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Development of a Quantitative Approach to Incorporating Stakeholder Values into Total Maximum Daily Loads: Dominquez Channel Case Study

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ABSTRACT

The federal Clean Water Act (CWA) Section 303(d)(1)(A) requires each state to conduct a biennial assessment of its waters, and 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 establish a priority ranking for waters on the 303(d) list of impaired waters and to develop and implement Total Maximum Daily Loads (TMDLs) for these waters. Over 30,000 segments of waterways have been listed as impaired by the Environmental Protection Agency (EPA). The EPA has requested local communities to submit plans to reduce discharges by specified dates or have them developed by the EPA. An investigation of this process found that plans to reduce discharges were being developed based on a wide range of site investigation methods. The Department of Energy requested Lawrence Livermore National Laboratory to develop appropriate tools to assist in improving the TMDL process. The EPA has shown support and encouragement of this effort.

Our investigation found that improving the stakeholder input process would facilitate many of the TMDL processes, given the resources available to the interested and responsible parties. The first model that we have developed is a stakeholder allocation model (SAM). The SAM uses multi-attribute utility theory to quantitatively structure the preferences of the major stakeholder groups, and develop both individual stakeholder group utility functions and overall stakeholder utility function for a watershed. The test site we selected was the Dominquez Channel watershed in Los Angeles, California. The major stakeholder groups interviewed were (1) nongovernmental organizations, (2) oil refineries, (3) the Port of Los Angeles, and (4) the Los Angeles Department of Public Works. The decision-maker that will determine the acceptable utility values is the Los Angeles Regional Water Quality Board. The preliminary results have shown some different values among stakeholders, especially in the areas of scheduling and cost of the implementation plan. However, the attribute list has also identified the value or importance of each area, giving the decision-maker the ability to make tradeoffs to maximize the groups overall utility. Final decisions are not disclosed in this paper due to ongoing negotiations by the stakeholders.

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

Stakeholder/Objectives	Transparency	Site Characterization	Implementation Plan	Public Health	Cost	Flexibility
Nongovernmental Organizations	X			X		
Oil refineries		X	X		X	X
Port of Los Angeles		X	X		X	X
City Agencies		X	X		X	X
City of Los Angeles				X		X

KEYWORDS

Total Maximum Daily Loads, Stakeholder Values, Multi-Attribute Utility Theory.

INTRODUCTION

The court mandate requiring the development of Total Maximum Daily Loads (TMDLs) has required the federal Environmental Protection Agency (EPA), local regulatory bodies, and stakeholders to make decisions on complex problems with limited resources. The 30,000-plus waterways that are required to have TMDLs developed, receive contaminant loadings from point, non-point and background sources. Atmospheric deposition, surface and subsurface waters, and legacy sources can contribute to the contaminant loadings in a watershed. A lack of information from any one of these potential sources can cause an increased burden of responsibility to reduce discharges from the known sources.

The receiving waters of the combined source dischargers are regulated by federal, state, and local government agencies. These agencies are required to limit discharges to a level considered safe for public use. The public is considered a stakeholder in the TMDL process and therefore has input into the process. This process brings stakeholders with multiple objectives together. A decision-maker, in this case the California Water Quality Control Plan, Los Angeles Region, (also known as the Los Angeles Regional Water Quality Board, or LARQWB) must weigh the various objectives of each stakeholder group when determining the final implementation plan.

Regulatory Background

The State of California's principal water quality law is the Porter-Cologne Water Quality Act (Porter Cologne). Porter Cologne is implemented in the Los Angeles region by the California Water Quality Control Plan, Los Angeles Region (Basin Plan). The Basin Plan sets water quality standards for the Los Angeles region, which include beneficial uses for surface and ground water with the numeric and narrative objectives necessary to support those uses, and the state's antidegradation policy. The Basin Plan also describes implementation programs to protect all waters in the region. The Basin Plan will serve as the State Water Quality Control Plan for Dominquez Channel.

These plans are required by and in compliance with the federal Clean Water Act (CWA).

Section 303(d)(1)(A) of the CWA requires each state to conduct a biennial assessment of its waters, and identify those waters that are not meeting water quality standards. The result of this assessment is called the 303(d) list. The CWA also requires states to establish a priority ranking for waters on the 303(d) list of impaired waters, and to develop and implement TMDLs for these waters.

