Effects of Post-fire Runoff on Surface Water Quality: Development of a Southern California Regional Monitoring Program with Management Questions and Implementation Recommendations

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Southern California Stormwater Monitoring Coalition

Southern California Coastal Water Research Project

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Executive Summary

Periodic wildfires are a natural component of southern California's forest and scrubland and essential to maintaining overall ecological health of these systems. However, the frequency and intensity of wildfires has increased in association with human activities in and near natural forest and foothill areas. The effects of fire on hydrologic response and sediment loads in southern California have been noted for over 80 years, yet no coordinated monitoring of water quality following fires currently occurs. The lack of coordinated monitoring is particularly problematic in southern California because watersheds affected by fire often drain to waterbodies that support sensitive resources or that have been designated as impaired under Section 303(d) of the Clean Water Act, often for the same constituents found in post-fire runoff. Consequently, the contribution of metals, nutrients, and organic contaminants from post-fire runoff to receiving waters is poorly understood in terms of both the magnitude and persistence of potential effects.

The lack of a coordinated post-fire monitoring program results from several factors. First, there is no procedure for post-fire water quality monitoring that identifies a standard set of constituents and monitoring protocols appropriate for assessing water quality following fires. Second, resources are often scarce following fires making it difficult for various entities to coordinate. Third, there is no regional entity responsible for coordinating post-fire sampling, compiling the resultant data, and disseminating the information back to mangers at the local and regional levels. Fourth, because fires occur unexpectedly, there is often insufficient available funding for conducting post-fire sampling.

This document describes a regional post-fire water quality monitoring program. The goal of the program is to help address the current information gaps by providing agreed upon regional post-fire water quality sampling procedures, including an implementation plan and a funding strategy. This plan was developed by a team of technical experts, stormwater managers, and regulators from academia, government, and the private sector. The plan provides a ready "off-the-shelf" response plan that can be quickly implemented after fires.

The post-fire monitoring program is organized around three priority management questions:

1. How does post-fire runoff affect contaminant flux?
2. What is the effect of post-fire runoff on downstream receiving waters?
3. What are the factors that influence how long post-fire runoff effects persist?

The general sampling design, site selection process, sampling approach, and recommended indicators for each of these questions are summarized in Table ES-1. Although they are related, monitoring to address each of the questions is not interdependent. The three major monitoring elements are separable and can be implemented as distinct units or as an integrated program.

Table ES-1: Summary of monitoring design for each priority monitoring question.

Management Question	MQ1: How does post-fire runoff affect contaminant flux?	MQ2: What is the likely effect of post-fire runoff on downstream receiving waters?	MQ3: What are the factors that influence how long post-fire runoff effects persist?
General Design	Comparison of runoff from burn areas to reference or control sites	Pre- vs. post-fire monitoring	Comparison of post-fire condition to regional ambient condition
Flow Conditions to Target	Stormwater runoff	Non-storm, dry weather flow	Non-storm, dry weather flow
Selection of Burned Sites	Terminus of burned catchment using established criteria	Bottom of watershed at confluence with receiving water of interest - after fire, before and after first runoff event	Overlay SCRMP* bioassessment sites and burn maps to select burn locations
Selection of Comparison Sites	Natural sites, urban sites, existing MS4 monitoring sites		Use existing pre-burn SCRMP ambient bioassessment data
Indicators	Water chemistry, constituent concentrations	Water chemistry, sediment toxicity (optional benthic response indicators)	IBI, CRAM, basic water chemistry
Period and Duration of Monitoring	At least three storms during first and/or second winter following fire	Before 1st storm and annually until measures return to baseline (pre-fire levels)	During spring index periods - annual visits over time

*SCRMP = Stormwater Monitoring Coalition's Southern California Regional Monitoring Plan

The regional plan includes site selection criteria that allow for pre-selection and prioritization of potential sampling sites based on the sensitivity of potentially affected resources, presence of previous and available monitoring data, feasibility, accessibility, and ability to coordinate with other monitoring programs. Pre-selection of sites and up-front coordination will allow for more rapid and effective response following fires. Finally, the plan includes preliminary recommendations for quality assurance procedures, data management, and communication that will facilitate information sharing and ongoing coordination.

Ongoing program development and coordination will be accomplished through a post-fire runoff working group that consists of the U.S. Forest Service, U.S. Geological Survey, CAL FIRE, the regional water quality control boards, major municipalities, key landowners, and local researchers. Those interested in participating in the working group should feel free to contact Eric Stein (erics@sccwrp.org, 714/755-3233) or Jeff Brown (jeffb@sccwrp.org, 714/755-3226).

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Motivation for the Plan

Periodic wildfires are a natural component of southern California's forest and scrubland ecosystems and are essential to maintaining their overall ecological health. However, the frequency and intensity of wildfires has increased in association with human activities in and near natural forest and foothill areas (Syphard *et al*. 2007) and is expected to continue increasing in association with changes in climate patterns (Westerling *et al*. 2006). The effects of fire on hydrologic response and sediment loads in southern California have been noted for over 80 years (Munn 1920, Tatum 1963, Campbell 1975, Howard 1981, Bruington 1982). Historical records for southern California indicate that total runoff volume may increase by 25% and peak storm flow rates may increase five-fold following fires (SAWPA 2004). Similar changes in hydrologic response have been observed in the arid southwestern U.S., where increases of 200-fold in peak flow rates and 50% in flow volume were observed following fires in New Mexico (Hinojosa *et al*. 2004).

Frequent wildfires can also alter soil chemistry and stormwater runoff characteristics, which can result in adverse effects to downstream water quality. Increased storm flow and sediment runoff following fires have been associated with increases in loads of nutrients, metals, and certain organic pollutants. Several researchers have found that dioxins are emitted, re-suspended, and volatilized by forest fires (Nestrick and Lamparski 1983, Sheffield 1985, Gullet and Touati 2003, Meyer *et al*. 2004). In addition, combustion of plants and natural materials also releases metals (Yamasoe *et al*. 2000), PAHs (Jenkins *et al*. 1996), and nitrogen compounds (Hegg *et al*. 1990). The magnitude and persistence of increased loading of sediment, organic matter, and nutrients is a function of fire intensity and may persist for months to several years (Gimeno-Garcia *et al*. 2000). Riggan *et al*. (1994) reported that increased nitrate export from the San Dimas experimental forest in Glendora, California following fires persisted for up to 10 years.

In addition to the direct effects of runoff from burned landscapes, the materials left behind at the burned location can be carried away from the fire in the form of smoke and ash. Subsequent atmospheric deposition can markedly increase the quantity of various constituents available to storm flows downwind of fires. For example, Sabin *et al*. (2005) report that during the severe 2003 southern California forest fire season, atmospheric deposition rates of copper, lead, and zinc, went up by factors of 4, 8, and 6, respectively, at an unburned site in the San Fernando Valley that was approximately 30 miles from the southeastern border of the Piru/Simi Fires. Similarly, Gerla and Galloway (1998) reported increased nitrate transport following the Yellowstone Park fires of the late 1980s associated with ash fallout, with increased rates persisting for approximately four years. Most recently, Plumlee *et al*. (2007) collected ash immediately following the 2007 southern California wildfires and reported that ash samples had high pH (12.5 - 12.7) and elevated levels of arsenic, lead, copper, and zinc (100s - 1000s ppm).

Because concentrations of nutrients, metals, and certain organic pollutants can be elevated in post-fire runoff, the receiving waters downstream of burned areas can also be affected. In southern California, watersheds affected by fire often drain to waterbodies that support sensitive resources or that have been designated as impaired under Section 303(d) of the Clean Water Act. Moreover, the contaminants elevated in post-fire runoff are often the same constituents already elevated in the receiving water.

Despite the potential effects on downstream water quality, routine monitoring and assessment of post-fire runoff seldom occurs. Consequently, the contribution of metals, nutrients, and organic contaminants from post-fire runoff to receiving waters is poorly understood, in terms of both the magnitude of potential effect and the persistence of the influence. Because of this, the relative contribution of contaminant loading from post-fire runoff compared to other sources (e.g., urban runoff or non-post-fire runoff) is also poorly understood. When monitoring does occur, efforts are poorly coordinated and the resulting data are difficult for stormwater managers to access.

The lack of a coordinated post-fire monitoring program results from several factors: First, there is no procedure for post-fire water quality monitoring that identifies a standard set of constituents and monitoring protocols appropriate for assessing water quality following fires. Second, resources are often scarce following fires making it difficult for various entities to coordinate. Third, there is no regional entity responsible for coordinating post-fire sampling, compiling the resulting data, and disseminating the information back to mangers. Fourth, because fires occur unexpectedly, there is often insufficient available funding for conducting post-fire sampling.

