Appendix E

GPRACSO Model Documentation

E.1 GPRACSO Database and GPRACSO Model

EPA developed the GPRACSO Database and GPRACSO Model to estimate CSO volume and the attendant pollutant loads on a national level. The GPRACSO Database contains information for all CSO communities in the United States. The GPRACSO Model estimates CSO volume and the BOD_5 load in CSOs for communities with combined sewer systems (CSSs). This documentation presents background on the sources of information and the methodology used to develop the GPRACSO Database and Model.

The GPRACSO Database includes information on all of the CSO communities across the United States. The primary sources of community-specific information include:

- EPA's CWNS (1992, 1996, and 2000)
- EPA's PCS database
- EPA's 2001 *Report to Congress- Implementation and Enforcement of the CSO Control Policy*
- EPA-sponsored municipal interviews with select CSO communities during 2002 and 2003
- Individual CSO community long-term control plan documentations
- Internet searches

The GPRACSO database contains information on how the CWNS Facility identifying numbers relate to CSO community names and NPDES numbers, and how complex CSO community systems connect to discharge into single regional POTWs. For highly detailed assessments of a single CSO community, the GPRACSO database may not have sufficiently accurate information. However, for EPA's efforts to summarize national conditions, the combination of the GPRACSO Database and the GPRACSO Model is sufficient for policy, cost, and technology assessments.

Each CSO community is represented as a specified land area within the GPRACSO Model, and each is associated with a known quantity of dry weather flow, and a known quantity of wet and dry weather treatment and wet weather storage. The GPRACSO Model is applied to represent annual average conditions. Typical rainfall years were developed from long-term meteorologic records for each CSO community. The key inputs to the GPRACSO model include: service area, population served, impervious cover, rainfall, temperature, treatment plant capacity, and wet weather storage. A detailed description of each of these parameters, including database sources, is provided in Table E.1

A "CSO community" is used herein to generically refer to the entity that terminates at a single POTW. Each POTW is evaluated as a single entity whether it is an individual sewer system or a totaled regional system. Wherever multiple CSO communities comprise a single regional system, a single data record, representing the total treatment capacity, wet-weather storage, and combined sewer service area of all the combined sewer communities in the regional system, is included in the GPRACSO Database.

The GPRACSO Model was used to estimate CSO volumes and BOD_5 concentrations for three national planning-level scenarios: baseline (1992) prior to CSO Control Policy, current level of control, and (future) full CSO Control Policy implementation. To accomplish this, the GPRACSO Model generates rainfall-derived runoff from each combined sewer area on an hourly basis, adds the runoff to dry weather flow, calculates the volume of combined sewage delivered to the POTW, and estimates CSO volume based on storage and treatment capacities. Hourly estimates of BOD_5 concentrations within CSSs are used to calculate the pollutant loads in CSOs and treated effluent from POTWs. The following sections provide more detail on the GPRACSO model algorithms and key assumptions.

Table E.1 Summary of Key Inputs to the GPRACSO Model

Combined Sewer System Description Parameters	
Service area acreage and population information	Estimated CSO service area data for 1992, 1996, and 2000 were obtained from a myriad of sources including CWNS. Where necessary, either population served or miles of sewer pipe were used to estimate source area. For a small fraction of the communities, other sources of service area included direct responses in EPA-sponsored interviews, published reports, and LTCPs.
Runoff coefficient	This coefficient was set to the impervious fraction of each community. Land use/land cover GIS layers from the USGS (EPA 2001) were used to aerial weight imperviousness based on five urban land use types. The boundary of each community was identified and was graphically superimposed on the USGS data.
Meteorologic data	
Rainfall	The United States was divided into 84 common hydrologic zones based on average annual precipitation, mean January air temperature, geography, and peak 2-year, 6-hour rainfall. For modeling purposes, rainfall is represented in terms of hourly rainfall amounts. It is presumed that all communities located in common zone would experience the same hydrologic conditions, including snow generation and melt. (EPA 2001)
Temperature	Once a "typical" rainfall year was identified for each of the 84 hydrologic zones, the associated hourly temperature record was taken from National Weather Service records such that snow generation and melting could be assessed. Estimated (modeled) snow accumulation and snow melt was based on hourly air temperatures using degree-day methodology (McCuen 1998).
Treatment System/Management System Parameters	
Dry weather and maximum wet weather POTW flow rates	Multiple sources have been reviewed to establish current and historic POTW treatment levels. The bulk of the information on POTWs originated from EPA's PCS database. For use in the GPRACSO model, the median value was calculated for both average and maximum design POTW flow based on up to two years of reported daily average and daily peak discharge rates.
End-of-pipe wet-weather treatment capacity	Data was obtained from the internet, published literature, responses in EPA-sponsored interviews, and LTCPs.
Secondary bypass with flow recombination	Data was obtained from the internet, published literature, responses in EPA-sponsored interviews, and LTCPs.
Wet weather storage capacity	Data was obtained from the internet, published literature, responses in EPA-sponsored interviews, and LTCPs.

