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Project Summary

EPA Macroscopic Planning Model (EPAMAC) for Stormwater and Combined Sewer Overflow Control: Application Guide and User's Manual

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A simplified stormwater management model known as EPAMAC (EPA Macroscopic Planning Model) has been developed to provide an inexpensive, flexible tool for planning and preliminary sizing of stormwater facilities. The purposes of this project were (1) to describe the application of the model to San Francisco (SFMAC), which lead to the generalized EPAMAC and (2) to write a user's guide. Documentation of the model and instructions for data preparation and application are included in the user's guide portion of the report.

The model was effectively used to compare a large number of alternative storage and treatment facilities and to optimize their sizing. The SFMAC was then generalized for use at any location as EPAMAC.

EPAMAC is a special purpose, continuous simulation model for surface runoff. The model has minimal input data requirements, broad areal and temporal coverage, and both flexibility and ease of application.

EPAMAC was developed as part of a methodology for managing stormwater that uses both simple computer programs and hand computations. The model consists of three uncomplicated but interrelated programs that can be used singularly or together: EPAMAC, HISTO, and VDAY. In addition to quantity and quality analyses for stormwater flows, model capabilities include dry-weather flow, hourly simulation of flows, overflow event analysis, determination of pollutant removals as a result of sedimentation in storage, and addition of dry-weather flow and lateral inflows from adjacent areas. Postprocessor programs can also provide histogram plots of flow and quality (HISTO) and analyses of violation days for coliform limits in receiving water for several coliform standards (VDAY).

The model proved to be useful to planners and engineers as well as public enforcement agencies. Information developed from application of the model in San Francisco (SFMAC) was used by the regional water quality enforcement agency in an evaluation of appropriate stormwater overflow frequency levels to be included in NPDES permits. Pollutant loadings developed from SFMAC application and coliform violation day data from VDAY were used in cost/benefit analyses to determine an allowable overflow frequency consistent with beneficial uses of the shoreline, ocean, and bay waters.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Complex stormwater models provide valuable data for the design and final sizing of stormwater facilities. But the detailed models generally require comprehensive, detailed input data and large blocks of time on relatively large computers for execution. In an attempt to provide an intermediate step between the large, complex models and the traditional desktop analysis used in facilities planning projects, the U.S. Environmental Protection Agency (EPA) has participated in the development of several simplified computer models for planning and preliminary sizing of facilities. These simplified models require very moderate expenditures for data preparation and execution, and they provide a flexible tool for analyzing a variety of system configurations.

The application guide and user's manual presented in the full report summarize the mathematical modeling work performed in support of the stormwater and combined sewage treatment master plan for the City and County of San Francisco and provide a compact reference base for applying the model to future locations. The model consists of three uncomplicated but interrelated programs that can be used singularly or together (EPAMAC, HISTO, and VDAY). This design allows the user to build on his individual data strengths and to focus on individual study objectives.

Background

San Francisco has a unique physical setting that must be considered in the development of wastewater facilities. The City is located on a peninsula, which allows for the option of effluent discharge to either the bay or ocean. The planning area contains 23 watersheds comprising 11,554 ha (28,550 acres) with numerous hills and peaks. Much of the land slopes steeply to the water, but a flat coastal strip exists along the east side of the City. Rainfall occurs mainly from October through May, and average annual rainfall is about 51 cm (20 in.).

The San Francisco combined sewer system conveys both dry- and wet-weather flows. To advance the planning concepts and to meet water quality requirements, a citywide computer modeling approach was necessary. During dry weather, major concerns are transportation and treatment of the flows, and the resulting quality of the effluent. Wet-weather concerns also include minimizing overflow volume and frequency through storage and pumping balance, and maximizing quality of overflow and effluent. Since flows from different sections of the city influence one another, the reaction of the whole system to one or a series of storm events must be examined. Runoff volumes from all 23 watersheds need identification and integration to obtain guidance on facilities necessary to process the flows cost effectively. Rainfall data for 70 years of record are available for analysis. Such an analysis needs to be accurate enough to be reliable but not so involved that it would hinder the planning process. Computer simulation using an appropriate model would achieve analysis of a large number of alternatives reasonably short time.

