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Practicability of Detention Basins for Treatment of Caltrans Highway Runoff Based on a Maximum Extent Practicable Evaluation

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ABSTRACT:

The Clean Water Act requires discharges of point source pollutants to be treated through implementation of Best Management Practices (BMPs) to the Maximum Extent Practicable (MEP). A BMP meets MEP if: 1) installation of the BMP is technically feasible, 2) installation of the BMP does not compromise compliance with applicable State and Federal laws, and 3) the cost of installing and maintaining the BMP does not greatly outweigh the probable benefit associated with the increase in receiving water quality. This paper evaluates whether detention basins meet the cost/benefit aspect of MEP by using a beneficial use valuation procedure developed by the University of California at Davis. The procedure involves identifying receiving water beneficial uses, quantifying the value of these uses, and determining the portion of that value attributable to improvements in water quality resulting from the hypothetical installation of a detention basin. Detention basin cost and the incremental increase in beneficial use valuation are determined for six sites throughout California. Based on this information, detention basin costs greatly outweigh associated benefits unless: 1) required land is available at little or no cost, 2) a high proportion of the total flow in the receiving water is from California Department of Transportation rights-of-way, 3) there exists the potential for substantial amounts of high value habitat in the receiving water, and 4) resources are available to operate and maintain the basin.

INTRODUCTION

The Clean Water Act requires dischargers of pollutants to reduce discharges of pollutants through the use of Best Management Practices (BMPs) to the Maximum Extent Practicable (MEP). This paper examines the feasibility of detention basins as a BMP for improving the quality of runoff from highways and freeways. Over the past decade, MEP has been subject to a number of interpretations, none of which have been widely accepted as definitive. The most thorough interpretation of MEP is provided in a Judicial Order issued as part of a lawsuit requiring the evaluation of the effective of BMPs at reducing storm water pollution. For the purpose of this evaluation, and to be consistent with the 1994 Court Order (1) the definition of MEP is as follows:

1. BMPs may be rejected if other effective BMPs will achieve greater or substantially the same pollution control benefits.
2. BMPs may be rejected if they are not technically feasible.
3. BMPs may be rejected if the cost of implementation greatly outweighs the value of the pollution control benefits in nearby receiving waters.
4. BMPs may be rejected if they cause violations of other state and/or federal laws

The aspect of MEP investigated in this paper is the benefit-cost analysis. The methodology used to develop the benefit-cost ratios relies on a procedure for beneficial use valuation developed by the University of California at Davis (2). The approach involves identifying beneficial uses of receiving waters and quantifying the value of these beneficial uses. The change in beneficial use value as a result of improved storm water quality resulting from the hypothetical installation of a detention basin is determined along with the cost of the detention basin to develop benefit-cost ratios. This paper summarizes the methods and results of a study performed for the California Department of Transportation (Caltrans) titled *Practicability of Storm Water Detention Basins For Highway Runoff Based on Maximum Extent Practicable.*

STUDY METHODOLOGY

This study began with a literature review to identify current design, performance, operation, and maintenance criteria associated with detention basins. Based on this research, designs for a detention basin were developed. Two documents developed by Caltrans, the Statewide Storm Water Management Plan (3) and the Caltrans Storm Water Quality Handbooks, Planning and Design Staff Guide, (4), and a document developed by the California Storm Water Quality Task Force, California Stormwater Best Management Practice Handbook (5) served as a foundation for detention basin design.

Next, California transportation improvement projects listings were reviewed and six sites were selected that typified the geographic and climatic settings in California and the types of new construction projects likely to be funded in the coming years. Detention basin costs were developed for each site using the design criteria already developed. Finally, the incremental change in beneficial use valuation as a result of the hypothetical detention basin installations were estimated. Details of the methods are included in each section of the paper.

BASIN DESIGN

General Objectives

The main mechanism through which basins accomplish treatment is by reducing the flow velocity in the basin to promote the settling of the heavier particulate matter. Volume requirements for water quality detention are less than that required for water quantity (i.e., flood control), as water quality basins are usually designed to capture small storms, or the first flush of larger storms. These basins are designed to provide adequate detention time to allow for sedimentation of particulate matter. An "80 percent capture" methodology is used to optimize water quality benefits, which is discussed in more detail below. A drawing showing a typical detention basin design is presented in Figure 1. A general summary of the applications, functions, limitations, and design criteria for detention basins follows.

