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Analysis of Alternative Watershed Management Strategies Addressing Aquatic Toxicity: A case study of Organophosphate Pesticide Loading in Newport Bay, CA

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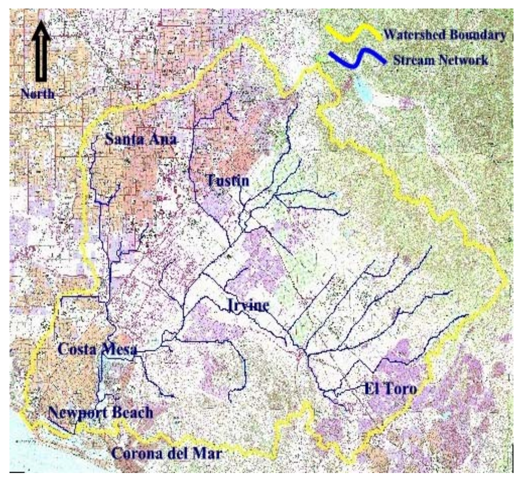
Problem Statement and Goals

In the late 1980s the Santa Ana Regional Water Quality Control Board (SARWQCB) listed Newport Bay and its main tributary, San Diego Creek, as being impaired under section 303(d) of the Clean Water Act, in part due to failure in meeting the Newport Bay Basin Plan objectives for toxic substances. These listings were based on bioaccumulation of DDT, PCBs and other toxic substances found in aquatic organisms collected from Newport Bay and San Diego Creek. In 1993 Orange County completed the "Newport Bay Watershed Toxicity Study," commissioned by the Regional Water Quality Control Board (RWQCB), which found that heavy metals were not the main causes of toxicity as initially expected. The Toxicity Identification Evaluation (TIE) section of the study identified the organophosphate (OP) pesticides Diazinon and Chlorpyrifos to be responsible for approximately 50% of the toxicity in Newport Bay and San Diego Creek[ii].

Diazinon and Chlorpyrifos pollution continues to threaten the human and ecological health of Newport Bay. In Orange County, most of which is drained by the Newport Bay Watershed, over 100,000 pounds of Diazinon and Chlorpyrifos are used annually. The principal use of these applications is residential structural pest control by both commercial and public users[iii]. Agricultural use of Diazinon and Chlorpyrifos also contributes to pesticide pollution in the Bay. Several nurseries located in the Newport Bay Watershed contribute runoff containing high concentrations of pesticides (specifically Diazinon and Chlorpyrifos)[ii]. High pesticide loading into Newport Bay threatens the health of human residents and visitors to the area, as well as the natural environment of the Bay. Both Diazinon and Chlorpyrifos have been associated with bird and fish kills, as well as child poisoning[iv].

Our goal for this project was to analyze non-point pesticide pollution resulting from toxic concentrations of Diazinon and Chlorpyrifos in Newport Bay and to develop management strategies for the control of that pollution.



The Newport Bay Watershed and the Major Cities Located Within Its Boundaries

Significance

Our analysis of management strategies provides a review of pesticide-related pollution in the Newport Bay Watershed and reviews solutions to the non-point pesticide pollution problem. Given the prevalence of non-point pollution and its widespread distribution throughout many watersheds with mixed urban, residential and agricultural landuses, this project has great significance. The assessment of a variety of Best Management Practices (BMPs) for the reduction of pesticide loading in Newport Bay provides a valuable analysis for use in water quality management. We believe this analysis will serve as a significant contribution to stakeholder groups interested in restoring and enhancing the beneficial uses of Newport Bay.

In light of the recent decision by the EPA to phase-out certain uses of both of the focus pesticides, there is uncertainty regarding future pesticide loading and related toxicity within Newport Bay. The uncertainty surrounding the phase-out highlights the necessity of making management decisions in the absence of complete information. This relationship between science and policy is the crux of our project and the platform on which our analysis is based.

Water quality management benefits from the usage of models to relate watershed processes to a given management practice that might control pollution. The implementation of computer models in the present study allowed the integration of spatial data for a given watershed with pollutant loading values to predict how a system will respond to a set of management alternatives. Such an analysis provides the framework for a decision-making process that could prove useful in other studies, including examination of other pollutants in watersheds throughout the world.

