Development of Long Term Precipitation and Infiltration Records for the Performance Evaluation of a Proposed Regional Tunnel

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This chapter describes how long-term precipitation and infiltration records were developed for use in the performance evaluation of a proposed regional drainage tunnel shared by the cities of Detroit and Dearborn, Michigan. The precipitation record includes hourly precipitation data (rainfall plus snowfall) plus a calculation for snowmelt. Methodologies were applied to this record to develop 36 y of rainfall and snowfall plus snowmelt at 15-min intervals. Infiltration parameters are varied monthly based on long-term rainfall/runoff records, rather than assumed to be constant throughout the year. In addition, allowances have been made for incorporation of spatially non-uniform precipitation into the evaluation. The application of these precipitation and infiltration records has allowed an improved representation of the hydrologic factors contributing to combined sewer overflow (CSO) in Southeast Michigan over an extended simulation length. The implementation of these records has improved the capabilities of the continuous model for computing the long-term performance of proposed CSO facilities in Southeast Michigan, including the Proposed Regional Tunnel Project.

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9.1 Background

The Detroit Water and Sewerage Department serves three million people in 77 communities, with a service area spanning approximately 900 mi² (2330 km²). The Greater Detroit Regional Sewer System (GDRSS) consists of both combined and separate sanitary and storm sewer systems.

The GDRSS tributary area has been modeled using the Stormwater Management Model (SWMM) Framework. This GDRSS SWMM Model has been an integral tool in evaluating the performance of various CSO control alternatives. Both continuous and event-specific simulations have been performed with the GDRSS Model in order to design and evaluate the expected performance of these alternatives.

The Long Term CSO Control Plan for the City of Detroit has served as a long-term, multi-faceted work plan for the reduction of CSO to the receiving streams of Southeast Michigan. Numerous alternatives were analyzed for their potential impact on reducing and treating CSO as part of this effort. Those alternatives then became components of the City of Detroit's Long Term CSO Control Plan (LTCP).

As part of the Long Term CSO Control Plan, regulatory criteria were examined and incorporated into CSO control facility design and planning. The presumptive approach taken by the United States Environmental Protection Agency (USEPA) is 85% treatment by volume, or an overflow frequency of four events per year. The Michigan Department of Environmental Quality (MDEQ) presumptive criteria include both 30-min contact time for the 10-y 1-h event and complete capture of the 1-y 1-h event. The MDEQ criteria are for basins. The City of Detroit utilized the demonstrative approach in the development of the LTCP, in which alternative selection is based on cost-effective performance. Hence, performance evaluations were an integral part of development of the LTCP.

9.2 Tunnel Project Evolution

The Detroit Tunnel is the largest component of the Long Term CSO Control Plan. Several alternatives were considered for the Detroit Tunnel, including both capture and flow-through alternatives. The currently planned system includes 120 MG (4.54×10^8 L) of volume within a 22.5-ft (6.9 m) diameter, 7.5-mi (12.1 km) long capture tunnel. Concurrently, the City of Dearborn,

Michigan, was evaluating CSO alternatives for their collection system. The City of Dearborn has also gone through numerous stages of alternative selection and performance evaluation. The most recent Dearborn plan consisted of a 60 MG (2.27×10^8 L), 17-ft (5.2 m) diameter, 5.5-mi (8.9 km) long flow-through tunnel.

To take into consideration all viable alternatives for both tunnel systems, the possibility of combining the two CSO projects into one regional project was examined. The rationale for a regional combined tunnel was that combining the two separate CSO tunnel projects into a combined regional tunnel would result in a potential net benefit in terms of overflow frequency and volume reduction due to the natural spatial variation of precipitation to be expected with the tributary areas.

Several alternatives were originally considered to connect the two existing tunnel projects. Due to constructability issues for the two separate (City of Detroit and City of Dearborn) tunnel projects, only two alternatives remained for the combined tunnel system. These two alternatives consist of connecting the two tunnels with approximately 10,000 ft (3,048 m) of additional tunnel, with the primary difference between the alternatives being the location of the dewatering pump station. The alternatives call for a combined regional tunnel operating in capture mode. This tunnel would have 210 MG (7.95×10^8 L) of available storage volume, which is a composite of the separate tunnel project volumes plus the 30 MG (1.13×10^8 L) available in the proposed connection. Figure 9.1 shows the layout of the proposed combined regional tunnel, including the Dearborn and Detroit Tunnels, and the proposed tunnel connection.