Applications

The detention basins in this study were designed with several intended functions: removal of particulate matter and other associated pollutants by means of sedimentation; capture of firstflush storm flows; and aesthetic enhancement of surroundings.

Limitations

Detention basins limitations and drawbacks include: high expense for small drainage areas; insufficient treatment of dissolved organics, nutrients, and pathogens; potential public hazard from basins located close to traveled roadways; and the potential requirement of additional land. Additionally, technical feasibility is constrained by topography, soil, and other site conditions (e.g., shallow bedrock, shallow groundwater, etc.).

Sizing Criteria

Detention basins are sized based on detention time and design storm volume. Recommended detention times for basins range from a minimum 10 hours (6) to 24 to 40 hours (5). Forty hours of detention was chosen for this study. Because water will start discharging soon after entering the basin, smaller volumes, caused by the more frequent, smaller storms, will take substantially less than 40 hours to discharge.

There are many methods for determining design volume. The method used in this analysis is from the California Storm Water Best Management Practices Hand Book (5) because it is simple to use and specific to California. The method determines the basin volume needed to capture 80 percent of the annual runoff. This study includes an additional 20 percent to allow for sediment accumulation. The preliminary volume of the detention basin is determined by using the information presented in Table 1. The table assumes that 90 percent of the rainfall on impervious areas will runoff and be captured and 15 percent of the rainfall on pervious areas will runoff and be captured. In addition the method assumes that 0.15 centimeters (0.06 inches) of rainfall does not contribute to runoff because it accumulates in depression storage and is retained.

Relative Basin Dimensions

The literature review revealed that a length-to-width ratio of at least 3:1 is the favored configuration. This ratio was used where possible, measured from midway up the embankment. The length excludes the forebay if one is to be provided. The forebay is a small basin at the inlet to the basin where large debris is collected. Side slopes will be kept to a maximum of 2:1 to minimize space required, but will be 4:1 on at least one interior side to allow for access into the basin for maintenance. Depth of the basin will be kept to 1.8-2.4 meters (6-8 feet) at the deepest point, with .3 meters (1 foot) of that provided for freeboard and emergency overflow.

Frequent Runoff Area

The frequent runoff area will be 0.6 - 0.9 meters (2-3 feet) deep provided near the outlet structure. This deeper area will allow detention of smaller events. The volume of the "frequent runoff" area is about 20 percent of the total basin volume. Providing a deeper zone near the outlet, with a sloped pond bottom to the outlet, also allows for good drainage and less potential for mosquito breeding. During site-specific basin design, this volume can be refined using hydrologic data.

Basin Inlet

The inlet to the basin will discharge storm water into a forebay where most of the large debris such as sticks and rocks will be collected. A concrete- lined forebay design eliminates erosion from the incoming flow and allows for easier removal of debris. This study assumes that the volume of the forebay will be about 5 percent of the detention basin volume

Basin Outlet

Several concepts for the design of basin outlets have been promoted. A perforated riser design is used for this analysis. This outlet consists of a concrete vault (box) with an adjacent riser pipe flowing into the vault. Perforations in the riser allow the quantity of water discharged to increase as the water level in the basin increases. The riser is encased in gravel so that the perforations do not clog with debris. The top of the vault is grated, to allow the water to enter at higher volumes for larger storms. The number and size of the perforations vary from site to site to allow the desired detention for the expected flow. An outlet pipe discharges from the vault to a downstream channel or storm drain. An example of a basin outlet is presented in Figure 2.

An emergency spillway provided in the basin wall (levee) will allow the largest storms to bypass the basin outlet and flow directly into the downstream channel or storm drain. This spillway should be designed for a maximum of 15 centimeters (6 inches) of backwater during the 100-year storm.

Summary of Design Criteria

A summary of the recommended design criteria for a Caltrans storm water detention basin is presented in Table 2. These design specifications promote particulate settling and sediment removal, provide adequate volume for anticipated storm events, minimize overflow or flooding potential, and mitigate soil erosion and scouring potential.

COSTS

Construction Costs

The method to estimate detention basin construction costs consisted of best engineering judgment using standard methods, with later verification using Brown and Caldwell's BAC-PAC model. Estimating construction costs consisted of six basic steps:

1. Determine the drainage area (pervious and impervious) that is present within the project area.
2. Determine the active volume required (i.e., the 80 percent average annual runoff capture method based on the California Storm Water Best Management Practice Handbook (5))
3. Create a preliminary design layout of the detention basin based on the general layout and dimensions.
4. Determine the land required.
5. Use the preliminary design layout to determine cost quantities for construction items such as earthwork and piping.
6. Apply generalized per unit cost values to the cost quantities.

