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Stormwater Research Needs in Southern California

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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.

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Introduction

Watersheds in southern California are among the most modified systems in the world (Brownlie and Taylor 1981). Stormwater conveyance systems have been built primarily to reduce flooding, but the infrastructure was not designed to improve water quality. Water quality issues are compounded by the high degree of urbanization of watersheds in southern California. More than 17 million people inhabit the six coastal counties of southern California making it among the most densely populated coastal region in the country (Culliton et al.. 1990). The large degree of urbanization, coupled with infrequent rainfall that enables build-up of non-point sources of pollutants, results in sporadic but tremendous loads to receiving waters. 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 point sources (Schiff et al.. 2001). Based upon the increasing population of southern California and the lack of storm water quality infrastructure, it is likely that stormwater loads will continue to increase.

There is some evidence that stormwater discharges impact receiving water quality. For example, regional monitoring of southern California beaches has shown that shorelines which receive dry weather flows are 10 times more likely to exceed water contact standards than those that are distant from storm drains (Noble et al.. 2000). More than 60% of the shoreline exceeds water contact standards following wet weather events. This has led to the permanent posting of warning signs near drain outlets and blanket warnings against body contact recreation at any beach for 72 hr following rain events. In addition, large loadings of nutrients have been measured from urban creeks and these have ultimately contributed to the over-enrichment of estuaries at the mouths of urban watersheds, as indicated in part by large blooms of macroalgae (Kamer et al.. 2001). As another example, storm drain discharges have been shown to be toxic to marine and freshwater organisms and this toxicity persists over large areas as discharge plumes spread through coastal receiving waters (Jirik et al.. 1998). After these plumes settle to the bottom of the ocean, the pollutants have been measured in nearshore sediments (Schiff 2000). Where these sediments must be dredged to maintain navigable harbors or marinas, the associated contamination increases the cost of dredging by orders of magnitude.

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 knowledge on which to base sound management decisions. For example, knowledge about reference, or expected, conditions is insufficient to enable managers to identify when impacts occur, which beneficial uses are most severely impaired, or clarify target endpoints for remediation. Similarly, we are often unable to differentiate between natural (e.g., storms) and anthropogenic (e.g., contamination, flow modification) impacts on biological communities. Moreover, when water quality impacts from specific constituents do occur, we are too often incapable of identifying, targeting, and reducing their specific contributions.

In parallel with the relatively poor level of scientific understanding of stormwater impacts, there is a lack of technical knowledge on how best to control stormwater discharges. Technical data gaps include source identification in urban watersheds where many small, diffuse sources may commingle. Further, assessments of the most effective and efficient treatment or management strategies for resolving stormwater impairments are typically absent or not well validated. For example, there is a lack of substantive and long-term data about how well best management practices (BMPs) work, which ones work best under a range of conditions, or which BMPs are most appropriate in specific applications for improving receiving water quality.

Finally, available stormwater management tools are typically inadequate to deal with existing needs for proper stewardship and decision making. The tools that do exist are often inadequate because they are either not specific enough (i.e., are based on inappropriate point source analogs) or have not been developed or tested in southern California. For example, managers do not have a tool for assessing the health of physical habitats and biological communities in freshwater environments. Although this tool has been effective at addressing physical and water quality impacts elsewhere around the nation, they have not been developed or applied successfully in southern California. An index or metric of physical and/or biological health would be an invaluable tool for environmental decision making.

Despite such information gaps, management actions (from both the regulated and regulator communities) 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.

Formation of the Stormwater Monitoring Coalition

As a result of the increasing regulatory focus and the lack of scientific knowledge base, both stormwater regulators and municipal stormwater management agencies throughout southern California have developed a collaborative working relationship. The goal of the relationship is to develop the technical information necessary to better understand stormwater mechanisms and impacts, and then develop the tools that will effectively and efficiently improve stormwater decision making. As individuals and agency representatives, there was early recognition that these issues are most often not localized, but oftentimes cross watershed and jurisdictional boundaries. The relationship culminated in a formal letter of agreement signed by all of the Phase I municipal stormwater NPDES lead permittees and the NPDES regulatory agencies in southern California to create the Stormwater Monitoring Coalition (SMC) (Appendix 1).

The SMC member agencies have developed a clear vision of regional cooperation. The vision includes combining resources to cost effectively address the data gaps. The vision includes improved effectiveness of existing monitoring programs by promoting standardization, coordination, and reducing duplication of effort across individual programs. In addition, this will lead to improving the basic infrastructure for exchanging, combining, and analyzing data from across the region. The multi-agency collaboration hopes to trade off redundant or ineffective monitoring program elements in order to allocate resources to the research projects necessary for improving stormwater management. The findings from these applied research projects can then be easily and quickly integrated into the existing stormwater management programs.

Once the agreement to work collaboratively was signed, the next step was to determine which research projects should be undertaken. The SMC developed a three step process to identify these projects. The process included: (1) creation of a white paper outlining the technical issues and management questions of interest (Appendix 2); (2) conduct a workshop to develop an agenda of research projects using experts in a variety of scientific disciplines (Appendix 3); and (3) establish a five-year research plan to implement based upon the workshop proceedings. This document represents step three in the process. The white paper and workshop details can be found in appendices to this document.

Research Themes

The experts who participated in the research agenda workshop generated more than 50 project ideas in less than four hours. This plethora of ideas were combined, clarified, and prioritized over the next day 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).

The 15 research projects developed by the workshop experts naturally fell into one of three categories. These categories included: (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 existing data, sampling and analysis, data management and sharing, and testing BMPs.

Research projects that improve our fundamental understanding of stormwater mechanisms and processes begin with creating a conceptual model of our existing understanding of these processes. This will help us to identify our knowledge gaps. *A priori* we expect that there will be at least three gaps in the conceptual model. These include an evaluation of reference conditions, an evaluation of beneficial uses, and identifying 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 we know 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 written as individual projects, many of the projects are inter-related. The final chapter of this document provides an overview of these relationships showing where the results from one project may feed into another project.

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

To date, historical stormwater monitoring data have not been used to their full potential, with the result that important questions at both the local and regional scale have not been addressed and significant opportunities for improving the effectiveness and efficiency of monitoring have not been taken advantage of. This project will address these issues by identifying, integrating, and evaluating available monitoring data from the region. This project would depend to some extent on the regional data infrastructure (Project 3) and would contribute to the definition of regional reference conditions (Project 6) and assessing beneficial uses (Project 7).

Problem statement

While stormwater monitoring programs in southern California have collected large amounts of data, there has been no systematic effort to integrate and analyze these data from a regional perspective. An estimated 1,700 wet weather site-events have been monitored by southern California monitoring programs between 1992 and 1999, which are more than most nationwide data sets. In addition, analysis efforts carried out by individual stormwater programs have not examined a consistent set of questions across the region. As a result, there is little information about the following questions, among others:

- what is the spatial extent of stormwater monitoring?
- 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?

Thus, available data have 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.

Desired outcome

This project would take advantage of 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 improve the effectiveness and efficiency of monitoring, on both the local and the regional levels, 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 indivdual agency monitoring effort.

Tasks

The major challenges facing this project involve collecting and integrating available data and defining and agreeing on key questions and the analysis approaches appropriate for addressing them.

This project would collaborate with or make use of information from other ongoing or planned studies. For example, the Contaminated Sediment Task Force in Los Angeles has already allocated funds for an analysis of contaminant sources in stormwater to the sediments in Marina del Rey and Los Angeles/Long Beach Harbors. In addition, SCCWRP has committed to a regional analysis of stormwater monitoring data from industrial discharges. Finally, SCCWRP has already compiled a portion of the regional stormwater monitoring data that would be needed for this project and this experience could provide a firm basis for planning and costing out the remainder of the data collection and integration effort. Datasets produced in this project would be formatted to the standards developed in Project 3 and would become part of the regional data infrastructure developed in that same project.

The specific tasks involved in this project include:
- identify existing relevant data
- develop list of specific questions and analyses needed to answer them
- develop a formal data management and analysis plan
- acquire or otherwise confirm access to needed data
- perform quality and consistency checks on data
- standardize and/or normalize data as needed
- conduct analyses
- prepare report(s).

This is a low risk / high benefit project. The probability of success is high because techniques for data integration, synthesis, and analysis are well established. The benefits are likely to be substantial because region-wide analyses have not been performed in the past. In such a situation, the marginal benefit of initial investments in synthesis and analysis are typically very high.

Schedule
This project could begin immediately and could be completed within 12 months.

Resources
Needed expertise includes data managers and data analysts with direct experience with a range of environmental data types. Expected costs are in the range of $100,000 to $250,000. Examples of similar projects include the regional assessments performed as part of the Bight ’98 project and watershed assessments performed at a variety of locations throughout the country. Potential partners include the Contaminated Sediments Task Force in Los Angeles and an analogous effort being conducted by San Diego County.

Project 2. Standardize sampling and analysis protocols

At present, the wide array of monitoring approaches used throughout southern California makes it difficult to readily compare findings across stormwater programs and address questions of regional importance. This project would 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. Senate Bill 72 (SB72) has allocated funds that could support this effort.

Problem statement

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.

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?). In addition, any attempt at regional standardization must 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.

Desired outcome

This project would produce a regionally consistent set of standardized monitoring protocols. These would 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 above.

Tasks

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.

This project could make use of efforts elsewhere in the country to develop 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 specific tasks involved in this project include:

- identify a list of management and technical questions that require regionally standardized data to answer
- review and compare relevant monitoring protocols from southern California and from other areas
- determine which protocols can be applied regionally in southern California
- determine which management questions and/or technical issues require further methods development
- develop detailed recommendations to guide implementation by appropriate working groups
- develop regional field operations manual
- conduct laboratory intercalibrations for bacteria, metals, nutrients, and organics.

This is a low to medium risk / high benefit project. The potential risks stem, not from technical problems, but from institutional issues that may make it difficult to achieve regional consensus about sampling methods. However, the potential benefits, in terms of improved efficiency and coordination, along with the ability to integrate data from across the entire region, are large.

Schedule

This project could begin immediately and be completed in 12 months.

Resources

Needed expertise includes a facilitator and in-kind time of one field operations staff person from each participating agency, as well as in-kind time of agency staff knowledgeable about chemical analyses. Expected costs are in the range of $50,000 to $150,000 to produce the field operations manual and another $100,000 to $500,000 to complete the laboratory intercalibrations for chemical analyses. Intercalibrations for bacteria, metals, and nutrients are relatively inexpensive compared to those for organics. Where in the range the costs actually fall depends largely on the constituents chosen. The Bight project undertook similar standardization efforts and these costs are based on that experience. Besides the stormwater agencies in the region, potential partners include the USGS, the SWQTF, and WERF.

Project 3. Develop a regional data infrastructure

The lack of a common data infrastructure in the region makes it extremely difficult to combine data from different programs to assess impacts and problems, quantify trends, evaluate the effectiveness of different solutions, and establish reference conditions on a regional scale. As a result of this situation, it is 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, along with a distributed data management system that will expedite finding and acquiring needed data.

Problem statement

At present, scientists and managers have limited ability to examine 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. In addition, the 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 clearing house 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.

