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The Application of Monitoring and Modeling in Watershed Management

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8390 Main St. 2nd Floor • Ellicott City, MD 21043 • 410-461-8323 (phone)
410-461-8324 (fax) • www.awsps.org • Bulletin@awsps.org

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KEY CONTACTS:

Co-Editors-in-Chief
Neely Law (nll@cwp.org)
Karen Cappiella (kc@cwp.org)

Associate Editor
Lisa Fraley-McNeal (bulletin@awsps.org)

Sponsorship Coordinator
Erin Johnson (etj@cwp.org)

AWSPs Membership
(membership@awsps.org)

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showing City of Elmhurst employees recovering a dissolved oxygen probe from Salt Creek in Illinois as part of a stream dissolved oxygen feasibility study.

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The State of the San Gabriel River Watershed:
Using Multiple Indicators To Assess Watershed Health

*Kristy Morris[a] * and Scott Johnson[b]*

Abstract

The San Gabriel River Regional Monitoring Program (SGRRMP), developed by a stakeholder workgroup to provide a multilevel monitoring framework combining probabilistic and targeted sampling of watershed-scale water quality, toxicity, bioassessment, and physical habitat condition, was the first such monitoring effort in California. To assess the condition of streams in the watershed, SGRRMP sampled 69 unique sites from 2005 through 2009 using multiple lines of evidence, including indictors for aquatic chemistry, toxicity, bioassessment, and physical habitat conditions. Results demonstrated that stream conditions, particularly water quality and physical habitat, were less degraded in the upper (undeveloped) portion of the watershed compared to the lower, developed watershed, which includes the concrete-lined mainstem. To assess whether conditions at sites of unique interest are getting better or worse, SGRRMP annually monitored eight sites upstream of confluence points in the upper and lower watershed to assess temporal trends. After five years of monitoring, it has not been possible to discern temporal trends in aquatic chemistry, toxicity, and physical habitat conditions. Index of biological integrity scores were consistently above the impairment threshold for confluence sites in the upper watershed and below reference conditions in the lower watershed. Results from SGRRMP are directly comparable to regional and statewide programs and have led to several collaborative special studies. SGRRMP has successfully shown that a combination of probabilistic and targeted sampling can address watershed-scale management questions and can provide a context for answering essential management questions on a watershed, regional, and statewide scale.

Introduction

To assess the condition of surface waters in their respective regions, many local, regional, and state government agencies have developed ambient water quality monitoring programs. Data from such programs are valuable for answering questions specific to particular watersheds. However, these programs do not enable comparisons among watersheds or data sharing across agencies because they do not share a common monitoring design framework and they lack procedural, geographic, and temporal coordination.

Monitoring in the San Gabriel River watershed prior to 2005 was largely uncoordinated, with numerous agencies independently collecting data from defined portions of the watershed—mostly around major discharges for permit compliance purposes—while much of the watershed was left unmonitored. The large inconsistencies among programs in relation to the constituents sampled and the frequency of measurement resulted in limited data comparability, redundancies among monitoring programs, and major data gaps. Realization of these deficiencies led to the development of a coordinated watershed monitoring program that integrates permit-mandated and ambient monitoring.

The San Gabriel River Regional Monitoring Program (SGRRMP), developed by a multistakeholder workgroup in 2004 to provide a framework for watershed-scale monitoring, is the first such program in California. It provides coordinated, multilevel, watershed-wide monitoring by expanding the monitoring of ambient conditions, improving coordination and cost-effectiveness of disparate monitoring efforts, and providing a framework for periodic and comprehensive assessments of watershed conditions.

The development of the monitoring design brought together watershed stakeholders consisting of representatives from state and federal water regulatory agencies, key permittees in the watershed, other resource management agencies, nonprofit organizations, and citizen monitoring groups. In the first steps in SGRRMP's development, the workgroup created a list of core monitoring questions and assessed the ability of current monitoring efforts in the watershed to answer these questions. The workgroup then recommended monitoring designs to effectively and efficiently answer these questions and achieve multiple objectives. The resulting program is a multilevel monitoring framework that combines probabilistic and targeted sampling for water quality, toxicity, bioassessment, and physical habitat condition (Figure 1).

[a] *Senior Scientist, Council for Watershed Health, Los Angeles, CA, kristy@watershedhealth.org*
[b] *Senior Scientist/Laboratory Manager, Aquatic Bioassay and Consulting Inc, Ventura, CA*
* *Corresponding author*

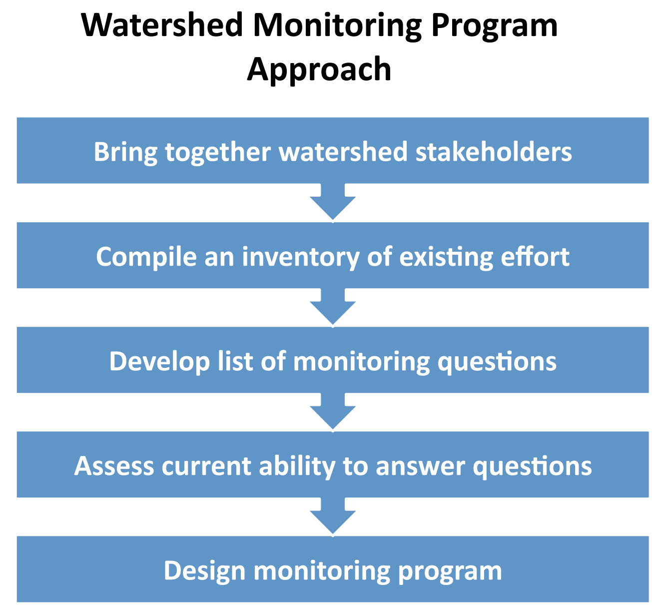

Figure 1. Approach for developing the San Gabriel River Regional Monitoring Program.