To help address the current knowledge gaps, the Stormwater Monitoring Coalition (SMC) initiated development of this regional post-fire water quality sampling program. The SMC is a cooperative of stormwater regulators and municipal stormwater management agencies throughout southern California that have developed a collaborative working relationship. The intent of this program is to facilitate integrated regional assessment in order to more effectively document the effects of fires, improve regional coordination, and provide a mechanism to communicate the acquired information back to managers. The program will consist of three components; an implementation plan, a funding strategy, and an outreach and information management plan.

Development of the coordinated regional post-fire monitoring program was initiated at a workshop held on August 18-19, 2008. The workshop included a diverse group of participants, with representatives from academia, government, and the private sector (Table 1). The workshop had three goals. The first goal was to summarize the status of the science of post-fire water quality effects, through a series of short presentations and a written synthesis of current post-fire effects research. A copy of the synthesis is included in the Appendix to this document. The second goal was to identify the elements important for assessing post-fire water quality effects by developing consensus management and technical questions. Management level questions include those that are used to determine the type and amount of resources that are needed to respond to a problem. These questions are asked to determine if the perceived problem exists, if so what the spatial and temporal scales of the problem are, and what can be done to remove or minimize the problem. Technical questions are designed to collect the information needed to address the management level questions. The third goal was to provide initial recommendations for developing the regional monitoring program.

Table 1. List of organizations represented at the post-fire effects workshop held August 18-19, 2008.

Regulatory and Municipality	Research
State Water Resources Control Board	University of California Los Angeles
San Diego Regional Water Quality Control Board	University of California San Diego / Scripps Institution of Oceanography
Los Angeles Regional Water Quality Control Board	University of California Extensions
California Department of Fish and Game	United States Forest Service
Los Angeles County Department of Public Works	United States Geological Survey
City of Los Angeles Watershed Protection Division	United States Navy / Space and Naval Warfare Systems Center San Diego
County of Orange / Orange County Flood Control District	Desert Research Institute
Riverside County Flood Control and Water Conservation District	Flow Science, Inc.
County of San Diego Department of Public Works	Geosyntec
	Southern California Coastal Water Research Project

This document discusses the initial management questions and recommendations that were developed during the workshop and provides recommendations for implementation of a regional post-fire water quality monitoring program. The goal of this document is to provide a framework for regional monitoring of post-fire effects on water quality. Specifically, the framework 1) identifies management questions related to water quality issues regarding runoff from burned areas, 2) provides recommendations on the sampling design, mobilization and implementation strategies, and 3) summarizes funding possibilities and avenues for communicating results of the post-fire monitoring program.

Management Questions

The regional monitoring program is designed around three priority management questions. Together, the answers to these questions provide a thorough understanding of the effects of fire on surface water quality. Because each of these questions addresses a different aspect of post-fire effects, the monitoring program can be implemented in phases, with any one of the three questions being prioritized based on specific agency needs or interests. The three priority management questions are:

1. How does post-fire runoff affect contaminant flux?
2. What is the effect of post-fire runoff on downstream receiving waters?
3. What are the factors that influence how long post-fire runoff effects persist?

Two additional, “second tier” questions are also discussed following the three priority questions.

MQ1: How does post-fire runoff affect contaminant flux?

This question can be divided into two parts, one that addresses the effect of fire on contaminant concentrations and one that compares contaminant flux following the fire to flux in the absence of fire. Concentrations of contaminants in stormwater runoff affect the ability of downstream receiving waters to support aquatic life and other designated beneficial uses. Contaminant runoff from burned areas is important to characterize because it often drains to areas with existing management concerns, such as water quality impairments, sensitive species habitats, or areas with contaminated sediments. Knowing the constituent concentrations from burn areas will allow managers to place this contribution in context of other sources.

Flux calculations allow for comparison of the relative mass contribution of constituents from different sources or different points in time. Such calculations contribute to an assessment of the “likely effect” of post-fire runoff. Comparisons could include pre- vs. post-fire runoff at a single site, comparison among different streams affected by fire, and comparison of post-fire runoff with other sources of contaminants such as urban runoff. Existing management endpoints such as Total Maximum Daily Loads (TMDLs) are based on mass emissions; therefore, it is important to understand all sources of a contaminant of concern to a potentially impacted area.

As the dataset grows, managers will better understand factors that contribute to high or low contaminant flux following fires. This will allow targeting of Best Management Practices (BMPs) and other control measures to areas of greatest concern and or greatest potential effect.

MQ2: What is the likely effect of post-fire runoff on downstream receiving waters?

The ultimate goal of this program is to improve our understanding of effects of fire on human or ecological health endpoints. Such effects extend beyond the initial streams that carry runoff from burned areas. Potential downstream affected areas (i.e., receiving waters) include impaired waterbodies, estuaries, bays, and harbors. Drinking water reservoirs and sensitive habitat areas may also be affected by the pollutants in runoff.

The importance placed on managing post-fire runoff will largely depend on its effect on biological endpoints of regulatory or management interest. These endpoints can be evaluated in terms of water column or sediment toxicity or via biological indices, where they exist. The benefits of biological indices and toxicity tests are that they provide an assessment of unmeasured contaminants, and can assess the synergistic effects of multiple contaminants below their individual toxic thresholds. In addition, potential effects can be evaluated by comparing concentrations of contaminants in runoff with the water quality criteria designed to protect sensitive aquatic organisms. Effects may be manifested shortly after the post-fire runoff reaches the receiving water (acute), or over time following extended or repeated exposure, (chronic). Both acute and chronic effects may be of interest to managers, although the sampling approach will vary for each.

Water quality effects may derive from both direct effects of runoff and indirect effects associated with aerial deposition of ash. Although both are important, this program will prioritize the investigation of effects of direct runoff from areas that have burned. Given the limited resources likely available for this program, understanding direct effects has a more direct connection to management actions that stormwater and land management agencies can address. Indirect effects associated with deposition of ash onto unburned watersheds are more complicated to assess and require involvement of additional management agencies. Therefore, this aspect will be deferred to a later phase of the program

Knowing the magnitude of effects will help managers target where to emphasize management measures and/or provide warnings of ecological or human health risk. Understanding effects will also allow the water quality effects of fire to be considered as part of the overall cost of southern California wildfires.

MQ3: What are the factors that influence how long post-fire runoff effects persist?

Post-fire management actions will need to be targeted to the period of greatest potential effect. Therefore, the regional monitoring program must evaluate the factors that influence how long after a wildfire the constituents in the runoff remain elevated. This will likely depend on several factors, including parameters related to the storms, the site, and the thresholds used for comparison. Parameters related to the storms include the number of storms, their intensity, and the amount of flow and accumulated rainfall. Relevant site characteristics include fire history, soil type, vegetation type and density, burn severity (as a predictor of soil hydrophobicity), watershed size, terrain slope, and land use. Persistence of effects can also be evaluated by measuring the health of biological communities via indices, such as a benthic Index of Biotic Integrity (IBI). The threshold used to evaluate whether contaminants are elevated can also vary (i.e., water quality objectives, comparison to reference conditions, concentrations from a nearby unburned site, or pre-fire concentrations), as can the distance from the threshold that is deemed to be acceptable before sampling is halted (e.g., within 20% of the threshold). Ultimately, analysis of the duration of effect should be expressed in terms of accumulated rainfall since fire effects may not be limited to a single storm season.

As with the first two questions, knowing how long effects are likely to persist will allow managers to better match the intensity and duration of management actions with expected duration of effects. Understanding persistence of effects will also allow for establishment of realistic restoration/rehabilitation targets.

Second Tier Management Questions

In addition to the three priority questions, the workgroup identified two additional management questions focused on developing management solutions. The approach to answering these questions depends in part on what is learned from the first three priority questions; therefore, this monitoring program identifies these second tier questions but does not include recommendations for how to address them. An implementation plan for these questions may be developed in the future.

MQ4: What are the likely sources of contaminants in post-fire runoff?

If post-fire runoff proves to be a substantial management concern, knowing the source of contaminants will be important to designing effective management strategies. Previous research has implicated volatilized constituents in fire gasses, combustion products in ash, pollutants bound to post-fire sediment runoff, and compounds associated with fire suppressants or retardants. It is likely that the sources are a complex mixture of the above, which vary over time and from location to location. Nevertheless, the regional monitoring program should include elements that provide insight into potential sources of contaminants in post-fire runoff and the phase in which these contaminants will most likely be transported (e.g., dissolved, attached to suspended sediment or bedload, or in some complex, low-density mixture of burned and partially burned organic matter). Such information will ultimately inform decisions about BMP implementation strategies.

MQ5: How can management practices reduce pollutant loading associated with post-fire runoff?

Management practices can range from type of BMPs to the method of post-fire erosion control, to pre-fire vegetation management practices. Some of the BMPs used to control erosion may also help reduce contaminant loading, including revegetation and application of mulch material such as straw wattles (Robichaud *et al*. 2000). Managers will be interested in how effective these BMPs are at reducing contaminants, how to maximize their effectiveness, how long they need to be deployed, which constituents should be targeted, and how the various BMPs compare with one another.