The types of alternatives to be analyzed involve major regrouping of watersheds and routing of flows to multiple locations. Four alternative concepts are presented in the master plan (Figure 1). Some of the alternative routes pass through politically sensitive areas. The ultimate planning goal is to determine for each alternative the ability to meet effluent discharge requirements, overflow frequency limitations, and the minimum cost for an optimized system.

Existing computer models were either too detailed to quickly survey multiple alternatives or too broad to examine storage and treatment interactions. Thus SFMAC (later generalized as EPAMAC) was developed to meet the needs of the San Francisco planning process. The relationship of the computer modeling to the overall planning process is shown in Figure 2.

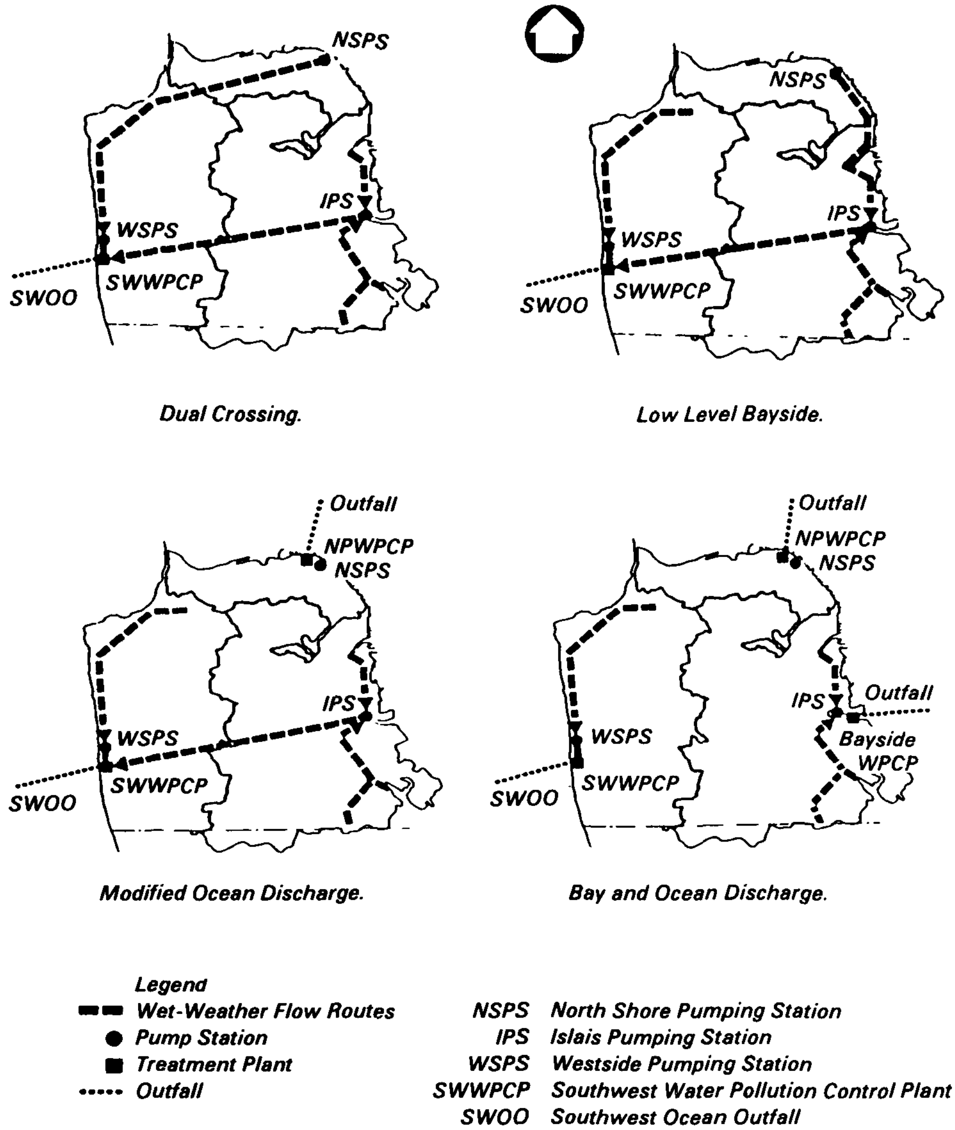

Figure 1. Alternative concepts for wet-weather master plan.

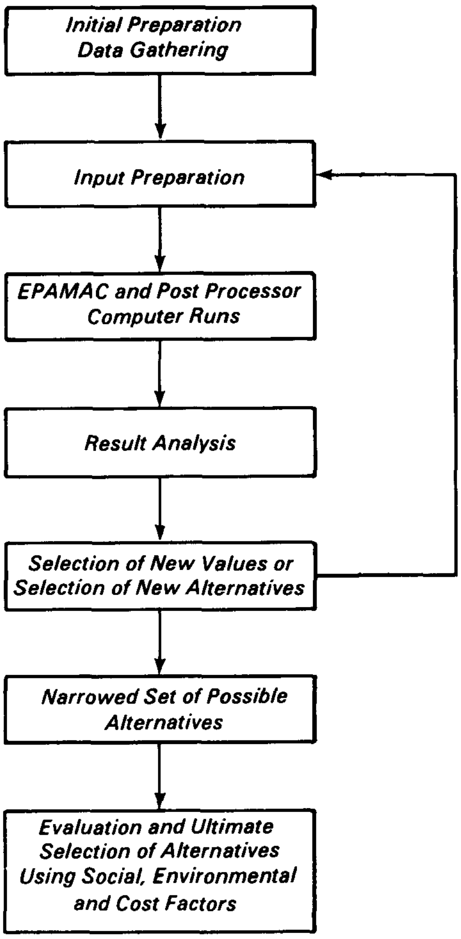

Figure 2. *Relationship of EPAMAC application to the planning process.*

Model Application

Input Preparation

The first step in applying SFMAC was the preparation of input data, which involved identification and gathering of watershed and collection system characteristic data.

The population, area, and general character of each watershed were determined. Information on watershed characteristics, potential sites for future storage facilities, and storage available in the existing system were identified. Watershed data were reviewed and regrouped because systemwide alternatives modified individual watershed configurations.

