among monitoring agencies. These projects included integrating and evaluating currently available data, standardizing sampling and analysis protocols, developing a regional data infrastructure, and assessing BMP effectiveness. One problem that hinders our ability to manage stormwater effectively is our incomplete understanding about the mechanisms and processes that control how pollutants move through a watershed. Four projects were identified for this category that included developing a systemwide conceptual model, determining appropriate reference conditions, developing a regional method for assessing beneficial use condition, and identifying relative contributions of nonpoint sources of pollutants. Finally, protecting receiving waters is one of the primary objectives of stormwater management. Therefore, seven projects were identified in this category that related to identifying receiving water impacts. These projects include identifying the causes of impacts in receiving waters, developing bioassessment indicators and protocols, developing improved toxicity testing procedures, developing rapid response indicators for microbial contamination, developing microbial source tracking protocols, evaluating BMP effects on receiving waters, and developing improved indicators of peak flow impacts. Altogether, these 15 projects form an integrated research program that will eventually lead to an integrated stormwater monitoring program.

INTRODUCTION

As the urbanization in southern California has grown over the last 100 years, stormwater managers have designed and built extremely effective stormwater conveyance systems that move surface runoff from the land to the sea. Even during large storm events, widescale property damage is minimal and drownings are extremely rare.

While managers have been effective at reducing flooding, the stormwater conveyance systems have not been designed to improve water quality. The problem is magnified in our semi-arid environment where extensive urbanization, coupled with infrequent rainfall that enables build-up of non-point sources of pollutants, results in sporadic and rapid delivery of tremendous loads to receiving waters. In fact, current estimates of pollutant mass emissions for the southern California region indicate loads to the coastal ocean from stormwater discharges rival, and often exceed, those from traditional point sources (Schiff *et al.* 2001). There is some evidence that these stormwater discharges impact receiving water quality, such as increases in exceedences of bacterial water contact standards along beaches (Noble *et al.* 2000), alterations to receiving water habitats (Schiff 2000), and the transport of toxic compounds to nearshore marine environments (Jirik *et al.* 1998).

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Although pollutant loads from stormwater are as large as those from municipal wastewater discharges (POTWs, or publicly owned treatment works), there has been no long-term and sophisticated effort, as there has been for POTWs, to reduce these loads. A primary reason for this lack of coordinated effort is the absence of an equivalent base of scientific and technical knowledge about reference conditions, impacts on beneficial uses, the relative importance of different sources, and the best measures for reducing or managing contamination and impacts from specific sources. In addition, available stormwater management tools are typically inadequate to deal with existing needs for proper stewardship and decision making. Tools that are available are often not specific to stormwater processes or have not been validated in southern California environments.

Despite such information gaps, management actions are being mandated by regulatory frameworks such as National Pollutant Discharge Elimination System (NPDES) Permit requirements and Total Maximum Daily Loads (TMDLs). In the absence of adequate information about stormwater impacts, regulatory requirements derived through such frameworks are likely to be questioned from a variety of perspectives and may not achieve their intended benefits.

This increasing regulatory pressure, combined with the lack of an adequate knowledge base, has led stormwater regulators and municipal stormwater management agencies throughout southern California to cooperate on developing the technical information and the tools necessary to improve stormwater decision making. This working relationship was formalized with the formation of the Stormwater Monitoring Coalition (SMC) that includes all the Phase I municipal stormwater NPDES lead permittees and the NPDES regulatory agencies in southern California (Table 1).

Table 1. Member agencies in the Stormwater Monitoring Coalition.

California Regional Water Quality Control Board, Los Angeles Region
California Regional Water Quality Control Board, San Diego Region
California Regional Water Quality Control Board, Santa Ana Region
City of Long Beach
County of Orange, Public Facilities and Resources Dept.
County of San Diego Stormwater Management Program
Los Angeles County Department of Public Works
Riverside County Flood Control and Water Conservation District
San Bernardino County Flood Control District
Southern California Coastal Water Research Project
Ventura County Flood Control District

The SMC member agencies have developed a clear vision of regional cooperation that includes:

- Combining resources to cost effectively address data gaps.
- Improving monitoring effectiveness by promoting standardization, coordination, and reducing duplication of effort across individual programs.
- Improving the ability to exchange, combine, and analyze data from across the region.
- Trading off redundant or ineffective monitoring program elements in order to allocate resources to the research projects necessary for improving stormwater management.
- Integrating findings from these applied research projects into existing stormwater management programs.

The SMC's first action was to develop a structured research agenda through a workshop with experts from a variety of scientific disciplines. Their recommendations are presented in the remainder of this article.

METHODS

The research agenda workshop was held October 15-17, 2001, in Costa Mesa, California. The workshop participants included experts from a broad spectrum of relevant disciplines, including hydrology, engineering, microbiology, toxicology, ecology, modeling, statistics, stormwater management and regulation, and public advocacy (Appendix 1). The workshop proceeded through the following three steps: (1) brainstorming project ideas; (2) clarifying and prioritizing these ideas; and (3) further developing of the highest priority research projects.