Desired outcome

Ultimately, this project would produce a distributed online system, with a centralized catalogue to facilitate search and retrieval, which would 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).

Tasks

The major challenges involved in addressing this problem include deciding what data types the system should accommodate, what design the system should be based on, what specific needs it should focus on, and establishing the necessary 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.

In addition, there are several examples of the successful development of regional information management systems that can provide guidance for this effort, including efforts by the Chesapeake Bay Program and the Gulf Ecosystem Monitoring Program in Alaska. The steps involved are relatively generic and include the following:

- identify data users (e.g., managers, regulators, environmental interests), how they use data now, and how they would like to use the data if they were more readily accessible
- reach agreement on users' needs and desires
- identify existing data generators and the nature of their data
- define an appropriate architecture that describes core functions and how they will be fulfilled
- develop a working prototype, including the user interface, as a focus for more obtaining more detailed user input and defining the system more clearly
- finalize the system design
- select hardware and software components to support the system design
- determine housing and administration needs and how these will be met
- implement system
- maintain and enhance the system over time.

While the development steps are relatively clear, there will nevertheless be significant challenges to be met. These will be primarily institutional, not technical, and will involve issues of funding, coordination, standard setting, access to data that is considered proprietary to some extent, and making provision for orphan datasets.

This is a low risk / high benefit project. The probability of success is high because of the lessons provided by other similar effort and the benefits to be obtained from wider access to regionally standardized data are substantial.

Schedule

With adequate funding, this project could be completed in two to three years. Major milestones include:

- system design
- final cost estimate and funding decis ion
- completion of the prototype
- implementation
- ongoing maintenance and enhancements.

The only significant rate limiting factors would be the availability of funding and speed with which the participants reach agreement on the system's major design features.

Resources

Needed expertise includes specialists in data management, database design, system architecture, and distributed networks. Expected costs are in the range of $50,000 to $150,000 to establish a data sharing format and an online catalog of existing datasets. This would require no new hardware or software. Developing the full distributed system that permits users to remotely access data over the Internet and integrate mapping and data analysis tools could cost between $1,000,000 and $1,500,000 and would require new hardware and software. The recent effort to standardize data sharing protocols for regional participants in ocean monitoring in southern California is a good model for the first phase of this project, while the two larger systems mentioned in the Tasks section (i.e. Chesapeake Bay)are models for the second phase. Potential partners are other agencies with needs to acquire and integrate data from a range of sources in order to perform larger-scale analyses and assessments. These may include the SWRCB, Caltrans, and the U.S. EPA, among others.

Project 4. Measure BMP effectiveness

At present, the lack of reliable information on the performance of a range of BMPs hampers decision making about how best to invest available resources to reduce loads. This project would address this problem by systematically evaluating stormwater BMPs using a standardized, regional protocol.

Problem statement

Best management practices (BMPs) are being applied without the benefit of systematic and neutral evaluations of their effectiveness in reducing loads. Available studies of whether propriatary 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 need for systematic, neutral, and regionally coordinated evaluations is pressing 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.

Desired outcome

This project will produce 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.

Tasks

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 should also consider the performance of alternative combinations of BMPs configured in networks relevant to circumstances in southern California.

This project should take advantage of, and integrate if possible, ongoing BMP evaluation efforts by academic researchers and individual stormwater programs. Specific tasks involved in this project include:

- define key management questions
- define primary technical questions and issues including constituents of concern
- identify priority list of BMPs to be evaluated for specific constituents
- describe possible alternative BMP networks for evaluation
- incorporate and/or coordinate with ongoing studies
- develop detailed study designs
- develop and/or adapt hydrological and water quality models as needed
- implement studies of individual BMPs
- evaluate testing protocols if third party testing is conducted
- implement studies of prototype alternative networks
- apply results to ongoing decision making.

This is a medium risk / high benefit project. The probability of success at the site-specific scale is good because techniques for evaluating the performance of some individual BMPs are relatively well developed. At the larger spatial scale of BMP networks, new modeling approaches may have to be developed or adapted from other applications. Because of the potential aggregate cost of stormwater BMPs in southern California, the potential benefits from improving the effectiveness of this investment are extremely high.

Schedule

This project could begin immediately. Its duration will depend on the number and complexity of BMPs selected for study.

Resources

Needed expertise includes in-kind time of decision makers and of agency staff with direct experience in implementing BMPs, as well as additional expertise in engineering, hydrology, modeling, and statistics. Expected costs are in the range of $50,000 to $150,000 to identify decision makers' priorities and develop the assessment design and $200,000 to $500,000 for the BMP network modeling, depending on the size and complexity of networks considered. Costs for evaluating individual BMPs are difficult to estimate at this time because they are dependent on the number and types of BMPs considered and on the constituents measured. The project costs do not include the BMP installation. Therefore, potential partners should include stormwater agencies that are currently implementing BMPs including the California Stormwater Quality Task Force, Caltrans, the Building Industry Association, WERF, and other entities such as Proposition 13 contractors. Specifically, coordination with the Los Angeles BMP Task Force is encouraged to provide a consistent basis for evaluating proposed proprietary BMP products and methods.

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

Stormwater management and monitoring efforts in southern California are often planned and undertaken on a case by case basis, without the benefit of a comprehensive regional framework that describes the 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. This project would 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. This model would lay important groundwork for all the subsequent projects in this research plan.

Problem Statement

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 these cause physical, chemical, and biological impacts in receiving waters. However, the details of the mechanisms and processes that control each step in this causal chain are poorly understood. For example, the mechanisms and processes that control the first flush of contmainants during a storm, or the seasonal flush of contaminants during initial storms of the year have been an area of uncertainty for a long time. 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, 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, that is, where to intervene to improve conditions and how to determine if such interventions are working as intended. 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.

Desired outcome

This project would produce a conceptual model of urban runoff processes that included 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 would 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 would 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.

Tasks

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.

Major tasks in this project include the following:

- identify all potential processes
- prioritize important pathways
- summarize existing knowledge
- evaluate the need for analytical, quantitative and predictive capability to 'reverse engineer' the impacts to the sources to resolve causation from correlation. For example:
  - attributing the cause of eutrophication to sources (e.g. land use) to receiving waters,
  - identifying locations for monitoring and testing to confirm or refute sources,
  - prioritizing sources on the basis of relative contributions to receiving water impacts to help separate biological impacts from physical and chemical impacts.
- develop framework conceptual model
- flesh out the conceptual model as needed with existing information
- develop an approach to applying the conceptual model to the decision support needs of managers and to structuring the research and monitoring agenda
- Develop a strategy for updating and refining the conceptual model as new information becomes available.

This is a low risk / high reward project. There is substantial knowledge available about many aspects of the stormwater system and conceptual modeling techniques are well established. The presence of a systemwide conceptual model will improve a wide range of research, monitoring, and management efforts, in part by providing a systematic and widely accepted framework for planning and decision making.

Schedule

This project could begin immediately and the intial conceptual model could be completed in 6 – 12 months.

Resources

Needed expertise includes modeling, hydrology, ecology, chemistry, engineering, and systems analysis. Expected costs are in the range of $100,000 to $250,000, with the exact amount depending on the degree of sophistication of the product (e.g., flow charts vs. a computerized decision support tool). Potential partners are stormwater agencies in the region and other agencies responsible for carrying out region-wide assessments of water-related issues.

Project 6. Determine appropriate reference conditions

Assessing impacts, setting management targets, and measuring progress toward these all require clear definitions of reference conditions in order to be maximally effective. While some reference conditions are, in effect, defined by regulatory water quality criteria, there are significant gaps in the systemwide identification of reference conditions throughout the region. This project would address this problem through a comprehensive effort to establish a regionally consistent set of reference definitions for physical, chemical, and biological components of the environment. This effort would depend to some extent on the conceptual model developed in Project 5 and would integrate closely with the following project to stratify beneficial use definitions (Project 7), as well as with all of the indicator research projects described below (Projects 10 – 12).

Problem statement

Quantifying impacts on beneficial uses and tracking progress in improving 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. 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 should be related in a more comprehensive definition of reference conditions. However, if an expectation of reference conditions were defined, mangers could use this information for establishing benchmarks for remediation of stormwater and other discharges that might commingle in receiving waters that might induce potential impairments.

Desired outcome

This project would produce a regional description of reference conditions that includes water quality, physical processes, biology, and human uses such as recreation and water supply. It would 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 would be defined quantitatively wherever possible and qualitatively where this is not possible.

Tasks

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. Two recent efforts in the region provide insight into the kinds of analyses that may be required. The Benthic Response Index (BRI) 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 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.

Major tasks in this project involve the following:

- examine and evaluate the relevance to southern California of methodologies developed elsewhere
- tailor these methodologies to southern California as appropriate
- use existing data and region-wide data collection, as needed, to identify reference locations and broadly characterize reference conditions for a variety of habitats and environmental components
- define potential indicators for each habitat and/or component, including multivariate indicators that include physical, chemical, and biological features
- analyze indicators in terms of spatial and temporal pattern and resolution
- refine list of potential indicators

- apply metrics (quantitative or qualitative) from Project 7 that define a measurable gradient from reference to highly impacted conditions
- conduct additional field surveys as needed to further refine indicators and/or identify and evaluate new ones
- field test indicators in ongoing monitoring programs.

This project 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. In addition, the conceptual model developed in Project 5 will help ensure that the initial characterization of reference conditions captures important functional relationships. This project will also of necessity be closely integrated with all the indicator projects (Projects 10 – 12) described below. 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. Finally, the definitions of reference conditions will provide the basis for the next project, which aims to stratify the degree of relative attainment of beneficial uses with respect to reference conditions.

This is a medium risk / high benefit project. The level of risk and difficulty will be low for some environmental components that have been well studied and higher for others that have been less well studied. The benefits to monitoring and management from a regionally consistent definition of reference conditions are substantial.

Schedule

This project could begin immediately and be completed in 5 years.

Resources

Needed expertise includes hydrology, geomorphology, ecology, water quality, and study design. Expected costs are in the range of $5,000 per site, inclusive of project planning, data management, and laboratory and data analysis costs. The total number of sites that might be required is in the range of 100 to 150. Examples of similar projects include the Bight Project, U.S. EPA's EMAP, and the California Department of Fish and Game's effort to develop bioassessment protocols. Potential partners include U.S. EPA's EMAP, the Statewide Ambient Monitoring Program, the California Department of Fish and Game, and the offshore marine regional monitoring consortium, which is increasingly interested in linkages between land and ocean in the coastal zone.

Project 7. Regional method for measuring beneficial use condition

The protection of beneficial uses is the fundamental motivation for stormwater monitoring and management. Despite existing frameworks for defining such uses and determining where they have been degraded, there is no regionally consistent system for quantifying how far a particular situation is from reference conditions or how it relates to conditions at other sites. This project addresses this problem by developing a regional scheme for stratifying beneficial use conditions in terms of a set of benchmarks that describe how far from reference a particular site is. This strategy is reflected in the most recent recommendations from the National Reseach Council[1] for improving the effectiveness of TMDLs and it has been an extremely useful tool for communicating benefical use condition to managers and the public in the Rouge River National Wet Weather Demonstration Project[2].