Since the conceptual stages of the proposed combined regional tunnel, efforts have been made to gauge the feasibility of such a venture. Before an in-depth, multi-faceted feasibility evaluation could be conducted for the combined regional tunnel, it was necessary to evaluate and quantify the potential long-term performance benefit of the combined system in relation to the performance of the separate tunnel systems.

It was determined that the GDRSS continuous model would be utilized to develop an estimate of the potential benefit of a combined tunnel system. The continuous model would be used to evaluate the long-term performance of the various tunnel scenarios. Then, a comparison would be made between those options in terms of overflow frequency and volume in order to quantify the beneficial performance of the combined tunnel system compared to the separate tunnel systems.

Figure 9.1 Proposed Combined Regional Tunnel layout.

9.3 Performance Evaluation Tool

9.3.1 Historical Tool

In previous performance evaluations for various CSO control projects, Version 3 of the GDRSS Continuous Model was utilized in combination with three years (1984-1986) of hourly rainfall data from the National Climatic Data Center’s (NCDC) Detroit Metropolitan Airport Gauge. The Detroit Metropolitan Airport

Gauge is the official National Weather Service precipitation gauge for Southeast Michigan. This weighing-bucket type gauge records rainfall and also water equivalent of any snowfall. These three years were considered representative years of the entire available NCDC data record. The precipitation data from the NCDC gauge was applied over the entire GDRSS tributary area represented by the model, assuming uniform precipitation over all model sub-areas.

In these historical continuous simulations, infiltration parameters were assumed to be constant throughout the calendar year. Infiltration from pervious areas was computed in the GDRSS Model using Horton's equation, with calibration of parameters based on summer rainfall events and sewer monitoring records.

9.3.2 The Need for an Improved Tool

To determine the performance benefit of connecting the two tunnels, a long-term continuous simulation was required to estimate the performance of the separate and combined tunnel options. Due to increased computational capabilities, a longer simulation length became possible with the continuous model. A rainfall/snowfall record consisting of 36 y of hourly data from NCDC was thus incorporated into the continuous model.

15-Minute Precipitation

During modeling efforts in support of the development of the Long Term CSO Control Plan for the City of Detroit, it was determined that 15-min rainfall/snowfall data was required to accurately represent the runoff inflow hydrographs. Therefore, it was determined that 15-min rainfall/snowfall data should be used in the improved continuous simulations. Without a dependable, long-term record of 15-min rainfall/snowfall data in the Detroit Metropolitan Area, two options were available. These options were to use hourly data knowing that the peak of hydrographs would be underestimated, or develop a methodology to generate 15-min rainfall/snowfall data from the hourly data. The latter option was selected on the grounds that it would provide better representation of the precipitation and would accurately represent the inflow runoff hydrographs.

Snowfall/Snowmelt

During the spring and winter months, large amounts of runoff due to both snowmelt alone and also snowmelt in combination with rainfall are observed in Southeast Michigan. Operations and maintenance staff at various CSO facilities

throughout the GDRSS have witnessed CSO events during times that minimal rainfall was recorded at local gauges during winter months. Therefore, it can be concluded that during these periods, the potential for snowmelt to trigger a CSO event is quite high. Since precipitation data from the Detroit Metropolitan Airport gauge is only a measure of rainfall and water equivalent of snowfall, no allowances are made for snowfall that becomes runoff due to snowmelt when using NCDC precipitation data alone in the continuous model simulations. A continuous simulation performed without allowances for snowfall and snowmelt underestimates wet weather flows throughout the winter and spring seasons. The previous GDRSS Model simulations do not consider snowfall and snowmelt and were found to underpredict CSO volume during the spring and winter seasons. Therefore, it is also necessary to consider snowmelt in the long-term continuous simulations to achieve an accurate estimate of performance throughout the year.