The areas and runoff coefficients for six different land use types were determined for each subarea. Runoff coefficients were determined from actual rainfall and sewer flow records.

Rainfall input data were developed from two sources. The first source was a network of 30 gages that the City of San Francisco established in December 1971. The second source was the National Weather Service (NWS), which has maintained a recording gage in San Francisco since January 1907. The NWS gage record for the 69-year period (1907-76) was compared with the 4-year (1972-76) data set. The storm duration, intensity, and magnitude characteristics of both sets of data showed very close agreement.

Water quality also was determined in the preparatory phase. Dry-weather data were obtained from influent records for the three existing sewage treatment plants. Projected per capita dry-weather loadings were used as input to the model.

Treatment plant influent data for storm days were analyzed to obtain a wet-weather quality characterization. Since the plant records were based on daily composite samples, a sampling program was developed to obtain additional wet-weather characterization data.

Watershed Data Analysis

After input preparation was completed, EPAMAC was run for each subarea. The hourly runoff volume and quality were established for each subarea and watershed in the initial EPAMAC runs. Pollutant loads from each watershed were obtained from the model. The next phase of the application was to route the subarea and watershed flows to storage/treatment facilities. A flow-routing diagram was developed for each system configuration. EPAMAC was then run again to model the system flow routes for the alternatives.