Problem statement

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.

Desired outcome

This project will produce 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.

Tasks

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

The major tasks in this project involve the following:

- develop inventory and framework for existing designated uses
- assess stratification schemes used elsewhere
- review range of conditions in southern California (Project 1)
- relate current conditions to regional reference conditions established in Project 6
- develop prototype stratification scheme, with benchmarks
- apply to selected water bodies as test cases using relevant indicators, including those developed in Projects 10 – 12 and 15
- refine stratification scheme as needed
- integrate stratification scheme into ongoing monitoring and assessment programs.

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[1] National Research Council. 2001. Assessing the TMDL approach to water quality management. National Academy Press. Washington, DC 109 pp.
[2] Rouge River National Demonstration Project. 1997. State of the Rouge River: Middle 1 subwatershed. Wayne County, MI 12 pp.

This is a medium risk / high benefit project. The successful development of stratification schemes elsewhere should provide a useful model for a similar effort in southern California. However, the actual benchmarks developed elsewhere will not necessarily be applicable in southern California because of significant differences in rainfall, flow regimes, and habitats. In addition, this project depends on the successful completion of other research projects (Projects 1, 6, 10 – 12, and 15). Despite these risks, the benefits of a regionally consistent set of strata and benchmarks for evaluating the status of beneficial uses will pay substantial dividends in management's ability to inform the public about the condition of beneficial uses and to prioritize monitoring and mitigation efforts.

Schedule

This project must await the completion of the region-wide assessment in Project 1 but could begin before the completion of Projects 6, 10 – 12, and 15. The first two tasks could be completed in six months and the remainder in an additional 12 months, assuming results from other projects are readily available, as shown in the task list above.

Resources

Needed expertise includes data analysts and GIS support, in-kind participation of managers and technical staff from participating agencies, and a facilitator. Expected costs are in the range of $50,000 to $75,000 for a test case and an additional $150,000 to apply the stratification scheme to the entire region. Examples of similar projects include the Bight Project's development of the Benthic Response Index and U.S. EPA's Rouge River Wet Weather Demonstration Project. Potential partners include both regulatory and stormwater management agencies in the region.

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

Stormwater monitoring and management has focused on a subset of sources that are either presumed to contribute the most to overall loads or are the most tractable to address. What has been missing to date is a comprehensive assessment of the relative contributions to total runoff loads of the full range of potential sources. These include the urban land uses traditionally monitored, as well as other sources that may be signficant in southern California such as aerial deposition, agricultural runoff, and forestry activities. This project addresses this problem in two steps. First, it will use available information to prepare an assessment of how much individual sources may be contributing to overall runoff loads. Using this assessment, it will then design a regional nonpoint source monitoring program to fill data gaps and monitor trends over time.

Problem Statement

With minor exceptions, urban runoff monitoring and assessment in southern California measures the concentration and loads of a suite of contaminants to receiving waters, along with the contribution to these loads from a range of land uses. As management moves from an 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 the full range of potential sources. 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.

Desired Outcome

This project would produce a design for a regional nonpoint source monitoring program that addresses the full range of potential nonpoint sources. This design would 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 would necessarily use information developed in Project 1 (Integrate Available Data) and Project 5 (Develop Conceptual Model). Data from such a monitoring program would 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.

Tasks

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.

Major tasks involved in this project include:

- identify significant known and potential nonpoint sources (overlap with Project 5, Develop Conceptual Model)
- acquire and integrate available data on these sources (overlap with Projects 1, Integrate Available Data, and 3, Develop Regional Data Infrastructure)
- using available data, estimate relative contribution of significant sources at several spatial scales (overlap with Project 1)
- develop framework of regional nonpoint monitoring design, taking account of the requirements of loading models
- identify relevant monitoring approaches to accomplish the design
- organize information on existing monitoring efforts that could constitute portions of the regional design
- develop detailed program design, including sampling methods and spatial and temporal replication.

These tasks should 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.

This is a low risk / high reward project. The monitoring and modeling involved will use readily available techniques. A more complete picture of how all nonpoint sources contribute to regional loadings will greatly assist decision making about how to best allocate monitoring and source reduction efforts.

Schedule

This project could begin as soon as input from the other research projects is available and could be completed in one year.

Resources

Needed expertise includes in-kind support from participating agencies' staff, statisticians, interdisciplinary scientists, air deposition and agricultural runoff specialists, and a facilitator/project manager. Expected costs are in the range of $50,000 to $125,000.

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

While there is information available on impacts in receiving waters, monitoring studies, with few exceptions, have yet to identify the specific causes of such 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. This project will address this problem by performing detailed field studies to link impacts and sources in one or more pilot watersheds.

Problem Statement

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. 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 been clearly identified.

Desired outcome

This project would produce a catalogue of important impacts in receiving waters, along with the specific kinds of sources that cause each. It would identify the mechanisms that link impacts and sources, as well as procedures for establishing causation from correlative monitoring data.

Tasks

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).

Major tasks involved in this project include:

- develop list of impacts
- develop list of candidate causes
- develop hypotheses for investigating correlation and causality between them
- assess information available to test specific mechanisms
- identify additional information needed to validate causal relationships
- select pilot watershed(s) suitable for field studies, i.e., where clear impacts exist and upstream tracking of sources is feasible
- design and implement a research plan to test hypothesized mechanisms. This might involve using relatively inexpensive screening techniques throughout the watershed(s), followed by more sophisticated tools focused on specific problem areas.
- update conceptual model with new understanding.

This is a medium to high risk / high benefit project. Assuming that results from Projects 11 (Toxicity Testing) and 13 (Microbial Source Tracking) are available, it should be relatively straightforward to identify the sources of most impacts. Cumulative impacts may present more problems. However, the benefits of an improved ability to reliably link impacts and sources will pay important dividends for source reduction programs.

Schedule

This project could begin when needed information from other projects is available and could be completed in two to five years.

Resources

Needed expertise includes in-kind participation from agency managers who are knowledgeable about the pilot watershed(s) and can help provide needed access for sampling, as well as a hydrologist, scientists skilled in relevant impact identification techniques (e.g., microbiology, toxicity, chemistry), field staff, laboratory facilities, data analysts, GIS support, and data managers. Expected costs are in the range of $250,000 for a single watershed and a single constituent and would scale up from there depending on the number of watersheds and constituents. Similar projects have been conducted elsewhere in the country focusing on individual constituents of concern, such as bacteria. Potential partners include local agencies and the Los Angeles Contaminated Sediment Task Force.

Project 10. Develop bioassessment indicators and protocols

The ultimate concern for both 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. However, few indicators exist and none have been universally accepted for those beneficial uses that are related to ecological conditions. This project would address this problem by developing a regionally consistent set of bioassessment indicators and protocols for a range of important habitat types and ecological assemblages in southern California.

Problem statement

Stormwater monitoring and management have focused primarily on the measurement of levels of contamination and other water quality conditions. However, a focus on contamination and its direct effects can miss other significant sources of impact and do not capture the ecological impacts of stormwater. 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 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.

Desired outcome

This project would produce a set of regionally standardized bioassessment protocols for macroinvertebrates, fish, algae, and macrophyte assemblages in fresh waters of southern California. 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 would help determine whether and to what degree a system is being ecologically degraded by stormwater inputs.

Tasks

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.

Major tasks in this project will include:

- evaluate existing efforts being conducted by U.S. EPA EMAP, California Department of Fish and Game, U.S. Geological Survey, U.S. Forest Service, and others
- define the degree to which each effort is applicable to specific habitats in southern California
- define baseline and reference conditions of each habitat, including defining subhabitats as needed, within the framework established in Project 6 (Determine Reference Conditions)
- test candidate methods and prospective indicators

- determine biological response signatures of indicator organisms to stormwater. This may require integrating information from toxicity testing. Simultaneously, measure potential physical and chemical confounding factors and the relationship of habitat type to ecosystem health.
- validate the protocols.
- develop QA/QC procedures.

This is a low to medium risk / high benefit project. The fact that current research on bioassessment protocols is underway in southern California, combined with relevant knowledge from similar successful efforts elsewhere in the country, increase the likelihood of success. The benefits of an improved ability to relate stormwater to ecological conditions would be substantial.

Schedule

Each habitat type may have a different schedule, depending on the availability of existing methods and associated data. The project should begin with freshwater systems, on the following schedule:

- Year 1 – literature search on potential indicators and methods; evaluate and select candidate protocols; exploratory analyses on available data to assess stormwater effects (may be a pilot study in one or more test areas)
- Year 2 – prepare study design for additional data collection (e.g., quantify spatial and temporal patterns and variability); field test protocols and indicators; identify indicators' response signatures
- Year 3 – validate procedures and indicators; conduct peer review; report results; identify strengths, weaknesses, recommendations

Resources

Needed expertise includes bioassessment in freshwater systems, indicator and protocol development for biological assemblages, familiarity with methods used in other key programs, field sampling, data analysis, and data management. Expected costs are in the range of $400,000 per year for three years, of which $150,000 would be required for filling data gaps. Similar projects have been carried out at several places throughout the country, most notably in Ohio under the auspices of U. S. EPA. Potential partners are the California Department of Fish and Game, U. S. EPA's EMAP, California State Water Resources Control Board (SWAMP), and volunteer monitoring networks such as those supported by Heal the Bay and the Stream Team in San Diego.

Project 11. Develop improved toxicity testing procedures

Despite their wide use, significant limitations constrain the application and interpretation of existing toxicity tests. There remain unresolved questions about the choice of indicator organisms, the interpretation of test results, and the identification of sources of toxicity with TIEs. This project will address these problems by developing and field testing a set of improved toxicity testing and TIE protocols.

Problem statement

Toxicity tests are widely used to measure stormwater impacts directly, especially where information on individual chemical contaminants is inconclusive or incomplete. However, 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, current toxicity testing 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) would improve the assessment of stormwater impacts.

Desired outcome

This project 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, should be used to develop a toxicity reduction evaluation (TRE) program.

Tasks

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.

This project will utilize results of Project 6 (Determine Reference Conditions) and Project 7 (Stratify Beneficial Uses) to help define the range of conditions toxicity testing should address. Major tasks in this project will include:

- establish prioritized list of problems and issues with toxicity testing approaches currently used in southern California
- develop set of criteria for ideal toxicity tests, e.g., ability to define spatial extent of toxicity, measure spatial and temporal variability of toxicity in relation to hydrology
- evaluate existing toxicity testing protocols in relation to problems and issues
- define areas where further research and development are most needed
- design needed laboratory studies
- design and implement field case studies (see detail below) focused on key habitats
- improve and/or develop ancillary TIE procedures
- develop regional toxicity testing protocols based on field test results and incorporating EPA standards.

