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SPATIAL AND QUANTITATIVE APPROACH TO INCORPORATING STAKEHOLDER VALUES INTO TOTAL MAXIMUM DAILY LOADS: DOMINGUEZ CHANNEL CASE STUDY

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INTRODUCTION

The Federal Clean Water Act (CWA) Section 303(d)(1)(A) requires each state to identify those waters that are not achieving water quality standards. The result of this assessment is called the 303(d) list. The CWA also requires states to develop and implement Total Maximum Daily Loads (TMDLs) for these waters on the 303(d) list. A TMDL specifies the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and allocates the pollutant loadings to point and non-point sources. Nationwide, over 34,900 segments of waterways have been listed as impaired by the Environmental Protection Agency (EPA 2006).

The EPA enlists state agencies and local communities to submit TMDL plans to reduce discharges by specified dates or have them developed by the EPA. The Department of Energy requested Lawrence Livermore National Laboratory (LLNL) to develop appropriate tools to assist in improving the TMDL process. An investigation of this process by LLNL found that plans to reduce discharges were being developed based on a wide range of site investigation methods. Our investigation found that given the resources available to the interested and responsible parties, developing a quantitative stakeholder input process and using visualization tools to display quantitative information could improve the acceptability of TMDL plans. We developed a stakeholder allocation model (SAM) which uses multi-attribute utility theory to quantitatively structure the preferences of the major stakeholder groups. We then applied GIS to display allocation options in maps representing economic activity, community groups, and city agencies. This allows allocation options and stakeholder concerns to be represented in both space and time. The primary goal of this tool is to provide a quantitative and visual display of stakeholder concerns over possible TMDL options.

Stakeholder Allocation Model (SAM)

The stakeholder allocation model (SAM) uses multi-attribute utility theory to quantitatively structure the preferences of the major stakeholder groups. These stakeholder preferences are then used to measure individual and overall interest, expressed as a utility value, of the various TMDL options that will be considered. A detailed discussion of this approach appears in the paper Stewart et al 2005. We incorporated the output of this model into GIS to convey the results spatially and temporally. GIS allows us to illustrate the impact of possible decisions on specific geographical areas that represent economic, environmental and social concerns. We selected the Dominguez Channel watershed in Los Angeles, California as a test site for the SAM. This site was selected because of its strategic importance to the local, state, and national economy. The major stakeholder groups interviewed were (1) non- profit organizations, (2) industry, (3) government agencies and (4) the city government. The decision-maker that will recommend a final TMDL plan is the Los Angeles Regional Water Quality Control Board (LARWQCB).

The SAM model gives the decision maker the ability to see how various TMDL plan options rank in order of preference from the perspective of each stakeholder and also to evaluate tradeoffs in selecting a plan that maximizes overall utility. We have included a preliminary example comparing two hypothetical TMDL plans based on stakeholder input and the decision makers’ preferences, but final decisions are not included due to an ongoing TMDL development process.

The Dominguez Channel Watershed

The Dominguez Channel watershed is in the Los Angeles basin as shown in Figure 1. It encompasses lands within 14 cities and Los Angeles County. The watershed is predominantly urban-industrial, with drainage occurring primarily through the storm drain system to the Dominguez Channel, and through the main ship channel to the Los Angeles Harbor (DWAC, 2003). Since the early 1900s, millions of gallons of point-source industrial wastewater have been discharged into the Dominguez Channel, contributing to the contaminant loading. The channel is also the main carrier for municipal and industrial non-point storm water runoff for a large area of southern Los Angeles County. The EPA, through the LARWQCB, has designated segments of the Dominguez Channel, Wilmington Drain, Torrance Lateral, Los Angeles and Long Beach Harbors and Machado Lake as "water quality impaired." (LARWQCB 2003)

FIGURE 1 HERE

By using GIS, we visualize the watershed and develop layers representing many of the concerns of the stakeholder groups. Figure 2 shows some of the GIS analysis that was done in the watershed. The left map shows the population density distribution of the people who live in the watershed. The same GIS data were used to calculate that more than 903,000 people reside in or adjacent to the watershed (U. S. Census Bureau 2001). The middle map highlights the

Nation Pollution Discharge Elimination System (NPDES) permit holders. The right map show the location of the water bodies on the 2002 303(d) list in the area surrounding the Ports of Los Angeles and Long Beach. These maps provide context information about the watershed for stakeholders and decision makers.