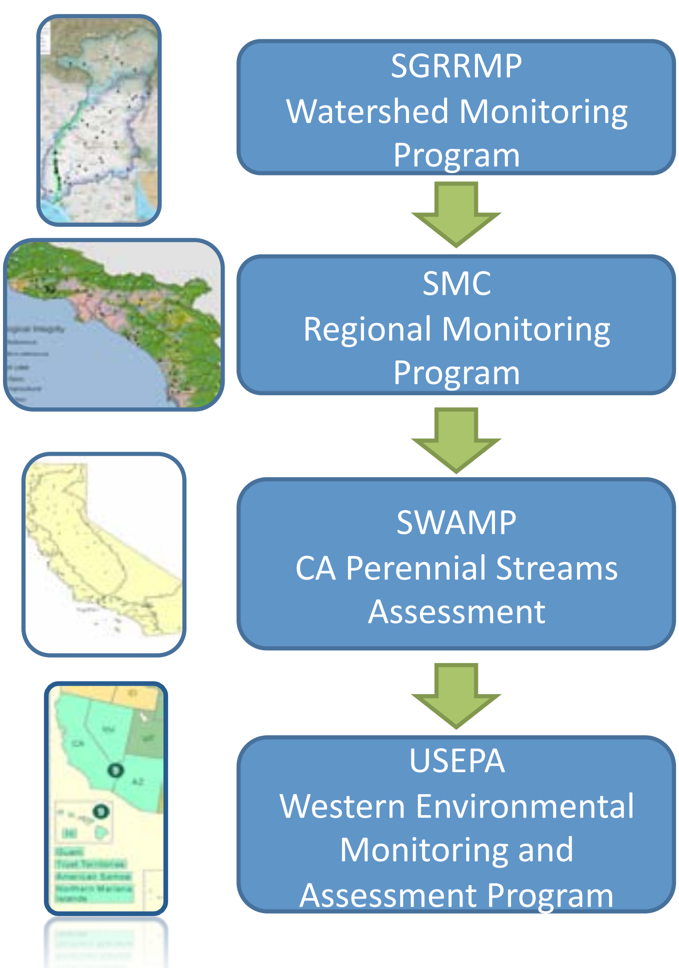

Figure 2. Integration of watershed monitoring programs.

The overall program design addresses each of the following five key management questions:

1. What is the condition of streams in the watershed?
2. Are conditions at areas of unique interest getting better or worse?
3. Are receiving waters near discharges meeting water quality objectives?
4. Is it safe to swim?
5. Are locally caught fish safe to eat?

These questions provide the rationale for the design approach, selection of monitoring indicators, sampling frequencies, and appropriate data products. The monitoring is focused on collecting data that help managers make scientifically informed decisions. The monitoring design is also intended to be adaptive, in terms of its ability both to initiate follow-up studies as needed and to make necessary changes based on monitoring findings.

Finally, SGRRMP was developed to complement, coordinate, and integrate with existing larger-scale monitoring efforts that address similar questions and concerns at the regional, state, and national levels. For example, the monitoring design to assess question 1, regarding the ambient condition of streams, can be seen as a watershed-scale counterpart to the Stormwater Monitoring Coalition's (SMC) Southern California Regional Monitoring Program, the state's Surface Water Ambient Monitoring Program (SWAMP), and the US Environmental Protection Agency's (USEPA) Western Environmental Monitoring and Assessment Program (Figure 2). These programs are embedded, one within the other, as a result of their shared probabilistic monitoring designs. This feature allows managers to compare the findings from their own watersheds to those of other watersheds in the region, the state, and the western United States. Other benefits of this program include the integration, coordination, and standardization of sampling protocols, laboratory methods, quality assurance programs, and data management efforts.

This paper describes the utility of integrated watershed monitoring programs for informing watershed managers, regulators, scientists, and the public regarding the current state of their watersheds. The results from five years of monitoring by SGRRMP provide an example of how this type of monitoring approach can address a wide range of management questions and improve monitoring efficiencies. The goals of this paper are to (1) provide a summary of the monitoring results for questions 1 and 2 for

SGRRMP's first five years (2005 to 2009), (2) show how these results have informed management decisions, and (3) describe how special studies are being designed to answer questions that arise as a result of this effort.

Methods

Study Area

The San Gabriel River watershed, located in coastal Southern California, is semi-arid with a Mediterranean climate (Figure 3). It is bounded by the San Gabriel Mountains to the north, the San Bernardino Mountains to the east, the watershed divide with the Los Angeles River to the west, and the Pacific Ocean to the south. Approximately half of the 1,785-km^2 watershed consists of extensive areas of undisturbed riparian, chaparral, and woodland habitats within the Angeles National Forest in the upper watershed. The heavily urbanized lower watershed is home to more than 2.3 million people. This part of the river and its major tributaries flow primarily in concrete-lined or heavily shored, soft-bottom channels. The river finally passes through the San Gabriel River Estuary, a shored, soft-bottom channel that discharges to the Pacific Ocean in the city of Long Beach.