Field tests for improved methods could follow the following format:

1. Identify a receiving water of interest
2. Design case study
   - 2.1. consider temporal variability (intra- and inter-storm)
   - 2.2. consider spatial variability
3. Conduct toxicity tests along gradient of exposure
4. Assess results along gradient relative to predefined criteria
   - 4.1. Relative sensitivity (stormwater, ambient water, and reference toxicants)
   - 4.2. Control response / reference site response
   - 4.3. Correlations with contaminants
   - 4.4. Correlations with bioassessment metrics (macroinvertebrates, phytoplankton, fish)
   - 4.5. Correlations with chemical and physical factors, and possible confounding factors

    4.6. Use in TIEs
    4.7. Ecological relevance
5. Conduct dose-response experiments with key indigenous species identified in bioassessment
6. Conduct in-situ tests to assess ecological linkages, temporal variability in response signal, and response to simultaneous multiple stressors
7. Identify causes of toxicity.

This is a low to medium risk / high benefit project. The responses of different test organisms to the suite of stormwater contaminants are complex and it may be difficult to make clear-cut decisions about which test organisms are the most appropriate in different circumstances. Similarly, the chemistry of toxic compounds is also complex, complicating the development of enhanced TIE procedures. However, if these difficulties can be overcome, the ability to more precisely quantify the level of toxicity and to link it to one or more specific contaminants would substantially improve monitoring and source tracking efforts.

Schedule

This project could begin immediately and be completed in three to five years, assuming results from Projects 6 and 7 were available as needed. Tasks preparatory to the field studies would take six to 12 months. Tasks 1 – 3 in the field tests could be completed in the second year, tasks 4 and 7 in the third year, and tasks 5 – 7 in the fourth year. Writing a protocols and standards document would take up the fifth year.

Resources

Needed expertise includes toxicity specialists, chemists, field teams, specialized laboratories, and in-kind support from agencies for field collection. Expected costs would be $300,000 to $350,000 at a minimum and could be as high as $1 million, depending on the number of sites and test organisms, and on the number and complexity of toxicants of concern. Potential partners include regional stormwater and regulatory agencies, academic researchers, and SCCWRP.

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

The absence of a real-time ability to detect microbial contamination in receiving waters prevents managers in some cases from reliably closing recreational waters when they are contaminated, but also causes a loss in economic revenue when sites are not reopened for public use as quickly as possible. This project addresses this problem by developing improved indicators that would quickly (within two hours) provide reliable measures of the presence of pathogens of concern. This project could be coupled with Project 13 (Microbial Source Tracking Tools) to get rapid measures of indicators that are of human origin.

Problem statement

The rapid detection of fecal contamination in receiving waters would 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 would provide a speedier and more reliable link to human health risk and do a better job of identifying sewage sources.

Desired outcome

This project would develop a rapid pathogen screening tool that would provide a result within two hours of sampling and would be applicable in marine, brackish, and freshwater environments. This rapid detection method would 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.

Tasks

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.

The major tasks involved in this project include:

- establish criteria for ideal indicator(s)
- evaluate the full range of existing technologies
- identify directly applicable technologies (if any)
- define development and testing procedure for directly applicable technologies
- carry out further development on directly applicable technologies as needed
- define and conduct needed research if no directly applicable technologies exist
- evaluate new technologies in system(s) of interest, including receiving waters, sources
- refine methods, to improve measurement capabilities and definition of endpoints
- integrate with current epidemiology studies to evaluate how new methods relate to actual human health risk
- conduct further testing and validation
- develop protocols for routine use.

This is a high risk / high benefit project. There are no off-the-shelf technologies that are directly applicable to this problem and also ready for routine use. The direct detection of pathogens, as opposed to indirect indicators such as fecal coliforms, has proved difficult, and the two-hour goal is a challenging one. However, the ability to reliably and quickly measure the presence of pathogens of relevant to human health concerns would provide substantial economic benefits because it would dramatically improve managers' ability to target closures where they are actually needed.

Schedule

This project could begin immediately and would take five years to complete, as follows:

- Year 1 – identify and select methods to be evaluated
- Year 2 – evaluate methods with regard to rapidity, sensitivity, and specificity. If technology is not available, develop new methods that meet above requirements.
- Year 3 – refine evaluated methods to optimize their capabilities with regard to measuring appropriate analytes in water environments or continue development of new methods.
- Year 4 – use method to measure water quality during the conduct of an epidemiology study. Analyze epidemiology study data to determine how well water quality data relates to health data.
- Year 5 – verify that the method works under a broad range of conditions and develop QA/QC protocols for routine use.

Resources

Needed expertise includes bacteriologists and epidemiologists, as well as in-kind support from regional agencies for field sampling. Expected costs are in the range of $300,000 to $500,000, assuming that the project can collaborate with at least one epidemiology study planned in the region. Potential partners include SCCWRP, U. S. EPA, the California State Water Resources Control Board, county health departments, and the NPDES ocean dischargers who conduct beach monitoring.

Project 13. Develop microbial source tracking protocol

At present, it is not possible to accurately and quickly identify the sources of microbial contamination in stormwater. This prevents the timely application of source controls and results in costs due to closures and other impacts on receiving waters. This project will address this problem by developing standard protocols for tracking the specific sources of contamination in local watersheds. This Project could be linked Project 12 (Rapid Measurements) for optimal source tracking potential, particulalry for transient or intermittant sources.

Problem statement

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, current approaches to partitioning fecal sources are not successful due to the inability to reliably differentiate among the several possible sources of contamination. 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.

Desired outcome

This project would develop 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 should 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 would 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.

Tasks

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.

Major tasks in this project include:

- identify possible methods (e.g. ribotyping, Terminal Restriction Fragment Length Polymorphism, antibiotic resistance patterns, nutrition patterns, coliphage serotyping and genotyping, virus detection, Pulse field gel electrophoresis, Rep-PCR, Quantitative PCR)
- evaluate alternative methods in terms of applicability to southern California watersheds and the balance between statistical rigor, cost, and size of watershed

- develop a standardized protocol and relevant databases, with attention to the size of database necessary for statistical rigor and accurately classifying sources
- develop tracking strategy, assessing both top down (evaluate relative contribution of known sources) and bottom up (tracking upstream from a contaminated waterbody or end of a pipe) approaches for use in different situations, and defining the other types of data that should be collected (e.g., flow, pH, salinity, TSS, nutrients)
- test and validate methods both in the laboratory and in the field
- develop QA/QC protocols for routine use.

This is a medium risk / high benefit project. Even given the limitations described above, currently available techniques have been used successfully to identify and mitigate sources of fecal contamination. These methods will undoubtedly improve with time and the likelihood of success is high, given time and funding enough to develop needed databases. As long as the source tracking goal is a general differentiation between sources, for example, differentiating between human and animal fecal contamination, or livestock and dog fecal contamination, available methods provide a suitably high level of correct source classification. However, in a watershed with many confounding factors, and high variability in sources and stormwater inputs, a relatively quick and clear differentiation between sources may not be possible with genetic tracking alone. Despite this, the benefits heavily outweigh the risks because the method will be useful in the large majority of situations, thus greatly improving the efficiency of source tracking and mitigation efforts.

Schedule

This project could be accomplished in three to four years, depending upon the complexity and size of the pilot watersheds. The following milestones could be used to track progress:

- Milestone 1: Identify and evaluate methods. This can be accomplished in six months, given a group that is already familiar with microbial source tracking techniques. First, the available methods must be narrowed to those that are applicable to the system. Second, many small projects using some of these methods have already been undertaken in southern California, so methods that are in existing use should be actively identified and evaluated.
- Milestone 2: Once a method or set of methods is identified that will work for a given system or watershed, it will take approximately 6 months to 1 year to develop a suitable database of existing possible sources, collect scat samples with representative viral or bacterial populations, and design a tracking strategy suitable for the particular watershed of interest. Other important components of this will be to successfully GIS map the system, identify all tributaries and inputs, study hydrological characteristics, and create a conceptual model of the system.
- Milestone 3: Implement microbial source tracking strategy and sampling. This will take approximately 1 year. Microbial source tracking samples will be taken given the tracking strategy outlined, in addition characteristics of the water body of interest will be incorporated to better understand the entire system, namely nutrients, flow, TSS, temperature, pH, etc.
- Milestone 4: Statistical analysis, and data reporting, and data visualization will be followed by transfer of knowledge to parties responsible for decision making and future legislative action. This will take approximately 6 months to 1 year.

Resources

Needed expertise includes microbiologists, molecular biologists, hydrological engineers, statisticians, and data managers. Specialized equipment specific to microbial techniques will also be necessary. Some of the techniques available (e.g., antibiotic resistance) require less large equipment. However, any laboratory using these approaches will need to be outfitted with a laminar flow hood, centrifuges, filter apparatus, incubators, water baths, and other equipment. Other larger cost items that may be needed include hybridization ovens, quantitative PCR machines, gel electrophoresis equipment, power supplies, among others. Expected costs are in the range of $200,000 to $800,000 for pilot studies in one or two smaller watersheds with one or two dominant sources each. The wide range of costs reflects in part the differences among the methods that might be used. Similar projects have been conducted at several places throughout the country. Potential partners include SCCWRP, U. S. EPA, the California State Water Resources Control Board, county health departments, and the NPDES ocean dischargers who conduct beach monitoring.

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. This assumption has not been systematically and rigorously tested and the ongoing implementation of TMDLs is raising the level of risk associated with the attendant increased investment in BMPs. 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 receiving water conditions.

Problem statement

As Projects 9 – 13 (which focus on developing a variety of improved indicators) make clear, our current understanding of causal linkages between a variety of 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.

Desired outcome

This project will produce a method for determining whether and to what extent BMPs 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.

Tasks

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).

Because of the large variability in ambient conditions, and length of time needed to detect changes in these, this project should consider focusing on small pilot watersheds that can be more easily manipulated and monitored.

The major tasks involved in this project include:

- enhance the systemwide conceptual model to include specific BMPs and their links to potential receiving water improvements
- select and prioritize BMP / receiving water relationships to examine
- identify one or more pilot watersheds for study
- conduct numerical modeling of the cumulative effects of BMP network(s) to guide design of the field study
- design field study, based on BACI (before-after-control-impact) design if possible
- begin monitoring
- implement BMPs, if necessary
- complete monitoring.

This is a high risk / high reward project. It depends on the successful completion of a number of other research projects. In addition, such an evaluation of BMPs effects on ultimate receiving water conditions has not previously been carried out and there is therefore no prior body of experience to draw on. However, the potential benefits of this project are substantial. Large investments in BMPs have been made and even larger ones are being contemplated in order to meet the requirements of TMDLs. It is therefore crucially important to better understand whether BMPs will produce hoped-for improvements in receiving water conditions.

Schedule

The initial steps of this project through development of the field study design will take at least one year. Monitoring both before and after the implementation of specific BMPs could require an additional five to ten years, depending on the kinds of receiving water conditions targeted. In addition, results can be achieved more quickly for constituents with short residence times (e.g., diazinon, TSS) or that can be more readily controlled. Monitoring would have to continue for a longer period to detect changes related to constituents with reservoirs in the system (e.g., nutrients, metals, bioaccumulative compounds).

Resources

Needed expertise includes in-kind support from stormwater agencies for BMP implementation and field monitoring, as well as engineers, statisticians, hydrologists, scientists knowledgeable in the specific constituents and impacts of concern, data analysts, and data managers. The initial steps of this project through development of the field study design could require up to $1 million. Expected costs for monitoring are in the range of $250,000 - $500,000 per year for ten years. It is not possible at present to scope the BMP implementation and it would be prudent to link monitoring to implementation that is already planned. Potential partners include Caltrans, the State Water Resources Control Board, Water Environment Research Foundation, BMP manufacturers, and stormwater agencies throughout the region, particularly the agency in whose jurisdiction the study will be done.