For this regional program, it was recommended that BMP effectiveness should only be evaluated if the BMP is in an area of concern, and that sites should not be selected just because a BMP was in place. The reason being that while BMPs are potentially important elements for reducing contaminants in runoff, the highest priority for sampling should be given to those sites with resources most at risk.

Monitoring Program Design

The monitoring design is organized around the three priority management questions. The general sampling design, site selection process, sampling approach, and recommended indicators for each of these questions are described below, and summarized in Table 2. Although they are related, monitoring to address each of the questions is not interdependent. The three major monitoring elements are separable and can be implemented as distinct units or as an integrated program.

Table 2. Recommended general sampling design, site selection process, and indicators for each priority management question.

Management Question	MQ1: How does post-fire runoff affect contaminant flux?	MQ2: What is the likely effect of post-fire runoff on downstream receiving waters?	MQ3: What are the factors that influence how long post-fire runoff effects persist?
General Design	Comparison of runoff from burn areas to reference or control sites	Pre- vs. post-fire monitoring	Comparison of post-fire condition to regional ambient condition
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Selection of Comparison Sites	Natural sites, urban sites, existing MS4 monitoring sites		Use existing pre-burn SCRMP ambient bioassessment data
Indicators	Water chemistry, constituent concentrations	Water chemistry, sediment toxicity (optional benthic response indicators)	IBI, CRAM, basic water chemistry
Period and Duration of Monitoring	At least three storms during first and/or second winter following fire	Before 1st storm and annually until measures return to baseline (pre-fire levels)	During spring index periods - annual visits over time

*Stormwater Monitoring Coalition's Southern California Regional Monitoring Plan (SCRMP)

Pre-Selection of Potential Sampling Locations

Determining whether a fire is substantial enough to warrant sampling potential water quality effects and selection of appropriate sampling locations are two of the most challenging aspects of this plan. In order to reduce the response time needed to mobilize the stormwater sampling effort, an array of potential monitoring sites should be pre-selected before a fire occurs (Figure 1). The choice of potential sampling sites takes into account all three priority management questions.

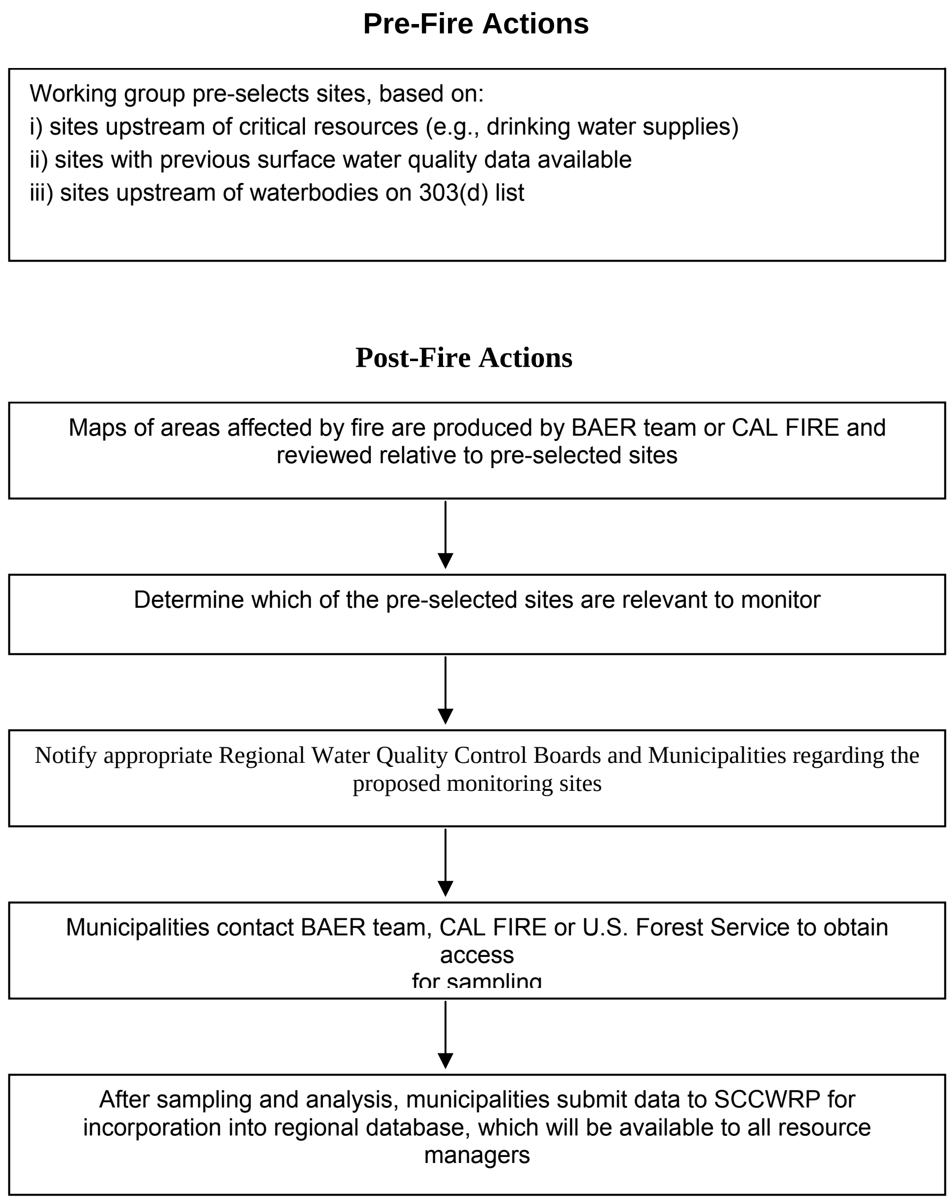

Figure 1. Interagency coordination and regional decision process for post-fire runoff monitoring.

Site selection will be made through a three-tiered set of decision criteria. Once a significant wildfire has occurred, the most appropriate of the pre-selected sites to be monitored will be determined[1]. The sites with the highest priority (tier one) are streams that discharge to the most sensitive areas within each watershed, potentially affecting the most important resources such as drinking water reservoirs and vulnerable habitat (Figure 2). Regulatory agencies and municipalities will be responsible for identifying and prioritizing potentially affected resources.

[1] Determinations will be made by agencies affected by or responsible for stormwater runoff in the burned areas. This may include local municipalities, regional water boards, fire agencies (i.e., CAL FIRE), and SCCWRP.

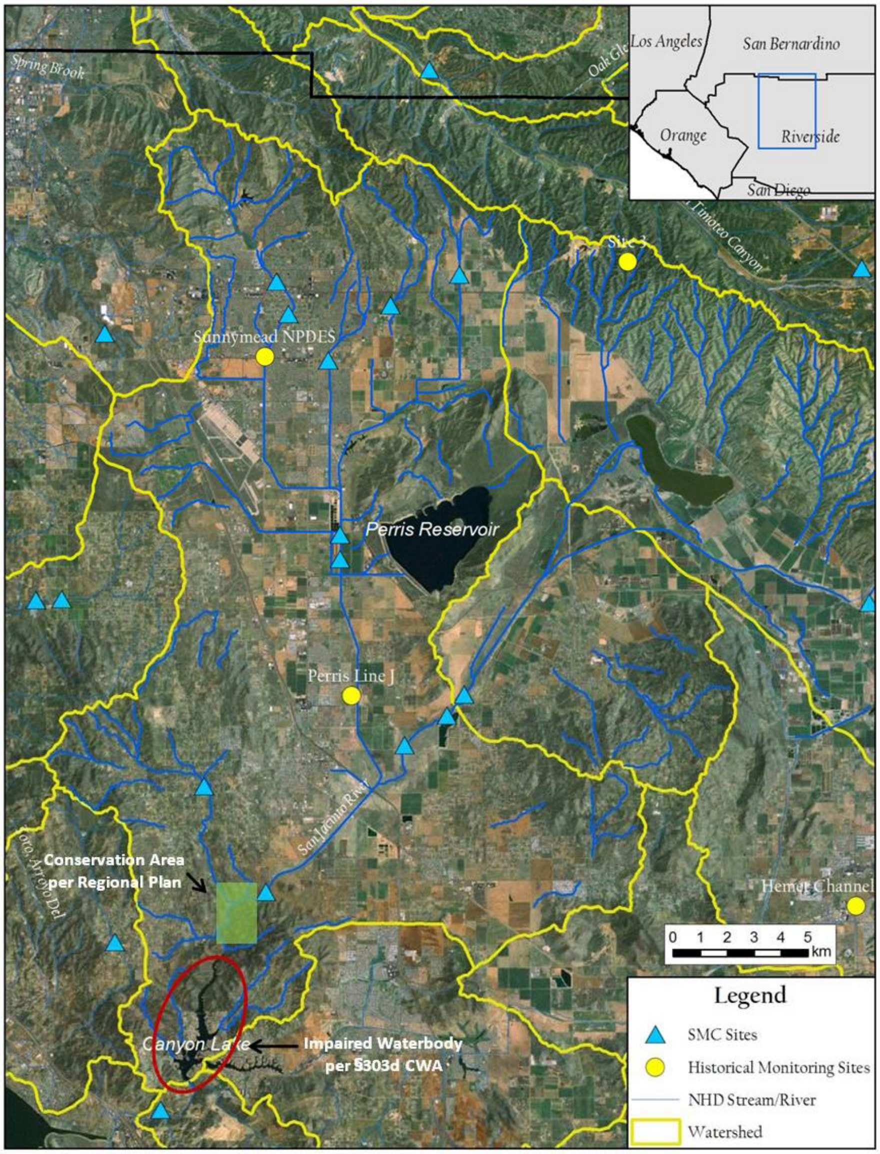

Figure 2. Example of sites included in the pre-selection process. This includes streams that discharge to drinking sensitive habitats, sites where prior monitoring has been conducted, and streams discharging to waterbodies that have previously been designated as impaired under Section 303(d) of the Clean Water Act (Canyon Lake).

