required for effective operation of the oil-water separator. Improved source-control measures at Caltrans maintenance stations have generally been effective in reducing hydrocarbon pollutant levels below that which OWS are effective in removing. In conclusion, none of the 25 maintenance stations in Districts 7 and 11 that were evaluated had sufficiently high concentrations of free oil for successful implementation of this technology. At these low levels, other conventional stormwater controls can provide better treatment of hydrocarbons, as well as other pollutants of concern in runoff; however, they may be appropriate in certain non-stormwater situations (e.g., where source controls cannot ensure low oil and grease concentrations).

## Cost

The incurred costs of constructing and operating the BMPs in this pilot study were documented in detail. These costs reflect the requirements of stormwater retrofit in the highway environment in the urban areas of southern California and may not be representative of those that might be incurred in other settings. There has been extensive discussion among the parties involved in this study regarding whether these numbers accurately represent the costs that would be incurred in a more extensive (widespread) retrofit program. Many reasons have been suggested for possible differences including, among others: costs specific to pilot projects, the bidding climate at the time the contracts were advertised, the lack of standard competitive bidding, and the dispersed nature of the construction activities. While the parties disagree to some extent about the degree of departure from a normal scenario, both parties agree that there were pilot-specific costs incurred in this project that would not be replicated in a larger scale retrofit implementation program. A separate study commissioned by the retrofit parties suggested ways to reduce costs. Additional cost information from elsewhere in the nation is provided in Appendix C.

The actual construction costs were reviewed on a site-by-site basis by a technical workgroup that included water quality specialists, construction managers and design engineers. The goal of the workgroup was to develop 'generic' retrofit costs that could reasonably be applied to other Caltrans BMP retrofit projects. The costs were developed by (1) reviewing the specific construction items for each site; (2) eliminating those that were atypical; and (3) adjusting the costs that were considered to be outside of what would 'routinely' be encountered in a retrofit situation. Specific construction items that were reduced or eliminated from the realized costs are discussed in the individual device chapters. The average adjusted construction costs for each of the technologies are presented in Table 3.

The construction costs for each of the BMPs have been normalized by the water quality volume rather than by tributary area to account for the significant differences in design storm depth used for sizing the controls in different parts of the study area and for the differences in the runoff coefficient at each site. For the flow-through devices, such as swales, the cost per unit volume calculations used the water quality volume for the tributary area that would be used for BMP sizing if a capture-and-treat type device, such

as a detention basin, were implemented at the site. Where more than one facility of the same type was constructed, the mean cost per water quality volume is reported.

Life-cycle costs were developed by adding the present value of normalized expected operation and maintenance cost to the normalized adjusted construction cost. The expected maintenance requirements were developed based on the recommended Operation and Maintenance Plan (Appendix D) and are also presented in Table 3. The present value calculation used a 20 year life-cycle and a 4 percent discount rate. There was a substantial range of values for the life-cycle cost of biofiltration strips and drain inlet inserts among the individual sites because the size of the devices was fixed, while the tributary areas varied greatly. Nevertheless, the average value observed in the study was used for computations in this table as it was for other devices.

The pilot program construction cost figures represented throughout this report are directly applicable only to Caltrans and its operations. The unique environment and constraints associated with retrofitting BMPs into the California Highway system makes comparison to other possible applications of the same BMPs difficult. Furthermore, even within the Caltrans system, information on construction costs will undoubtedly increase greatly as BMPs continue to be developed and implemented, such that the construction cost information in this report will be of limited value over time. It should be recognized that the Operation and Maintenance cost information was based partly upon estimates and projections of future needs.

The parties engaged the assistance of outside experts to review the costs experienced in the retrofit pilot program and to make suggestions for cost reductions and improvements in efficiency. Eventually these consultants prepared a report, which is appended to this report in Appendix C.

**Table 3 Cost of BMP Technologies (1999 dollars)**

| BMP Type (No. of installations) | Avg. Adjusted Construction Cost | Adjusted Construction Cost/$m^3$ of the Design Storm | Annual Adjusted O&M Cost | Present Value O&M Cost/$m^3$ | Life-Cycle [a] Cost/$m^3$ |
|---|---|---|---|---|---|
| Wet Basin (1) | $ 448,412 | $ 1,731 | $ 16,980 | $ 452 | $ 2,183 |
| Multi-chambered Treatment Train (2) | $ 275,616 | $ 1,875 | $ 6,410 | $ 171 | $ 2,046 |
| Oil-Water Separator (1) | $ 128,305 | $ 1,970 | $ 790 | $ 21 | $ 1,991 |
| Delaware Sand Filter (1) | $ 230,145 | $ 1,912 | $ 2,910 | $ 78 | $ 1,990 |
| Storm-Filter™ (1) | $ 305,355 | $ 1,572 | $ 7,620 | $ 204 | $ 1,776 |
| Austin Sand Filter (5) | $ 242,799 | $ 1,447 | $ 2,910 | $ 78 | $ 1,525 |
| Biofiltration Swale (6) | $ 57,818 | $ 752 | $2,750 | $ 74 | $ 826 |
| Biofiltration Strip (3) | $ 63,037 | $ 748 | $2,750 | $ 74 | $ 822 |

| BMP Type (No. of installations) | Avg. Adjusted Construction Cost | Adjusted Construction Cost/$m^3$ of the Design Storm | Annual Adjusted O&M Cost | Present Value O&M Cost/$m^3$ | Life-Cycle [a] Cost/$m^3$ |
|---|---|---|---|---|---|
| Infiltration Trench (2) | $ 146,154 | $ 733 | $ 2,660 | $ 71 | $ 804 |
| Extended Detention Basin (5) | $172,737 | $590 | $ 3,120 | $ 83 | $ 673 |
| Infiltration Basin (2) | $ 155,110 | $ 369 | $ 3,120 | $ 81 | $ 450 |
| Drain Inlet Insert (6) | $ 370 | $ 10 | $1,100 | $ 29 | $ 39 |

[a] Present value of operation and maintenance unit cost (20 yr @ 4%) plus construction unit cost.

Despite the uncertainty in the projected costs of a wholesale BMP retrofit program, the cost data can be used to rank BMPs by life-cycle costs, which can serve as the first step in selecting the most cost-effective technology for a given site.

Recurring issues that strongly affected the capital cost of the devices were the discovery of unsuitable material in the subsurface and buried utilities at the sites selected for implementation of the devices. Unsuitable material included both natural and manmade objects that increased the cost of excavation. At several sites, large boulders had to be removed and the site over-excavated and backfilled. Other sites had been used as disposal areas, the extent of which was not realized until after construction began. Rarely did the as-built plans correctly identify the location of utilities, requiring their relocation or the repositioning of the BMP during construction. These types of conditions may be encountered fairly frequently in retrofit construction. Consequently, average published costs may be appropriate for planning purposes, but should not generally be used to estimate the cost for a particular site, unless supplemented with a detailed site assessment.

In addition to construction costs, it is also important to consider the operation and maintenance costs for each technology. An important element in selecting the most appropriate BMP for a site is an understanding of the amount and type of operation and maintenance required. BMPs that require less maintenance are preferred, other factors being equal.