ALLOCATION MODELING FOR METALS TMDLs IN AN URBAN INDUSTRIALIZED WATERSHED

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ABSTRACT

How TMDL allocations are structured can have a large impact on the total cost for water pollution control and on who pays what share of this cost. Development of more cost-effective TMDLs on a watershed basis creates opportunities to reduce the overall cost, maximize the effectiveness of pollution control, and shift pollution control responsibilities from high cost controls over point source discharges to comparatively low cost controls over non-point sources. However, ad hoc allocation procedures, such as equalization of effluent concentrations, do not address cost, effectiveness or implementation schedule, and the complexity of real watersheds also rules out the use of most ad hoc allocation procedures. Cost, effectiveness, and implementation metrics must be formalized in a model capable of predicting and optimizing the performance of the whole system. An added benefit of this systematic approach is that it also allows the "fairness" of the allocation procedure to be addressed.

The model described here is being developed for a watershed in Los Angeles with cooperation from the US Environmental Protection Agency Region 9 and the Los Angeles Regional Water Quality Control Board. This test case will examine TMDL allocation scenarios for heavy metal discharges into a highly urban and industrialized watershed subject to periodic and severe storm events. The model is based on a material balance around the entire watershed and includes both spatial and temporal effects. Spatial effects are handled using a tanks-in-series mixing model of the interconnected sub-watersheds. Individual sources and sinks are considered within each sub-watershed. Temporal effects are handled by considering various time-average pollutant concentrations and loadings, such as annual, seasonal, and rain event specific. The cost, effectiveness, and implementation schedule for control technologies and strategies for each source are input data to the model. The optimization procedure is flexible and allows the objective function and constraints to be easily modified; for example, the overall cost can be minimized subject to implementation schedule constraints. Various allocation procedures, such as equalization of effluent concentrations or waste loads, are built into the model for comparison.

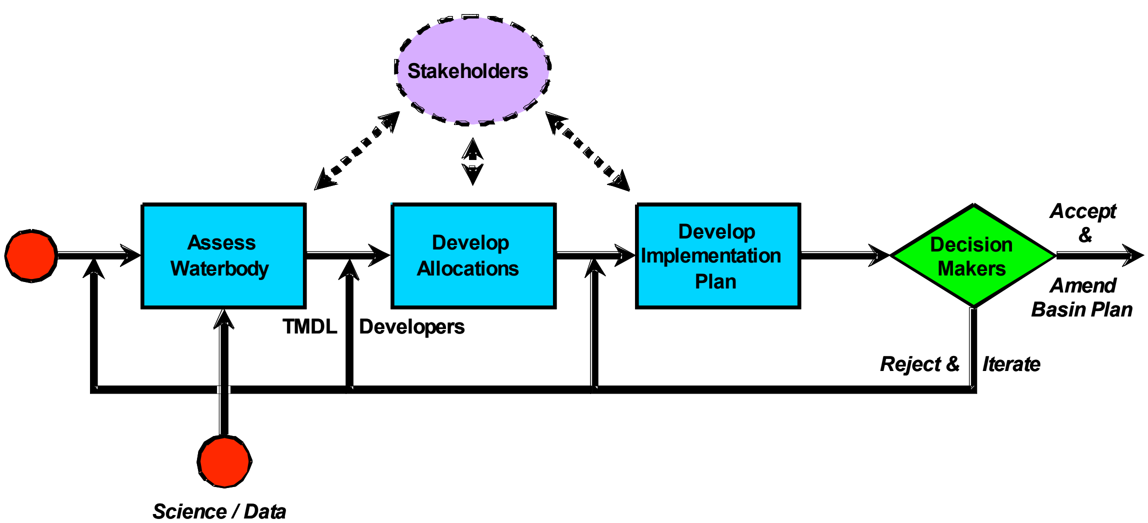
KEYWORDS

TMDL, Allocation, Modeling, Waste Load, Implementation Plan, Water Body, NPDES, Heavy Metals