FIGURE 2 HERE

TMDL Process

Typically, the creation of a TMDL plan is based on information from one or more of the following sources: historical studies, local insight, sampling data, hydrology models, fate and transport models, and stakeholder input. The decision to use all or part of these sources is based on budgets, time, and regional decisions. Because many local agencies do not have adequate resources to conduct comprehensive studies on their respective watersheds, they often look to the stakeholders to provide data that will help in the determination of the TMDL. In the Dominguez Channel, the choice has been made to use all of these sources. Once the input data is gathered, the LARWQCB will propose a TMDL. Implementation plans will be created and reviewed both before and after implementation. The review before implementation is a time when stakeholders have some input and can voice their opinions of the plans. Multi-attribute utility analysis can be used to evaluate the alternative plans faced by the decision maker, from the perspective of each of the different stakeholders.

Multi-Attribute Utility Theory

Multi-attribute utility (MAU) theory is a useful approach to aiding the decision-maker when faced with multiple and often conflicting objectives. In many situations, increasing the decision-maker's position relative to one objective will decrease his or her position relative to another objective. MAU theory allows one to structure decisions with multiple objectives, and formally conduct tradeoffs among competing objectives to achieve an overall best decision, or highest expected utility. A more complete explanation of the MAU theory can be found in Keeney and Raiffa, 1993.

The main results of multi-attribute decision analysis theory cover *conditions* for which the ranking function can be expressed in a simple mathematical form, and meaningfully and consistently calibrated using preference information gathered from the stakeholders. The key aspect of such preference models is that they are derived formally on a mathematically sound basis.

The best problems to apply MAU theory have the following characteristics:

1. A single decision-maker is undecided which of several viable options is the best way to solve a particular problem.
2. The problem can be structured in a way that clearly identifies the possible options, when the decision needs to be made, and if new information can be gained in future time steps that will influence future decisions.
3. If the outcomes of certain decisions are uncertain, the modeler and decision-maker need to assign probabilities to the range of possible outcomes.
4. The decision-maker assigns utility values to the consequences of each possible decision. These values will have levels of benefits and/or costs explicitly expressed with each possible

decision. These consequences will be ranked to reflect the decision-maker's preferences (e.g., $C^{/}$ is preferred to $C^{//}$, which is preferred to $C^{///}$). For consistency; $C^{/}$ must also be preferred to $C^{///}$.

$$C^{/} > C^{//} > C^{///}$$

Each consequence will have an associated utility value (e.g., $C_i^{/} \rightarrow u_i^{/}$ and $C_j^{//} \rightarrow u_j^{//}$). The assignment of utility values will also reflect the same preference:

$$\sum_{i=1}^{m} p_i^{/} u_i^{/} > \sum_{j=1}^{n} p_j^{//} u_j^{//}$$

Where $p_i^{/}$ equals the probability and $u^{/}_i$ equals the utility value for each possible consequence of a decision. The sum is called an expected utility, and maximizing the expected utility proves to be the optimal decision.

5. The final step is to select the levels(s) that maximizes the expected utility.

In our approach, we structure the problem into the following characteristics: goal(s) that identify a concern a decision-maker wants to address; sub-goals or objectives that indicate the sub-concern to address as part of an overall concern; and attribute(s) that define the measure used to quantify the degree to which any alternative addresses a sub-concern.

MAU value function theory provides practical functional forms for quantifying values, including the following

$U(x_1, x_{2,....,} x_n) = \sum w_i v_i (x_i)$ (additive form)

$U(x_1, x_2, ..., x_n) = [\prod (1 + K w_i v_i (x_i)) - 1] / K$ (multiplicative form)

where:

U is the overall summary (utility/value) number; x_i are the levels for individual attributes; v_i are individual attribute utility/value functions (scaled between 0 and 1); w_i are scaling constants or weights reflecting the relative importance of the different attributes (tradeoffs) ranging from their worst to best levels (scaled between 0 and 1, with $\sum w_i = 1$ for the additive form); K is a normalizing constant (computable by first solving for the variables $C_i = Kw_i$ and then letting $K = [\prod (1+ C_i)-1]$ for the multiplicative form

Stakeholders Objectives

We have conducted multiple interviews from 2002 to 2004, with representatives of each of the stakeholder groups. Those interviews gave us a list of concerns and issues that are representative of their stakeholder groups. Each individual stakeholder did not participate due to time and resource constraint. However, all stakeholders were invited to participate in larger discussions of the issues and concerns. The feedback from the interviews has been structured into the following general categories: transparency; establishing a well-characterized watershed; schedule; cost; and flexibility. Table 1 below shows the major categories of concern for each stakeholder.