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. The elements of a TMDL are described in 40 CFR 130.2 and 130.7, and Section 303(d) of the CWA, as well as in U.S. EPA guidance (U.S. EPA, 1991). A TMDL is defined as the "sum of the individual waste load allocations for point sources and load allocations for non-point sources and natural background" (40 CFR 130.2) such that the capacity of the water body to assimilate pollutant loads (the loading capacity) is not exceeded. TMDLs must take into account seasonal variations and include a margin of safety to address uncertainty in the analysis (40 CFR 130.7(c)(1)). Finally, states must develop water quality management plans to implement the TMDLs (40 CFR 130.6).

The U.S. EPA has oversight authority for the 303(d) program, and is required to review and either approve or disapprove the state's 303(d) list and each TMDL developed by the state. If the state fails to develop a TMDL in a timely manner, or if the EPA disapproves a TMDL submitted by a state, the EPA is required to establish a TMDL for that water body (40 CFR 130.7(d)(2)).

In the Los Angeles region, as part of its 1996 and 1998 regional water quality assessments, the Regional Board identified over 700 local water body-pollutant combinations where TMDLs would be required (LARWQCB, 1996, 1998). A 13-year schedule for development of TMDLs in the Los Angeles region was established in a consent decree approved on March 22, 1999 (Heal the Bay Inc., et al. v. Browner, et al., C 98-4825 SBA).

As required by the CWA and Porter-Cologne, Basin Plans include beneficial uses of waters, water quality objectives to protect those uses, an antidegradation policy (water quality standards), and other policies necessary to implement water quality standards. TMDL implementation plans are incorporated into the Basin Plan.

Land Use

The Dominguez watershed is predominantly urban-industrial (96%) and approximately 62% of the land surface is impervious, 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).

For decades, the area called "consolidated slip" at the mouth of the channel has acted as a sink for contaminated sediments. The Dominguez watershed, located upstream of the slip, is highly urbanized and discharges into the port through consolidated slip. 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.

Climate

The area has a Mediterranean climate, with warm summers, mild winters, and rain occurring primarily November through April. The annual rainfall for a typical dry year and wet year are 5.53 inches and 20.67 inches, respectively.

The Dominquez Channel Watershed

The Dominquez Channel watershed is in the Los Angeles basin. It encompasses lands within the cities of Torrance, Hawthorne, Los Angeles, Rolling Hills, Rolling Hills Estates, Lomita, Lawndale, Manhattan Beach, El Segundo, Inglewood, Gardena, Carson, Ranchos Palos Verdes, Palos Verdes Estates, and Los Angeles County. The Dominguez watershed faces tremendous challenges including high-density development; conversion of remaining open space; flooding and development on floodplains; intense transportation pressures; increased demands for water and sewer services; reduction of wetland, riparian areas, and fish and wildlife habitat; and pollution of waterways. The EPA, through the California State Water Quality Control Board, has designated segments of the Dominguez Channel, Wilmington Drain, Torrance Lateral, Los Angeles and Long Beach Harbors and Machado Lake as "water quality impaired."

Reference System

Waste load allocations (WLAs) and load allocations (LAs) are expressed as the number of daily or weekly sample days that may exceed the single sample targets at a monitoring site. WLAs and LAs are expressed as allowable exceedance days because the bacterial density and frequency of single sample exceedances are the most relevant to public health protection. Allowable exceedance days are “appropriate measures” consistent with the definition in 40 CFR 130.2(i).

For each monitoring site, allowable exceedance days are set on an annual basis as well as for three other time periods. These three periods are (1) summer dry-weather (April 1 to October 31), (2) winter dry-weather (November 1 to March 31), and (3) wet-weather (defined as days of 0.1 inch of rain or more plus three days following the rain event). The contaminants listed in the Dominquez Channel are nutrients, trash, bacteria, and metals (Cu, Pr, Pb, Zn, TBT).

METHODOLOGY

Multi-attribute utility 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. For example, choosing to improve water quality may cause an increase in clean-up cost. Thus, one’s position regarding water quality has increased while one’s position relative to cost has decreased. Multi-attribute utility 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.

Models based on multi-attribute preference theory have been developed to help decision-makers logically and systematically address decision problems involving multiple attributes or criteria. These models adopt a set of reasonable preference assumptions that can be used to simplify the problem of comparing alternatives. With these assumptions, a decision-maker (or expert) indicates preferences for relatively simple decision situations to calibrate a preference model. The model is then used to establish how more complicated comparisons should be made to be consistent with the simpler comparisons and the preference assumptions.