Balance of Storage and Treatment Requirements

In addition to routing the flows, the second series of EPAMAC runs was used to determine the optimal sizes of storage and treatment facilities. During this stage, storage and pumping requirements along with treatment plant capacity were balanced to obtain the desired overflow frequency during wet weather.

The relationship between pumping or treatment rates and overflows is illustrated in Figure 3. Since several storage and treatment size combinations can produce a given overflow frequency, a separate hand cost computation optimized the selection for each system configuration.

Effect of Sedimentation in Storage Facilities

One feature of EPAMAC is the ability to model the pollutant removal effect of storage (sedimentation) on overflows from storage. A constant pollutant removal efficiency factor is applied only to the overflow volume to determine the effect of storage on improvements in overflow water quality. Additional EPAMAC

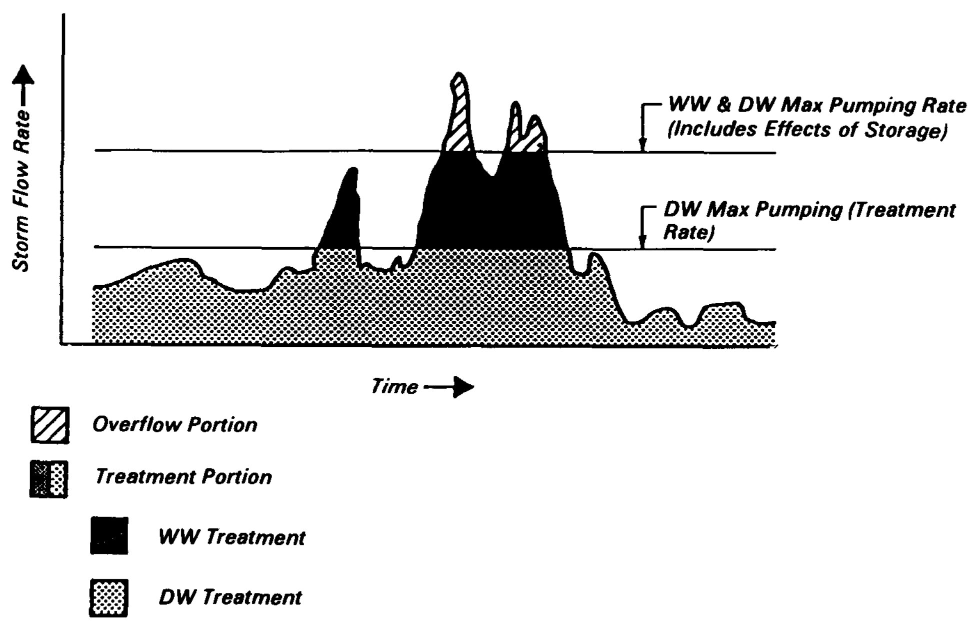

Figure 3. *Overflow and dry- and wet-weather flow relationships to pumping rates.*

runs compared the effects of pollutant removal during storage on receiving water quality.

Analysis of Receiving Water Quality

After EPAMAC runs established watershed characteristics and system treatment and storage interactions, the postprocessor programs were used on EPAMAC output to glean information about water quality impacts on receiving waters. The violation day postprocessor program (VDAY) was used to determine the effect of the overflows for various storage/treatment capacity options on the receiving water coliform concentration limits.

The postprocessor program HISTO, which produces histogram plots of flow, concentration, and mass loads, was used to evaluate the frequency, volume, and pollutant load of overflows and treatment plant discharges.

Plant Operation Frequency

Once the storage and treatment capacities were established, it was necessary to estimate the length of time the wet-weather portion of the plant would operate for each storm and the time available between storm events to drain and clean sedimentation tanks and grit chambers.