E.2 Simulation of Dry Weather Sanitary Flows

Average daily dry weather sanitary flows for CSO communities are based on discharge monitoring reports available in PCS. Typical flow peaking factors based on literature values are used to represent the hourly variation of sanitary flows relative to the average daily flow rate within the CSS and entering the POTW (Metcalf & Eddy 1991). For example, the GPRACSO model sets the minimum and maximum hourly sanitary inflows to 32 percent and 141 percent of the average daily reported POTW inflow. Wherever PCS or other data on both average and maximum POTW capacity are available for a CSO community, GPRACSO peaking factors are modified accordingly. Regardless of the conditions encountered, simulated average dry weather sanitary inflow into a POTW always matches the average inflow obtained from the best available source for each CSO community. The maximum daily dry weather inflow never exceeds the reported maximum daily POTW treatment capacity.

E.3 Dry Weather Sanitary Pollutant Concentration Estimation

For the purposes of this report, the GPRACSO Model was used to estimate the BOD_5 load associated with CSO discharges. The GPRACSO Model assumes that the average dry weather BOD_5 concentration entering the POTW is 158 mg/L, with minimum and maximum hourly values of 40 and 290 (mg/L), respectively. The average dry weather concentration and the diurnal (i.e., hourly) variations in pollutant concentration are based on the trend reported by Metcalf & Eddy (1991) for the City of Chicago. There were no other influences on hourly dry weather concentrations unless there were additional inflow from snowmelt or from stored combined sewage returned from wet weather storage facilities. Algorithms associated with these two inputs are:

Flow source #1: The GPRACSO Model identifies that there is a snow pack present in the CSO community and that hourly air temperature is above 32 degrees.

Model Response	**Assumptions**
From the calculated melt rate, an estimate of the snowmelt is made, all of which is assumed to flow into the CSS. The relative volumes of dry weather sewage and snowmelt are used to calculate a reduction in the BOD_5 concentration entering the POTW.	It is assumed that snowmelt contains zero pollutant and as a result dilutes the inflow entering the POTW.

Flow source #2: A CSO community has dedicated wet weather storage available to capture any wet weather flows in excess of the POTW maximum treatment capacity.

Model Response	**Assumptions**
The GPRACSO model tracks all of the storage volume along with the amount of pollutant (BOD_5) it contains on an hourly basis.	GPRACSO assumes that the stored flow is discharged to the POTW as soon as there is available treatment capacity (i.e., the hourly POTW inflow is less than the reported maximum POTW treatment capacity).

E.4 Estimation of CSO Volume

The GPRACSO Model performs many hydrologic computations as it evaluates the potential and actual wet-weather inflow into the CSS. The data sources used and the computations performed are as follows.

Typical meteorological conditions were estimated for each CSO community based on a review of long-term data from the National Weather Service. CSO communities were geographically grouped based on hydrology into 84 common zones, and a typical rainfall year was identified for each zone. As a rule, the typical year contained within +/-10 percent of the annual average precipitation for that zone or location, and had no single rainfall event larger than the two-year return period rainfall. Depending on the zone evaluated, the typical rainfall year presents between 30 and 80 potential overflow-producing events for each CSO community within the zone. Hourly temperature records was associated with rainfall records for each zone so that snow accumulation and melting could be included in the GPRACSO Model simulation.

Runoff calculations were performed using the rational method, which multiplies hourly rainfall by a single coefficient to calculate the runoff. The coefficient was set to equal the overall impervious cover of each CSO community. As described in Table E.1 under runoff coefficient, land use/land cover GIS layers from the USGS were used to help estimate the geographically weighted imperviousness for the land area found within the political boundaries of the CSO communities.

Snow accumulation and melting were calculated using a degree-day approach applied on an hourly basis (McCuen 1989). The GPRACSO Model monitors the conditions in each CSO community to determine if snow pack is present and if it is aggregating or shrinking in any simulated hour. Each hour's temperature was evaluated to establish the potential snowmelt, and snowmelt was simulated if a snow pack existed.

POTW wet weather treatment capacity is an important management feature. The GPRACSO model assumes the average event-period wet weather POTW treatment capacity is 130 percent of the reported maximum daily treatment rate. Rainfall and CSO events often occur over a period between two and eight hours, a period short enough for POTWs to "max-out" their systems at a greater rate than possible for a full 24-hour period. For example, if DMR data for a single POTW indicates 100 MGD is the maximum daily discharge rate (the median of maximum monthly values reported in PCS), then GPRACSO assumes that the POTW can actually treat 130 MGD over the short-term (i.e., during wet weather conditions). This 130 percent rule was developed from in-depth comparison between GPRACSO simulations and the results of local models/studies for four CSO communities.