The experts who participated in the research agenda workshop generated more than 50 project ideas. This plethora of ideas was combined, clarified, and prioritized over the next days, ultimately leading to 15 research projects. Each project was then developed in terms of a problem statement, desired outcome (products), tasks, schedule, and necessary resources (expertise, costs, and potential collaborators).

RESULTS

The 15 research projects developed by the workshop experts fell into one of three categories including: (1) developing a regional stormwater monitoring infrastructure; (2) improving the fundamental understanding of stormwater mechanisms and process; and (3) identifying stormwater impacts in receiving waters. Monitoring infrastructure includes projects that find ways to integrate, standardize, or maintain comparability among programs throughout southern California. These projects include mining the existing data, sampling and analysis, data management and sharing, and testing BMPs.

Research projects that improve fundamental understanding of stormwater mechanisms and processes begin with creating a conceptual model of existing understanding of these processes. This will help to identify important knowledge gaps, which workshop participants expected to include an evaluation of reference conditions, an evaluation of beneficial uses, and an identification of relative contributions of nonpoint sources to stormwater discharges.

Identifying stormwater impacts in receiving waters is the research theme with the greatest number of projects, reflecting how little is known about this subject. Five research projects are geared specifically towards developing tools for assessing conditions in receiving waters. These tools include freshwater bioassessments, toxicity testing, faster and more specific methods for identifying microbial contamination, and identifying indicators of impacts resulting from increased peak flows.

Although the projects are described individually, many of them are interrelated, as shown in Figure 1 (see Discussion).

Developing a stormwater monitoring infrastructure.

The following four projects focus on improving the basic knowledge and tools available for addressing questions on a regional scale. They are intended to increase the efficiency of monitoring and improve data integration and interpretation.

Project 1. Integrate and evaluate available data

There has been no ongoing systematic effort to integrate and analyze the large amounts of stormwater data from a regional perspective, nor have individual programs' analysis efforts examined a consistent set of questions. Available data have thus not been fully utilized, on a regional basis, to characterize monitoring effort, identify significant sources, describe impacts on receiving waters, and improve the effectiveness and efficiency of monitoring efforts by, for example, removing redundancies among programs. This means that there is little information about specific, important questions, such as:

- What is the spatial extent of stormwater monitor ing?
- What percentage of the total estimated flow of stormwater is monitored on an annual basis?
- What kinds of data types are being sampled throughout the region, and to what extent?
- What is the regional distribution and variability among runoff coefficients from specific land uses?
- What is the regional distribution and variability in contaminant concentrations and loadings from specific land uses?
- What is the regional distribution and variability in impacts on receiving waters?
- Are there specific watersheds or sources that contribute disproportionately to mass emissions on a regional basis?

This project will address these issues by identifying, integrating, and evaluating available monitoring data from the region. It will depend to some extent on the regional data infrastructure (Project 3) and will contribute to the definition of regional reference conditions (Project 6) and assessing beneficial uses (Project 7).

This project will use available monitoring data to help lay the groundwork for important aspects of a regional stormwater monitoring program. It will fully describe monitoring efforts in terms of the parameters sampled and their spatial and temporal coverage. By integrating available information on sources and impacts, it will also take the first steps toward a regional assessment of impacts and beneficial uses (Project 7) and toward a regional definition of background or reference conditions (Project 6). Together, these results will help focus management attention on areas and problems of greater significance, and improve understanding of where and how impacts on receiving waters occur. For example, the data may suggest common findings that are relatively consistent across the region that could be used as justification to reduce or redirect individual agency management and monitoring effort.

The major challenges facing this project involve

FIGURE 1

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collecting and integrating available data and defining and agreeing on key questions and the analysis approaches appropriate for addressing them. This project will collaborate with or make use of information from other ongoing or planned studies and datasets produced in this project will become part of the regional data infrastructure developed in Project 3.

Project 2. Standardize sampling and analysis protocols

Monitoring programs throughout southern California often approach the same question in different ways, sample different sets of parameters, and use a range of field and laboratory methods to collect and analyze samples. This inconsistency makes it difficult, if not impossible, to address questions on a broader spatial scale, to compare monitoring results across programs, and to improve efficiency by taking advantage of opportunities for exchanging data and coordinating monitoring responsibilities across the region.

This project will address this problem by developing a standardized set of monitoring protocols for use throughout the region, guided in part by insights gained from Project 1's regional assessment. These protocols will provide the technical basis for addressing questions of regional importance while at the same time maintaining local flexibility where it is essential. Standardization efforts could move in succession through each of the four levels identified below.

In spite of its clear benefits, there are several significant issues involved in any attempt to establish regional standards. Standardization can be approached at four distinct levels. The highest level involves the issue of what to monitor (e.g., should loads be monitored?). The next level involves the approach to use once a decision has been made to monitor a particular parameter (e.g., should time-weighted or flow-weighted sampling be used?). The third level is procedural and focuses on what specific instrumentation and/or techniques to apply (e.g., should the Mark IV or Mark V Tricorder be used?). Finally, the lowest level of detail involves sampling design issues (e.g., how many samples should be collected? How long should monitoring continue for?). Any attempt at regional standardization must also balance the benefits of standardization against the costs in lost flexibility at the local level. Finally, robust sampling approaches for many stormwater-related issues have not yet been fully developed, making it difficult to readily select a common standard.