INTRODUCTION

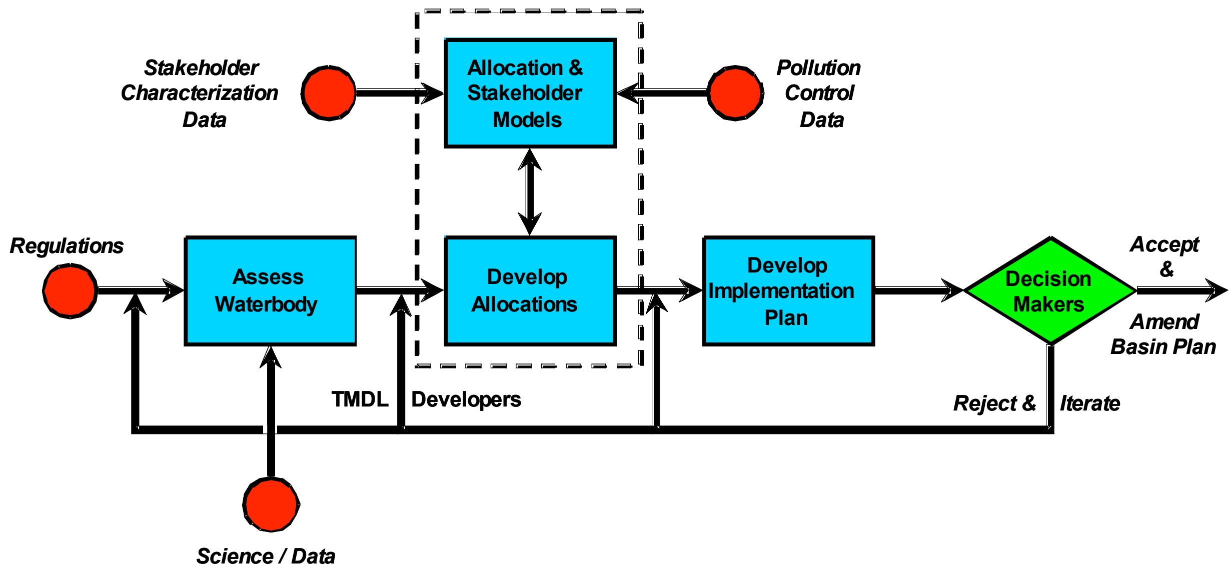
The federal Clean Water Act (CWA) Section 303(d) requires each state to conduct a biennial assessment of its waters, and identify those waters that are not achieving water quality standards. The result of this assessment is called the 303(d) list. Over 30,000 segments of waterways have been listed as impaired by the Environmental Protection Agency (EPA). The CWA also requires states to establish a priority ranking for waters on the list and to develop and implement Total Maximum Daily Loads (TMDLs) for these waters. The process steps to be followed in developing a TMDL are shown in Figure 1.

Figure 1 – Current Approach to TMDL Development



The current approach to developing TMDLs shown in Figure 1, suffers from some potential drawbacks. Stakeholder involvement is *ad hoc* and lacks formalism to ensure stakeholder values are fairly represented and truly considered in the process. In addition, the process can easily be marginalized by such factors as emotions, politics and poor communications. A more integrated approach is depicted in Figure 2. This approach formally brings technology, economics and decision science into the allocation process; improving communications between all involved parties. This is accomplished by the use of allocation and stakeholder modeling tools.

Figure 2 – An Integrated Approach to TMDL Development



While a great deal of effort has gone into developing methods to assess water bodies, very few tools exist to assist TMDL developers with engaging stakeholders, developing fair and equitable allocations, and developing transparent and effective implementation strategies. With this aim in mind, Lawrence Livermore National Laboratory (LLNL) and the National Energy Technology Laboratory (NETL) are collaborating on tools to "close the loop" between stakeholders and regulators in the TMDL process. The major objectives of the effort are to develop modeling tools for effectively engaging stakeholders and formulating allocation and implementation plans that can be used nationwide and that are accepted by regulators and stakeholders. Once completed, these tools will be made available to interested stakeholders and the EPA.