The second tier sites are those where prior monitoring has been conducted. This would include sites that have had water quality measurements made as part of other studies, including National Pollution Discharge Elimination System (NPDES) permit compliance and TMDL monitoring, as well as those sites that are monitored for the reference envelope portion of the proposed regional program (i.e., should a reference site burn, it would be considered as a potential monitoring site). The benefit of sampling these sites after a fire is that they would have previous water quality data available for comparison to the post-fire runoff data.

The third tier in the site selection process is to examine streams discharging to waterbodies that have previously been designated as impaired under Section 303(d) of the Clean Water Act. It is important to characterize the contaminants in these streams because they may be those that are already elevated in the receiving water. Many of the sites on the 303(d) list have historic contaminant data that can be used in comparison to the post-fire data.

A central on-line database should be created that lists the pre-selected sites within a given watershed and county, for each of the three tiers. The database should also include information on access issues for each site, such as ownership, contact information for access permission, and which government agency is managing the various parcels.

MQ1: How does post-fire runoff affect contaminant flux?

Contaminant concentration and flux will be assessed by sampling stormwater runoff from the terminal end of burned catchments and comparing those data to reference or control sites. Note that this is the only management question that requires sampling during storms.

Selection of Burned Sites

Following a fire, the CAL FIRE/BAER maps should be overlaid on the map of pre-selected watersheds (Figure3). Identification of potential watersheds for post-fire sampling should be based on the following criteria:

1. A stream can be identified where at least 80% of the contributing drainage area to the sampling location has burned.
2. The candidate site should not have burned within the previous three years.
3. The sampling location must be readily and safely accessible for field crews immediately before and after a storm. In most cases, automated sampling will be used so field crews will not need to be present during the storm. However, there should be a high likelihood that access to the site to retrieve samples and equipment following the storm will be readily available.
4. The landowner or responsible agency must provide permission to sample the site for at least one full season following the fire.
5. Flow data must be available at the sampling site or the site lends itself to flow monitoring. If the site is not currently gauged, the sampling location must have a stable defined cross-section that can be rated for flow.
6. There must be sufficient area adjacent to the stream to secure equipment from damage during high flows and/or vandalism.
7. Although not absolutely required, presence of a nearby watershed that can be used as a comparison site is preferred (see section below).
8. Existence of pre-fire flow or water quality data is desirable, but not necessary.

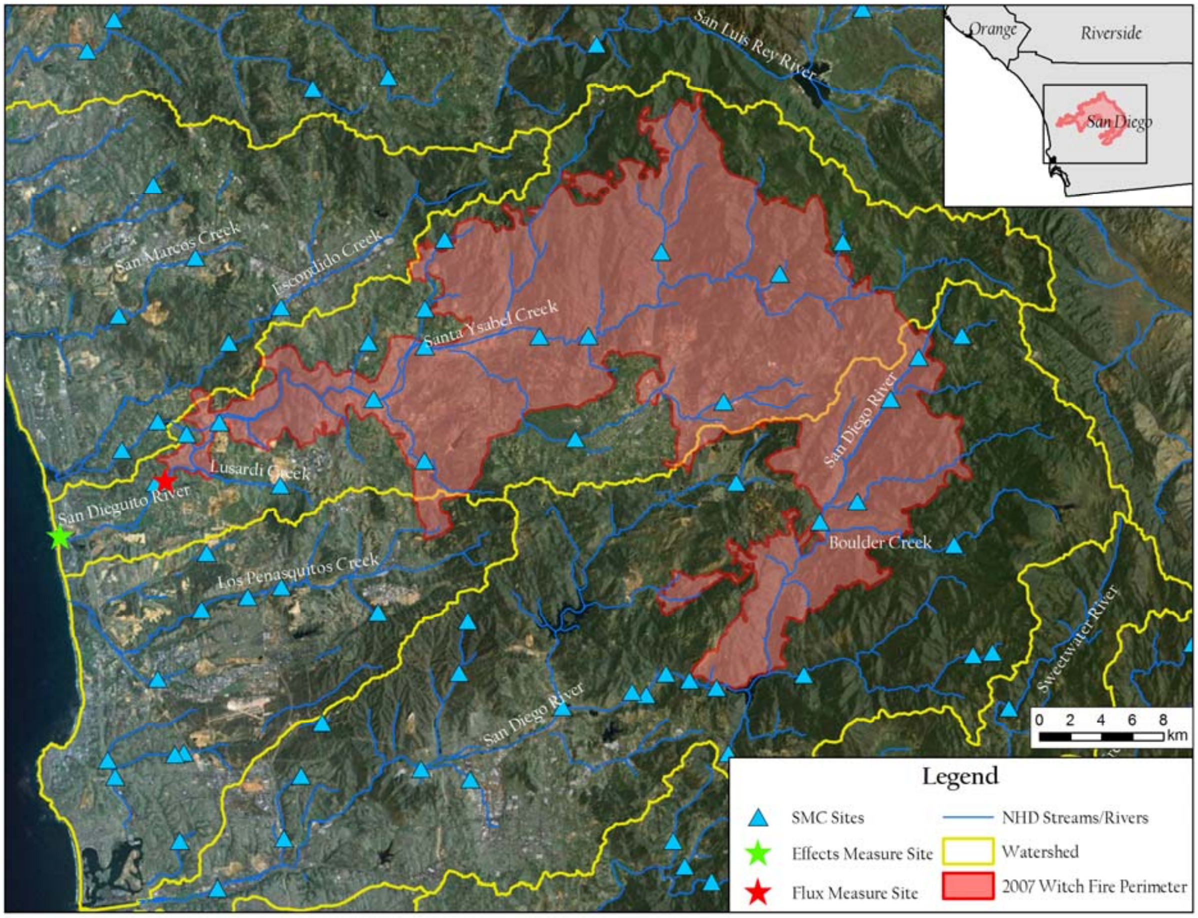

Figure 3. Location of the 2007 Witch Fire relative the SMC regional monitoring sites. Stars show potential locations for assessment of contaminant flux (Management Question 1) and effects (Management Question 2).

Selection of the actual sites that are sampled will be made in consultation with affected resource and regulatory agencies, local municipalities, and fire officials. Every opportunity will be made to coordinate with other monitoring and data collection efforts associated with the selected sites.

Selection of Comparison Sites

Ideally comparison or control sites should be in nearby unburned catchments of similar size and land cover. Control watersheds can be pre-selected concurrent with selection of burned areas. If identification of such "paired watershed" is not possible, data from other existing (or past) monitoring efforts may also be used as a basis of comparison. Municipal stormwater monitoring programs can provide data from streams draining urban, natural, or mixed land uses. A previous Southern California Coastal Water Research Project (SCCWRP) study on water quality loadings from natural landscapes (Stein and Yoon 2007) provides stormwater runoff data from 18 undeveloped sites distributed over 11 watersheds and 6 southern California counties. Both of these data sets can be used to provide a frame of reference for contaminant concentrations and flux from burned areas.