There are a few basic types of questions asked in calibrating a preference model. They involve a comparison of simple hypothetical alternatives labeled A and B. The questioning proceeds by varying one of the alternatives until the decision-maker is indifferent between (equally prefers) A and B. A set of model equations is then solved to compute model parameters that will reflect the decision-maker's preferences expressed by the comparisons of A and B.

This value judgment information is used to calibrate, in a defensible manner, a multi-attribute ranking function. The function takes as input for any alternative the level assignments for each of the ranking criteria, and produces as output a single number suitable for comparing or ranking alternatives.

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 like that described above. The key aspect of such preference models is that they are derived formally on a mathematically sound basis.

The best problems to apply multi-attribute utility theory have the following characteristics:

1. A single decision-maker is undecided about the best way to solve a particular problem. There are viable options to choose from to address the problem, and the decision-maker must select among more than one possible path.

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. Decision trees are useful steps in structuring problems that have these characteristics.

3. If there are uncertainties in the outcomes of certain decisions, the modeler and decision-maker need to assign probabilities to the range of possible outcomes. There are numerous ways to approach this, including eliciting expert judgment, examining past empirical data, and using stochastic and dynamic programming.

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 probabilities 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 alternative(s) that maximizes the expected utility. By testing each alternative, one will find the optimal path.

Multi-attribute utility theory has many rules to ensure that the methods are used correctly. While a comprehensive review of all of those rules falls outside the scope of this paper, a bibliography of detailed theoretical sources is provided in the reference section. However, a few of the desirable properties for developing attributes are as follows:

1. *Comprehensive* to ensure that all important aspects are covered;

2. *Non-redundant* to avoid double counting;

3. *Operational* enough to be estimatable for alternative actions and to be meaningful to decision-makers for tradeoffs;

4. *Decomposable* to simplify both consequence and value modeling (e.g., satisfy helpful independence assumptions);

5. *Minimum number of attributes* to show meaningful differences between alternative actions;

6. *Appropriate scales*, either natural (such as time or dollars) or constructed (discrete levels, each associated with a well-defined description of conditions). Arbitrary 0-10 scales are not well defined.

Dominquez Channel

In the Dominquez Channel, the California Regional Water Quality Control Board, Los Angeles Region, must propose a TMDL that, after several approval steps, must ultimately be approved by the EPA. Like many TMDL plans, a local agency is tasked with determining the sources of discharges; proposing a timetable to reduce discharges to legal limits; and periodically monitoring the water body to ensure that the implementation agreement is has been instituted by the stakeholders and that the implementation plan is actually meeting the goals of reducing specific types of discharges to the targets specified in the TMDL plan. If the plan is not meeting the original goals, a revised plan may be implemented at a future date. In Figure 1, a satellite image of the Dominquez Channel shows a predominantly urban and industrialized part of Los Angeles and Long Beach. The ports of Los Angeles and Long Beach border each other in the lower right quadrant of the image. The port of Los Angeles is mainly to the right of the Dominquez Channel, and the Port of Long Beach to the left of the channel. Traveling up the channel from the port area, major oil refineries dominate the landscape (outlined in the rectangle and smaller image). This area refines approximately 10% of the nation’s transportation fuel. Outside of those two areas, the watershed is comprised of other industries, residential, commercial, and some recreation areas. The Pacific Ocean can be seen in the lower left quadrant.