TABLE 1 HERE

Within these general objectives we have developed attributes based on the interview sessions. The objectives were drafted, shown to the stakeholder groups, and refined based on further input. These general descriptions were broken down further until we developed a list of attributes that explained the stakeholders' concerns and met the requirements of MAU theory. Table 2 shows the eight attributes we have developed and the specific levels associated with each attribute.

TABLE 2 HERE

Stakeholder Attribute Model Implementation

The SAM was implemented in the commercially available Logical Decisions For Windows® (LDW), a software designed to handle multi-attribute decision-making. It allows the user to structure multi-measure utility functions (MUF) to assign values of importance to the decision makers overall objective.

Choosing the Best TMDL Plan: An Example

Below is an example of two TMDL plans and how a decision maker could choose the best TMDL plan.

TABLE 3 HERE

The illustrative alternative plan information in Table 2 was analyzed using LDW. We can obtain results like the following graph below comparing the overall utilities for the two TMDL plans.

FIGUER 3 HERE

Figure 3 includes a "Stacked bar ranking" of results created in LDW. As shown, the "non-profit," "city government," and "government agencies" stakeholders prefer Plan 2. Industrial stakeholders, on the other hand, preferred Plan 1 to Plan 2 because it had higher utility values for the "trading," "timetable," and "cost" attributes. The map in Figure 3 shows the potential stakeholder areas of interest. The combined map and chart quickly and efficiently convey not only the stakeholder preferences for each plan but also where those stakeholders concerns are located geographically.

CONCLUSIONS

The TMDL process has required federal, state, and local agencies and stakeholder groups to create plans to reduce discharges into impaired waterways, with minimal resources and data to make the scientifically proven "best choice." The development of the SAM model and use of GIS was explicitly selected with this in mind. The SAM model's advantages are (1) cost relative to other modeling approaches, (2) perceived fairness given unresolved source uncertainty, and (3) increased transparency to stakeholders. By formally incorporating stakeholder values, the decision-maker can select an implementation plan that systematically and explicitly addresses the values of each stakeholder group. The use of GIS provides an ability to integrate scientific results with social and economic issues that are comprehensible to large audiences. By improving the understanding of information, decision-makers and stakeholders can better understand each others positions and represent their own to a wide audience. This method does not claim to make each group come out with the overall best solution; rather it provides a tool that allows the decision-maker the ability to weigh each stakeholder group's goals and determine the best tradeoffs, given quantitative information on each group's value system.

As of the date of this publication the implementation schedule for the Dominguez Channel watershed has been delayed to allow for more data to be collected and hydrological modeling to be completed by the stakeholder groups. The stakeholder attribute model we have built has allow the decision-maker, the LARWQCB to formally assess various stakeholders' attitudes and concerns about the various implementation plans from which they must ultimately select. The stakeholder community has also been able to view the same information improving both transparency in the process and confidence that each group has had their concerns formally expressed to the decision-makers. The final outcome has not been decided and conclusions on the stakeholders' final level of satisfaction cannot be reported at this time. However, it can be reported that this process has helped improve the process for both stakeholders and decision-makers by improving transparency, formalizing the concerns of major stakeholder groups and illustrating the range of realistic tradeoffs decision-makes can make to balance the concerns of a diverse set of stakeholders.