Figure 3. The San Gabriel River watershed and San Gabriel River Regional Monitoring Program sampling sites, 2005–2009.

Sampling

To assess question 1, regarding the condition of streams in the watershed, SGRRMP sampled a total of 69 sites from 2005 through 2009 (Figure 3). SGRRMP determined sampling locations using a "master list" approach to integrate sampling efforts by multiple agencies and to facilitate collaboration with other monitoring programs (Larsen et al. 2008). Between 2005 and 2008, USEPA randomly selected sites for SGRRMP using a spatially balanced, generalized, random-tessellation design (Stevens and Olsen 2004). Sites were drawn with the entire watershed representing a single stratum, but weighted so that an even number of sites were drawn from each of three distinct watershed subregions: the upper watershed, lower watershed, and mainstem channel (Figure 3). Starting in 2009, SGRRMP integrated into the newly developed and larger regionwide SMC program, which uses a master list of more than 50,000 sites that are randomly distributed across the stream network of the entire Southern California region using the same spatially balanced, generalized, random-tessellation design. SGRRMP then assigned sites to the watershed using a geographic information system. SGRRMP classified sites by (1) Strahler stream order, using the National Hydrography Dataset Plus and (2) land use, based on the designation of the stream segment. SGRRMP excluded streams below second order from the survey because these sites are typically non perennial or inaccessible in mountainous regions.

SGRRMP employed a monitoring approach using multiple lines of evidence to assess stream conditions, including measurements for chemical, toxicological, biological, and physical habitat (Figure 4).

SGRRMP used bioassessment, a measure of the structure of one or more components of the instream biological community, to assess the ecological status of instream benthic macroinvertebrate (BMI) communities. The field protocols and assessment procedures followed the California SWAMP (2007) stream bioassessment protocol. SGRRMP identified BMIs to level II (generally, the species level), as specified by the standard taxonomic effort list of the Southwest Association of Freshwater

Invertebrate Taxonomists (Richards and Rogers 2006). Using BMI data collected from perennial streams, SGRRMP calculated biological metrics including diversity, average tolerance scores, and functional feeding groups. SMC's Regional Monitoring Program defines perennial steams for Southern California as those flowing through September 30 because of the highly intermittent nature of stream flow in the region. From these metrics, SGRRMP calculated the multimetric Southern California index of biological integrity (IBI) for each site (Ode et al. 2005). The IBI score derived for each site allows for a comparison of that site's biological community with that of "undisturbed" reference sites in Southern California. The sampling index period for surveys of all components of stream condition was May through July.

SGRRMP assessed physical habitat conditions using two methods. The first is a method originally developed by USEPA and modified by SWAMP (2007) for use in California. This method focuses on the habitat conditions found in the streambed and riparian corridor, including streambed morphology (e.g., width, depth, and bankfull width), vegetative density and canopy cover, substrate composition, sedimentation, human influences, and flow regimes. The second measure, the California Rapid Assessment Method (CRAM), more broadly characterizes the overall function and quality of the riparian and buffer zone system (Collins et al. 2008). The CRAM score includes the hydrologic, physical, biological, and buffer zone conditions of the habitat out to 500 m on either side of the streambed. The maximum possible score represents the best condition likely to be achieved for the type of wetland being assessed. The overall score for a site therefore indicates how it is doing relative to the best achievable conditions for that wetland type in the state.

SGRRMP used a target-site approach to address question 2, which asks whether conditions at sites of unique interest are getting better or worse. This target-site approach differs from the random sampling design used to assess ambient stream conditions for question 1 because target sites are revisited annually as opposed to only once. SGRRMP monitored stream confluences and four wetland sites to determine how the chemical, toxicological, biological, and physical habitat conditions might be improving or declining over time.

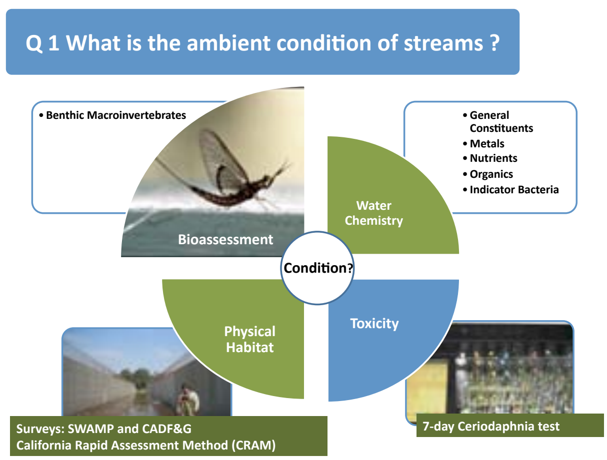

Figure 4. Multiple lines of evidence used to assess stream condition. CADF&G, California Department of Fish and Game.

SGRRMP selected the four wetland sites because of their relatively natural state in otherwise heavily urbanized areas. Assessing the baseline condition of these sites and following them over time will inform either restorative or protective management actions. The four sites included one estuarine habitat, Los Cerritos wetland in Long Beach, and three riverine wetlands: Santa Fe dam scrub habitat in Irwindale, Walnut Creek County Park in San Dimas, and a localized wetland area at Whittier Narrows. SGRRMP performed CRAM assessments annually (in 2008 and 2009) at the three riverine wetlands, and visited Los Cerritos wetland on three separate occasions in 2008 only.