Despite the fact that these issues are often difficult to resolve, the benefits of appropriate regional standardization have been amply demonstrated in numerous instances around the country and in many different types of programs. Such efforts could provide useful insights into the development of uniform approaches to stormwater monitoring. However, the unique features of climate and geography in southern California often make it difficult to apply such approaches directly and without modification.

The major challenges facing this project involve obtaining agreement among a diverse set of participants on, first, the set of priorities for standardization and, second, the standards themselves. The multiyear efforts involved in standardizing monitoring protocols for the marine coastal environment in southern California provide a useful template for this project.

Project 3. Develop a regional data infrastructure

Scientists and managers have only a limited ability to combine data from across the region to search for patterns or trends, compare impacts and BMP effectiveness across locations, assess local conditions against regional background or reference conditions, or ensure regionally consistent quality control of raw and processed data. This inability to combine and integrate data from throughout the region leads to duplication of effort and other inefficiencies in individual monitoring programs. Thus, because there is no central data clearinghouse or network, based on common standards, to make data readily and broadly available, stormwater monitoring and research are less cost effective than they otherwise could be. Further, this situation makes it impossible both to make the best use of available historical data and to realistically consider developing a coordinated regional monitoring program that reduces duplication of effort.

This project addresses this problem by creating a set of agreements and standards that will streamline data integration. Ultimately, this project will produce a distributed online system, with a centralized catalogue to facilitate search and retrieval, which will provide a wide range of users access to stormwater data from throughout the region. The system could be developed in stages, as follows:

- A simple catalogue of datasets, their locations, and descriptions.
- A catalogue with search functions and links to

permit users to access and/or retrieve specific datasets.
- The implementation of regional data quality control and formatting standards to aid data integration.
- The addition of data summaries, analysis results, and other data products (optional).
- The addition of modeling, mapping, and other analysis tools to support regional investigations (optional).

While the development steps are relatively clear, there will nevertheless be significant challenges to be met. These primarily will be institutional, not technical, and will include identifying the core set of user needs, prioritizing data types for inclusion in the system, developing common data standards, agreeing on the system design and its development stages, establishing protocols for data access and sharing, and fostering needed agreement and coordination among participants. However, the availability of modern distributed database technology will help any such effort avoid the problems inherent in older, centralized systems such as STORET and ODES.

Project 4. Measure BMP effectiveness

Best management practices (BMPs) are currently being applied without the benefit of systematic and neutral evaluations of their effectiveness in reducing loads. Available studies of whether proprietary BMPs meet manufacturers' claims are often not performed by neutral third parties and are difficult to compare because of inconsistencies in their methods, settings, and timeframes. In addition, the absence of a coordinated regional evaluation strategy means that individual stormwater programs engage in studies that, from a regional perspective, are inefficient and insufficiently comparable. The lack of systematic, neutral, reliable, and regionally coordinated information on the performance of a range of BMPs hampers decision making about how best to invest available resources to reduce loads. This is a pressing situation because the ongoing implementation of TMDLs for stormwater contaminants is raising both the regulatory and economic stakes involved in reducing loads and their impacts. Many proposed BMPs (e.g., large settling basins, treatment plants) are expensive and smaller scale ones are often ineffective (e.g., storm drain inlet filters). As a result of the lack of reliable evaluation studies, decisions involving substantial investments of time, effort, and money are being made based on incomplete and/or faulty information.

This project will address this problem by producing a regionally consistent, standardized framework for evaluating stormwater BMPs and will apply this to a priority set of BMPs. The evaluation will focus not only on the performance of individual, or stand-alone, BMPs but also on how alternative networks of BMPS (e.g., fewer, larger BMPs vs. more, smaller BMPs) perform. The project will also take advantage of efficiencies to be gained from using the entire region as a study area and will also take advantage of, and integrate if possible, ongoing BMP evaluation efforts by academic researchers and individual stormwater programs.

The major challenge involved in this project will be designing a series of evaluation studies that address decision makers' current and future information needs. In addition to examining the performance of individual BMPs, the project will also consider the performance of alternative combinations of BMPs configured in networks relevant to circumstances in southern California.

Improving fundamental understanding of stormwater mechanisms and processes

The following four projects focus on filling crucial gaps in the understanding of basic mechanisms and processes in the stormwater system. They are intended to bolster the conceptual and empirical foundation for developing improved indicators, assessing conditions, and better targeting management strategies where opportunities are greatest.