Background Information

The Newport Bay Watershed is located in Orange County, and like the rest of southern California it has undergone many changes resulting from decades of urban growth. Open space and agricultural lands have been replaced by high-density residential and urban development. With urbanization, the landscape is now characterized by an altered drainage network, stormflow pattern and increased sediment and pollutant loading to stream channels and to Newport Bay. The watershed has a large population (~800,000) and is located in a semi-arid region with a small amount of annual rainfall. The combination of impervious surfaces due to urbanization, and the short-duration high-intensity precipitation inputs common in Mediterranean climates, results in fairly flashy hydrographs. This translates into very low infiltration rates within the landscape and high levels of overland flow, which are discharged quickly to adjacent water bodies.

Urbanization around Newport Bay

Included in the overland stormflow is a suite of pollutants, including Diazinon and Chlorpyrifos, two OP pesticides. These pesticides, while highly toxic to aquatic life, have a short half-life of less than six months. It follows that it is not the persistence of the pesticides (such as is the case with many legacy pollutants such as DDT), but rather the high loading and toxicity of OP pesticides, specifically Diazinon and Chlorpyrifos, at levels that are toxic to aquatic biota. Due to the flashy nature of the stormflow hydrograph, high inputs of pesticides from urban, residential and agricultural areas and the extent of impervious surfaces, the pesticides are frequently found in both soil and water samples at levels that exceed the stated water quality criteria. Given the current state of the stormflow hydrograph and the altered landscape it is very difficult to manage the loading of non-point pollutants such as OP pesticides.

In the last two years the U.S. Environmental Protection Agency (EPA) initiated a re-registration program for Diazinon and Chlorpyrifos that targets over the counter sales and other non-agricultural uses. This phase-out and registration program is designed to reduce residential loads from entering watershed/storm water systems and is predicted to reduce this source by between 50-75% for Chlorpyrifos and Diazinon respectively.

Approach

In order to develop management strategies for control of non-point pesticide pollution resulting from Diazinon and Chlorpyrifos in Newport Bay, our group evaluated the efficacy of strategic management alternatives designed to reduce the toxicity of urban runoff being discharged within the Newport Bay Watershed. We first identified the key pollutants responsible for the aquatic toxicity in freshwater and saltwater environments, which were determined to be two organophosphate (OP) pesticides, Diazinon and Chlorpyrifos. We traced the major contributors of these pesticides to a corresponding landuse and developed export rate coefficients for each pesticide over coarse landuse classes. We analyzed the risks currently posed to ecological and human health from the pesticides Diazinon and Chlorpyrifos using the RivRisk 4.0 computer model developed by Tetra Tech, Inc for the Electric Power Research Institute.

In order to explore options for reducing toxicity in the Bay, our study evaluated the efficacy of strategic management alternatives designed to reduce the level of toxicity in urban runoff being discharged within the Newport Bay Watershed. Model-based predictions were used to evaluate the persistence of these pollutants over an array of management alternative scenarios, simulating base-case, policy-related usage restrictions and management practices aimed at improving water quality. The computer models used for assessment were the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) software, version 2.0, which was developed by Tetra Tech, Inc., for the U.S. EPA's Office of Water, and the Watershed Analysis Risk Management Framework (WARMF), which is a watershed decision program developed by Systech[v].

We reviewed the management alternatives presented in each model scenario to determine which management alternative best achieves improvement of water quality in Newport Bay. We identified the BMPs which are best suited for the physical environment of the watershed, and isolated the most effective practices for removing sediment (and thus the focus pesticides as they sorb to the sediment), based on the output of the two computer models. We then analyzed the price to construct and maintain structural BMPs, as well as the implementation costs of non-structural BMPs.

The following structural BMPs were considered: retention and detention basins, infiltration basins and trenches, vegetated swale and filter strips, sand filters and street sweeping. The following non-structural BMPs were considered: educational programs (media campaigns, intensive training and integrated pest management), household hazardous material collection programs and public policy standards. Those BMPs found to be most suitable for pesticide pollution removal were evaluated by costs. In evaluating the cost of the proposed management practices, we applied cost equations published by Wiegand et al. to analyze the price of construction and maintenance or implementation of structural and non-structural Best Management Practices (BMPs)[vi].

Results and Discussion

Results from our fate and transport analysis find that both Diazinon and Chlorpyrifos are highly toxic at low concentrations. Their short half-lives of six months or less in the environment illustrate that the danger presented by these pesticides is not their lengthy persistence, but rather a high level of toxicity occurring over a short duration. Due to its physicochemical properties, Diazinon is more likely to be found in aqueous systems and occasionally in sediments, while Chlorpyrifos is consistently found in both water and sediments throughout the watershed. As both soil and water must be considered in effective management alternatives, we evaluated options that addressed toxicity removal in both media. Furthermore, our source analysis showed that virtually all of the pesticides loading came from surface runoff as opposed to atmospheric deposition, sediment remobilization or groundwater sources.