To assess temporal trends at the sub watershed level, SGRRMP monitored eight sites upstream of confluence points in the upper and lower watersheds. SGRRMP has collected a total of 40 samples from the eight target sampling locations—1 sample per site for five years, from 2005 to 2009. SGRRMP analyzed target site samples for aquatic chemistry, toxicity, biota, and physical habitat condition as described above for question 1.

Laboratory Analysis

Table 1 lists the chemical constituents measured at each site and the method's detection limits. The analytical methods for each chemical constituent, as well as data quality objectives for each group of constituents, can be found in the SGRRMP quality assurance project plan (Los Angeles & San Gabriel Rivers Watershed Council and Aquatic Bioassay & Consulting Laboratories 2010). SGRRMP performed toxicity testing on 100% stream water using the water flea (*Ceriodaphnia dubia*) seven-day survival and reproduction test (USEPA 2002).

Table 1. Methods and minimum detection limits for measured water quality parameters in freshwater.

Analyte	Method	Minimum Detection Limit
Ammonia as N	SM 4500-NH3 D[b]	0.03–0.05 mg/L
Dissolved Organic Carbon	EPA 415.1[c]	0.013 mg/L
Nitrate as N	EPA 300.0[c]	0.013 mg/L
Nitrite as N	EPA 300.0 [c]	0.01 mg/L
Alkalinity as $CaCO_3$	SM 2320B[b]	1–1.2 mg/L
Hardness as $CaCO_3$	SM 2340B[b]	0.089–1 (mg $CaCO_3$/L)
Total Nitrogen	Calculated	Calculated (mg/L)
Total Kjeldahl Nitrogen	EPA 351.3 [c]	0.74 mg/L
Total Organic Carbon	EPA 415.1 [c]	0.13–0.32 mg/L
Orthophosphate as P	SM 4500-P E[b]	0.00083–0.01 mg/L
Phosphorus as P	SM 4500-P C[b]	No value[a]
Total Suspended Solids	SM 2540D[b]	0.5–5 mg/L
Trace Metals (total and dissolved)	EPA 200.8 [c]	0.008–0.6 µg/L
Mercury (total and dissolved)	EPA 1631 [c]	0.0005–0.0039 µg/L
Toxicity	(*Ceriodaphnia dubia*) test [d]	

Note: $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus.
[a] *No minimum detection limit reported; reporting limit range = 0.1–0.5 mg/L.*
[b] *American Public Health Association (2005)*
[c] *USEPA (n.d.[a])*
[d] *USEPA (2002)*

Data Analysis

SGRRMP characterized aquatic chemistry and physical habitat data from each of the three subregions using descriptive statistics, including the means, standard deviations, medians, and ranges of concentrations (R-CRAN statistical software). Where applicable, SGRRMP compared aquatic chemistry values to numeric regulatory thresholds, such as those specified in the Los Angeles basin plan objectives (Los Angeles Regional Water Quality Control Board 1994) and the California Toxics Rule (CTR; USEPA n.d.[b]), to determine the number of times they exceeded these values.

To assess the biological condition of streams, SGRRMP compared area-weighted IBI scores against reference site conditions in Southern California. IBI scores below 39 (on a scale of 100) represent communities that are below reference conditions, and those 39 and above represent sites where biological conditions are similar to reference site conditions in the region.

The determination of toxic endpoints for the water flea seven-day survival and reproduction test was based on (1) a statistically significant difference in either survival or reproduction between water fleas held in 100% stream water and those held in laboratory control water and (2) a response of less than 80% for either survival or reproduction.

SGRRMP calculated an overall CRAM score for each site from four main attribute scores and their metrics: landscape context and buffer, hydrology, physical structure, and biotic structure. No regulatory thresholds are described for CRAM scores; the lowest CRAM score possible for these sites is 27, and the maximum score is 100. SGRRMP compared the overall scores across sites and years to determine temporal and spatial trends.

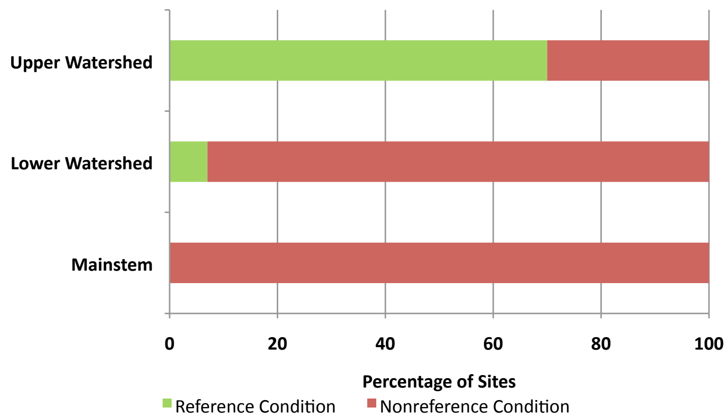

Figure 5. Biological condition (IBI scores) for different watershed subregions.

Results

Q1: What is the condition of streams in the watershed?

SGRRMP collected and assessed aquatic chemistry, toxicity, bioassessment, and physical habitat data from 69 randomly selected sites throughout the San Gabriel River watershed from 2005 through 2009. During this five-year period, BMI communities in the upper watershed had IBI scores greater than 39, indicating that BMI communities there were similar to those found at reference sites throughout Southern California (Figure 5, Table 2). Only 30% of stream miles in the watershed had IBI scores similar to those of reference sites. When evaluated by subregion, 70% of upper watershed sites were in good condition, whereas only 7% of the lower watershed tributaries and none of the mainstem sites were in good biological condition. Interestingly, several upper watershed sites that appeared to have good water quality and physical habitat conditions had biological communities that were impaired relative to reference sites. This has triggered follow-up studies to investigate the source of the impairment.