Project 5. Develop a systemwide conceptual model

The stormwater system is a complex combination of natural processes and engineered components, all characterized by poorly understood interactions and a high degree of variability. A basic conceptual model is widely accepted – rainfall causes runoff that mobilizes a variety of contaminants as well as sediment and this causes physical, chemical, and biological impacts in receiving waters. However, the details of the mechanisms and processes that control each step in this causal chain (e.g., generation, transport, and fate of contaminants in both wet and dry weather, as well as the operation of important causes of disturbance such as increased flow) are poorly understood. For example, the mechanisms and processes that control the first flush of contaminants during a storm, or the seasonal flush of contaminants during initial storms of the year have long been an area of uncertainty. In addition, currently used conceptual models do not adequately represent the ocean and there are serious knowledge gaps in conceptual models of biological processes.

As a result, stormwater management and monitoring efforts in southern California are often planned and undertaken on a case-by-case basis and it is often difficult to choose appropriate indicators (i.e., where along the causal chain to gather information). It is also difficult to decide where the best leverage points for management action might be. This requires enough knowledge about the system's behavior to make reasonably accurate predictions about what will happen under a range of different conditions. At present, the lack of such knowledge is a serious impediment to the development, implementation, and evaluation of improved management and monitoring strategies.

This project will address this problem by creating a regional conceptual model of the processes linking sources of impact and endpoints of concern to managers and the public. It will incorporate a wide range of urban runoff processes, including both wet and dry weather conditions; the full geographical range of the hydrological system (from headwaters to the ocean); and all key system components including hydrology, aerial deposition, chemistry, biology, land use, and physical conditions of the drainage systems and receiving waters. This model will begin as a qualitative summary of knowledge, with quantitative aspects (up to and including mathematical models) where knowledge is more advanced. Its ability to identify linkages between different parts of the system will provide the basis for prioritizing and coordinating management, research, and monitoring on a common set of problems. The ultimate product could range from a linked set of flow charts and system diagrams to a computerized decision support tool.

There are two major challenges involved in this project. The first will be the collection and integration of available knowledge about the complete stormwater system in southern California. The second will be the development of a conceptual framework that adequately prioritizes and structures this knowledge.

Project 6. Determine appropriate reference conditions

Quantifying impacts on beneficial uses, setting related management targets, and tracking progress toward these requires a definition of reference conditions. These can be numerical regulatory criteria, a description of the natural or unimpacted condition, or a more abstract definition of what might be theoretically possible at a particular site. Whatever form they take, definitions of reference conditions are essential for providing needed context to monitoring and management. Despite the use of numerical water quality criteria, the overall definition of reference conditions in southern California is spotty and there are significant gaps in the systemwide identification of reference conditions throughout the region. Numerical criteria, by themselves, do not take into account broader system hydrology and network linkages. In addition, there is no common agreement about reference for biological conditions or for important physical disturbances such as flow and structural modifications. Nor is there an explicit understanding of how water quality, physical disturbances, and biological processes are related in a more comprehensive definition of reference conditions. However, if an expectation of reference conditions were defined, managers could use this information for establishing benchmarks for remediation of stormwater and other discharges that might commingle in receiving waters might induce potential impairments.

This project will address this problem through a comprehensive effort to establish a regionally consistent set of reference definitions that include water quality, physical processes, biology, and human uses such as recreation and water supply. It will describe functional links between these to ensure that management focuses as much on the functionality of the entire system as on its individual parts. Reference conditions will be defined quantitatively wherever possible and qualitatively where this is not possible. This effort will depend to some extent on the conceptual model developed in Project 5 and will use the tools developed in Project 1 (Evaluate Available Data) and Project 3 (Develop Regional Data Infrastructure) to improve the efficiency of the characterization and analysis steps. This project will also provide the basis for Project 7, which aims to stratify the degree of relative attainment of beneficial uses with respect to reference conditions. In addition, it will integrate closely with all of the indicator research projects described below (Projects 10 – 12).

The major challenges involved in this project are the collection and organization of a wide array of data types from across the region, followed by analyses needed to develop appropriate reference frameworks for a variety of habitats. The regional survey that is an integral part of this task will, in an iterative fashion, both depend on and help to define appropriate indicators that can capture the full range of conditions from reference to severely impacted. Two recent efforts in the region provide insight into how this approach will work. The Benthic Response Index (BRI) (Bergen *et al.* 2000) defines a reference condition for marine infaunal communities and a method for measuring how far any particular site is from reference. It is based on regional analyses of data from sites along the entire gradient of conditions from undisturbed to highly impacted. In the second example, the development of the iron normalization technique for sediment samples (Schiff and Weisberg 1999) provided a quantitative method for measuring the increase of metals concentrations above the natural background. Iron normalization essentially calibrates each sample with respect to reference conditions.