The GPRACSO simulation assumes the POTW secondary treatment capacity above the simulated hourly dry weather inflow (the annual average daily POTW inflow multiplied by the appropriate hourly peaking factor) is available for treating potential CSO. So a POTW with a daily 100 MGD maximum secondary treatment capacity and an estimated *hourly* dry weather flow rate of 76 MGD (at 2 pm) would have 54 MGD capacity available between 2 and 3 pm to manage any wet weather flows (resulting from 100 MGD *1.3 - 76 MGD). At 3 pm, the estimated dry weather flow would be about 71 MGD, so any wet weather flows entering the system between 3 and 4 pm would be treated up to 59 MGD (resulting from 100 MGD *1.3 - 71 MGD).

Wet weather end-of-pipe (EOP) treatment was assumed to occur only after both the maximum wet weather treatment capacity of the POTW and any wet weather storage is fully utilized during a CSO event. The GPRACSO Model uses EOP as a last resort treatment, and it cannot be used to drain stored wet weather flows. EOP treatment technologies considered by the GPRACSO Model include things like vortex treatment facilities.

Wet weather storage was simulated using a built-in algorithm within the GPRACSO Model. The algorithm assesses the operation of wet weather storage facilities designed to capture and hold wet weather flows until treatment capacity is available. The operation of wet weather storage is simulated such that any hourly flows in excess of POTW treatment would go directly to wet weather storage. Only after all available wet weather storage is filled and EOP treatment capacity is exceeded will GPRACSO simulate a CSO discharge. Available POTW capacity for draining storage is defined as the difference between the maximum POTW treatment rate and the flow entering the simulated POTW for any given hour.

Conveyance limits for combined sewer interceptor systems are not considered by the GPRACSO Model. The GPRACSO Model assumes that the total interceptor system discharging into a POTW has a capacity greater than the maximum treatment rate of the POTW. As a result, the limiting factor within the GPRACSO Model is the POTW wet weather treatment capacity. While it is acknowledged that this assumption is not appropriate for some CSO communities, maximization of flows to the POTW is a required minimum control measure under EPA's CSO Control Policy.

E.5 Estimation of CSO Pollutant Loads

The GPRACSO Model attempts to recognize the major influences on CSS pollutant concentration on an hour-to-hour basis. The influences accounted for include:

- Flushing of accumulated materials from the CSS
- Dilution of sanitary flows by storm water inflow late in the overflow periods
- Variation in sanitary flow rate and concentration through the day

The first two influences are lumped into a single load or calculation referred to as "storm water pollutant load". This load represents the combination of *pollutants flushed from pipes* and *pollutants washed from the urban surface*, independent of any sanitary inflow rates. In order to estimate the BOD_5 loadings attributable to storm water (including the flushing of settled pollutant in pipes), the following exponential relationship between time and BOD_5 concentration was applied:

Equation 1. $C = (200 * 10^{-1.5*(t)}) + 15$
Where:
C = the BOD_5 concentration in mg/L used to calculate the storm water load
t = time in hours since the overflow started
15 = the BOD_5 concentration in mg/L assumed to be in urban storm water

Information from two data sources was used to develop the above relationship. The first data source is multi-event CSO monitoring results of first-flush concentrations in combined sewers for a medium-sized east coast CSO community. The second data source was from 90th percentile event mean concentration BOD_5 concentrations reported in EPA's Nationwide Urban Runoff Program (EPA 1985). The first data source suggests that BOD_5 concentrations (grab samples in sewers) at the very start of runoff events range between 200 and 400 mg/L, but that concentrations decrease rapidly within the first hour of runoff. As a result, the average first hour BOD_5 concentration is set to be 215 mg/L, using the equation above. The second data source suggests a high-end long-term urban runoff BOD_5 concentration in the absence of CSOs is approximately 15mg/L, a feature also provided by the equation above.

