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WATERSHED MANAGEMENT MODEL FOR OPTIMAL ALLOCATION OF BEST MANAGEMENT PRACTICES

USER'S GUIDE AND CASE STUDY

Prepared for:

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TABLE OF ACRONYMS

BMP	Best Management Practice
GIS	Geographic Information System
PPF	Production Possibilities Frontier
SCS	Soil Conservation Service
SWFWMD	Southwest Florida Water Management District
TBNEP	Tampa Bay National Estuary Program
TBRPC	Tampa Bay Regional Planning Council
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USDA	U.S. Department of Agriculture

EXECUTIVE SUMMARY

The goal of the Tampa Bay National Estuary Program (TBNEP) for this project is to assist the local Tampa Bay governments with the process of selecting optimal pollution management strategies. The watershed management model was developed in accordance with the TBNEP's role as a facilitator for the selection process. Specifically, the watershed management model will provide a method for evaluating the most cost effective and optimal methods of controlling nutrient and sediment runoff from specific areas of the watershed.

There are multiple objectives to be addressed by the watershed management model. These objectives include the reduction of total nitrogen (TN) loads, total suspended solids (TSS) loads, and total phosphorus (TP) loads, and the minimization of costs of BMP implementation.

The watershed management model was developed to provide a method for evaluating the most cost effective and optimal methods of controlling nutrient and sediment runoff from specific areas of the watershed. Several Tampa Bay region-specific datasets were compiled for BMP costs and efficiencies. However, the model is intended to be flexible and to be used in conjunction with specific pollutant load and subbasin characteristic datasets developed by individual users for specific areas of interest.

The specific objectives of this project were:

1) to complete the development of a TBNEP database of BMP costs, constraints, and efficiencies specific to the Tampa Bay region,

2) to develop a computer program that will evaluate management data and that will compile a list of optimal BMP allocation strategies given appropriate data,

3) to demonstrate the application of the model through an example case study, and

4) to provide a technical users manual for the local governments for which the model was developed.

An example case study is presented in the final chapter of this users manual, and the example data files for this case study are included on the diskette containing the computer software.

1.0 BACKGROUND

The goal of the Tampa Bay National Estuary Program (TBNEP) for this project is to assist the local Tampa Bay governments with the process of selecting optimal pollution management strategies. The watershed management model was developed in accordance with the TBNEP's role as a facilitator for the selection process. Specifically, the watershed management model will provide a method for evaluating the most cost effective and optimal methods of controlling nutrient and sediment runoff from specific areas of the watershed.

All methods of controlling nutrient and sediment runoff to the receiving waterbodies of the Tampa Bay watershed and ultimately to the bay proper are operationally defined for this project as "best management practices" or "BMPs," and they include a variety of structural and nonstructural techniques ranging from construction of stormwater treatment ponds to providing public education regarding the use of excessive amounts of fertilizers on residential lawns.

There are two levels of decisions to be made with regard to the implementation of BMPs in a watershed. One level is concerned with making detailed engineering decisions regarding the design and implementation of a BMP on a specific site (e.g., the routing of stormwater, the construction materials and plantings for a specific pond, the location and orientation of a stormwater filtration trench on a specific slope). The second level is concerned with making BMP allocation decisions regarding which types of BMPs should be implemented and how many should be implemented in each subbasin on a regional or local basis. Although there is no clear dividing line between these two levels of decision making, the focus of this project is on the second level of decisions regarding the allocation of BMPs and development of overall management strategies either for a region or for a specific subbasin.

When making decisions regarding the allocation of BMPs, Tampa Bay watershed managers are faced with two distinct challenges. These challenges are:

- there are multiple management objectives to be addressed (e.g., the reduction of TN, TSS, TP, and the minimization of costs), and

- there is a very large number of combinations of management options and sites to be considered.

Each of these challenges and the specific questions to be addressed by the watershed management model are discussed in the following sections.

The Multiple Management Objectives for Tampa Bay

There are multiple objectives to be addressed by the watershed management model. These objectives include:

- the reduction of total nitrogen (TN) loads,
- the reduction of total suspended solids (TSS) loads,
- the reduction of total phosphorus (TP) loads, and
- the minimization of costs associated with BMP implementation.

In particular, long-term observations suggest that nutrient loadings to the bay have contributed to the decreased extent of naturally occurring seagrass meadows. The TBNEP is currently completing ongoing research to link nutrient loads to water quality conditions (i.e., chlorophyll *a* concentrations) and the light environments required by seagrasses (Janicki and Wade, 1996). The results of this work suggest that total nitrogen loads are currently the most important pollutant load factor to be addressed as impacts to seagrass survival and distribution, and that TN loads should be held in check at current levels to continue the process of seagrass restoration. However, the TBNEP has also identified total suspended solids loads and total phosphorus loads as additionally important management considerations.

Because the watershed management model must consider these multiple objectives, the standard linear optimization approaches will not suffice for the development of overall BMP allocation strategies. Many of these standard approaches maximize the return for a given one dimensional objective function (e.g., the allocation of BMPs that will result in the maximum load reduction per cost for nitrogen). Clearly, this is an important step in the optimization process. However, the watershed management model must also consider tradeoffs between multiple objectives that may be difficult to directly compare. For example, the model should define the allocation of BMPs that would provide a high level of load reduction for nitrogen while providing a high level of load reduction for total suspended solids.

The watershed management model must provide important information to the managers as they carefully balance the expected benefits of each objective against:

- the optimal allocation strategy for all of the objectives considered;
- management practice costs and feasiblities;

- the optimal distribution of management resources among the governmental jurisdictions in the watershed; and

- the potential for adverse social effects (e.g., the loss of recreational resources, health and safety issues, the inhibition of economic development).

The Large Number of Applicable Management Options for Tampa Bay

There are many BMP alternatives that have been or potentially can be employed within the Tampa Bay watershed. Wanielista and Yousef (1992) have recently reviewed the major categories of some of these storm water quality management practices. In summary, these management strategy categories include:

- Structural/Semistructural management strategies such as

  - End of pipe management strategies (e.g., online detention ponds, offline diversion/infiltration, reuse systems);

  - Overland flow modification (e.g., swales, parking lot storage, retention);

  - Physical treatment (e.g., sediment basins, upflow filters, rotating disk screens);

  - Porous pavement; and

  - Point source treatment.

- Nonstructural management strategies such as

  - Surface sanitation (e.g., air pollution control, anti-litter ordinances, street cleaning);

  - Chemical use control (e.g., lawn chemical management, industrial spillage prevention and response);

  - Sediment control (e.g., seeding, sodding, mulching, fertilization);

  - Use of natural drainage (e.g., marsh treatment, wetland preservation); and

  - Permit requirements and enforcement.

A particular BMP allocation strategy may employ any number of these BMPs within a single subbasin or a group of subbasins. Thus, a very large number of combinations of possible BMPs and subbasins must be considered for the development of management plans.

The combination of the large number of possible BMP allocation strategies and the previously described multiple management objectives presents the watershed manager with hundreds of thousands of benefits and costs to be compared between alternative strategies. Hence, a tool must be developed to assist in the evaluation of this large and complex set of information.

The Questions to be addressed by the Watershed Management Model

One solution to evaluating the large number of alternative strategies is to develop a computer-based watershed management model that will compare all of the options and identify a small subset of the most optimal strategies based on the overall characteristics of the subbasins and the potential BMPs. Once a subset of optimal strategies has been identified, the manager can then focus on a more detailed evaluation of the specific feasibilities and consequences expected for each strategy (e.g., the distribution of management resources, the loss of recreational resources, health and safety issues, and the inhibition of economic development). The development of such a watershed management tool was the goal of this project.

The types of questions to be addressed by the watershed management model are of equal or greater importance than the specific optimization techniques to be used. Examples of specific questions that the watershed management model may be tasked to address include:

- How should joint TN, TP, and TSS load reduction strategies be allocated to subbasins in order to obtain the optimal reduction for a given capital budget?
- What is the expected cost of meeting a particular nutrient load reduction target?
- What is the optimal pollutant load reduction marginal return for a given range of possible resources to be allocated?
- What combination of point source, nonpoint source, and fugitive emissions reduction strategies is optimal for a specific bay segment loading target?

It is clear that an optimization model developed to answer these types of questions must be adaptable to a diverse set of intended uses. The utility and success of the model will be judged by its flexibility and the manner in which it is capable of answering these questions and capable of providing an adaptable tool for responding to future questions.

2.0 SPECIFIC PROJECT OBJECTIVES

The watershed management model was developed to provide a method for evaluating the most cost effective and optimal methods of controlling nutrient and sediment runoff from specific areas of the watershed. Several Tampa Bay region-specific datasets were compiled for BMP costs and efficiencies. However, the model is intended to be flexible and to be used in conjunction with specific pollutant load and subbasin characteristic datasets developed by individual users for specific areas of interest.

The specific objectives of this project were:

1) to complete the development of a TBNEP database of BMP costs, constraints, and efficiencies specific to the Tampa Bay region,

2) to develop a computer program that will evaluate management data and that will compile a list of optimal BMP allocation strategies given appropriate data,

3) to demonstrate the application of the model through an example case study, and

4) to provide a technical users manual for the local governments for which the model was developed.

In order to ensure that the model will meet the specific management needs of its intended users, representatives from the local government watershed management agencies were consulted. In summary, the results of these consultations indicated that:

Scope of the Model

- The pollutant loading input data should allow both nonpoint and point sources to be evaluated.
- The model should focus primarily on structural BMPs (e.g., stormwater retention ponds), but should allow input of other types by the users.
- The geographic and hydrologic resolution of the model should be flexible, and should allow analyses ranging from major basins to specific project sites.

Model Function

- The model should be flexible and easy to use.
- The model should allow the evaluation of alternative objectives.
- The model should allow the simultaneous evaluation of multiple objectives.
- Constraints on BMP application should be flexible and modifiable by the user.
- Once the optimal management strategies have been identified, the model should use these strategies to allow two types of further analyses.

  Type 1) The user would specify a nutrient load reduction target, and the model would then estimate the total cost for meeting the load reduction target.

  Type 2) The user would specify a monetary budget, and the model would then estimate the amount of load reduction possible for that expenditure.

Data Sets

- All primary input data sets should be expandable, modifiable, and replaceable (e.g., land costs, pollutant loads, subbasins, BMP constraints, BMP efficiencies, BMP costs).

Technical Specifications

- The watershed management model should be useable on a standard PC, use a minimum of memory, be relatively simply constructed, and not be linked to or dependent on a specific software product (e.g., Arc/Info).
- The watershed management model should be well documented.

3.0 SELECTION OF A GENERAL APPROACH TO OPTIMIZATION

The watershed management model has been implemented by adapting a technique known as *multiple objective programming* to meet the specific needs and objectives of this project. This technique will identify a group of the most desirable management alternatives. The following sections discuss several alternative optimization techniques, the features of each technique that were adopted for the TBNEP model, and the reasons why the multiple objective programming technique was chosen as a basic approach for the final watershed management model.

3.1 MODEL FEATURES ADOPTED FROM LINEAR PROGRAMMING TECHNIQUES

Linear programming is one of several types of well-known optimization techniques that was considered for use in the watershed management model to select optimal allocation strategies for BMPs. Other similar types include derivatives of objective equations, and dynamic programming.

Linear programming, like many historical approaches to optimization, involves the formulation and solution of maximization problems for an objective function and a set of constraint equations. For example, linear programming is a technique that can be used to determine the least-cost TN load reduction from different subbasins necessary to reach a desired TN load reduction target. The data required for this approach might include the present loading of TN, unit costs and benefits for alternative management strategies, and the percent reduction goal for the particular bay segment or tributary being evaluated. The nature of this methodology allows flexibility in the formulation of the problem, so that additional constraints on BMP implementation can be incorporated.

The objective function of a useful linear programming model might minimize the total cost of implementing each of the management practice options (***X***) with individual costs (***C***). The objective function can be formulated as follows:

minimize:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$$

where:

X_{ij}	=	the number of acres of land use i managed with BMP type j,
C_{ij}	=	the total cost ($/acre treated) for implementing BMP type j in land use i,
n	=	the number of management practice options considered, and
m	=	the number of land use categories identified.

A set of constraint equations could then be specified to define the desired TN loading goal, describe load reduction efficiency characteristics of each BMP, and incorporate the limitations of each BMP option in relation to its feasibility, land use, and soil requirements. These constraint equations could be written for each land use type and BMP option for the entire watershed.

The first set of constraints would establish the TN load target. This would be accomplished by computing the expected nonpoint source nutrient loading from each land use, and coupling it with the expected BMP treatment efficiencies for TN. Therefore, the constraints would force the summation of nonpoint source nutrient loadings released from each land use after treatment by the set of BMPs to be equal to the TN load reduction target.

The second set of constraints would describe the functional characteristics of the BMPs, and would set bounds on the suitability of these BMPs in relation to the physical characteristics of different land uses, watershed sizes, and soils. These constraints would provide a series of screening tools for the optimization problem to choose among the alternative sets of BMPs that are most feasible from both a technical and economical standpoint. For example, consider a BMP option that could only be used for a specific land use and would be most feasible to manage a certain area of that land use. The soil cover underlying that land use could also be used as a selection factor.

The third and final set of constraints would insure that all of the land use areas in the watershed are being considered in the optimization process. For example, if no BMP option is recommended for a particular land cover, then that land cover should still be considered in the overall optimization process and included as an area having no treatment for its TN loading.

The overall linear programming/dynamic programming approach was used by the TBNEP as a starting point for the development of the watershed management model. The use of constraints based on suitability of land use and soils for specific BMPs was adopted for use in the final watershed management model. However, the specific mathematical techniques of linear programming are quite complex, difficult to communicate and document, and would prove relatively difficult to be modified by the potential users of the TBNEP model.

3.2 MODEL FEATURES ADOPTED FROM COMPUTER INTENSIVE OPTIMIZATION TECHNIQUES

Computer intensive optimization techniques provide a much simpler and more flexible approach to selecting a desirable set of BMPs than those provided by linear programming. The previously described linear programming techniques were most useful before the advent of inexpensive desktop computers. They were one of a variety of techniques developed to simplify the number of calculations to be made to find a solution. However, the maximization of a one-dimensional objective (i.e., find the minimal cost solution to meeting a fixed TN load target) can be relatively quickly solved on a modest desktop computer by simply comparing all possible allocations of suitable BMPs, and simultaneously keeping track of the least expensive solution encountered.

The computer intensive principles of making best use of the power of the computer, and keeping the optimization algorithm of the programs as simple to use and as flexible as possible were adopted for use in the final watershed management model.

3.3 THE DILEMMA OF MULTIPLE OBJECTIVE MANAGEMENT PROBLEMS

Both the linear programming approach and the computer intensive approach considered for the watershed management model are one-dimensional (i.e., they only consider one pollutant load at a time). However, the problem confronting the governmental entities participating in the TBNEP is not a one-dimensional problem. As previously discussed the most important of these objectives have been identified as:

- the reduction of TN loads,
- the reduction of TSS loads,
- the reduction of TP loads, and
- the minimization of costs for implementing BMPs.

Thus, there is a need for an optimization model that is capable of determining the joint solution of multiple and sometimes conflicting objectives. In other words, the TBNEP and its participating local governments are faced with a *multiple objective problem.* For example, Keeney and Raiffa (1976) point out that "you cannot maximize benefits and at the same time minimize costs, nor can you share a pie by giving the maximum amount to each child." In terms of this project, an example of a multiple objective problem is to attain a target TN load under a given budget, while simultaneously maximizing TSS load reductions per unit cost.

One cannot formulate a mathematical equation or computer algorithm that will provide a maximization solution to a problem with multiple objectives. In other words, an unequivocally "best" solution cannot be determined simultaneously for all objectives. This is due to the fact that it is unlikely that the **"best"** solution for one objective is simultaneously the **"best"** solution for each and every other objective. Rather, watershed managers must use a subjective decision making process to compare the tradeoffs between the different objectives.

3.4 THE SELECTION OF MULTIPLE OBJECTIVE PROGRAMMING TECHNIQUES AS THE GENERAL APPROACH

Fortunately, the TBNEP watershed management model can aid the watershed managers in making these subjective decisions by adapting *multiple objective computer programming techniques* to formalize and organize the decision making process, keep track of constraints, and provide the information needed to make the decisions. A multiple objective programming approach provides a tool for identifying the **set of "nearly the best" solutions** simultaneously for each objective. Thus, the answer is not a single "best" answer, but is a set of desirable options. In the study of economics, this set has been classically termed the Pareto Optimal set (Keeney and Raiffa, 1976). The advantage to this type of solution is that it presents the manager with a workable set of subjective decisions to be made, and it allows flexibility in the selection of management strategies.

The basic rule for the multiple objective approach can be stated as follows:

> **The multiple objective approach identifies a set of optimal BMP allocation strategies by eliminating all strategies from the set for which another strategy would provide a better solution for every objective considered.**

A two-dimensional graphic example of this process is useful in presenting the general approach. In Figure 3-1, an example BMP allocation strategy (A) is plotted according to two objectives: its estimated total TN reduction and its total cost. The shaded region indicates the portion of this two-dimensional objective space that is "dominated" by strategy A. Any other management strategy that lies within the region dominated by strategy A would provide a worse solution with respect to every objective (i.e., both TN load reduction and cost in this two-dimensional case), and it would be eliminated from the set of desirable solutions.

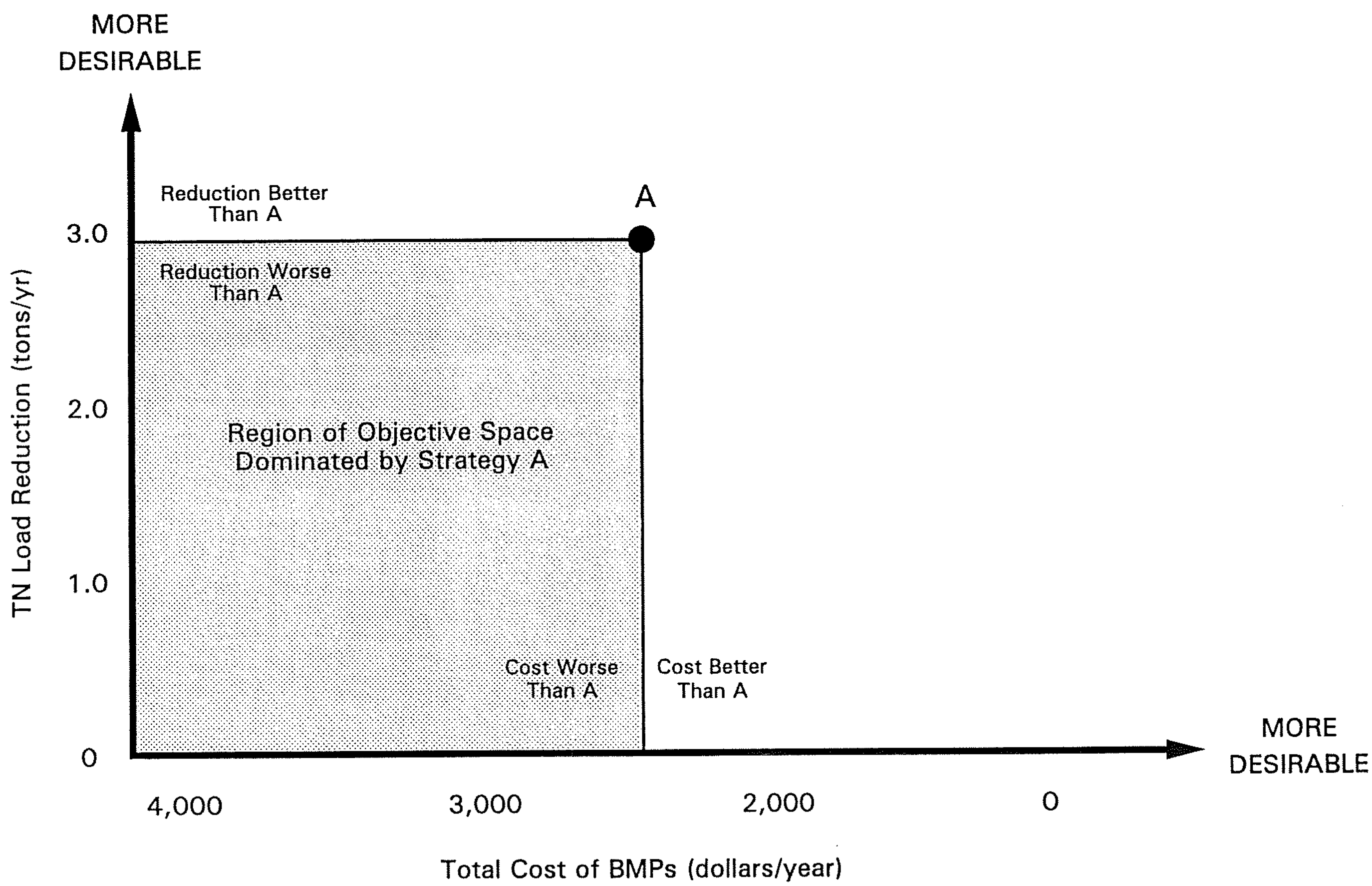

Figure 3-1 A conceptual example of a Pareto Optimal set of management strategies with one member (A).

Figure 3-2 presents several BMP allocation strategies and their respective regions of dominance (shaded area). The desirable solutions (A, B, and C) comprise the Pareto Optimal set for these strategies, because no other options are better than they are with respect to every management objective. Conversely, each of the undesirable solutions (D, E, and F) lies in the region of dominance of one or other solutions. The members of the Pareto Optimal set (A, B, and C) form an outer boundary that delineates the better alternatives without having to directly compare the value of one management objective to another. This outer boundary has been termed "the efficient frontier" or "Production Possibilities Frontier (PPF)." Although, the efficient frontier can be thought of as a curved line (Figure 3-2), we can see that it is actually a stair-step shaped line resulting from the regions of dominance of each member of the Pareto Optimal set. Any solution lying on the "worse" side of this frontier is inefficient and undesirable according to the available information, and need not be further considered.

If some of the solutions lying in the undesirable portion of the objective space (D, E, and F) are thought to be desirable for other reasons (e.g., they would provide wildlife habitat, or recreational uses, or they would be more socially acceptable), then the multiple objective model could be expanded by adding additional dimensions for each additional management objective desired. The efficient frontier is then determined using the same approach, but for multi-dimensional space.

The specific objectives of the TBNEP watershed management model were to include a four dimensional objective space defined by TN load reduction, TSS load reduction, TP load reduction, and cost. An optimal subset of the most cost effective solutions for all three of the pollutant load reduction management objectives can be identified using this four dimensional objective space.

3.5 USING THE MULTIPLE OBJECTIVE PROGRAMMING APPROACH

Using the multiple objective approach, the model computer program assists the manager by making all of the routine objective decisions regarding which management strategies are better. These objective decisions are mechanical and are based on the available data on pollutant loads, BMP efficiencies, and physical limitations to BMP construction. The specific types of data for which the model was developed are discussed in Section 4.0.

Once a set of optimal management solutions has been identified and documented based on all of the objective decisions made by the computer, the watershed manager must make subjective decisions concerning a final strategy. The TBNEP watershed management model will assist the manager in making these subjective decisions by:

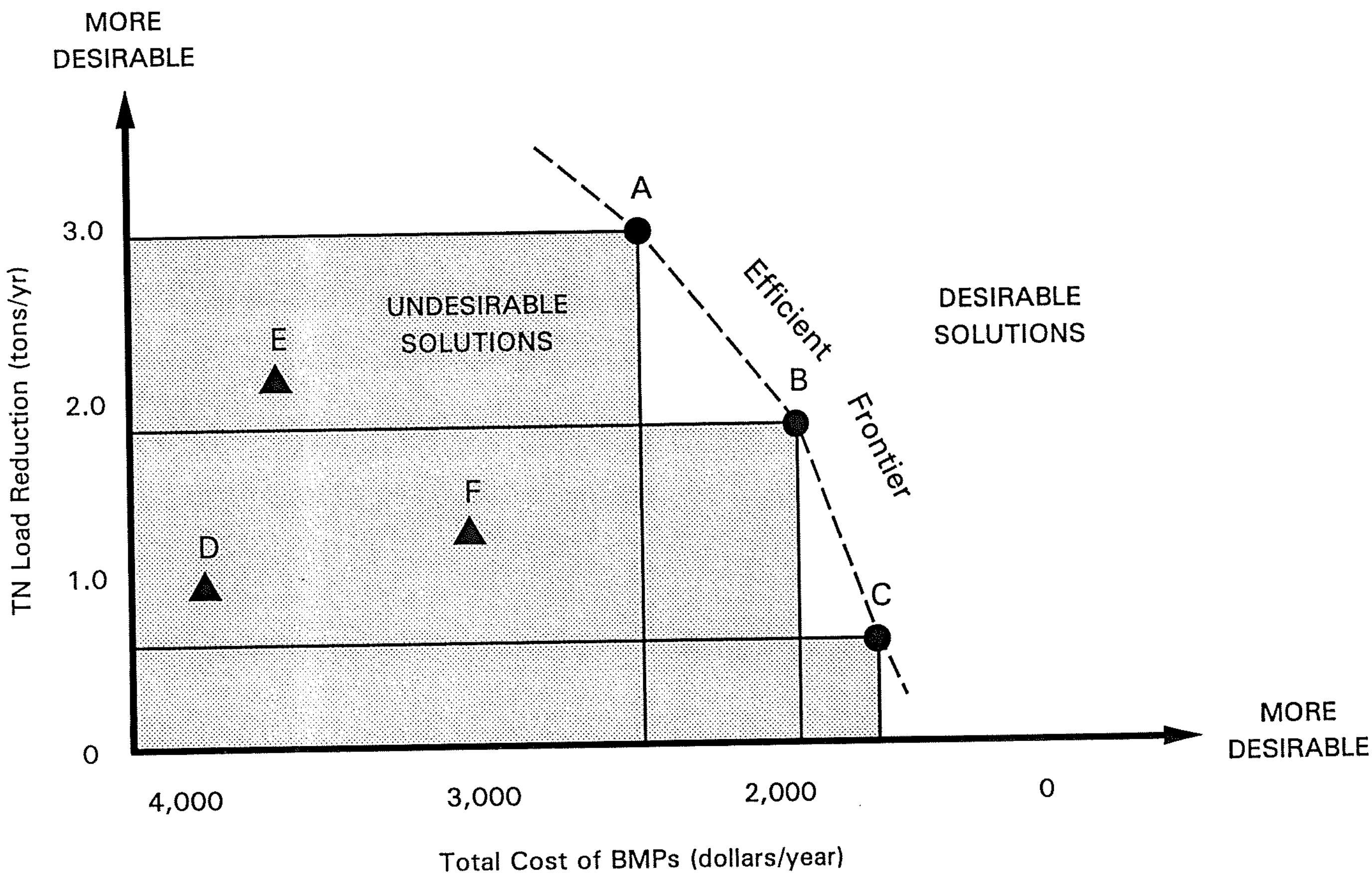

Figure 3-2 A conceptual example of a Pareto Optimal set of management strategies with three members (A,B,C), and three strategies which were excluded from the set (D,E,F).

- allowing the user to assign a relative importance to each of the management objectives (i.e., weights),
- allowing the user to specify quantitative nutrient load reduction targets, and/or
- allowing the user to specify a budget for implementation.

The details of how the watershed management model functions and the specific products it provides are presented in Section 5.0.

4.0 EXPLANATION OF DATA USED TO OPERATE THE MODEL

As discussed in the previous section, the watershed management model is able to make all of the objective decisions involved in selecting an optimal management strategy. These decisions are strictly mechanical, have deterministic outcomes, and are based on the best available information that can be provided as input.

The watershed management data for which the model was developed were organized into several categories as follows:

- soil characteristics data,
- subbasin characteristics data,
- pollutant loading data,
- BMP cost data,
- BMP efficiency data,
- BMP constraints data, and
- regionally specific real-property values.

The model was designed so that each of these data sets can be input as a separate data file to be created by the user for his or her particular application. All of the datasets are flexible, and can be expanded, modified, or replaced according to the user's needs. Because the format of the data files was developed to be very flexible, it can be used to model a variety of management scenarios ranging from broad-based investigations of nonpoint source control BMPs to complex combinations of specific point sources, regional stormwater BMP alternatives, and nonpoint source control BMPs. A discussion of each of the data categories is presented within this report section, and a more detailed description of how the contents of each data category are used to control the model's operation is presented in Section 5.

One of the three objectives (Section 2.0) of this project was to complete the development of Tampa Bay region specific datasets for BMP cost, efficiency, and constraints. This information was fully presented and discussed in Appendix B of this report, 1995), and has been compiled into a series of ASCII datasets as described in Section 5 of this report. As a convenience to the reader, the quantitative components of this information have also been presented in tabular format in Appendix A.

4.1 SOIL CHARACTERISTICS DATA

Soil characteristics can be used to determine whether a particular parcel of land is suitable for the implementation of a particular structural BMP. The watershed management model has been developed to consider:

- soil permeability rates,
- slopes, and
- depths to the underlying water table.

Each of these soil characteristics influences the behavior of surface water and groundwater, and hence, the suitability of a parcel of land for a specific type of stormwater management structure (e.g., wet retention pond versus extended detention dry pond) or a specific design (e.g., the size of a wet retention pond relative to the drainage area to be treated).

Because each of these soil characteristics is variable and continuous for any particular soil type, the distribution of each of the soil parameters is useful information for estimating the proportion of land expected to be suitable for implementation of a BMP on a regional basis. The watershed management model has been developed to use a variety of measures of these parameters including:

- minimum values,
- maximum values,
- ranges, or
- triangular distributions defined by a central tendency parameter and two parameters for the tails of the distribution.

This use of flexible parameters allows the user to specify a level of soil characteristic detail desired for his or her particular application.

Potential Data Sources

Detailed soil characteristics data have been developed for the Tampa Bay watershed by the U.S. Department of Agriculture, Soil Conservation Service. Published maps and tables of these data are available from the Department of Agriculture for each of the counties within the Tampa Bay region. These maps were developed at a scale of 1:24,000 and define approximately 50 soil categories for each county.

The Southwest Florida Water Management District (SWFWMD) GIS and Mapping Section maintains 1:24,000 scale Geographic Information System (GIS) data sets for the soil series data mapped by the USDA. Digital data files of the soil series may be obtained from the GIS and Mapping Section. The TBNEP data library includes copies of the digital USDA soil series data as originally obtained from SWFWMD. A set of soil attribute data files which correspond to selected parameters of the soil series data and USDA county soil atlases was also developed by the TBNEP.

For more detailed applications of the watershed management model for specific site plans, a custom data set may be readily developed by delineating soil regions within each of the subbasins of the site, and measuring the permeability, slope, and depth to water table within each of these regions. The model's existing USDA soil characteristics data can then be easily replaced with the more detailed measured data.

4.2 SUBBASIN CHARACTERISTICS DATA

The geographic and hydrologic operational unit of the watershed management model is the subbasin, and the level of detail to be evaluated is determined by the size of the subbasins used. Subbasins may range in size from large regional drainage areas to small sections of a specific development site. The model was developed to use subbasin characteristic data in the form of individual parcels of land or combinations of parcels having unique soil and land use combinations. The variables of interest are:

- subbasin identifier,
- soil code,
- land use/cover code, and
- the area of the parcel or group of parcels.

The subbasin characteristics data are used by the model to determine the amount of land suitable for construction of each BMP in each subbasin.

Potential Data Sources

Subbasin characteristics data may be developed using GIS software to overlay subbasin boundaries, land use/cover data, and soil series data. The area of each combination of subbasin, land use, and soil can then be tabulated in a simple data file for use by the model.

GIS land use data sets are generally available for all areas of the Tampa Bay region. The SWFWMD GIS and Mapping Section has developed a complete data set for 1990 at a scale of 1:24,000 scale using the Florida Department of Transportation (FDOT) Florida Land Use and Cover Classification System (FLUCCS), and these data were updated in 1995. In addition, many of the local governments (e.g., Pinellas County, Hillsborough County) have developed independent land use/cover datasets for their jurisdictions. The TBNEP and Tampa Bay Regional Planning Council have each developed expected future land use GIS data layers for 2010, and these may be useful for planning future implementation of BMPs.

Although useful, GIS data analyses are not required to apply the watershed management model. The model is not linked to any specific GIS software package or data format. Analyses ranging from broad based regional studies to detailed site evaluations can be conducted by delineating subbasins and parcels on maps and site drainage plans, and estimating the proportion of land use/cover within each area.

4.3 POLLUTANT LOADING DATA

One of the key sources of information needed to determine optimal pollutant load management strategies is detailed and adaptable information for the major pollutant loads. Three of the model's four objective functions are concerned with the reduction of pollutant loads. The model has been developed to use detailed data on the sources, geographic distribution, and quantities of pollutant loads. There are seven categories of major sources of total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) loads. These categories are:

- Atmospheric deposition directly to the receiving water bodies,
- Domestic point sources,
- Industrial point sources,
- Nonpoint sources,
- Groundwater sources (loaded to surface waters),
- Significant natural springs, and

- Fugitive emissions (e.g., transportation and processing losses of fertilizer products).

Although the focus of this project is on nonpoint sources of pollutants, the model has been developed to be flexible and to allow the incorporation of each of the seven sources of pollutant loads.

Potential Data Sources

Nonpoint source pollutant loadings can be modeled using a variety of levels of detail ranging from land use specific unit-area-load spreadsheet models, to empirical loading models, to mechanistic models based on calibrated physical models of surface water and contaminants. The watershed management model is not dependent on any single pollutant load model. Rather, the model was developed to use tabular loading data specific to particular land uses or point sources.

The TBNEP has developed estimates of pollutant loads for the entire watershed on a regional basis (Zarbock et al., 1996). These results indicate that the most significant sources of pollutant loads include atmospheric deposition and nonpoint sources. Atmospheric deposition loads have been estimated on a bay segment basis, and nonpoint source loads have been estimated on a subbasin and land use specific basis.

4.4 BMP COST, EFFICIENCY, AND CONSTRAINT DATA

BMP specific cost, efficiency, and constraint data are used by the watershed management model to compute the total costs and benefits of each BMP allocation strategy evaluated. The total costs are estimated in terms of dollars/acre treated/year, and the total benefits are estimated in terms of individual pollutant load reductions for TN, TSS, and TP.

BMP cost data comprise one of the four dimensions of the multiple objective approach, and the watershed management model has been developed to consider:

- BMP life span (years),
- construction costs (dollars/acre treated),
- operation and maintenance costs (dollars/acre treated/year), and

- land required for implementation (acres used by BMP/acre treated).

Each of these cost components is used to compute the total unit cost of each type of BMP.

BMP efficiency data are combined with pollutant load data to estimate the benefits of particular management strategies, and the model has been developed to include:

- percent TN removal efficiency,
- percent TSS removal efficiency, and
- percent TP removal efficiency.

BMP constraint data are used to determine all of the possible places where particular BMPs could be located in the area of interest, and the model has been developed to include:

- suitable land use,
- minimum and maximum drainage areas,
- minimum and maximum soil infiltration rates,
- minimum and maximum depths to the water table, and
- minimum and maximum slopes.

Potential Data Sources

As discussed previously, one of the four objectives of this project was to complete the development of Tampa Bay region specific datasets for BMP cost, efficiency, and constraints. This information is discussed in Appendix B of this report. As a convenience to the reader, this information has also been presented in a compact tabular format in Appendix A. The BMP cost, efficiency, and constraint data may all be replaced, augmented, or modified with specific information compiled by an individual user of the model.

4.5 REGIONALLY SPECIFIC REAL-PROPERTY VALUES

The watershed management model was developed to compute total land costs for BMP construction using a data set of regionally specific real-property values in combination with estimates of land area required. The real-property value information is comprised of the variables:

- geographic region within the Tampa Bay watershed,
- land use code, and
- minimum value (dollars/acre),
- mean value (dollars/acre), and
- maximum value (dollars/acre).

Potential Data Sources

The TBNEP developed a set of property value estimates for the Tampa Bay watershed (Appendix A). The minimum, mean, and maximum values were estimated on a regional and land use basis from samples of assessed values recorded by county tax assessors. These estimates were developed for ten major drainage basins and seven land use categories. The ten major drainage basins included the four major rivers (i.e., Hillsborough R., Manatee R., Little Manatee R., and Alafia R.) and the coastal areas of the six major segments of the bay (i.e., Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ciega Bay, Terra Ceia Bay).

Users may also develop their own property value data bases. For broad based regional applications of the watershed management model, property values obtained from assessed taxable values will allow evaluation of BMP alternatives. The multiple objective programming approach only requires relative values for BMP costs, because cost is one of the dimensions of the multiple objective space. However, when property values must be combined with significant construction and/or maintenance costs, the user may wish to adjust the assessed property values to market values.

For detailed site specific applications of the watershed model, market property values may be estimated for all parcels of land considered. The purchase of environmental easements on private lands may also be modeled on a parcel by parcel basis. For sites where all of the land is already owned by the managing government, property values of a constant such as 1.0 may be assigned to eliminate their consideration.

5.0 EXPLANATION OF THE MODEL

A watershed management computer model has been developed to meet the criteria presented in Section 2, to implement the optimization approach presented in Section 3, and to make best use of the data sources presented in Section 4. The overall criteria for development of the model can be summarized as:

the model should be easy to use, and it should be flexible in the types of management strategies it can evaluate.