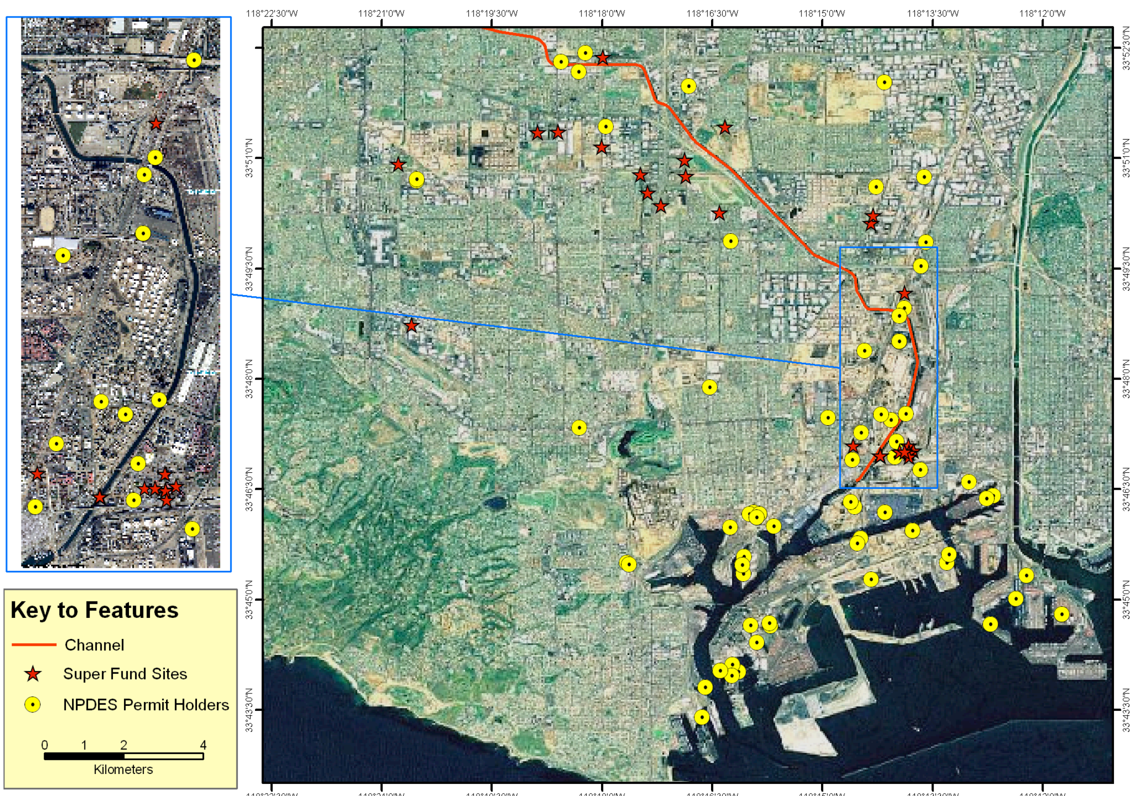


Figure 1. Dominquez Channel

Typically, the creation of a TMDL plan is based on information from the following sources:

1. Historical studies and local insight;
2. Sampling data;
3. Hydrology models;
4. Fate and transport models;
5. 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 Dominquez Channel, the choice has been made to use all of these sources. Because the data collection and analysis is done in part with the decision-maker's resources and in part by a subset of the stakeholders, the final set of information will likely be different from what any single entity would collect.

Once the data are received by the Dominquez Channel TMDL decision-maker (the California Regional Water Quality Control Board, Los Angeles Region), the process described in Figure 2 will take place. Implementation plans will be created and tested both before and after implementation. The testing before implementation is the crucial time when stakeholders have some input and can voice their early opinions of the plan. (In multi-attribute analysis, this is called utility value.) As discussed above, this will lend insight into the potential reaction of various stakeholders to the way the plan was developed and the type of plans proposed. Even though the decision-maker does not specify exactly how the responsible party will reduce discharges, the decision-maker does have an indirect say by setting a timetable and having the ability to evaluate plans by dischargers.

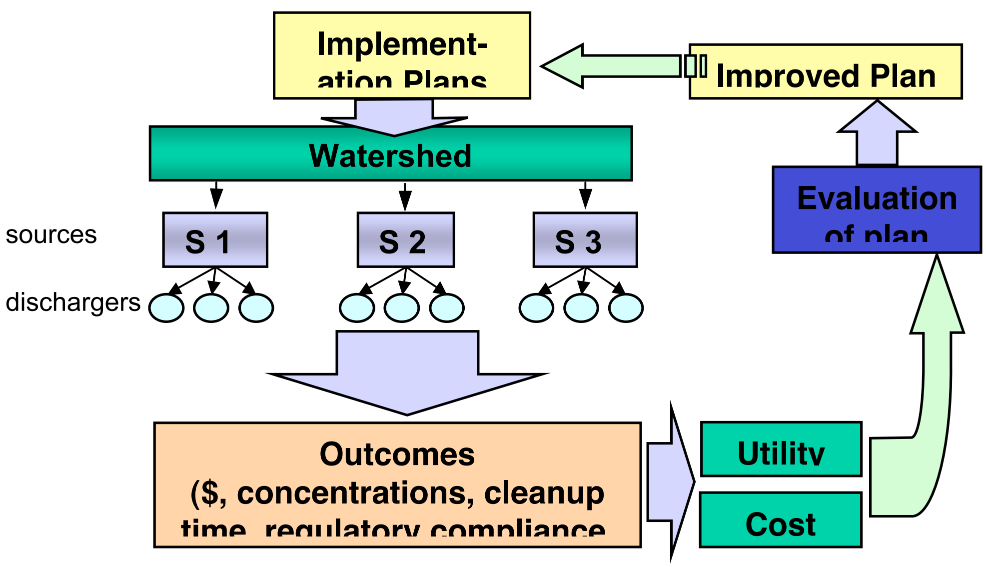
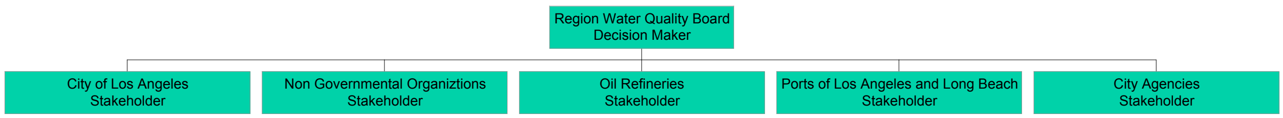