Drainage Area

Drawings, when available, were obtained from Caltrans personnel. If possible, grading, drainage, and as-built drawings were obtained for the surrounding area. Local county and city maps showing some additional drainage features and slopes were also obtained. The collected documents were reviewed to determine: project extent, drainage patterns, receiving water location, and highway drainage discharge locations. From this information, the newly constructed area expected to drain to the detention basin was estimated. It was assumed that pumping was not necessary to deliver storm water runoff to the proposed detention basin location.

Volume

Determining the detention basin's usable volume followed the method described in the *Caltrans Storm Water Quality Handbook, Planning and Design Staff Guide (4)* and described in further detail in the *California Storm Water Best Management Practice Handbook (5)*.

Preliminary Layout

A preliminary layout of the detention basin was based on the required volume and the design criteria and guidelines identified previously. The preliminary layout included main detention area, forebay, overflow, discharge structure, and site access. The determination of the actual dimensions of the basin is an iterative process, because dimensions must meet the depth, side slope, length-to-width ratio criteria, and allow for the size, turning radius requirements, and clearance requirements of heavy equipment (front-end loaders and dump trucks) for removal of sediment and maintenance activities.

Land Required

Once a preliminary layout was completed, the site was re-examined to determine if the detention basin could be located within land presently owned by Caltrans. Possible locations included cloverleaf's, space between ramps and the main roadway, or in adjacent areas already used for drainage. If land was not available on current Caltrans holdings, the amount of additional land needed to construct the detention basin was estimated. Land costs were based on interviews with realtors in urban areas, and Caltrans assessors for rural sites. An additional 3.8 meters (12 feet) was added around the basin perimeter for access roads and safety setback from traveled lanes. There were no attempts to redesign roadways.

Cost Quantities

Cost categories that contributed substantially to the cost of constructing the detention basin were identified. Quantities were then determined for each category based on the preliminary layout of the detention basin. The categories identified were:

Soil excavation and disposal. This item includes the rough excavation of the basin and the disposal of excess soil.

Grading and compaction. Once the basin has been excavated, the soil is graded to the required elevations, slopes, and configuration. The soil is compacted to eliminate future settlement and to prepare areas for paving or structures.

Inlet piping. Additional piping required to transport the storm water the additional distance from the original discharge point (without the detention basin) to the discharge point at the detention basin. Manholes are required to provide access for cleaning and other maintenance. Excavation costs were not included in the estimate.

Outlet piping. Piping is required to discharge the effluent from the detention basin to the ultimate discharge location. Manholes are required to provide access for cleaning and other maintenance. Excavation costs were not included in the estimate.

Outlet structure. The outlet structure is a combination concrete vault and perforated riser, designed to release storm water slowly.

Concrete. Certain areas of the detention basin were assumed to receive concrete lining: the bottom and one side of the forebay (to allow vehicle access for debris removal and reduce erosion), at the channel between the forebay and main basin, and at the overflow spillway.

Oil absorbing booms. Disposable booms were used to absorb oil that floats to the surface of the basin.

Irrigation. Landscape irrigation was assumed necessary to keep the grass in the basin minimally alive during the summer months. This item includes piping, valving, and timer/controllers.

Seeding. This item includes the initial preparation of the soil (tilling and addition of any soil amendments) and seeding of grass.

Access road. Access to the site is needed all year for maintenance. This item included the construction of a gravel road along one side of the detention basin and any special soil or gravel compaction associated with the road construction.

Security. Access to the site must be limited to maintenance personnel. Also, vehicles leaving the roadway must not enter the detention basin. This item includes 1.8 meter (6 foot) chain link fencing around the basin, a gate, and guardrails where the site is adjacent to a roadway. While guardrails may not be necessary at all sites, the estimates included a guardrail cost.

Applying Cost Values

Unit costs were applied to the above categories. The unit costs were determined from industryaccepted estimating manuals and recent projects. The unit costs include contractor administration and profit. Land costs were estimated through interviews with Caltrans personnel and realtors familiar with the site location. Table 3 shows the costs used.

