



MONITORING TOOLS FOR WATERSHED ASSESSMENTS

Prepared by:

Christopher Warn
Weston Solutions, Inc. (WESTON®)

For Presentation at:

2006 StormCon

24 - 27 July 2006
Denver, CO, USA

MONITORING TOOLS FOR WATERSHED ASSESSMENTS

Christopher T. Warn, Weston Solutions, Inc., Sarasota, FL

ABSTRACT

Weston Solutions, Inc. (WESTON[®]) has designed and implemented a watershed-based monitoring program with the San Diego County Copermittees. The monitoring program includes three elements: Mass Loading Station (MLS) Monitoring, Stream Bioassessment Monitoring, and Ambient Bay and Lagoon Monitoring.

The core program includes the collection and analysis of stormwater runoff during three storm events at 10 MLSs. Samples are analyzed for chemical constituents, biological indicators, and toxicity to bioassay test organisms. In addition to flow, rainfall for each MLS is recorded for each of the three monitored storm events. Rainfall distributions and totals are calculated by interpolating between rainfall amounts from available National Weather Service, San Diego County, and MLS rain gauges.

Statistical tools are used to make comparisons between watersheds. Statistical analyses for cross watershed comparison include scatterplot analysis, regression analysis, analysis of variance (ANOVA), and multivariate cluster analysis. The relationships between toxicity and constituents of concern (COCs) are evaluated using two statistical tools. The first method uses a multiple regression model to correlate changes in toxicity to changes in COC levels in the water. A second method, threshold analysis, is used to test relationships for COC with established thresholds.

In addition to monitoring, predicted pollutant loads and event mean concentrations (EMCs) expected from MLSs are calculated using a spreadsheet model. The model provides a comparison of anticipated results based upon land uses to measured results at MLSs during storm events.

These monitoring and assessment tools provide the basis for water quality assessments and processes for watershed stakeholders to evaluate the conditions and improvements of watershed water quality through time.

INTRODUCTION

The County of San Diego, City of San Diego, San Diego Unified Port District, San Diego Regional Airport Authority, and 17 other cities (collectively referred to as “Copermittees”) are covered under a municipal National Pollutant Discharge Elimination System (NPDES) permit for discharge of runoff to U.S. waters. A monitoring program was designed with the Copermittees to be adaptive and provide long-term trend information for predicting short- and long-term impacts to receiving waters that result from changes in land use within each watershed, and provide data that can be analyzed to develop pollutant reduction strategies for those impacts.

The monitoring program includes three elements: Mass Loading Station (MLS) Monitoring, Stream Bioassessment Monitoring, and Ambient Bay and Lagoon Monitoring. The tools used for these programs are outlined below.

MONITORING TOOLS

The core program includes the collection and analysis of stormwater runoff during three storm events at 11 MLSs. The MLSs monitor large drainage areas with mixed land-use characteristics. The MLSs were selected to directly measure pollutant loads being discharged into San Diego’s receiving waters by the major watersheds within the San Diego region. Monitoring sites were installed where flow from the

catchment area passes a single hydrologically ratable point, and is suitable for measurements and sampling. In some instances, sites were located upstream of the drainage area discharge point for accessibility and/or to avoid tidal influences. Samples are analyzed for chemical constituents, biological indicators, and toxicity to bioassay test organisms.

The MLSs consist of an integrated system of American Sigma 950 flow meters, 900 MAX automatic samplers, tipping bucket rain gauges, and cellular modems for real-time telemetry (Figure 1). A variety of flow measurement technologies are utilized to calculate flow rates including ultrasonic sensors, bubblers, and area velocity pressure transducers.



Figure 1. Mass Loading Station.

Stormwater samples are flow-weighted composites of the storm event. Scientists monitor the incoming storm events and remotely program the MLS to sample based on forecasted rainfall amounts and expected runoff. The flow meter then paces the autosampler based on these calculations. Field crews periodically visit the site to collect grab samples and change composite bottles as needed. Grab samples are collected for those constituents that are not amenable to composite sampling. Field measurements are taken for pH, temperature, and conductivity using Oakton pH CON 10 meters.