Our analysis of the risks posed to environmental and human health by Diazinon and Chlorpyrifos suggests that the pesticides create an unacceptable threat for the ecosystem and human populations of Newport Bay. These findings indicate that a management plan that addresses unsafe concentrations of pesticides in the Bay is necessary. Given the expected phase-out of certain Diazinon and Chlorpyrifos uses, such a management plan should consider both current and future pesticide loading concentrations and implement BMPs accordingly.

The results of our watershed modeling analysis establish that after the partial phase-out of these two pesticides, Diazinon could persist in stormflow events above both the Criterion Chronic Concentration (CCC) and Criterion Maximum Concentration (CMC) for aquatic toxicity. The results indicate that, on average, Diazinon could be found in toxic concentrations in all storm events in Newport Bay after the phase-out. In contrast, Chlorpyrifos concentrations appear to be within the criterion limits more often, even during storm events. Chlorpyrifos concentrations exceed the CCC levels between 1 and 4 days per rain year, and the CMC levels between 0 and 3 days per rain year. These violations highlight the importance of storm water in the transport processes.

These model simulations suggest that the phase-out will be more effective at reducing the number of days above the criteria for Chlorpyrifos than Diazinon. Additionally, we discovered that, short of a stricter command and control policy revision, a complete reduction in urban Diazinon uses is necessary to keep the concentrations below criteria levels. These findings provided the impetus to evaluate various BMPs as further toxicity-reduction will be necessary to protect the biological integrity of the Bay.

Upper Newport Bay

Conclusions and Findings

Table 1. Structural BMP Cost Effective Summary

BMP Type	Effectiveness Ranking	Cost Ranking	Overall Ranking
Infiltration Basins	1	1	1
Street Sweeping	1	1	1
Retention/Detention Basins	1	2	3
Vegetated Swales	3	2	4

The BMPs listed in Table 1 are designed to treat an appropriate volume of storm water that is a function of the type of practice and the size of the catchments intercepting the storm water. Costs were calculated assuming sufficient number of BMP units would be installed in the watershed to meet the mandated water quality criterion. The effectiveness of pesticide removal was extrapolated from the efficiencies of suspended solid removal and the results from the fate and transport analysis.

After evaluating the various structural BMPs, we concluded that infiltration ponds and street sweeping are the most cost-effective solution followed by infiltration basins and grass swales. The construction cost of the infiltration basins would be between $16-$67 million dollars. This cost range reflects the number of basins necessary, and is assumed to be sufficient to lower the concentrations below the criteria. The cost of the street sweeping program would be close to $200,000 with a maintenance costs between $0.5-1.5 million per year. This type of program sweeps frequently during the dry season can achieve sediment removal efficiencies of up to 80%. Municipalities within the watershed could purchase 100 vacuum sweepers for the same price as installing the required infiltration basins, however the operation and maintenance costs for this many machines may outweigh the benefits. A more detailed analysis is needed to evaluate the costs and benefits of both programs to find the optimal combination of practices.

Additionally, the installation of these basins could provide supplementary water quality functions to Newport Bay as they effectively capture and store sediment as well as other non-point pollutants such as fertilizers, metals and pesticides common in urban watersheds.

Based on the analysis presented in this project a comprehensive management program that eliminates sources, educates the public and trade people while physically treating storm water would be the most effective solution to reduce toxicity in urban runoff and thus Newport Bay itself.

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ii. *Final Problem Statement for the Total Maximum Daily Load for Toxic Substances in Newport Bay and San Diego Creek* (Santa Ana Regional Water Quality Control Board, January, 2001).

iii. Lee, G. Fred. *Stormwater.* **2**, 1 (2001).

iv. U.S. Environmental Protection Agency. *Chlorpyrifos Revised Risk Assessment and Agreement with Registrants.* (2000).

v. EPRI. *User's Guide to WARMF: Documentation of Graphical User Interface.* (EP-P2346/C1054, 2000).

vi. U.S. Environmental Protection Agency. *Preliminary Data Summary of Urban Storm Water Best Management Practices.* (Washington, D.C: *EPA-821*-R-*99-012,* 1999).