Sample Collection

Typical sampling strategies for stormwater include collecting grab samples, time- or flow-weighted composite samples, or multiple grab samples to produce time vs. concentration (pollutograph) plots. Because post-fire monitoring questions pertain to storm-averaged concentration or flux estimates, time- or flow-weighted composite sampling will generally be appropriate. If possible, the preferred approach is a flow-weighted composite sampling approach with four discrete samples collected for analysis, each representing a portion of the overall storm volume (Figure 4). Flow-weighting typically produces more accurate results than time-weighted samples, but requires prior knowledge of expected flow from a given site. Such knowledge is often lacking, particularly at wildland sites, and even when it does exist, it may not be relevant to post-fire runoff conditions. In such circumstances, time-weighted composite sampling with multiple discrete samples analyzed is an acceptable substitute. If analyzing four bottles per storm for chemical constituents is cost-prohibitive, two bottles may be analyzed (one capturing runoff prior to the peak flow and one capturing runoff from peak flow through approximately half the descending hydrograph). A more intensive sampling plan using a pollutograph (high resolution) approach should be employed only if the data are intended for use in model calibration. Determining when a high resolution sampling regimen is appropriate should be the responsibility of the specific agencies or program managers for a given site.

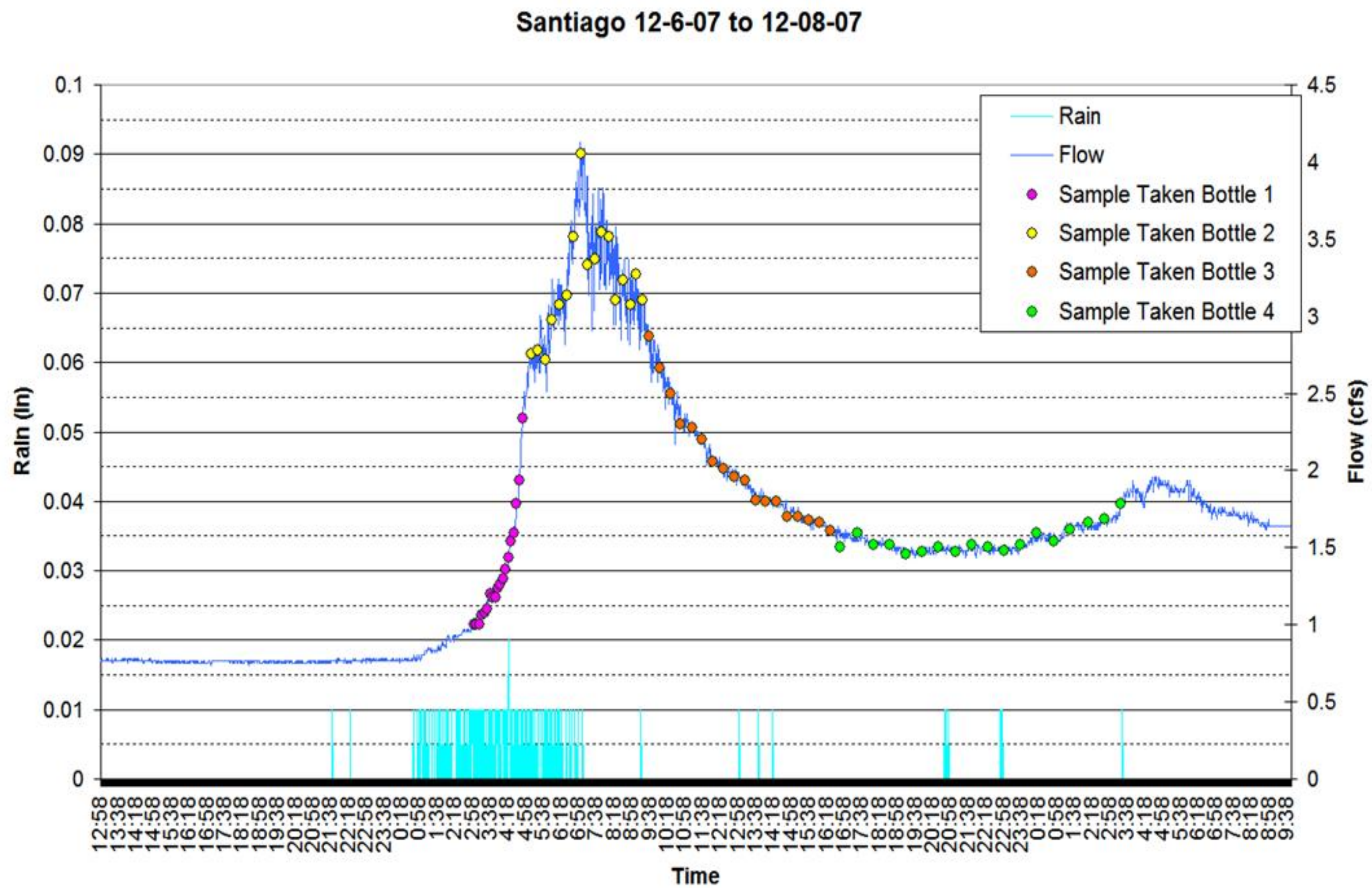

Figure 4. Example of multiple discrete sample composite sampling regimes.

Flow data must be collected at all sampling sites using an acoustic-velocity bubbler or other comparable approach. Sampling sites should be located at cross-sections that facilitate flow rating to produce discharge estimates. To the extent possible, flow measurements should begin prior to the initiation of storm flow and continue until flow decreases to 25% of peak flow or within 20% of baseflow, whichever is higher.

Optional Measurements

In addition to the measurements described above, optional measurements (or special studies) could be conducted to help elucidate potential sources of contaminants. Priority analyses could be investigation of the effect of aerial deposition of ash and/or the effect of fire retardant and fire suppressant chemicals on downstream water quality. Ash deposition measurements would provide greater insight into the source of contaminants from the wildfires. Because of the ephemeral nature of these measurements, both aerial deposition and ash would require samples to be collected prior to the stormwater runoff sampling, either during the fires (aerial deposition), or immediately after a fire incident (ash samples from the burned area). With coordination by the agencies interested in the ash sample analyses, agencies throughout southern California may be able to assist with the ash sample collection. In addition to aerially deposited ash, analysis of ash and soils from burned areas would further contribute to the understanding of potential sources of contaminants and possibly provide an early indicator of future water quality effects.

Previous researchers have found that ammonium or phosphorous based compounds used to fight fires may contribute to elevated nutrient concentrations in stormwater (Pappa *et al*. 2006). Sampling of paired watersheds with and without use of fire suppressants would provide information on the relative contribution of these chemicals to downstream nutrient loads.

Safety

Stormwater sample collection can be hazardous, an issue that is only exacerbated by sampling in remote wildland areas. The number of people required to safely collect a sample should be assessed for each site, but in general at least two people should be on-site to conduct the sampling. Each of the people should have adequate training in collecting stormwater samples. Each crew should also be familiar with the proper sampling equipment for a particular site (right tool for the job), including adequate safety equipment (e.g., cell phone, rope, harness, gloves, flashlight, traffic cones, road flares, etc.). Autosamplers should be set up prior to the event, when there is adequate forewarning of a storm, to reduce the potential dangers of sample collection. The field crew has the authority to determine whether conditions of the planned sample collection are safe enough to proceed.

Sample Analysis

A successful regional monitoring program requires a core level of consistency in the constituents analyzed. However, there must also be flexibility to expand upon the core list to address specific management questions where there is interest or need. The core and optional constituents recommended for the regional program are listed in Table 3. Decisions regarding inclusion of optional constituents/analyses should be based on the following considerations: 1) Measure constituents that are already elevated in the water bodies receiving runoff from burned areas — this is particularly relevant for constituents that have caused a waterbody to be listed as impaired on the 303(d) list, since it will contribute to an understanding of the loading from fire relative to other sources; 2) Analyze constituents that have concentrations close to water quality effects thresholds in samples from nearby reference sites (measured in previous storm events); 3) Include compounds that can serve as specific markers indicative of wildfire (e.g., high molecular weight polycyclic aromatic hydrocarbons (PAHs), dissolved organic matter); and 4) Include constituents that may be mobilized based on the geology of each site (e.g., mercury). Recommendations for sample collection and handling, as well as for laboratory measurement quality objectives are given in Tables 4 and 5.

Table 3. Comprehensive list of suggested constituents for analysis. Right column indicates whether constituents are part of the core list that should be analyzed at all sites or optional based on specific management questions. The metal constituents in surface waters represent both total and dissolved phases.

General		
	Flow	Core
	Local rainfall data	Core
	Specific conductance	Core
	Temperature	Core
	Dissolved oxygen	Core
	pH	Core
	Alkalinity	Optional
	Hardness (as $CaCO_3$)	Core
	Dissolved organic matter	Core
	Total dissolved solids	Optional
	Total suspended solids	Core
	Total organic carbon	Core
	Particle size distribution	Optional
Metals		
	Al, Fe, Cd, Cu, Pb, Mn, Ni, Zn	Core
	Hg, Se, As	Optional
Nutrients		
	Nitrate, nitrite, ammonia, TKN	Core
	Phosphate, orthophosphate	Core
	Sulfate	Core
Organics		
	PAHs	Optional
	Dioxins	Optional
Toxicity testing		
	Water column and sediment	Optional

Table 4. Recommendations for sample collection and handling for laboratory analysis. All parameters are for surface water, unless noted otherwise.