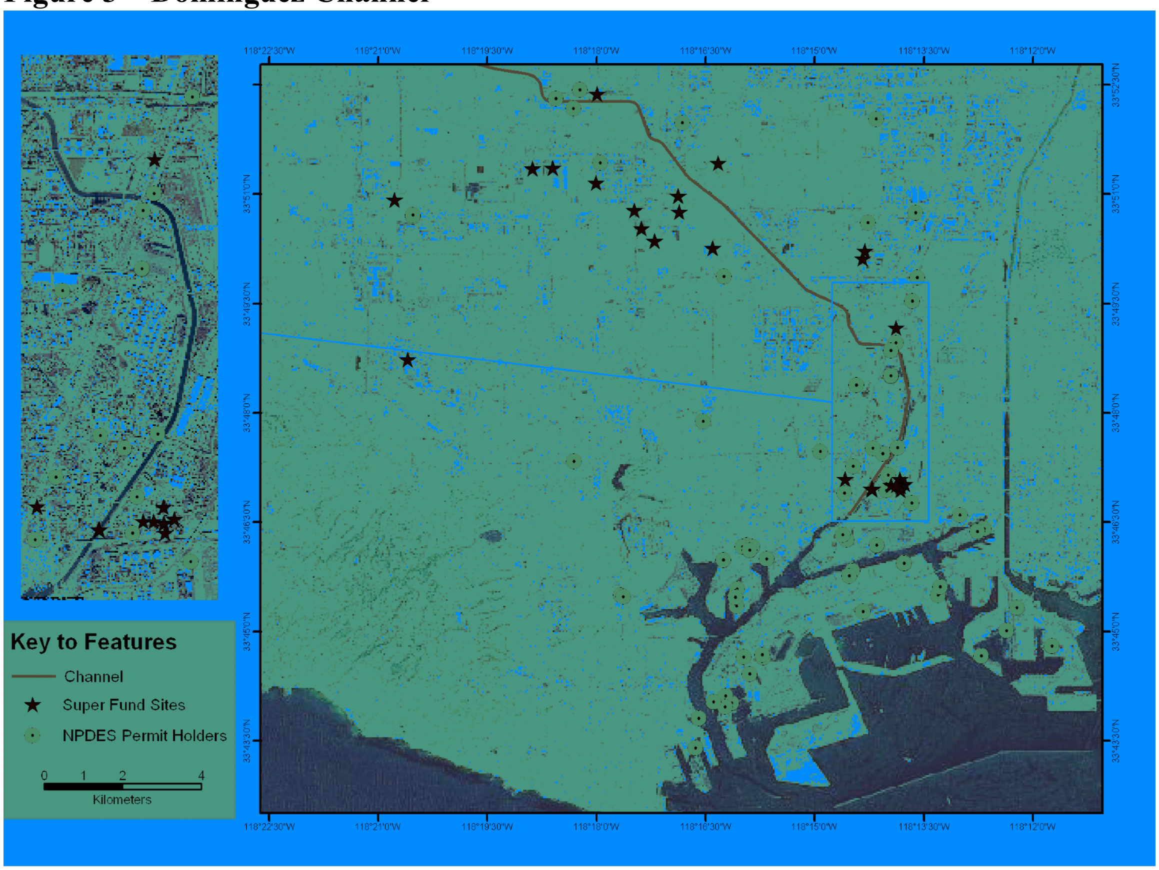
The current suite of models being developed will initially be populated with data from the Dominguez Channel located in the Los Angeles Basin. TMDL development for a variety of heavy metal pollutants impairing this water body is just beginning. Prototype Stakeholder Preference and Allocation models have been developed and are being refined for use in the TMDL development (Stewart, 2004). The Stakeholder Model includes the major stakeholder groups, nongovernmental organizations, oil refineries, the Port of Los Angeles, and the Los Angeles Department of Public Works.

The allocation and stakeholder tools being developed for the Dominguez Channel TMDL are general and will be applicable to other watersheds and pollutants. The focus of this current paper is on the development of the Allocation Model.

Dominguez Channel

Figure 3 is a satellite image of the Dominquez Channel. 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 3 – Dominguez Channel



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). 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 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 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."