Operation and Maintenance Costs

The primary categories of operations and maintenance costs included:

General cleaning and repair

This item includes semi-annual site visits to inspect the inlet and outlet structures, security fencing, and access roads, and to perform minor repairs to the piping and the basin. This item also includes the removal of debris and sediment from the inlet forebay and main basin as needed. This includes regrading and reseeding the bottom of the basin after sediment removal at appropriate frequencies, generally every other year. This estimate assumes sediment is nonhazardous, will not require dewatering, and will need to be removed every other year.

Post storm maintenance and inspection

This item includes visual inspection of the basin after each storm to ensure the system is working properly. This activity includes draining and removal of standing water in order to avoid mosquito breeding.

Debris and sediment disposal

This item includes the cost of transporting and disposing of the debris and sediment collected in the basin.

Landscape maintenance

This item includes the maintenance of the area landscaping, which will consist primarily of mowing the grass, trimming natural vegetation around the basin, irrigation repairs, and reseeding grass areas as needed.

Replacement of oil-absorbing booms

The booms will be replaced annually.

Miscellaneous supplies

This item includes any materials and supplies that might be needed for the maintenance of the facility such as grout, extra rock, concrete for patching, payment of utility bills (electrical and water), etc.

Costs will vary according to each location based on the size of the basin and proximity to other facilities. Facilities located away from populated areas and Caltrans maintenance yards will require significantly greater travel time to maintain the detention basin, increasing costs accordingly. The present worth value of the operation and maintenance costs are calculated for an assumed basin life of 20 years at a 4 percent interest rate. Labor rates were assumed to be $30.00 per hour. The cost for equipment related to maintenance was assumed to be zero.

BENEFITS

VALUATION METHODOLOGY

The Wilchfort et al. methodology (1) was applied to six construction projects to determine if including a detention basin was economically desirable. The valuation analysis consists of the

following three primary tasks:

1. Benefits identification
2. Benefits assessment
3. Benefit analysis

These tasks are achieved through a general methodology that is summarized in the UC Davis report entitled An Economic Valuation of Stormwater Quality Improvement for Ballona Creek, California (1). Each of these three tasks is briefly described below.

Benefits Identification

Benefits identification defines all significant beneficial uses (benefits) within the receiving water that might be improved or supported by storm water quality improvements and identifies storm water pollutants that may limit or negate one or more beneficial use. Benefit identification began by identifying the receiving water to which the runoff flows. Once the receiving water was known, the beneficial uses existing and potentially existing for the waterbody were determined by examining the basin plan promulgated by the applicable Regional Water Quality Control Board. Finally, the beneficial uses likely to be impacted by storm water runoff quality were determined. This analysis only examines those beneficial uses dependent on storm water quality.

Benefits Assessment

Benefits assessment defines the limits and economic values of beneficial uses associated with the receiving water. This task estimates the relationship between receiving water pollutant concentrations and each beneficial use. Pollutant concentrations have a 'lower threshold value' and an 'upper threshold value' within which they affect a beneficial use. The lower threshold value is the maximum pollutant concentration where full beneficial use can be achieved. The upper threshold value is the minimum pollutant concentration that causes a beneficial use to be entirely eliminated (see Figure 3 for an illustration of this concept). Benefits that may be impaired by storm water quality are assigned dollar values. The dollar values estimated for beneficial uses are conservatively high (likely upper bound values) to ensure that the benefit-cost ratio developed is favorable to environmental protection.

Benefit Analysis

Benefit analysis estimates the net benefit attributable to installation of the detention basin. This was done by estimating the pollutant concentrations in storm water effluent with the detention basin installed, followed by estimating the pollutant concentration in receiving water. The marginal improvement of each beneficial use, and corresponding dollar value, can then be calculated by comparing the projected pollutant concentration with the concentration threshold determined in the benefits assessment.

RESULTS

Benefit-cost ratio results are presented for the six sites in Table 4. Costs outweighed benefits by factors of between five and thirty-six to one. Based on the findings of this analysis, detention basins do not meet the definition of maximum extent practicable and should not be considered on a statewide basis except under special circumstances. The circumstances limit consideration of detent ion basins to sites where all of the following conditions are present: 1) little or no cost for the added land necessary to accommodate the detention basin, 2) a high proportion of Caltrans runoff within the total flow to the receiving water, 3) substantial amounts of highly valuable habitat potentially affected by Caltrans storm water runoff, and 4) resources are available for proper operation and maintenance of detention basins.