In order to satisfy this overall criteria, a programming strategy was developed so that:

- the model uses a single command to run the program without menus or interrogations of the user,
- the model breaks up each process of the approach into five distinct program modules, and
- the model allows complete control of all functions through flexible input data sets (i.e., there is no need for source code programming).

An overview of each of the five program modules, input datasets, and output datasets is presented in Figure 5-1. All of the input and output data files are simply formatted ASCII data files that can be copied and modified with any convenient word processing program. Each input and output data file contains a free form header area at the top that allows the user to make notes describing the particular scenario or data source. The model is not linked to any particular software package, database, or spreadsheet program, and it can be run on any DOS-based computer.

As a general approach, each module is executed by typing the name of the module and the name of a control file at the DOS prompt (Figure 5-1). The control file simply contains a list of the names of each of the input and output data files desired to be used by that module. Upon execution of a module, the computer program will evaluate the input data sets, and produce a single output data set and an output log file. The output data set contains an ASCII data file of the specific results of that module, and the output log file records the data sites which were used any important messages to the user.

The specific functions of each of the five modules are discussed within the following sections.

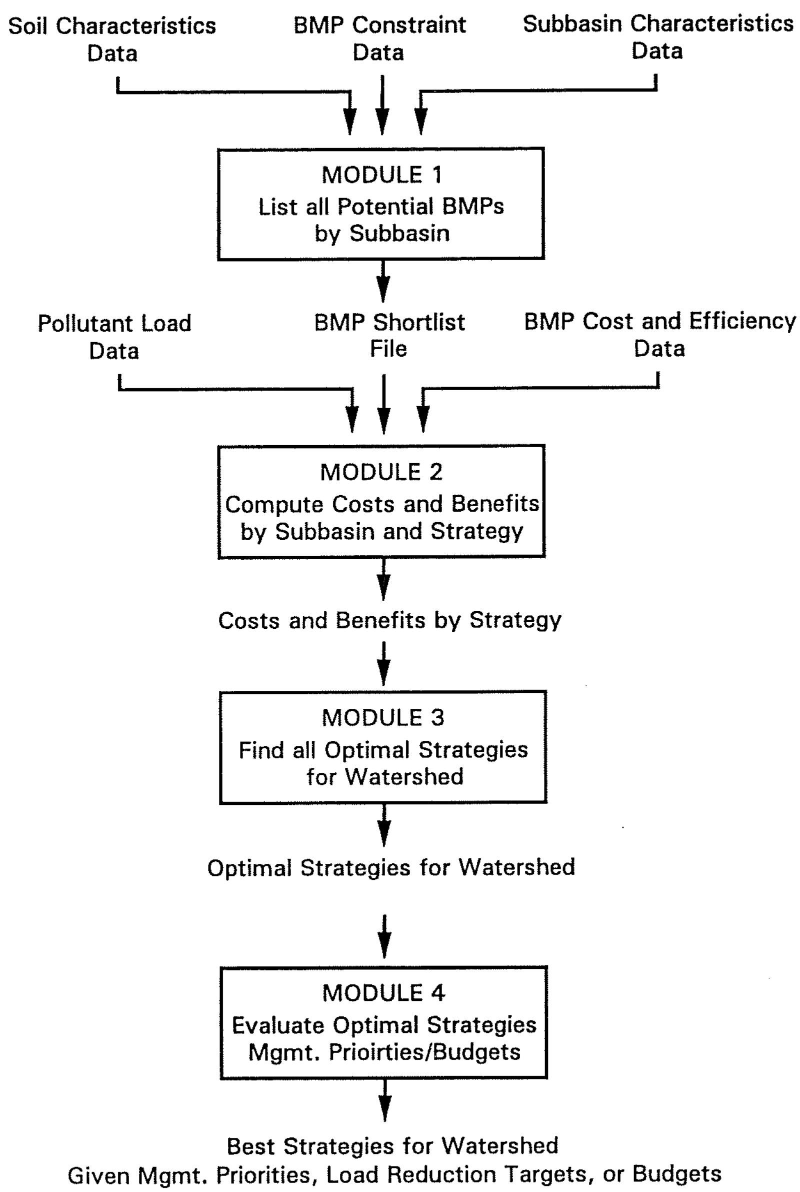

Figure 5-1 Overview of the Watershed Management Model Processes (Boxes), Input Data, and Products.

5.1 MODULE 1: COMPILE LIST OF POTENTIAL BMPs BASED ON SITE CONSTRAINTS

Module 1 reads a list of potential BMP options and evaluates which options are feasible based on soil and land use characteristics. It then outputs a list of all of the feasible BMPs by subbasin. Because the data sets are flexible and expandable, a wide variety of management scenarios can be easily evaluated.

Module 1 Input Data

Soil Characteristics Data

Of the three data sets input to this program module (Figure 5-1), the soil characteristics data are the most straightforward. This data set has one line of data for each unique type of soil, and is structured as follows:

- soil type code,
- minimum slope (%),
- mean slope (%),
- maximum slope (%),
- minimum depth to water table (ft),
- mean depth to water table (ft),
- maximum depth to water table (ft),
- minimum permeability rate (in/hr),
- mean permeability rate (in/hr),
- maximum permeability rate (in/hr).

A missing value may be indicated for any of these parameters by the value "-999", and it will not be used for eliminating BMPs.

Subbasin Characteristics Data

The subbasin characteristics data set has a line of data for each subbasin, BMP category, and land use as follows:

- subbasin identifier,
- BMP category,
- soil type code,
- land use type code,
- and area available for BMP construction (acres).

Each line of this data set specifies the total acreage of a particular land use on which BMPs of a particular category may be constructed within that subbasin.

This dataset may be generated by many techniques ranging from simply typing in land use estimates, to output basic information from a GIS overlay, to using a complex GIS-based landscape design model. In the simplest case, a user could input a line of data for each land use in a subbasin, and label the subbasin category "1" for each of these lines of data. Thus, the model would consider placing BMPs anywhere within the subbasin where land use and soil characteristics were suitable.

In order to add complexity to this simple case, the user could add additional records having another subbasin category (e.g., "2") to the data base. These additional records could describe special locations within the subbasin where a particular type of BMP could be constructed (e.g., a large regional stormwater retention pond might be possible at the confluence of two tributaries). There is no limit to the number of additional BMP categories that can be entered to the model, and the lands described by the BMP categories can be located in separate places in the subbasin or they can overlap. Point source BMPs can also be modeled using this approach by assigning a separate BMP category and an arbitrary land use code and acreage.

BMP Constraint Data

The BMP constraints data base has a line of data for each BMP type as follows:

- BMP identifier code,
- BMP category,
- land use type code,
- minimum area treated by BMP (acres),
- maximum area treated by BMP (acres),
- minimum suitable soil permeability (in/hr),
- maximum suitable soil permeability (in/hr),
- minimum suitable depth to water table (ft),
- maximum suitable depth to water table (ft),
- minimum suitable slope (%),
- maximum suitable slope (%).

The BMP dataset may also be expanded by the user. In addition to adding more BMPs, the user may evaluate alternative sizes or designs of a single BMP by copying lines of this database and changing the BMP identifier code and parameters of interest. The BMP cost and efficiency datasets would also be modified to reflect these new options. Upstream and downstream combinations of BMPs can also be evaluated using this approach.

Module 1 Process

Module 1 reads the list of potential BMP options from the constraint data file, and evaluates which options are feasible based on the soil and land use characteristics. It then outputs a list of all of the feasible BMPs by subbasin and land use type.

For each area of land described in the subbasin characteristics data file, the computer program for Module 1 determines the amount of this land in acres that is likely to be suitable for construction of the BMP. This is accomplished in four steps:

Step 1: For each soil type within the land use of interest, the computer program draws a triangular distribution for each soil parameter based on the minimum, mean, and maximum value listed in the soil characteristics data base.

Step 2: The computer program then overlays the constraint boundaries for a BMP (either a minimum, maximum, or range of acceptable values) on each of the soil parameter triangular distributions, and calculates the area of overlap.

Step 3: The proportion of the area of overlap is equal to the proportion of that particular land use and soil that is expected to be suitable for construction of the BMP considered.

Step 4: The areas corresponding to each soil type within a land use parcel are then summed to estimate the area of that land use suitable for construction of the BMP considered.

These four steps are repeated until all of the potential BMPs for a subbasin and land use have been considered.

A variety of types of distributions of soil characteristics may be approximated by the use of triangular distributions. These include single point means, ranges, uniform distributions, normal distributions, skewed distributions, and peaked or flattened distributions.

Module 1 Output Data

The output data file from this module is a list of all of the types of BMPs listed in the BMP constraint database for which the conditions are suitable for construction, and the land area that is expected to be suitable for construction. This list of potential BMP types is listed by either by subbasin and land use type, or by subbasin and specific land use parcel depending on the input subbasin characteristics database. The following variables are included:

- BMP identifier code,
- BMP category,
- BMP minimum drainage area,
- BMP maximum drainage area,
- subbasin identifier,
- land use type code,
- suitable area for BMP construction (acres).

5.2 MODULE 2: EVALUATE UNIT COST AND BENEFIT FOR EACH POTENTIAL BMP

Module 2 evaluates the total cost and total benefits (i.e., TN, TP, TSS load reduction) for a single unit of each of the potential BMPs short listed by Module 1. For example, the total cost in dollars per acre treated per year may be estimated for a single 10 acre wet retention pond, or for a single square foot of porous pavement. Combinations of multiple units of BMPs are evaluated later in Modules 3, 4, and 5.

Module 2 Input Data

The BMP shortlist file generated by Module 1 is the first input file for this module. The user may examine this file before running Module 2, and may decide to further eliminate BMP options based on any additional management considerations not included in the Module 1.

Pollutant Load Data

The pollutant load dataset has a line of data for each subbasin, BMP category, and land use to be treated in the watershed as follows:

- subbasin identifier code,
- BMP category,
- land use type code,
- treatment area (acres),
- TN load (tons/yr),
- TP load (tons/yr),
- TSS load (tons/yr).

The lands to be treated are linked to the potential BMPs and lands on which BMPs are to be constructed by the BMP category variable. Complex modeling scenarios may be easily developed using the BMP category variable, and the lands to be treated may or may not overlap with the lands on which BMPs may be constructed. For example, a user may wish to have a category of BMPs where the lands to be treated are the same as the lands on which BMPs are to be constructed, such as for onsite vegetated swales or concrete paving blocks. In this case, the pollutant load land use data are repeated in the subbasin characteristics data set. A user may also wish to have a category of BMPs for which the lands to be treated are separated from the lands to be considered for BMP construction. For example, the lands to be considered for BMP construction may represent a specific site identified for a potential regional stormwater pond, and the lands to be treated may represent the drainage area for this regional pond within the subbasin.

BMP Cost Data

The BMP cost dataset has a line of data for each BMP, BMP category, and land use code as follows:

- BMP identifier code,
- BMP category,
- land use type code,
- BMP life span (years),
- BMP construction cost ($/acre treated),
- BMP operation/maintenance cost ($/acre treated/yr),
- BMP land required (acres).

BMP Efficiency Data

The BMP efficiency dataset has a line of data for each BMP and BMP category as follows:

- BMP identifier code,
- BMP category,
- minimum TN efficiency (%),
- mean TN efficiency (%),
- maximum TN efficiency (%),
- minimum TP efficiency (%),
- mean TP efficiency (%),
- maximum TP efficiency (%),
- minimum TSS efficiency (%),
- mean TSS efficiency (%),
- maximum TSS efficiency (%).

Module 2 Process

Module 2 evaluates the total cost and total benefits (i.e., TN, TP, TSS load reduction) for a single unit of each of the potential BMPs short listed by Module 1. Costs and benefits are computed for each combination of BMP, BMP category, and land use as follows:

Step 1: The unit cost for each BMP and land use parcel is calculated according to the equation:

$$\frac{\left(\frac{(UV)}{T}+C\right)}{S}+O$$

where,

U = the acres of land used to construct the BMP,

V = the value of the land used per acre,

T = the acres of land treated by the BMP,

C	=	the BMP construction cost per acre treated,
S	=	the BMP life span in years, and
O	=	the operation and maintenance cost per acre treated per year.

Step 2: The unit benefit for each BMP and land use parcel is calculated by multiplying the triangular distribution of load reduction efficiency values by the total load to be treated.

Step 3: The total costs and benefits for each BMP and subbasin is calculated by computing a weighted sum of the costs and benefits over all land uses within the subbasin.

Total costs are calculated as follows:

$$Total\ Cost = \frac{\sum_{k=1}^{K} (C_k)\ (L_k)}{\sum_{k=1}^{K} (L_k)}$$

and

$$Total\ Land\ Available = \sum_{k=1}^{K} (L_k)$$

where,

C_k	=	BMP cost for the kth land use ($/yr), and
L_k	=	land available for construction of the BMP for the kth land use (acres).

Total benefits are calculated as follows:

$$\mathit{Total\ Load\ Reduction} = \frac{\sum_{k=1}^{K} (R_k)\,(T_k)}{\sum_{k=1}^{K} (T_k)}$$

and

$$\mathit{Total\ Treatable\ Area} = \sum_{k=1}^{T} (T_k)$$

where,

R_k = Load Reduction for the kth land use (tons/yr), and

T_k = land available for construction of the BMP for the kth land use (acres).

Module 2 Output Data

The output data file from this module is a list of each type of BMP, BMP category, and subbasin listed in the BMP shortlist. Each line of this list is accompanied by a total unit cost value, and a total unit benefit value for TN, TP, and TSS.

5.3 MODULE 3: COMPILE SET OF OPTIMAL MANAGEMENT SOLUTIONS

Module 3 compiles a set of optimal management solutions by considering all of the possible quantities of the BMPs listed by module 2 that could be implemented.

Module 3 Input Data

The input data for Module 3 is the unit cost and benefit data set produced by module 2.

Module 3 Process

Module three applies a multiple objective programming approach (as discussed in detail in Section 3) to identify a subset of optimal management strategies for each subbasin in the four dimensional objective space of TN load reduction, TP load reduction, TSS load reduction, and cost. All quantities of BMPs allowed by the available land to be treated and land to be used for BMP construction are considered.

Module 3 Output Data

The output data file from this module is a set of optimal strategies from the "efficient frontier" of each subbasin within the watershed.

The output data file from this module is comprised of two data sets that describe the set of optimal strategies from the "efficient frontier" for the watershed as a whole.

The first data set describes each of the management strategies in detail by listing all of the individual BMPs recommended.

The second data set has a single record for each management strategy that includes a name that can be matched to the data in the first data set, a total cost, and the total benefits in terms of load reductions.

5.4 MODULE 4: EVALUATE MANAGEMENT SOLUTIONS WITH REGARD TO BUDGETS AND LOAD REDUCTION TARGETS

Once a set of optimal management solutions has been identified and documented in the form of the two Module 3 output data files, then all of the objective decisions have been made by the computer. The watershed manager must then make subjective decisions concerning a final strategy. The final module of the watershed management model can assist the manager in making these subjective decisions according to the following steps.

Step 1: The user specifies a real number weight value ranging from 0 to 1 for each of the three load reduction targets. If the user wishes to consider only a single objective such as TN, then the TN weight would be assigned a value of 1.0 and TP and TSS weights would be assigned values of 0.0. If the user does not wish to compare between the benefit objectives, then they would simply print the list of solutions provided by Module 3.

Step 2: The Module 4 output data base listing each management strategy name, total cost, and total benefits is read in, and a weighted average benefit is computed using the weights assigned in Step 1.

Step 3: The benefit/cost ratio of each of the solutions from step 2 is then calculated, and the data are sorted by this ratio.

Step 4: The user may now enact one or both of two options:

Option A: The user specifies a nutrient load reduction target in tons/year, and the model lists the management options with the best benefit/cost ratio until the load reduction target is met. The list of management options and the total cost are then reported.

Option B: The user specifies a budget in dollars/year, and the model lists the options with the best benefit/cost ratio until the budget is met. The list of management options and the total nutrient load reduction are then reported.

6.0 CASE STUDY

In order to allow users to begin using the model quickly, a narrative case study is presented in this chapter. The case study illustrates how the computer programs could be used to support the development of an actual watershed management plan. Upon reviewing the case study, the reader will understand,

- how to define a watershed management problem in terms of the model framework,
- how to construct the input data sets needed by the model,
- how to run the model, and
- how to interpret the results.

This case study was designed to demonstrate the variety of functions provided by the model, and to demonstrate its flexibility.

6-1 THE SETTING OF THE CASE STUDY

The principal character of this case study is a stormwater management engineer, Casey Jones. Mr. Jones works for a fictitious coastal county on the shores of Tampa Bay, and was assigned the task of developing a watershed management plan for one of the drainage basins in the county. This narrative walks through how Mr. Jones used the optimization model to assist in his assigned task.

The county had been participating in a regional pollutant load reduction effort developed through the Tampa Bay National Estuary Program, and had decided to reduce the county's total annual pollutant loads to Tampa Bay by a target amount. The Chief Engineer for the county has assigned each of the County's stormwater management engineers a drainage basin, and instructed them to reduce annual pollutant loads from their particular drainage basin by a given portion of the target amount. Casey Jones was assigned the Round Bay drainage basin, and instructed to reduce annual total nitrogen loads by 0.2 tons/year and minimize TSS loads. A capital budget for the county-wide project was not finalized, and the Chief Engineer instructed Casey Jones to first develop a management plan that will meet the pollutant load reduction targets and second report back to him how much it will cost to implement the plan.

Casey wrote down the formal management objective of the plan, and began working on compiling the available data.

> *Primary Management Objective of the Round Bay Plan:*
>
> *Reduce annual total nitrogen loads from the Round Bay drainage basin by 10 tons/year, and minimize total suspended solids loads.*

He then began work on the management plan by first reviewing all of the data he had on hand for the Round Bay Basin. He made a plot of the GIS databases, and compiled files other sources of information and reports. Figure 6-1 presents the basic layout of the Round Bay Basin. The drainage basin consists of three large subbasins. Named after their stream channels, these subbasins are the heavily developed Long Lake Canal subbasin, and the rural Crooked Creek and the Bent Branch subbasins.

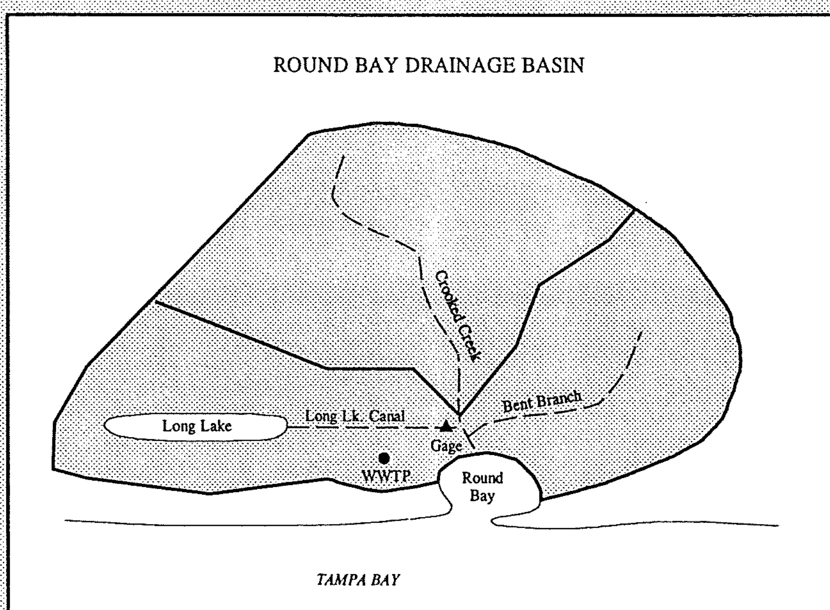

Figure 6-1 Basic features of the Round Bay Drainage Basin

The available information for each of the three subbasins was summarized as follows.

Crooked Creek Subbasin:

Hydrography	*An ungaged creek which discharges to Round Bay.*
Land Cover	*Low density residential land us interspersed with patches of forested uplands and freshwater wetlands.*
Loadings	*Land use-specific TSS, TN, and TP loadings were estimated by an earlier special study of the subbasin.*
Special Considerations	*None.*

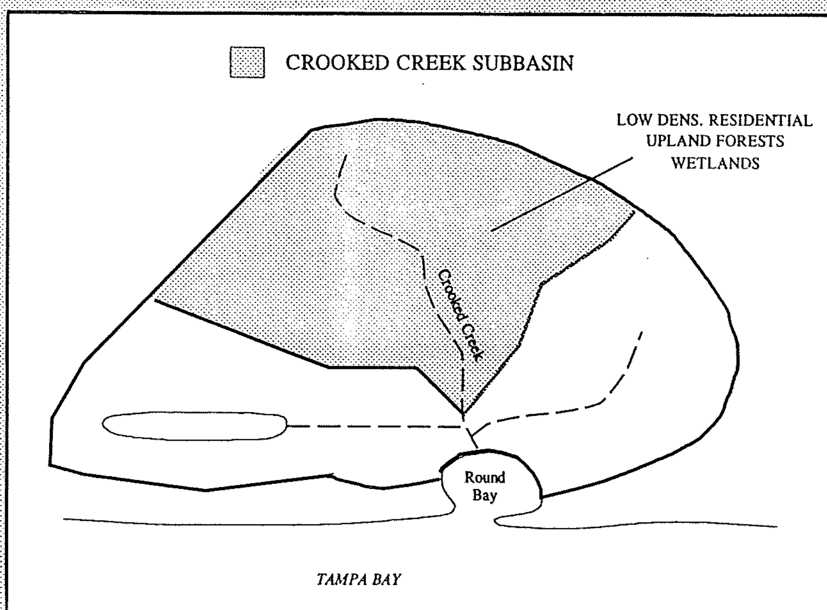

Figure 6-2 Crooked Creek Subbasin.

Bent Branch Subbasin:

Hydrography	*An ungaged creek which discharges to Round Bay via lower Crooked Creek.*
Land Cover	*Low density residential land use interspersed with patches of forested uplands and freshwater wetlands.*
Loadings	*Land use-specific TSS, TN, and TP loadings not available from other sources, so Casey estimated these loads by applying a unit area load calculation to the GIS land use data.*
Special Considerations	*None.*

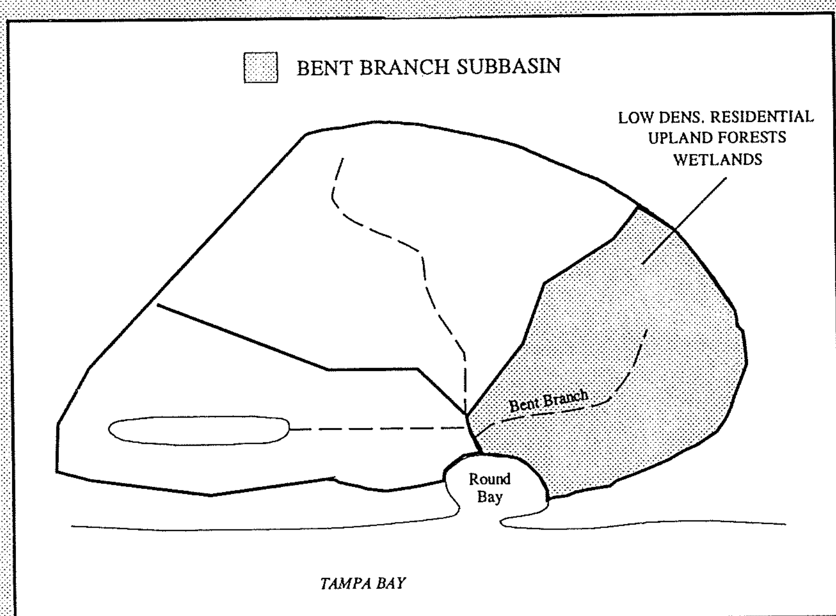

Figure 6-3 Bent Branch Subbasin

Long Lake Subbasin:

Hydrography	*A man-made canal which discharges to Round Bay via lower Crooked Creek. There is a stream gaging station at the outfall where both water quantity and quality are measured.*
Land Cover	*Medium and high density residential land use surrounding a man-made lake.*
Loadings	*Land use-specific TSS, TN, and TP nonpoint source loadings were estimated from water quality and quantity data measured at the gage.* *Point source loads from the Long Lake Wastewater Treatment Plant (WWTP) were recorded monthly.*
Special Considerations	*- The basin is gaged.* *- The Long Lake WWTP discharges into the canal.*

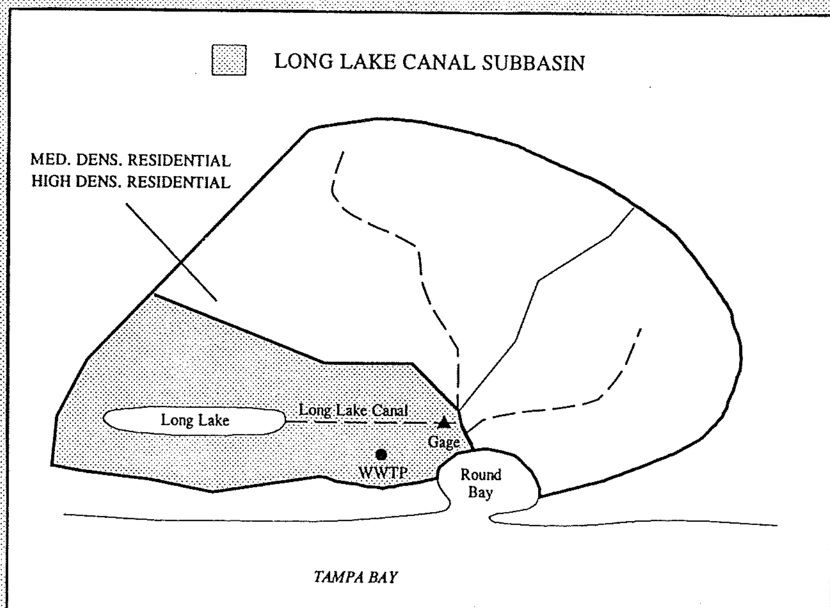

Figure 6-4 Long Lake Subbasin.

After reviewing the available information for the three subbasins, Casey realized that there were two management objectives that would be important to the development of the plan, nitrogen load reduction and TSS load reduction. He also realized that an important implicit objective for the plan would be to minimize costs. Thus, he defined the final formal objectives of the plan were defined as:

> *Management Objectives of the Round Bay Plan:*
>
> *Reduce annual TN loads from the basin by 10 tons/year,*
>
> *Reduce annual TSS loads from the basin and*
>
> *Minimize costs associated with the acceptable management actions.*

In looking over this list of objectives, it became apparent that the overall problem was a multiple objective problem as discussed in the introductory chapters of this report. Although, there was a definite, numeric minimum target for TN load reduction, there was not a numeric target for TSS load reduction, and there was no information as to how much any one of the objectives was more important than the others. For example, he did not know whether 1 ton of TN load reduction was equal in value to 1 ton of TSS load reduction. In addition, there was not an actual budget to work with yet, but only the general objective that costs should be minimized.

He defined a **"management plan"** as a set of individual management actions (e.g., BMPs) which could be purchased or constructed in the watershed. Thus, an example management plan might be:

- construct a 2 acre wet detention pond in the Crooked Creek Basin,
- install 10 acres of porous pavement in the Long Lake Basin,
- install equipment at the Long Lake WWTP to reduce TN loads by 2 tons per year.

The expected benefits and costs of any specific management plan could then be calculated in terms of the three objectives the total TN load reduction, the total TSS load reduction, and the total cost of the set of management actions.

Because of the multiple-objective nature of the problem, he realized that an absolutely best "management plan" could not be objectively defined based on the available data alone. However, the TBNEP optimization model could be used to define a set of "management plans" which are clearly better than all other groups of actions with respect to the three objectives, and then he could work with the other watershed managers to use subjective information (e.g., community acceptance, aesthetic appeal, professional judgement) to choose the best plan.

Casey realized that even in this fairly simple case of three subbasins, there would be thousands of possible combinations of management actions to be compared to identify the group of better options (i.e., the Pareto optimal set). He decided to solve the problem using the TBNEP optimization software in a series of steps, and noted these in his project log:

Project Logbook - Round Bay Management Plan *Casey Jones*

Analysis Approach for Round Bay Management Plan Development

Step 1:	*Put together a list of all BMPs which should be considered, and use site-specific constraints and the Optimization Module 1 to generate a shortlist of BMPs which would be feasible for the Round Bay Basin.*
Step 2:	*Use Optimization Module 2 to identify the costs and benefits of each BMP in the shortlist.*
Step 3:	*Use Optimization Module 3 to identify the best types of BMPs in terms of costs and benefits.*
Step 4:	*Once a Pareto optimal set of management plans has been identified, use Module 4 to evaluate management priorities, budgets, and load reduction targets, and then use this information to select a final management plan.*

6-2 STEP 1: APPLYING MODULE 1 TO BMP SCREENING AND OPTIONS LIST GENERATION

Casey's first task was to compile a list of all BMPs that should be considered for the Round Bay Basin Management Plan. He decided to use the TBNEP Optimization model to assist in compiling the list of feasible options based on site-specific constraints in the watershed and a set of BMP characteristics. The results of Module 1 would be output in the form of a table of feasible BMP's by subbasin and land use together with an estimate of the suitable area in the watershed for implementing each BMP.

As an alternative to running Module 1, Casey realized that he could have visited the watershed and recorded specific suitable areas and sizes of feasible BMP's. This information could then have been typed into a table in the same format as the output table from Module 1. Thus, he could have started running the Optimization programs with Module 2. However, in this case he only had GIS databases of land use and soil information for the three subbasins of the Round Bay Watershed.

Casey remembered that each module of the TBNEP Optimization Model computer program has four types of files:

- **a program control file** - which contains a set of simple instructions to a particular module,

- **a program log file** - which repeats and verifies the instructions given in the program control file and lists any notes or error messages that may have occurred during the run,

- **input data files** - which contain all of the data needed to run a particular module, and

- **output data files** - which contain tables of the results of the run.

Each of these files is a simple ASCII text file that could be edited with a word processing program or text editor program.

For example, he was using Wordperfect software at the time, and to edit a data file he had to take the following steps:

Step 1) open the file using the [FILE] [OPEN] buttons,

Step 2) select the [line printer] font to make the file easier to read,

Step 3) make the necessary edits to the file, and

Step 4) save the file using the [FILE] [SAVE AS] [ASCII (DOS) TEXT] buttons.

Creating the Program Control File for Module 1:

Casey copied an existing program control file for Module 1 and edited the contents using his word processing program. The completed file appeared as follows:

```
r1-1.co1       TBNEP BMP Optimization Model,  Module 1 Control File          ①

Round Bay Management Plan
   Initial screening run of BMP options using default TBNEP BMP constraint data

Initial Run,        Aug 1, 1996   Casey Jones
Q.C. Reviewed,      Aug 3, 1996   B.G. Fireman


r1-1.o1                       - output data file                 line 11     ②
r1-const.bmp                  - BMP constraints data file        line 12
r-sub.bmp                     - Subbasin description file        line 13
soil.dat                      - Soil characteristics data        line 14
```

① The first 10 lines of the program control file are free space in which Casey could type whatever notes he wanted to record with respect to this model run. He typed in the name of the control file, a title and description of the run, and a brief history of who worked on the analysis.

② The remaining lines of the control file identified the input and output data files for this model run. The program log file was named "r1-1.o1", a list of BMP's and associated constraints was named "r1-const.bmp", a subbasin description file was named "r-sub.bmp", and a soil characteristics table was named "soil.dat."

The program output file would be automatically named the same name as the program control file with an extension of "p1." Thus, the output file would be created by Module 1 as "r1-1.p1."

Creating the Input Data Files for Module 1:

Casey needed three input data files. These were a BMP list with constraint data, a subbasin description list, and a soil characteristics list. He copied existing input data files supplied with the TBNEP programs and edited the contents using a word processing program.

He then developed a list of the feasible BMP's by copying the default BMP list "const.bmp" as "r-const.bmp." After reviewing the BMP's in this file, he decided that he was comfortable building three designs: a constructed wetland, a small wet retention pond, and a large wet retention pond. Therefore, he deleted all of the other lines in the default file other than these three. He then reviewed the default constraints for these three and decided they were acceptable.

In addition, the County had just completed a feasibility study for a new type of porous pavement that could be installed on parking lots owned by the County. As part of this study, the County had compiled detailed inventories of the suitable parking lot areas independently from the GIS land use databases. This was a special case that could be handled by assigning a second "BMP category" to the porous pavement option. Casey then added a line to the BMP list file to represent the constraints for porous pavement installation and labeled it as BMP category 2. The inventory of suitable parking lot areas by subbasin was added to the subbasin description file.

A sample of the contents of this file follows (the actual file listed more land uses and BMP's):

```
r1-const.bmp         Best Management Practice Constraint Data
                     Values for Round Lake Management Plan


BMP   BMP       BMP  BMP    BMP      BMP          BMP           BMP
     Category   Land Trtmt  Area     Soil       Depth to       Slope
                Use  Area        Infiltration  Water Table
                                  min    max    min   max    min  max
                     acres  acres in/hr  in/hr  ft    ft     %    %
--- --------- ------ -----  ----- ------------ ------------ -------------
CW      1        1     50    2    0.02   8.27    0   -999  -999 -999
CW      1        2     50    2    0.02   8.27    0   -999  -999 -999
CW      1        3     50    2    0.02   8.27    0   -999  -999 -999
PP      2        6     50   20    0.52  30.00    2   -999     3   18  Porous Pavement
WP1     1        1    100    2    0.02   8.27    2   -999     3   18
WP1     1        2    100    2    0.02   8.27    2   -999     3   18
WP1     1        3    100    2    0.02   8.27    2   -999     3   18
```

As with all of the input files for the Optimization programs, the first 10 lines are free space for documenting runs. A code of -999 indicated missing data, the BMP codes were "CW" for constructed wetland, "PP" for porous pavement, "WP1" for the small pond, and "WP2" for the large pond. Casey included a line in this file for each land use and each BMP that should be considered.

He then developed a data file ("r-sub.bmp") of the land use and soil by subbasin in the watershed:

```
r-sub.bmp               Subbasin and BMP category specific land use and soil data
                        Describes areas suitable for BMP implementation
                        (sorted by subbasin/BMP cat/land use)
                        Round Bay Basin Management Plan

  BMP     Subbasin     BMP        BMP      BMP
  Soil                Category    Land     Area
                                  Use      Available
 (MUID)                                    (acres)
-------- ----------  ----------  ------   ---------
103005       1          1          1       130.391
103018       1          1          1       142.336
103041       1          1          1        38.804
103027       1          1          1         5.986
103041       1          1          3       225.667
103018       1          1          3       141.052
103027       1          1          3       322.842
103002       1          1          5       151.796
103005       2          1          1       230.391
103018       2          1          1        42.336
103041       2          1          1       138.804
103027       2          1          1         5.986
103041       2          1          3       125.667
103018       2          1          3        41.052
103027       2          1          3       122.842
103002       2          1          5        51.796
103005       3          1          1       230.391
103018       3          1          1       142.336
103041       3          1          1        38.804
103027       3          1          1       105.986
103041       3          1          3       225.667
103018       3          1          3        41.052
103027       3          1          3        22.842
103002       3          1          3        51.796
103041       3          1          5       225.667
103018       3          1          5        41.052
103027       3          1          5        22.842
103002       3          1          5        51.796
103041       3          2          6       325.667
103018       3          2          6       141.052
103027       3          2          6       122.842
103002       3          2          6       151.796
```

These data were obtained by printing a table from his department's GIS database. The soil codes were taken from the U.S. Soil Conservation Service soil atlas for his County, and the land use codes were defined to match the TBNEP land use codes used in the previous BMP constraint list. He realized, however, that he could have readily substituted any other soil or land use codes that he would be comfortable using.

As discussed previously, the inventory of suitable parking lot areas for installation of porous pavement was added to the subbasin description file based on an existing detailed study. These areas were independent of the GIS-based land use data. Thus, they were assigned a BMP category of "2".