ACKNOWLEDGMENTS

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Table 1. Dominguez Channel Stakeholder Groups and High-Level Objectives

Stakeholders	Transparency	Establishing a well-characterized watershed.	Schedule	Cost	Flexibility
Non-profit Organizations	X	X	X		
Industry		X	X	X	X
City Government			X		
Government Agencies		X	X		

Table 2. Attributes and Levels used in Dominguez Channel SAM

Attribute	Levels
Characterization Plan Contract Selection	1)Non-profit organizations are included in selection process. 2) Non-profit organizations are not included in selection process.
Parties who agree upon Characterization Plan	1) Plan is agreed upon by all stakeholders. 2) Plan is agreed upon by permit holders and LARWQCB. 3) Plan is agreed upon by permit holders.
Quality of discharge estimations	1) Estimates all source discharges and requiring a small margin of safety 2)Estimates most (meaning all major point and likely non point) source discharges requiring a small-medium margin of safety. 3) Estimates some (meaning all major point and few if any non point) source discharges and requiring a medium margin of safety. 4) Estimates few (meaning only few major point sources) source discharges and requiring a large margin of safety
Timetable of Implementation Plan	1) 0-0.5 Years (Immediately) 2) 0.5-2 Years

	3) 2-5 Years 4) 5-7 Years 5) Time Frame Unknown/ Calls for Extension
Cost of Implementation Plan	1) Implementation Plan Requires System Upgrades but No Reduction of Output. Cost < $250,000 2) Implementation Plan Requires System Upgrades but No Reduction of Output. Cost > $250,000 but < $1,000,000 3) Implementation Plan Requires System Upgrades but No Reduction of Output. Cost > $1,000,000 but < $5,000,000 4) Implementation Plan Requires System Upgrades and Reduction of Output. Cost > $5,000,000
Third Party Monitoring of Implementation Plan	1) Allows third party monitoring 2) Does not allow third party monitoring
Upgrades in Implementation Plan	1) Requires future upgrades. 2) Does not require future upgrades
Trading of discharge permit restrictions	1) Allows trading. 2) Does not allow Trading

Table 3. Illustration of two different TMDL plans.

Attribute	**Plan 1**	**Plan 2**
Cost	Less than 250,000	Greater than 250,000 and less than 100,000,000
Trading	Allows trading	Does not allow trading
Discharge Estimation	Estimates some source discharges	Estimates all source discharges
Third Parting Monitoring	Allows third party monitoring	Does not allow third party monitoring

Timetable	5-7 years	2-5 years
Upgrades	Requires System Upgrades	Does not require System Upgrades
Characterization Plan Selection	Non-profit organizations are **not** included	Non-profit organizations are included
Parties Who agree Upon Plan	NEPDES and LARWQCB	NEPDES