HISTO was run on EPAMAC output during a year of typical rainfall. The time between storms was determined for each event. Thus it was possible to determine a representative number of times the tanks would be clean at the start of a storm and also the number of times the tanks would still contain water or sediment at the start of the next storm event.

Model Description

The EPAMAC model (Figure 4) computes the runoff and eventual discharge to the receiving water. Multiple lateral inflows, dry-weather flows, pumping rates, and storage operation modes are included in the model. HISTO prints summary tables and graphs from EPAMAC results for statistical analysis. The VDAY program features include coliform concentration calculation in receiving water (including die-off over time), a statistical analysis of overflow events and violation days, and the option to select specific time periods for analysis.

Technical Basis and Assumptions

The fundamental theory behind EPAMAC is the rational method of computing runoff. The rational method relates flow to the contributing area, rainfall, and runoff coefficient for the area to determine the runoff volume for each time step.

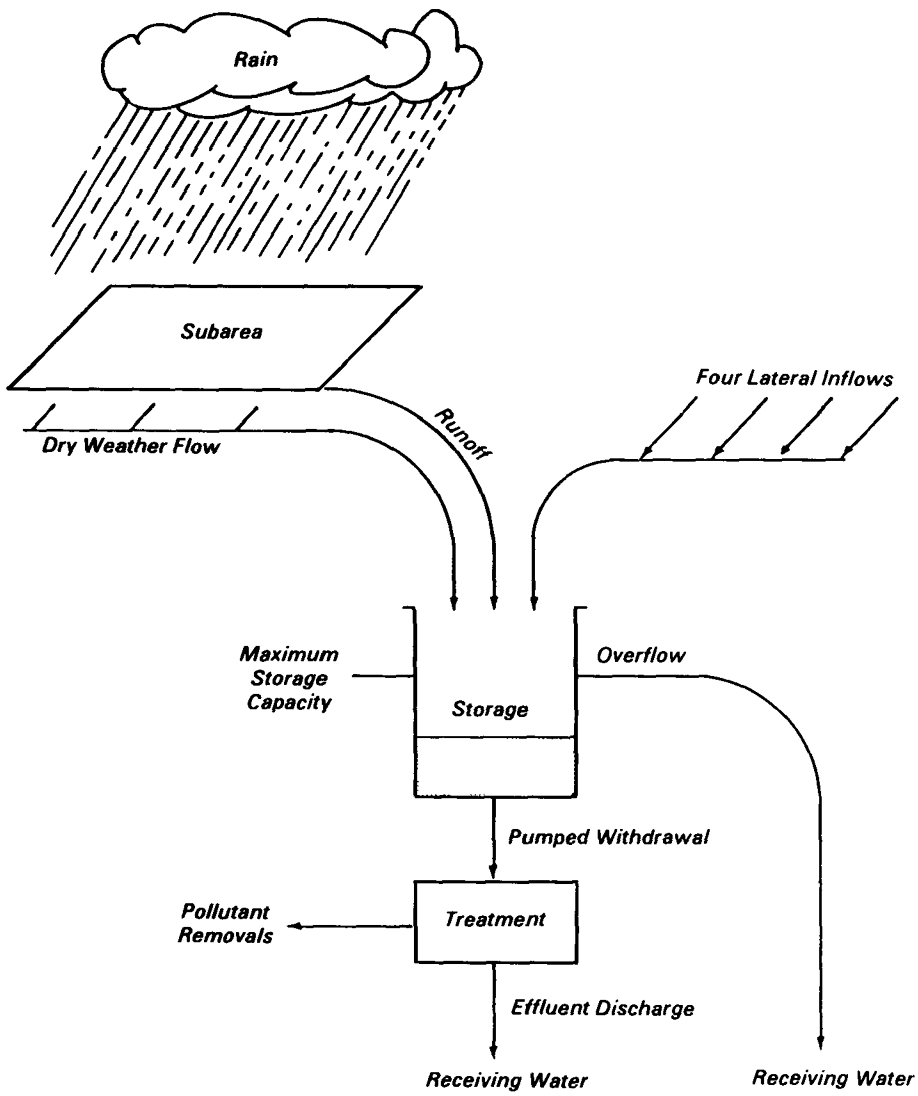

Figure 4. EPAMAC schematic.