DISCUSSION

The study examined whether detention basins meet the cost-benefit aspect of MEP. Based on the results, detention basins do not meet MEP and should not be considered for deployment unless certain criteria are met. On the cost side of the equation, the most significant factors in this determination were the cost of additional land if needed and the percentage of Caltrans area in the watershed. The most significant benefit was associated with habitat present in the receiving water. However, sensitivity analysis showed little change in the results associated with a reasonable change in the cost of extra land, the percentage of Caltrans area in the watershed, or slight increases in the amount of habitat.

Benefit estimates were consciously made high to provide a likely upper bound for the value of the benefit. However, several things made the benefits associated with installation of the detention basins lower than expected. First, little change in receiving water quality was expected because the Caltrans fraction of the runoff was generally small. If regional water quality basins were implemented, greater increases in receiving water quality could be achieved with commensurate greater increases in benefits. (See discussion of basin size below.) Additionally, the benefit valuations were based solely on current use values. No attempts were made to monetize any value associated with more esoteric concepts such as option value or legacy value. Therefore, even though we attempted to err on the side of environmental benefit, the benefits may have been substantially undervalued.

The cost estimates, on the other hand, were likely reasonable for the sites examined. However, due to the small drainage areas, the per-acre cost of these basins is likely high compared to basins treating substantially larger areas. This is due to certain fixed cost (e.g., maintenance mobilization, access roads, gates, etc.) that are relatively large because they are only spread over a small treatment area. Per-acre basin costs for larger drainage areas may be substantially lower. Additionally, several features were included which may or may not increase the removal efficiency of the basin while adding cost (e.g., forebay and frequent runoff area).

CONCLUSION

The uncertainties discussed in the two previous paragraphs reveal one main findings of this study, the need for additional research in several areas relating to storm water BMP selection. First, reliable figures are needed for BMP performance, either removal efficiencies or performance standards (i.e., reduces TSS to a certain concentration). Second, real cost figures are needed for the analysis. These point to the need for a comprehensive BMP pilot program. Additionally, the valuation technique relied on use values for beneficial uses that were engineering best estimates. Research is also needed into the true value society places on various beneficial uses. Finally, regarding detention basins specifically, research is needed to determine whether all elements of this design are necessary for the basins function, and to optimize other elements such as the outlet structure.

ACKNOWLEDGMENTS

Brown & Caldwell prepared the report upon which this paper is based. Yulya Borroum (nee Davidova) contributed substantially to the original report. The Caltrans Storm Water Program under the direction of Steve Borroum provided funding for the report and this paper.

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List of Tables and Figures

TABLE 1 Storage Basin Size Requirements For 80 Percent Annual Runoff Capture [a]

Rain Gauge Location	Unit Basin Storage Volumes (m3/ha) Percentage of Directly Connected Impervious Area				
	20%	40%	60%	80%	100%
Bakersfield	24.4	38.1	47.2	61.0	71.6
Bishop	30.5	45.7	59.4	70.1	85.3
Fresno	36.6	53.3	70.1	88.4	108.2
Los Angeles	50.3	73.2	99.0	125.0	147.8
Oakland	45.7	67.0	88.4	100.6	125.0
Riverside	39.6	54.9	73.2	94.5	112.8
Sacramento	45.7	70.1	89.9	112.8	131.1
Thermal	33.5	54.9	65.5	76.2	99.1
Truckee	45.7	67.0	88.4	109.7	128.0

[a] From California Storm Water Best Management Practice Handbooks - Municipal (CDM 1993).

TABLE 2 Design Criteria

Basin Volume Method presented in the Caltrans Storm Water Quality Handbook plus 20% for sediment

Parameter	Value
Detention time	40 hours
Length to width ratio	3:1
Embankment slopes	3:1 or 4:1, 2:1 maximum
Primary basin depth [(a)] (upper volume)	0.9 – 1.5 meters (3 – 5 feet)
Frequent runoff volume (lower volume)	20 percent of total basin volume
Frequent runoff area depth	0.6 – 0.9 meters (2 – 3 feet)
Forebay volume	5 percent of total basin volume
Forebay depth [(a)]	1.8 – 2.4 meters (6 – 8 feet)
Outlet Structure	Concrete box with perforated riser pipe
Emergency spillway	15 centimeter (6 inch) maximum backwater with 100-year storm.