Lastly, he then typed in a soil characteristics data file based on information contained in the U.S. Soil Conservation Service Soil Atlas for his county. This file appeared as follows:

```
soil.dat           Soil characteristics data

TBNEP Optimization Model - Default Soil Data from USDA Soil Atlases
                              Version 1.0  May 1996


 Soil           Slope              Depth to WT           Permeability
           min   mean   max     min   mean   max      min   mean   max
 MUID       %     %      %       ft    ft     ft     in/hr in/hr  in/hr
-------- ----- ----- ------   ----- ----- ------    ----- ----- ------
103002    -999  -999  -999     0.0   -999  0.8       20.0  -999  30.0
103003    0     -999  5        6.7   -999 10.0       20.0  -999  30.0
103004    5     -999  12       6.7   -999 10.0       20.0  -999  30.0
103005    -999  -999  -999     3.3   -999  5.0       20.0  -999  30.0
103006    -999  -999  -999     0.0   -999  0.8        6.3  -999  20.0
103007    -999  -999  -999     0.0   -999  0.8        6.3  -999  20.0
103008    -999  -999  -999     0.0   -999  1.3       20.0  -999  30.0
103009    -999  -999  -999     0.0   -999  0.001     20.0  -999  30.0
103010    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103011    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103012    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103013    5     -999  8        0.0   -999  0.8        0.1  -999   2.0
103014    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103015    -999  -999  -999     -999  -999  -999       -999 -999   -999
103016    -999  -999  -999     -999  -999  -999       -999 -999   -999
103022    -999  -999  -999     3.3   -999  5.0       20.0  -999  30.0
103023    -999  -999  -999     0.0   -999  0.8        0.6  -999   2.0
103024    0     -999  5        6.7   -999 10.0       20.0  -999  30.0
103025    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103026    -999  -999  -999     0.0   -999  0.8        6.3  -999  20.0
103027    -999  -999  -999     0.8   -999  3.3        2.0  -999  20.0
103028    -999  -999  -999     0.0   -999  0.8        6.3  -999  20.0
103029    -999  -999  -999     0.0   -999  0.8        6.3  -999  20.0
103030    -999  -999  -999     -999  -999  -999       -999 -999   -999
103031    0     -999  5        6.7   -999 10.0       20.0  -999  30.0
103032    5     -999  12       5.0   -999 10.0       20.0  -999  30.0
103033    -999  -999  -999     0.8   -999  3.3       20.0  -999  30.0
103034    -999  -999  -999     0.0   -999  0.8        6.3  -999  20.0
103035    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103036    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103037    -999  -999  -999     -999  -999  -999       -999 -999   -999
103038    0     -999  8        6.7   -999 10.0       20.0  -999  30.0
103039    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103040    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103041    -999  -999  -999     0.8   -999  3.3        2.0  -999  20.0
103042    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103043    -999  -999  -999     0.0   -999  0.8        0.6  -999  20.0
103044    0     -999  5        0.0   -999  0.8        0.6  -999   6.3
103045    -999  -999  -999     -999  -999  -999       -999 -999   -999
103099    -999  -999  -999     -999  -999  -999       -999 -999   -999
103WAT    -999  -999  -999     -999  -999  -999       -999 -999   -999
```

Running the Computer Program for Module 1:

Once he had completed making the program control file and the three data input files, Casey ran the computer program for Module 1 as follows:

At the DOS prompt of his personal computer, he ran Module 1 using program control file "r1-1.co1" by typing:

```
opt-1   r1-1.co1
```

To which the computer responded:

```
Optimization analysis has commenced
Output printed to r1-1.o1
Intermediate BMP file r1-1.p1 created
```

The program had completed its run very quickly, and had produced two data files. These files were the program log file "r1-1.o1" and the table of the results "r1-1.p1." He opened both of these files with his word processing program to inspect the results.

The program log file ("r1-1.o1") appeared as follows:

```
                          Tampa Bay National Estuary Program
                      BMP Allocation Strategy Optimization Model

                         Output from execution of r1-1.co1 control file

Control file header:
r1-1.co1        TBNEP BMP Optimization Model,  Module 1 Control File

Round Bay Management Plan
   Initial screening run of BMP options using default TBNEP BMP constraint data


Initial Run,        Aug 1, 1996   Casey Jones
Q.C. Reviewed,      Aug 3, 1996   B.G. Fireman

*** Model run using the following data files
    Program control file = r1-1.co1
    Program output file  = r1-1.o1
    BMP constraints data = r1-const.bmp
    Subbasin data        = r-sub.bmp
    Soil data            = soil.dat

*** Program Run Completed
```

He noted that the top of the log file repeated the 10 lines of comments he had entered in the control file so that it would be easy to document the results. The program confirmed and restated the data input files that it had been instructed to use. And lastly, it indicated that the run had been completed without any error messages.

Interpreting the Results from Module 1:

The results of Module 1 were to list all of the feasible BMP's for the watershed. The output data file ("r1-1.p1") containing the results of the Module 1 run appeared as follows:

```
r1-1.p1           Intermediate BMP file r1-1.p1
Created by control file r1-1.co1


BMP      BMP         BMP          BMP     Subbasin   Land         Suitable
       Category    Treatment      Area                Use           Area
                     Area
code    (code)     (acres)      (acres)    (code)   (code)         (acres)
----  ---------  ----------   ----------  --------  --------       --------
CW         1        50.000       2.000         1         1          55.366
CW         1        50.000       2.000         2         1          48.372
CW         1        50.000       2.000         3         1          79.634
CW         1        50.000       2.000         1         3         177.204
CW         1        50.000       2.000         2         3          73.140
CW         1        50.000       2.000         3         3          73.140
CW         1        50.000       2.000         3         5          73.140
PP         2        50.000      20.000         3         6         241.836
WP1        1       100.000       2.000         1         1           5.861
WP1        1       100.000       2.000         2         1          18.946
WP1        1       100.000       2.000         3         1          18.946
WP1        1       100.000       2.000         1         3          71.772
WP1        1       100.000       2.000         2         3          32.517
WP1        1       100.000       2.000         3         3          32.517
WP1        1       100.000       2.000         3         5          32.517
WP2        1       640.000      13.000         1         1           5.861
WP2        1       640.000      13.000         2         1          18.946
WP2        1       640.000      13.000         3         1          18.946
WP2        1       640.000      13.000         1         3          71.772
WP2        1       640.000      13.000         2         3          32.517
WP2        1       640.000      13.000         3         3          32.517
WP2        1       640.000      13.000         3         5          32.517
```

This results table indicated which BMP's would be feasible given the soils, land use, and available area of each subbasin. For example, the first data line of this file indicates that:

- constructed wetlands ("CW") could be implemented given the land use/soil,
- that each constructed wetland would treat 50 acres of drainage area,
- that each constructed wetland would occupy 2 acres, and
- that in subbasin 1 and land use 1 there would be an estimated 55,366 acres of suitable area for building constructed wetlands given the land use, soil infiltration rates, depths to the water table, and slopes of the soils present.

6-3 STEP 2: APPLYING MODULE 2 TO THE COSTS AND BENEFITS COMPILATION

Casey's second task was to identify the costs and benefits in terms of pollutant load reduction for each of the BMP's in the list of feasible BMPs produced by Module 1. He would require nonpoint source pollutant loading data, BMP cost data, and BMP load reduction efficiency data. He decided to use the TBNEP Optimization model Module 2 to analyze this information. The results of Module 2 would be output in the form of a table of BMP's with specific costs and pollutant load reduction benefits.

As an alternative to running Module 2, Casey realized that he could have developed detailed and specific BMP designs with costs and modeled load reduction efficiencies. This information could then have been typed into a table in the same format as the output table from Module 2. Thus, he could have started running the Optimization programs with Module 3.

Creating the Program Control File for Module 2:

The program control file for Module 2 was very similar to that used in Module 1. Casey copied an existing program control file for Module 2 and edited the contents using a word processing program. The completed file appeared as follows:

```
r1-1.co2        TBNEP Optimization Model,  Module 2 Control File
                Round Lake Management Plan


The first 10 lines of this control file provide a free form space which users
may use to document the specifics of each run.




r1-1.o2                         - output data file                    line 11
r1-1.p1                         - BMP shortlist file                  line 12
r-load.bmp                      - BMP load data file                  line 13
r-cost.bmp                      - BMP cost data file                  line 14
r-eff.bmp                       - BMP efficiency file                 line 15
```

As was the case for Module 1, the first 10 lines of the program control file are free space in which Casey could type whatever notes he wanted to record with respect to this model run. He typed in the name of the control file and a title and description of the run

The remaining lines of the control file identified the input and output data files for this model run. The program log file was named "r1-1.o2", the list of feasible BMP's from Module 1 was named "r1-1.p1", a list of subbasin specific nonpoint source pollutant loads was named "r-load.bmp", a list of BMP cost data was named "r-cost.bmp", and a list of BMP efficiency data was named "r-eff.bmp."

As was the case for Module 1, the program output file would be automatically named the same name as the program control file with an extension of "p2." Thus, the output file would be created by Module 2 as "r1-1.p2."

Creating the Input Data Files for Module 2:

Casey needed four input data files. These were:

- a list of feasible BMP's either typed in or from the Module 1 output,
- a subbasin-specific nonpoint source pollutant load data file,
- a BMP-specific cost data file, and
- a BMP-specific pollutant load reduction data file.

Again, he copied existing input data files supplied with the TBNEP programs and edited the contents using a word processing program.

Casey Jones called a meeting with his department and went over the list of feasible BMP's with the County's Chief Engineer. The Chief Engineer had just been informed that the local Water Management District had completed a study of combining several BMPs in series. They had combined wet retention ponds and downstream constructed wetlands to achieve higher pollutant load reduction efficiencies. Casey and the Chief Engineer revised the data file containing the feasible BMP options ("r1-1.p1") to reflect this new information. They added "treatment train" BMP options by assuming that they could be implemented anywhere a small wet pond could be implemented. Thus, they copied the data records for the small wet pond option ("WP1"), labeled the new records as treatment train BMP's ("TT"), and updated the pollutant load reduction efficiency and cost data based on the results of the Water Management District study.

The revised data file was named "r1-2.p1", and the contents of this file are presented on the following page. Note the new lines indicating treatment train options.

```
r1-2.p1            Intermediate BMP file
Created by control file r1-1.co1
Added treatment train option based on Fireman, Aug 1995 Study     C. Jones
```

BMP code	BMP Category (code)	BMP Treatment Area (acres)	BMP Area (acres)	Subbasin (code)	Land Use (code)	Suitable Area (acres)
CW	1	50.000	2.000	1	3	177.204
CW	1	50.000	2.000	1	1	55.366
CW	1	50.000	2.000	2	3	73.140
CW	1	50.000	2.000	2	1	48.372
CW	1	50.000	2.000	3	3	73.140
CW	1	50.000	2.000	3	5	73.140
CW	1	50.000	2.000	3	1	79.634
PP	2	50.000	20.000	3	6	241.836
TT	1	140.000	4.000	1	1	5.861
TT	1	140.000	4.000	1	3	71.772
TT	1	140.000	4.000	2	3	32.517
TT	1	140.000	4.000	2	1	18.946
TT	1	140.000	4.000	3	5	32.517
TT	1	140.000	4.000	3	1	18.946
TT	1	140.000	4.000	3	3	32.517
WP1	1	100.000	2.000	1	1	5.861
WP1	1	100.000	2.000	1	3	71.772
WP1	1	100.000	2.000	2	3	32.517
WP1	1	100.000	2.000	2	1	18.946
WP1	1	100.000	2.000	3	5	32.517
WP1	1	100.000	2.000	3	1	18.946
WP1	1	100.000	2.000	3	3	32.517
WP2	1	640.000	13.000	1	1	5.861
WP2	1	640.000	13.000	1	3	71.772
WP2	1	640.000	13.000	2	3	32.517
WP2	1	640.000	13.000	2	1	18.946
WP2	1	640.000	13.000	3	5	32.517
WP2	1	640.000	13.000	3	1	18.946
WP2	1	640.000	13.000	3	3	32.517

Casey modified the program control file to read this new data file. As with all of the input files for the Optimization programs, the first 10 lines are free space for documenting runs. Thus Casey, typed a note in this space indicating that treatment train options had been added based on the Water Management District 1995 Study.

As discussed in the introduction to this case study, Casey had previously computed nonpoint source pollutant loads for these three subbasins on an average annual basis. The estimates from ungaged subbasins were estimated using unit area loading calculations based on the land use, soil, and rainfall data. The estimates from gaged subbasins were computed by multiplying measured pollutant concentrations by the total flows recorded at the gages. He used a spreadsheet software package to compile these loading estimates into a simple data file in the format required by the TBNEP Optimization programs.

The pollutant loading file appeared as follows:

```
r-load.bmp            Subbasin and land use specific pollutant loads
                      Round Lake Management Plan


                     Treatment Treatment
Subbasin    BMP       Area       TN          TP          TSS
         Category
                      acres   tons/yr    tons/yr     tons/yr
--------  --------    ------ --------  ----------  -----------
1               1     1584.5   1.874      1.217      144.022
2               1     1951.9   5.117      1.631      280.460
3               1     1553.8   1.929      1.211       93.687
3               2      500.0   0.524      0.443       73.932
```

Casey had to develop a separate set of nonpoint source pollutant load estimates for the parking lot areas considered for installation of porous pavement. These loads were entered into the data file as BMP category 2. Together with the drainage areas that would be drain to these particular parking lots.

He then compiled a BMP specific cost data file using the format required by the TBNEP computer programs. He started by copying the default cost data file "cost.bmp", and modifying it slightly to include the treatment train options and the specific cost data he possessed for porous pavement. The cost data file is presented on the following page. Note that the land cost for the porous pavement option had been entered as zero since the County already owned these parking lots.

r-cost.bmp   Best Management Practice Cost Data
Round Lake Management Plan
Sorted by BMP/BMP cat/land use

BMP	BMP Category	BMP Land Use	BMP Life Span (Yr)	BMP Construction Cost ($/Acre Treated)	BMP O&M Cost ($/acre treated /Year)	Land Cost ($/acre)
CW	1	1	20	2800	75.00	365462.00
CW	1	2	20	2800	75.00	365462.00
CW	1	3	20	2800	75.00	398573.00
CW	1	4	20	2800	75.00	38950.00
CW	1	5	20	2800	75.00	376497.00
CW	1	6	20	2800	75.00	34723.00
CW	1	6	20	2800	75.00	34723.00
CW	1	7	20	2800	75.00	38950.00
CW	1	8	20	2800	75.00	34723.00
CW	1	9	20	2800	75.00	34723.00
CW	1	10	20	2800	75.00	34723.00
CW	1	11	20	2800	75.00	61929.00
CW	1	12	20	2800	75.00	61929.00
CW	1	13	20	2800	75.00	61929.00
CW	1	14	20	2800	75.00	61929.00
PP	2	6	10	6000	2000.00	0.00
TT	1	1	20	4600	85.00	365462.00
TT	1	2	20	4600	85.00	365462.00
TT	1	3	20	4600	85.00	398573.00
TT	1	4	20	4600	85.00	38950.00
TT	1	5	20	4600	85.00	376497.00
TT	1	6	20	4600	85.00	34723.00
TT	1	6	20	4600	85.00	34723.00
TT	1	7	20	4600	85.00	38950.00
TT	1	8	20	4600	85.00	34723.00
TT	1	9	20	4600	85.00	34723.00
TT	1	10	20	4600	85.00	34723.00
TT	1	11	20	4600	85.00	61929.00
TT	1	12	20	4600	85.00	61929.00
TT	1	13	20	4600	85.00	61929.00
TT	1	14	20	4600	85.00	61929.00
WP1	1	1	20	2600	65.00	365462.00
WP1	1	2	20	2600	65.00	365462.00
WP1	1	3	20	2600	65.00	398573.00
WP1	1	4	20	2600	65.00	38950.00
WP1	1	5	20	2600	65.00	376497.00
WP1	1	6	20	2600	65.00	34723.00
WP1	1	6	20	2600	65.00	34723.00
WP1	1	7	20	2600	65.00	38950.00
WP1	1	8	20	2600	65.00	34723.00
WP1	1	9	20	2600	65.00	34723.00
WP1	1	10	20	2600	65.00	34723.00
WP1	1	11	20	2600	65.00	61929.00
WP1	1	12	20	2600	65.00	61929.00
WP1	1	13	20	2600	65.00	61929.00
WP1	1	14	20	2600	65.00	61929.00
WP2	1	1	20	2600	65.00	365462.00
WP2	1	2	20	2600	65.00	365462.00
WP2	1	3	20	2600	65.00	398573.00
WP2	1	4	20	2600	65.00	38950.00
WP2	1	5	20	2600	65.00	376497.00
WP2	1	6	20	2600	65.00	34723.00
WP2	1	6	20	2600	65.00	34723.00

Lastly, Casey compiled a table of the pollutant load reduction efficiencies for each BMP. He started with the default table provided with the TBNEP programs, modified it slightly to reflect the County's preferences, and added efficiency data for treatment trains and for porous pavement.

The pollutant load reduction efficiency data file appeared as follows:

```
r-eff.bmp          Best Management Practice Efficiency Data
                   Round Lake Management Plan



BMP  BMP              TN                   TP                  TSS
     Category   min mean   max    min mean   max    min   mean  max
                 %   %      %      %   %      %      %     %     %
---- -------- ----- ----- ----- ----- ----- ----- ----- ----- -----
ED      1        10   30    60     30   60    90      5    48    90
WP1     1        10   30    60     30   60    90     30    60    90
WP2     1        10   30    60     30   60    90     30    60    90
CW      1         0   25    40     10   35    65   -999    75  -999
VS      1         0   10    25   -999   15    30   -999    35    70
VF      1         0   35    70      0   45    90     20    50    80
IB1     1        45   58    70     50   63    75     75    87    99
IB2     1        45   58    70     50   63    75     75    87    99
IT      1        40   57    80     40   57    80     60    83   100
TT      1        10   65    70     50   75    95     35    65    95
PP      2         0   35    70      0   45    90     20    50    80
```

Note that certain minimum and maximum efficiency values were not available in the literature, and a -999 code was entered for these values. Also note that porous pavement has again been assigned a separate BMP category.

Running the Computer Program for Module 2:

Once he had completed making the program control file and the four data input files, Casey ran the computer program for Module 2 as follows:

At the DOS prompt of his personal computer, he ran Module 2 using program control file "r1-1.co2" by typing:

```
opt-2   r1-1.co2
```

To which the computer responded:

```
Optimization analysis has commenced
Output printed to r1-1.o2
Intermediate BMP file r1-1.p2 created
```

The program had completed its run very quickly, and had produced two data files. These files were the program log file "r1-1.o2" and the table of the results "r1-1.p2." He opened both of these files with his word processing program to inspect the results.

The program log file ("r1-1.o2") appeared as follows:

```
                         Tampa Bay National Estuary Program
                     BMP Allocation Strategy Optimization Model

                        Output from execution of r1-1.co2 control file


Control file header:
r1-1.co2       TBNEP Optimization Model,  Module 2 Control File
               Round Lake Management Plan


The first 10 lines of this control file provide a free form space which users
may use to document the specifics of each run.







*** Model run using the following data files
    Program control file = r1-1.co2
    Program output file  = r1-1.o2
    BMP short list file  = r1-2.p1
    BMP efficiency file  = r-eff.bmp
    Pollutant load file  = r-load.bmp

*** Program Run Completed
```

He noted that the top of the log file had again repeated the 10 lines of comments he had entered in the control file and had confirmed the data input files that it had been instructed to use. Lastly, it indicated that the run had been completed without any error messages.

Interpreting the Results from Module 2:

The results of Module 2 were to list the costs and benefits of each of the feasible BMP's for the watershed. The output data file ("r1-1.p2") containing the results of the Module 2 run appeared as follows:

```
r1-1.p2          Intermediate BMP file r1-1.p2
Created by control file r1-1.co2


BMP    BMP       BMP       BMP       Sub-     Avail.  Avail.     BMP        TN       TP       TSS
     Category   Trtmnt     Area      basin     BMP    Trtmt.     Cost      Reduct.  Reduct.   Reduct.
                 Area                          Area    Area
code  (code)   (acres)   (acres)    (code)   (acres) (acres)    ($/yr)    (ton/yr) (ton/yr)  (ton/yr)
---- -------- --------- ---------- ------- ---------- ------- ----------- --------- --------- ---------
CW         1      50.0       2.0        1     232.6   1584.5    49819.05      0.01      0.01      3.41
CW         1      50.0       2.0        2     121.5   1951.9    49289.20      0.03      0.01      5.39
CW         1      50.0       2.0        3     225.9   1553.8    48725.43      0.02      0.01      2.26
PP         2      50.0      20.0        3     241.8    500.0   130000.00      0.02      0.02      3.70
TT         1     140.0       4.0        1      77.6   1584.5   123314.65      0.11      0.08      8.27
TT         1     140.0       4.0        2      51.5   1951.9   121376.65      0.24      0.09     13.08
TT         1     140.0       4.0        3      84.0   1553.8   120611.06      0.11      0.08      5.49
WP1        1     100.0       2.0        1      77.6   1584.5    59107.32      0.04      0.05      5.45
WP1        1     100.0       2.0        2      51.5   1951.9    58138.33      0.08      0.05      8.62
WP1        1     100.0       2.0        3      84.0   1553.8    57755.53      0.04      0.05      3.62
WP2        1     640.0      13.0        1      77.6   1584.5   382247.61      0.23      0.29     34.90
WP2        1     640.0      13.0        2      51.5   1951.9   375949.11      0.50      0.32     55.18
WP2        1     640.0      13.0        3      84.0   1553.8   373460.95      0.24      0.30     23.15
```

This results table listed costs and benefits by BMP's. For example, the first data line of this file indicates that:

- a single constructed wetland ("CW") if implemented would treat up to 50 acres, and would occupy 2 acres,
- subbasin 1 has 232.6 acres where the wetlands could likely be built,
- subbasin 1 has 1584.5 acres of drainage area that could likely be treated,
- the estimated cost of a typical constructed wetland in subbasin 1 would be $49,819.05 per year, and
- the BMP would reduce TN loads by 0.01 tons per year, TP loads by 0.01 tons per year, and TSS loads by 3.41 tons per year.

6-4 STEP 3: APPLYING MODULE 3 TO IDENTIFY THE BEST TYPES OF BMPS FOR THE WATERSHED

Casey's third task was to identify the best types of BMPs to build in terms of costs and pollutant load reduction. The only data he would require would be the table of BMP's with specific costs and pollutant load reduction benefits output from Module 2. Module 3 of the TBNEP programs would permute through all of the hundreds of thousands of possible combinations of BMPs that could be implemented in the Round Bay Watershed, and it would present the set of options that would be better than all of the other options. Using the Pareto optimal techniques described in detail in the introductory chapters of this report, a small manageable subset of optimal solutions would be produced.

Creating the Program Control File for Module 3:

The program control file for Module 3 was very similar to those used in Modules 1 and 2. Casey copied an existing program control file for Module 3 and edited the contents using a word processing program. The completed file appeared as follows:

```
r1-1.co3        TBNEP Optimization Model,  Module 3 Control FILE

Round Bay Management Plan

The first 10 lines of this control file provide a free form space which users
may use to document the specifics of each run.




r1-1.o3                          - output data file                   line 11
r1-1.p2                          - BMP strategy shortlist             line 12
r1-1.p3a                         - BMP strategy with permutation indices line 13
r1-1.p3b                         - BMP strategies with costs/benefits line 14
r-load.bmp                       - Load data file (need subbasins only) line 15

Choose the Criteria to Consider in Optimization
(Enter "y" or "n" in first column)
------------------------------------------------------------------
y = Cost
y = Total Nitrogen Load Reduction
n = Total Phosphorous Reduction
y = TSS Load Reduction
```

As was the case for Modules 1 and 2, the first 10 lines of the program control file are free space in which Casey could type whatever notes he wanted to record with respect to this model run. He typed in the name of the control file and a title and description of the run

The remaining lines of the control file identified the input and output data files for this model run. The program log file was named "r1-1.o3", the detailed list of Pareto optimal BMP's from Module 3 was named "r1-1.p3a", and a summary list was named "r1-1.p3b." The pollutant load data file from Module 2 was entered here again only because Module 3 would need to use the subbasin records for its computations.

At the bottom of the control file, there were lines to specify which of the cost/benefit dimensions the user wished to build the Pareto optimal "efficient frontier" in. As described previously, Casey knew that Round Bay was not phosphorous limited, and that he was interested in minimizing costs, maximizing TN load reduction, and maximizing TSS load reduction. Therefore, he would have a three-dimensional efficient frontier. He also realized that by only selecting the dimensions of interest for building the frontier that he could minimize the size of the optimal set of strategies. To select the dimensions he wanted, he enter "y" in the first column of the line pertaining to each of the desired dimensions.

Creating the Input Data Files for Module 3:

Casey Jones called another meeting with his department and went over the list of feasible BMP's and associated costs and benefits with the County's Chief Engineer. The Chief Engineer had just been informed that the Public Works Department of the County had completed a feasibility study of improving the Wastewater Treatment Plant in the Long Lake subbasin (subbasin 3). This looked like a promising alternative to nonpoint source control of nitrogen inputs to Round Bay, and they wanted to include it in the optimization analysis. Casey and the Chief Engineer revised the data file containing the BMP options ("r1-1.p2") to reflect this new information. They added two different Long Lake Wastewater Plant improvement options. A less expensive option that involved upgrading an existing treatment unit and a more expensive option that involved adding a new treatment unit. Thus, they added two data records for the plant improvement options, labeled the new records as "WW-A", and updated the pollutant load reduction efficiency and cost data based on the results of the Public Works Department feasibility study.

The revised data file was named "r1-2.p2", and it appeared as follows:

```
r1-2.p2          Intermediate BMP file r1-1.p2
Created by control file r1-1.co2
Added 4 Long Lake WWTP Improvement Options based on Ray Elroad 1994 Report    C. Jones
```

BMP code	BMP Category (code)	BMP Trtmnt Area (acres)	BMP Area (acres)	Sub-basin (code)	Avail. BMP Area (acres)	Avail. Trtmt. Area (acres)	BMP Cost ($/yr)	TN Reduct. (ton/yr)	TP Reduct. (ton/yr)	TSS Reduct. (ton/yr)
CW	1	50.0	2.0	1	232.6	1584.5	49819.05	0.01	0.01	3.41
CW	1	50.0	2.0	2	121.5	1951.9	49289.20	0.03	0.01	5.39
CW	1	50.0	2.0	3	225.9	1553.8	48725.43	0.02	0.01	2.26
PP	2	50.0	20.0	3	241.8	500.0	130000.00	0.02	0.02	3.70
TT	1	140.0	4.0	1	77.6	1584.5	123314.65	0.11	0.08	8.27
TT	1	140.0	4.0	2	51.5	1951.9	121376.65	0.24	0.09	13.08
TT	1	140.0	4.0	3	84.0	1553.8	120611.06	0.11	0.08	5.49
WP1	1	100.0	2.0	1	77.6	1584.5	59107.32	0.04	0.05	5.45
WP1	1	100.0	2.0	2	51.5	1951.9	58138.33	0.08	0.05	8.62
WP1	1	100.0	2.0	3	84.0	1553.8	57755.53	0.04	0.05	3.62
WP2	1	640.0	13.0	1	77.6	1584.5	382247.61	0.23	0.29	34.90
WP2	1	640.0	13.0	2	51.5	1951.9	375949.11	0.50	0.32	55.18
WP2	1	640.0	13.0	3	84.0	1553.8	373460.95	0.24	0.30	23.15
WW-A	3	1	1	3	1	1	50000.00	0.02	0.01	1.00
WW-A	3	1	1	3	1	1	125000.00	0.05	0.04	4.00

Note that the wastewater plant improvement options were identified as BMP category 3. There would only be the one plant to improve, so the treatment area, BMP area, available BMP area, and available treatment area were all set to 1 to result in only one choice for implementation representing the one wastewater treatment plant.

Casey then modified the program control file to read this new data file, and typed a note in the header space indicating that the new options had been added based on the Public Works Study.

Running the Computer Program for Module 3:

Once he had completed making the program control file and the four data input files, Casey ran the computer program for Module 3 as follows:

At the DOS prompt of his personal computer, he ran Module 3 using program control file "r1-1.co3" by typing:

```
opt-3   r1-1.co3
```

To which the computer responded:

```
Optimization analysis has commenced
Output printed to r1-1.o3

Please enter a limiting budget value:
```

The limiting budget value is a way of speeding up the execution of this module by excluding BMP strategies which would be unreasonable expensive. Thus, instead of comparing hundreds of millions of combinations of BMP's, the program will compare hundreds of thousands of combinations.

Casey knew that anything more than $200,000 dollars per year for the management of Round Bay would be clearly unreasonable, so he entered $200,000 as the limiting budget. He typed:

```
200000
```

to which the computer responded:

```
Comparing 512000 combinations of 12 BMP's
```

The program had completed its run after four to five minutes, and had produced three data files. These files were the program log file "r1-1.o3" and two tables of the results "r1-1.p3a" and r1-1.p3b." He opened each of these files with his word processing program to inspect the results.

The program log file ("r1-1.o3") appeared as follows:

```
                         Tampa Bay National Estuary Program
                     BMP Allocation Strategy Optimization Model

                        Output from execution of r1-1.co3 control file


Control file header:
r1-1.co3        TBNEP Optimization Model,  Module 3 Control File

Round Bay Management Plan

The first 10 lines of this control file provide a free form space which users
may use to document the specifics of each run.






*** Model run using the following data files
    Program control file = r1-1.co3
    Program output file  = r1-1.o3
    BMP short list file  = r1-2.p2
    BMP strategy key     = r1-1.p3a
    Optimal strategy set = r1-1.p3b
    Subbasin input data  = r-load.bmp

    Criteria used for optimization
    ------------------------------
    Cost                y
    TN Load Reduction   y
    TP Load Reduction   n
    TSS Load Reduction  y

  Comparing 512000 combinations of 12 BMPs.
  Using a maximum budget of          200000.00
  Finding optimal set from 512000 combinations of 12 BMPs.
  Optimal set completed with 20 members.


*** Program Run Completed
```

He noted that the top of the log file had:

- repeated the 10 lines of comments he had entered in the control file,
- confirmed the data input files that it had been instructed to use,
- confirmed the cost/benefit dimensions requested,
- reported that 12 BMP's met the $200,000 budget,
- the 12 BMP's could be combined in 512,000 different combinations,
- that 20 strategies were better in all dimensions (cost, TN, TSS) than all of the other 511,080 strategies, and
- lastly, it indicated that the run had been completed without any error messages.

Interpreting the Results from Module 3:

The results of Module 3 were to list the best combinations of BMP's possible given the costs and benefits of each of the feasible BMP's for the watershed. The Pareto optimal method was used to identify these 20 BMP strategies without the need to specify whether cost, TN load reduction, or TSS load reduction was more important (see detailed discussion in introductory chapters of this report). The output data file ("r1-1.p3b") contained a summary of the results of the Module 3 run appeared as follows:

BMP permutation key filer1-1.p3b
Created by control file r1-1.co3

Strategy Number	Total Cost ($)	TN Reduct. (ton/yr)	TP Reduct. (ton/yr)	TSS Reduct. (ton/yr)
1	0.00	0.000	0.000	0.000
5	57755.53	0.040	0.050	3.620
17	58138.33	0.080	0.050	8.620
21	115893.86	0.120	0.100	12.240
33	116276.66	0.160	0.100	17.240
37	174032.19	0.200	0.150	20.860
49	174414.99	0.240	0.150	25.860
513	121376.65	0.240	0.090	13.080
517	179132.18	0.280	0.140	16.700
529	179514.98	0.320	0.140	21.700
4097	48725.43	0.020	0.010	2.260
4113	106863.76	0.100	0.060	10.880
4129	165002.09	0.180	0.110	19.500
4609	170102.08	0.260	0.100	15.340
20481	49289.20	0.030	0.010	5.390
20497	107427.53	0.110	0.060	14.010
20513	165565.86	0.190	0.110	22.630
20993	170665.85	0.270	0.100	18.470
40961	98578.40	0.060	0.020	10.780
40977	156716.73	0.140	0.070	19.400

This results table listed costs and benefits by BMP's. For example, the second data line of this file indicates that:

- strategy number 5 if implemented would cost $57,755.53,
- would remove 0.04 tons of TN per year,
- would remove 0.05 tons of TP per year, and
- would remove 3.62 tons of TSS per year.

The first data record in the file is a "do nothing strategy" with zero costs and zero benefits. Following the definition of a Pareto optimal set, all of these 20 strategies are better than all of the other 511,080 strategies in cost, TN reduction, and TSS reduction. However, none of the 20 is clearly better than any other of the 20 in all three dimensions. Thus, from a strictly **objective** point of view these strategies cannot be further ranked. Casey is now faced with applying his professional judgement and other **subjective** information to decide on a final strategy. He decides to run Module 4 to assist in the final subjective selection of a strategy.

In addition to running Module 4, Casey also knew that he wanted to use his professional judgement to examine the details of each of the BMP strategies identified by the model. In order to look at these 20 strategies, Casey opened the more detailed output file "r1-1.p3a" with his word processing software. This file lists the individual BMP's that make up each of the 20 strategies in the Pareto optimal set. For example, the entry for strategy number 4609 appears as follows:

```
          Pareto-Optimal BMP Strategy Details
-------------------------------------------------------

   Strategy         Total         TN            TP             TSS
    Number           Cost        Reduct.       Reduct.        Reduct.
                     ($)        (ton/yr)      (ton/yr)       (ton/yr)
---------------- ------------ ----------- ------------- ----------------
     4609       170102.08        0.260         0.100         15.340

        BMP          BMP                      Quantity
        Name       Category    Subbasin    to Implement
     ----------  -----------  ---------   ------------
        CW            1           3            1
        TT            1           2            1
```

where,

- the total cost is $170,102.08 per year and total load reductions are given,
- the strategy calls for two BMP's to be built,
- 1 constructed wetland ("CW") in subbasin 3, and
- 1 treatment train BMP ("TT") in subbasin 2.

6-5 STEP 4: APPLYING MODULE 4 TO EVALUATE MANAGEMENT PRIORITIES, BUDGETS, AND LOAD REDUCTION TARGETS

Once a Pareto optimal set of 20 management strategies had been identified, Casey decided to use Module 4 to evaluate management priorities, budgets, and load reduction targets, and then use this information to select a final management strategy. He would require a data set of the Pareto optimal strategies, costs, and benefits ("r1-1.p3b"). The results of Module 4 would be output in the form of an ordered list of strategies sorted by a weighted benefit/cost ratio.

In this case, Casey knew that nitrogen load reduction was the most important objective of the Round Bay Watershed Management Plan. Thus this criteria would be given more weight in the final analysis.

Creating the Program Control File for Module 4:

The program control file for Module 4 was very similar to that used in the other modules. Casey copied an existing program control file for Module 4 and edited the contents using a word processing program. The completed file appeared as follows:

```
r1-1.co4        TBNEP Optimization Model,  Module 4 Control FILE

Round Bay Management Plan

The first 10 lines of this control file provide a free form space which users
may use to document the specifics of each run.




r1-1.o4                         - output data file                      line 11
r1-1.p3b                        - BMP strategies with costs/benefits    line 12
r1-1.p4                         - BMP strategies sorted by benefit/cost line 13

Choose the Weights to Use in Weighted Cost/Benefit Average
(a real number between 0 and 1, where 1 is given the most weight)
-------------------------------------------------------------------
1.0           Total Nitrogen Load Reduction
0.0           Total Phosphorous Reduction
0.0           TSS Load Reduction
```

The control file identified the input and output data files for this model run. The program log file was named "r1-1.o4", and the list of optimal strategies from Module 3 was named "r1-1.p3b." As was the case for Module 1, the program output file would be automatically named the same name as the program control file with an extension of "p4." Thus, the output file would be created by Module 4 as "r1-1.p4." Weights for benefits were entered at the bottom of the file.

Creating the Input Data Files for Module 4:

No new data input files needed to be created.

Running the Computer Program for Module 4:

Once he had completed making the program control file, Casey ran the computer program for Module 4 as follows:

At the DOS prompt of his personal computer, he ran Module 4 using program control file "r1-1.co4" by typing:

```
opt-4   r1-1.co4
```

The program had completed its run very quickly, and had produced two data files. These files were the program log file "r1-1.o4" and the table of the results "r1-1.p4." He opened both of these files with his word processing program to inspect the results.

The program log file ("r1-1.o4") appeared as follows:

```
                    Tampa Bay National Estuary Program
                BMP Allocation Strategy Optimization Model

                   Output from execution of r1-1.co4 control file


Control file header:
r1-1.co4       TBNEP Optimization Model,  Module 4 Control FILE

Round Bay Management Plan

The first 10 lines of this control file provide a free form space which users
may use to document the specifics of each run.

*** Model run using the following data files
    Program control file = r1-1.co4
    Program output file  = r1-1.p4
    Optimal strategy set = r1-1.p3b

    Weights used for Cost/Benefit
    ------------------------------
    TN Load Reduction    1.0000000000E+00
    TP Load Reduction    0.0000000000E+00
    TSS Load Reduction   0.0000000000E+00

*** Program Run Completed
```

He noted that the log file had confirmed the data input files and benefit weights, and that the run had been completed without any error messages.