Biological communities in the upper watershed exhibited a wide range of feeding strategies and were characterized by pollution-sensitive organisms (Figure 6). Collector species dominated this subregion, but a wide range of other groups, including grazers, filterers, and predators, made up a combined 20% of the population. The upper watershed was the only subregion where highly sensitive species were found, such as stoneflies (*Calineuria californica*, *Makenka sp.*, and *Sweltsa sp.*), mayflies (*Drunella sp.*, *Ephemerella sp.*, and *Epeorus sp.*), and caddisflies *Micrasema sp.*, *Parapsyche sp.*, *Rhyacophila sp.*, and *Lepidostoma sp.*). In contrast, the biological communities in the lower watershed were more degraded, as evidenced by lower IBI scores (below 39); less diverse feeding strategies, such as fewer predator and collector taxa; and the dominance of organisms more tolerant of pollution, such as Oligochaetes, Ostracoda, *Hyalella sp.* (Amphipoda), and gastropods (*Physa sp.*).

A comparison of chemical constituents revealed differences in concentrations in the upper watershed, lower watershed, and mainstem (Table 2). Nutrient and metal concentrations were consistently lower at upper watershed sites than in the lower tributaries and the mainstem. Nutrients were greatest in the mainstem, whereas most metals were greatest in the lower tributaries. An exception to this was dissolved zinc, which was much greater in the mainstem compared to the other subregions. Aquatic chemistry concentrations rarely exceeded numeric regulatory thresholds during the five-year period. Nitrate and ammonia were well below toxicity thresholds, and SGRRMP found no exceedances of the hardness-adjusted CTR threshold for any dissolved metal. Nearly all organic constituents, including organophosphorus and pyrethroid pesticides, were always below the limits of detection.

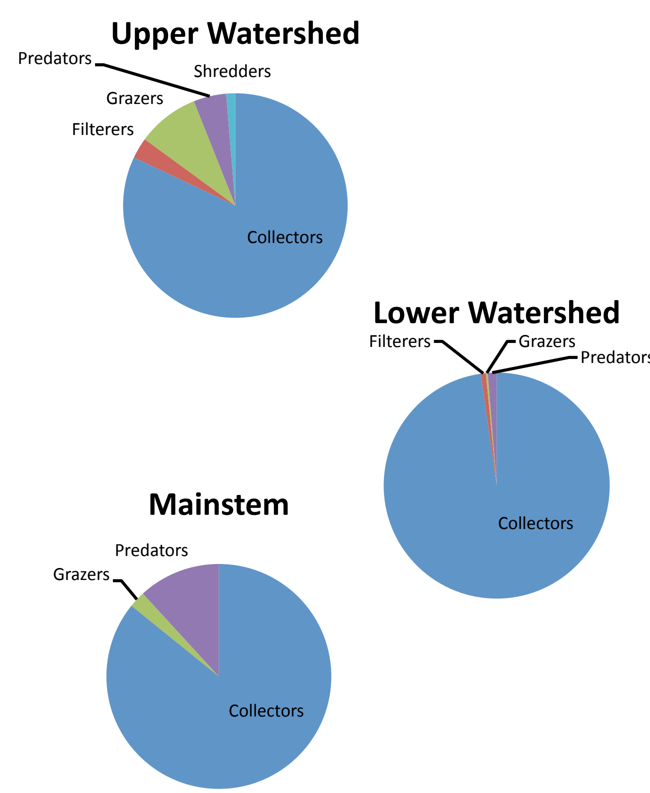

Figure 6. Relative proportions of macroinvertebrate functional feeding groups in each watershed subregion for all random sites combined, 2005 to 2009.

Table 2. Summary statistics for samples collected from three subregions of the San Gabriel River watershed and compared against regulatory water quality objectives where applicable.