Spatially Non-Uniform Precipitation

It is not uncommon to experience a storm event that produces more precipitation in one area than another, especially over a large area. Generally speaking, winter events display more spatially uniform patterns, as compared to spring and summer precipitation events, which typically display more spatial non-uniformity. Applying the data from a single source gauge over a large tributary area assumes spatial uniformity of precipitation. This may be appropriate for small tributary areas, which may not experience significant non-uniformity of precipitation, or for winter-type precipitation events, which often produce more uniform precipitation patterns even over a relatively large area.

Multiple reasons exist as rationale for incorporating the non-uniformity of precipitation into performance evaluations. For one, the NCDC Detroit Metropolitan Airport Gauge is a significant distance from the tributary area to the proposed joint tunnel and may not experience the same precipitation as the tunnel tributary area for specific events. Also, the proposed combined tunnel tributary area is approximately 28,000 acres (11,331 ha), which is large enough to experience a wide variation in precipitation patterns especially in summer-type events. Therefore, a more spatially-distributed precipitation data record is required to better represent expected overflow performance.

Using precipitation records from precipitation gauges in and near tributary areas of the combined tunnel should allow for a better representation of localized precipitation by taking into account the spatial non-uniformity of precipitation characteristic of all precipitation events. This localized precipitation should lead to an improved estimate of the frequency of overflow events from a combined

regional tunnel especially during the summer months, when overflows are more detrimental to public health (full-body contact during summer months versus partial-body contact during winter months).

Monthly Infiltration

The SWMM framework for continuous simulations uses a set of infiltration parameters for the entire year. Infiltration from pervious areas in the GDRSS Model is computed using Horton's equations, with constant values for the minimum infiltration capacity, maximum infiltration capacity, and decay coefficient used consistently throughout the length of the simulation. However, using a set of maximum and minimum infiltration parameters throughout a continuous simulation does not take into account the variation in infiltration capacities over a calendar year. Infiltration rates tend to vary during the year due to changes in ground conditions. For instance, in the late fall, winter, and early spring, the ground may be frozen or partially frozen to some level still permitting limited infiltration. Assuming one set of maximum and minimum infiltration capacities throughout the year leads to an overestimation of infiltration capacities for events occurring during these months and therefore underestimates runoff resulting in computed overflow. This one set of infiltration capacities are usually determined from spring and summer flow monitoring, which does not reflect ground conditions that may exist over the year. This highlights the need for incorporation into the long-term simulation, infiltration parameters which vary through the calendar year.

9.3.3 Development of an Improved Tool

Thirty-six years of hourly precipitation data were obtained from the NCDC for 1960 through 1995. The NCDC also records 24-h snowfall. This information is used in combination with average daily temperature to segregate precipitation due to rainfall from precipitation due to snowfall resulting in a rainfall record at the NCDC Detroit Metropolitan Airport Gauge. Any precipitation occurring as snowfall was then separated from the rainfall records and used in the calculation of snowmelt reported later in this paper.

15-Minute Rainfall

The method to distribute the NCDC hourly rainfall into 15-min rainfall was based on research done J. Sherrill and E. Brater at the University of Michigan on rainfall-runoff relations specific to Southeast Michigan. This research is

summarized in *Rainfall-Runoff Relations on Urban and Rural Areas*, a May 1975 publication of the National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency (EPA-670/2-75-046). As part of this research, Sherrill and Brater developed intensity-duration curves based on summer events and winter events that had occurred in Southeast Michigan over a period of 13 y. The original research has been updated with information presented in NOAA Technical Memorandum NWS HYDRO-35, June, 1977. The updated intensity-duration curves developed by Sherrill and Brater provide a basis for the method used in this discussion to distribute hourly rainfall into 15-min rainfall.

The equations for these curves are of the following form:

$$P/t = \frac{A}{(t+B)^n} \quad (9.1)$$

A , B and n are constants, with P/t representing the percentage (P) of 24 h precipitation per hour over the duration (t) in h. The resulting equations are:

$$P/t = \frac{75.46}{(t+0.3)^{0.892}} \quad (9.2)$$

for summer, and

$$P/t = \frac{68.0}{(t+12.4)^{0.849}} \quad (9.3)$$

for winter.