Interpreting the Results from Module 4:

The results of Module 4 were to rank the Pareto optimal BMP strategies by a weighted benefit/cost ratio. In this case the benefit/cost ratio requested was merely TN reduction per dollar of cost. The output data file ("r1-1.p4") containing the results of the Module 4 run appeared as follows:

Sorted Optimal Solutions file r1-1.p4
Created by control file r1-1.co4

Strategy Number	Total Cost ($)	TN Reduct. (ton/yr)	TP Reduct. (ton/yr)	TSS Reduct. (ton/yr)	Weighted Benefit/Cost Ratio
513	121376.65	0.240	0.090	13.080	1.9773160653E-06
529	179514.98	0.320	0.140	21.700	1.7825810414E-06
20993	170665.85	0.270	0.100	18.470	1.5820388203E-06
517	179132.18	0.280	0.140	16.700	1.5630915674E-06
4609	170102.08	0.260	0.100	15.340	1.5284939490E-06
49	174414.99	0.240	0.150	25.860	1.3760285168E-06
17	58138.33	0.080	0.050	8.620	1.3760285168E-06
33	116276.66	0.160	0.100	17.240	1.3760285168E-06
37	174032.19	0.200	0.150	20.860	1.1492126830E-06
20513	165565.86	0.190	0.110	22.630	1.1475795795E-06
4129	165002.09	0.180	0.110	19.500	1.0908952729E-06
21	115893.86	0.120	0.100	12.240	1.0354301772E-06
20497	107427.53	0.110	0.060	14.010	1.0239460965E-06
4113	106863.76	0.100	0.060	10.880	9.3577092926E-07
40977	156716.73	0.140	0.070	19.400	8.9333155433E-07
5	57755.53	0.040	0.050	3.620	6.9257437340E-07
20481	49289.20	0.030	0.010	5.390	6.0865260544E-07
40961	98578.40	0.060	0.020	10.780	6.0865260544E-07
4097	48725.43	0.020	0.010	2.260	4.1046328375E-07

This results table indicates that strategy 513 is the best strategy in terms of TN load reduction per cost. Because it is in the Pareto optimal set, we also know that no other strategy of the 511,999 compared was better simultaneously in terms of cost and TN load reduction and TSS load reduction.

Casey wanted to review strategy 513, and he remembered that one of the program output files from the Module 3 program contained detailed descriptions of each strategy. He opened the more detailed output file "r1-1.p3a" with his word processing software.

The entry for strategy number 513 appeared as follows:

```
------------------------------------------------
 Strategy        Total        TN           TP            TSS
  Number          Cost       Reduct.      Reduct.       Reduct.
                  ($)       (ton/yr)     (ton/yr)      (ton/yr)
--------------- ------------ ---------- ------------ ----------------
    513       121376.65       0.240        0.090        13.080

        BMP        BMP                    Quantity
        Name     Category    Subbasin   to Implement
     ---------- ----------- ---------  -----------
         TT          1          2          1
```

where,

- the total cost is $121,376.65 per year,
- the total nitrogen load reduction is 0.24 tons per year,
- the total phosphorus load reduction is 0.90 tons per year,
- the total suspended solids load reduction is 13.08 tons per year, and
- the strategy calls for one treatment train BMP to be built in subbasin 2.

Casey was then instructed by the Chief Engineer to see what the Round Bay Watershed Management Plan could provide in order to meet the TN load reduction goal of 0.20 tons per year and to stay under a capital budget of $150,000 per year. He prepared a figure (Figure 6-1) which presented how he selected the final strategy in three steps. The final strategy was number 513, and it entailed constructing single treatment train facility in the Bent Branch subbasin (subbasin 2) at a cost of $121,376.00 per year. This facility would exceed the TN load reduction goal and provide Pareto optimal load reductions in TSS as well.

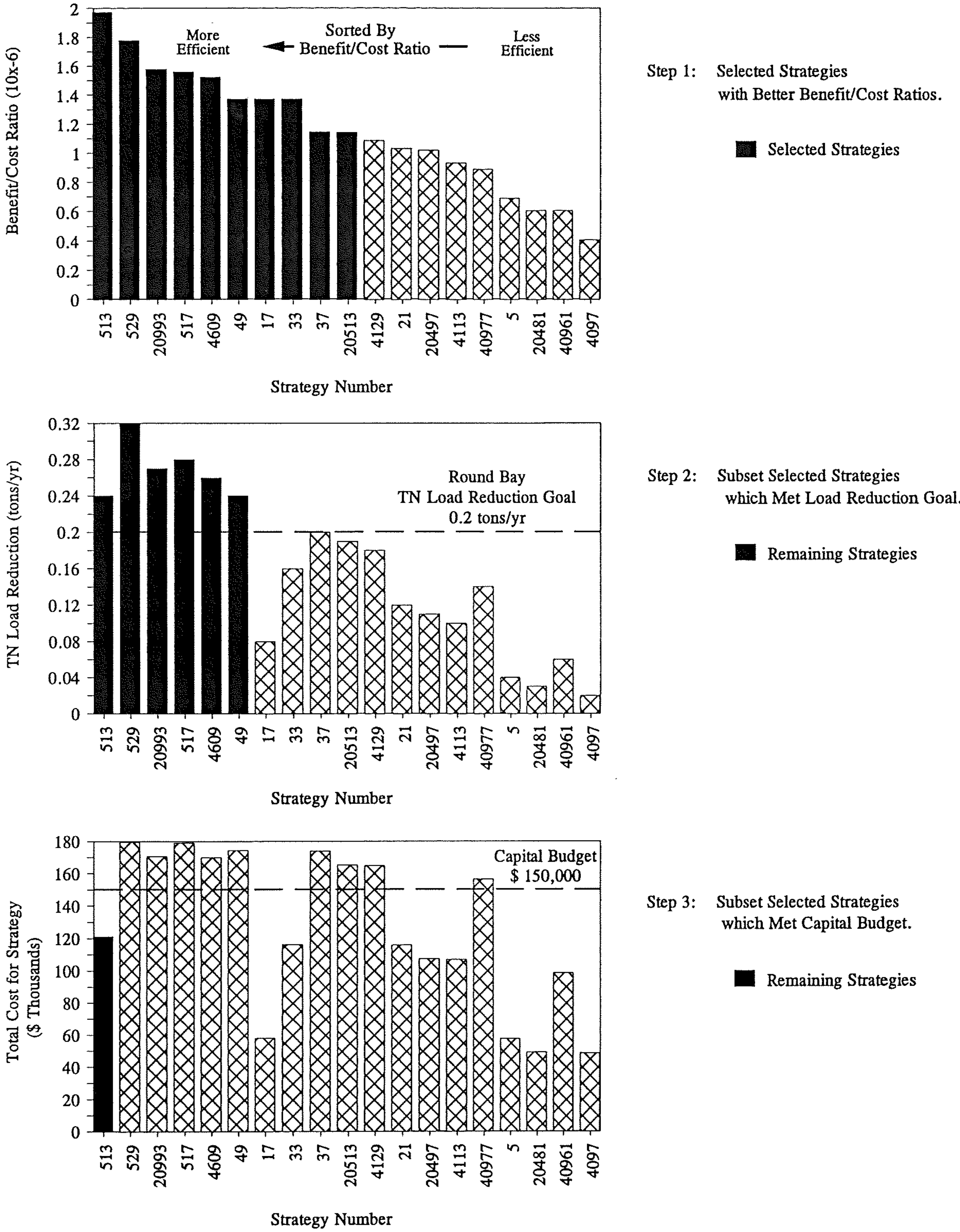

Figure 6-5 Three steps for selecting final management strategy for the Round Bay Watershed Plan.

6-6: FURTHER APPLICATION OF THE OPTIMIZATION MODEL

The flexible nature of the Optimization Model will allow analyses at many different level of detail. After choosing the strategy of building a treatment train BMP in the Bent Branch subbasin, Casey and the Chief engineer realized that the TBNEP Optimization Model could also be applied to the more specific design tasks needed for implementation of the plan. They would compile detailed information regarding the Bent Branch subbasin such as identifying specific parcels of land that could be purchased; surveying local topography, drainage, and wetland features. They would then use a hydrodynamic model and a water quality model to investigate a suite of alternative designs for the treatment train BMP. Using the more detailed data, Casey would again run Module 3 of the TBNEP programs. However, this time the model would be comparing the cost and benefits of specific design alternatives in terms of the project objectives.

7.0 LITERATURE CITED

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APPENDIX A

QUANTITATIVE BMP DATA COMPILED FOR THE TAMPA BAY REGION

Best Management Practices treatment efficencies, default data set for the TBNEP Optimization Model, expressed as percent pollutant removed.

BMP Type	Total Nitrogen			Total Phosphorus			Total Suspended Solids		
	min	mean	max	min	mean	max	min	mean	max
Extended Detention Pond	10	30	60	30	60	90	5	48	90
Wet Pond 1	10	30	60	30	60	90	30	60	90
Wet Pond 2	10	30	60	30	60	90	30	60	90
Constructed Wetland	0	25	40	10	35	65	ND	75	ND
Vegetated Swale	0	10	25	ND	15	30	ND	35	70
Vegetated Buffer Strip	0	35	70	0	45	90	20	50	80
Infiltration Basin 1	45	58	70	50	63	75	75	87	99
Infiltratin Basin 2	45	58	70	50	63	75	75	87	99
Exfiltration Trench	40	57	80	40	57	80	60	83	100

ND = no data

Best Management Practices cost data, default data set for the TBNEP Optimization Model. Land cost data from King Engineering, Inc., 1995.					
BMP TYPE	Land Use	BMP Life (years)	BMP Constr. Cost ($)	BMP O&M Cost ($)	Land Cost ($/acre)
Constructed Wetland	1	20	2800	75.00	365462.00
Constructed Wetland	2	20	2800	75.00	365462.00
Constructed Wetland	3	20	2800	75.00	398573.00
Constructed Wetland	4	20	2800	75.00	38950.00
Constructed Wetland	5	20	2800	75.00	376497.00
Constructed Wetland	6	20	2800	75.00	34723.00
Constructed Wetland	6	20	2800	75.00	34723.00
Constructed Wetland	7	20	2800	75.00	38950.00
Constructed Wetland	8	20	2800	75.00	34723.00
Constructed Wetland	9	20	2800	75.00	34723.00
Constructed Wetland	10	20	2800	75.00	34723.00
Constructed Wetland	11	20	2800	75.00	61929.00
Constructed Wetland	12	20	2800	75.00	61929.00
Constructed Wetland	13	20	2800	75.00	61929.00
Constructed Wetland	14	20	2800	75.00	61929.00
Extended Detention Pond	1	20	2000	50.00	365462.00
Extended Detention Pond	2	20	2000	50.00	365462.00
Extended Detention Pond	3	20	2000	50.00	398573.00
Extended Detention Pond	4	20	2000	50.00	38950.00
Extended Detention Pond	5	20	2000	50.00	376497.00
Extended Detention Pond	6	20	2000	50.00	34723.00
Extended Detention Pond	6	20	2000	50.00	34723.00
Extended Detention Pond	7	20	2000	50.00	38950.00
Extended Detention Pond	8	20	2000	50.00	34723.00
Extended Detention Pond	9	20	2000	50.00	34723.00
Extended Detention Pond	10	20	2000	50.00	34723.00
Extended Detention Pond	11	20	2000	50.00	61929.00
Extended Detention Pond	12	20	2000	50.00	61929.00
Extended Detention Pond	13	20	2000	50.00	61929.00
Extended Detention Pond	14	20	2000	50.00	61929.00
Infiltration Basin 1	1	5	2600	75.00	365462.00
Infiltration Basin 1	2	5	2600	75.00	365462.00
Infiltration Basin 1	3	5	2600	75.00	398573.00
Infiltration Basin 1	4	5	2600	75.00	38950.00
Infiltration Basin 1	5	5	2600	75.00	376497.00
Infiltration Basin 1	6	5	2600	75.00	34723.00

Best Management Practices cost data, default data set for the TBNEP Optimization Model. Land cost data from King Engineering, Inc., 1995.					
BMP TYPE	Land Use	BMP Life (years)	BMP Constr. Cost ($)	BMP O&M Cost ($)	Land Cost ($/acre)
Infiltration Basin 1	6	5	2600	75.00	34723.00
Infiltration Basin 1	7	5	2600	75.00	38950.00
Infiltration Basin 1	8	5	2600	75.00	34723.00
Infiltration Basin 1	9	5	2600	75.00	34723.00
Infiltration Basin 1	10	5	2600	75.00	34723.00
Infiltration Basin 1	11	5	2600	75.00	61929.00
Infiltration Basin 1	12	5	2600	75.00	61929.00
Infiltration Basin 1	13	5	2600	75.00	61929.00
Infiltration Basin 1	14	5	2600	75.00	61929.00
Infiltration Basin 2	1	5	2600	75.00	365462.00
Infiltration Basin 2	2	5	2600	75.00	365462.00
Infiltration Basin 2	3	5	2600	75.00	398573.00
Infiltration Basin 2	4	5	2600	75.00	38950.00
Infiltration Basin 2	5	5	2600	75.00	376497.00
Infiltration Basin 2	6	5	2600	75.00	34723.00
Infiltration Basin 2	6	5	2600	75.00	34723.00
Infiltration Basin 2	7	5	2600	75.00	38950.00
Infiltration Basin 2	8	5	2600	75.00	34723.00
Infiltration Basin 2	9	5	2600	75.00	34723.00
Infiltration Basin 2	10	5	2600	75.00	34723.00
Infiltration Basin 2	11	5	2600	75.00	61929.00
Infiltration Basin 2	12	5	2600	75.00	61929.00
Infiltration Basin 2	13	5	2600	75.00	61929.00
Infiltration Basin 2	14	5	2600	75.00	61929.00
Exfiltration Trench	1	5	3500	75.00	365462.00
Exfiltration Trench	2	5	3500	75.00	365462.00
Exfiltration Trench	3	5	3500	75.00	398573.00
Exfiltration Trench	4	5	3500	75.00	38950.00
Exfiltration Trench	5	5	3500	75.00	376497.00
Exfiltration Trench	6	5	3500	75.00	34723.00
Exfiltration Trench	6	5	3500	75.00	34723.00
Exfiltration Trench	7	5	3500	75.00	38950.00
Exfiltration Trench	8	5	3500	75.00	34723.00
Exfiltration Trench	9	5	3500	75.00	34723.00
Exfiltration Trench	10	5	3500	75.00	34723.00
Exfiltration Trench	11	5	3500	75.00	61929.00
Exfiltration Trench	12	5	3500	75.00	61929.00

Best Management Practices cost data, default data set for the TBNEP Optimization Model. Land cost data from King Engineering, Inc., 1995.					
BMP TYPE	Land Use	BMP Life (years)	BMP Constr. Cost ($)	BMP O&M Cost ($)	Land Cost ($/acre)
Exfiltration Trench	13	5	3500	75.00	61929.00
Exfiltration Trench	14	5	3500	75.00	61929.00
Vegetated Buffer Strip	1	20	1700	50.00	365462.00
Vegetated Buffer Strip	2	20	1700	50.00	365462.00
Vegetated Buffer Strip	3	20	1700	50.00	398573.00
Vegetated Buffer Strip	4	20	1700	50.00	38950.00
Vegetated Buffer Strip	5	20	1700	50.00	376497.00
Vegetated Buffer Strip	6	20	1700	50.00	34723.00
Vegetated Buffer Strip	6	20	1700	50.00	34723.00
Vegetated Buffer Strip	7	20	1700	50.00	38950.00
Vegetated Buffer Strip	8	20	1700	50.00	34723.00
Vegetated Buffer Strip	9	20	1700	50.00	34723.00
Vegetated Buffer Strip	10	20	1700	50.00	34723.00
Vegetated Buffer Strip	11	20	1700	50.00	61929.00
Vegetated Buffer Strip	12	20	1700	50.00	61929.00
Vegetated Buffer Strip	13	20	1700	50.00	61929.00
Vegetated Buffer Strip	14	20	1700	50.00	61929.00
Vegetated Swale	1	20	2300	50.00	365462.00
Vegetated Swale	2	20	2300	50.00	365462.00
Vegetated Swale	3	20	2300	50.00	398573.00
Vegetated Swale	4	20	2300	50.00	38950.00
Vegetated Swale	5	20	2300	50.00	376497.00
Vegetated Swale	6	20	2300	50.00	34723.00
Vegetated Swale	6	20	2300	50.00	34723.00
Vegetated Swale	7	20	2300	50.00	38950.00
Vegetated Swale	8	20	2300	50.00	34723.00
Vegetated Swale	9	20	2300	50.00	34723.00
Vegetated Swale	10	20	2300	50.00	34723.00
Vegetated Swale	11	20	2300	50.00	61929.00
Vegetated Swale	12	20	2300	50.00	61929.00
Vegetated Swale	13	20	2300	50.00	61929.00
Vegetated Swale	14	20	2300	50.00	61929.00
Wet Pond 1	1	20	2600	65.00	365462.00
Wet Pond 1	2	20	2600	65.00	365462.00
Wet Pond 1	3	20	2600	65.00	398573.00
Wet Pond 1	4	20	2600	65.00	38950.00
Wet Pond 1	5	20	2600	65.00	376497.00

Best Management Practices cost data, default data set for the TBNEP Optimization Model. Land cost data from King Engineering, Inc., 1995.					
BMP TYPE	Land Use	BMP Life (years)	BMP Constr. Cost ($)	BMP O&M Cost ($)	Land Cost ($/acre)
Wet Pond 1	6	20	2600	65.00	34723.00
Wet Pond 1	6	20	2600	65.00	34723.00
Wet Pond 1	7	20	2600	65.00	38950.00
Wet Pond 1	8	20	2600	65.00	34723.00
Wet Pond 1	9	20	2600	65.00	34723.00
Wet Pond 1	10	20	2600	65.00	34723.00
Wet Pond 1	11	20	2600	65.00	61929.00
Wet Pond 1	12	20	2600	65.00	61929.00
Wet Pond 1	13	20	2600	65.00	61929.00
Wet Pond 1	14	20	2600	65.00	61929.00
Wet Pond 2	1	20	2600	65.00	365462.00
Wet Pond 2	2	20	2600	65.00	365462.00
Wet Pond 2	3	20	2600	65.00	398573.00
Wet Pond 2	4	20	2600	65.00	38950.00
Wet Pond 2	5	20	2600	65.00	376497.00
Wet Pond 2	6	20	2600	65.00	34723.00
Wet Pond 2	6	20	2600	65.00	34723.00
Wet Pond 2	7	20	2600	65.00	38950.00
Wet Pond 2	8	20	2600	65.00	34723.00
Wet Pond 2	9	20	2600	65.00	34723.00
Wet Pond 2	10	20	2600	65.00	34723.00
Wet Pond 2	11	20	2600	65.00	61929.00
Wet Pond 2	12	20	2600	65.00	61929.00
Wet Pond 2	13	20	2600	65.00	61929.00
Wet Pond 2	14	20	2600	65.00	61929.00

Physical constraints to Best Management Practice use, default data set for the TBNEP Optimization Model.										
				Soil Infiltration		Depth to Water Table		Land Slope		Min or Max
BMP Type	Land Use	Treatment Area (ac)	BMP Area (ac)	Min. (in/hr)	Max. (in/hr)	Min. (ft)	Max. (ft)	Min. (%)	Max. (%)	Treament Area
Extended Detention Pond	1	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	1	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	1	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	1	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	1	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	1	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	1	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	1	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	1	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	2	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	2	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	2	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	2	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	2	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	2	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	2	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	2	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	2	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	3	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	3	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	3	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	3	50	2	0.02	8.27	0	NA	ND	ND	min

Physical constraints to Best Management Practice use, default data set for the TBNEP Optimization Model.

BMP Type	Land Use	Treatment Area (ac)	BMP Area (ac)	Soil Infiltration		Depth to Water Table		Land Slope		Min or Max Treament Area
				Min. (in/hr)	Max. (in/hr)	Min. (ft)	Max. (ft)	Min. (%)	Max. (%)	
Vegetated Swale	3	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	3	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	3	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	3	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	3	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	4	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	4	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	4	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	4	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	4	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	4	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	4	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	4	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	4	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	5	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	5	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	5	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	5	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	5	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	5	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	5	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	5	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	5	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	6	100	5	0.05	8.27	2	NA	3	18	min

Physical constraints to Best Management Practice use, default data set for the TBNEP Optimization Model.

BMP Type	Land Use	Treatment Area (ac)	BMP Area (ac)	Soil Infiltration		Depth to Water Table		Land Slope		Min or Max Treament Area
				Min. (in/hr)	Max. (in/hr)	Min. (ft)	Max. (ft)	Min. (%)	Max. (%)	
Wet Pond 1	6	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	6	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	6	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	6	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	6	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	6	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	6	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	6	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	7	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	7	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	7	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	7	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	7	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	7	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	7	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	7	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	7	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	8	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	8	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	8	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	8	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	8	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	8	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	8	20	10	0.52	8.27	3	NA	0	5	min

Physical constraints to Best Management Practice use, default data set for the TBNEP Optimization Model.

BMP Type	Land Use	Treatment Area (ac)	BMP Area (ac)	Soil Infiltration Min. (in/hr)	Soil Infiltration Max. (in/hr)	Depth to Water Table Min. (ft)	Depth to Water Table Max. (ft)	Land Slope Min. (%)	Land Slope Max. (%)	Min or Max Treament Area
Infiltration Basin 2	8	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	8	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	9	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	9	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	9	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	9	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	9	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	9	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	9	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	9	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	9	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	10	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	10	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	10	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	10	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	10	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	10	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	10	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	10	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	10	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	11	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	11	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	11	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	11	50	2	0.02	8.27	0	NA	ND	ND	min

Physical constraints to Best Management Practice use, default data set for the TBNEP Optimization Model.

BMP Type	Land Use	Treatment Area (ac)	BMP Area (ac)	Soil Infiltration		Depth to Water Table		Land Slope		Min or Max Treament Area
				Min. (in/hr)	Max. (in/hr)	Min. (ft)	Max. (ft)	Min. (%)	Max. (%)	
Vegetated Swale	11	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	11	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	11	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	11	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	11	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	12	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	12	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	12	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	12	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	12	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	12	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	12	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	12	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	12	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	13	100	5	0.05	8.27	2	NA	3	18	min
Wet Pond 1	13	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	13	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	13	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	13	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	13	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	13	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	13	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	13	50	0.2	0.52	8.27	3	NA	ND	5	NA
Extended Detention Pond	14	100	5	0.05	8.27	2	NA	3	18	min

Physical constraints to Best Management Practice use, default data set for the TBNEP Optimization Model.

BMP Type	Land Use	Treatment Area (ac)	BMP Area (ac)	Soil Infiltration		Depth to Water Table		Land Slope		Min or Max Treament Area
				Min. (in/hr)	Max. (in/hr)	Min. (ft)	Max. (ft)	Min. (%)	Max. (%)	
Wet Pond 1	14	100	2	0.02	8.27	2	NA	3	18	min
Wet Pond 2	14	640	13	0.02	8.27	2	NA	3	18	max
Constructed Wetland	14	50	2	0.02	8.27	0	NA	ND	ND	min
Vegetated Swale	14	50	10	0.06	8.27	2	NA	0	5	max
Vegetated Buffer Strip	14	50	10	0.09	8.27	3	NA	0	5	max
Infiltration Basin 1	14	20	10	0.52	8.27	3	NA	0	5	min
Infiltration Basin 2	14	150	10	0.52	8.27	3	NA	0	5	max
Exfiltration Trench	14	50	0.2	0.52	8.27	3	NA	ND	5	NA

ND = no data NA = not applicable

APPENDIX B

STORMWATER BEST MANAGEMENT PRACTICES IN THE TAMPA BAY AND CENTRAL FLORIDA REGIONS

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December 17, 1996

FOREWORD

This appenidx was completed under contract number T-94-06 Optimization Model for Best Management Practices for the Tampa Bay National Estuary Program.

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1.0 Introduction

Stormwater runoff is a potentially significant source of nutrients, i.e., nitrogen and phosphorus, as well as other pollutants, for many coastal systems. For example, stormwater runoff accounts for approximately 50% of the loadings of total nitrogen to Tampa Bay on an annual basis (Zarbock et al. 1994). Excessive inputs of nitrogen have resulted in acceleration of the eutrophication process. Management of coastal resources has in many ways focused on the problems associated with eutrophication: high algal biomass, low dissolved oxygen, increased light attenuation, etc. Ultimately, effective management of the eutrophication process depends on recognizing the sources of the nutrients in stormwater runoff and identifying methods, i.e., best management practices (BMPs), that can be employed to reduce nutrient inputs via runoff.

This technical appendix, *Stormwater Best Management Practices*, is a compilation of information obtained by an review of available peer-reviewed and grey literature sources and a series of interviews with permitting agency staff, developers, researchers, and local design engineers. The focus of the review and interviews was urban runoff. In particular, information was obtained on BMPs that are most applicable in the Tampa Bay and central Florida regions. As discussed below, information on costs, operations & maintenance, design criteria, pollutant removal efficiency, etc. were obtained for a wide variety of urban BMPs. These data will assist local planners and developers in selecting BMPs that will have the best potential for meeting State Water Policy standards, which mandate that new stormwater management systems shall be designed to achieve at least 80% reduction of the average annual load of pollutants that would cause or contribute to violations of state water quality standards, and at least 95% reduction on the average annual load of pollutants that would cause or contribute to violations of state water quality standards in Outstanding Florida Waters (Chapter 62-40.432, F.A.C.).

The data base that has been assembled also provided much of the information necessary to exercise the Tampa Bay National Estuary Program (TBNEP) BMP Optimization Model (Wade and Janicki, 1995), as presented in Appendices 1, 2, and 3. The Optimization Model was developed for the TBNEP to assist local governments in making decisions about what BMPs are most applicable and efficient in managing nutrient inputs via stormwater runoff from urbanized areas. Beyond supporting the BMP Optimization Model, this document can be used as a general reference to both urban and agricultural runoff BMPs.

It should be noted that effective management of nutrient inputs via stormwater runoff must also include nonstructural, pollution prevention BMPs such as sound site planning and design features that avoid or minimize impacts early in the urbanization process. An excellent example is the Florida Yards and Neighborhoods Program which can help to reduce the generation of stormwater pollutants, especially nutrients and pesticides, from residential yards and commercial landscaping. Stormwater runoff-related impacts typically result from reduction in the ability of an area to infiltrate or otherwise attenuate stormwater inputs. Thus, plans that minimize disruption of the basic hydrology of the area to be developed are clearly desirable. Local government land use planning ordinances should minimize imperviousness and require the evaluation of such options as can be used to address the issues associated with stormwater runoff.

In addition to information on urban BMPs, we have also assembled pertinent information on agricultural BMPs for the Tampa Bay and central Florida regions. Interviews with local agricultural extension service staff and literature searches were completed to identify and obtain this information.

2.0 Urban BMPs

Most activities that occur in conjunction with the construction, operation, and use of urban land have the potential for introducing pollutants to surface water through stormwater runoff. Construction activities, operation of motor vehicles, landscape maintenance, and industrial activities all have the potential to increase pollutant loadings from runoff. In addition, rainfall falling on buildings, roads and parking lots, and other impervious surfaces often produces in runoff that carries some polluting substance to a receiving water body.

A wide variety of BMPs is available to control stormwater quantity and quality impacts to the environment. BMPs may be based on facilities such as ponds, storm drains, or other constructed facilities. These BMPs are typically classified as structural BMPs. BMPs also include management practices that do not depend on built structures. These BMPs are typically classified as non-structural BMPs. Non-structural BMPs involve activities such as public education regarding appropriate use of landscape chemicals, development standards that preserve natural vegetation, or the use of alternative biological pest controls in place of chemical pesticides.

The following descriptions of the urban BMPs are based on the reviews of many documents. The primary references include USEPA (1993), Schueler et al. (1992), Livingston et al. (1993), NVPDC (1980), Schueler (1987), Dillaha et el. (1987), Lowrance et al. (1985), Natter and Gaskin (1989), and USDA-Soil Conservation Service (now the Natural Resources Conservation Service) (1988). These descriptions provide a basic framework for understanding other BMPs which are typically variants of the categories listed below.

In addition to the literature reviews we contacted and interviewed a number of people closely involved with the stormwater issues. Table 1.2 presents a list of those people. The questions asked in these interviews focused on their recent experiences in the application of BMPs.

Telephone interviews were conducted to obtain information regarding the frequency of use in Florida, and the reasons for use, of different urban stormwater BMPs. A cross-section of regulators (permitting and enforcement), developers (homebuilders and site development engineers), and researchers (academic and government agency) were called to record experiences and professional opinions of individuals with experience in the design, permitting, construction, monitoring, and maintenance of BMPs. A series of questions regarding BMP practices was asked of the contacted individuals. The text below summarizes responses that were received. The following Table 1.2 lists all those who were contacted to discuss BMPs.

<u>1) What stormwater BMPs are most commonly used in your project/permit applications?</u>

By far the most common urban stormwater quantity and quality BMPs used or permitted by those contacted were on-site depressional facilities such as ponds or low-lying open spaces. Common design alternatives included wet detention, percolation ponds, and sand filtration. Other alternatives were generally used only under special circumstances (little available land, physical site constraints, etc.). The decision to use wet or dry ponds appears frequently to be driven by site constraints. If a site has good infiltration features, dry ponds are used. If a high water table exists or soils have a low percolation capacity, wet ponds are more common.

In cases where the less common BMP alternatives were used, they often appear in series, as a "treatment train" (e.g., swale with filter inlet discharging to an exfiltration trench). This may be necessitated by the generally lower capacity of many alternative BMPs. Regulators perceived a preference of applicants for wet detention ponds for residential development, and dry detention, swales, and exfiltration for commercial. This was thought to be a function of lower land availability (or higher land cost/square foot) on commercial sites.

Table 1.2 Individuals contacted for interviews for urban stormwater BMPs.	
Richard Alt	SWFWMD MSSW Engineer
William Copeland	SWFWMD MSSW Biologist
Alba Evans	SWFWMD MSSW Enforcement
Betty Rushton	SWFWMD Resource Projects
Hank Higgenbotham	SWFWMD Resource Permits Technical Staff
Betty Barton	USEPA Region IV Nonpoint Source
Jeannie McNeill	USEPA Region IV Stormwater NPDES
Eric Livingston	FDEP Surface Water
Martin Wanielista	University of Central Florida
Carlos DeRojas	SFWMD MSSW permitting
Jeff Needles	SWFWMD - IRLNEP research
Allen Baggett	SJRWMD MSSW Engineer
J.P. Marchon	Sarasota County Stormwater Utility
Paul Dewey	Pinellas County Stormwater Permitting
Elie Araj	Hillsborough County Engineering Services
Lynn Johnson	City of Orlando Street and Drainage Dept.
Michael Burwell	City of Tampa Stormwater Planner
William Chamberlin	City of Orlando Stormwater Utility
Rod Lynn	Orange County Stormwater Management
Jeff Spence	Polk County Water Resources
Curtis Watkins	City of Tallahassee Stormwater Management
Matt Forbes	Disney Development Corporation
Mahmound Elsabaugh	Reedy Creek Improvement District
William Walwick	Sarasota County Homebuilders
Rodney Fischer	Pinellas County Homebuilders
Brenda Kunkel	Hillsborough County Homebuilders
Keith Tracey	Florida Association of Homebuilders
Richard Harris	Cumbey & Fair Engineers
Tyler Johnson	Westchase Development

2) Which are the most difficult/easiest to construct?

Applicants and regulators agree that the more common BMPs (wet and dry ponds) are easiest to construct. Both the logistical aspects of construction, cost, the need to remain in conformance with permit design criteria, and the ability to meet performance standards, are factors that affect construction degree of difficulty. Swales were intermediate in construction difficulty. BMPs that were said to be hardest to construct include sand filters, exfiltration trenches, and porous pavement, mainly because the specifications for proper construction are more demanding than those for ponds, and because the site conditions that necessitated the alternative BMP use are often unfavorable for standard construction techniques.

3) Which are the most difficult/easiest to permit? Are any mandatory?

Obtaining permits (regulatory acceptance) was said to be easiest for wet and dry ponds. No BMP type is mandatory, but site constraints often dictate that one of a few alternatives be selected. Many BMPs alternatives were perceived to be harder to permit, but were most easily permittable under special conditions. The relative difference in permitting ease is based on such factors as regulatory familiarity, existence of feasible design standards and achievable performance standards, past performance, and the relative need for enforcement actions of previously permitted projects.

4) What are typical construction costs per acre or per acre of drainage area?

Construction costs for BMPs vary greatly, depending on the BMP type and land cost. Land cost is often the single greatest expense in BMP development. Wet or dry detention ponds with no enhancements (underdrains, special inlets, exfiltration system, etc. typically cost \$25,000 to \$35,000 per acre of pond, depending on the site characteristics. Constructed wetlands are somewhat more expensive on a per-acre basis. Water quality inlets can cost between \$5000 to \$8000 each, infiltration trenches may cost approximately \$7000 to \$8000 per acre of area treated, while seeding and mulching totals approximately \$1000 to \$2000/acre. Within the region, costs were relatively similar for the same BMPs.

5) What are typical Operating&Maintenance (O&M) costs?

O&M for a stormwater facility may include a wide range of activities, including landscaping, inspection and upkeep of control structures, cleaning inlets and outlets, sediment removal, repairing erosion, etc. Annual O&M costs were found to vary from 2-5% of construction costs for most types of ponds (lower for dry ponds, higher for wet ponds), to 5-10% of construction costs for the more maintenance-intensive BMPs such as exfiltration systems or porous pavement.

6) Is an O&M manual needed for maintenance crews?

In many cases no O&M manual is supplied. However, the District does have a checklist of recommended maintenance procedures, and some site development engineers routinely provide maintenance manuals for drainage facilities, particularly for commercial sites. Also, the District requires a periodic report (signed and sealed by the Engineer of Record) for permitted facilities that attest to the continued maintenance and proper functioning of stormwater ponds and other BMPs.

7) What BMPs do you anticipate using/would you rather use in the future?

Those interviewed did not foresee any drastic changes in BMP selection in the immediate future. Wet and dry detention ponds, infiltration basins, swales, and other now-common BMPs were seen as most likely to be used in the future.

2.1 Structural BMPs

As stated above, structural BMPs can include any management practice that is based on a constructed facility, including ponds, swales, control structures, pipes, etc. These BMP alternatives may utilize a variety of processes, including "end of pipe" treatment, overland flow routing, physical or chemical treatment, recycling, wetland systems with biological treatment, or infiltration.

Structural BMPs can be very versatile. They may be planned and designed as an integral part of the site development process, or they may be added after development has occurred, which typically is referred to as a retrofit application. Although the most flexibility in BMP selection occurs during the site planning and design stage, many BMPs are feasible for use in a retrofit situation. These often include alternatives with minimal land requirements, such as underground vaults, water quality inlets, or swales.

BMPs may be used individually, or in series. Using sequential BMPs (for example, a grassed swale discharging through a structure with a skimmer to a detention pond with underdrains) increases the net treatment effectiveness and usually results in a higher percent removal of pollutants from the stormwater. The practice of combining several BMPs in series is often called a "treatment train."

Structural BMPs may also be classified as "on-line" or "off-line." The entire flow of stormwater is channeled through an on-line BMP, while an off-line BMP receives only a fraction of the total flow. Off-line BMPs can be designed to capture the first volume of stormwater (the "first flush"), which often carries proportionally higher pollutant loads than the later flows.

The following introduces some of the more common categories of structural BMPs. Because many BMPs serve multiple purposes, their categorization is mainly a matter of convenience, and distinct separations in function are often not identifiable. Therefore, a BMP may be appropriate to list in more than one category.

- Runoff Control Practices

  Runoff control practices are designed to manage stormwater runoff in a manner that minimizes its negative impacts on the environment. This may be accomplished by the use of diversion berms, swales, overall site grading, detention or retention storage of stormwater, biological treatment, or infiltration.

- Erosion Control Practices

  Erosion control practices are intended specifically to minimize soil loss and erosion from a site, which serves two purposes. By reducing erosion physical damage to property, such as a construction site with exposed soil, is reduced. Also, erosion results in soil particles becoming entrained in runoff. This pollutant load of suspended solid material can cause environmental damage by covering desirable benthic habitats, smothering aquatic vegetation, or by carrying other pollutants such as metals or organic compounds that have become attached to the soil particles.

  Erosion control can be accomplished by structurally oriented means such as site grading (terracing and contouring), use of runoff control methods described above to contain runoff on-site, or by the stabilization of exposed soil using rip rap or gravel. Vegetation can also be used to stabilize soil areas through the use of vegetated buffers, grass, mulch, ground covers, preservation of trees, etc.

2.2 Nonstructural BMPs

Nonstructural stormwater BMPs are as diverse as structural options. Numerous alternatives for managing stormwater are available that do not depend on physical structures. As with structural BMPs, nonstructural BMPs may be included in more than one category. In addition, the issue of public education could be a separate class of nonstructural BMPs, but is really a factor in each of the listed categories. The following general categories include many of the nonstructural alternatives that are discussed separately below.

- Good Housekeeping

Good housekeeping includes general maintenance and policing activities that reduce the amount of debris, litter, and garbage available for contact with stormwater. If implemented on a wide scale, these activities can be very effective, as well as relatively inexpensive. Examples of good housekeeping include general surface sanitation - anti-litter measures, streetsweeping (wet or dry, with vacuum or brush), cleaning drainage inlets of debris, controlling air pollution from both mobile and stationary sources, cleaning debris from constructions sites daily, and good solid waste collection and disposal methods. Good housekeeping is a BMP that can be implemented by governmental agencies and/or commercial entities (construction companies, private citizens, public interest groups, etc.). Good housekeeping efforts can often be enhanced through public education and changing old habits regarding waste disposal and treatment of the land. Adopt-a-Road and Adopt-a-Pond programs are examples of good housekeeping projects that can ameliorate stormwater pollutant loading.

- Source Control

Source control is a broad category of BMP activities that addresses stormwater pollution at the true source of pollutant inputs. Traditional BMPs act to reduce the pollutant load after runoff has become contaminated. Source controls attempt to reduce the initial distribution of pollutants to the environment. Source control practices can apply to changing the rate of fertilizer application or using natural fertilizer and pesticide products; storage, use and release of industrial chemicals; etc. As with structural BMPs, there is a certain degree of overlap in the categorization of nonstructural BMPs. For example, one important aspect of source control is good housekeeping.