	Upper Watershed		Mainstem		Lower Watershed		Min	Max	No. of Exc.
	Mean ± Std. Dev.	Median	Mean ± Std. Dev.	Median	Mean ± Std. Dev.	Median			
General Chemistry									
DO (mg/L)	8.3 ± 1.9	8.8	12 ± 4.2	12	11 ± 4.9	9.9	1.9	24	4
pH (-log[H+])	8.1 ± 0.28	8.2	8.1 ± 0.6	8.3	8.4 ± 0.79	8.1	7.2	10	16
Salinity (mS/cm)	0.2 ± 0.07	0.2	0.59 ± 0.08	0.60	5.8 ± 18	0.6	0.08	79	no obj.
Temperature (°C)	16 ± 2.4	16	28 ± 1.7	28	23 ± 5.7	23	12	36	
Alkalinity (mg/L)	196 ± 56	183	154 ± 19	154	203 ± 109	199	64	448	
Hardness (mg/L)	185 ± 88	162	197 ± 47	200	398 ± 315	266	74	1480	
TSS (mg/L)	2.86 ± 1.89	2.5	7.6 ± 5.5	5.0	38 ± 89	38	0.50	408	
TOC (mg/L)	1.7 ± 0.79	1.8	6.4 ± 0.87	6.9	12 ± 13	6.6	0.47	46	
Dissolved Metals (µg/L)									
As	11 ± 1.7	0.50	1.0 ± 0.37	0.90	2.1 ± 2.4	1.9	0.20	12	0
Cr	0.22 ± 0.07	0.25	0.74 ± 0.65	0.60	0.82 ± 0.88	0.6	0.08	4.1	0
Cu	0.6 ± 0.32	0.50	3.5 ± 1.9	2.7	6.1 ± 5.7	3.6	0.13	22	2[b], 1[c]
Fe	36 ± 36	25	72 ± 27	70	82 ± 108	48.3	1.25	465	no obj.
Pb	0.19 ± 0.48	0.05	0.27 ± 0.17	0.22	0.45 ± 0.74	0.2	0.01	2.5	0
Ni	0.28 ± 0.11	0.25	3.8 ± 0.89	4.0	3.4 ± 4.7	2.5	0.01	23	0
Se	0.33 ± 0.13	0.28	0.61 ± 0.34	0.50	2.4 ± 2.0	2.2	0.00	6.7	3c
Sr	348 ± 121	333	528 ± 130	548	817 ± 508	732	174	2176	no obj.
Zn	1.5 ± 1.9	0.50	36 ± 2.9	37	11 ± 9.3	8.5	0.02	39	0
Nutrients (mg/L)									
NH_4^+ (total)	0.04 ± 0.02	0.05	0.23 ± 0.26	0.19	0.11 ± 0.14	0.1	0.01	0.90	
NO_3^- N (dissolved)	0.27 ± 0.29	0.10	4.4 ± 4.4	3.4	1.2 ± 1.6	0.0	0.01	21.5	1
NO_2^- N (dissolved)	0.02 ± 0.01	0.02	0.18 ± 0.1	0.19	0.03 ± 0.03	0.0	0.01	0.38	0
TN-Kjeldahl	0.44 ± 0.47	0.25	1.78 ± 0.6	1.7	1.9 ± 1.9	1.1	0.05	7.4	
PO_4 (total)	0.12 ± 0.12	0.09	0.3 ± 0.26	0.25	0.16 ± 0.25	0.1	0.01	1.2	
TP	0.03 ± 0.01	0.03	0.26 ± 0.13	0.21	0.31 ± 0.41	0.1	0.02	1.6	
Physical Habitat Assessments									
CRAM Score	82 ± 11	82	34 ± 3.4	34	42 ± 15	37	27	96	
IBI Score	52 ± 17	52	17 ± 9.9	16	16 ± 13	10	0	89	40

Note: As, arsenic; Cr, chromium; Cu, copper; DO, dissolved oxygen; Exc., exceedances; Fe, iron; NH_4^+, ammonium; Ni, nickle; NO_2^-, nitrite; NO_3^-, nitrate.; no obj., no objective; Pb, lead; PO_4, orthophosphorus; Se, selenium; Sr, strontium; TN, total nitrogen; TOC, total organic carbon; TP, total phosphorus; TSS, total suspended solids; Zn, zinc.

DO water quality objective: 5 or ≥ 7.

pH water quality objective: 6.5 – 8.5.

NO_3^- N water quality objective: 10 mg/L.

NO_2^- N water quality objective: 1 mg/L.

[a] Hardness-adjusted dissolved metals compared to the CTR

[b] CTR acute threshold value

[c] CTR chronic threshold value

SGRRMP tested a total of 61 water samples for acute and chronic toxicity using water fleas. Out of 122 survival and reproduction endpoints measured, 13 (11%) indicated toxicity in at least one sample. Toxic endpoints indicative of toxicity were most frequent in 2005, when 6 of the 23 samples (26%) showed reproductive toxicity. All of the toxic endpoints measured during the five years were in the lower or upper watershed; no toxicity was measured on the San Gabriel River mainstem (Table 3).

Q2: Are conditions at areas of unique interest getting better or worse?

Assessing the baseline condition of sites and following them over time can inform managers regarding the success or necessity of restorative or protective measures. SGRRMP chose major stream confluences to act as water quality sentinel sites for the main subwatersheds. The four wetland sites chosen by stakeholders represent some of the last relatively natural ecosystems in the highly urbanized lower watershed; by understanding their status, managers may be able to make better decisions regarding their protection and/or restoration.

The results from the target sampling sites support the spatial variability in IBI scores shown by random sites. Biological communities were consistently similar to reference conditions at upper watershed confluence sites and impaired at sites in the lower watershed (Figure 7). Interestingly, Site 505 is

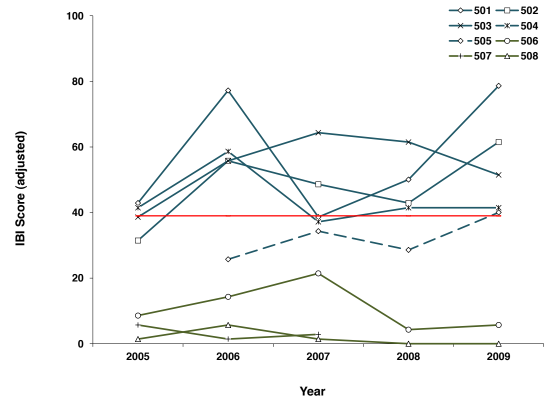

Figure 7. Southern California IBI scores at confluence sites. Sites with an IBI ≥ 39 (red horizontal line) have biological communities similar to those of reference sites for the region; sites with an IBI < 39 have biological communities that are degraded relative to reference conditions.

located immediately below Morris dam, the last reservoir in the upper watershed before the river enters the highly urbanized lower watershed. The riparian zone at this site is in relatively good condition; however, the intermittent discharges from the dam are evidenced in the impaired IBI score.