Project 7. Regional method for measuring beneficial use condition

The protection of beneficial uses is the basic motivation for stormwater monitoring and management, and the assessment of receiving water conditions is fundamental to the regulation, management, and mitigation of stormwater impacts. While there are frameworks for this assessment in the Basin Plans and Section 305b of the Clean Water Act, the lack of regionally based reference conditions (see Project 6) and of more sophisticated indicators of both water quality and ecosystem condition (see Projects 10 – 12) has made such assessment more difficult. In addition, there is no regionally consistent definition of benchmarks along the gradient from extremely degraded to reference conditions. Without such benchmarks, it is not possible to quantify just how far from reference conditions a particular location is, to then describe and compare the status of beneficial uses across the region, and to more efficiently manage the application of BMPs. For example, the U.S. EPA's Rouge River Wet Weather Demonstration Project developed quantitative benchmarks for five indicators of river quality (dissolved oxygen, flow, bacteria, Index of Biotic Integrity, and habitat) and used these to rate the status of key beneficial uses along different segments of the river.

This project addresses this problem by developing a region-wide system for quantifying the status of key beneficial uses and relating their status to a set of benchmarks that rate their relative distance from ideal or reference conditions. This system will then be integrated with existing monitoring and assessment programs in order to begin producing regionally consistent information on the status of beneficial uses. The system could be developed to the point where metrics are converted to colors that visually indicate the status of beneficial uses on maps.

The major challenges involved in this task are the technical ones related to producing a consistent regional framework for inventorying beneficial uses, developing improved indicators of their status (Projects 10 – 12, 15), and the institutional challenge of achieving region-wide agreement on a set of benchmarks of status.

Project 8. Identify relative contributions of nonpoint sources to urban runoff loads

Urban runoff monitoring and assessment in southern California has predominantly measured the concentration and loads of a suite of contaminants to receiving waters. Source measurements during wet weather have largely been in the form of measurements from a range of urban land uses. What has been missing to date is a comprehensive assessment of the relative contributions of the full range of potential sources to total runoff loads. These include the urban land uses traditionally monitored, as well as other sources that may be significant in southern California such as aerial deposition, agricultural runoff, and forestry activities. While treated discharges are relatively well characterized, there remain gaps in our understanding of runoff from nonpoint sources. Thus, there is no monitoring program in southern California that looks at all nonpoint sources and quantifies loads and impacts related to these. As management moves from an

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earlier emphasis on characterization to a greater concern with reducing impacts (with TMDLs as a primary tool), it will become increasingly important to quantify the contributions to runoff loads of this full range of potential sources.

This project will produce a design for a regional nonpoint source monitoring program that addresses the full range of potential nonpoint sources. This design will be based in part on a best estimate, using currently available data, of the relative contribution to urban runoff loads of these nonpoint sources. This estimate would necessarily use information developed in Project 1 (Integrate Available Data) and Project 5 (Develop Conceptual Model). Once the regional monitoring is implemented, it will produce data that will allow stormwater and wastewater managers and regulatory agencies to carry out improved water quality assessments, develop more appropriate TMDLs, and better prioritize pollution prevention efforts.

The major challenges involved in this project are the integration of existing data (see Projects 1 and 3) and the development of robust sampling designs for all relevant nonpoint sources, especially those that are not part of traditional stormwater monitoring programs. Further, special attention must be given to developing an approach to sampling on private agricultural lands. This project will be carried out in coordination with, or at least with full knowledge of, related efforts by the State Board's SWAMP, U.S. EPA's EMAP, and others to assess loadings and effects.

Projects related to identifying receiving water impacts

The following seven projects focus on enhancing the tools available for identifying and quantifying stormwater impacts on receiving waters. They are intended to increase the breadth, specificity, and timeliness of methods currently in use and to bring new methods to the level of development where they can be used routinely.

Project 9. Identify the causes of impacts in receiving waters

Past stormwater monitoring has successfully identified important sources of contamination and disturbance, although there are some data gaps and remaining questions about the relative contribution of different sources (see Project 8, Identify Relative Contributions). At the "downstream" end of the system, monitoring has also documented specific impacts, such as elevated levels of contaminants in water and sediment, instream toxicity, habitat damage, and eutrophication. What is missing in most cases, however, is accurate knowledge about which sources are related to which impacts and the specific mechanisms causing these impacts. This is because the upstream tracking and identification of sources can be difficult and the causal mechanisms by which sources lead to impacts are not always clearly understood. For example, the sources of persistently elevated levels of bacteria in Aliso Creek in Orange County and of organophosphate pesticides in Chollas Creek in San Diego County have not been clearly identified.

This project will address this problem by performing detailed field studies in one or more pilot watersheds that produce a catalogue of important impacts in receiving waters, along with the specific kinds of sources that cause each. It will identify the mechanisms that link impacts and sources, as well as procedures for establishing causation from correlative monitoring data.

The major challenges involved in this project are identifying and then documenting the particular intermediate mechanisms that lead from sources to impacts. While the systemwide conceptual model (Project 5) will provide a starting point, this project will depend on field investigations to validate presumed relationships and search for currently undefined causal linkages. An additional challenge may involve unraveling the relative contribution of multiple sources to cumulative impacts. This project will also depend on the results of the regional synthesis of existing data (Project 1), as well as improved indicators from Projects 11 (Toxicity Testing), 13 (Microbial Source Tracking), and 15 (Peak Flow).