Figure 2. Illustration of our proposed TMDL process

In our approach, we structure the problem into the following characteristics:

1. Goal(s)—define the level of success a decision-maker strives toward;
2. Objectives—indicate the path that one should select to move toward a goal;
3. Attribute(s)—define the measurements used to determine the relative success of a particular objective.



Goals are helpful in determining the level of achievement to strive toward. In our situation, the goal could be that the Dominquez Channel will meet the legal requirements for safe use by 2010. Goals may not be formally used in the modeling exercise, but they play an important role in defining what the objectives and attributes will be. Note that no date has been selected for the Dominquez Channel. This will happen once the TMDL plan is submitted.

Objectives are more important in the analysis because they allow the problem to be broken down into measurable components. In the example TMDL case, one objective could be described as *characterization of contaminant sources.*

Attributes must be comprehensive and measurable. To be comprehensive, each individual level must clearly inform the decision-maker the extent that its associated objective is achieved. To be measurable, one must be able to obtain a probability distribution over the possible levels of the attribute or assign a point value, and it must be able to assess the decision-maker's preferences for different levels of the attribute. Either a utility function or a rank ordering can do this.

Multi-attribute utility/value function theory provides defensible assumptions and practical functional forms for quantifying values.

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

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

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 $C_i = K w_i$ and then letting $K = [\prod (1 + C_i) - 1]$ for the multiplicative form.

RESULTS

We have conducted multiple interviews during 2003 and 2004 with representatives of each of the stakeholder groups listed in Table 1. Those interviews gave us 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. Any feedback from these less-frequent meetings has also been incorporated in the analysis. The feedback from the interviews has been structured into the following general categories:

- Transparency
- Cost
- Schedule
- Minimal Uncertainty
- Public Safety
- Flexibility

Within these general areas we have developed objectives and 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 objectives that explained the stakeholders' concerns and allowed for the creation of attributes that met our definitions listed above, both *comprehensive and measurable*. The objective for the general area of transparency is to *improve public confidence*. For example, possible outcomes for the characterization plan include the following scenarios:

- Characterization plan is agreed upon by all stakeholders, uses mutually agreed upon parties for characterization, and estimates discharges from all sources;
- Characterization plan is agreed upon by NEPDES permit holders and LARQWB, and estimates sources from portion of watershed;
- Characterization plan determined by NEPDES permit holders and provides no new information on sources.

This list expresses the concerns of the community and non-profit groups who feel left out of assessment aspect of the watershed. The ideal situation for this stakeholder is to have a say on the selection of the group(s) that will be conducting the background studies, preferring a neutral party rather than firms that regularly depend on the industrial stakeholders for business. The worst situation for this group would be to have the industrial permit holders determine the types of background studies that will be conducted and no new information is discovered after the time consuming process.

The two alternatives in between express ranges of satisfaction between the two extremes of best and worse. They are clearly distinguishable from one another and provide a clear and measurable difference for the decision-maker.

A review of the *cost* attribute for the refinery stakeholder group identified the lower-level objective of *minimizing the reduction of refinery output*. The list below expresses the oil refineries' concern over the cost of the implementation plan. These numbers are illustrative since negotiations have not been completed for this TMDL.• Implementation plan requires no system upgrades or reduction of output.