<u>Calculation of hourly overflow concentration in storm water/sanitary mix</u>. While the first flush effect results in a high concentration of BOD_5, later in the CSO event storm water dilutes the more concentrated sanitary flows. As a result, the GPRACSO Model continuously mixes the sanitary flow/pollutant load with the storm water runoff/pollutant load each hour to calculate the average hourly concentration. It is assumed that the mixing of sanitary and storm water is 100 percent complete for each hour simulated and that any CSOs that occur will contain the same pollutant concentration as what enters the simulated POTW. The logic used to select the uniform BOD_5 concentration for any particular hour is:

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If EventTime = 0 (the runoff has just started entering the CSS), then
CSCConc(ttt,0)  = $(200 * 10^{-1.5*(\text{event time})}) + 15$

If EventTime > 0 (the overflow event is progressing), then
CSCConc(ttt,0) = $(200 * 10^{-1.5*(\text{event time})}) + 15$

If CSCConc(ttt,0) < DWBODconc * hours, then
CSCConc(ttt,0) = (HRDischarge(ttt,0) - HRDWF(ttt,0)) * (CSCConc(ttt,0) +
                      HRDWF(ttt,0) * DWBODconc * hours) / HRDischarge(ttt,0)

EventTime                  = time since the start of the overflow event (hours)
CSCConc                    = uniform concentration of the storm water/sanitary mixture (mg/L) from the combined sewer
                             community
DWBODconc * hours          = the sanitary flow concentration in the absence of overflow (mg/L)  for the "hour" under
                             simulation
HRDischarge(ttt,0)         = the simulated total hourly flow in the combined sewer (MGD)
HRDWF(ttt,0)               = the hour's sanitary flow rate in the absence of overflow (MGD)
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The CSCConc(ttt,0) value is used to compute the CSO BOD_5 load, the inflow load entering the POTW, and the pollutant load stored in any wet weather storage that may be present in the system. For BOD_5, the assumed storm water concentration for the first hour when overflow occurs is 215 mg/L regardless of when it occurs in the day. For any subsequent hour in which overflow can occur, the BOD_5 concentration is the greater of (1) the value taken from Equation 1 based on the time elapsed since the start of the overflow, or (2) the flow weighted combination of Equation 1 and the dry weather sanitary flow concentration based on hourly variation. The first flush is recognized as the strongest influence on concentration at the beginning of the event, the dominant role of storm water dilution is recognized later in the event, and the daily variation in sanitary flow concentration is accounted for throughout the event.

E.6 Comparison with Other Estimates

EPA compared GPRACSO results against those of "local CSO models" of varying complexity and sophistication in five CSO communities. While there is no guarantee that they are correct, the local CSO models were developed to support LTCPs, and were assumed to be reasonably accurate. EPA used the departure from local CSO model estimates to gage the relative accuracy of the GPRACSO Model. Based on the local CSO model results, EPA established the following error brackets for GPRACSO estimates:

- CSO volumes are within +/- 50 percent of local CSO model estimates
- CSO community-wide average annual pollutant EMCs are at +/- 80 percent of local CSO model estimates
- CSO pollutant loads are within +/- 80 percent of local model estimates

Overall, errors originate from two principal sources: inaccuracies in data describing CSO communities, and errors resulting from the GPRACSO Model algorithms. EPA believes that the larger error is associated with the first source; that the bulk of the model error originates from errors in the basic system data (e.g., the combined sewer service area in each CSS). For several years, EPA has collected data to improve its understanding of historic, current, and future conditions in communities with combined sewers, obtaining better data each year. Additional investigation of CSO communities is anticipated to improve the assessment with the GPRACSO Model and its associated database.

To date, an in-depth comparison of local models and GPRACSO algorithms has not been performed. For the GPRACSO Model, extensive efforts were made to account for the majority of physical and hydrologic factors encountered in the generation of sanitary and storm water flows. Reasonable data sources are used to estimate the performance of POTWs and the operation of wet weather treatment and storage. However, the GPRACSO Model greatly simplifies the influence of geographic dissimilarities to each city, e.g., network of sewer pipes and pump stations are not explicitly modeled.

E.7 Summary

The GPRACSO Database and application of the GPRACSO Model have been applied to estimate the CSO volume and annual BOD_5 load for all combined sewer communities nationwide. The GPRACSO Model has been applied to estimate the current annual performance expected under rainfall that are both local to each community and typical on an annual basis. In addition, GPRACSO model results are conditions based on historic POTW performance data. Recent POTW upgrades and/or new wet weather management facilities may not be incorporated within the current version of the GPRACSO database. (Note: EPA is continuously collecting data on CSS facilities that can be used to update the GPRACSO database). For this reason, the estimates produced by the GPRACSO simulation may not fully recognize current management.

For its analysis of CSO regulations, EPA has used the typical or average meteorologic conditions faced by each community to analyze annual CSO management performance, and then summed all communities to obtain a national total performance. The GPRACSO Model estimates of the typical performance will vary from the *actual* performance measured at a specific place and time, in a single community. This is because the actual meteorologic conditions (e.g., the weather at 12 PM on May 1, 2002) will vary from that found in the matching hours meteorologic record for the selected typical year.

References

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