Project 10. Develop bioassessment indicators and protocols

Stormwater monitoring and management have focused primarily on the measurement of levels of contamination and other water quality conditions. However, the ultimate concern for managers, regulators, and the public is not the levels of contaminants in a waterbody but the status of beneficial uses and trends in these over time. Thus, a focus on contamination and its direct effects can miss other significant sources of impact and does not capture the ecological impacts of stormwater. For example, adequate or excellent water quality can coexist with serious impairments to biological conditions. Increased flow volume and velocity change sediment budgets, erode banks and streambeds, and damage instream habitat. Channelization removes riparian vegetation and increases water temperatures, creating a lethal barrier to fish migration. Maintenance practices designed to preserve channels' ability to convey stormwater efficiently also remove instream habitat for fish and invertebrates. Development that spreads to the very edge of creeks, streams, and other waterbodies can remove important riparian habitat and damage or destroy a waterbody's ability to respond to natural perturbations by expanding/contracting its extent or changing course.

Bioassessment methods, as developed by the U.S. EPA, the U.S. Forest Service, and the California Department of Fish and Game, among others, provide a means of reflecting overall ecosystem health, as well as measuring the status of specific biological conditions, independent of a focus on chemical contamination. Such bioassessment methods can integrate both episodic and long-term exposure to perturbation and can also be used in concert with chemical and other monitoring, as a screening tool, to focus attention on areas of particular concern. While these methods can help to rank sites in relative terms, incomplete understanding of relationships between stressors and biological indicators, along with the lack of accepted biocriteria for assessment, make it impossible to say with any certainty (except in more extreme situations) whether conditions meet minimum levels of acceptability. In addition, specific methods for southern California have yet to be developed and widely accepted, although there is progress being made.

This project will address this problem by producing a set of regionally standardized bioassessment protocols for a range of important habitat types and ecological assemblages in southern California (e.g., macroinvertebrates, fish, algae, and macrophyte assemblages in fresh waters). The protocols will define procedures for routinely measuring and interpreting appropriate indicators of ecosystem health. In combination with the regional reference framework (Project 6) and the stratification of beneficial uses (Project 7), these protocols will help determine whether and to what degree a system is being ecologically degraded by stormwater inputs. The major challenges involved in this project are those related to identifying sensitive measures of biological response for each assemblage and then developing appropriate indicators that capture that response. Bioassessment protocols are currently under development for fresh waters in southern California, primarily by the California Department of Fish and Game and U.S. EPA's EMAP. These efforts will provide an important framework for this project and mean that, for many habitat types, new techniques will not be needed.

Project 11. Develop improved toxicity testing procedures

Toxicity tests are widely used to measure stormwater impacts directly, especially where information on individual chemical contaminants is inconclusive or incomplete. However, despite their wide use, there are several important unresolved issues with toxicity testing, including selecting appropriate test organisms, interpreting conflicting and variable test results, and better defining and expanding the scope of toxicity evaluations (TIE). Because of these shortcomings, significant limitations constrain the application and interpretation of existing toxicity tests. For example, current procedures are often limited to use in specific environments and their results are often not well integrated into a complete understanding of the ecosystem. In addition, integrating toxicity tests into a regional reference framework (see Project 6) will improve the assessment of stormwater impacts.

This project will address these problems by developing and field testing a set of improved toxicity testing and TIE protocols. It will evaluate available methods of toxicity testing (including TIEs), identify the method(s) most applicable in specific types of systems (estuarine, marine, freshwater), and propose improvements to existing methods where needed. The project will enable managers to focus on the specific constituents, and in the proper bioavailable fraction, to reduce toxicity. This, in turn, will be used to develop a toxicity reduction evaluation (TRE) program.

The major challenges involved in this project relate to the complex responses of test organisms and the complex chemical characteristics of toxic compounds, both singly and in combination. It will utilize results of Project 6 (Determine Reference Conditions) and Project 7 (Stratify Beneficial Uses) to help define the range of conditions toxicity testing shall address.

Project 12. Develop rapid response indicator(s) for microbial contamination

The rapid detection of fecal contamination in receiving waters will improve public health managers' ability to protect the health of those using receiving waters for recreation. This is important in southern California, where beach visitation in the millions coincides with the large-scale stormwater inputs that can carry a variety of human pathogens into waters designated for recreational use. However, current methods for fecal indicator bacteria have a lag time of 24 – 48 hours, which means that it is impossible to provide real-time information to the public about the relative risk of water contact recreation. This not only makes it impossible in some instances to reliably close or post recreational sites when they are contaminated, but also causes a loss in economic revenue when sites are not reopened for public use as quickly as they might be. In addition to their lack of timeliness, current indicators are not necessarily reliable indicators either of animal and/or human waste products or of the presence of pathogens that may cause illness in humans. Improved indicators will provide a speedier and more reliable link to human health risk and do a better job of identifying sewage sources.

This project addresses this problem by developing improved indicators that will quickly (within two hours) provide reliable measures of the presence of pathogens of concern in marine, brackish, and freshwater environments. This rapid detection method will be accurate, reliable, require little technical training, and might include viruses, bacteria, protozoans, and chemical indicators of sewage (e.g., caffeine). Optimally, the method could be used either in the lab or in the field to provide a quick determination of whether the stormwater from a particular storm event presents a hazard to public health.