Field crews measure the flow rate of streams using U.S. Geological Survey (USGS) stream profiling guidelines prior to the beginning of the storm season, and periodically throughout the storm season. This is accomplished by manual rating techniques using a hand-held flow meter (Figure 2). A Marsh-McBirney Model 2000 portable flow meter connected via cable to an electromagnetic open channel velocity sensor is used to conduct the stream ratings.



Figure 2. Stream Rating.

The resulting discharge rates are used to calculate a discharge equation, which is utilized by the flow monitoring equipment at some stations. At other stations where a discharge equation cannot be developed, velocity, stage, and geometry measurements are utilized to calculate discharge rates using the area velocity method. Two of the MLSs are collocated with USGS stream gauging stations. At these sites, the established USGS ratings are used.

Data from the field measurements are entered into a computer model that calculates the stream's cross-sectional profile from the depth and distance from bank measurements. Total flow across the channel is determined by integrating the velocity measurements over the cross-sectional surface area of the stream channel. The result is an instantaneous flow measurement in cubic feet per second. Several stream ratings are measured for each of the streams where flow is measurable after a storm and combined to produce a rating curve for each stream. Information from the rating curve is used to more accurately predict expected flow rates and appropriate sampling frequencies during storms.

In addition to flow, rainfall for each MLS is recorded for each of the three monitored storm events. Rainfall distributions and totals are calculated by interpolating between rainfall amounts from available National Weather Service, San Diego County, and MLS rain gauges. The rainfall over each watershed is interpolated and calculated in ArcView GIS. With this technique, rainfall over the entire watershed can be visualized.

WESTON conducts stream bioassessment to assess the ecological health of the watershed units in San Diego County. The assessment utilizes a protocol that samples and analyzes populations of benthic macroinvertebrates (BMIs). The sampling protocol includes the collection of stream benthic macroinvertebrates and also assesses the quality and condition of the physical habitat. Utilizing species-specific tolerance values and community species composition, numerical biometric indices are calculated, allowing for comparison of relative habitat health among streams in a region. Over time, this information is used to identify ecological trends and aid analyses of the appropriateness of water quality management programs. This information complements the MLS program that tests the water quality parameters and provides a measure of habitat conditions at the moment sampling occurs. The addition of bioassessment to chemical, bacterial, and toxicological approaches to watershed monitoring programs gives a comprehensive indication of water quality and the effects of ecological impacts.

Benthic invertebrates are collected using a 1-ft-wide, 0.5-mm-mesh, D-frame kick-net. A 2-ft² area upstream of the net is sampled by disrupting the substrate and scrubbing the cobble and boulders, so that the organisms are dislodged and swept into the net by the current. For each monitoring reach sampled, the physical habitat of the stream and its adjacent banks are assessed using U.S. EPA Rapid Bioassessment Protocols. Habitat-quality parameters are assessed to provide a record of the overall physical condition of the reach. Parameters such as substrate complexity, channel alteration, frequency of riffles, width of riparian zones, and vegetative cover help to provide a more comprehensive understanding of the condition of the stream. Additionally, specific characteristics of the sampled riffles are recorded, including riffle length, depth, gradient, velocity, and substrate composition.

Water quality measurements are taken at each of the monitoring sites using a YSI Model 6600 multiprobe meter. Measurements include water temperature, conductivity, pH, DO, and chlorophyll. Stream flow is measured with a Marsh-McBirney Model 2000 portable flow meter.

The Ambient Bay and Lagoon Monitoring (ABLM) Program was designed to assess the overall health of the receiving waters and monitor the impact of urban runoff on ambient receiving water quality. This monitoring program includes evaluations of sediment chemistry, sediment toxicity, and ecological community (benthic infauna) structure in the coastal embayments (lagoons and bays) of San Diego County. Data from these evaluations are intended to provide an indication of how marine life in the bays and lagoons is affected by pollution, and allow prioritization of outfall areas of coastal embayments for additional investigation in subsequent years.

The ABLM program consists of two phases: Phase I targets contaminants by identifying the three areas in each embayment with the finest grain size and highest total organic carbon (TOC) concentration using a stratified random design. Phase II assesses the sediments in the areas identified in Phase I using the same triad approach that is being utilized for the stormwater runoff program—chemistry, toxicity, and biology of the sediments.