In the Dominquez Channel, the California Regional Water Quality Control Board, Los Angeles Region, must propose a TMDL that, after the local approval process is complete, 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 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.

The Water Quality Control Board's initial focus was on the development of a TMDL for bacteria in the Dominguez Channel. Emphasis has now shifted to heavy metals (Smith, 2004). Of particular concern are cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. Possible sources of heavy metals in the Dominguez Channel watershed include industrial and municipal wastewater treatment plant discharges (~141 permits), storm water runoff (~539 permits), vessel discharges, leaching of contaminated groundwater and sediments, and atmospheric deposition. A toxics TMDL is also slated for development at a later date.

METHODOLOGY

A TMDL (Total Maximum Daily Load) is an estimation of the maximum amount of a given pollutant that a water body can receive and still meet water quality standards. It includes an allocation of that amount to a pollutant's point and non-point sources. It must also include a margin of safety to ensure compliance, and must also account for seasonal variations in water quality. Expressed in equation form:

TMDL = WLA + LA + MOS

where:
- WLA – Waste Load Allocation for point sources
- LA – Load Allocation for non-point sources
- MOS – Margin of Safety

A variety of units may be used to express the quantities given in the above equation; for example, kg/yr or μg/L.

The development of the TMDL requires the consideration of:

- Cost, technical achievability and effectiveness
- Political social and economic factors, and equity
- Administrative polices and procedures

In performing the TMDL determination, The State of California requires the cost on implementation to be considered. California has also employed "adaptive implementation" strategies which allow partial implementation over time with subsequent adjustments to the TMDL based on measured water quality improvement. Finally, it should be noted that the U.S. EPA is experimenting with watershed pollutant trading programs. All of these efforts are being considered as a means of achieving "lowest-cost" solutions for meeting water quality requirements. Typical annualized costs for heavy metals treatment options are given in Table 1.

Table 1 – Heavy Metals Treatment Options, annualized costs per 1,000 gal
(Applied Biosciences, 2003)

Chemical Precipitation ++	**\$1.00 – 5.00**
Ion Exchange +	**\$1.50 – 3.00**
Filtration +	**\$3.00 – 8.00**
Reverse Osmosis +	**\$3.50 – 9.00**
Ferrihydrite (for Se +++)	**\$13.00+**
Adv. Biotreatment +++	**\$0.30 – 1.20**

where '+' denotes overall, standalone effectiveness

Balanced against minimizing the cost of implementation are other objectives, such as achieving a balance between point source waste load allocations and non-point source load allocations, ability to pay and equity considerations. A variety of allocation approaches have been proposed to "equitably" distribute costs between dischargers. Some of these are:

1. Equalization of Effluent Concentrations
2. Minimum Total Treatment Cost
3. Equal Percent Removal
4. Percent Removals Proportional to Raw Loads
5. Equalization of Waste Loads
6. Equalization of Waste Load Reductions
7. Equalization of Costs for Reductions