The major challenge involved in this project is the development of methods that can directly detect pathogens themselves or reliable indicators of their presence. This may require a shift away from standard culture approaches and toward more modern techniques such as biosensors or DNA probes. This project could be coupled with Project 13 (Microbial Source Tracking Tools) to obtain rapid measures of indicators that are of human origin.

Project 13. Develop microbial source tracking protocol

Fecal contamination in stormwater can derive from agricultural activities, livestock, wastewater, urban runoff, leaking septic systems, and soils, among others. The ability to determine which sources are most important in any particular situation can not only provide a basis for cost-effective source reduction efforts, but can also help determine relative public health risk associated with poor water quality in receiving waters. In addition, successful source tracking techniques are vital to implementing coliform TMDLs, because partitioning of fecal contamination will permit waste load allocation of tributaries or upstream sources in a watershed. However, at present, it is not possible to accurately and quickly identify the sources of microbial contamination in stormwater and partition contamination among the range of potential sources. In addition, current approaches do not provide results in a timely manner. As a result, it is nearly impossible to follow a “hot spot” or contaminated parcel of water upstream. Nor is it possible to efficiently apply source control measures where and when they are needed.

This project will address this problem by developing standardized protocols for microbial source tracking that will allow stormwater managers to quickly identify the relative contribution of different sources of fecal contamination in any particular situation. The method developed will be accurate and reliable, capable of consistently providing correct classification of sources of fecal contamination, and shall be applicable for use in different water body types (i.e., marine, brackish, and freshwater). This project will also provide guidance on the use of this method, including implementation, interpretation of results, its degree of geographic specificity (i.e., whether it is equally applicable in watersheds of different types). The research project will also identify strengths and limitations of the method developed, especially in the context of other available methods, and make suggestions for improved applicability in other systems. This project could be linked to Project 12 (Rapid Measurements) for optimal source tracking potential, particularly for transient or intermittent sources.

The major challenges involved in this project are related to the difficulty in establishing a broadly usable database of microbial fingerprints. Currently used microbial source tracking techniques depend on the development of a watershed-specific database of genetic fingerprints of existing sources of fecal contamination. For example, if the watershed is dominated by residential homes and ranches, and contains very little area where wildlife reside, a typical database might be created that is based upon fingerprints of collected fecal samples from horses, cows, dogs, cats, and humans. Not only are the necessary databases for different systems inherently different, but microbial populations can also vary within individual populations within a system and among systems. Given this, it is often difficult or impossible to use an available database from one watershed for identifying sources of fecal contamination in another watershed. Developing these libraries, or databases, can be time consuming and tedious, especially because the size of the database required increases exponentially with the size of the watershed. This is because scat samples must be collected from a representative portion of the animal and human populations in the watershed. Therefore, this project will identify the technique(s) that are most appropriate for the southern California region, test them in one or more pilot watersheds, and develop standardized protocols for their application throughout the region.

Project 14. Evaluate BMP effects on receiving water impacts

The large regional investment in BMPs has been based on the assumption that BMPs, by reducing loads of various kinds, will ultimately result in significant improvements in the condition of receiving waters. However, as Projects 9 – 13 (which focus on developing a variety of improved indicators) make clear, our current understanding of causal linkages between sources and impacts is limited. Such limitations extend to our understanding of linkages between BMPs and their potential reductions of impacts in receiving waters. It is possible to measure the immediate effect of a BMP in terms of reductions in loading of contaminants at a particular point in the drainage system (see Project 4, Measure BMP Effectiveness). However, it is much more difficult to estimate the cumulative effect of a network of both source control and treatment BMPs on loadings in an entire watershed and even more difficult to determine if such reductions have improved conditions in the receiving waters. Thus, stormwater programs have made significant commitments to activities such as street sweeping and catch basin cleaning, but there have as yet been no rigorous studies of whether these and other actions actually improve water quality. In this context, the ongoing implementation of TMDLs is raising the level of risk associated with the increasing investment in BMPs without adequate knowledge of their ultimate effectiveness.

This project addresses this problem by developing a method, based on conceptual and numerical modeling and on field monitoring, to evaluate the degree to which BMPs actually improve conditions in their ultimate receiving waters. This will be extremely valuable in deciding which BMPs to use to achieve the goals of the TMDLs being implemented in the region. Because of the large variability in ambient conditions, and length of time needed to detect changes in these, this project will consider focusing on small pilot watersheds that can be more easily manipulated and monitored.

The major challenges involved in this project are related to understanding the causal relationships among the different components of the stormwater system. Thus, answering the question whether BMPs have improved receiving water conditions depends on the results of several other projects in this research program. It will require a comprehensive framework that describes the operation of the hydrological system and how sources create impacts (Project 5, Conceptual Model), an estimate of the relative contribution of different kinds of sources to regional loadings (Project 8, Relative Contribution of Nonpoint Sources), improved knowledge about the causes of specific impacts (Project 9, Identify Causes of Impacts), and better indicators of ecological condition (Project 10, Develop Bioassessment Indicators). It will also require improved estimates about the ability of individual BMPs to reduce loads of contaminants in their immediate receiving waters (Project 4, Measure BMP Effectiveness).