Another important aspect of source control is to ensure that users of chemicals and any material that could contaminate runoff know the proper application rates, methods, and timing for their uses. This can be accomplished through packaging, public interest groups, private interest groups, local government programs (i.e., Extension Service), etc.

2.3 Potential Criteria for Use in the Selection of Effective Urban BMPs

The purpose of BMPs is to reduce pollution loads and, in some cases, peak runoff. Two main criteria for establishing the effectiveness of BMPs are, therefore, the effectiveness of pollutant removal and peak flow reduction. There are specific pollutants of interest in stormwater and these pollutants are treated with different degrees of effectiveness.

The primary nutrients that generally control phytoplankton growth are nitrogen and phosphorous. Previous research has shown Tampa Bay to be nitrogen-limited. Therefore, nitrogen control is of primary importance. However, since phosphorus is the other primary nutrient, phosphorus control is also important. Total suspended solids and the associated trace metal (cadmium, lead, chromium, etc.), organic (PCBs, polyaromatic hydrocarbons (PAHs)), and biological (bacteria, viruses) pollutants also can significantly impact Tampa Bay biota. Consequently, the stormwater pollutants of interest have been identified as total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS).

To compare the effectiveness of specific BMPs, the degree of pollutant removal is typically rated in terms of "efficiencies". For example, a 90% nitrogen removal efficiency means that the BMP reduces the nitrogen concentration of water leaving the BMP by 90%, relative to the concentration of stormwater flowing into the system. Based on the above, the effectiveness of BMPs for the Tampa Bay watershed can be established as the efficiencies of removing nitrogen, phosphorus, and total suspended solids from stormwater. There is, however, other critical information that is important in comparing the effectiveness of BMPs. Included are area treated, design storm peak discharge control, depth to water table, site slope, construction and O&M cost, land use, soil characteristics, amount of land used, life span, and other constraints such as adverse social impacts. The criteria can be grouped into four categories: benefits, costs, constraints, and potential advantages/ disadvantages.

BENEFITS

Total Nitrogen Removal Efficiency	The proportion of the total nitrogen (TN) load entering a BMP that is removed by that BMP.
Total Phosphorus Removal Efficiency	The proportion of the total phosphorus (TP) load entering a BMP that is removed by that BMP.
Total Suspended Solids Removal Efficiency	The proportion of the total suspended solids (TSS) load entering a BMP that is removed by that BMP.
Peak Discharge Control	The ability of the BMP to attenuate maximum stormwater runoff rates for specific return period storms.

COSTS

Construction Cost	A major criterion affecting the selection and implementation of specific BMPs. Construction cost is often expressed as a unit cost (e.g., \$/pound of TN removed).
Operation & Maintenance Cost	A potentially major criterion affecting the selection and implementation of specific BMPs, such as infiltration trenches and water quality inlets. O&M cost is often expressed as an annual cost (\$/year).
Amount of Land Used	This will determine the cost of the land and consequently the cost of the BMP implementation.
Life Span	The life span is also related to the overall cost. Projects with long life spans are usually more economically beneficial than those with short life spans.

CONSTRAINTS

Area Treated	The area of the watershed that provides stormwater inflow to the BMP. It is assumed that the channel(s) convey all water generated on the watershed to the stormwater treatment system.
Depth to Water Table	An indicator of the depth of soil available for infiltration systems. It also provides information for designing wet detention systems.
Slope	Slope is an important constraint for construction purposes as it may limit the type of BMP that may be constructed.
Soil Characteristics	Important factors for BMP construction. Each BMP requires specific soil characteristics for efficient operation of the BMP.
Land Use Type	A major constraint for the implementation of specific BMPs since some BMPs are not universally applicable to all land use and land cover types.
Peak Discharge	The maximum stormwater runoff flow rate during a rainfall event is often a limiting factor in the design of a BMP.

ADVANTAGES/DISADVANTAGES

Adverse Environmental Impacts	Potential adverse impacts such as groundwater contamination by infiltration trenches and loss of upstream habitat by wet pond construction.
Adverse Social Impacts	Potential adverse impacts such as loss of property or aesthetic value, potential nuisance conditions such as mosquito breeding.
Augmentation of Groundwater Recharge	The increase in infiltration of stormwater into the groundwater table.
Waterfowl, Fish, and Wildlife Habitat	The added benefit afforded by some BMPs by providing new and often valuable habitat.

The following is a presentation of the more commonly used BMPs, with summaries of relative feasibility in terms of permitting, construction cost, maintenance requirements, and effectiveness. Many less widely used, but none the less significant BMPs, are also summarized. The information presented below is intended to assist in the process of selecting stormwater BMPs that would be feasible under specific circumstances. Location, land use, land cost, required treatment levels, and other factors may mandate the use of certain BMPs and make the use of others infeasible. Each BMP is described below under the following sub-headings

Description and Function: This section describes the form and function of the BMP. The overall feasibility, purpose, and operating principal of the BMP is explained in this section.

Design Guidelines: This section lists specific design criteria and considerations for the effective operation of the BMP. For example, travel time through a swale or pond, or area to depth ratios are discussed.

Related facilities. Similar facilities, or BMPs that work well in concert with the subject BMP are listed in this section.

Regulatory Considerations: Ease of permitting, frequency of use, and acceptability to regulators is discussed in this section.

Overall Advantages and Disadvantages: The overall feasibility, the BMP's major strong points and weaknesses are listed in this section.

Site Constraints: Land requirements for the effective functioning of the BMP, in terms of site size, maximum feasible size, site slope, soil infiltration rates, and water table depth are listed in this section.

Operational Efficiencies: Ranges of TN, TP, and TSS removal as documented in the literature are given in this section.

O&M Requirements: Types and frequencies of O&M activities are listed in this section.

Cost: Ranges of construction, and O&M costs are given, either on a unit cost, total cost, or annual cost basis.

EXTENDED DRY DETENTION BASIN

Description and Function:

Extended detention dry basins are impoundments in which stormwater runoff is temporarily stored until it gradually leaves the basin through an outflow control structure. The control structure is designed to allow a gradual bleed-down of the collected surface water to receiving waters. This produces the benefits of attenuated peak flood flow rates and reduced risk of downstream flooding caused by development. Some reduction in surface flows may also occur through infiltration, evaporation, and transpiration, although these are not the primary mechanisms of release from the impoundment. As a result, peak flood flow rates are kept low through the use of detention basins, but the overall flood volume is virtually unchanged. Extended detention dry ponds are, as the name implies, to be designed so that no standing water remains in the basin after the bleed-down period.

Water quality benefits are also realized primarily through settling, or sedimentation, of particulate matter that may contain metals and organic contaminants, especially larger, heavier particles. Treatment is also afforded, though to a lesser degree, through the biological cycling of nutrients. In addition, runoff that infiltrates to the surficial aquifer receives water quality treatment through bacterial action and straining through the soil particles. Dry basins can also be incorporated into multi-use facilities, and serve as playgrounds, parks, recreation areas, or upland habitat during dry periods.

Dry detention basins are used most effectively in areas with a moderately deep water table (several feet below the bottom of the basin). Although it is not necessary to obtain significant infiltration rates at a dry detention basin site, the basin bottom should remain unsaturated when not holding stormwater, so as to maintain aerobic bacteria. Also contributing to the effective functioning of dry detention basins is a design that allows sufficient retention time to allow settling of particulate material and some biological uptake. Dry detention basins are not commonly permitted for stormwater treatment in west-central Florida. They have been shown to frequently not meet water quality treatment standards established by the Florida State Water Policy, and require frequent maintenance to remove accumulated sediment to prevent resuspension and discharge. The South Florida Water Management District (SFWMD) does permit the use of these BMPs, and the St. Johns River Water Management District (SJRWMD) considers extended dry detention basins to be an experimental BMP for use only on small sites with very specific design criteria.

Design Guidelines:

Performance generally benefits from design features to prevent short circuiting, e.g.: two or more distinct cells to promote plug flow; preferred effective length-to-width ratio 5:1, minimally 2:1; inlet and outlet either located far apart or shielded by baffling; low inlet velocity; uniform flow distribution across the inlet pond; and discharge of water with minimum turbulence from mid-depth via bleed-down from the outlet structure, located at the lowest part of the site. The removal capabilities of plants may be incorporated by managing part of the basin as a shallow wetland. Side slopes should be grassed. Side slope grades of no shallower than 8 horizontal to 1 vertical (8:1) are preferred, 4:1 side slopes are common, and 2:1 grades are the steepest allowed, but only on fenced sites. SJRWMD design criteria include providing off-line detention for the first one inch of runoff or the first 2.5 inches of runoff from impervious surfaces, which ever is greater, with additional treatment for discharge to protected Waters of the State. Additional design criteria address facility construction to prevent the discharge of accumulated sediments and the potential for clogging, to ensure adequate maintenance, and to direct the flow of stormwater evenly and with minimal turbulence through the system.

References 13, 19, 35, 36

EXTENDED DRY DETENTION BASIN

Related Facilities:

Inlet structures; overflow outfall with erosion control

Regulatory Considerations:

Dry detention basins are not commonly permitted for stormwater treatment in west-central Florida. They have been shown to frequently not meet water quality treatment standards established by the Florida State Water Policy, and require frequent maintenance to remove accumulated sediment to prevent resuspension and discharge. The South Florida Water Management District (SFWMD) does permit the use of these BMPs, and the St. Johns River Water Management District (SJRWMD) considers extended dry detention basins to be an experimental BMP for use only on small sites with very specific design criteria.

Overall Advantages/Disadvantages:

Advantages: Extended detention dry basins are somewhat effective for capturing solids or other contaminants connected with particulates, given adequate maintenance. This BMP has relatively low construction cost, and can be incorporated into passive recreational use.

Disadvantages: Removal efficiencies are typically half of that obtained using wet ponds. The site must have adequate depth to the water table and permeable soils for infiltration. Frequent maintenance is required to remove accumulated sediment to prevent resuspension and discharge. Land requirements may be up to 12% of commercial sites.

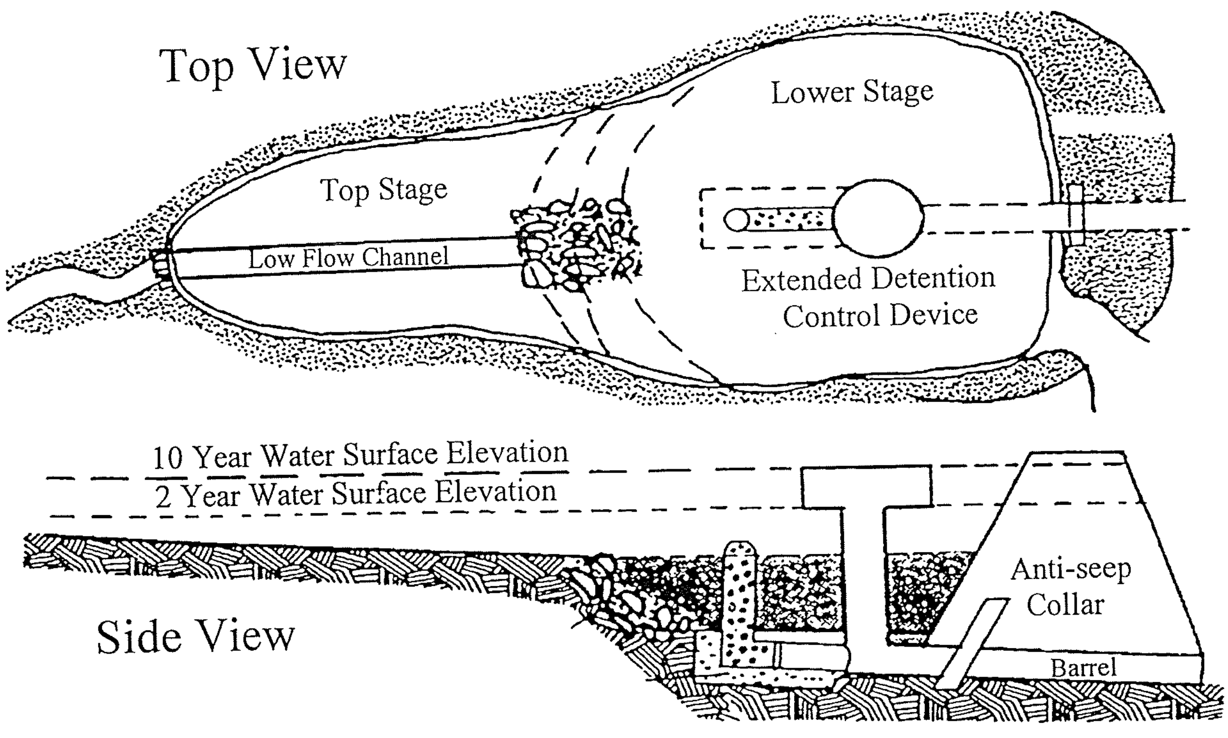
References 10, 13, 45

Site Constraints:		**References**
Treated Area:	1) At least 10 acres	33
	2) 15 - 100 acres	13
	3) 22.5 - 100 acres	37
	4) 5 acres or less	36
BMP Area:	1) Less than 5% of total drainage area: 0.50 acre	30
	2) Up to 12% of site	10
Depth to Water Table:	1) Minimum=2 feet	33
	2) Minimum=1 foot to seasonal high groundwater	36
Site Slope:	1) Range=3%-20%; slopes greater than 29% should be stabilized with riprap	30
	2) Less than 5%	14
Soil Permeability:	0.05 in/hr (sandy clay) to 8.27 in/hr (sand)	30

EXTENDED DRY DETENTION BASIN		
Operational Efficiencies:		
TN Removal:	1) Range=20%-60%	41
	2) Mean=25%, Maximum=52%	30
	3) Range=0%-30% improvement in water quality	16
	4) Range=0%-20% for 40 hr detention	13
	5) Range=20%-40% for first-flush detained 6-12	30
	hrs;	21
	6) Range=20% - 60%; Mean=30%	
TP Removal:		41
	1) Range=10% - 55%	33
	2) Range=10% - 30%	30
	3) Range=15% - 70%	16
	4) Range=0% - 30% improvement in water quality	13
	5) Range=10% - 20% for 40 hr detention	30
	6) Range=20% - 40% first-flush detained 6-12 hours	
	7) Range=40% - 60% for runoff from 1 inch detained 24 hrs; 60% - 80% for runoff from 1 inch detained 24 hrs with shallow marsh in bottom stage	30
	8) Range=10%-55%; Mean=25%	30
TSS Removal:	1) Range=5%-90%	41
	2) Range=30%-70%	33
	3) Mean=65%	30
	4) Range=0%-30% improvement in water quality	16
	5) Range=50%-70% for 40 hr detention	13
	6) 85%	18
	7) Range=60%-80% for first-flush detained 6-12 hrs	30
	8) Range=80%-100% for runoff from 1 inch detained 24 hrs;	30
	9) Range=5%-90%; Mean=45%	21
Flood Attenuation Capacity:	1) 25-year 24-hour storm	35
	2) 100-year	13
Operations & Maintenance Requirements:		
Required Activities:	Landscaping, erosion control at inlet, sediment removal, outfall structure maintenance	
Relative Level of O&M Required:	Moderate to high	
Maintenance Period:	A minimum of 6 times annually	

EXTENDED DRY DETENTION BASIN			
Costs:			
	Construction:	1) \$2,510/acre treated	6
		2) \$0.50/ft^3 of runoff treated	14
		3) Cost = $10.71V_s^{0.69}$ in 1985 dollars, plus 25% for miscellaneous costs, where V_s is detention volume.	30
	Operations & Maintenance:	1) 3-5% of construction cost annually: \$100 per treated acre, or about \$300 - \$500 per maintained acre, which is the pond and buffer, or about 3 times the surface area of the pond.	30

Extended Detention Dry Basin Schematic



Adapted from: Schueler (1987)

WET POND

Description and Function:

Wet ponds (extended detention wet basins) are impoundments in which stormwater runoff is temporarily stored until it gradually leaves the basin through an outflow control structure. The control structure is designed to gradually bleed-down the collected surface water. This produces the benefit of attenuating peak flood flow rates and reducing the risk of downstream flooding. Some reduction in surface flows also occurs through infiltration, evaporation, and transpiration. Therefore, peak flood flow rates are kept low through the use of wet ponds, but the overall flood volume is virtually unchanged. Wet ponds are, as the name implies, to be designed so that a pool of standing water remains in the basin after the bleed-down period. This permanent pool can be used to support emergent vegetation, which can enhance pollutant removal from the stormwater. Water quality benefits are also realized through settling of particulate matter that may carry metals and organic contaminants, and through the biological cycling of nutrients. In addition, runoff that infiltrates to the surficial aquifer receives water quality treatment through bacterial action and straining through the soil particles, although infiltration is not a significant factor in wet pond functioning. The treatment efficiency of wet ponds is largely a function of residence time of stormwater in the pond. As a result, wet ponds are generally more effective at removing many pollutants than dry retention ponds. Wet ponds can also be incorporated into multi-use facilities, providing aesthetic, recreational, and habitat benefits.

Wet ponds are most effective in areas with a water table that is far enough below the land surface to allow several feet of storage capacity within the pond at all times, but not below the pond bottom. This promotes the survival of wetland vegetation during periods of no rain. Effective functioning of wet ponds depends on designs that allow sufficient residence time (up to 72 hours) to allow settling of particulate material and some biological uptake. The use of wet ponds is very common in Florida. The relatively low cost of construction, ease of maintenance, site water table characteristics, and extended growing season make this an attractive method of stormwater control. In addition, wet ponds are frequently incorporated into development site designs as open water body amenities, and can serve a secondary function of providing fill material for building foundations and road beds. Because of their frequency of use and overall effectiveness, wet ponds are popular with regulators and are relatively easy to obtain permits for, given an appropriate design and site.

WET POND

Design Guidelines:

Large surface area-to-volume ratio shortens solids settling distance, and allows better aeration and light penetration enhancing pollutant loading biological mechanisms. Other features which reduce the tendency of inflow water to "short circuit" include: two or more distinct cells to promote plug flow; preferred effective length-to-width ratio 5:1, minimally 3:1; inlet and outlet either located far apart or shielded by baffling; low inlet velocity; uniform flow distribution across the inlet pond cross section; and discharge of water with minimum turbulence from mid-depth. Side slopes above seasonal high water of 4:1, or 2:1 with site fencing, are preferred. A littoral shelf with a slope of 3% - 6% should be incorporated. The pond should be designed for a 14-day residence time, with at least 35% of the surface area in littoral zone planted with appropriate aquatic vegetation. The outfall structure should provide for gradual release of the treatment volume over a 120-hour (five-day) period. Sediment traps or forebays should be located at all inlets. Safety features include an emergency overflow weir stabilized to avoid erosion and possible failure during high flow; a shallow safety bench at least 10 feet wide at the toe of the slope surrounding the perimeter; a vegetative buffer and fencing to keep children away from the pond; and an outlet structure placed out of reach of children.

References 13, 16, 19, 35

Related Facilities:

Inlet structures; Control structures for outfall

Regulatory Considerations:

This BMP is widely and frequently used, and is generally acceptable given appropriate site characteristics. In the SWFWMD wet ponds are required to treat the first one inch of runoff, rather than the runoff from the first one inch of rainfall required for other stormwater treatment options.

Overall Advantages/Disadvantages:

Advantages: Wet ponds offer greater treatment advantages than ponds that dry out between storms. Maintenance and construction costs are relatively low, and this BMP is acceptable to regulators. Wet ponds can be used in areas with a high water table, and can be considered multi-use facilities, providing habitat and recreational opportunities.

Disadvantages: Maintenance level is lower than for dry ponds because of the reduced need for sediment removal. However, vegetation control and harvesting is necessary. Wet ponds provide limited storage in areas with high water table levels, and safety and aesthetic problems can arise if the pond is not appropriately maintained. Land requirements can be a factor determining the use of this BMP.

Reference 13

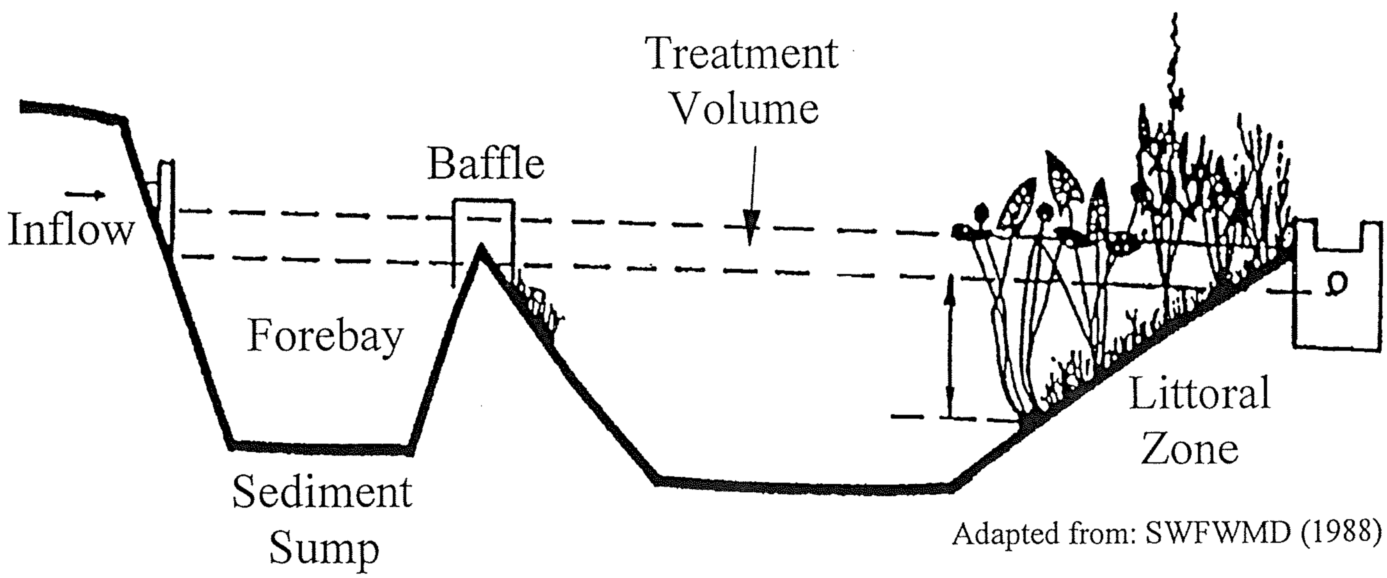
WET POND		
Site Constraints:		
Treated Area:	1) Range=10-640 acres	33
	2) Range=10-100 acres	13
	3) Range=20-100 acres	37
	4) Minimum=10 acres	13, 30
	5) Range=15-100 acres	11
	6) Minimum=8 acres	16
BMP Area:	1) Range=1-3% of total drainage area	33
	2) 1 acre-foot per 4 acres of treated area	30
	3) Minimum=5% of treated area	16
	4) Range=3-7% of treated area	13
	5) Up to 12% of a commercial site	10
Depth to Water Table:	None specified	
Site Slope:	1) Range=3-20%	30
	2) Less than 5%	14
	3) Littoral shelf slope of 10:1 or less out to 2-3 feet below normal water level, then no more than 6:1.	16
	4) Side slopes less than 20%	13
Soil Permeability:	Less than 0.02 in/hr (clay) to 1.0 in/hr (sandy loam)	47

WET POND

Operational Efficiencies:		
TN Removal:	1) Range=40-80%	33
	2) Mean=30%	28
	3) Mean NO_3=60%; Range TN: 0%-45%	30
	4) 80% or greater	16
	5) Range=20-40% with permanent pool equal to 0.5 inch storage per impervious acre; and for permanent pool equal to 2.5(Vr), Vr is mean storm runoff	30
	6) Range=40-60% with permanent pool equal to 4.0(Vr), or approximately 2 weeks retention	30
	7) Range=5-85%; Mean=35%	21
	1) Range=30-90%	
TP Removal:	2) Mean=54%	33
	3) Mean OrthoP=80%; Range=TP 30-90%	28
	4) 80% or greater	30
	5) Range=40%-60% with permanent pool equal to	16
	0.5 inch storage per impervious acre; and for permanent pool equal to 2.5(Vr), Vr is mean storm runoff	30
	6) Range=60%-80% with permanent pool equal to 4.0(Vr), or approximately 2 weeks retention	30
	7) Range=10%-85%; Mean=45%	21
TSS Removal:		33
	1) Range=30%-90%	28
	2) Mean=61%	30
	3) Range=0%-98%; Mean=54%	45
	4) Range=40%-90%	30
	5) Range=60%-80% with permanent pool equal to 0.5 inch storage per impervious acre; and for	
	permanent pool equal to 2.5(Vr), Vr is mean storm runoff	30
	6) Range=80%-100% with permanent pool equal to	21
Flood Attenuation Capacity:	4.0(Vr), or approximately 2 weeks retention	
	7) Range=30%-91%; Mean=60%	35
	25-year 24-hour storm	

WET POND			
Operations & Maintenance Requirements:			
	Required Activities:	Landscaping, aquatic vegetation harvesting, outfall structure maintenance	10
	Relative Level of O&M Required:	Lower than dry pond	10
	Maintenance Period:	2 times annually	10
Costs:	Construction:	1) $2,800/acre treated	6
		2) For volumes less than 10,000 ft^3, Cost=$6.1V_s^{0.75}$	14, 30
		3) For volumes greater than 10,000 ft^3, Cost=$34V_s^{0.64}$	30
	Operations & Maintenance:	1) 3-5% of construction cost annually: $112 per acre treated	33, 30
		2) $300 - $500 per maintained acre, which is the pond and buffer, or about 3 times the surface area of the pond	30

Wet Pond Schematic



Adapted from: SWFWMD (1988)

CONSTRUCTED WETLANDS

Description and Function:

Constructed wetlands serve primarily to provide water quality treatment to stormwater runoff that has been directed into a detention area. Water quality benefits are realized through physical (settling and entrapment of particulate material) and biological (plant uptake of nutrients) processes. Pollutants subject to these mechanisms are subsequently removed, at least temporarily, from the stormwater when it is released from the treatment system. If emergent vegetation is not harvested and is allowed to decay in the system, or if accumulated sediments potentially rich in nutrients and toxic contaminants are not periodically removed but allowed to accumulate, detritus and resuspended sediments may be flushed from the treatment areas during periods of high flow, thus re-introducing these pollutants into surface waters. Constructed wetlands can also be incorporated into multi-use facilities, providing aesthetic, recreational, and habitat benefits.

Treatment wetlands are typically constructed as an integral part of a wet detention system. Biological treatment littoral zones in wet detention ponds are planted with a wide variety of native and desirable aquatic vegetation and are maintained to prevent invasion by cattails or other nuisance species.

Constructed wetlands are most effective in areas with a water table that is shallow enough to sustain the wetland vegetation during periods of no rain. However, the water table must be far enough below the land surface to allow several feet of storage capacity at all times within associated flood attenuation ponds. Designs that allow sufficient retention time (up to 72 hours) to allow particulate material to settle and to promote biological uptake of nutrients also enhance the functioning of constructed wetlands.

The use of constructed wetlands is very common in Florida. Water table characteristics, the extended growing season, and overall effectiveness in pollutant removal make this an attractive method of stormwater control. Because of their frequency of use, overall effectiveness, and benefits to habitat, constructed wetlands are popular with regulators and are relatively easy to obtain permits for, given appropriate design and site characteristics.

CONSTRUCTED WETLANDS

Design Guidelines:

A runoff quantity control device should be placed on-line and a constructed wetland should be placed off-line to treat all runoff up to a certain volume, as the shallow depths are not consistent with the large storage volume needed for quantity control, and large surges of water can damage the wetland. A constructed wetland should have a permanent pool zone for treatment and a fluctuating storage zone and discharge control sized for peak runoff rate control. Wetlands should be constructed only for treatment in situations where quantity control is not required. Wetlands are normally constructed with a wet pond, and should have a bleed-down time of 5 days.

At least two distinct cells should be created by restricting the flow to a narrow passageway between high marsh features. The minimum littoral zone is 35% of the site. The wetland should be relatively wide at the inlet to distribute flow, and the distance between the inlet and outlet should be maximized. The preferred effective length-to-width ratio is 5:1, a minimum of 3:1 is recommended. At the entrance to the wetland, a forebay should be created as a separate cell, 4-6 feet deep, and placed where influent water discharges to trap coarse sediments, reduce incoming velocity, and distribute runoff evenly. Maintenance access to the forebay must be provided, with the bed hardened to prevent disturbance during clean out. At the outlet, a micropool should be placed, 4-6 feet deep, with a reverse-sloped pipe installed 12 inches below the permanent pool elevation to avoid clogging. A drain should be installed for dewatering within 24 hours to allow maintenance on the wetland. An emergency spillway is required when the wetland is used for runoff quantity control.

Sheet flow should be created to the maximum possible extent, and where flow must be channeled, multiple meandering channels should be used, with flow velocity minimized to prevent erosion. Open water areas should be interspersed with marsh. A buffer should be provided around the wetland, with a minimum width of 20-26 feet, measured from the maximum water surface elevation, plus 16 feet to the nearest structure. This serves to separate the treatment area from the human community, and reduces exposure of any wildlife to external factors. At least 75% of the buffer should be forested to repel geese and provide better protection and habitat. The maximum side slope should be less than 15% unless a fence is built around the perimeter.

Mosquitoes can be prevented by creating habitats that support predatory insects. Aesthetic considerations can be addressed by establishing attractive vegetative communities. Undesirable plant monocultures can be limited through structural diversity and a range of depths, and by planting diverse native selections.

Loams and silt loams work best to establish plants, capture pollutants, retain surface water, and permit groundwater discharge. Muck soils are favorable for plant and microorganism growth and metal and organic pollutant adsorption. Soils should contain seed banks or rhizomes of obligate and facultative wetland plants, so that vegetation is established more quickly and effectively.

References 13, 16, 35

Related Facilities:

Wet ponds; Inflow and outflow structures

References 13, 35

CONSTRUCTED WETLANDS

Regulatory Considerations:

All federal, state, and local laws and regulations must be considered. Archaeological and cultural resources must be avoided, as well as critical wildlife habitat areas. This BMP is widely and frequently used, and is generally acceptable given appropriate site characteristics as described below.

Reference 13

Overall Advantages/Disadvantages:

Advantages: Constructed wetlands can be diverse in structure, which offers potential for relatively effective control of most pollutants, and contributes to flood attenuation. They possess a wider range of potential side benefits, and require relatively low maintenance costs. They are more widely applicable and provide more reliable service than infiltration. Aesthetic and habitat benefits are associated with constructed wetlands.

Disadvantages: Constructed wetlands require more land for equivalent service than do wet ponds and other systems, especially if intended to serve quantity as well as quality control purposes. Maintenance and construction costs are higher than those associated with dry ponds. Plants must be well-established before pollutant removal efficiencies reach required levels, and uncertainties in design, construction, and operating criteria exist. Public concern about nuisances must be addressed in siting, design, construction, and operation phases.

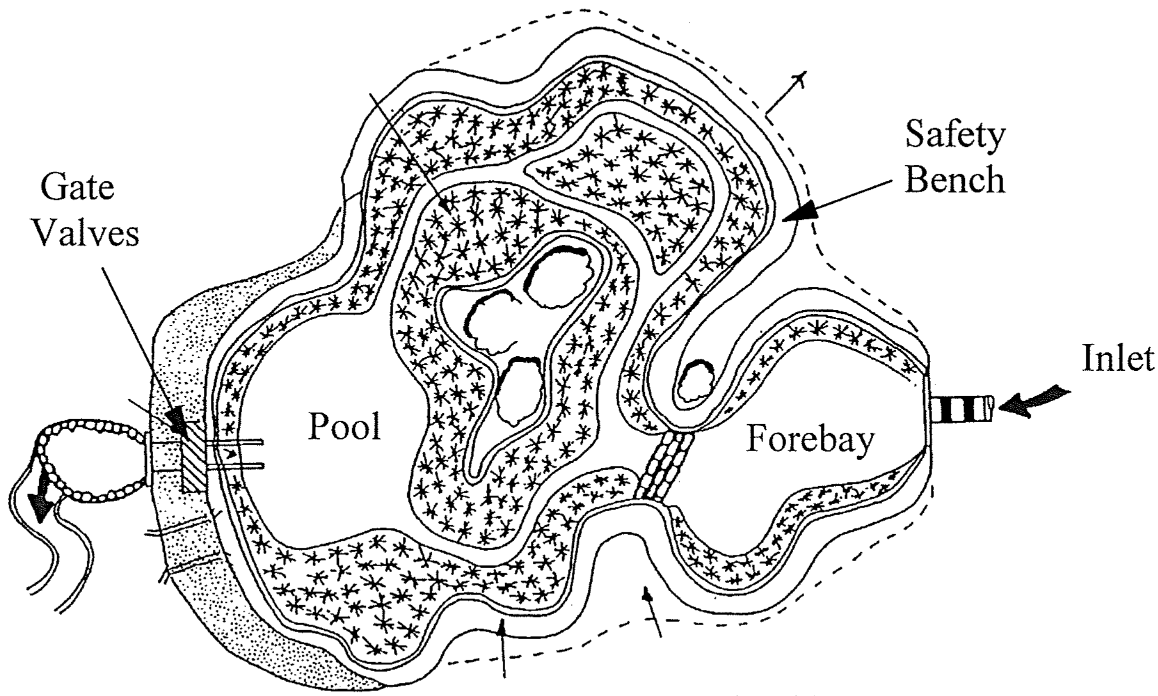
References 13, 16, 19

Site Constraints:

Treated Area:	5 - 99 acres	13, 33
BMP Area:	1) Range=2% - 5% of total drainage area: typically 0.1-5 acres	33
	2) Up to 3,473 acres in North America	15
Depth to Water Table:	N/A	
Site Slope:	1) Less than 1% along-flow, 0% perpendicular to flow, less than 20% side slope	13
	2) Less than 15% side slope without a fence	35
Soil Permeability:	Less than 0.02 in/hr (clay) to 1.0 in/hr (sandy loam)	30

CONSTRUCTED WETLANDS		
Operational Efficiencies:		
TN Removal:	1) Mean=25%; Maximum=40% 2) Range=-15%-40%; Mean=20% 3) Mean=51%	13 21 15
TP Removal:	1) Mean=45%; Maximum=65% 2) Range=-120%-100%; Mean=25% 3) Mean=31%	13 21 15
TSS Removal:	1) Mean=75% 2) Range=-20%-100%; Mean=65% 3) Mean=71%	13 21 15
Flood Attenuation Capacity:	1) 2-5 year storm (without auxiliary water body)	16
Operations & Maintenance Requirements:		
Required Activities:	Landscaping, vegetation harvesting, sediment removal, structure maintenance, erosion control, debris removal	19
Relative Level of O&M Required:	Higher than dry ponds	
Maintenance Period:	2-3 times annually	
Costs:		
Construction:	1) $2,800/acre treated 2) $985 - $134,886 per BMP acre, $23,682 per BMP acre average in North America	6 15
Operations & Maintenance:	3-5% of construction cost annually: $112 per acre treated	33

Constructed Wetland Schematic



Adapted from: Schueler (1991)

VEGETATED SWALE

Description and Function:

A vegetated swale is a shallow linear depression, usually grassed, that is used to capture, store, and convey stormwater runoff. Both flood attenuation, through temporary storage and diversion, and water quality treatment, through infiltration, settling of particulate material, and biological uptake of nutrients are provided. Vegetated swales serve as stabilized stormwater conveyance channels and reduce runoff velocities, thus reducing erosion. Swales should be constructed in areas with a low water table and permeable soils so that infiltration can occur, and no standing water will remain except directly following a storm event. Swales may be used in conjunction with other BMPs as part of a treatment train, such as for pre-treatment of runoff prior to discharge to an infiltration basin. Swales may also be used alone with raised outfall structures to promote longer detention times and groundwater recharge.

Vegetated swales are useful as an alternative to ponds in areas where land availability is limited. Many roadway projects, with only a narrow right-of-way to use for stormwater management facilities, often have swales designed for flood attenuation and water quality effects.

The use of vegetated swales is fairly common in Florida. The relatively low cost of construction, ease of maintenance, and convenience in siting (low land requirement) make this an attractive method of stormwater control. Because of their frequency of use, overall effectiveness, and ability to be placed in perimeter zones, medians, or other otherwise unusable portions of sites, vegetated swales are popular with regulators, given appropriate design and site characteristics.

Design Guidelines:

Vegetated areas should utilize fine-stemmed plants which exhibit dense, uniform growth and are tolerant of the area's water, climatological, soil, and pest conditions. The best properties are normally found in native plants. A residence time of nine minutes is needed to achieve the highest and most reliable performance, with deteriorated performance when residence time falls below five minutes, recommended as the minimum. Swales should be located away from building and tree shadows to avoid poor plant growth from lack of sunlight. Water-resistant vegetation should be planted if the along-flow slope is less than 2%, or if the water table can reach the root zone. Swale blocks, or check dams, should be constructed every 50 to 100 feet if the along-flow slope is 4% - 6%, to reduce velocity. If the slope on which the swale is installed is greater than 6%, construct the swale so that it traverses the slope, so that along-flow slopes are less than 4%, or less than 6% with check dams. To avoid channelization of flow, make the lateral slope entirely uniform. Inflow velocities to the swale should be reduced quickly, with flow distributed uniformly, to avoid erosion.