By using continuous rainfall records, the method can be used to approximate a continuous simulation model.

The rational method is most appropriately used in urban areas of less than 100 acres (41 ha) or where runoff is spread over the surface and collected in numerous inlets. The method is somewhat simplistic; but the simplicity is appropriate for EPAMAC, since it is a broad-scale model for use in estimating long-term results rather than simulating individuals storm events.

Another theory used in EPAMAC involves mixing in storage. The complete mix theory assumes that flow and the associated pollutants are immediately dispersed throughout storage. The particles then leave in proportion to the average concentration and flow volume removed from storage at any time step.

Sedimentation theory is involved in estimating the effect of storage on the percent removal of solids from storage overflows. The ideal, theoretical settling velocity of a material in water is a function of particle size, shape, and specific weight. Other factors such as turbulence and horizontal velocity affect how a particle will actually settle in a transport or storage facility. The detailed procedure for making the estimate is included as Appendix C.

Several assumptions were chosen to maintain the EPAMAC model simplicity and serviceability. The major assumptions are:

- Pollutants are conservative and do not degrade.
- Suspended solids removal efficiencies that are due to settling overflow volumes in storage are constant over varying flowrates.
- Three wet-weather flow quality concentrations can be input as separate values for the first hour, second hour, and all subsequent hours of a storm to simulate first flush effects.

The HISTO program is simply a data transformation program: It takes the input data and prints them in a new format — namely, histogram plots and range summary tables.

The fundamental theory behind VDAY is that the time variation of the coliform concentration in the receiving water after an overflow event follows Chick's law (i.e., the longer the time since the end of the overflow, the greater the die-off of the organisms).

The user should keep in mind that the values for the coliform die-off decay rate were determined through regression analysis of data specific to San Francisco. The user should determine, whenever possible, the appropriate values for these coefficients for any other location where the program is applied. The decay rates for San Francisco can be used as default values, if necessary; but the results should then be used for relative comparisons only.

Limitations

As a consequence of the simplifying assumptions used in the program, the programs should be executed with at least 10 to 20 year's worth of rainfall records to provide results that represent the actual ranges that can be expected to occur. Shorter periods of record can be used, but the results may be less representative of what can actually be expected.

Other limitations of EPAMAC include:

- BOD and SS are the only pollutants modeled.
- Wet-weather flow quality for each pollutant is based on three input values: One for the first hour, one for the second hour, and one for the third and any subsequent hours of a storm.
- Printout is in units of Mgal, klb, and mg/L only for the appropriate time period selected.
- A maximum of four lateral inflows (flows from previously simulated adjacent areas) is allowed.
- Values from monthly and annual summaries are considered representative of the actual periods simulated. Values from hourly and daily summaries cannot be considered truly representative of actual storm events because of simplifying assumptions used in the model.

Limitations of the VDAY program include:

- The attenuation rate of coliforms in receiving water can be a default value based on the overflow volume (included in program) or a user-supplied value developed for the specific area being simulated.
- Printout is in units of Mgal and violation days.
- Printout is on an annual basis and is only generally representative of conditions being modeled. Values from shorter time periods (less than 20 years) will produce an incomplete statistical analysis based on the ranked values only.

Benefits

The major benefits from application of EPAMAC were the ability to evaluate a large number of alternatives, the ease of understanding the results, the quickness of obtaining results, and the acceptance of results in decision-making processes.

The use of EPAMAC met the planning objectives of examining a large number of alternatives (58 in the case of San Francisco) at a technical level sufficient to determine differences in the water quality effects and the overflow frequencies. System configurations were identified and used as a basis for comparing the cost-effectiveness of the alternatives. EPAMAC results were also used to achieve the objective of establishing reasonable allowable overflow frequency limits.