Project 15. Develop improved indicators of peak flow impacts

Land development and consequent increases in impervious area increase runoff volumes and peak flows and can lead to downstream erosion and flooding. Traditionally, concerns about increased peak flows have focused on the hydraulic capacity of 25 – 100 year storm events and the potential for destructive flooding. A variety of methods have therefore been developed to shave, retard, and/or channel peak flows and reduce flooding potential. However, development changes the hydrograph and increases runoff volume and velocity even for much smaller flows. Concern is therefore growing that such smaller changes, when they occur on a persistent basis, can create more subtle yet long-term and potentially important impacts on habitat and the beneficial uses related to them. Such impacts will occur primarily through changes in sediment movement and redeposition and streambed scouring. While regulatory criteria are beginning to be established on increases in peak flow, there are no well-established relationships between various levels of increased flow and downstream impacts on which to base such criteria.

This project addresses this problem through an integrated modeling, experimental, and monitoring program in pilot watersheds. It will produce indicators that quantitatively link a range of downstream impacts, primarily those related to stream bank and stream bed erosion, to increased peak flows due to land development and increases in impervious area. These indicators could help provide the basis for eventually establishing regulatory criteria for peak flows from smaller and more frequent storms.

The major challenges involved in this project stem from the relative lack of quantitative information in the region about the effects of sustained increases in peak flows. Information available from other regions is only partly applicable because of the semi-arid nature of the southern California environment and the highly episodic nature of flows. This project will necessarily depend on the results of several other projects in this research program. It will require a comprehensive framework that describes the operation of the hydrological system and how increased flows might create impacts (Project 5, Conceptual Model), an assessment of historic and current conditions (Project 1, Integrate Available Data), an estimate of the relative contribution of different kinds of sources to regional loadings (Project 8, Relative Contribution of Nonpoint Sources), improved knowledge about the causes of specific impacts (Project 9, Identify Causes of Impacts), and better indicators of ecological condition (Project 10, Develop Bioassessment Indicators).

DISCUSSION

The preceding section described 15 distinct research projects that address key gaps in the knowledge base and the monitoring and management tools needed to adequately address stormwater impacts in southern California. While they are presented individually, they have two important features, as a group, that are important to emphasize. First, many of the projects are directly related, with some depending on the output of other projects for their success. For example, Projects 1 (Integrating Available Data), 3 (Create Regional Data Infrastructure), and 5 (Develop Conceptual Model) lay important groundwork for many other projects. Conversely, projects such as Projects 9 (Identify Causes of Impacts) and 14 (Evaluate BMP Effects on Receiving Waters) depend strongly on the availability of results from other projects. Ultimately, the interconnectedness among projects demonstrates that the workshop panelists have devised not a list of individual wish-list projects, but a comprehensive research program.

Second, these projects lay the necessary groundwork for a comprehensive and region-wide stormwater monitoring program. Thus, the research program will improve not only individual stormwater programs, but also the overall regional approach to stormwater management. It will identify where there are uneven levels of effort and help bring parity to monitoring programs throughout southern California. It will also enhance the efficiency of individual programs and regional programs by ensuring comparability and quality. Finally, the research program will improve effectiveness by identifying areas where all agencies can use commonly generated information, thereby reducing redundancies or repetitive effort.

Finally, the workshop experts set an expectation that the research plan will eventually lead to a model stormwater monitoring program at the end of five years. The expectation included at least three levels of monitoring effort including: (1) an ongoing regional monitoring program where agencies interact at large spatial scales; (2) local monitoring focused on their individual discharges of concern; and (3) an ongoing research component consisting of specific projects, not unlike those described herein, where there is a defined beginning, middle, and end, whose results feed directly back into the monitoring and management decision-making framework.

The proposed research program is a potentially costly undertaking. However, the fact that it is spread out over time and that there are numerous opportunities for partnering with other interested parties who are undertaking related projects, will lower the overall cost to the Consortium's participants. For example, the California Department of Fish and Game is engaged in ongoing development of bioassessment indicators and both U.S. EPA and the State Water Resources Control Board are preparing to fund development of improved indicators of microbial contamination. If past experience is any guide, the presence of an active stormwater research consortium in southern California will serve as a magnet for partners such as these with an interest in improving stormwater monitoring and management.

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ACKNOWLEDGEMENTS

This document represents a remarkable first step towards regional cooperation in stormwater science and management for southern California. The culmination of this research agenda was, for the most part, a voluntary activity initiated by both stormwater management agencies and regulators in a spirit of mutual collaboration.
The authors wish to thank the workshop panelists who gave freely of their time and talents. The wonderful mix of local and national experts across a wide variety of disciplines and backgrounds provided a unique opportunity for us.

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