[(a)] includes freeboard

TABLE 3 Typical Unit Costs

Item	Unit	Unit Price, $
soil excavation and disposal	CY	12.00
grading and compaction	SY	1.50
piping (inlet and outlet)	LF	size dependent
manholes (inlet and outlet)	EA	2000.00
gravel (for perf. Riser)	CY	25.00
Concrete	SF	5.00
oil absorbing booms	EA	60.00
outlet structure	EA	5000.00
Irrigation	SY	1.50
seeding w/ soil prep	SY	2.00
access road (gravel)	SF	0.75
chain link fence- 6 foot high	LF	15.00
Guardrail	LF	40.00
land - urban	AC	650,000
land - rural	AC	3,000-200,000

CY-cubic yards, SY-square yard, LF -linear foot, EA -each, SF-square foot, AC- acre

TABLE 4 Summary of Benefit/Cost Ratio Calculations

Site	Benefit/Cost Ratio
Ventura - urban marine	1:9
Solano - urban marine	1:5
San Diego - urban freshwater	1:34
Del Norte - rural freshwater	1:10
Mono - rural freshwater	1:13
Yolo - urban freshwater	1:36

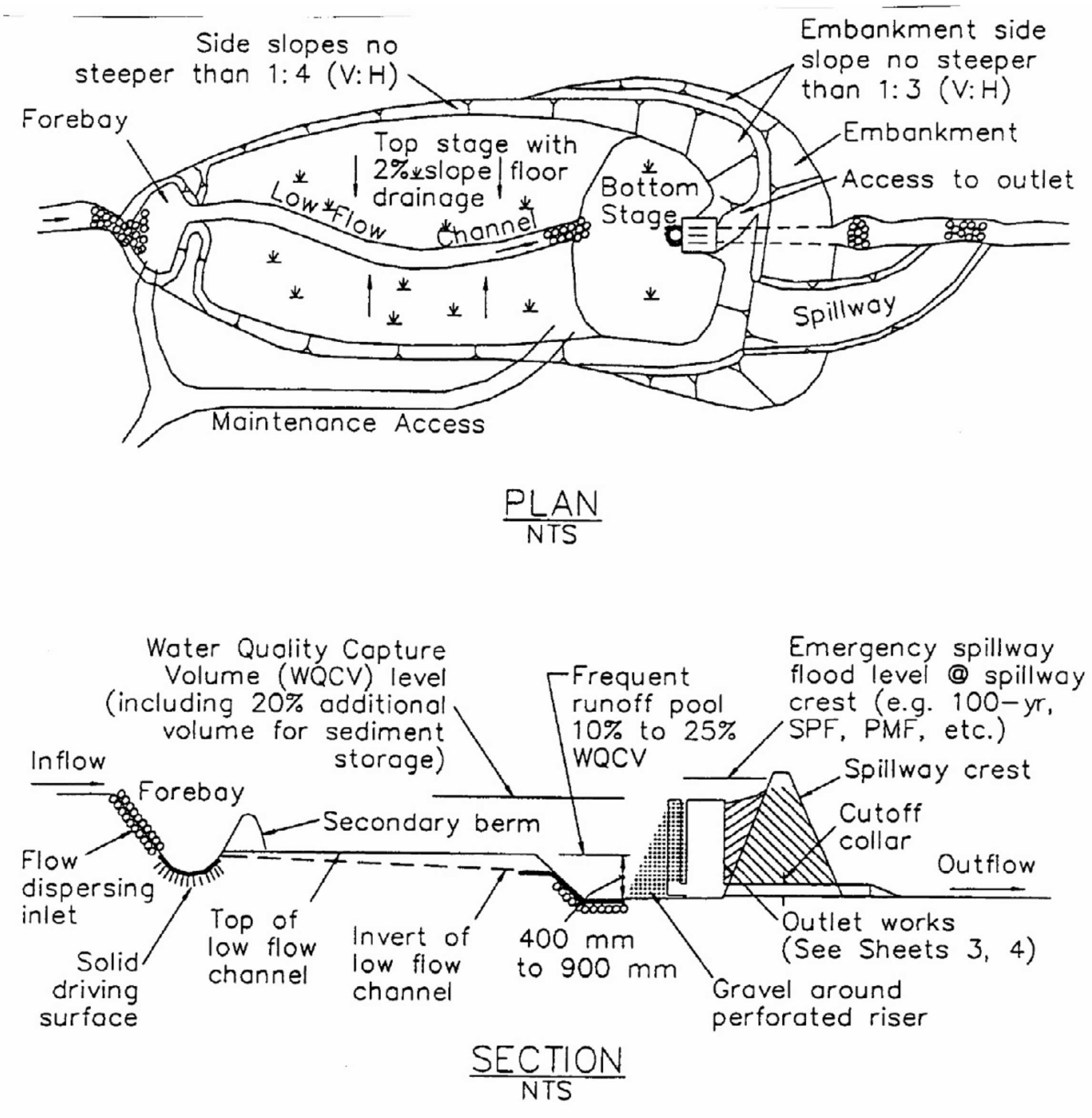

FIGURE 1 Typical detention basin (after *Caltrans Storm Water Quality Handbook* 1996).

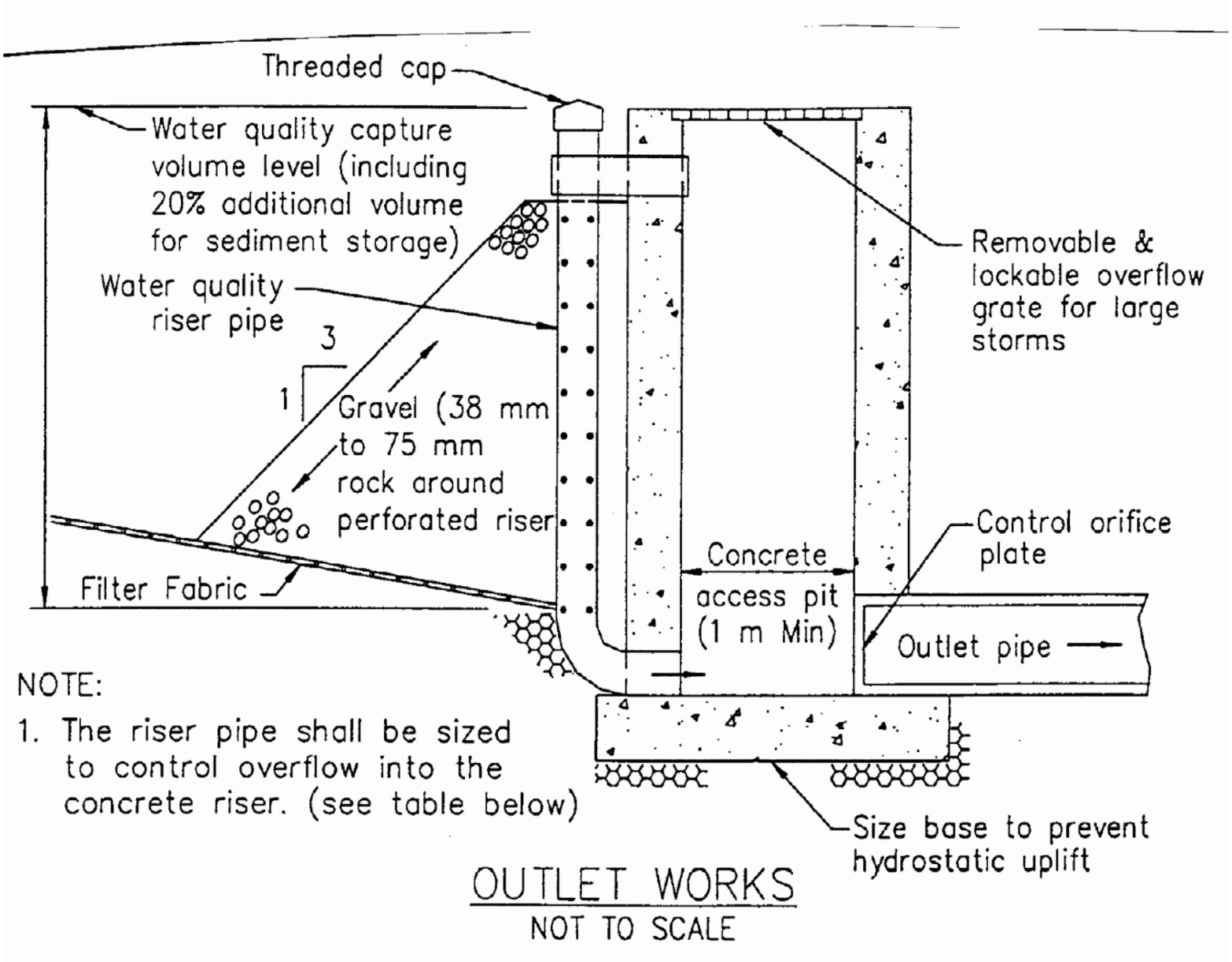

FIGURE 2 Detention Basin Outlet (after *Caltrans Storm Water Quality Handbook* 1996).