Project 15. Develop improved indicators of peak flow impacts

Land use changes that increase impervious area lead to increased flows. While this increases the flood potential during major storms, it also increases flows during periods of low to moderate rainfall. These increased flows can cause downstream impacts on water quality and habitat through increased erosion and sedimentation. However, there are no well-established relationships between various levels of increased flow and downstream impacts. This project addresses this problem through an integrated modeling, experimental, and monitoring program in pilot watersheds.

Problem statement

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 would 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 is insufficient knowledge about peak flow impacts on which to base such criteria.

Desired outcome

This project would 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.

Tasks

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).

The major tasks involved in this project include:

- refine or expand the portion of the conceptual model dealing with peak flows
- analyze available data to build a picture of likely changes over time due to increased peak flows
- select pilot watersheds
- design field and modeling study to quantify changes in peak flows and relate these to impacts
- implement field study, including manipulative experiments involving, for example, controlled increases in flow
- develop recommendations for establishing management or regulatory criteria related to peak flows
- evaluate the potential contribution to flow mitigation associated with implementation of traditional BMPs (i.e. detention basins).

This is a medium to high risk / high benefit project. The highly variable nature of rainfall and flows in southern California makes it extremely difficult, in a short period of time, to develop reliable relationships between peak flows and downstream impacts. In addition, the lack of prior attention to this issue means that historical data are not likely to provide a useful database for establishing such relationships.

Schedule

This project could begin in concert with development of the conceptual model in Project 5 and could produce results within three years. Longer time periods that cover storms with lower return rates would benefit the project.

Resources

Needed expertise includes in-kind support from agencies with field monitoring staff, as well as hydrologists, engineers, and modelers. Expected costs for gaging stations, field manipulations, and monitoring range from $75,000 to $250,000 per year, depending on the number of sites and the complexity of field experiments. Modeling would require an additional $200,000. Potential partners include the State Water Resources Control Board, regional stormwater agencies, SCCWRP, the U. S. Army Corps of Engineers, and the U. S. Geological Survey.

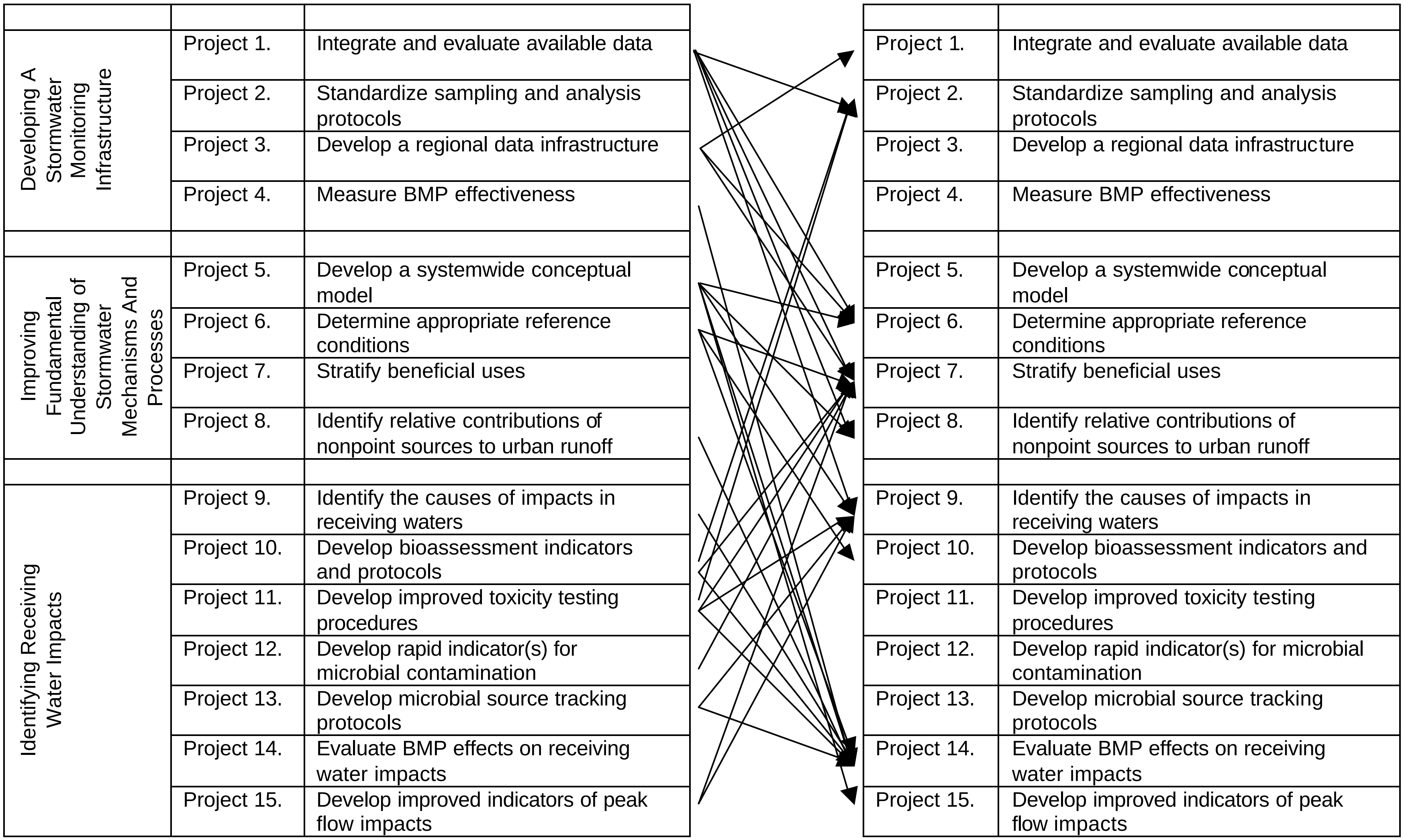
Research Plan Overview

The preceding sections describe 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, as the individual descriptions make clear, many of the projects are directly related, with some depending on the output of other projects for their success. The following figure illustrates the major groupings and relationships among the 15 projects. The projects on the left with several arrows emanating from them are projects that should be attempted first. These include integrating available data, creating a regional data infrastructure, developing a conceptual model, and developing or improving assessment tools for identifying receiving water impacts. Similarly, there are projects on the right with several arrows pointing towards them that should be left until the initial work is completed. These include stratifying beneficial uses, identifying causes of impacts, and evaluating the effect of BMPs on receiving water quality. Ultimately, the interconnectedness among projects demonstrates that the workshop panelists have devised not just a list of individual wish-list projects, but a comprehensive research program.

Second, they lay the necessary groundwork for a comprehensive and region-wide stormwater monitoring program that focuses on high-priority problems and takes advantage of opportunities for regional coordination. In this sense, the information and tools the research program produces will not only improve individual stormwater programs, but will improve all of the stormwater programs in the region. The research projects will identify where there is uneven levels of effort and help to bring parity to monitoring programs throughout southern California. They will enhance the efficiency of individual programs and regional programs by ensuring comparability and quality. Finally, the research projects 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 deciosn-making framework.

Figure 1. Relationship among the projects identified in the Southern California Stormwater Monitoring Consrtioum research agenda.



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APPENDIX 1.
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APPENDIX 2.
White Paper

ISSUE PAPER:

Stormwater Research Needs In Southern California

Brock Bernstein and Kenneth Schiff

September 10, 2001

Introduction

Why stormwater research is important

Watersheds in southern California are among the most modified systems in the world (Brownlie and Taylor 1981). This reflects the intense urbanization of much of the region and the fact that stormwater conveyance systems have been built primarily to reduce flooding during the large, but infrequent storm events. Hence, most storm drain systems in southern California are effective and efficient conveyances where flows can increase from less than 5 cfs to more than 20,000 cfs in less than an hour (Tiefenthaler et al. 2001). The engineering involved is truly a marvel, considering that hundreds of people routinely drowned during large wet weather events prior to construction of the storm sewer infrastructure, whereas drownings are rare in recent times.

Although the storm sewer infrastructure has succeeded at protecting against floods, it was not designed and built with water quality issues in mind. In fact, wet weather discharges are separate from sanitary sewers and little or no treatment occurs prior to discharge into rivers, lakes, bays, or the ocean. Water quality issues are compounded by the high degree of urbanization of watersheds in southern California. More than 17 million people inhabit the six coastal counties of southern California making it among the most densely populated coastal region in the country (Culliton et al. 1990). Cumulatively, southern California coastal watershed areas exceed 5,600 sq miles with more than 45% of this watershed area developed; at least 1,300 sq miles are residential land uses. The large degree of urbanization, coupled with infrequent rainfall that enables build-up of non-point sources of pollutants, results in sporadic but tremendous loads to receiving waters. 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 point sources (Schiff et al. 2001). Based upon the increasing population of southern California and the lack of storm water quality infrastructure, it is likely that stormwater loads will continue to increase.

There is some evidence that stormwater discharges impact receiving water quality. For example, regional monitoring of southern California beaches has shown that shorelines which receive dry weather flows are 10 times more likely to exceed water contact standards than those that are distant from storm drains (Noble et al. 2000). Moreover, more than 60% of the shoreline exceeds water contact standards following wet weather events. This has led to the permanent posting of warning signs near drain outlets and blanket warnings against body contact recreation at any beach for 72 hr following rain events. In addition, large loadings of nutrients have been measured from urban creeks and these have ultimately contributed to the over-enrichment of estuaries at the mouths of urban watersheds, as indicated in part by large blooms of macroalgae. As another example, storm drain discharges have been shown to be toxic to marine and freshwater organisms and this toxicity persists over large areas as discharge plumes spread through coastal receiving waters. After these plumes settle to the bottom of the ocean, the pollutants have been measured in nearshore sediments. Where these sediments must be dredged to maintain navigable harbors or marinas, the associated contamination increases the cost of dredging by orders of magnitude.

Important uncertainties exist

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 knowledge on which to base sound management decisions. For example, knowledge about wet weather plume dynamics is insufficient to enable managers to identify where impacts on beneficial uses are most likely. Moreover, water quality impacts from specific constituents of concern are in most cases not well enough characterized to permit their identification, targeting, and reduction. Similarly, we are often unable to differentiate between natural (e.g., storms) and anthropogenic (e.g., contamination, flow modification) impacts on biological communities.

In parallel with the relatively poor level of scientific understanding of stormwater impacts, there is a lack of technical knowledge on how best to control stormwater discharges. Technical data gaps include source identification in urban watersheds where many small, diffuse sources may commingle. Further, assessments of the most effective and efficient treatment or management strategies for resolving stormwater impairments are typically absent or not well validated. For example, there is a lack of substantive and long-term data about how well BMPs work, which ones work best under a range of conditions, or which BMPs are most appropriate in specific applications.