Most of the sampling sites are accessed from the water using an inflatable boat. For Phase I a sediment sample is taken with a push core. After sediment samples from the 9 sites in each of the 12 embayments are analyzed, the sites in each embayment are ranked based on the percentage of fine-grained sediments and TOC levels. The sites with the smallest grain size (i.e., the highest percentage of fine-grained sediments) receive the highest rank for grain size and the sites with the highest TOC content receive the highest rank for TOC. The ranks for grain size and TOC at each site are then summed to produce an overall rank for that site. The three sites in each embayment with the highest ranks are assessed in Phase II of the program.

During Phase II, several water quality parameters are measured and sediment samples collected for analyses. At each station, water quality parameters are collected with a YSI Model 6600 multiprobe meter. Measurements include depth, temperature, DO, pH, conductivity, and salinity. Three separate sediment samples are collected with a 0.1-m² Van Veen sampler for sediment chemistry, sediment toxicity, and infaunal assessment.

STATISTICAL TOOLS

Comparisons between watersheds are performed using several different statistical tools. Watersheds are compared by both examining constituents of concern (COC) concentrations across watersheds and by grouping similar watersheds by COC relationships.

Statistical analyses for cross watershed comparison includes scatterplot analysis, regression analysis, analysis of variance (ANOVA), multivariate cluster analysis, and multiple regression analysis. Scatterplots provide a visual representation of the relative concentrations of COCs between stations and storm events. Scatterplots are simple plots of concentrations of COCs plotted on the y axis against the MLS identified on the x axis.

The trend analysis of long-term data sets is intended to track increases or decreases of the COC through time. An increasing trend that shows that concentrations or levels of pollutants are nearing a water quality objective (WQO) or continue to increase (when the WQO is already exceeded) are of particular concern and should be considered in the development of watershed actions that attempt to slow or reverse the trend.

ANOVA is used to determine differences between MLS for the COC. The term analysis of variance is sometimes a source of confusion. In spite of its name, ANOVA is concerned with differences between means of groups, not differences between variances. The analysis uses variances to detect whether the means are different. The ANOVA determines the variation (variance) within the groups that are being compared (e.g., monitoring stations), then compares that variation to the differences between the groups, taking into account the number of subjects in the groups. If the observed differences between the means of groups are larger than those expected by chance relative to the underlying variance, statistical significance is achieved. For this study, each COC that was observed in any sample above the method detection limit was tested by ANOVA.

Multivariate cluster analysis is applied to the COC and the toxicity endpoints in terms of no observable effect concentration (NOEC) values for each MLS and sampling time. This approach groups the station/times by the commonality of the COC concentrations found at each one. Likewise, it groups the COC according to similar loadings at stations. Cluster analyses were performed to determine the degree of similarity among stations and/or storm events relative to the COC concentrations for those events. They can be useful in assessing the characteristics of a site in relation to stormwater runoff as well as providing information on the interrelationships of the COC.

The relationships between toxicity and COCs have been evaluated using two methods. The first method uses a multiple regression model to correlate changes in toxicity to changes in COC levels in the water. A second method, threshold analysis, uses the COC levels reported to be toxic in the literature where available and compares them to COC levels in the stormwater samples.

MODELING

Predicted pollutant loads and event mean concentrations (EMCs) expected from MLSs are calculated using a spreadsheet model. The static pollutant loadings model calculates annual pollutant loads expressed in pounds per year. The loadings and EMCs are estimated based upon land-use types within the MLS watersheds, associated EMC values representative of each land use, and volume of runoff from the watershed. The model provides a comparison of anticipated results based upon land uses to measured results at MLSs during storm events (Figure 3).

The land-use EMCs are calculated from results obtained from monitoring under the San Diego County Copermittee Program, Nationwide Urban Runoff Program (NURP), Los Angeles County-based data, and Federal Highway Administration data (FHWA). The San Diego Association of Governments (SANDAG) geographic information system (GIS) database and the SANDAG 2000 Generalized Land Use maps were used to determine land use within the catchments of the MLSs. SANDAG data were supplemented with information from San Diego State University and USGS.