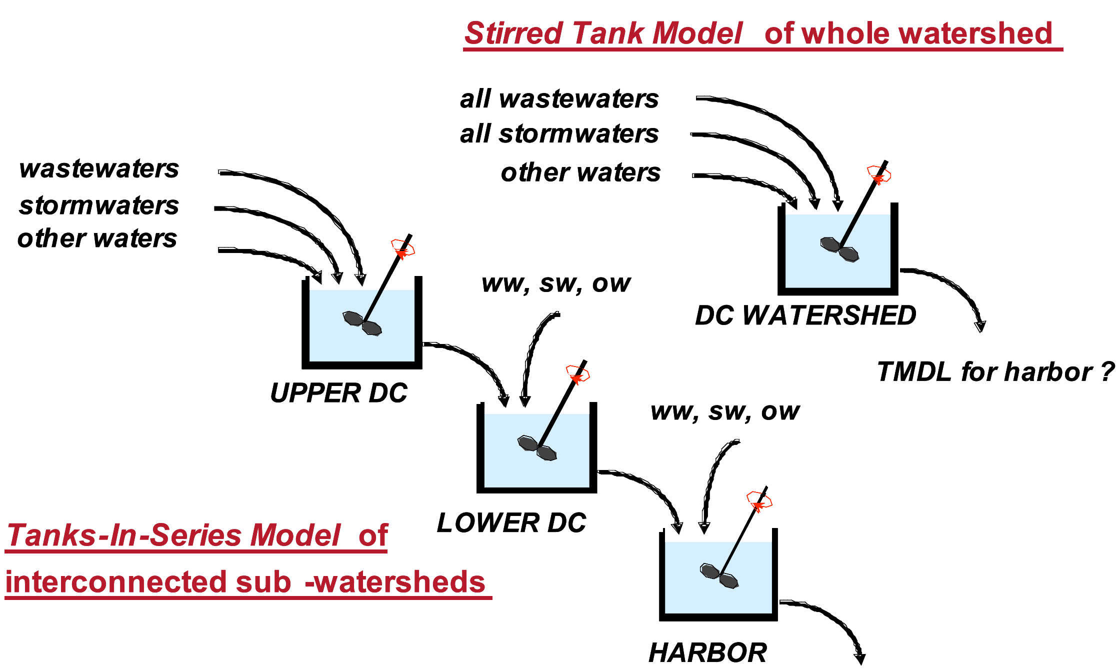
Administratively, it is also necessary to be able to translate any required waste load reductions into NPDES (National Pollutant Discharge Elimination System) permits and any load reductions into "best practices" implementation plans.

Allocation Model

For allocation, the watershed model need not be a detailed hydrological model, though such models can be quite useful for developing data for allocation. Rather, the Allocation Model involves performing material balances for each pollutant of interest. Both spatial and temporal effects must be considered. Spatial effects include identifying all sources and sinks for the pollutant. These may be point or non-point sources, and may include "active" sediments and atmospheric deposition. Transformation of pollutants must also be included. For example, due to toxicity effects, it is important to know for a heavy metal such as mercury, if it is present in metallic, ionic or organic form. Temporal effects can also be critical. Instantaneous, as well as various time-average concentrations are of interest, such as annual, seasonal, or rain event specific, (*e.g.*, the average during the first 30 minutes of a given rain event).

Spatial effects within the watershed can be handled using a tanks-in-series mixing model of interconnected sub-watersheds. Individual sources and sinks are then considered within each sub-watershed. Two models of varying degrees of aggregation are being developed for the Dominguez watershed. Schematically, these are depicted in Figure 4.

Figure 4 – Levels of Aggregation of Watershed



A prototype Allocation Model based on the single Stirred Tank Model has been completed. While the level of detailed provided by this model is insufficient to capture the complexity of the Dominguez Channel watershed, it does serve as a good tool for illustrating the impacts of various allocation procedures on the total cost of achieving the TMDL. This will be illustrated by means of a hypothetical example. This example looks at the reduction of an unidentified heavy metal from industrial and municipal wastewater discharges. Other assumptions used for this example are:

1. Stirred-Tank Model of watershed
2. Annual basis for loadings
3. Only wastewater treatment considered
4. 2.5 μg/L achievable using BACT (Best Available Control Technology)
5. Anti-degradation rule in effect (loadings are not allowed to increase)
6. Only treat portion of wastewater to meet target
7. Technology will reduce treated water concentration to "zero"
8. Wastewater discharges are kept constant
9. Treatment costs not function of concentration
10. Table 2 lists the loadings assumed before the imposition of the waste load allocations

Table 2 – Current Loading for Waste Load Allocation Example

	Flow	Total Metal	
Wastewater Source	Discharge MM gpd	Concentration μg/L	Load kg
Discharger 1 - Industrial	650.0	18.0	16176
Discharger 2 - Municipal	175.0	24.0	5807
Discharger 3 - Municipal	40.0	45.0	2489
Discharger 4 - Industrial	25.5	3.0	106
Discharger 5 - Industrial	10.5	3.2	46
Discharger 6 - Industrial	8.0	4.5	50
Discharger 7 - Industrial	2.8	4.0	15
Discharger 8 - Industrial	1.3	1.2	2
Other Dischargers*	60.0	5.0	415
Total	973.1	12.0	25106