We found no clear temporal trends in aquatic chemistry parameters, particularly for those constituents with inherently high daily variability, such as pH and water temperature. Similarly, we observed very little annual variability for

Table 3. Water flea (*Ceriodaphnia dubia*) survival and reproduction—significant response endpoints.

Year	Endpoint	Significant Endpoints		Significant Response by Subregion		
		n	Signif. Tox.	Mainstem	Lower	Upper
2005	Survival	23	1	0	0	1
	Reproduction	23	5	0	2	3
2006	Survival	10	0	0	0	0
	Reproduction	10	0	0	0	0
2007	Survival	9	0	0	0	0
	Reproduction	9	2	0	1	1
2008	Survival	9	2	0	1	1
	Reproduction	9	2	0	1	1
2009	Survival	10	0	0	0	0
	Reproduction	10	1	0	1	0
	Totals	**122**	**13**	**0**	**6**	**7**
	%		**11**	**0**	**5**	**6**

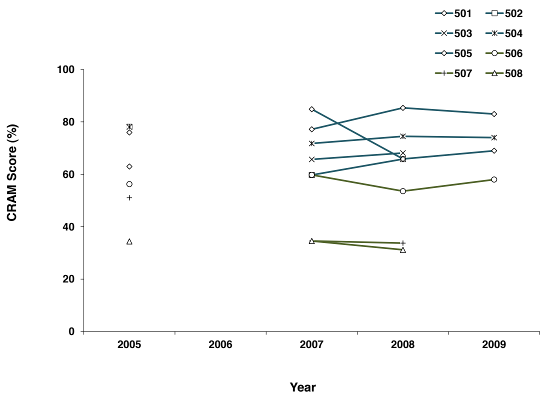

Figure 8. California Rapid Assessment Method scores at confluence sites.

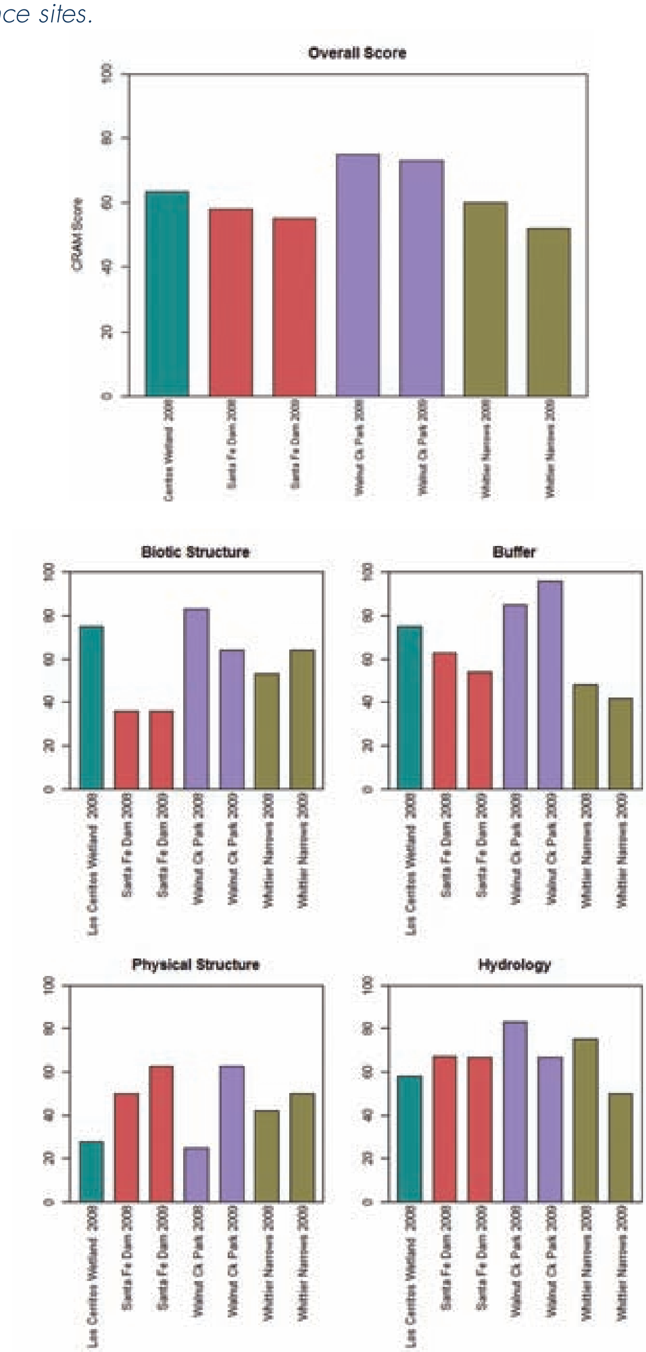

Figure 9. California Rapid Assessment Method attribute and overall scores for four unique habitats.

physical habitat conditions, as measured by CRAM, over the period (Figure 8).