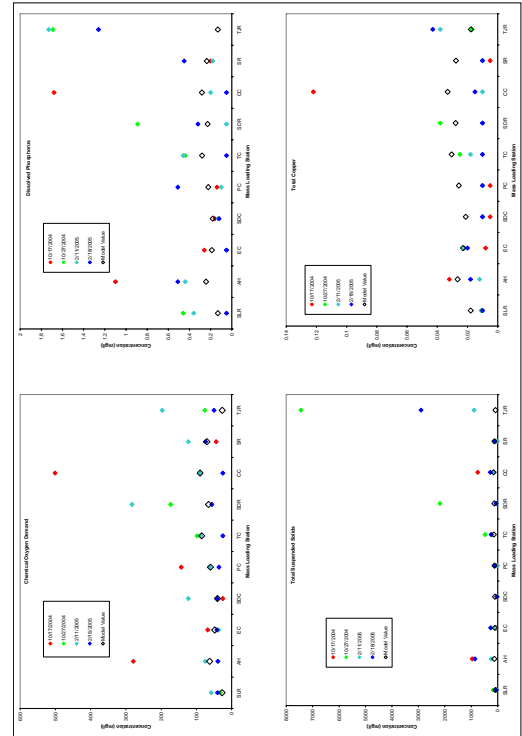


Figure 3. Model Results Comparisons.

The data for San Diego County land use, annual rainfall distribution, and drainage areas contributing to runoff to the MLSs are geographically linked together in an ArcView[®] GIS. The total loading values for each MLS are determined by multiplying the contributing runoff volume from each land-use type by the various input constituent land use-based EMCs. This total load is divided by the estimated total runoff volume. The runoff volume for each land-use type is calculated by factoring in average annual rainfall, total acreage, and percent of precipitation that is expected to run off the land for each land-use type.

Measured results that are significantly higher than the model results (EMC values) suggest a higher concentration of the COCs in the watershed during storm events than expected. Alternatively, EMC values that are higher than measured results provide an additional tool to document reductions in COC loads that may be a result of Best Management Practices (BMPs) within the watershed. This tool also complements the long-term trend analysis that indicates COC reduction through time that may be a result of BMP implementation.

Understanding the relationship between water quantity and water quality can lead to more accurate models of water quality, suggest potential sources of pollutants, and provide information to develop BMPs to address water quality concerns. Improvements to the estimates from the model may provide a predictive tool to allow for estimating improvements to water quality from different BMPs. Future land-use patterns can also be explored to determine their effects on the estimates of pollutant loads and concentrations.

WATERSHED ASSESSMENTS

The watershed assessments are intended to provide a management tool for Copermittees to utilize in the development of short- and long-term actions to address potential or actual water quality problems in the watershed. During the annual water quality assessment, the high, medium, or low frequency of occurrence for COC(s) is evaluated for each watershed using the latest data collected and potential water

quality issues are determined. In some cases, confirmation of water quality problems requires that additional data be collected or assessed to understand the extent of the problem. Additional information may be available from third-party data or a special study that can be used to answer questions relating to sources of the COC(s) and to define the problem both spatially and temporally. The watershed assessment process leads to a prioritization of water quality issues and assists in short- and long-term planning efforts and developing activities directed at maintaining or improving water quality.

The watershed assessment process can be broken into seven steps:

1. Compare chemistry results to action levels and WQOs
2. Examine exceedance percentages, bioassessment rankings, and toxicity results
3. Apply the Interim Criteria Ranking System to results
4. Evaluate third-party data and 303(d) listing information
5. Examine any available trend information
6. Apply triad decision matrix to data
7. Identify priorities and recommend actions

SUMMARY

The monitoring and assessment methods presented here are just some of the many tools available to stakeholders for watershed assessments to evaluate the conditions and improvements of water quality through time.

This monitoring program was designed to be adaptive and allow for more focused studies to answer specific questions that may arise. These questions can be answered on either a regional or a watershed scale depending upon the question at hand. As various watersheds identify issues of concern, special studies can be designed to answer those questions. These potential studies can help answer specific questions that address which management actions will best remedy the identified water quality problems.