Finally, available stormwater management tools are typically inadequate to deal with existing needs for proper stewardship and decision making. The tools that do exist are often inadequate because they are either not specific enough (i.e., are based on inappropriate point source analogs) or have not been developed or tested in southern California. For example, the existing watershed models in southern California are screening level tools that examine processes on long-term (i.e., annual) scales, even though many of the regulatory requirements such as Standard Urban Stormwater Mitigation Plans (SUSMPs), are focused on changes from within-storm processes. Of those existing models that can deal with complex within-storm dynamics, they have been designed, built, and tested on the east coast of the United States where rivers and creeks behave much differently than they do in southern California.

Despite such information gaps, management actions (from both the regulated and regulator communities) 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.

By increasing the base of scientific knowledge, stormwater managers can improve the accuracy and relevance of environmental impact assessments, ensure that efforts focus on resolving critical issues, and enhance the effectiveness and efficiency of management decision making and implementation. The goal of this paper is to outline the major knowledge gaps, describe specific issues within each, and identify roadblocks that have, thus far, hindered progress on resolving them.

Research Themes

Challenges facing stormwater monitoring and management can be grouped into four major issue areas or themes. While these are universally important across the country, the semi-arid nature of southern California's environment poses particular difficulties, in part because approaches developed elsewhere are less applicable here. In addition, the continued influence of concepts borrowed from traditional point source management programs can hinder the development of approaches that are more appropriate to the more diffuse, episodic, and highly variable nature of stormwater sources, flows, and impacts in southern California. The following sections describe each theme in general terms, provide background material and illustrative examples, discuss current roadblocks to progress, and outline a set of unresolved questions and issues. These latter are meant to be a starting point for discussion and have not been prioritized in any way. We fully expect the workgroup to add or reword some items, delete others, and prioritize them according to different criteria (e.g., feasibility, potential cost, importance to basic understanding).

Monitoring approaches

Introduction

Well thought out monitoring approaches[1] are fundamental to the success of any monitoring program and one essential ingredient for such success is the close integration of management questions and data

[1] By "monitoring approaches" we mean the functional combination of basic management questions and/or objectives with the overall data gathering and analysis methods used to address them.

gathering methods. This link is essential because data gathered to address one particular objective or question cannot always be used to address others. For example, data gathered on a flow weighted basis to estimate loads are not suitable for determining whether, on the average over time, concentrations of a particular contaminant are above a compliance threshold. Similarly, data gathered to determine if compliance objectives are being met are not often suitable for assessing whether stormwater-related ecosystem impacts are occurring.

Management objectives and questions can also be framed on two important scales – regional and local.[2] Regional issues typically involve questions of larger-scale spatial patterns and longer-term trends, comparison among a variety of locales, and what the appropriate background or reference conditions should be for assessing more localized questions. Monitoring on local scales typically involves questions about compliance, trends at specific sites where impacts have occurred or are likely to occur, and the performance of BMPs. While distinct in many ways, objectives and questions on these two scales are clearly interdependent in that both fundamentally focus on determining if conditions have improved or not and the role that management actions have played in such changes. Monitoring at both scales should therefore be considered in relation to each other. Despite this, the challenges inherent in monitoring design are different at these two scales. Both necessarily involve technical issues such as field sampling techniques and laboratory analysis methods. However, program design at the regional scale is dominated to a much greater degree by the organizational issues involved in coordinating and standardizing efforts across a number of agencies and programs.

As the following Background section makes clear, the time is ripe for reconsidering the basic management questions and objectives that motivate stormwater monitoring and for assessing whether the monitoring approaches that have been used in the past must be revised to accommodate updated questions and objectives.

Background

In Southern California, stormwater monitoring has been dominated by two major questions and one subsidiary question. The major questions are: 1) what are the loads of key contaminants conveyed by channels, creeks, and rivers? and 2) Are levels of key contaminants in channels, creeks, and rivers above established compliance thresholds? The subsidiary question is: What are the sources of elevated levels of key contaminants? Most municipal programs employ either a land use design, a mass emissions design, or a combination of both to characterize loads, coupled in some cases with a network of instream stations to test for compliance. The relative emphasis given to source identification, and the methods used, vary from program to program.

This set of monitoring approaches has provided important information about the characteristics of stormwater flows. However, in the current management environment, it is limited in several ways. First, it does not reflect the knowledge gained from past monitoring and research. Information about patterns of contamination, trends in loads and levels, and sources have not been systematically integrated into either management questions and objectives or into study designs. The same is true of findings from recent research into improving sampling and analysis methods. In short, most monitoring programs are not flexible enough to adapt and mature as new information is gathered, old management questions are answered, or new management questions are asked. Second, current monitoring approaches do not adequately address new regulatory and management initiatives such as TMDLs and BMPs. These embody new questions and objectives, along with their attendant new data requirements. Third, the wide variability in monitoring approaches across stormwater programs inhibits comparison of findings across programs. It also prevents leveraging available resources by combining similar data from different programs and/or developing cooperative approaches in which different programs focus on different issues. Fourth, and in a related vein, the lack of regional standardization prevents addressing issues on regional scales, where this is appropriate. Recent experience in the marine environment with the Southern California Bight Regional

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[2] In addition to straightforward management questions about trends and patterns of change on local and regional scales, more open-ended questions about basic processes, and the special studies designed to answer them, can cut across both scales.

Monitoring Program demonstrates how regional standardization of monitoring protocols has significantly increased the level of quality assurance in the region and has enabled rigorous evaluation of monitoring groups, including volunteer monitoring. The lack of such standardization in stormwater monitoring reflects the fact that, fifth, current approaches do not support analyzing data on scales not specifically defined by NPDES permits (e.g., over multiple jurisdictions or regionwide). Sixth, and finally, current approaches do not incorporate a well-developed feedback loop that evaluates their effectiveness and efficiency on a range of management and technical criteria. As a result of these factors, the stormwater monitoring efforts that are currently under way are disconnected from each other, not always targeted at the highest priority management issues, and less than optimally efficient.

Thus, the experience and knowledge gained over the last two decades, combined with evolving management priorities, provide an opportunity to rethink both the basic management questions driving stormwater monitoring, as well as the sampling and analysis methods used to address these. It is time to redefine what we need to know to make decisions.

Roadblocks

Methods, both technical and procedural, for designing and optimizing monitoring programs are well developed. There are reliable processes for eliciting management objectives and linking them to decision criteria and similarly reliable methods for crafting the specifics of monitoring designs. Thus, the roadblocks to updating and improving stormwater monitoring approaches are primarily institutional. These include "selling" the value to decision makers of improved and regionally standardized monitoring approaches, obtaining agreement across a range of agencies, stakeholders, and legislators and garnering the commitment of time and resources needed to identify and then implement improvements.

While these roadblocks are quite real, there are nevertheless good reasons to believe they can readily be surmounted. Regulatory and management agencies are well aware of the fact that new management priorities demand new monitoring approaches, as evidenced by the creation of this cooperative regional research initiative. In addition, the success in the marine environment of the Southern California Bight Monitoring Program, which includes many of the regulatory agencies represented here, provides a ready model for how to overcome the roadblocks described above.

Issues and questions

There are several issues and/or questions the panel should consider, including:

- What are the explicit and implicit objectives embodied in current stormwater management and monitoring programs?
- Are these appropriate to current goals and mandates?
- Should existing objectives be modified and, if so, how?
- What are the most effective and efficient monitoring designs for addressing these modified objectives?
- What mix of regional and localized monitoring would be most appropriate?
- How can field, laboratory, and data analysis approaches be standardized?
- Are there management questions and/or objectives that cannot be realistically addressed through monitoring?
- What management decisions are going to occur once monitoring results are gathered?
- Is there sufficient flexibility in the new monitoring design to accommodate adaptations to new monitoring questions?
- What are examples of monitoring approaches that have been successful, here and abroad?
- How can the use of volunteers/students be incorporated into a regional monitoring plan, and what problems have others run into?
- What issues/criteria should be considered in prioritizing waterbodies to be monitored?
- How do we evolve monitoring programs without losing consistency and comparability with historical data?
- How should a pollutant of concern be defined?
- Are there pertinent national data sets that can/should be used for comparing local monitoring results?

- What are the appropriate factors that need to be considered to achieve regional treatment/reduction solutions?
- Is pollutant trading a feasible concept for stormwater discharges and, if so, what is the appropriate monitoring design for such a program?
- What is the best design for a source tracking program?

System mechanisms and processes

Introduction

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 these cause physical, chemical, and biological impacts in receiving waters. However, as the following paragraphs demonstrate, the details of the mechanisms and processes that control each step in this causal chain are poorly understood. As a result, 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, that is, where to intervene to improve conditions and how to determine if such interventions are working as intended. This requires enough knowledge about how 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.

The issues discussed in the following paragraphs provide much of the foundation for the discussion in the subsequent three sections (Monitoring Approaches, Management Tools, and Indicators).

Background

Shortcomings in our understanding of fundamental mechanisms and processes stem largely from poorly developed and/or inappropriate conceptual models. These in turn affect our ability to describe loading processes and predict loads on the one hand, and, on the other, to understand which contaminants cause impacts and how they do so.

Currently used conceptual models are adequate for describing the hydrology of the stormwater conveyance system. However, there are no linked receiving water models that adequately include the ocean. Instead, these models generally represent receiving waters as a large river or lake, water bodies that behave quite differently from the nearshore marine environment. This is an important issue in southern California because most development is near the coast, watersheds are steep and short relative to east coast rivers, and the nearshore marine environment is the ultimate receiving water for stormwater flows. Thus, it is crucial to understand how stormwater flows enter and disperse in the ocean because many issues of concern are not confined only to inland water bodies, but relate to impacts along the coast. However, there have been no systematic studies of the dynamics of stormwater plumes in the marine environment, although a recent study has demonstrated that toxicity related to such plumes can extend for some distance along the coast. There is a similarly poor linkage with regards to sediment dynamics, with watershed sediment budgets not at all well integrated with modeling and measurement of sediment transport and budgets along the coast. Because sediment flows are critical for maintaining sandy beaches in many areas, this issue is becoming increasingly important to the coastal economy.

Conceptual models of biological processes also have serious knowledge gaps. These are discussed at more length in the Indicators section below with regards to assessing the health of habitats and ecological communities. However, it is worth mentioning an additional example that involves both physical/chemical and biological processes. In enclosed water bodies like Newport Bay, it seems apparent that increased nutrient loads result in macroalgal blooms. However, beyond this broad generalization, the details are unclear. For example, the role of sediments in storing and/or processing nutrients is unknown, as are the specifics of nutrient uptake and storage in the algae themselves. As a result, it is not possible to make accurate predictions about how macroalgae will respond to a specified reduction in nutrients, whether time lags, thresholds, or step changes will be involved, and whether and how the response depends on other factors such as season, water chemistry, and so on.

Historically, stormwater monitoring and management in southern California has focused a great deal of attention on loads. As a result, we know that loads can be large, but this information alone does not provide a firm basis for designing and implementing effective strategies to reduce loads. The inherent variability in the system, where the large majority of the loads can be transported in a small percentage of the yearly flow, is frustrating. Despite the assumption of a "first flush" in which accumulated contaminants are washed off of urban surfaces in the early stages of a storm (or rainy season), there is inconsistent and contradictory evidence about this mechanism. The ways in which surface characteristics, the type of contaminant, storm frequency and intensity, and other factors affect contaminant build up and washoff are virtually unknown. There have been some initial attempts to use simulated rainfall in an experimental setting to begin teasing apart basic processes, but these efforts have not yet produced any fundamental insights.