The ratio of the top width-to-depth is 6:1 at a minimum, and side slopes of 3:1 are the maximum. Swales should remain wet only during and after a storm event, and SJRWMD require swales to percolate 80% of the 3-year 1-hour storm.

References 4, 13, 16, 36, 43, 45

VEGETATED SWALE

Related Facilities:

Raised outfall structure; Swale blocks; Receiving water ponds

References 16, 19

Regulatory Considerations:

Although a relatively common BMP, swales are usually proposed when land availability is an issue, as is the case for narrow sites (roadways). A safety factor of two or more should be applied to the design to account for uncertainty regarding subsurface conditions.

Overall Advantages/Disadvantages:

Advantages: Swale systems are a better choice than oil separators to remove low concentrations of oil and grease from urban runoff. Vegetated swales also provide an alternative to ponds where sufficient land is unavailable, and address both water quality and water quantity concerns. Swales are relatively inexpensive to construct and maintain, and can be used as part of a treatment train.

Disadvantages: Vegetated swales are not very effective for phosphorus or nitrogen removal, or for fecal coliform capture. Steep slopes will lead to erosion, and they are ineffective where the water table is high. Standing water in swales promotes mosquito breeding and the growth of undesirable vegetation, and can lead to aesthetic problems.

References 13, 16, 19, 43

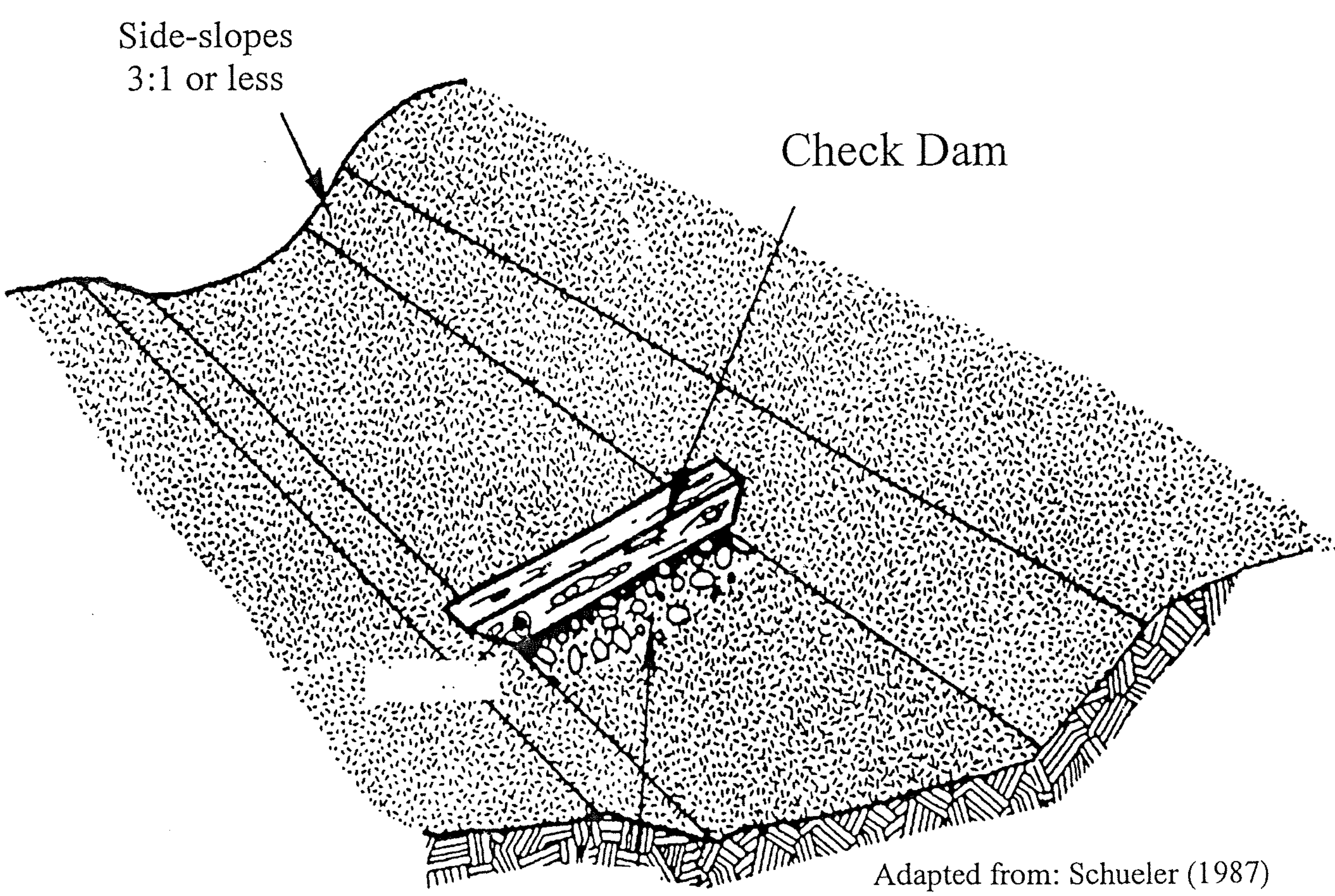
Site Constraints:

Treated Area:	1) Maximum=5 acres	14
	2) Maximum=150 acres	9
BMP Area:	Varies	
Depth to Water Table:	Minimum=2 feet	
Site Slope:	1) Less than 20% sideslope	33
	2) Less than 11% treated area slope	16
	3) Less than 3%	14
	4) Less than 5% along-flow slope	33
	5) Less than 4% along-flow slope, up to 6% with swale blocks.	13
Soil Permeability:	Less than 0.09 in/hr (clay loam) to 8.27 in/hr (sand).	30

VEGETATED SWALE		
Operational Efficiencies:		
TN Removal:	1) Minimum=10%	13
	2) Maximum=25%	33
	3) Range=0%-20% for high slope, with no check dams	30
	4) Range=20%-40% for low gradient, with check dams	30
	5) Range=0%-40%; Mean=10%	21
TP Removal:	1) Minimum=10%	13
	2) Maximum=30%	33
	3) Range=0%-20% for high slope, with no swale blocks	30
	4) Range=20%-40% for low gradient, with swale blocks	30
	5) Range=0%-100%; Mean=20%	21
TSS Removal:	1) Minimum=10%	13
	2) Maximum=70%	33
	3) 60%	41
	4) Range=0%-20% for high slope, with no swale blocks	30
	5) Range=20%-40% for low gradient, with swale blocks	30
	6) Range=0%-100%; Mean=60%	21
Flood Attenuation Capacity:	10-year 24-hour storm	16
Operations & Maintenance Requirements:		
Required Activities:	Landscaping, erosion repair, structure maintenance	19
Relative Level of O&M Required:	Moderate to low, except if designed on inappropriate soils or high water table	16
Maintenance Period:	2-3 times annually	19

VEGETATED SWALE			
Costs:			
	Construction:	1) $2,300/acre treated	6
		2) $13.25/linear foot	14
		3) $6.83/linear foot for 15 feet wide, 18% sideslope	30
		4) Approximately $1,700/acre for seeding	30
		5) $10,900/acre for sodding	30
	Operations & Maintenance:	3-5% of construction cost annually: $92 per treated acre	13

Grassed Swale Schematic



Adapted from: Schueler (1987)

VEGETATED FILTER (BUFFER) STRIP

Description and Function:

Vegetated buffer strips are best used as borders to areas of impervious surface, and serve to stabilize side slopes, reduce erosion, lower noise levels, slow the velocity of runoff flow, allow some infiltration, capture suspended solids, and remove nutrients through plant uptake. In addition, habitat and aesthetic benefits often result from maintaining vegetated buffer areas, which are also effective when located adjacent to floodplains, wooded areas, and wetlands. Vegetated buffer strips, which are typically 20 to 50 feet wide, may contain either native vegetation that is saved and maintained, or be landscaped. Maintenance of these strips varies depending on the type of vegetation used. Vegetation should completely cover the buffer strip to promote uniform protection. Private land owners can maintain the vegetated buffer adjacent to their property, thus lowering the cost to local governments.

Design Guidelines:

Vegetated areas should utilize fine-stemmed plants which exhibit dense, uniform growth and are tolerant of the area's water, climatological, soil, and pest conditions. The best properties are normally found in native plants. A residence time of nine minutes is needed to achieve the highest and most reliable performance, with deteriorated performance when residence time falls below five minutes, recommended as the minimum. Biofilters should be located away from building and tree shadows to avoid poor plant growth from lack of sunlight. Water-resistant vegetation should be planted if the along-flow slope is less than 2%, or if the water table can reach the root zone. Check dams should be constructed every 50 to 100 feet if the along-flow slope is 4% - 6%, to reduce velocity. Inflow velocities should be reduced quickly, with flow distributed uniformly, to avoid erosion. Typical minimum widths of filter strips are in the range of 20-30 feet.

References 13, 16, 19

Related Facilities:

Swales and ponds, as part of a treatment train

Reference 19

Regulatory Considerations:

Vegetated filter strips are not acceptable for flood attenuation or pollutant removal by themselves, but are usually included as part of local government development standards or comprehensive plans.

Overall Advantages/Disadvantages:

Advantages: Vegetated filter strips provide aesthetic and habitat benefits, in addition to erosion control. Construction and maintenance costs are very low, with the maintenance possibly provided by the property owner.

Disadvantages: This BMP does not address regulatory requirements for flood attenuation, and its effectiveness is reduced if the vegetative cover is sparse.

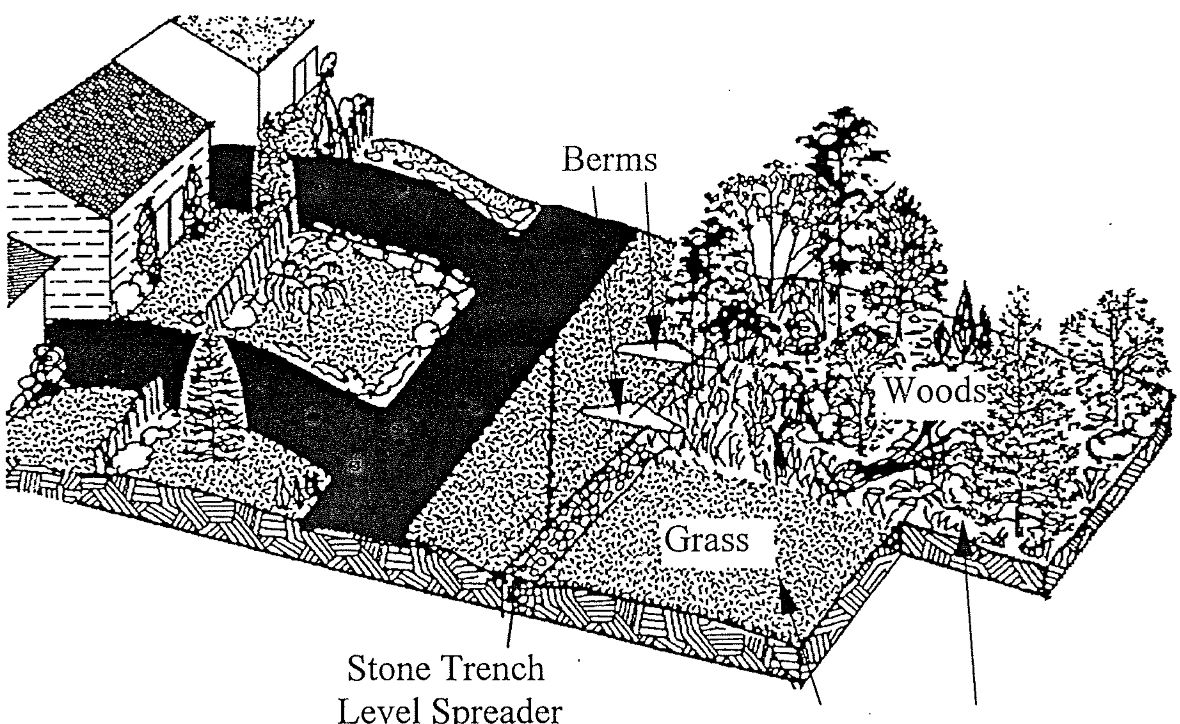
Reference 19

VEGETATED FILTER (BUFFER) STRIP

Site Constraints:		
Treated Area:	Less than 5 acres	14, 37
BMP Area:	1) 100-300 feet long and 20 feet wide, or 0.05-0.14 acres	30
	2) 50-75 feet long and 20 feet wide, plus four feet for any one percent increase in slope	33
	3) Minimum=20 feet wide	19
Depth to Water Table:	Maximum=3 feet	33
Site Slope:	1) Maximum=5%	33
	2) Less than 15%	30
	3) Less than 3%	14
Soil Permeability:	0.09 in/hr (clay loam) to 8.27 in/hr (sand).	30
Operational Efficiencies:		
TN Removal:	1) Range=0%-70%	41
	2) Range=0%-20% for 20 foot wide turf strip	30
	3) Range=40%-60% for 100 foot wide forested strip, with level spreader	30
	4) Range=0%-70%; Mean=40%	21
TP Removal:	1) Range=0%-90%	41
	2) Range=0%-20% for 20 foot wide turf strip	30
	3) Range=40%-60% for 100 foot wide forested strip, with level spreader	30
	4) Range=0%-95%; Mean=40%	21
TSS Removal:	1) Range=20%-80%	41
	2) Range=20%-40% for 20 foot wide turf strip	30
	3) Range=80%-100% for 100 foot wide forested strip, with level spreader	30
	4) Range=20%-80%; Mean=65%	21
Flood Attenuation Capacity:	N/A	

VEGETATED FILTER (BUFFER) STRIP			
Operations & Maintenance Requirements:			
	Required Activities:	Landscaping, erosion control	19
	Relative Level of O&M Required:	Low, may be performed by property owner	
	Maintenance Period:	Varies with type of vegetation	
Costs:	Construction:	Approximately $1,700/acre with seeding	33
	Operations & Maintenance:	2-4% of construction cost annually: $50 per treated acre	33

Filter Strip Schematic



Adapted from: NJDEP (1994)

INFILTRATION (DRY RETENTION) BASIN

Description and Function:

Infiltration basins are impoundments in which incoming urban runoff is temporarily stored until it gradually leaves the basin by infiltrating into the soil at the bottom and edges of the basin. Stormwater should leave the dry retention basin as surface flow over the spillway only during extreme high flow periods. Filtration (via adsorption and straining) and microbial processes act on the pollutants that enter the soil, with the net result of lower pollutant concentrations in water leaving the soil. The major benefit afforded by infiltration basins is groundwater recharge. Infiltration basins generally have only a slight habitat value. Some concerns have been voiced about potential local groundwater contamination but few data support this concern. The most effective applications of infiltration basins have included a forebay, sediment trap, or vegetated filter strip, where the runoff entering the basin is pretreated to remove coarse sediment that may clog the surface soil pores on the basin floor. Underdrains located at the downstream end of the basin enhance infiltration and direct water to the basin outlet. Other factors that contribute to the success of infiltration basins are non-concentrated flows, dense vegetative cover, short dewatering times, and small contributing basins. Those factors that limit the effectiveness of infiltration basins include high sediment loads, large contributing basins, long dewatering times, high water tables, and clay soils. Infiltration basins should drain within 72 hours to maintain aerobic conditions, which favor bacteria that aid in pollutant removal, and to ensure that the basin is ready to receive the next storm. The life span of infiltration basins is generally short, with most failures due to clogging, often shortly after construction. The standing water that often results from the clogging encourages colonization by wetland vegetation which may provide some water quality benefit not unlike a retention pond.

Design Guidelines:

For best operating success, infiltration basins should be built on deep to excessively drained soil, and not near seasonal high water tables or low spots in drainage catchments. Soil is the most critical consideration, and where native soils are inappropriate, a soil system can be constructed with sand and/or peat. Clay soils provide limited percolation, and gravel and coarse sands lead to the risk of groundwater contamination. To prevent clogging, infiltration facilities should require a pretreatment device to settle larger solids and reject runoff from eroding construction sites. Pretreatment should remove 80% of total suspended solids, and the basin should capture the first inch of runoff, with a drawdown time of 72 hours. Banks and other areas must be stabilized to prevent erosion. The facility should be at least 50 feet from any slope greater than 15%, and at least 100 feet upslope or 20 feet downslope of any building. After final grading, so that the bottom is flat, the bed should be deeply tilled, and the basin and sides should be planted with appropriate vegetation, with maintenance for performance and appearance.

References 13, 16

Related Facilities:

Overflow spillway and inlet, with erosion control
Reference 19

Regulatory Considerations:

Although infiltration basins are not uncommon, their inconsistency and tendency to clog reduce their popularity with regulators.

INFILTRATION (DRY RETENTION) BASIN

Overall Advantages/Disadvantages:

Advantages: Only soil infiltration systems have been reliable in removing soluble phosphorus, and removal efficiencies for total nitrogen and suspended solids are high as well. Infiltration basins provide groundwater recharge, and address both water quantity and water quality concerns.

Disadvantages: Infiltration practices have the highest failure rates among all alternatives, requiring great care in site selection, design, operation, and maintenance. The potential exists for groundwater contamination, especially in karst zones. Infiltration basins are not feasible in areas where the water table is high or soils have low permeability. There are no effective means of preventing clogging of an infiltration basin, and there is distrust among regulatory bodies of this BMP. The land requirement may also be too much for treatment areas of limited size.

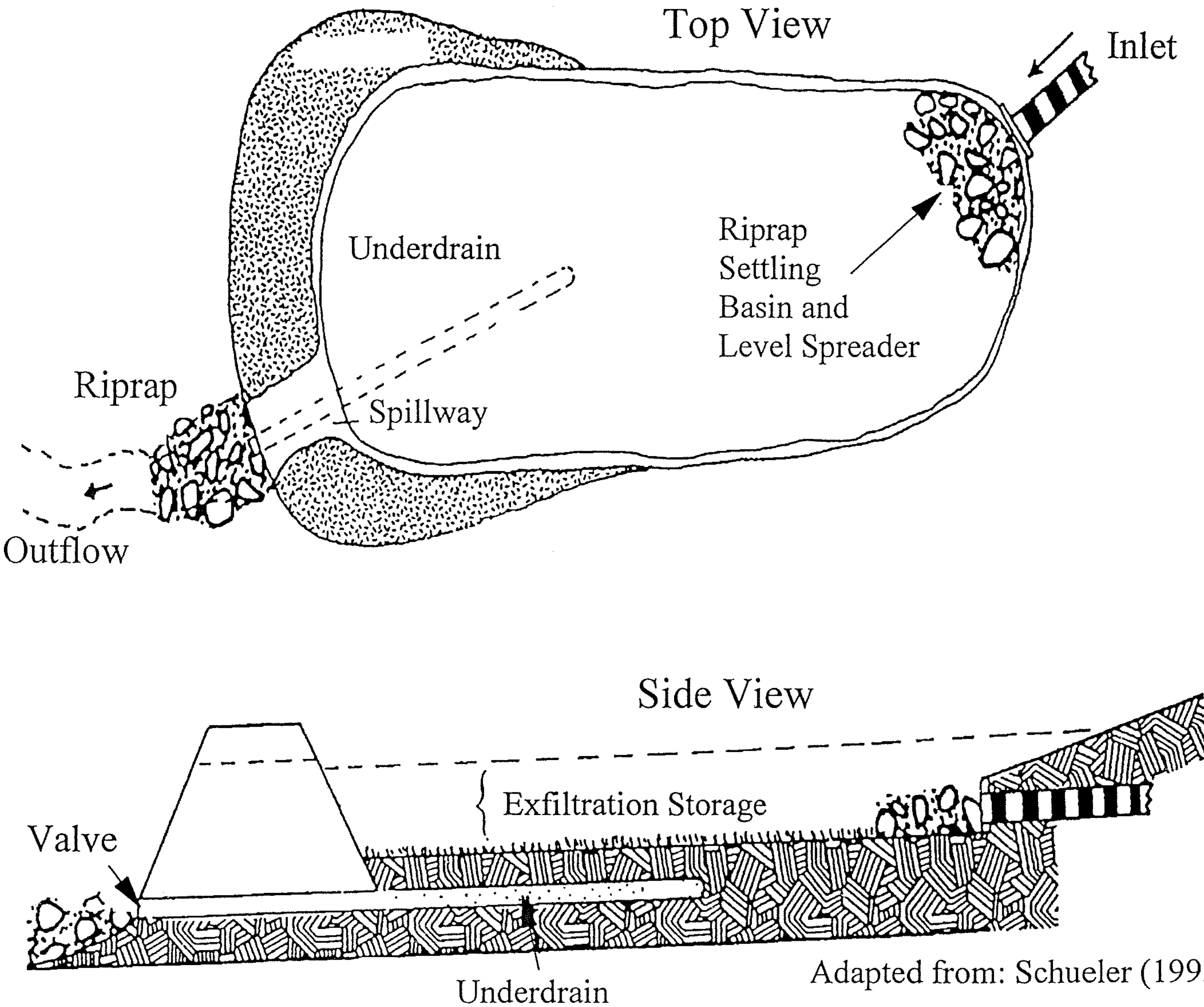
References 13, 16, 19

Site Constraints:

Treated Area:	1) Minimum=50 acres	13, 30
	2) Range=5-20 acres	37
	3) Range=1-50 acres	30
	4) Range=2-15 acres	33
	5) No minimum	13
BMP Area:	Range=5-10% of total drainage area: less than 5 acres	13
Depth to Water Table:		33
	1) 3 feet minimum	37
	2) 4 feet maximum	13
	3) Bed should be 3-5 feet above water table	
Site Slope:		30
	1) Less than 20% treated area slope	14
	2) Less than 3%	13
	3) Less than 15% slope of BMP site	
Soil Permeability:		13
	1) From 0.3-0.5 in/hr	30
	2) Maximum percolation rate of 2.4 in/hr when facility provides all runoff treatment and when it drains to groundwater.	30
	3) 0.52 in/hr (loam) to 8.27 in/hr (sand)	

INFILTRATION (DRY RETENTION) BASIN			
Operational Efficiencies:			
	TN Removal:	1) Range=45%-70%	13, 30
		2) Range=40%-60% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre; and exfiltrates 1 inch runoff per impervious acre	30
		3) Range=60%-80% exfiltrates all runoff, for 2 year storm	30
		4) Range=45%-100%; Mean=60%	21
	TP Removal:	1) Range=50%-75%	13, 30
		2) Range=40%-60% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre; and exfiltrates 1 inch runoff per impervious acre	30
		3) Range=60%-80% when facility exfiltrates all runoff, up to 2 year design storm	30
		4) Range=45%-100%; Mean=65%	21
	TSS Removal:	1) Range=75%-99%	13, 30
		2) Range=60%-80% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre	30
		3) Range=80%-100% when facility exfiltrates 1 inch runoff per impervious acre; and exfiltrates all runoff, up to 2 year design storm	30
		4) Range=45%-100%; Mean=75%	21
	Flood Attenuation Capacity:	25-year 24-hour flood	35
Operations & Maintenance Requirements:			
	Required Activities:	Landscaping, cutting grass, removal of sediments and debris, scoring of basin bottom to penetrate the surface	19
	Relative Level of O&M Required:	Moderate to low	
	Maintenance Period:	2-3 times annually	
Costs:			
	Construction:	Approximately $2,890/acre treated	33
	Operations & Maintenance:	3-5% of construction cost annually: $115/ treated acre	30, 33

Infiltration Basin Schematic



Adapted from: Schueler (1992)

EXFILTRATION TRENCH

Description and Function:

An exfiltration trench is a linear excavation that is backfilled with coarse stone aggregate and/or a perforated pipe. Stormwater that enters the trench is detained until it infiltrates into the groundwater through the bottom and sides of the trench, or until it evaporates. Among the benefits of this BMP are flood attenuation, water quality treatment, groundwater recharge and maintenance of base flows. The potential for groundwater contamination does exist with this alternative, but is not well documented. For this reason, and to reduce the potential for clogging the filtration system, exfiltration trenches are often used in conjunction with other stormwater BMPs, such as vegetated swales for pre-treatment and diversion inlets to capture the first flush of runoff, or are used to provide water quantity and quality benefits to small, isolated parts of a site.

Common designs include a relatively narrow (three to five feet wide), shallow (two to eight feet deep) excavated trench with filter fabric covering stone fill, and/or a large diameter perforated pipe, also fabric covered. Because the primary method of treatment and attenuation is through infiltration, exfiltration is only useful in areas where the depth to the seasonal high water table is sufficient (Florida Administrative Code Ch. 40D-4 states one foot minimum). In addition, soils must be permeable enough to allow an acceptable percolation rate (generally over 0.5 to 1.0 inch/hour). Because sediment from runoff can clog the filter fabric and interstitial voids in the stones, periodic maintenance is necessary to sustain exfiltration trenches' efficiency. Filter fabric must be replaced as it clogs, and even the stones should be replaced on a less frequent basis.

The use of exfiltration trenches is limited in central Florida. Their use is more common in the southern part of the state, because there is no design requirement for having the water table below the trench bottom. The relatively high cost of construction, high level of maintenance, requirement for a low water table or high infiltration rates, and frequency of failure from clogging make this BMP most useful only in specific situations, such as those areas where land availability is limited. Infiltration trenches are most appropriate when their ability to be placed in perimeter zones, medians, or other otherwise unusable portions of sites can be exploited.

Design Guidelines:

Soil is the most critical consideration, and where native soils are inappropriate, a soil system can be constructed with sand and/or peat. Clay soils provide limited percolation, and gravel and coarse sands lead to the risk of groundwater contamination. To prevent clogging, infiltration facilities should require a pretreatment device to settle larger solids and reject runoff from eroding construction sites. Pretreatment should remove a portion of the total suspended solids to reduce the potential for clogging. Banks and other areas must be well-constructed and stabilized to prevent erosion and subsequent clogging of the exfiltration system. The facility should be at least 50 feet from any slope greater than 15%, and at least 100 feet upslope or 20 feet downslope of any building. Trenches should be at least 3 feet wide, and 2-8 feet deep, with the stone aggregate fill enclosed in a filter fabric, with a maintenance sump at inlets.

References 13, 19, 29, 35, 44

EXFILTRATION TRENCH

Related Facilities:

Other parts of the treatment train, i.e. receiving water pond or swale; Diversion inlets

Reference 19, 29, 44

Regulatory Considerations:

Exfiltration trenches are not uncommon for water quality treatment, but are not common for flood attenuation.

Overall Advantages/Disadvantages:

Advantages: Only soil infiltration systems have been reliable in removing soluble phosphorus. Trenches provide reduction in stormwater volume and enhance groundwater recharge and baseflow. Trenches can serve small drainage areas, and can be constructed in narrow medians and perimeters to capture the "first flush" of runoff.

Disadvantages: Exfiltration practices have a high failure rates relative to all BMP alternatives, requiring great care in site selection, design, construction, operation, and maintenance. Pollutant removal efficiencies and infiltration capacity may decrease with time, with high maintenance required to keep efficiencies high. The potential for groundwater contamination exists, and trenches are not suitable in areas with high water table or low soil infiltration rates.

References 13, 16, 19, 29, 44

EXFILTRATION TRENCH		
Site Constraints:		
Treated Area:	1) Less than 5 acres 2) 1-9 acres	12,30,33,37 4
BMP Area:	1) 150 feet long, 6 feet wide (0.02 acre) 2) Side area to bottom area ratio less than 4:1	30 16
Depth to Water Table:	1) Minimum=3 feet 2) Bed should be 3-5 feet above water table 3) Minimum=1 foot	12, 33 13 35
Site Slope:	1) Less than 5% 2) Less than 3% 3) Less than 20% 4) Side slopes of 27% - 34% for sand 5) Less than 15% slope of BMP site	12, 30, 33 14 12 16 13
Soil Permeability:	1) Minimum percolation rate of 0.3 - 0.5 in/hr 2) Max. perc. rate of 2.4 in/hr when facility provides all runoff treatment and when it drains to groundwater. 3) From 0.5 in/hr (loam) to 8.27 in/hr (sand)	13 30 47

EXFILTRATION TRENCH

Operational Efficiencies:			
	TN Removal:	1) Range=40%-80%; Mean=57%	14
		2) Maximum=60%	33
		3) Range=-10%-100%	41
		4) Range=45%-70%	30
		5) Range=40%-60% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre; and exfiltrates 1 inch runoff per impervious acre	30
		6) Range=60%-80% when facility infiltrates all runoff, up to 2 year design storm	30
		7) Range=-10%-100%; Mean=55%	21
	TP Removal:	1) Range=40%-80%; Mean=57%	14
		2) Maximum=60%	12, 33
		3) Range=50%-70%	30
		4) Range=40%-60% when facility infiltrates first-flush, 0.5 inch runoff per impervious acre; and exfiltrates 1 inch runoff per impervious acre	30
		5) Range=60%-80% when facility exfiltrates all runoff, up to 2 year design storm	30
		6) Range=40%-100%; Mean=60%	21
	TSS Removal:	1) Range=60%-100%; Mean=83%	14
		2) Maximum=90%	12, 33
		3) Range=45%-100%	41
		4) Range=75%-90%	30
		5) Range=60%-80% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre	30
		6) Range=80%-100% when facility exfiltrates 1 inch runoff per impervious acre; and exfiltrates all runoff, up to 2 year design storm	30
		7) Range=45%-100%; Mean=75%	21
	Flood Attenuation Capacity:	Low	

EXFILTRATION TRENCH			
Operations & Maintenance Requirements:			
	Required Activities:	Inspection and replacement of stones and filter fabric if clogging occurs, maintenance of inlet structures	16, 19
	Relative Level of O&M Required:	Moderate	
	Maintenance Period:	Annual inspection, with stone replacement when reduced functioning is observed	
Costs:			
	Construction:	1) $4/cubic foot, so that 0.5" on 1 acre: $7,300	14
		2) Cost=$26.6V_s^{0.63}$	30
		3) French drain system, 24-inch pipe costs	30
		$28/linear foot (1979 dollars)	16
	Operations & Maintenance:	1) 5% - 10% of construction cost annually for surface trench: $550, includes rehabilitation every 5 years	16, 30
		2) 10% - 15% of construction cost annually for underground trench: $910, includes rehabilitation every 15 years	16, 30

POROUS PAVEMENT

Description and Function:

Porous pavement is a high-void aggregate-based paving material (concrete or asphalt) that allows water to flow through it. When used and maintained correctly, flood flows are attenuated and pollutant loading to surface waters are reduced by the seepage of stormwater through the pavement and underlying soils into the groundwater. As stormwaters pass through the pavement and soils, they are stripped of suspended particles, oil and grease, and other pollutants. Another benefit of using porous pavement includes the reduction in stormwater ponding that would occur on impervious pavement. However, because the accumulated particulates and vehicle-based oils and grease tend to quickly clog the pavement pores, frequent cleaning (vacuuming followed by pressure washing or the use of an environmentally-safe solvent) is necessary to maintain effectiveness. In addition, as the subbase soils become more compacted from pavement loads over time, infiltration rates may decrease and the soil may remain saturated for extended periods, thus reducing the structural stability of the paved area. Porous pavement is most appropriate for parking lots or low traffic areas. It should only be used where natural or enhanced subsurface drainage will allow the soils under the pavement to remain unsaturated for most of the time. Because of the limited capacity to reduce runoff volume and the reduced pollutant removal benefits over time, porous pavement is good as a temporary management method, or when used in conjunction with other BMPs. Although porous pavement has been permitted for stormwater management in some specific cases, it is generally not recognized by regulators as a valid permanent solution to runoff management problems.

Design Guidelines:

The modular block type of porous pavement system, or a continuous pored layer, can be used. The BMP design consists of perforated concrete slabs underlain with gravel, and is specified for use in low traffic areas like airports, parking lanes, driveways, and paved paths without traffic. Soil is the most critical design consideration, and where native soils are inappropriate, a soil system can be constructed with sand. Clayey soils provide limited percolation, and gravel and coarse sands lead to the risk of groundwater contamination. To prevent clogging, facilities should require a pretreatment device to settle larger solids from off-site flows and reject runoff from eroding construction sites. Removal of suspended solids from stormwater prior to infiltration through porous pavement will reduce the potential for clogging. Banks and other areas must be stabilized to prevent erosion. The facility should be at least 50 feet from any slope greater than 15%. A typical porous pavement system includes a porous concrete surface course (layer) 2.5 to 4 inches thick, underlain by a two-inch thick filter course of ½ inch aggregate. A reservoir base course lies beneath, composed of one-two inch aggregate. The reservoir course thickness is based on site conditions and storage needs, and should be lined with filter fabric. A bottom filter layer may also be installed directly above the filter fabric. The paved area should be flat to allow uniform infiltration, and minimum compaction of the subbase is desirable. The system may require underdrains. The "Pervious Pavement Manual", published by the Florida Concrete and Products Association (1988) provides a thorough description of design criteria for pervious paving.

References 13, 16

Related Facilities:

Water quality inlets; Overflow BMPs; Underdrains

Reference 19

POROUS PAVEMENT

Regulatory Considerations:

Porous pavement's low infiltration, high maintenance, and frequent failure make it unpopular in most cases.

Overall Advantages/Disadvantages:

Advantages: Porous pavement provides relatively high removal efficiencies via infiltration for total phosphorous, nitrogen, and suspended solids. Porous pavement is used where land availability is a constraint, and reduces ponding.

Disadvantages: Porous pavement is subject to clogging, and is not suitable in areas of high water table or where soils have low infiltration rates. The potential for groundwater contamination exists, but has no been demonstrated. There is a low rate of reduction in runoff volume, required maintenance is high, and failure or greatly reduced effectiveness is likely even with maintenance. A saturated subbase may become structurally unsound.

References 13, 16, 19, 35

Site Constraints:

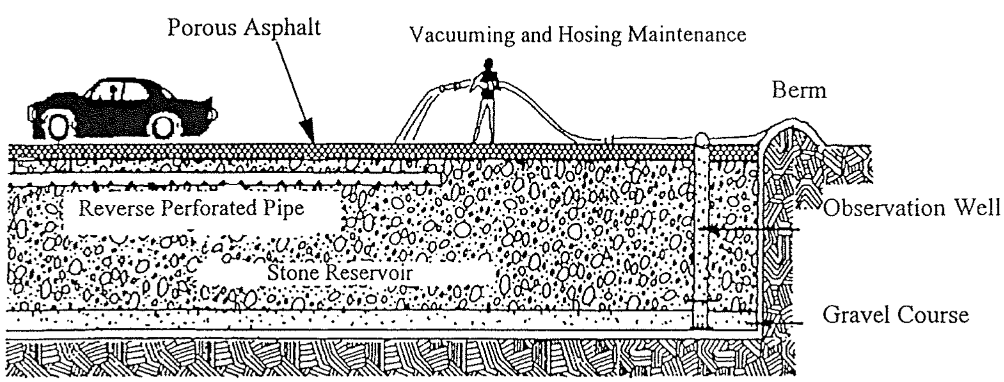
Treated Area:	1) Range=0.25-10 acres	30
	2) Less than 10 acres	33
	3) Less than 17 acres	13
	4) Range=2.5-5 acres	37
	5) 10 acres	12, 33
BMP Area:	Usually used when there is little unused space available: 1 acre	16, 30
Depth to Water Table:	1) Minimum=3 feet	12, 33
	2) Bed should be 3-5 feet above water table	13
	3) Range=2-4 feet	19
Site Slope:	1) Less than 5%	30, 33, 37
	2) Less than 3%	14
	3) Less than 15% slope of BMP site	13
Soil Permeability:	1) Minimum percolation rate of 0.3 - 0.5 in/hr	13
	2) Maximum percolation rate of 2.4 in/hr when facility provides all treatment and drains to groundwater.	30
	3) From 0.5 in/hr (loam) to 8.27 in/hr (sand)	30

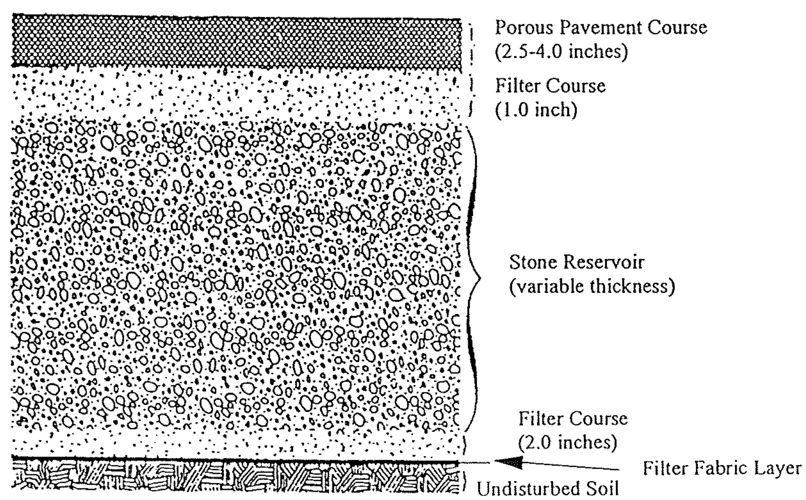
POROUS PAVEMENT		
Operational Efficiencies:		
TN Removal:	1) Range=40%-80%; Mean=57%	14
	2) Range=75%-85%	30
	3) Maximum=80%	12, 33
	4) Range=80%-85%	41
	5) Range=80%-99%	13
	6) Range=40%-60% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre	30
	7) Range=60%-80% exfiltrates 1 inch runoff per impervious acre; or all runoff, for 2 year design storm	30
	8) Range=80%-85%; Mean=85%	21
TP Removal:	1) Range=40%-80%; Mean=57%	14
	2) 65%	30
	3) Maximum=60%	12, 33
	4) Range=60%-80% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre; exfiltrates 1 inch runoff per impervious acre; and exfiltrates all runoff, up to 2 year design storm	30
	5) Range=60%-90%; Mean=65%	21
TSS Removal:	1) Range=60%-100%; Mean=83%	14
	2) Range=85%-95%	30
	3) Maximum=80%	1, 33
	4) Range=80%-95%	41
	5) Range=80%-99%	13
	6) Range=40%-60% when facility exfiltrates first-flush, 0.5 inch runoff per impervious acre	30
	7) Range=80%-100% when facility exfiltrates 1 inch runoff per impervious acre; and exfiltrates all runoff, up to 2 year design storm	30
	8) Range=80%-95%; Mean=90%	21
Flood Attenuation Capacity:	Low	
Operations & Maintenance Requirements:		
Required Activities:	Vacuum or high pressure wash, repair structural faults	19
Relative Level of O&M Required:	High	
Maintenance Period:	4 times annually	

POROUS PAVEMENT

Costs:			
	Construction:	1) $1.5/ft^2, or $65,340/acre of pavement	14
		2) $1.30 - $2.00/ft^2, or $56,628 - $87,120/acre of pavement	30
	Operations & Maintenance:	$0.01/ft^2 annually, or $653/acre of pavement	14

Schematic of Porous Pavement System





Adapted from: Schueler et al. (1992)

MODULAR GRID PAVEMENT

Description and Function:

Modular grid pavers consist of strong structural materials having regularly spaced void areas filled with permeable material, such as sod, gravel, or sand, that allows water to flow through it. When used and maintained correctly, flood flows are attenuated and pollutant loading to surface waters are reduced by the seepage of stormwater through holes in the pavers and underlying soils into the groundwater. As stormwaters pass through the pavers and soils, they are stripped of suspended particles, oil and grease, and other pollutants. Another benefit of using modular grid pavers includes the reduction in stormwater ponding that would occur on impervious pavement.