Analyte	Bottle Type/Size	Preservative	Maximum Holding Time
General			
Specific Conductance	250mL Plastic	Cool at <4°C	24 h
Dissolved Oxygen	Field analysis		
pH	250mL Plastic	Cool at <4°C	24 h
Alkalinity	250mL Plastic	Cool at <4°C	24 h
Hardness (as $CaCO_3$)	100mL Plastic	Cool at <4°C	6 months
Total and Dissolved Organic Carbon	250mL Glass	Cool at <4°C Acidify <2 pH	Acidified within 24 h; 28 days
TDS	1L Plastic	Cool at <4°C	7 days
TSS	1L Plastic	Cool at <4°C	7 days
Particle size distribution	2L Plastic	Cool at <4°C	48 h
Metals (total and dissolved)[1]			
As, Cd, Cr, Cu, Pb, Mn, Ni, Zn	1L Plastic	Cool at <4°C Acidify <2 pH	4 h filtration and acidification/ 6 months analysis
Hg, Se	1L Plastic	"	"
Fe	1L Plastic	"	"
Nutrients			
Nitrate, nitrite, NH_3	250mL Plastic	Cool at <4°C Acidify <2 pH	Acidified within 24 h; 28 days
TKN	500 mL amber glass		"
Orthophosphate (as P)	250mL Plastic	"	"
Sulfate	250 mL Plastic	"	"
Organics			
PAHs	2L Amber Glass	Cool at <4°C	7 days extraction/ 40 days analysis
Dioxin	2L Amber Glass	Cool at <4°C	30 days extraction/ 45 days analysis
Toxicity			
Ceriodaphnia dubia chronic water column test	4 L Polyethylene	Cool at <4°C	48 h[2]
Hyalella azteca acute sediment test	4 L Polyethylene	Cool at <4°C	2 weeks

[1]Dissolved filtered through 0.45 µm filter within 4 h
[2]This deviates from the EPA recommended holding time of 36 h, but is a more logistical time frame.

Table 5. Laboratory measurement quality objectives. NA = not applicable.

Analyte	% Recovery[1]	RPD[2]	Method Detection Limit	Completeness
General				
Hardness	75-125%	0-20%	1 mg/L	90%
Dissolved Organic Carbon	70-130%	0-20%	0.1 mg/L	90%
Total Organic Carbon	70-130%	0-20%	0.1 mg/L	90%
NH_3	70-130%	0-20%	0.03 mg/L	90%
pH	70-130%	0-20%	0.1 pH unit	90%
Alkalinity	70-130%	0-20%	1 mg/L	90%
Specific Conductance	70-130%	0-20%	10 µmhos/cm	90%
Total Dissolved Solids	70-130%	0-20%	0.1 mg/L	90%
Total Suspended Solids	70-130%	0-20%	0.5 mg/L	90%
Metals (total and dissolved)[3]				
As, Cd, Cr, Cu, Pb, Mn, Ni, Se, Zn	80-120%	0-20%	0.2 µg/L	90%
Hg	80-120%	0-20%	0.01 µg/L	90%
Fe	80-120%	0-20%	5.0 µg/L	90%
Organics				
PAHs	70-130%	0-30%	1 ng/L	90%
Dioxins	70-130%	0-30%	3 pg/L	90%

[1] For constituents <10x the method detection limit in the non-spiked samples.
[2] For constituents >10x the method detection limit.
[3] Dissolved filtered through 0.45 µm filter within 4 h.

Period and Duration of Monitoring

Every attempt should be made to begin sampling with the first storm event following a fire. This will allow first flush effects to be captured, since the first pulse of runoff following a fire usually contains the highest concentrations of contaminants (Bertrand-Krajewski *et al*. 1998).

The duration of post-fire runoff monitoring during a season should be based on the cumulative volume of flow, or rainfall, and not on the number of storms that have occurred. The reason being that concentrations are believed to be reduced as a function of cumulative flow, and that the amount of precipitation from any given storm is variable. Nevertheless, the relationship between accumulated flow and changes in contaminant concentrations has not been well characterized, and may be refined as part of the implementation of this program. There is limited information from SCCWRP's past post-fire runoff investigations suggesting concentrations of metals and PAHs may return to background levels after the first year following a wildfire. Therefore, a preliminary recommendation would be to sample three storms during the first year following a fire.

MQ2: What is the likely effect of post-fire runoff on downstream receiving waters?

Effects of post-fire runoff will be assessed by monitoring for sediment chemistry and toxicity (with macroinvertebrate response as an optional indicator) at receiving water locations downstream of burned areas. Receiving waters may be freshwater, such as lakes or reservoirs, or saltwater such as bay margins, estuaries, and harbors. Measurements will allow for a multiple lines of evidence approach to assessing effects. Samples will be collected during non-storm conditions before and after the first runoff event following a fire (pre- vs. post-monitoring).

Selection of Burned and Unburned Sites

The receiving water selected for this investigation should be downstream of one of the pre-selected watersheds, where at least 80% of the contributing area catchment burned. Following a fire, the CAL FIRE/BAER maps will be used to identify likely candidate receiving waters. As stated above, priority should be given to receiving waters with sensitive ecological or human health endpoints (e.g., drinking water reservoirs). Attempts should be made to estimate the general amount of ash fallout (if any) at the site prior to collection of the pre-storm samples. If high constituent concentrations are observed in receiving waters, it may be useful to add additional measurements between the burned area and the receiving waters to establish a longitudinal gradient of contamination.

The comparisons will be between pre- and post-storm samples from the same location; therefore, separate reference sites will not be sampled. However, reference data are incorporated into the toxicity testing process, through the use of sediment controls. These control samples represent sediment that was collected along with the test organisms, usually from an area with minimal contaminant disturbance.

Sample Collection

Sediment samples should be collected from the receiving waters, at a location nearest to the primary source of post-fire runoff. As such, the sediment will likely represent the highest levels of toxicity in these receiving waters. Because contaminants are typically associated with smaller particle sizes, samples should be collected in areas with a higher proportion of fine grained sediment. The top 2 cm of sediment should be collected, to represent the most recent deposition, and because this is the zone where most benthic macroinvertebrates reside. Approximately four liters of sediment are required for a standard acute toxicity test: 10 liters for a phase I Toxicity Identification Evaluation (TIE) and 1 L for sediment chemistry. Sediment from multiple grabs should be composited and distributed to precleaned containers for analysis. All containers should be held on ice until distributed to the analytical laboratories.

Optional Measurements

Collection of benthic invertebrates is an optional measurement that should be made in circumstances where the management needs necessitate a more definitive answer regarding effects. The protocol and the associated index will vary depending on the receiving water environment. For wadeable streams, California's Surface Water Ambient Monitoring Program (SWAMP) multi-habitat protocol will be used to sample benthic macroinvertebrates (Ode 2007). For lakes, ponds, and other lentic freshwater systems, the California Department of Fish and Game (CDFG) bioassessment procedures (CDFG ABL 1996) and the Environmental Protection Agency (EPA) protocols for benthic macroinvertebrate index (BMI) sampling in ponded environments (EPA 1990) should be used. For marine systems, benthic macroinvertebrates should be sampled following Ranasinghe *et al*. 2007.

Sample Analysis

The core and optional metal and organic constituents recommended to investigate sediment chemistry for effects are listed in Table 3.

Sediments should be assessed for toxicity using the 10-day survival and growth tests with the amphipod *Hyalella azteca* (for freshwater samples), *Eohaustorius estuarius* (for marine or estuary samples), or a comparable toxicity test. General water quality characteristics should be measured on the overlying and pore water, including pH, dissolved oxygen, conductivity and ammonia. Sediment samples should also be analyzed for grain size distribution and total organic carbon, to help determine if observed toxicity is related to noncontaminant factors.

If toxicity is found, a preliminary TIE investigation may be conducted. With this type of testing, sediment or pore water is selectively manipulated to enhance or remove the toxicity, to help characterize the type of contaminants responsible for the toxicity.

If macroinvertebrate sampling is conducted, composite samples should be counted to the major taxonomic group level (approximate order and family level) to document the diversity and relative abundance of BMI taxa. This is similar to a reconnaissance level assessment of biological condition as is typically used for citizen monitoring programs (Harrington and Born 2000, CDFG ABL 1996).

Period and Duration of Monitoring

In order to differentiate effects resulting from post-fire runoff, each site should be sampled and tested before and after the first storm event. Greater observed effect in the post-storm samples may indicate sampling is warranted the following year. Additional sampling may be desired until the observed effects are diminished, or are equivalent to the samples collected before the first storm event.

MQ3: What are the factors that influence how long post-fire runoff effects persist?