In parallel with the emphasis on loads, stormwater programs in southern California have focused on the concentrations of key contaminants. As described in more detail in the Indicators section, it is not always clear that currently used regulatory thresholds are related to actual impairments of aquatic life and/or human health. Nor do we always understand (as the Indicators section also summarizes) which chemical species are responsible for impacts. Current monitoring designs focus relatively little attention on speciation issues and the situation in southern California is complicated because the speciation of many constituents changes drastically when stormwater enters the marine environment. The ways in which saltwater changes ionic balances, and the effects of such changes on bioavailablilty and toxicity, are poorly understood. Thus, the fine-scale chemistry of contaminants of concern is vitally important to our ability to predict and measure impacts, assess ecological risks, and develop effective management strategies.

In general, stormwater monitoring and management in southern California has emphasized routine, repeated measurements but has not balanced this with special studies designed to improve the understanding of key mechanisms and processes. Hydrological and biological models developed for other regions have provided a useful starting point but do not capture key aspects of the semi-arid, near coastal environment in southern California. In addition, the underlying point source analogy adopted from the management of wastewater outfalls has outlived its usefulness. Stormwater systems are not simply pipes delivering water from one point to another, nor are their behavior as stable and predictable as that of engineered wastewater systems. New conceptual models are needed, ones that address the dynamics of build up and wash off, transport and transformation in the network of channels and rivers, physical impacts on the conveyance system itself due to increased flows and sedimentation, and the behavior of stormwater plumes in the nearshore marine environment.

Roadblocks

There are both technical and institutional roadblocks to improving our ability to predict and measure the flow of contaminants through the stormwater system and their consequent impacts along the way.

On the technical side, these issues are exceptionally complex and demand the integration of several different scientific fields. In addition, the southern California environment is a difficult one to work in. There are often only a few storms a year and the bulk of the flow and contaminant transport can occur in a very short period of time. As a result, it may take several years for a local agency to replicate studies and test a series of hypotheses. One important benefit of the regional research program will be its ability to speed progress by simultaneously replicating measurements or studies in a range of conditions across the entire region.

On the institutional side, an important roadblock to date is that no permits have contained numeric criteria that can drive an improved understanding of basic processes. In fact, what few numeric criteria that exist are often questioned as to their relevance and ability to protect the environment. While more thorough understandings are beginning to happen now as a result of TMDL implementation, managers and scientists in many cases have only a small amount of basic process knowledge to start from.

One roadblock that incorporates both technical and institutional aspects is that channels and streams are used for many purposes in addition to flood control, such as groundwater recharge, passive recreation, and conduits for discharge of upstream POTWs and industrial facilities. There is virtually no understanding of how these various activities affect waterbodies as integrated wholes. Nor has there been any examination of the potential trade offs among flow rate and volume, flood protection, recreational uses, temperature, beach replenishment, dredging, stream morphology, erosion control, pollutant flushing, and assimilative capacity. It will be crucial to move beyond the old, simplified conceptual model of the stormwater system as a set of pipes delivering runoff to a receiving water in order to predict and manage stormwater's impacts on these and other beneficial uses.

Issues and questions

There are several issues and/or questions the panel should consider, including:

- What are the mechanisms that control build up and wash off of stormwater constituents from urban and non-urban surfaces?
- How are sediments and contaminants transported downstream in southern California's highly modified watersheds and channels?
- What are the physical and chemical processes that control speciation at different points along the way from surfaces to the nearshore marine environment?
- What are the primary mechanisms that control mixing, dilution, and dispersion of runoff plumes in receiving waters?
- What are the primary mechanisms that control transport, settling, and incorporation of stormwater particles into sediments, in both inland waters and the nearshore marine environment?
- What sorts of conceptual models would better capture the range of mechanisms and processes at play in the stormwater system?
- Is first flush an important water quality problem and, if so, where and when should this problem be addressed?
- What is the connection between stormwater loads and sediment contamination?

Other issues and questions related to mechanisms and processes are listed in the subsequent sections, particularly those dealing with indicators and management tools.

Efficiency and effectiveness of management tools

Introduction

There is no argument that stormwater management and monitoring approaches must be based on reliable scientific and technical understanding. However, the current lack of detailed and substantive data, models, and other tools hampers the development of such approaches. It is therefore difficult to assess what will work, how well it work, and how long it will take to work. This reflects the facts, mentioned above, that attention to stormwater is relatively recent and initial approaches were based on analogies to point sources that have outlived their usefulness.

Background

There are three main areas in which the development of improved tools would pay significant dividends. These include models, the systematic evaluation of BMP effectiveness, and the use of information technology.

As the preceding section on mechanisms and processes made clear, our understanding of basic processes at work in the stormwater system is not well developed. This is reflected particularly in the types of models that are used to estimate the loadings, transport, and fate of contaminants. The most commonly used modeling approach in this region is what hydrologists call the “rational method.” This approach begins with the amount of rainfall and the percentage of land area in different land use types. A runoff coefficient is calculated for each type of land use, as well as a concentration of each contaminant typical of the runoff from each land use. Loadings are then calculated by simply multiplying the runoff volume from each land use by the applicable concentration of each contaminant. These calculations can be performed in a spreadsheet and such models can be used to estimate, on an average basis, the effects of reducing either the runoff amount or the contaminant concentration, or both, for specific land use types. Efforts to validate such models for southern California show that they provide usable results for yearly loading totals and for averages over long time periods.

These static models have been helpful in demonstrating that stormwater loads are large enough to be of concern. However, because of their inherent simplifying assumptions, they are not suited to current management questions about the effectiveness of specific management strategies over shorter time frames. For example, assuming that everything in the watershed is transported to the receiving water with equal efficiency, as the static models do, does not permit investigation of the tradeoffs from implementing different spatial patterns of BMPs. Answering these and similar questions requires predictive models that produce accurate results on a storm by storm, or even within storm, basis, and with a higher degree of spatial resolution. As another example, the Los Angeles Regional Water Quality Control Board has recently enacted stormwater regulation that requires all new construction to retain the first ¾ inch of rain on site. Questions about whether this is sufficient, whether it should be extended other areas, and what kinds of water quality improvements are likely to result, require dynamic water quality models able to handle shorter time frames and finer spatial resolution. Unlike currently used models, such models should incorporate terms for the transport efficiency, transformation, and/or degradation of key contaminants. Models with these features exist and have been used in other situations but have not yet been adapted to southern California’s semi-arid environment and effluent-dominated waterways.

Best management practices (BMPs) have been, and still are being applied without regard to whether the change in stormwater quality will have any meaningful impact on beneficial use protection. There is a pressing need for systematic, neutral evaluation of BMPs because the ongoing implementation of TMDLs for stormwater contaminants is raising both the regulatory and economic stakes involved in reducing loads and their impacts. For example, costs for typical BMPs can exceed $100,000 per acre and some estimates of region-wide implementation of BMPs for stormwater that include a treatment process or involve extensive acreage for settling basins run into the billions of dollars. The most commonly used BMPs to date are storm drain filters, which have proven to be ineffective, particularly when they are not maintained. Another BMP that is receiving more attention, especially along the coast where health risk to beachgoers is an important concern, is the diversion of stormwater flows to a sanitary treatment plant. This is expensive on an ongoing basis and does not help during with high-volume flows during wet weather. In addition, because many existing treatment plants are already at capacity, this BMP would require construction of new plants. Other BMPs that focus on large particles and debris, do not typically retain or reduce small particles or dissolved fractions, although contaminants are most often associated with these fractions.

A final area in which improved tools would pay important dividends is information management. Many satellite, computer, Internet, and GIS tools are becoming widely available and could enhance conventional monitoring and data distribution practices. Currently, southern California stormwater agencies do not share a common information management system. This limits data integration and compromises their ability to achieve economies of scale by comparing among programs or among watersheds. For example, coordinated BMP assessment across a wider range of sites could improve understanding of how well they work under a variety of conditions. Similarly, combining data from numerous land use sites could significantly increase the accuracy of mass loading models. Information technologies could further enhance monitoring effectiveness by capturing images previously unavailable (e.g., with remote sensing), providing an improved mechanism to present monitoring results in an easily understandable format (e.g., GIS maps), and making these products available to a wide audience (e.g., via the Internet). Where this has been accomplished elsewhere (e.g., the Santa Monica Bay Restoration Project’s data exchange standards for surf zone bacteriological monitoring), it has greatly increased the utility of monitoring information for both managers and the public.

Finally, broader standardization of sampling, analysis, and data presentation methods will greatly improve the ability to achieve valuable economies of scale among southern California stormwater agencies. This will enable participating agencies, as appropriate, to move away from the isolated approach in which each agency is responsible for improving understanding of the full range of issues and impacts.

Roadblocks

Roadblocks to developing improved tools are both technical and institutional. Dynamic water quality models depend on data collected either continuously or at very frequent intervals. Such data exist in southern California for flow but not for contaminants. Gathering such data, as opposed to the data needed to calculate only event mean concentrations, is expensive, perhaps an order of magnitude greater than present efforts. While some managers may not yet be convinced that such detailed data are necessary, TMDL implementation and the cost of BMPs needed to meet TMDL targets are forcing the issue. As is usually the case with the introduction of new methods, another institutional roadblock will be the resistance of managers and technical staff to using a new class of models and to dealing with the sometimes steep learning curve involved.

One roadblock to the more systematic evaluation of BMPs is that permits currently say only that contaminants must be reduced to maximum extent practicable; they do not contain numeric targets or criteria. As a result, there is no ongoing pressure to rigorously evaluate BMP performance. However, TMDL targets will force this issue as well. Even with that pressure, however, the cost of evaluating a broad range of BMPs would be prohibitive for individual agencies. A cooperative regional effort is needed to accomplish this. Any evaluation will have to deal with the difficulty of getting adequate replication, problems of cost and the scale of field tests, the wide variance in the amount of runoff and flow rates/volumes, the absence of standardized evaluation approaches, poorly developed expectations or criteria about what good performance means, and the shallow basis of experience about requirements and costs related to long-term maintenance of BMPs.

Despite the abstract benefits of a more integrated information management infrastructure, there has been little past incentive for such integration. Permittees are generally regulated as individual entities and regulatory agencies generally operate independently of each other. Existing information management systems represent an expended investment and their owners are unwilling to change these absent a strong motivation to do so, with clear benefits. In addition, there are high up-front costs involved in the data management efforts and the interaction needed to develop useful standardization. At present, there are no clear champions within the system for data integration and the development of new analysis and presentation tools. Another roadblock is that the technology involved has not yet reached the point where off-the-shelf solutions to the stormwater data integration problem are readily available.