However, because the accumulated particulates and vehicle-based oils and grease may clog the surface pores, cleaning is often necessary to maintain effectiveness. If sod fills the paver voids, typical landscape maintenance is required. In addition, as the subbase soils become more compacted from pavement loads over time, infiltration rates may lower and the soil may remain saturated for extended periods, thus reducing the structural stability of the pavement. Also, if grid pavers leave significant areas of bare soil exposed, erosion may occur, especially on sloped areas.

Pavers are most appropriate for parking lots or low traffic areas. This BMP should only be used where natural or enhanced subsurface drainage will allow the soils under the pavers to remain unsaturated for most of the time. Because of the limited capacity to reduce runoff volume and the reduced pollutant removal benefits over time, pavers are a good temporary management method, and work well when used in conjunction with other BMPs. Although pavers have been permitted for stormwater management in some specific cases, they are generally not recognized by regulators as a valid permanent solution to runoff management problems in some situations. One of their main applications is for new development in urban areas where the drainage system is already at or over capacity.

Design Guidelines:

The area in which this BMP is to be used should be flat, and have low vehicular and pedestrian traffic. This system must percolate 80% of the 3-year 1-hour storm in 1 hour.

References 4, 16

Related Facilities:

Overflow inlets; Underdrains

Regulatory Considerations:

Modular pavers are feasible and acceptable as a substitute for traditional BMPs in certain circumstances.

MODULAR GRID PAVEMENT

Overall Advantages/Disadvantages:

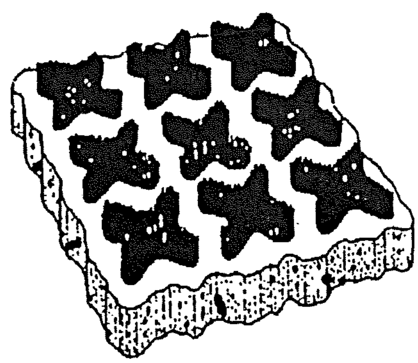
Advantages: Modular pavers can be used in areas of no land availability, promote groundwater recharge, reduce surface water pollutant loads, and reduce surface water flows to some degree.

Disadvantages: Paved areas must have very light or only pedestrian traffic. Modular paving is subject to erosion, and has relatively high maintenance requirements. The potential exists for groundwater contamination as well.

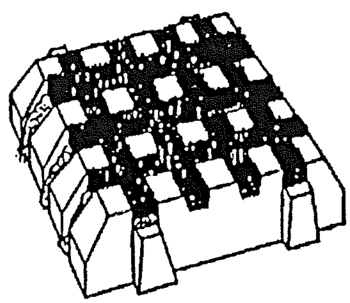
References 13, 16, 31

Site Constraints:		
Treated Area:	1 - 10 acres	14
BMP Area:	Usually used when there is little unused space: 1 acre	16, 33
Depth to Water Table:	Minimum=3 feet	33
Site Slope:	Less than 5%	30
	Less than 3%	14
Soil Permeability:	From 0.5 in/hr (loam) to 8.27 in/hr (sand)	30
Operational Efficiencies:		
TN Removal:	1) Range=60%-90%; Mean=75%	14
	2) Range=65%-100%; Mean=90%	21
TP Removal:	1) Range=60%-90%; Mean=75%	14
	2) Range=65%-100%; Mean=90%	21
TSS Removal:	1) Range=60%-90%; Mean=75%	14
	2) Range=65%-100%; Mean=90%	21
Flood Attenuation Capacity:	Low	

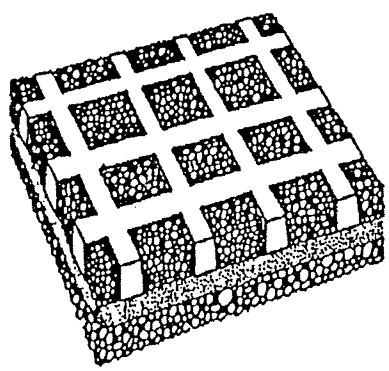
MODULAR GRID PAVEMENT		
Operations & Maintenance Requirements:		
Required Activities:	Landscaping, repair of erosion impacts	16
Relative Level of O&M Required:	Moderate	
Maintenance Period:	2 times annually	
Costs:		
Construction:	$1.0/ft^2, or $43,560/acre of pavement	14
Operations & Maintenance:	$0.04/ft^2 annually, or $1,742/acre of pavement	14



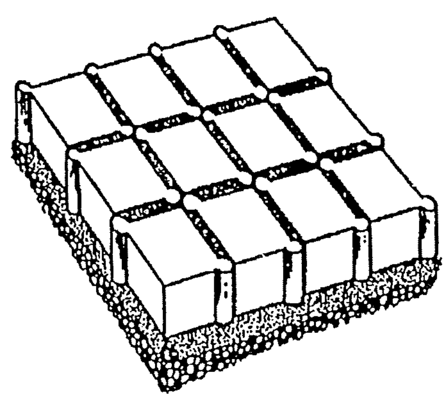
Poured-in-Place Slab



Castellated Unit



Lattice Unit



Modular Unit

From: Livingston et al. (1993)

WATER QUALITY INLET

Description and Function:

Water quality inlets, as their name implies, provide or facilitate water quality treatment, but do not alleviate flooding. They can either be incorporated into newly-designed urban drainage systems, or can be placed in existing systems for retrofits. The specific benefits derived from water quality inlets vary with their design.

The term "water quality inlet" is used here in a general sense and may include one of several principals and designs. One general inlet type is a "smart" inlet that diverts the initial flush of stormwater to another treatment or storage facility and allows subsequent runoff flows to pass by the treatment facility. This type of inlet is most commonly used in association with BMPs of limited capacity, such as exfiltration trenches, underground storage vaults, or parallel pipe storage. The smart inlet has no treatment capacity in itself, but only conveys water to another BMP.

Another general type of water quality inlet is a filter inlet (also discussed in the "Underdrain and Filtration System" section below), which consists of a chamber filled with filter fabric covered with sand, gravel, or other filter material. A sedimentation chamber is also often included to allow larger particles to settle out of the stormwater prior to the stormwater entering the filter chamber. Water that enters the filter chamber must pass through the sand prior to discharging. Pollutants that may be removed from the runoff using sand filters include oil and grease, suspended particles with adsorbed metals and organic compounds, and some nutrients through bacterial action or adsorption of phosphorus. Because the flow rate through a sand filter is very slow in relation to runoff inflows to the inlet, a filter inlet is best designed as an "off-line" chamber. In addition, the accumulation of pollutants and fine particulates in the sand necessitates labor intensive maintenance, which includes cleaning or replacing the filter material.

A variation on these designs is an inlet with built-in skimmers that divert the top layer of runoff with associated oil, grease, and floating debris to an off-line holding chamber for removal by maintenance crews.

Several types of these inlets have been permitted in Florida as alternatives to traditional BMPs in situations where land is not available, where urban growth in already developed areas has overwhelmed the drainage system, or other specialized circumstances. More often, water quality inlets are incorporated into the design of a stormwater management system that includes other BMPs for flood attenuation and more complete treatment.

Design Guidelines:

Water quality inlets must be designed to provide adequate treatment yet still convey design storms. They are used for pre-treatment of stormwater prior to the water entering the drainage system.

Reference 19

Related Facilities:

Other parts of the treatment train - swales, ponds, underdrains, etc.

Regulatory Considerations:

These structures are fairly specialized, and are most feasible for urban retrofits or where land is not available for traditional BMP usage.

WATER QUALITY INLET

Overall Advantages/Disadvantages:

Advantages: This BMP has no land requirement, with filtering inlets most suitable for small areas of mainly impervious land surfaces.

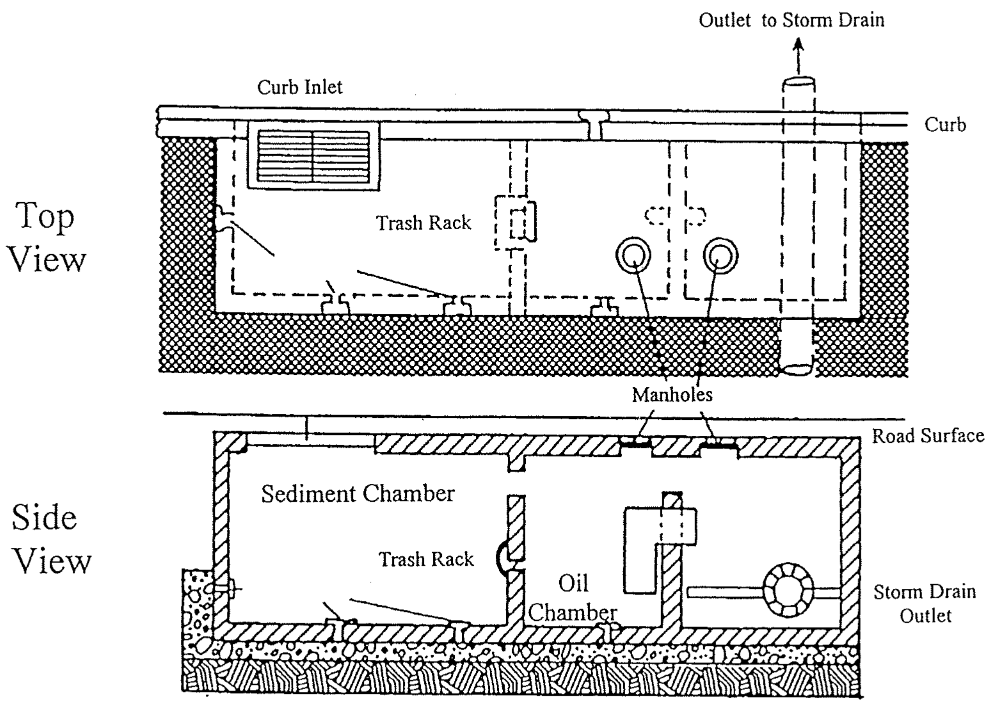
Disadvantages: Some types of inlets are relatively expensive. Sand filter inlets require high maintenance, have limited capacity, and are subject to failure.

Reference 9

Site Constraints:		
Treated Area:	Less than 2 acres	33
BMP Area:	400 ft^3/acre, underground	33
Depth to Water Table:	All	14
Site Slope:	N/A	
Soil Permeability:	N/A	
Operational Efficiencies:		
TN Removal:	1) Range=5%-10%; Mean=8% 2) Range=5%-55% 3) Range=5%-55%; Mean=20%	14 41 21
TP Removal:	1) Range=5%-10%; Mean=8% 2) Range=5%-10% 3) Range=5%-10%; Mean=5%	14 41 21
TSS Removal:	1) Range=10%-25%; Mean=18% 2) Maximum=25% 3) Range=0%-20% for 400 ft^3 wet storage per impervious acre 4) Range=0%-95%; Mean=35%	14 41 30 21
Flood Attenuation Capacity:	N/A	

WATER QUALITY INLET			
Operations & Maintenance Requirements:			
	Required Activities:	Clean debris from inlet, change sand from filters	16, 45
	Relative Level of O&M Required:	Moderate to high	
	Maintenance Period:	1 time annually	
Costs:	Construction:	1) \$8,000/unit, \$10 - \$40/ft^3 treated 2) \$5,000 - \$15,000/unit, \$7,000 - \$8,000 average	33 30
	Operations & Maintenance:	\$600 annually	20

Water Quality Inlet Schematic



Adapted from: NJDEP (1994)

UNDERDRAINS AND FILTRATION SYSTEMS

Description and Function:

The central principal of underdrain systems is to collect and convey stormwater through a system of pipes or gravel-filled trenches after the stormwater has infiltrated into the soil. This method of stormwater treatment may be incorporated into a detention basin, or it may be constructed as a separate linear or grid system of conveyances. When used in concert with a detention pond, underdrains provide enhanced infiltration so that when stormwater enters the basin it is retained until it infiltrates into the groundwater, evaporates, or transpires. No stormwater should leave the facility as surface water, except under very high flows via an emergency spillway. Flood attenuation (lower peak flow rates and volume reduction), base flow maintenance, and water quality benefits result from the use of this BMP.

Underdrains are typically constructed by burying a perforated pipe wrapped in filter fabric, or by excavating a trench, lining the trench with filter fabric and then partially filling the trench with gravel covered with filter fabric, and filling the top of the trench to grade with dirt. A layer of tile drains may also be used. This serves to intercept infiltrated stormwater and direct it to areas where the water can dissipate into the surficial aquifer. Although a certain amount of natural infiltration is necessary to make this BMP function, areas with low infiltration often most appropriate for using underdrains.

Filtration systems are of similar design but serve a different purpose. Stormwater filters typically are constructed of a series of filter fabric-wrapped perforated pipes or gravel filled trenches surrounded by a sand layer designed to provide water quality treatment through filtration of infiltrated stormwater. Filters are often constructed in the banks or near the outfall structure of detention areas to treat, intercept, and collect infiltrated stormwater prior to discharge from the detention area. Filters may be used for underdrains that discharge stormwater to the surficial aquifer, or may be a last treatment step prior to discharge via the surface water flow.

Because infiltration is the primary treatment means and discharge pathway, it is important to prevent clogging of the underdrain system, and associated detention basin bottom. To this end, a sediment trap should be constructed to allow particulate material to settle out of the stormwater prior to entering the basin. The sediment trap should be cleaned periodically, and the basin bottom should be cleaned and scarified to maximize infiltration rates.

Underdrain and filtration systems used with detention basins are not uncommon, but are not as readily accepted as other (wet detention basins) BMPs, mainly because of the relatively high construction cost (for enhanced systems), requisite high level of maintenance, frequency of failure, and reliance on subsurface conditions to allow continued infiltration. Under desirable site conditions filtration basins work very effectively, but their reliability is much reduced under adverse conditions (clogging, high water table, etc.).

UNDERDRAINS AND FILTRATION SYSTEMS

Design Guidelines:

Small sites are generally most appropriate for this BMP, (less than 5 acres). The planning and design of underdrains and filters entails several steps, including a site reconnaissance (survey, determination of water table depth and infiltration rates, etc.), determination of the length, spacing, and volume of underdrains required to drain and filter the regulatory volume within 72 hours, and integrating the underdrain and filters with a detention pond, if appropriate. Minimum pipe diameter is 12 inches and minimum trench width is 3 feet. Filter fabric must wrap material in trenches and a sediment sump is required at the inlet. Design criteria and methods for design of underdrains and filtration systems are thoroughly discussed by Livingston et al. (1988).

References 13, 16, 35

Related Facilities:

Inlets, detention ponds, other parts of treatment train

Regulatory Considerations:

Underdrains and filtration systems are perceived as requiring high maintenance and being subject to clogging. They are not popular with regulators, but are permitted as a General Permit.

Overall Advantages/Disadvantages:

Advantages: This BMP requires limited land surface, recharges groundwater, and enhances low natural infiltration rates.

Disadvantages: Underdrains and filters are subject to clogging thus often requiring maintenance, and the potential for groundwater contamination exists.

Site Constraints:

Treated Area:	1) 0.5 - 50 acres 2) Less than 5 acres (sand filter)	14 13
BMP Area:	1) 5-10% of total drainage area: 0.03-5 acres 2) 360 ft^2/per treated acre, at least 18 inches deep	30 13
Depth to Water Table:	2 - 4 feet minimum	33
Site Slope:	1) Less than 5% for basin floor 2) Less than 3%	30 14
Soil Permeability:	From 0.5 in/hr (loam) to 8.27 in/hr (sand)	47

UNDERDRAINS AND FILTRATION SYSTEMS			
Operational Efficiencies:			
	TN Removal:	1) Range=20%-40% 2) Range=75%-87% 3) Range=20%-40%; Mean=35%	41 13 21
	TP Removal:	1) Range=0%-90% 2) Range=19%-61% 3) Range=0%-90%; Mean=50%	41 13 21
	TSS Removal:	1) Range=60%-95% 2) Range=75%-87% 3) Range=60%-95%; Mean=80%	41 13 21
	Flood Attenuation Capacity:	25-year 24-hour flood	35
Operations & Maintenance Requirements:			
	Required Activities:	Clear debris from structure, change sand in filter as needed	16, 19
	Relative Level of O&M Required:	Moderate to high	
	Maintenance Period:	Clean inlet - 2-3 times annually. Replace sand every 1-2 years	
Costs:			
	Construction:	$6,375/acre treated	33
	Operations & Maintenance:	5% of construction cost annually: $320 per treated acre	33

2.4 Other Urban Best Management Practices

The following descriptions are for those BMPs that are in some ways less capital-intensive and less traditional. These BMPs have been grouped as being nonstructural, structural or erosion controls. For each BMP the objective being addressed, the principle underlying the practice, and a description of the BMP are presented.

- **Nonstructural Source Controls**

The traditional approach to utilizing stormwater BMPs involves the placement of structural facilities intended to remove pollutants from the runoff stream. This methodology assumes that runoff has become contaminated, and works to reduce loadings after potentially harmful chemicals have already entered the environment, the remedial approach. An alternate, pro-active, approach for limiting stormwater-borne pollution is to control the amount of chemical compounds that enter the environment and runoff at the chemicals' source.

Limiting the initial distribution of chemicals into the environment is preferred to cleaning up polluted stormwater for several reasons. Traditional stormwater treatment facilities do remove pollutants from the runoff at the time of treatment, but the pollutants in many cases are not "removed" from the environment but are only detained, for example, in pond sediments. Although providing a sink to accumulate harmful substances is beneficial in many ways, a disturbance to the system such as extremely high floods or a physical disruption to the treatment facility such as dredging can re-introduce the pollutants into the surface water system. Reducing the amount of chemicals that enter the environment in the first place removes the risk of pollutants re-entering surface waters in the future. In addition, limiting the release of excess polluting chemicals reduces the amount of fertilizer, pesticides, etc. that must be used to accomplish their purpose, and results in cost savings to the users.

Source control can include a variety of approaches such as user education as to the optimal application rates and methods for a compound, packaging information, promoting good disposal practices of contaminated material such as empty containers, as well as activities such as street sweeping, cleaning construction debris, etc. An important aspect of source control is to change longtime habits of use and disposal of potentially contaminating materials. For example, longtime users of agri-chemicals may be reticent to change practices to more environmentally friendly biological controls. Also, good housekeeping measures such as frequent removal of debris from construction sites can prove very effective in pre-empting pollutant loading to surface waters. The following table summarizes the objectives, principles, and methods of implementing various source controls on stormwater pollutants.

Fertilizer Application Control	References: 16, 19, 45

Objective:

The objective of fertilizer application control is to limit the amount of fertilizer that is applied on agricultural, residential, or commercial land to the optimal rate, without overfertilizing.

Principle:

Excess fertilizer that is put on the land is not assimilated by the plants and can be washed off to contribute to pollutant loading to surface waters. Excess fertilizer can also seep into groundwater to cause elevated nutrient levels in the surficial aquifer. By limiting fertilizer application, only as much material as the plants can assimilate will be applied to the land, thus reducing the potential for nutrient-rich runoff to damage receiving waters.

Description:

This management practice can be implemented through public education, packaging labels stressing the results of over-fertilizing, use of alternative or natural fertilizer products, and optimizing the application times of fertilizer. Also, soil testing may reveal the best mix of fertilizer to obtain good plant growth. Other techniques, such as the application of fertilizer in irrigation water, "fertigation", can be used. The unnecessary loss of fertilizer can also be reduced by controlling erosion, as described below. Knowledgeable groups such as the Cooperative Extension Service or the USDA Natural Resources Conservation Service may be queried for methods to optimize fertilizer application.

Solid Waste Collection and Disposal	References: 16, 19

Objective:

The objective of reviewing solid waste practices is to reduce pollutant loadings to urban stormwater resulting from solid waste handling, storage, and disposal methods.

Principle:

The generation of and the need to dispose of solid waste is a fact of life. However, if precautions are not taken to limit the exposure of waste materials to the environment, pollutant loadings to surface water and groundwater can increase because of unnecessary contact between solid waste material and the air, rainfall, and stormwater runoff.

Description:

Improvements to solid waste management techniques may include public education, revised procedures for the handling and collection of waste vegetative matter (leaves, landscape debris, etc.), disposal and collection of white goods and other potential contaminants, opportunities for recycling, etc.

Pesticide Use Control	References: 16, 19, 45

Objective:

The objective of pesticide use control is to limit the amount and extent of pesticides that are released into the environment.

Principle:

The excessive use of pesticides can result in unnecessary impacts to living organisms, including humans. By limiting the use of these chemicals to the appropriate application procedures and rates, and by using alternate pest control methods, pesticide loadings to surface waters can be lowered and the potential for environmental degradation can be reduced.

Description:

Several mechanisms can be used for this objective, including legal requirements for pesticide application, stringent review of minimum useful application rates, methods of application, equipment cleaning, disposal of unused chemicals and empty containers, chemical storage, alternate pest control methods (such as crop rotation or biological controls), and public education. Both commercial scale and private home owners are subject to these issues. The unnecessary loss of pesticides can also be reduced by controlling erosion, as described below. Knowledgeable groups such as the Cooperative Extension Service or the USDA Natural Resources Conservation Service may be queried for methods to optimize pesticide application. Integrated Pest Management (IPM) combines all approaches in pest reduction using a thorough understanding of pest life cycles and constraints of the site.

The following guidelines may be used for pesticide management:

- it is generally best to use the least toxic material that will accomplish the purpose.
- pesticides that degrade the most rapidly are least likely to become water pollutants.
- pesticides with low solubility in water are less likely to cause water pollution by dissolving in stormwater runoff.
- broad spectrum pesticides should be used instead of a series of chemicals with very specific target applications.
- improve pesticide labeling - use larger print for legibility and make directions more easily understood

All labeling should be read to determine the best methods of application. Application rates may be influenced by the following factors:

- weather, climate, and seasonal characteristics;
- characteristics of soils, terrain, geology, etc.;
- presence of fish, wildlife, humans, livestock, or other non-target organisms; and
- drainage patterns.

Source Control on Construction Sites	References: 16, 19

Objective:

The objective of implementing source control on construction sites is to reduce the potential for increasing stormwater pollutant loadings through contact with construction debris, erosion of bare earth construction sites, inappropriate handling of hazardous materials at sites, etc.

Principle:

Many activities take place at construction sites that may impact stormwater runoff. Disturbed land is subject to increased erosion, trash and debris from construction sites may end up in runoff stream, and hazardous contaminants such as paint and stains, gasoline and oils, etc. may be spilled or otherwise released into the environment. Several steps can be taken to reduce the risk of such occurrences.

Description:

This management practice includes safe materials handling and plain "good housekeeping". Impacts from erosion can be minimized by grading the site to retain all runoff in temporary or permanent detention basins, protecting storm drain inlets, using erosion control barriers such as hay bales or silt screen, and keeping as little of the site unvegetated as possible. Materials handling procedures include keeping chemicals and toxic materials in covered, locked storage areas, cleaning up the site and removing trash and debris at the end of each day, cleaning up spills when they happen, designating protected areas for equipment and machinery cleaning, and using proper sanitary controls.

Street Cleaning	References: 16, 19, 45

Objective:

The objective of street sweeping is to remove pollutants, including oil and grease, other organic materials, metals, dust and particulate matter, and deposited atmospheric pollutants from the street surface before it is entrained or dissolved in stormwater runoff.

Principle:

Urban roads and streets are virtually impervious, so all rainfall that lands on the road surface becomes runoff. Thus, all pollutants on the road will enter the runoff stream unless removed prior to rain. Street sweeping physically removes the dry weather accumulation of these chemicals for safe disposal.

Description:

Street sweeping uses vacuuming, brush sweeping, water sprays, or other physical processes to remove pollutants from street surfaces. This technique is used with varying success on roads, parking lots, driveways, and all hard surfaces subject to vehicular traffic. Studies have shown that the frequency of street sweeping greatly affects the effectiveness of this management practice.

- Structural Runoff Controls

Structural runoff controls are the most commonly used means of managing stormwater quantity and quality. Ponds, swales, diversions, drains, and filters are included in this category of runoff BMPs. Some of the most commonly applied structural BMPs have been discussed in detail in preceding section. The following tables summarize the objectives, principles, and methods of addressing stormwater management issues through the implementation of some of the less-frequently used structural BMPs. There are many factors that affect the likelihood of a particular type of BMP being used in a given situation. Some of the important aspects of BMP selection are cost, site physical characteristics (site size and shape, depth to water table, soil permeability, surface slope, vegetative cover), land availability for BMP use, level of effort required for operating and maintenance, permittability, and design life of the facility. The integration of all these factors results in a determination of the feasibility of using one or more BMPs of a certain type. The BMPs described in the preceding section have repeatedly ranked high in one or more of the limiting BMP selection criteria, resulting in their frequent application in a wide variety of circumstances. Other BMPs, while not as widely usable as those listed above, have their own merits for certain situations. For example, a BMP such as porous pavement may not be practicable for use in most cases because of its cost, maintenance requirements, and low volume capacity. But in some situations, such as an urban retrofit site with no available open land, it may be the most feasible option.

Therefore, the following BMPs should be considered for use where one or more selection factors make the use of a traditional BMP infeasible. It should be noted that, for practical considerations, the selection criterion that most influences BMP selection is cost. If site characteristics make the use of several different types of BMPs equally feasible, the least expensive alternative will usually be selected. The cost of a BMP involves several considerations, including the cost of land necessary to place the BMP, construction cost, operating cost, aesthetics, and maintenance or replacement cost. These costs must be integrated over the design life of a BMP to determine the real or relative cost of feasible alternatives. As site physical characteristics become more restrictive, more expensive BMP alternatives must be considered.

Rooftop Runoff Storage	References: 16, 19, 45

Objective:

The objective of rooftop runoff storage is to replace direct connections of roof drains to storm sewers with local stormwater dispersal systems that dispose of runoff without burdening the regional drainage system.

Principle:

Roof drainage represents virtually 100% of the rainfall that falls on the roof surface, as no infiltration (hopefully) occurs. It is practical in many cases to "disconnect" the link between roof drains and the storm sewer system, and to promote localized stormwater management practices.

Description:

Site-specific disposal of roof drainage can be accomplished through a variety of small-scale methods, including french drains or exfiltration trenches, cisterns used to recycle rainfall for landscape irrigation, on-site underdrain systems, etc. These systems can be designed into the building's original stormwater plans, or can be added later. Many of these methods are relatively inexpensive, if sufficient land is available.

Parking Lot Storage	References: 16, 19, 45

Objective:

To attenuate flood peak flows through temporary storage of stormwater in parking lots.

Principle:

Many parking lots, especially for large commercial sites, are designed to be at capacity for only a few days per year. The resulting excess surface area is therefore generally available to assist in the storage of temporary stormwater prior to entering the drainage system. This technique can be especially useful in urban areas where the existing drainage system has reached its capacity. By holding stormwater directly in the parking lot and gradually releasing it, peak flood flows can be reduced.

Description:

Many parking lots, especially large commercial lots, have many empty spaces except for a few days each year. It may be feasible to construct a temporary retention area in the vacant portions of the parking lots to assist in stormwater management. Also, new parking lots may be designed in terraced levels to designate the lowest level as a stormwater storage area. It would be necessary to maintain the safety and convenience of the individuals parking in the lot, but the expanses of asphalt commonly seen around shopping malls could well be used for this purpose. Runoff would be drained from the lot via site grading, porous pavement, modular grid pavers, or inlets and underdrains.

Physical Treatment	References: 16, 19

Objective:

The objective of physical treatment alternatives is to provide water quality treatment using processes more commonly employed for potable water treatment.

Principle:

In some cases, it is feasible to utilize processes normally used to treat potable water, or domestic or industrial sewage to treat stormwater runoff. This alternative is especially attractive in highly concentrated runoff, or if stormwater has become contaminated on a site (at airplane deicing stations, for example), and must be treated prior to leaving the site.

Description:

Processes such as settling, filtration, screening, flocculation, and disinfection may be used. Also, use of a mechanical oil/water separator may be called for in some circumstances, often in conjunction with other, conventional BMPs. These unit processes may be used at a small scale and using simple technology so as to not cost as much as an equivalent process on a treatment plant scale.

Alum Injection	

Objectives:

The objective of alum injection is to provide a chemical means of flocculating suspended material into particles large enough to settle out of the water column, subsequently removing the pollutants that adhere to the particulate matter.

Principles:

Suspended particles in stormwater are solid, but are very small and may remain suspended even with very low flow rates. Many compounds, including metals, organic compounds, and phosphorus, tend to adhere, or adsorb, to these particles. Adding alum to stormwater can promote small particles to bind together (flocculate). The larger pieces of solid material will more readily sink to the bottom of the water column and become bound to sediments, thus stripping the water of pollutants.

Description:

Alum addition can be accomplished through several approaches. Open water bodies such as lakes can benefit from "whole lake" treatment, in which alum is added to the lake surface from a boat or airplane. Floc forms as particulate material aggregates and the enlarging solids sink to the bottom, becoming bound to existing sediments. Also, alum can be injected directly into stormwater. The direct injection approach has both positive and negative aspects. Suspended material in stormwater can be inoculated directly, without waiting for it to reach a receiving water body. However, the potential for aluminum toxicity to benthic organisms resulting from settled floc remains an unresolved issue. Application to a lake takes advantage of the buffering activity that will have occurred once the runoff mixes with the lake waters. Also, the equipment required for stormwater injection of alum is relatively expensive, and high levels of operating and maintenance activities are necessary. Whole lake treatment requires much less expensive equipment, and little or no maintenance is required.

- Erosion and Sediment Control Practices

Stormwater runoff can be a powerful physical process, and is capable of removing significant amounts of soil from a site. The subsequent pollutant load of suspended solid (particulate) material can cause environmental degradation by silting over wetland areas or smothering benthic habitats, producing sediment loads that clog streams, ditches and other surface water conveyances, or by transporting other pollutants such as metals and organic compounds. Erosion also results in problems for many types of urban land, and can make roads, foundations, bridges, drainage structures, and other infrastructure physically unstable. However, methods do exist to reduce soil loss and erosion, and subsequently reduce potential harm to the environment. A review of erosion and sediment control practices is also given in Livingston et al. (1998).

Erosion and sediment control practices are often considered as a sub-category of stormwater management BMPs. Although most stormwater BMPs directly or secondarily act to remove suspended particulate material (sediments) from runoff, some types of BMPs are more effective at this than others. In general, ponds, created wetlands, and other BMPs that serve to slow runoff flow velocities or entrap suspended particles are best suited to sediment control.

Other stormwater management practices help to limit the amount of soil lost to runoff and on-site erosion by reducing the potential for erosion to occur at all. These practices are essentially source controls for erosion control, similar in concept to chemical source controls addressed above. Two general types of erosion controls are structural and vegetative practices. Structural erosion control practices use site grading to divert on-site runoff to temporary holding ponds, silt screens, stabilizing exposed soils and drainage ditches, diversion berms, drains, and other constructed measures to control runoff on a site. Vegetative controls include preparing a site for planting, and planting ground cover, establishing vegetated buffer strips adjacent to areas of exposed soils, mulching or grassing exposed soils, etc. Both these measures can be effective erosion control methods, if implemented properly, as described below.

- Structural Practices

Structural erosion control practices include any constructed means of preventing significant loss of soil from a site through the action of stormwater runoff. As stated above, the control of soil loss can occur either as a recovery of particulate material from runoff after erosion has occurred, or as a pro-active means of preventing soils from being entrained in runoff altogether. Many structural methods of accomplishing these objectives are commonly used today. Although land with little topographic relief, such as many of Florida's coastal communities, does not have as great a potential for erosion as more pronounced variation in land surface elevation, providing erosion is still a problem, especially under certain conditions such as on construction sites or along stream channels.

Structural erosion control practices may include activities such as stabilizing areas subject to vehicular traffic, stabilizing areas of exposed soil or around drainage structure inlets and outlets, site grading to retain stormwater on-site, constructing temporary or permanent berms to divert stormwater to sedimentation basins, erecting silt barriers, providing erosion-resistant runoff conveyances such as concrete or rip rap lined channels, constructing subsurface drains to channel runoff down steep slopes without causing erosion, and other methods. The following table summarizes some of these alternatives.

Road Stabilization	References: 16, 19

Objective:

To minimize sediment loss and erosion from disturbed land during construction activities.

Principle:

Allowing exposed soil to erode during site or roadway construction activities increases the pollutant load on surface water bodies through the entrainment of particulate materials in stormwater runoff. Temporary measures can be taken to stabilize construction site access points and roadways to reduce the potential for erosion during construction, before areas are stabilized with vegetation, pavement, or rip rap.

Description:

Gravel and small stones used to construct a temporary pad at the ingress/egress point of a construction site. This reduces the amount of dirt carried onto the road from the site, and prevents rutting and damage to the edge of the roadway. Gravel can be used as a temporary road bed material prior to final treatment (paving) to reduce erosion of the roadway. Parking areas, driveways, and access points can also be covered with gravel for the same effect.

Sediment Barriers	References: 16, 19

Objective:

To construct a physical obstruction to prevent particulate matter from leaving a site entrained in stormwater runoff.

Principle:

Allowing exposed soil to erode, especially during construction activities, increases the pollutant load on surface water bodies through the entrainment of particulate materials in stormwater runoff. Measures can be taken to reduce the potential for erosion during construction, or on a permanent basis.

Description:

Several types of sediment barriers can be used to reduce the amount of particulate matter entrained in stormwater. Hay bales can be arranged in single or double rows along a toe of a slope, or at the lowest edge of a construction site, and staked for stability. This will retain suspended sediment and slow runoff flow velocity. Using the same principle, a silt fence, or screen, can be constructed using filter fabric supported by stakes. Silt fences are usually temporary erosion control measures. Sediment barriers can also be constructed of brush, limbs, vines, or other material found on-site to obstruct sediment release and slow runoff flows. Sediment barriers are often subject to deterioration after a short time in use and should be regularly inspected and replaced. An alternative to sediment barrier construction is to erect a partial barrier to flows at drop or curb inlets using hay bales. This is most often implemented during construction activities, and should be designed to not impede high flows.

Dikes and Diversions	References: 16, 19

Objective:

The objective of using a dike for surface water flow diversion is to direct stormwater runoff to treatment areas, or to keep stormwater on a site, so as to minimize soil loss and pollutant loadings from erosion.

Principle:

Stormwater runoff can be managed on a site by constructing temporary or permanent dikes or berms to divert the flow to treatment areas, or to otherwise manage the flows. Diversions are used to retain stormwater on-site, to intercept overland flow on a slope, to slow runoff flow velocity, or to control on-site flow patterns and prevent off-site discharge. This allows particulates to settle out of runoff and not be transported into receiving surface waters.

Description:

Diversion berms can be constructed at the toe of a slope to direct runoff to a temporary or permanent storage or treatment facility, thus preventing runoff-borne sediment from leaving the site. On construction sites, temporary berms may be located at the lower edge of areas of disturbed land with exposed soils, directing runoff away from areas with high erosion potential. Small berms may also be constructed parallel to site slopes mid-way down the slope to reduce the flow path length and intercept sheet flow before erosion occurs. Runoff can then be directed to a stabilized area. Such diversion structures are effective on either a temporary or permanent basis, and can be incorporated into site landscaping.