- Implementation plan requires system upgrades but no reduction of output.
  Cost < $1X

- Implementation plan requires system upgrades but no reduction of output.
  Cost > $1X < $2.5X

- Implementation plan requires system upgrades but no reduction of output.
  Cost > $2.5X < $10X

- Implementation plan requires system upgrades but no reduction of output.
  Cost > $10X < $50X

- Implementation plan requires system upgrades and reduction of output.
  Cost > $50X

The oil refineries' main concern is more about the impact a TMDL may have on refinery output than the dollar amount for plant upgrades. The best outcome for this stakeholder would be to have no system upgrades or reduction of output. The worst situation would be to have a system upgrade and a reduction of output. The scales show that they would be willing to make more expensive upgrades before they would be willing to reduce refinery capacity. Therefore, the easiest concession to make would be to upgrade the system.

The high-level objective *schedule* produced the lower-level objective *ability to respond* by government agencies that may have to upgrade city-owned facilities such as water treatment plants. The three attributes reflect the reality of acquiring funds through government financing options (e.g., taxes, user facility rate increases). Most cities have guidelines for capital expenditures. Once they hit a certain threshold, there may be a requirement to obtain the mayor or city council's approval. If this is necessary, the city agencies value *time* to get the financing in place and value *confidence* that any request to the mayor or council is likely to be one-time request. This is closely linked with *minimizing uncertainty*.

- Plan will not require future upgrades, has a gradual schedule, and does not exceed requirements.

- Plan is on a short schedule but will not require future upgrades.

- Plan is on a short schedule and may require future upgrades.

Minimizing uncertainty is the high-level objective that produced the lower-level objective *establish well-characterized watershed*. Since the decision-maker has the right to revise the implementation plan after it has been put into effect, and a poorly characterized site could lead to conservative discharge limits, the “city agencies” stakeholder group expressed the following value list:

- Characterization plan accurately estimates discharges from all sources before developing an implementation plan.
- Characterization plan accurately estimates discharges from most sources before developing an implementation plan.
- Characterization plan does not capture the entire watershed but estimates some areas well.
- Characterization plan does not estimate sources without high uncertainty.

This list expresses the desire by this group to address this problem once instead of multiple times.

Public safety is the high-level objective to *ensure safe water recreation on the Dominquez Channel area.* This objective has been expressed by the mayor’s office as part of his overall environmental plan. A priority for this stakeholder is to accelerate the cleanup of the Dominquez Channel.

- Plan provides clean areas throughout the Dominquez Channel for public use within two years.
- Plan provides clean areas throughout the Dominquez Channel for public use within four years.
- Plan maintains some contaminated areas but increases areas safe for public use.
- Plan maintains some contaminated areas and does not reduce areas safe for public use.

The worst attribute listed for this group is an implementation plan that does not provide any new safe areas for the public to use.

Flexibility has been mentioned as a high-level objective by the oil refineries. The corresponding lower-level objective is *encourage discharge permit trading.* The list of attributes below expresses the concern that regulations may unnecessarily disrupt their business activities. The refineries expressed the idea of expanding the creative ways businesses can respond to meet the regulation while minimizing adverse impacts to the business community.

- Trading is allowed, and the timetable does not disrupt business activities.
- Trading is allowed but on a strict timetable.
- No trading is allowed, but a long-term time table allows business time to find a reasonable technology/solution that does not disrupt activities.
- No trading is allowed, and a tight implementation plan may disrupt business activities.

The worst situation for the oil refineries would be a short implementation schedule that does not allow trading within the watershed, or time to find cost-effective solutions.

DISCUSSION

The implementation schedule for the Dominquez Channel watershed has been delayed to allow for more studies to be completed by the stakeholder groups. The stakeholder value model we have built will allow the decision-maker, the California Regional Quality Water Board, Los Angeles Region, to formally assess various stakeholders' attitudes and concerns about the various implementation plans from which they must ultimately select.

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 was explicitly selected with this in mind. The SAM model does take a considerable amount of time and resources to build; however, the cost is within reach of many state and local agencies. The model's advantages are (1) cost relative to other modeling approaches, (2) usefulness given source uncertainty, and (3) increased fairness to stakeholders. By formally incorporating stakeholder values, the decision-maker can select an implementation plan that balances out the appropriate weights assigned to the values of each stakeholder group. 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.

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