*All dischargers less than 1.0 MM gpd

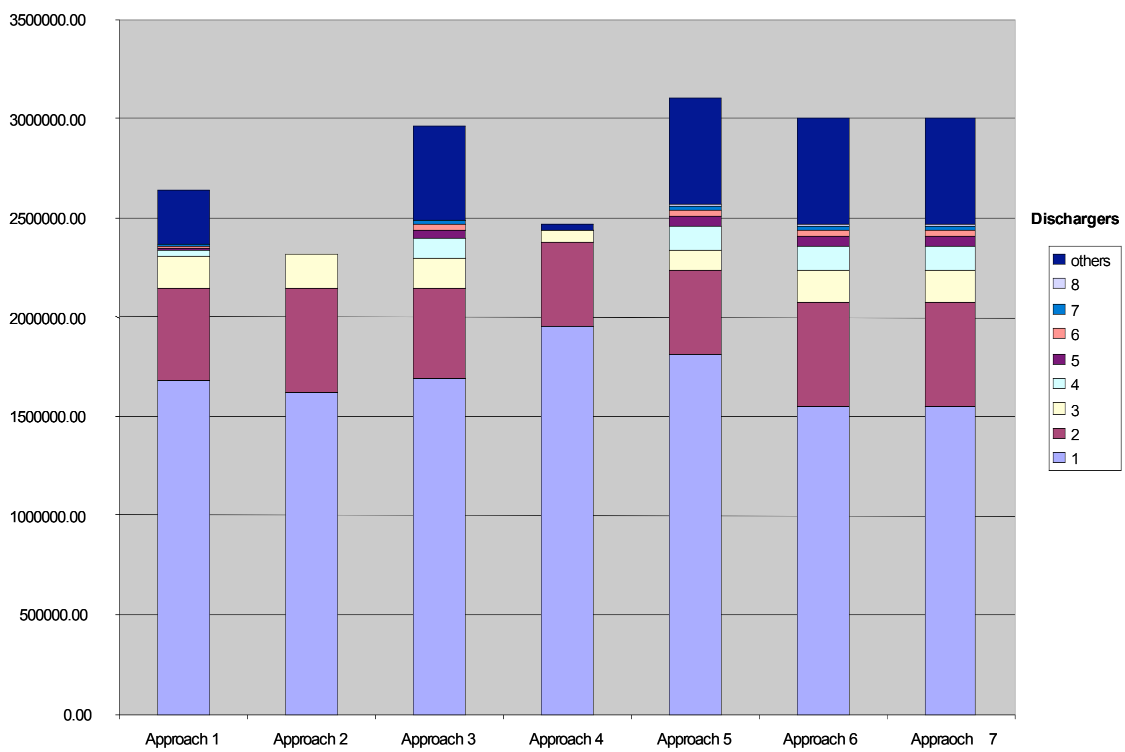
RESULTS

All seven of the "equity" allocation strategies mentioned above were considered for reducing the heavy metal loading in the watershed to 2.5 μg/L. This results in an overall load reduction of 21,745 kg/yr, an 86% reduction. The optimization procedure used in the model is flexible and allows the objective function and constraints to be easily modified to match the given strategy being considered. The model output for the "equalization of discharger effluent concentrations" is shown in Table 3.

Note that due to the anti-degradation restriction, Discharger 8 listed in Table 3 is not allowed to increase effluent concentration from its current level of 1.2 μg/L to 2.5 μg/L.

Treatment costs for all seven scenarios considered in the example are summarized in Figure 5.

Figure 5 – Treatment Cost Summary for Waste Load Allocation Example



DISCUSSION

The first thing to note from Figure 5 is that the total cost of achieving the TMDL target varies dramatically between roughly $2.3 and $3.1 million per day. Approach 2, the lowest cost option, is based on minimizing the total treatment cost and takes full advantage of "economies of scale" for the waste water treatment process. Approach 5,