Issues and questions

There are several issues and/or questions the panel should consider, including:

- What kinds of dynamic modeling approaches are most appropriate for the conditions in arid southern California?
- How do these relate to the modeling approaches already in use in the region or in other parts of the country?
- What steps are necessary to properly validate the model, particularly to the point where regulatory and stormwater agencies are comfortable using them?
- What would be involved in applying improved models to stormwater issues in southern California?
- What is already known about which BMPs are most effective at reducing loads and concentrations for specific constituents?
- What is already known about the relative costs and benefits of alternative BMP approaches within given watersheds (i.e., most improvement at most reasonable cost)?
- Taking into account impacts due to non-stormwater inputs, will expenditures on stormwater BMPs, and the consequent improvements due to these, promote beneficial use protection?

- What are the potential benefits from the more widespread use of data integration and data presentation/dissemination tools?
- What specific management needs might drive the development and acceptance of such tools?
- What kinds of applications for data tools would help meet these needs?
- What alternative development scenarios might be considered if the tool were developed?
- What are the pitfalls involved in these scenarios?
- What is involved in developing the cost/benefit data needed to evaluate tradeoffs among approaches for protecting the full range of beneficial uses?
- What sorts of concepts and/or tools would be needed to evaluate tradeoffs among attempts to address the full range of beneficial uses, including the management of flow rate and volume, flood protection, recreational uses, temperature, beach replenishment, dredging, stream morphology, erosion control, pollutant flushing, and assimilative capacity?
- How can GIS or other information technology be used to integrate water quality, potential effects, and stormwater management? Which GIS layers would be required?
- How can we use and apply existing monitoring programs and local data to assist in source control?
- Can new source tracking tools be developed to find problem areas within the watershed?

Indicators

Introduction

Indicators are the nuts and bolts of any monitoring program. They connect basic scientific understanding of how the monitored system works, and how impacts occur, with the management decision-making process. Indicators must therefore measure important causal processes or ecosystem conditions and, at the same time, be meaningful enough to provide a basis for management action. To be credible, indicators must also reflect current scientific understanding; they must be updated and adapted as science improves and management questions evolve. At present, increasing knowledge and evolving management information needs are highlighting the need for improved, and in some cases new, indicators. Across the board, there is a need for careful reexamination of previously accepted endpoints and standards and development of new ones.

Background

Indicators used in stormwater programs to date have primarily focused on basic measures such as levels of chemical contaminants and the magnitude of overall loads. These reflect the core motivating questions stated above in the Approaches section: 1) What are the loads of key contaminants conveyed by channels, creeks, and rivers? 2) Are levels of key contaminants in channels, creeks, and rivers above established compliance thresholds? and 3) What are the sources of elevated levels of key contaminants? However, these indicators do not directly measure impacts. They are at or near the beginning of the causal chain in any conceptual model of how stormwater contamination causes impacts on the receiving water and beneficial uses. Thus, levels and loads of key contaminants are of concern, not in and of themselves, but because they may cause impacts such as toxicity on biota, impair drinking water quality, or damage aesthetic values.

As knowledge of the chemistry of contaminants in stormwater has improved, it has become clear that some metals and/or forms of metals commonly used as indicators may not be toxic or may be toxic only under certain circumstances. A source of added complexity is the fact that the behavior of some contaminants is affected by the chemistry of stormwater itself. For example, in terms of concentration, the percentage of total copper found in the dissolved fraction changes in response to changes in hardness through the course of a storm. With respect to contaminant loads, their calculation is simple in concept (i.e., load = concentration x volume) but in problematic in practice. Relationships between land use type and runoff characteristics are extremely variable, calling into question loading estimates based on supposedly representative land use stations. In addition, runoff coefficients can change dramatically over time, even within the same watershed. These and other complications have hampered efforts to develop management approaches based on precise estimates and/or projections of the loads of specific contaminants.

As a result of such issues, toxicity tests are widely used to measure impacts more directly. *Ceriodaphnia* (freshwater zooplankton), fathead minnow, and *Selenastrum* (algae) are commonly used in freshwater and mysids (marine zooplankton) and the sea urchin fertilization test in the marine environment. The 10-day amphipod survival test is used for evaluating marine sediment toxicity. However, there are unresolved issues with the application of this apparently straightforward concept. Inappropriate organisms are sometimes used and there are often inconsistent results across test organisms. No one organism is sensitive to all aquatic toxicants, requiring careful interpretation of test results. For example, for *Ceriodaphnia* the LC_{50} for diazinon is 450 ng/L and for fathead minnow it is 6,600,000 ng/L. Although mysids are very sensitive to chlorpyrifos (LC_{50} = 35 ng/L) they are not sensitive to diazinon (LC_{50} = 4500 ng/L) at the concentrations normally found in urban stormwater runoff. *Ceriodaphnia* on the other hand are sensitive to both diazinon and chlorpyrifos (LC_{50} = 80 ng/L). In addition, there are questions regarding the precision and accuracy of some of these tests and the comprehensiveness of toxicity evaluation (TIE) with respect to all constituents of concern.

More important than these technical issues, in some instances, is the fact that a focus on contamination and its direct effects can miss other significant sources of impact. There are many examples of streams with adequate or excellent water quality but 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 U.S. EPA, the U.S. Forest Service, and the California Department of Fish and Game, among others, provide a means of measuring the status of biological conditions, independent of a focus on chemical contamination. Such bioassessment methods can 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 to physical, chemical, and biological indicators of condition, concerns about human health have focused primarily on coliform indicators as a measure of potential health risk from body contact recreation. Coliforms are natural residents in the guts of warm blooded animals and it has been assumed that elevated counts of these indicators demonstrate the presence of animal and/or human waste products and thus the possible presence of pathogens. While the validity of this assumption has been questioned, current knowledge is insufficient to improve the situation. One of the advantages of the currently used indicators is that they are the basis for bathing water standards. Because sampling and analysis procedures are straightforward and results can be obtained fairly quickly (compared to the time required to measure pathogens themselves), these indicators enable managers to quickly assess whether or not sample results are within compliance limits. However, their major disadvantage is that the relationship between their presence in stormwater and illness in humans in unclear. Ideally, improved indicators would provide a more reliable link to human health risk and do a better job of identifying sewage sources (see Management Tools section above).

Finally, new contaminants periodically become identified as actual or potential problems. At present, there are no widely accepted protocols to screen for new contaminants of concern.

Roadblocks

Research needs for the issues identified above have been discussed for some time and research and/or development programs are in some cases well developed. However, there are three key roadblocks that are relevant to southern California that may impair local agencies' ability to apply the results of such research. The first is the lack of focused research that directly takes into account the hydrological regime in southern California, where the bulk of loading, toxicity, and/or habitat damage may occur in brief pulses that represent only a short portion of the rainfall year. The second is the absence of accepted approaches for applying thresholds and/or numeric criteria to a situation with such high temporal variability and inherent difficulty in quantifying basic parameters. As a result, indicators, and the ways they are measured and presented, are not directly linked to beneficial uses that people care about and can easily relate to. The third is a lingering use of inappropriate point source analogies to explain underlying mechanisms and processes (see System Mechanisms and Processes section above).

Issues and questions

There are several issues and/or questions the panel should consider, including:

- How to best accurately measure contaminant loadings to receiving waters
- What speciation forms of heavy metals cause toxicity in receiving waters
- What is the relationship of the aquatic toxicity of different speciation forms of heavy metals to water quality thresholds?
- How appropriate are current water quality thresholds?
- What are the best analytical procedures for quantifying the concentrations of toxic forms of metals?
- What are the best analytical procedures for measuring the complexing agents that may reduce heavy metal toxicities?
- What toxicity test organisms are most appropriate for each contaminant of concern?
- What toxicity test organisms best represent native fauna in the receiving waters?
- What TIE approaches are most appropriate for stormwater?
- Can these be improved and, if so, how?
- Are bioassessment methods under development by U.S. EPA and the State Water Resources Control Board applicable to inland water bodies in southern California?
- What is the best approach for applying bioassessment in southern California?
- Can biocriteria be developed for southern California streams?
- What are the issues involved in directly measuring human pathogens in stormwater?
- Are there methods for improving the efficiency and accuracy of existing pathogen indicators?
- Are there reliable indicators of sewage contamination in stormwater runoff?
- What are the issues involved in assessing actual health risks from body contact recreation?
- What thresholds are relevant and useful for contaminants of concern and for biological indicators?
- Are numeric criteria appropriate for all contaminants of concern and for biological indicators?
- Are thresholds and numeric criteria appropriate for other sources of impact (e.g., flow, erosion)?
- Are there cheaper surrogates of stormwater pollutants that can be measured more frequently to assess loads and concentrations?

The Time Is Now

There is a challenge before us to fill the data gaps and improve our ability to regulate and manage stormwater impacts and reductions. The hurdles we face, as described in the previous sections, are both technical and institutional. However, these roadblocks must be overcome before managers can confidently move forward knowing that their actions will be effective at resolving the difficult and complex problems stormwater managers now face.

Although the challenge is large, the time has never been better to seize an opportunity to move forward in such a constructive manner. The Regional Stormwater Workgroup is supported by both regulated and regulators. This collaboration enables us to deal with issues at local and regional spatial scales, as well as short- and long-term temporal scales. Finally, the cooperative interaction can influence the regulatory framework so that monitoring programs can be an effective feedback mechanism for ensuring responsible environmental stewardship.

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APPENDIX 3.
Agenda of the Stormwater Research Agenda Workshop

Stormwater Research Agenda Workshop

Sponsored by the

Stormwater Monitoring Coalition of Southern California

October 15 – 17, 2001
Costa Mesa Hilton

October 15: Newport Room

Open Forum: ***Stormwater management questions in southern California***

1:00 PM	Introduction and announcements Ken Schiff - *Southern California Coastal Water Research Project*
1:15	Regulated Community Issues Jon VanRhyn - *County of San Diego Department of Environmental Health*
1:45	Regulatory Community Issues Mark Smythe - *Regional Water Quality Control Board, Santa Ana Region*
2:15	Environmental Community Issues Bruce Reznick – *San Diego Baykeeper*
2:45	Resource Community Issues Jim Harrington - *California Department of Fish and Game*
3:15	Discussion
3:45	Break for hotel check-in
5:00	Dinner for Workshop Panelists
6:00	Workshop Panelist Discussion (*Invited participants only*)
8:00	Adjourn

Tuesday, October 16, 2001 Newport Room

8:00 AM	Continental Breakfast
8:30	Workshop Panelist Discussion (*Invited participants only*)
12:00 PM	Lunch
1:00	Workshop Panelist Discussion (*Invited participants only*)
5:00 PM	Dinner for Workshop Panelists

Wednesday, October 17, 2001 Bristol Room

8:00 AM	Continental Breakfast
8:30	Workshop Panelists Discussion (*Invited participants only*)
12:00 PM	**Open Forum**: ***Research agenda goals and projects*** Lunch for SMC members and panelists
1:00	Panelist Findings Brock Bernstein - *Research Agenda Workshop Facilitator*
2:00	Discussion
2:30	Adjourn

Workshop Participants

Brian Anderson
University of California Santa Cruz Marine Pollution Studies Laboratory

Michael Barbour
Tetra Tech

Jon Bishop
Regional Water Quality Control Board, Los Angeles Region

Chris Crompton
Orange County Public Facilities and Resources Department

David Dilks
LimnoTech

Al Dufour
US EPA

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