For planning and comparing alternatives, EPAMAC is sufficiently accurate. Verification indicated that the real situation is adequately modeled. As with all models, the accuracy of the results depends strongly on the input data.

Applying a model to San Francisco can become unreasonably complex because of the size and intricacy of the sewerage system. But the EPAMAC adequately handled the task. Results were understandable, and the volume of computer output was under user control. The overflow event data and mass balance summaries provided sufficient detail without generating a volume of data that would be impossible to review or comprehend. The model was a tool for comprehending a complex system without obscuring the goals. The results could be used to determine further implications of storage and treatment balances. The postprocessors also provided necessary information and understandable results.

The EPAMAC algorithm is simple and straightforward, unlike those used in some detailed, single-event simulation models. An extensive educational program is not needed to help the user comprehend the model and its required input.

The most significant benefit of EPAMAC application was not just in analysis of alternatives in the facilities plan. Information developed was also used by the regional water quality enforcement agency to evaluate appropriate, allowable overflow frequency levels to be included in NPDES regulations. Pollutant loadings developed from EPAMAC simulation runs and violation day data from VDAY were used in cost/benefit analyses to determine allowable overflow frequency levels consistent with beneficial uses of the shoreline, ocean, and bay waters. In conclusion, the model results were accepted at several levels of the decision-making process and were used to establish policy.

Model Documentation and User's Guide

The report includes a section that provides EPAMAC documentation and serves as a user's guide. This section includes (1) general description, (2) user instruction, (3) technical concepts, and (4) program documentation.

The general description includes the capabilities, features, restrictions, and limitations of the EPAMAC and postprocessor programs.

User instructions are provided for the program processing steps, system schematics, alternative analysis, execution logistics and input data preparation. Example input data sets, example outputs, and interpretation of the results are also described. The theory, assumptions, and limitations for EPAMAC, HISTO, and VDAY are presented in the technical concepts section of the report.

Program documentation for EPAMAC and the postprocessor programs includes the mode of operation, program functions and internal algorithms, and program segments and subroutines. A section on job control statements and input/output file descriptions is provided for the EPAMAC program.

A list of each program and a description of the variables are included in Appendix A.

Summary and Recommendations

- The EPAMAC is a generalized version of the SFMAC used during the development of San Francisco's Southwest Water Pollution Control Plant Facility Plan and Master Plan.
- EPAMAC is a special purpose, continuous simulation model of surface runoff with minimal input data requirements, broad areal and temporal coverage, and both flexibility and ease of application.
- In addition to quantity and quality analyses for stormwater flows, capabilities of the model include dry-weather flow, hourly simulation, overflow event analysis, pollutant removal as a result of sedimentation in storage, and lateral inflows. Postprocessor programs can also provide histogram plots of flow and quality as well as analyses of violation days for coliform limits in receiving water for several coliform standards.
- Information developed by the model was used by decision-makers for establishing allowable overflow frequency limitations for NPDES permits for wet-weather discharges.
- The overall effectiveness of the model in this application was high. The client and consultant were both able to contribute significantly to the model application process. Also, the flow and quality concerns in a combined sewer system were adequately addressed. In addition, the planning objectives were met, and preliminary sizing of a large number of diversified alternatives was accomplished.
- The EPAMAC and postprocessor programs should be implemented as a preliminary design and planning tool.
- The EPAMAC should be used repeatedly to analyze various combinations of storage capacities and treatment plant rates to determine possible optimum conditions. The EPAMAC should be used to examine seasonal and yearly periods.

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The complete report, entitled "EPA Macroscopic Planning Model (EPAMAC) for Stormwater and Combined Sewer Overflow Control: Application Guide and User's Manual," (Order No. PB 83-259 689; Cost: $26.50, subject to change) will be available only from:
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