Figure 1: Location of Dominguez Channel Watershed

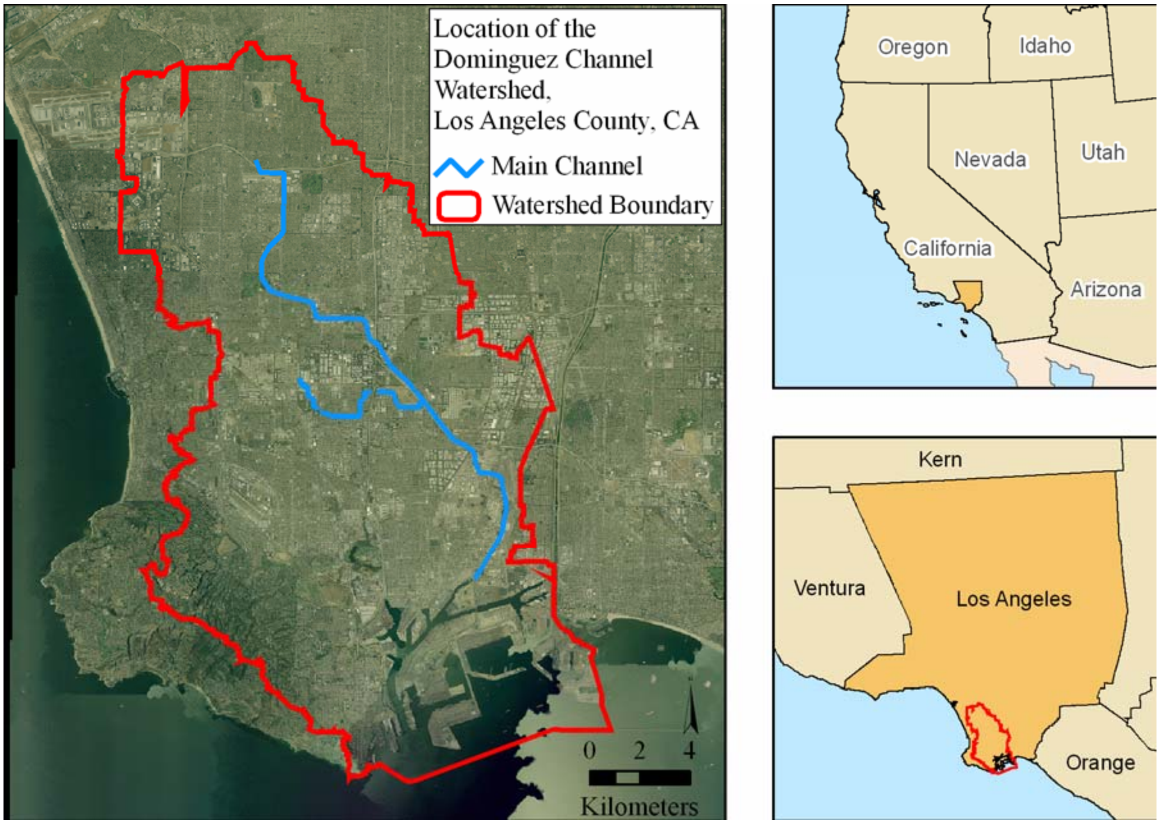

Figure 2: Examples of GIS Visualization

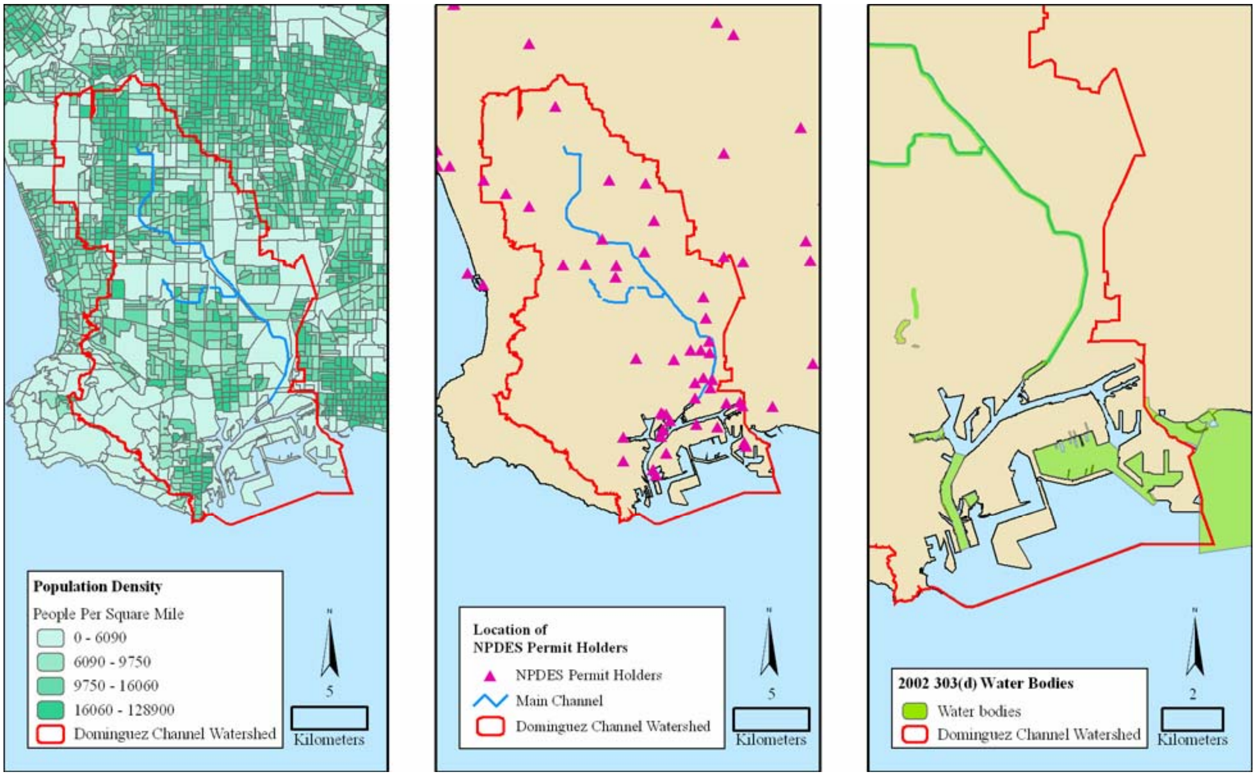

Figure 3: Ranking for the Best TMDL Plan.