CRAM assessment at each of the three riverine wetland habitats was relatively stable over the two-year period (Figure 9). The highest scores were calculated for Walnut Creek Park, which is characterized by a relatively natural streambed, wide and pervious buffer zones, good vegetative cover and layering, and few nonendemic species. Whittier Narrows and Santa Fe dam had lower CRAM scores, mostly because of the relatively poor buffer zone and poor biotic structure, respectively. CRAM scores at Los Cerritos wetland in 2008 were moderate. One of the last functioning estuarine wetlands in the greater Los Angeles area, Los Cerritos wetland is encroached upon from all sides by break walls, shoring, and heavy urbanization. A large effort is underway to protect and restore this habitat.

Discussion

Prior to 2005, managers knew little about the ambient water quality condition of streams in the San Gabriel River watershed, other than at fixed points located around discharges monitored under the National Pollutant Discharge Elimination Systems mainly in the cement-lined mainstem channel. As a result, the conditions in the lower watershed tributaries and upper watershed were unknown. The results from the first five years of monitoring clearly demonstrate the value of combining randomized watershed-scale sampling with targeted sampling at confluences and sites of unique interest. The multiple lines of evidence collected by SGRRMP (bioassessment, aquatic chemistry, aquatic toxicity, and physical habitat) have (1) provided a basis for investigating the factors contributing to the degradation of stream condition and (2) enabled stakeholders to begin to draw conclusions about the condition of the entire watershed.

Most importantly, the state of the biological communities was strongly associated with the physical habitat conditions of the streambeds and riparian zones. This suggests that protective measures should include efforts to reduce impacts to physical habitat in the upper watershed while simultaneously restoring riparian and stream habitat in the lower watershed where possible. SGRRMP did not find evidence of widespread impairment of water quality based on levels of individual chemicals or measures of toxicity.

When we observed toxicity, it was confined to sites in the upper watershed. For individual chemical constituents, such as copper, selenium, and zinc, the exceedances of regulatory objectives are localized; managers can use this information to implement best management practices to reduce the sources and/or concentrations of the contaminants.

A clear benefit to managers who choose to use the probabilistic sampling design will be the ability to compare the San Gabriel River watershed with other watersheds in the state and throughout the western United States. For example, in 2009, SMC's Regional Monitoring Program identified aquatic toxicity at numerous upper watershed sites throughout Southern California (Mazor et al. 2009). Prior to this, SGRRMP stakeholders assumed that the toxicity measured in the upper San Gabriel River watershed was an anomaly in the region. Potential sources of this toxicity, which are currently under investigation, include contaminants that are not being measured, underlying geologic features of the region, or naturally occurring cyanotoxins (products of blue-green algal metabolism).

Moreover, although biological communities in the upper watershed were generally similar to reference conditions, IBI scores were below the impairment threshold (39) at several sites during the five-year period. These sites had good physical habitat conditions and did not exceed regulatory thresholds for measured chemical constituents. Data from regional and statewide monitoring programs support these results; this has led to a much larger discussion regarding which stream reaches in California are truly perennial. This is important because the IBI scores developed for each of the state's ecoregions are based on biological condition data collected from perennial streams. It is not known how intermittent drying of a streambed might affect the biological communities.

The areas of concern identified after five years of monitoring by SGRRMP are consistent with the findings from other regional and state monitoring programs. As a result, collaborative efforts to design, fund, and conduct special follow-up studies are preferred over watershed-specific studies with more limited applicability. The follow-up toxicity study will potentially revisit sites that previously showed evidence of toxicity throughout the Southern California region to conduct toxicity identification evaluations, a process designed to identify the contaminant(s) causing toxicity. SMC is designing a stream perenniality study; this study will require site revisits throughout the Southern California region at the end of the dry season (September) to determine whether streams are still flowing. These studies have resulted from the probabilistic sampling design employed at the local, regional, and state levels.

Results from five years of monitoring at confluence sites and sites of unique interest demonstrated that trends are not discernible at this monitoring frequency. Other longer-term monitoring programs, such as the US Geological Survey's National Stream Quality Accounting Network, suggest that many more years of monitoring at target sites will be required to clearly discern trends.

The design of SGRRMP is based on clear statements of rationale and criteria for decision making about design options. SGRRMP also reflects a high degree of consensus among a broadly representative group of stakeholders in the watershed. It represents a significant advance toward the regional integration of monitoring efforts and the assessment of watershed condition. However, it is important to recognize that, although the program will enhance the ability to assess the status of some beneficial uses, it will not provide the means, across the entire watershed, to (1) fully determine compliance with water quality objectives, (2) define impairment, or (3) determine whether the requirements of the listing/delisting process under Section 303(d) of the Clean Water Act are being met. Such purposes require more spatially and temporally intensive sampling efforts, the requirements of which are met by only some of the components of SGRRMP.

Conclusion

SGRRMP has successfully shown that an integrated watershed monitoring program can provide context to essential management questions, improve monitoring efficiencies, and provide a collaborative platform for the comparison of monitoring results at the local, regional, and state levels. In the future, SGRRMP will continue to address specific issues, such as changes in the condition of critical habitat areas and public health risks associated with swimming or consuming fish. During 2011–2012, the program will (1) fund pilot studies to gain a better understanding of the speciation of mercury in fish tissues, (2) collaborate with the State Water Board's SWAMP to monitor polybrominated diphenyl ethers (flame retardants) in sediments within the watershed, and (3) continue sampling at sites burned by the 2009 Morris fires to monitor their recovery. SGRRMP is focused on assisting watershed managers in identifying areas of concern to prioritize management actions.

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