Sediment Traps and Basins	References: 16, 19

Objective:

The objective of sediment traps and basins is to provide a receiving area for sediment-laden runoff. This reduces suspended solids loading in surface runoff, and retains stormwater to reduce erosion.

Principle:

Sediment traps and basins provide an area to collect runoff and allow sediment to settle out of the water column. Particle settling occurs as the flow velocity of the runoff drops upon entering the basin. Solids and associated pollutants are thus left behind in the trap as the runoff discharges off-site or infiltrates into the groundwater.

Description:

Sediment traps and basins can be used as temporary storage and treatment areas during construction, or on a permanent basis. They can be used as isolated settling ponds, or be incorporated into other stormwater treatment and storage facilities. For example, sediment basins, sometimes called "forebays", are used as the initial impoundment that runoff enters, slowing flow velocity and allowing particulate materials to settle out. The clarified stormwater then flows to another storage and treatment area without its initial load of sediment. This serves two purposes: accumulated sediment is easily removed from the smaller forebay trap, and the sediment does not enter the main storage/treatment facility. By removing sediment first, infiltration rates in the main pond are maintained, and potential impacts to emergent vegetation in the main pond resulting from sediment accumulation are minimized.

Subsurface Drain	References: 19

Objective:

The objective of using subsurface drains is to move excess water away from surficial soils, to prevent excess moisture from creating unstable soil conditions and allowing subsequent erosion.

Principle:

Excess moisture in surficial soils causes soil saturation and a diminishing of the soil stability. Removing excess soil water reduces the tendency for erosion.

Description:

A perforated pipe, usually small diameter, can be buried underground in areas subject to saturation and erosion. Surficial soil water will tend to drain into the pipe, and be carried downgradient or infiltrate to a lower level out the bottom of the pipe. Subsurface drains can be used to improve slope stability and to stabilize berms and drainage structures. Tile underdrains can be used for the same purpose, but are usually more expensive to purchase and install.

Flumes	References: 16

Objective:

The objective of using flumes, or channelized flow paths, for runoff is to reduce erosion caused by excess overland flow of stormwater.

Principle:

Overland flow of runoff can cause significant erosion and soil loss, especially on slopes and in areas with high topographic relief. Flumes provide a stabilized channel to direct runoff to appropriate areas, thus reducing erosion.

Description:

Flumes are open channel or piped constructions that intercept and direct stormwater to appropriate receiving areas. They can be either temporary, for use during construction activities, or permanent fixtures on a site. An example of a temporary flume is a slope drain, which consists of a flexible or rigid pipe that is embedded in a side slope to carry stormwater from the top of the slope to the bottom without eroding the land surface. This type of flume is typically employed on a construction site prior to placement of final drainage structures. An example of a permanent flume is a concrete-lined open channel built into the side of a slope to convey stormwater from the top to the bottom of the slope. This application is often seen along highway shoulders with a significant grade. Runoff flow energy is frequently dissipated at the bottom of open channel flumes by embedding bricks in the concrete slope, or other methods of creating turbulence.

Waterway and Outlet Protection	References: 16, 19

Objective:

The objective of providing waterway and outlet protection is to minimize erosion in stormwater conveyances by providing stable channels and reducing flow velocities in erosion-prone areas.

Principle:

Conveyance of stormwater in channels often results in high velocity flow which can cause erosion and damage to channels and outlet structures. Protection of waterways and structures minimizes both degradation to drainage infrastructure and reduces pollutant loads from suspended particles. Although no water quality treatment is afforded by channel and structure protection, these measures prevent additional degradation to stormwater quality during its transport.

Description:

Man-made channels such as drainage ditches can be protected from erosion by lining the channel sides and bottom with a stable material, such as concrete or rip rap (large, erosion-resistant stones placed to form channel sides and bottom). Likewise, stabilization can be provided to natural stream channels by the selective use of similar material. However, discretion must be used in altering natural channels, as it is desirable to preserve natural features such as habitat value as much as possible. Also, the entire reach of many channels does not need stabilization. To limit costs and to promote natural functions of these waterways, only portions of channels subject to erosion from high flow velocity, sharp changes in direction, unstable bed material, etc. should be artificially stabilized.

Erosion and damage to structures can occur when stormwater is discharged from a drainage system at high flow rate or high velocity. Placing energy dissipating devices in the flow path (introducing turbulence in the flow or placing check dams in the channels to temporarily obstruct flow), or constructing stilling wells at stormwater discharge points reduces runoff flow velocity and subsequent impacts. This can be accomplished through use of paved aprons or spreader structures to disperse flows at discharge points, or by installing rip rap, providing drop structures to allow stormwater to "step down" inclines without traveling a high-grade slope, or other structural means.

3.2 Vegetative Practices

The primary objective of vegetative erosion control practices is to provide vegetative cover for soils that may be eroded is left exposed. Vegetation acts to control erosion by reducing the overland flow velocity of runoff, trapping particulate material, preventing the entrainment of soil particles by an interwoven root network, and reducing the physical impacts of rainfall on soil that leads to erosion, by providing a ground cover to deflect the force of falling rain drops.

This objective can be met by either preserving existing vegetation on a site, or by planting desirable vegetation for erosion control, as well as for landscaping purposes. Existing vegetation is often desirable to leave on a site, because the plant community is already established, and the living root mat is well developed. The survival of existing vegetation is relatively well-insured because of the plants' exposure to site conditions, unlike planting new vegetation and hoping that it adapts to local sunlight and water availability.

Vegetation is an ideal means of reducing erosion in Florida. The long growing season and mild winters ensure that a viable plant community will be active all year. Most types of vegetation will help reduce erosion. Grass is very well suited for this purpose because of its homogeneous coverage and thick root structure. However, advantageously located vines, bushes, shrubs, or non-woody ground covers are also desirable. Trees are beneficial also, their canopy reducing the force of falling rain and their roots holding soil in place under most conditions, including stream banks and steep slopes.

The level of effort required for the maintenance of vegetation erosion controls varies with the type of plants used. Natural species will require the least care, possibly only annual pruning. Many common landscape plants may require more care, including watering, fertilization, cutting back or pruning, and application of pesticides. It can be seen that using in-place vegetation can be a considerably less expensive means of controlling erosion than using either structural methods or by using introduced vegetation.

Preparation of Site for Vegetation	References: 16, 19

Objective:

The objective of preparing a site for vegetation establishment is to maximize the surviving ratio of plants, when planted.

Principle:

If vegetation intended to aid in erosion control or other hydrologic functions is planted in unprepared sites, conditions may not be suitable for its survival and plantings may be unsuccessful. By ensuring that a site has appropriate conditions for plant growth, more effective erosion control can be accomplished.

Description:

Site preparation ensures that a site's soil composition and stability, hydrologic features, and other factors important to plant survival are ready for planting to begin. Activities that can apply include site grading to establish surface drainage patterns, soil surface roughening (scarifying), adding topsoil or fertilizer, testing soil for moisture content, fertilization, ensuring that sufficient sunlight is available for the target species, removing nuisance plants, etc. All these items should be accomplished prior to planting to ensure that desirable vegetation becomes established quickly and provides adequate protection against erosion and soil loss.

Grass Establishment	References: 16, 19

Objective:

The objective of establishing grass on a site to address water quality of stormwater is to provide a stable ground cover to cover bare soil and reduce erosion and the entrainment of particulates in runoff.

Principle:

Bare soil is subject to sediment loss from erosion by stormwater. Grass ground cover provides a stable, cost-effective, easily maintainable means of reducing soil loss through erosion. This is accomplished through a reduction in flow velocity caused by grass stems, and by the root network adding cohesiveness to the soil surface.

Description:

Establishing grass on a site can be accomplished in several different ways. Temporary grass cover can be accomplished through scattering of an annual grass such as rye. Permanent grass cover can also be accomplished by seeding. Sod is often used when a stable ground cover is needed immediately. Sometimes, a single row of sod will be located at the edge of an area of bare soil for stability, and the remainder of the site will be seeded. Watering and fertilization is usually necessary to ensure good survival. Also, sod is often used to establish grass on slopes, where seed would tend to wash off in the rain or when watered.

Mulches	References: 16, 19

Objective:

The objective of using mulch is to provide an organic layer for soil stabilization or base for grass seed dispersion.

Principle:

Grass seed, if cast alone, is subject to removal by wind, water, or other disturbance. Placing a layer of mulch on bare soil supplies an intermediate level of stability until the area is sodded or until the grass seed or ground cover becomes established.

Description:

Mulches are shredded organic material that is spread on bare soil to stabilize it, or to serve as an organic base for grass seed or other ground cover. Mulch can be manually spread, distributed mechanically off the back of a truck or wagon, or can be "shot", usually as a slurry of water, mulch, seed, and fertilizer, out of a large diameter spray nozzle. Mulch is a good method, intermediate in cost, effort, and effectiveness between seeding and sodding, of establishing grass on bare soil.

Other Vegetation	

Objective:

The objective of any vegetative erosion control is to provide stability to soils to reduce soil loss to stormwater through erosion.

Principle:

Any type of vegetation tends to add stability to the underlying soils. This results from the above-ground plant slowing the velocity of runoff flow, and by the root structure adding cohesiveness to the soil.

Description:

Other types of vegetation stabilization include many forms of ornamental ground cover, preservation of natural vegetation, and landscaping to place plants in the most advantageous location to assist in erosion control and stormwater quality treatment. A variety of plants are available that are well-suited for erosion control, and that provide additional benefits of aesthetics, wildlife habitat, climate control, edible fruits, noise abatement, dust control, site security, and privacy. Candidate species include ground covers, bushes, shrubs, vines, and trees.

3.0 Agricultural BMPs Applicable in the Tampa Bay Watershed

Agricultural BMPs applicable in the Tampa Bay watershed were identified using the "BMP Selector" from the Florida Cooperative Extension Service, IFAS, SP-15; the NRCS Field Office Technical Guide; and personal communications and discussions with Dr. Phyllis Gilreath, Cooperative Extension Service, Manatee County, Florida.

The following defines the BMPs identified as being most applicable to the agricultural land uses practices and physical settings in the Tampa Bay watershed. Table 3-1 summarizes the BMPs and identifies the anticipated benefits according to agricultural land use. The anticipated benefits include nitrogen load reduction, pesticide load reduction, erosion control, and water conservation. The major agricultural land use types include row crops, citrus groves, and pasture and livestock. A number of the agricultural BMPs examined offer multiple benefits and can be implemented for more than one agricultural land use.

NUTRIENT CONTROL BMPs

Fencing - Fencing is the dividing or enclosing of land areas with a suitable permanent structure that acts as a barrier for livestock, game, or people. Fencing serves to: subdivide grazing land to permit use of planned grazing systems; exclude livestock or big game from plant communities that cannot withstand grazing; confine livestock or big game on an area; regulate access to areas by people and prevent trespassing; distribute grazing pressures more evenly thereby enhancing the quality of runoff water; and allow deferment periods to be incorporated with brush management practices thereby improving the efficiency of water use.

Fertigation - The delivery of fertilizer materials via an irrigation system.

Irrigation Water Management - The use of proper irrigation water management involves the determination and control of the rate, amount, and timing of irrigation water application in a planned and efficient manner through use of flow meters and potentiometers. The purpose of irrigation water management is to effectively use available irrigation water supply in managing and controlling the moisture environment of crops to promote the desired crop response and to minimize soils erosion, runoff, and fertilizer and pesticide movement, and to protect water quality. In order for the above stated purpose to be achieved, the irrigator of a conservation irrigation system must have the capability and knowledge to: determine when irrigation water should be applied based on the rate of water use by the crop and the stages of plant growth; measure or estimate the amount of water required for each irrigation, including the leaching needs; determine the normal time needed for the soil to absorb the required amount of water and how to detect changes in intake rates; adjust stream size, application rate, or irrigation time to compensate for changes in such factors as intake rate or the amount of water to be applied; recognize erosion caused by irrigation; estimate the amount of irrigation runoff from an area; and evaluate the uniformity of water application.

Land Absorption Wetland Use - This practice serves to provide, through use of existing wetland areas, an adequate land absorption area downstream from grazed areas so that soil and plants absorb nutrients and animal wastes.

Mulching - Mulching is the practice of applying plant residues, or other suitable materials not produced on the site, to the soil surface. Mulching conserves moisture, prevents surface compaction or crusting, reduces runoff and wind and water erosion, controls weeds, and helps establish plant cover. Mulching is applicable to soils subject to erosion on which low-residue-producing crops are grown, on critical areas and on soils that have a low infiltration rate.

Nutrient Management - Nutrient management practices involve the managing of the amount, source, form, placement, and timing of applications of plant nutrients. It may include the management of plant nutrients associated with organic waste, commercial fertilizer, legume crops, and crop residues. Such practices can be applied to all lands to which materials containing plant nutrients are applied. Nutrient management practices serve to supply adequate plant nutrients for optimum (maximum economic) forage and crop yields, to minimize entry of nutrients to surface and ground water, and to maintain or improve the chemical and biological condition of the soil. Proper nutrient management practices reduce the availability of nutrients that could pollute surface or groundwater by managing the application method and amounts of nutrients applied to the soil.

The NRCS Field Office Technical Guide includes several planning considerations for proper nutrient management practices. It should be recognized that several other listed BMPs could be grouped as a nutrient management practice (e.g., waste utilization, soil testing, plant analysis, and timing and placement of fertilizers).

Rotational Grazing - Rotational grazing is a system in which two or more grazing units are alternately rested and grazed in a planned sequence for a period of years. The rest periods may be throughout the year or during the growing season of key plants. Rotational grazing serves several purposes, including: to maintain existing plant cover or hasten its improvement while properly using the forage of all grazing units; to improve water quality and reduce erosion; to increase grazing efficiency by uniformly using all parts of each grazing unit; to provide adequate forage throughout the grazing season; to improve forage quality and increase production; to enhance wildlife habitat; to promote flexibility in the grazing program and buffer the adverse effects of drought; and to promote energy conservation by using reduced amounts of fossil fuel.

Shade Areas - Shade areas serve to lessen the need for animals to enter water for relief from heat by using trees or artificial shelters to provide shade at selected locations. Such practices minimize animal contact with surface waters and thereby serve to protect surface waters from animal waste contamination. This practice may also serve to reduce erosional processes along stream banks due to reduced animal traffic.

Slow Release Fertilizer - The use of slow release fertilizers minimizes nitrogen losses from soils prone to leaching. Slow release fertilizer is used somewhat for strawberries and citrus crops in the Tampa Bay watershed.

Soil Testing and Plant Analysis - These practices involve testing of soil and plants to avoid overfertilization and subsequent losses of nutrients in runoff water.

Timing and Placement of Fertilizers - The proper timing and placement of fertilizers provides for maximum utilization by plants and minimum leaching or movement by surface runoff. The practice works well with drip irrigation systems. Citrus growers use split applications to save fertilizer.

Waste Management Systems - These are planned systems in which all necessary components are installed for managing liquid and solid waste, including runoff from concentrated waste areas, such that air, soil, and water resources are not degraded. The purpose of this practice is to manage waste in rural areas such that air, soil, and water resources are not degraded, and to manage waste in order to protect public health and safety. These systems should preclude pollutant discharges to surface or ground water and should recycle waste through soil and plants to the fullest extent practicable. The practice applies where: waste is generated by agricultural production; waste from municipal and industrial treatment plants is used in agricultural production; all practice components necessary to make a complete system are specified; and soil, water, and plant resources are adequate to properly manage waste. These systems may consist of a single component, such as a diversion, or may consist of several components. Examples of components that could be used in a waste management system include fencing, pond sealings or linings, subsurface drains, water storage ponds, waste treatment lagoons, and grassed waterways or outlets.

Waste Utilization - Waste utilization is the practice of using agricultural wastes and other wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources. Waste utilization is a means to safely use wastes to provide fertility for crop, forage, or fiber production; to improve or maintain soil structure; to prevent erosion and to safeguard water resources. The practice involves the use of wastes for application to crops. Recommended waste application rate guidelines are listed in the NRCS Field Office Technical Guide. This practice may also include recycling of waste solids for animal feed supplement.

Water Table Management - Water table management or control is the practice of controlling the water table through proper use of subsurface drains, water control structures, and water conveyance facilities for the efficient removal of drainage water and distribution of irrigation water. The practice improves the soil environment for vegetative growth by regulating the water table to remove excess runoff and subsurface water, facilitate leaching of saline or alkali soil, and regulate or manage ground water for subirrigation. The practice applies where: a high water table exists; topography is relatively smooth and flat; adequate water is available; the benefits of subirrigation, in addition to controlling ground water and surface runoff, justify system installation; soil depth and permeability will permit effective operation of the control system; saline or sodic soil conditions can be maintained of an acceptable level for efficient production of crops; a suitable outlet exists; and improvements for off-site water quality are needed and can be achieved through water table management techniques.

Water Tolerant Crops - This practice involves the careful selection of water-tolerant crops for organic soils so higher water tables can be maintained to reduce oxidation and release of nutrients to drainage water.

Water/Feeder Location - This practice involves the locating of feeders and watering facilities a reasonable distance from streams and water courses. The practice serves to reduce livestock concentrations, particularly near streams, and to encourage more uniform grazing. Properly locating watering and feeding facilities can improve surface water quality and reduce erosion around stream and creek banks.

WATER/IRRIGATION BMPs

Irrigation Water Conveyance - An irrigation water conveyance consists of a fixed lining of impervious material installed in an existing or newly constructed irrigation field ditch, irrigation canal, or lateral. Irrigation water conveyances are used to prevent waterlogging of land, to maintain water quality, to prevent erosion, and to reduce water loss. The practice is applicable to ditches and canals that serve as integral parts of an irrigation water distribution or conveyance system that has been designed to facilitate the conservative use of soil and water resources on a farm or group of farms.

Irrigation Water Management - The use of proper irrigation water management involves the determination and control of the rate, amount, and timing of irrigation water application in a planned and efficient manner through use of flow meters and potentiometers. The purpose of irrigation water management is to effectively use available irrigation water supply in managing and controlling the moisture environment of crops to promote the desired crop response and to minimize soils erosion, runoff, and fertilizer and pesticide movement, and to protect water quality. In order for the above stated purpose to be achieved, the irrigator of a conservation irrigation system must have the capability and knowledge to: determine when irrigation water should be applied based on the rate of water use by the crop and the stages of plant growth; measure or estimate the amount of water required for each irrigation, including the leaching needs; determine the normal time needed for the soil to absorb the required amount of water and how to detect changes in intake rates; adjust stream size, application rate, or irrigation time to compensate for changes in such factors as intake rate or the amount of water to be applied; recognize erosion caused by irrigation; estimate the amount of irrigation runoff from an area; and evaluate the uniformity of water application.

Land Leveling (with Laser) - Land leveling is the practice of reshaping the surface of the land to be irrigated to planned grades. Land leveling permits uniform and efficient application of irrigation water without causing erosion, loss of water quality, or damage to land by waterlogging, yet at the same time provides for adequate surface or subsurface drainage. Soils should be deep enough so that after leveling work is completed an adequate and usable root zone remains that will produce satisfactory crop production with proper conservation measures. In the Tampa Bay watershed, land leveling is most important for crops utilizing seep irrigation systems.

Mulching - Mulching is the practice of applying plant residues, or other suitable materials not produced on the site, to the soil surface. Mulching conserves moisture, prevents surface compaction or crusting, reduces runoff and wind and water erosion, controls weeds, and helps establish plant cover. Mulching is applicable to soils subject to erosion on which low-residue-producing crops are grown, on critical areas and on soils that have a low infiltration rate.

Pasture and Hayland Management - Pasture and hayland management involves the proper treatment and use of pastureland and hayland. The practice serves to prolong life of desirable forage species; to maintain or improve the quality and quantity of forage; and to protect the soil and reduce water loss. Pasture and hayland management practices can be used on all pastureland or hayland. An important aspect of these practices focuses on balancing fertilization according to production needs. Most Florida soils need fertilization to produce optimum yields of forage crops. Fertilization programs must consider the production needs and nutrient requirement of the forage crop, as well as the ability of the soil to retain and deliver nutrients and water. Although the NRCS Field Office Technical Guide provides specifications on fertilization of forage crops without the benefit of soil test results, the NRCS highly recommends the use of annual soil testing to assess fertilization requirements.

Pasture and Hayland Planting - Pasture and hayland planting practices primarily serve to establish forage plants on erodible soils to reduce runoff and erosion.

Prescribed Burning - Prescribed burning is the practice of applying fire to predetermined areas such that the intensity and spread of the fire are controlled. Prescribed burning practices control undesirable vegetation; prepare sites for planting and seedings; control plant diseases; reduce fire hazards; improve wildlife habitat, forage production, and forage quality; and facilitate distribution of grazing and browsing animals.

Range Seeding - Range seeding is the practice of establishing adapted plants by seeding on rangeland. Range seeding prevents excessive soil and water loss; produces more forage on rangeland or land converted to range from other uses; and improves the aesthetic quality of the grazing land. This practice is applicable on rangeland, native pasture, grazable woodland, and grazed wildlife land.

Trickle Irrigation System - A trickle irrigation system (e.g., spray jet irrigation or drip irrigation) is a planned system in which necessary facilities are installed for efficiently applying water directly to the root zone of plants via small diameter pipes, and by using special applicators (orifices, emitters, porous tubing, perforated pipe) operated under low pressure. The applicators may be placed on or below the ground surface. These systems maintain soil moisture within the range for good plant growth without excessive water loss, erosion, reduction in water quality, or salt accumulation. The design of a trickle irrigation system is based on an evaluation of the site and the expected operating conditions. The soils and topography must be suitable for irrigation of the proposed crops, and the water supply must be sufficient in quantity and quality for the intended crops to be grown. Trickle irrigation is suited to most orchard (or grove) crops and row crops as well as for gardens, flowers, and shrubs in urban settings where small flow rates of water can be used efficiently. According to the NRCS's Technical Guide for agricultural BMPs, the field application efficiency of trickle irrigation systems may reach 90%.

Water Table Management - Water table management or control is the practice of controlling the water table through proper use of subsurface drains, water control structures, and water conveyance facilities for the efficient removal of drainage water and distribution of irrigation water. The practice improves the soil environment for vegetative growth by regulating the water table to remove excess runoff and subsurface water, facilitate leaching of saline or alkali soil, and regulate or manage ground water for subirrigation. The practice applies where: a high water table exists; topography is relatively smooth and flat; adequate water is available; the benefits of subirrigation, in addition to controlling ground water and surface runoff, justify system installation; soil depth and permeability will permit effective operation of the control system; saline or sodic soil conditions can be maintained at an acceptable level for efficient production of crops; a suitable outlet exists; and improvements for off-site water quality are needed and can be achieved through water table management techniques.

Water Tolerant Crops - This practice involves the careful selection of water-tolerant crops for organic soils so higher water tables can be maintained to reduce oxidation and release of nutrients to drainage water.

PESTICIDE USE BMPs

Correct Pesticide Application - Correct pesticide application practices involve the responsible use of pesticides to minimize pesticide movement from the field where applications are made. Practices may include the spraying of pesticides when conditions for drift are minimal, mixing the pesticide properly with soil when specified, and avoiding applications when heavy rain is forecast.

Correct Pesticide Container Disposal - Correct pesticide container disposal practices refer to the use of the accepted methods for pesticide container disposal (such as those specified on the pesticide label).

Cultural Control of Pests - The cultural control of pests refers to using cultural practices, such as elimination of host sites and adjustment of planting schedules (i.e., crop rotation), to partly substitute for pesticides. The use of this practice should reduce the amount of pesticides introduced into the environment and thus protect surface and ground water quality from pesticide contamination.

Integrated Pest Management (IPM) - IPM practices encompass a variety of techniques to minimize or preclude the use of pesticides on agricultural crops. Practices include the use of crop rotation to reduce buildup of insects, the use of alternate control methods such as cover crops to foster populations of beneficial insects, the determination of economic pest thresholds, the adjusting of planting and harvest periods, and the use of field scouting. Additional components that may be part of an IPM program include the use of natural enemies and pheromones. These later components are primarily used in ornamental horticulture.

Irrigation Water Management - The use of proper irrigation water management involves the determination and control of the rate, amount, and timing of irrigation water application in a planned and efficient manner through use of flow meters and potentiometers. The purpose of irrigation water management is to effectively use available irrigation water supply in managing and controlling the moisture environment of crops to promote the desired crop response and to minimize soils erosion, runoff, and fertilizer and pesticide movement, and to protect water quality. In order for the above stated purpose to be achieved, the irrigator of a conservation irrigation system must have the capability and knowledge to: determine when irrigation water should be applied based on the rate of water use by the crop and the stages of plant growth; measure or estimate the amount of water required for each irrigation, including the leaching needs; determine the normal time needed for the soil to absorb the required amount of water and how to detect changes in intake rates; adjust stream size, application rate, or irrigation time to compensate for changes in such factors as intake rate or the amount of water to be applied; recognize erosion caused by irrigation; estimate the amount of irrigation runoff from an area; and evaluate the uniformity of water application.

Pesticide Selection - Proper pesticide selection practices refer to the selection of pesticides which are least toxic, persistent, soluble, and volatile as feasible for worker safety and protection of environment.

EROSION CONTROL BMPs

Conservation Cropping System - Conservation cropping is a system of growing crops in combination with needed cultural and management measures to improve the soil and protect it during periods when erosion occurs. Conservation cropping practices provide vegetative cover (often weed fallow) between crop seasons. The practice may include cover cropping and crop rotation.

Critical Area Planting - Critical area planting is the planting of vegetation such as trees, shrubs, grasses or legumes on critical areas. Critical area planting serves to stabilize the soil, reduce erosion and runoff to downstream areas, improve wildlife habitat, and enhance natural beauty. Applicable areas include sediment-producing, highly erodible or severely eroded areas, such as dams, dikes, ditches, mine spoil, levees, cuts, fills, surface-mined areas, and denuded or gullied areas where vegetation is difficult to establish with usual seeding or planting methods.

The NRCS Field Office Technical Guide includes detailed specifications for five categories of critical area plantings; they include:

342-I Permanent Seedings;
342-II Temporary Seedings;
342-III Sod;
342IV With Ground Cover, Vines, Shrubs and Other Plants; and
342-V On Coastal Dune Areas.

Deferred Grazing - Deferred grazing practices postpone grazing for a prescribed period to improve vegetative conditions and reduce soil loss. Deferred grazing promotes natural revegetation by improving the health of the forage stand and permitting desirable plants to produce seed. Deferred grazing also serves to provide a feed reserve for fall and winter grazing or emergency use, reduce soil loss and improve water quality, and maintain or improve wildlife habitat. Deferred grazing practices which employ planned deferment periods can be applied to all rangeland, native pasture, grazable woodland, and grazed wildlife land. Planned deferment periods should be based on: the type of plants managed for, timing of "green-up" and active growth period, and plant vigor; the vigor and growth habits of the key forage species; weather and growing conditions; and the land user's goals. The planned deferment, however, must not cause overuse or have an adverse impact on the rest of the operating unit.

Fencing - Fencing is the dividing or enclosing of land areas with a suitable permanent structure that acts as a barrier for livestock, game, or people. Fencing serves to: subdivide grazing land to permit use of planned grazing systems; exclude livestock or big game from plant communities that cannot withstand grazing; confine livestock or big game on an area; regulate access to areas by people and prevent trespassing; distribute grazing pressures more evenly thereby enhancing the quality of runoff water; and allow deferment periods to be incorporated with brush management practices thereby improving the efficiency of water use.

Field Windbreak - A field windbreak is a strip or belt of trees (e.g., cedar tree wind blocks for potato farms) established in or adjacent to a field. Field windbreaks serve to reduce soil erosion from wind; conserve moisture; protect crops, groves, livestock, and wildlife; and increase the natural beauty of an area. Field windbreaks can be grown in or around open fields needing protection against wind damage, or where strips of trees or shrubs increase the natural beauty of an area or provide food and cover for wildlife.

Grassed Waterways or Outlet - This BMP includes natural or constructed channels or outlets that are shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff. This BMP applies to natural or constructed channels that are to be established to vegetation and used for water disposal. Grassed waterways serve to convey runoff from terraces, diversions, or other water concentrations without causing erosion or flooding, and to improve water quality. This practice is applicable to all sites where added capacity, vegetative protection, or both are required to control erosion resulting from concentrated runoff and where such control can be achieved by using this practice alone or combined with other conservation practices. The practice should not be used where its construction would destroy important woody wildlife cover and where the present watercourse is not seriously eroding.

Irrigation Water Conveyance - An irrigation water conveyance consists of a fixed lining of impervious material installed in an existing or newly constructed irrigation field ditch, irrigation canal, or lateral. Irrigation water conveyances are used to prevent waterlogging of land, to maintain water quality, to prevent erosion, and to reduce water loss. The practice is applicable to ditches and canals that serve as integral parts of an irrigation water distribution or conveyance system that has been designed to facilitate the conservative use of soil and water resources on a farm or group of farms.

Irrigation Water Management - The use of proper irrigation water management involves the determination and control of the rate, amount, and timing of irrigation water application in a planned and efficient manner through use of flow meters and potentiometers. The purpose of irrigation water management is to effectively use available irrigation water supply in managing and controlling the moisture environment of crops to promote the desired crop response and to minimize soils erosion, runoff, and fertilizer and pesticide movement, and to protect water quality. In order for the above stated purpose to be achieved, the irrigator of a conservation irrigation system must have the capability and knowledge to: determine when irrigation water should be applied based on the rate of water use by the crop and the stages of plant growth; measure or estimate the amount of water required for each irrigation, including the leaching needs; determine the normal time needed for the soil to absorb the required amount of water and how to detect changes in intake rates; adjust stream size, application rate, or irrigation time to compensate for changes in such factors as intake rate or the amount of water to be applied; recognize erosion caused by irrigation; estimate the amount of irrigation runoff from an area; and evaluate the uniformity of water application.

Land Leveling (with Laser) - Land leveling is the practice of reshaping the surface of the land to be irrigated to planned grades. Land leveling permits uniform and efficient application of irrigation water without causing erosion, loss of water quality, or damage to land by waterlogging, yet at the same time provides for adequate surface or subsurface drainage. Soils should be deep enough so that after leveling work is completed an adequate and usable root zone remains that will produce satisfactory crop production with proper conservation measures. In the Tampa Bay watershed, land leveling is most important for crops utilizing seep irrigation systems.

Mulching - Mulching is the practice of applying plant residues, or other suitable materials not produced on the site, to the soil surface. Mulching conserves moisture, prevents surface compaction or crusting, reduces runoff and wind and water erosion, controls weeds, and helps establish plant cover. Mulching is applicable to soils subject to erosion on which low-residue-producing crops are grown, on critical areas and on soils that have a low infiltration rate.

Pasture and Hayland Management - Pasture and hayland management involves the proper treatment and use of pastureland and hayland. The practice serves to prolong life of desirable forage species; to maintain or improve the quality and quantity of forage; and to protect the soil and reduce water loss. Pasture and hayland management practices can be used on all pastureland or hayland. An important aspect of these practices focuses on balancing fertilization according to production needs. Most Florida soils need fertilization to produce optimum yields of forage crops. Fertilization programs must consider the production needs and nutrient requirement of the forage crop, as well as the ability of the soil to retain and deliver nutrients and water. Although the NRCS Field Office Technical Guide provides specifications on fertilization of forage crops without the benefit of soil test results, the NRCS highly recommends the use of annual soil testing to assess fertilization requirements.

Pasture and Hayland Planting - Pasture and hayland planting practices primarily serve to establish forage plants on erodible soils to reduce runoff and erosion.

Prescribed Burning - Prescribed burning is the practice of applying fire to predetermined areas such that the intensity and spread of the fire are controlled. Prescribed burning practices control undesirable vegetation; prepare sites for planting and seedings; control plant diseases; reduce fire hazards; improve wildlife habitat, forage production, and forage quality; and facilitate distribution of grazing and browsing animals.

Proper Grazing Use - Proper grazing use is the practice of grazing at an intensity which will maintain enough vegetative cover to protect the soil and maintain or improve the quantity and quality of desirable vegetation. This practice serves to increase the vigor and reproduction of key plants; accumulate litter and mulch necessary to reduce erosion and sedimentation and improve water quality; improve or maintain the condition of existing vegetation; increase forage production; maintain natural beauty; reduce hazard of wildfire; and improve or maintain wildlife habitat. The practice is applicable on all rangeland, native pasture, and grazed wildlife land.

Range Seeding - Range seeding is the practice of establishing adapted plants by seeding on rangeland. Range seeding prevents excessive soil and water loss; produces more forage on rangeland or land converted to range from other uses; and improves the aesthetic quality of the grazing land. This practice is applicable on rangeland, native pasture, grazable woodland, and grazed wildlife land.

Rotational Grazing - Rotational grazing is a system in which two or more grazing units are alternately rested and grazed in a planned sequence for a period of years. The rest periods may be throughout the year or during the growing season of key plants. Rotational grazing serves several purposes, including: to maintain existing plant cover or hasten its improvement while properly using the forage of all grazing units; to improve water quality and reduce erosion; to increase grazing efficiency by uniformly using all parts of each grazing unit; to provide adequate forage throughout the grazing season; to improve forage quality and increase production; to enhance wildlife habitat; and to promote flexibility in the grazing program and buffer the adverse effects of drought.

Runoff Management System - This is a system for controlling excess runoff caused by construction operations at development sites, changes in land use, or other land disturbances such as the preparation of a field for a new crop. Proper runoff management serves to regulate the rate and amount of runoff and sediment from development sites during and after construction operations to minimize undesirable effects such as flooding, erosion, and sedimentation. Runoff management systems should be used to control runoff, erosion, and sedimentation to compensate for increased peak discharges and erosion resulting from construction activities. The practice involves the planning, design, installation, operation, and maintenance of runoff management systems, including adequate outlet facilities and components necessary for adequate management of storm runoff. Components may include dams, excavated ponds, exfiltration trenches, parking lot storage, rooftop storage, and underground tanks.

Shade Areas - Shade areas serve to lessen the need for animals to enter water for relief from heat by using trees or artificial shelters to provide shade at selected locations. Such practices minimize animal contact with surface waters and thereby serve to protect surface waters from animal waste contamination. This practice may also serve to reduce erosional processes along stream banks due to reduced animal traffic.

Water/Feeder Location - This practice involves the locating of feeders and watering facilities a reasonable distance from streams and water courses. The practice serves to reduce livestock concentrations, particularly near streams, and to encourage more uniform grazing. Properly locating watering and feeding facilities can improve surface water quality and reduce erosion around stream and creek banks.

Woodland Site Management - Woodland site management is the practice of managing soils and vegetation in woodland areas to encourage rapid growth of desirable trees in order to reduce soil erosion runoff.

Table 3-1. Agricultural BMPs applicable in the Tampa Bay watershed including the problems addressed by agricultural land use type.

PROBLEM →	NITROGEN LOADING			WATER USE/ IRRIGATION			PESTICIDE USE			EROSION		
LAND USE TYPE → RC= Row Crop CG=Citrus Grove P/L=Pasture/Livestock	RC	CG	P/L	RC	CG	P/L	RC	CG	P/L	RC	CG	P/L
BMP												
Conservation Cropping System										X		
Correct Pesticide Application							X	X				
Correct Pesticide Container Disposal							X	X				
Critical Area Planting										X	X	X
Cultural Control of Pests							X	X		X		
Deferred Grazing												X
Fencing			X									X
Fertigation	X	X		X	X							
Field Windbreak										X		
Grassed Waterways or Outlet			X									X
Integrated Pest Management							X	X	X			
Irrigation Water Conveyances				X	X					X	X	
Irrigation Water Management	X	X		X	X		X	X		X	X	
Land Absorption/Wetland Use			X									
Land Leveling (with Laser)				X								
Mulching	X			X						X		
Nutrient Management	X	X	X									
Pasture & Hayland Management			X			X			X			X
Pasture and Hayland Planting			X			X			X			X
Pesticide Selection							X	X				
Prescribed Burning						X						X
Proper Grazing Use												X
Range Seeding						X						X
Resistant Crop Varieties							X	X				
Rotational Grazing			X									X
Runoff Management System	X	X	X	X	X	X	X			X	X	X
Shade Areas			X									X

Table 3-1. Agricultural BMPs applicable in the Tampa Bay watershed including the problems addressed by agricultural land use type.

PROBLEM →	NITROGEN LOADING			WATER USE/ IRRIGATION			PESTICIDE USE			EROSION		
LAND USE TYPE → RC= Row Crop CG=Citrus Grove P/L=Pasture/Livestock	RC	CG	P/L	RC	CG	P/L	RC	CG	P/L	RC	CG	P/L
Slow Release Fertilizer	X	X	X									
Soil Testing & Plant Analysis	X	X	X									
Timing & Placement of Fertilizers	X	X	X									
Trickle Irrigation System				X	X							
Waste Management System			X									
Waste Utilization			X									
Water Table Management				X	X							
Water Tolerant Crops				X	X	X						
Water/Feeder Location			X									X
Woodland Site Management												X

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