Evaluation of the persistence of fire effects has two components. The first is monitoring to determine the time period until a system returns to pre-burned conditions. This question will be partially answered by data on concentration, flux, and toxicity over time collected to answer the first two management questions (see sections above). Recovery time will also be evaluated by collecting basic water quality and bioassessment data from streams in burned catchments for several years following a fire and comparing them to similar data collected at the same sites prior to the fire (pre vs. post monitoring) and to the regional assessment of ambient condition. The second component will involve evaluating data on recovery time relative to a series of independent variables that may affect the persistence of effects, such as time since last burn, pre-fire vegetation community, rainfall patterns, etc. Statistical relationships (if they occur) between these variables and the post-fire response variables will provide insight into factors that influence the persistence of effects.

Although biological effects are not the focus of this plan, data collected to address this management question will provide some insight into effects of fire on in-stream benthic communities.

Selection of Burned Sites

Sites will be selected from the Southern California Regional Monitoring Program (SCRMP), which is administered by the SMC and SWAMP)[2]. The SCRMP evaluates ambient condition of wadeable streams via basic water chemistry, bioassessment, and the California Rapid Assessment Method (CRAM; Collins *et al*. 2007)[3]. The SCRMP consists of 450 probabilistically sampled sites distributed across 15 watershed management units throughout southern California. The probabilistic sample design ensures an unbiased set of sites that represent the range of conditions across the region. Approximately 90 sites are sampled annually over 5 years to complete one full cycle of the SCRMP. Use of the SCRMP probabilistic sample draw will ultimately (once enough different sites are sampled) allow managers to draw inferences from this data set to expected recovery patterns for the entire region.

Following a fire, the CAL FIRE/BAER maps will be overlaid on a map of the SCRMP sites sampled during the previous three years. Sites where pre-fire bioassessment data is available (through the

[2] The SMC is a coalition of stormwater management agencies and Regional Water Quality Control Boards (RWQCBs) from Ventura to San Diego whose mission is to cooperatively answer the technical questions that enable better environmental decision-making regarding stormwater management. The SWAMP is a statewide receiving water monitoring program administered by the State Water Resources Control Board (SWRCB).

[3] CRAM is a rapid assessment tool designed to evaluate general ecological condition based on a set of readily observable field indicators

SCRMP) will be reoccupied for post-fire sampling, provided they meet several criteria: 1) sites are logistically and legally accessible; 2) site conditions have not substantially changed due to change in land use, significant flood, etc.; and 3) more than 80% of the contributing catchment is within the burned area. The SMC will be notified of sites selected for inclusion in the regional post-fire monitoring program in order to facilitate information sharing and coordination.

Selection of Comparison Sites

Initial comparisons can be made to the pre-fire data collected at the sampling site by the SCRMP. However, this comparison may have limited value. The SCRMP data represents a single point in time at a single location, which may or may not be representative of typical conditions at that location. A more appropriate comparison will be to the overall ambient data compiled by the SCRMP. These data provide a regional representation of ambient (pre-fire) conditions, which serve as an excellent reference to the post-fire data collected at a subset of the SCRMP sites.

Sample Collection

The persistence of effects/system recovery question will be assessed based on four indicators (Table 6). The first indicator is benthic macroinvertebrate bioassessment (eg., BMI, benthic IBI). Benthic macroinvertebrates will be sampled following SWAMP standard operating procedures (SOP) for multi-habitat sampling (Ode 2007). That is, a D-frame kick net will be used to collect benthic macroinvertebrates from eleven transects at 25, 50, and 75% of the stream width. This approach ("multi-habitat sampling") is appropriate for calculations of the southern Califorina IBI and River Invertebrate Prediction and Classification System (RIVPACs)-type observed over expected (O/E) scores (Rehn *et al*. 2007). For quality assurance (QA) purposes, one replicate sample per site will be collected. Collection of replicate samples will be off-set 5 m upstream from regular bioassessment samples. Samples will be preserved in the field and sent to taxonomists for sorting and identification. Taxa will be identified to Level I resolution, as defined by the Southwest Association of Freshwater Invertebrate Taxonomists(SAFIT), i.e., genus level for most taxa and Chironomidae left at family (Richards and Rogers 2006).

The second indicator is SWAMP physical habitat assessment (PHAB), which will be sampled using the existing SWAMP SOP (Ode 2007). The PHAB assessment evaluates a series of physical properties that can be used to interpret results of the benthic IBI (Table 6). The third indicator is an evaluation of the overall ecological condition of the stream and immediately adjacent riparian area riparian status using CRAM. California Rapid Assessment Method is a rapid, diagnostic tool that is part of a comprehensive statewide program to monitor the health of wetlands and riparian habitats throughout California (Collins *et al*. 2007; Table 6).

Table 6. Indicators measured at each site to address Management Question #3.

Indicator	Method	Accuracy	Precision	Reporting Limit
Biological				
Benthic macroinvertebrates	Ode 2007	Re-sort frequency: 100% Re-sort accuracy: ≥95% Lab ID frequency: 10% Lab ID Accuracy: ≥95%	Field duplicates: 10%	SAFIT* Level 2
Riparian condition (CRAM)	Collins 2007			
Toxicity				
Ceriodaphnia dubia assays	EPA 1993	NA	Lab duplicates 10%	NA
Water Chemistry				
Conventional water chemistry				
Temperature	Probe	NA	± 0.5 C	NA
pH	Probe	± 0.5 units of SRM*	± 0.5 units	0 - 14 pH units
Conductivity	Probe	±5% of SRM	±5%	2.5 mS/cm
Dissolved oxygen	Probe	±0.5 mg/L of SRM	±0.5 mg/L	0.5 mg/L
Alkalinity		±10% of SRM	±10%	10 mg/L
Hardness				
Physical habitat				
Location (latitude and longitude)	Ode 2007	NA	NA	10^{-5}°
Channel dimensions				1 cm
Channel substrate				1 mm
Embeddedness				NA
Gradient and sinuosity				NA
Human influence				NA
Riparian vegetation				NA
Instream habitat complexity				NA
Flow habitats				NA
Discharge				NA
Rapid bioassessment scores				NA
Additional habitat characterization				NA

*SAFIT: Southwest Association of Freshwater Invertebrate Taxonomists; SRM: Standard Reference Material

The fourth indicator is basic water chemistry including, temperature, pH, conductivity, dissolved oxygen, and alkalinity or hardness. These parameters will be measured in the field using a standard field meters. Measurements will be taken in triplicate at each monitoring site and values will be reported as the average of the three measurements. Calibration, operation and maintenance of these meters will follow the manufacturer's recommendations.

Stream discharge will also be measured at all sites using a magnetic head or a propeller cup pygmy flow meter at a minimum of three transects displaying uniform flow. The cross-sections will be divided into at least 10 equally-sized intervals; however, if the stream is narrow such that the intervals would be less than 15 cm, a smaller number of 15-cm intervals will be used. Velocity will be measured at 60% of the total depth at the midpoint of each interval. If discharge is too low for accurate use of a flow meter, a neutrally buoyant object will be used to measure velocity. If flow is too low to measure using a neutrally buoyant object, a qualitative observation of flow will be used instead (e.g., visible flow, isolated stagnant pools, etc.).

General data quality objectives (DQOs) for all indicators are provided in Table 7.

Table 7. Data quality objectives for field measurements.

Parameter	Accuracy	Precision	Recovery	Target Reporting Limit
Dissolved Oxygen	± 0.5 mg/L	10%	NA	0 mg/L
Temperature	± 0.5 °C	5%	NA	-5 °C
Specific Conductance	± 5%	5%	NA	0-100mS/cm
pH by meter	± 0.5 units	5%	NA	2-12
Depth	± 0.2 meters		NA	0 m
Turbidity	± 10% or 0.1, whichever is greater	± 10% or 0.1, whichever is greater	NA	0-3000 NTU
Flow			NA	
Local rainfall			NA	

Sample Analysis

The majority of indicators for this management question are measured in the field, except for the IBI. The Southern California IBI (Ode *et al*. 2005) and the California RIVPACS O/E taxa ratio will be calculated for each sample. The IBI is a multimetric index made up of seven semi-independent metrics (e.g., Coleoptera richness, percent non-insect taxa, etc.) that have been shown to decline in response to disturbance in southern Californian coastal streams. In contrast, RIVPACS is a multivariate approach which detects impairment as a loss of specific taxa expected to occur under observed environmental conditions (Hawkins *et al*. 2000). The California model has been validated for use across the State. Although both the IBI and RIVPACS have been used to assess nonperennial streams, it is unclear if these tools are valid throughout the entire drying period in nonperennial streams.

Duration of Monitoring

Each site shall be sampled only once per year for a minimum of three years following the fire. Results from the three annual post-fire samples will be compared to the pre-fire data collected by the SCRMP. Because the persistence of effects is unknown at this time, results should be reviewed in year three to determine if extension of the post-fire monitoring is warranted. As a general guideline if the year three IBI scores are more that 25% different than the pre-fire scores, monitoring should be extended until the scores are within this range.