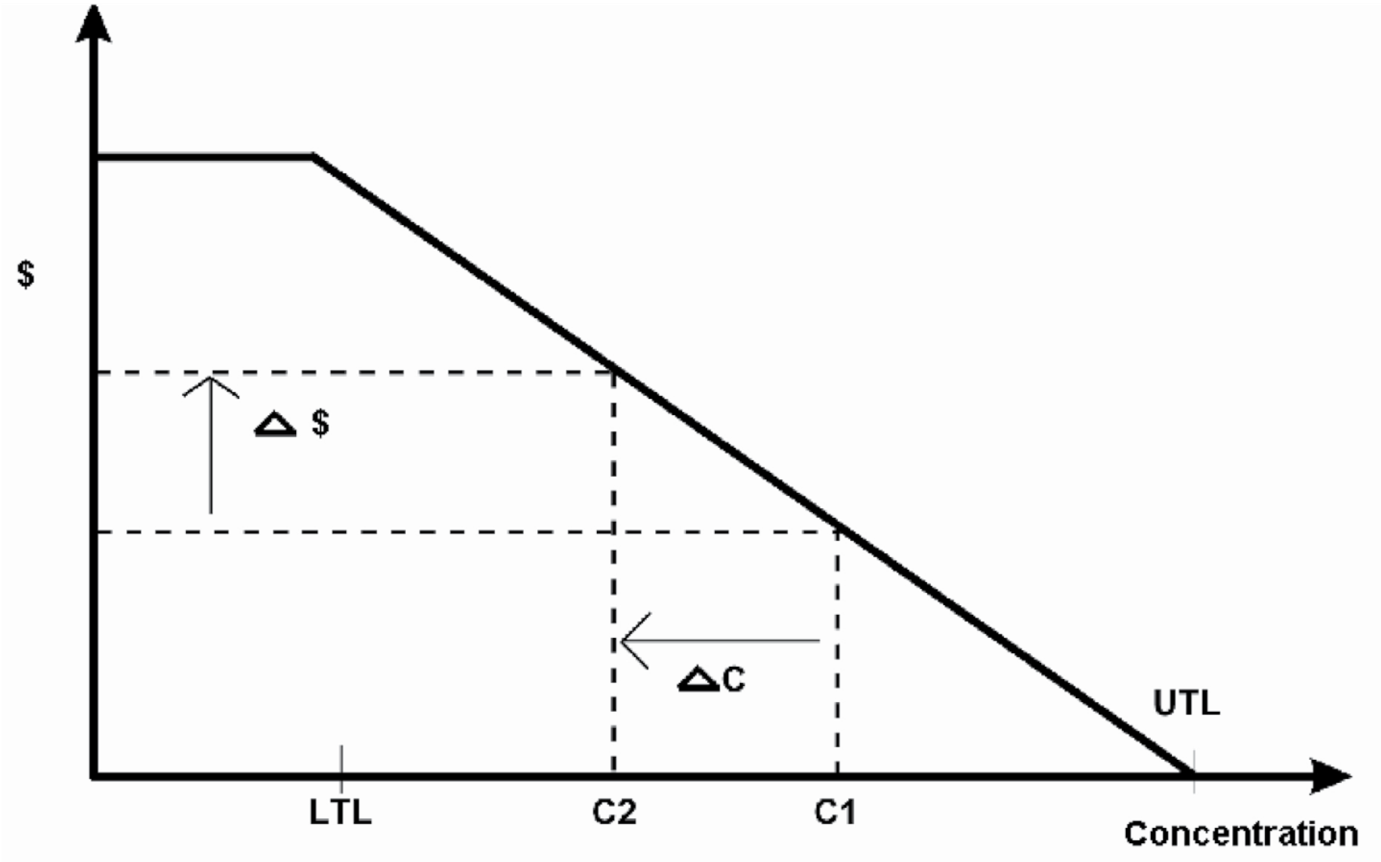

FIGURE 3 Generalized Relationship between Beneficial Uses and Water Quality (after *Wilchfort et al*. 1996).