Post-fire samples will be collected during an index period beginning four weeks following the last significant rainfall and no more than 12 weeks following the last rainfall. Significant rainfall is defined as precipitation that produces sufficient scouring to disrupt benthic communities. In addition, no sampling shall occur within 72 hours of any measureable rainfall. Based on historical rainfall records, the wet season in southern California ends April 15th; therefore, the default index period is from May 15 to July 15.

Program Implementation

Mobilization

Three mobilization decisions need to be made for each storm event following a fire: Is the fire substantial enough to warrant sampling? When (and where) should sampling commence? How long after a wildfire should sampling continue?

Potential monitoring sites will be identified using the pre-selection criteria discussed above. Monitoring will be considered for a given site if a fire was extensive enough for federal or state agencies to produce a burned area map. Agencies responsible for producing the maps are part of the Burned Area Emergency Response (BAER) teams, which typically include the California Department of Forestry and Fire Protection (CAL FIRE), U.S. Forest Service (USFS), and the Regional Water Quality Control Board. Maps from these agencies can be used to identify which resources are at risk within the burned areas, and therefore which of the pre-selected sites in the proposed monitoring program should be sampled. The likely sequence of events for mobilization would be:

1. Review the BAER maps for potential sampling locations
2. Consult with representatives of the CAL FIRE/BAER teams regarding size of the affected area, the burn severity, sensitive resources that potentially may be affected, and access issues.
3. Consult with a regional oversight team to produce a list of recommended priority sites for sampling. This information will be communicated to the Regional Boards, stormwater agencies, and back to the CAL FIRE/BAER teams to coordinate access for sampling.
4. Final selections will be made based on agency input, access, and safety considerations.

Data Management

A common data management system, such as California Environmental Data Exchange Network (CEDEN), will be necessary to integrate and disseminate data collected by multiple agencies throughout southern California. A single regional agency should serve as the data repository, with participating agencies agreeing to use a set of standard data transfer formats. This will allow each agency to retain control and ownership of the data they collect, while allowing data to be shared among all participating agencies through a regional "data center". The data center should include a secure web-based data portal that can be used to access all submitted data. The preliminary recommendation from the August 2008 workshop was that SCCWRP serve as the data center. This would facilitate coordination with the proposed SWAMP/CEDEN regional data center which would also reside at SCCWRP. Specifics of the data management system will be finalized in a subsequent information management plan.

Quality Assurance

Quality assurance procedures are necessary for managers to have confidence in the quality of the data used to support their decisions. Data Quality Objectives are quantitative and qualitative statements that clarify study objectives, and specify the tolerable levels of potential errors in the data. As defined in this plan, DQOs specify the quantity and quality of data required to support the study objectives. DQOs are generally used to determine the level of error considered to be acceptable in the data produced by the sampling or monitoring program. They are used to specify acceptable ranges of field sampling and laboratory performance. Confidence in the data requires standardized procedures for sample collection, processing, analysis, and data reporting. Some of the recommended QA procedures, including appropriate sample containers, holding conditions, analytical methods, and approximate costs can be found in Tables 4 through 7.

Standard operating procedures for field, laboratory, and data management tasks should be developed and updated on a regular basis in order to maintain procedural consistency. As a starting point, the SMC model monitoring program can provide initial standardization. The maintenance of an SOP Manual will provide project personnel with a reference guide for training new personnel as well as a standardized information source that personnel can access. Finally, the laboratory intercalibration requirements developed by the SMC should apply to participants of this program to ensure comparability of analytical results.

Funding

One of the main impediments to answering key management questions related to fire effects is that existing monitoring programs do not include provisions for sampling following periodic fires. Rather, funding is allocated toward meeting permit requirements and other local priorities.

The effect of fire on water quality is a regional question, and therefore, is best addressed and funded through a regional program that leverages resources between programs. Implementation of the regional program will require that necessary funding mechanisms are identified and committed in advance by both regulatory and discharger agencies.

Approximate costs to implement each of the three priority management questions are summarized in Table 8. The costs are provided on a per event basis and as overall costs to implement each element for the minimum duration recommended in this plan. These costs should be considered approximate and used for general planning purposes only.

Table 8: Approximate costs to implement design for each priority management question.

MQ 1: Flux		**MQ2: Effects**		**MQ3: Persistence**	
		Reconnaissance and site preparation			
storm site scouting	$5,000	receiving waters selection	$1,000	site recon	$2,500
		Sample collection			
automated storm sampling	$5,000	water and sediment	$500	bioassessment	$1,000
		Sample analysis			
basic constituents (4 bottles)	$1,000	sediment toxicity	$700	IBI	$1,500
nutrients (4 bottles)	$500	Phase 1 TIE* (optional)	$4,000	CRAM	$600
metals	$1,000	basic chemistry	$500	basic chemistry	$300
selected organics	$4,000				
		Totals			
Total cost per event	*$16,500*		*$2,700 - $3,200 w/o TIE*		*$5,900*
Min. recommended events	3		4		3
Approximate cost	*$49,500*		*$10,800 -$12,800*		*$17,700*

*TIE = Toxicity Evaluation Identification.

Several possible funding sources have been identified, including joint funding through the SMC, submittal of proposals for SEP (Supplemental Environment Projects), Department of Public Health, OEHHA (Office of Environmental Health Hazard Assessment), FEMA (Federal Emergency Management Agency) / Department of Homeland Security, WERF (Water Environment Research Foundation), land managers (e.g., Bureau of Land Management (BLM) and USFS), water supply agencies, and private industry. The ideal situation would be to secure an ongoing funding source, which will be more reliable than bond or grant monies, which are usually available for a limited time.

Another recommendation was to find opportunities to leverage off of existing programs. Two approaches were suggested. The first was for municipalities to reallocate part of their Municipal Separate Storm Sewer System (MS4) monitoring budgets to accommodate post-fire monitoring. This arrangement would need to be approved by both the municipalities and regulatory agencies, however both types of agencies agreed this would be a mutually beneficial arrangement. The other approach was for third party groups that have a vested interest in post-fire effects to leverage resources to the sampling effort. The potential groups identified included water supply purveyors (e.g., Santa Ana Watershed Project Authority (SAWPA), which is a collection of water districts), Integrated Regional Water Management Plan (IRWMP), USFS/Natural Resources Conservation Service (NRCS), Surface Water Ambient Monitoring Program (SWAMP), Federal Environmental Monitoring and Assessment Program (EMAP), California Stormwater Quality Association (CASQA), Water Environment Research Foundation (WERF), American Water Works Association (AWWA), Water Environment Federation (WEF), California Department of Fish and Game (CDFG), and Federal Wildlife Service (FWS). Securing funding mechanisms up-front will be a key element that determines the ability to implement plan.

Communication

The primary audiences for the information developed under this plan are those groups that will make a decision based on the data. This includes regulators who set standards and water quality limits, those who manage resources potentially affected by the runoff (e.g., USFS, BLM, CAL FIRE, Nature Conservancies, water suppliers/public health), managers that will make decisions about BMPs, and research scientists. Members of the media (who have a large impact on public perceptions of environmental-related issues) may also be interested in the findings.

It is anticipated that results of post-fire monitoring would be compiled at the southern California regional data center (currently hosted by SCCWRP). Use of standard data transfer formats (described above) will facilitate information sharing through the data center. This will also allow comparison of post-fire runoff characteristics to other data sets compiled through the data center (e.g., urban stormwater runoff). The workgroup recommended that a web-based map be developed to display and provide post-fire monitoring data compiled through this program and other related programs. Such a system would increase data availability and facilitate future collaborations. Additional mechanisms for communicating findings to target audience include conferences, reports, journal articles, fact sheets, and outreach meetings with specific groups (e.g., fire-specific agencies, resource managers). Risk area and damage assessment maps may be particularly useful products of this program for communicating the results. A long–term goal would be to have water quality effects be added as a data layer to future burn area maps produced by CAL FIRE and others.

Next Steps

The next step in creating a regional monitoring program is to initiate the phases of implementation. Each year, a record should be kept of all fires to help determine if they meet the mobilization criteria. In addition, appropriate pre-selected monitoring sites and reference sites should be indentified and mapped and a regional oversight team created that will determine when and where monitoring is most appropriate. This team should have strong participation from the CAL FIRE, USFS, the regional water quality control boards, and major municipalities. Finally sources of the funding should be defined and the process used to distribute the funds or leverage existing programs.

Ongoing program development and coordination can be accomplished through the post-fire runoff working group. This group will consist of participants from the workshop held in August, who want to be further involved in developing the region-wide program. Those interested in participating in the working group should feel free to contact Eric Stein (erics@sccwrp.org, 714/755-3233) or Jeff Brown (jeffb@sccwrp.org, 714/755-3226).

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Appendix A

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