Figure 9.2 contains the summer precipitation intensity-duration distribution expressed as a percentage of 24-h rainfall occurring in each 15-min period. That is, this graph shows that the maximum 15 min period within the 24-h event receives 32.2% of the total 24-h rainfall, the 2nd greatest 15-min period receives 13.9%, and so on. Figure 9.3 shows the chronological time distributions of storms about the maximum 15 min of rain, with the 2nd greatest 15 min, 3rd greatest 15 min, and so forth, applied away from the maximum 15 min.

A 15-min rainfall distribution of the hourly NCDC precipitation data was generated to imitate actual 15-min rainfall based on the work done by Sherrill and Brater on rainfall in southeast Michigan. To develop the 15-min rainfall data set, NCDC hourly rainfall data was first discretized into distinct events by specifying an inter-event duration of one hour. The maximum hour of rainfall, the second greatest hour, and the third greatest hour of rainfall were then

Figure 9.2: 15-minute values for 24-h summer rainfall hyetograph.

Figure 9.3 15-minute distribution of summer 24-h rainfall hyetograph.

determined for each distinct rainfall event. The distribution protocol reported herein was developed for the maximum 3-h period of any event, with events defined as described above.

Once the three greatest hours of precipitation were identified for each distinct event, a distribution into 15-min data could be preformed. Sherrill and Brater’s research provided a typical summer distribution of 24-h rainfall into

15-min periods over the event. Since the NCDC rainfall data is hourly, Sherrill and Brater's relationships were applied to each of the three identified hours.

According to the research, the maximum hour of rainfall comprises the four greatest 15-min rainfall amounts, as follows:

- the greatest 15-min period within the maximum hour receives 32.2% of the total 24-h rainfall,
- the second greatest receives 13.9%,
- the third greatest receives 8.1%, and
- the fourth greatest receives 5.5%.

Therefore, the rainfall in the four greatest 15-min periods contributes 59.7% of the total 24-h event rainfall. These percentages of total 24-h rainfall occurring in the four greatest 15-min periods in the 24-h event were expressed as a percentage of the total precipitation occurring in the maximum hour. That is, the greatest 15-min period within that maximum hour receives 32.2% of 59.7%, or 54%, of the total rainfall occurring within that maximum hour. The 2nd, 3rd, and 4th greatest 15-mins within that maximum hour receive 23%, 14%, and 9% of the maximum hour precipitation, respectively. The maximum hour of each discretized event could then be distributed into 15-min rainfall according to these percentages.

Distributions for the 2nd and 3rd greatest hours follow a similar logic, with the greater of the previous and subsequent hours to the maximum hour receiving the 15-min distribution common to the 2nd greatest hour, and the lesser of the previous and subsequent hours receiving the 15-min distribution common to the 3rd greatest hour. The rainfall distribution for hours outside of the maximum, previous and subsequent hours was assumed to be uniform. The rainfall distribution used in the 15-min data set development is best described by Figure 9.4, which shows what percentage of hourly precipitation is distributed in each of four 15-min periods within the maximum hour, the 2nd greatest hour, the 3rd greatest hour, and all other hours of the event.

Some rainfall events are characterized with the maximum hour preceding the next two largest hours or the maximum hour occurring after the next two largest hours. In these cases, the synthetic 15-min distribution was developed as above, with the synthetic 15-min distribution for the second largest hour was applied to the adjacent hour and the synthetic 15-min for the 3rd greatest hour was applied to the remaining hour. An example of this application is presented in Figure 9.5.

To demonstrate the effectiveness of the synthetic 15-min distribution of hourly rainfall data in generating representative inflow hydrographs, a comparison was made between hydrographs generated using recorded 15-min data,

Figure 9.4 15-min precipitation hyetograph development.

Figure 9.5 15-min precipitation hyetograph development with maximum hour occurring after 2nd and 3rd greatest hours.

hourly data, and synthetic 15-min data generated from hourly data. 15-min rainfall data was available for a short period at the Detroit City Airport. Therefore, RUNOFF was used to compare the hydrographs generated by this actual 15-min rainfall record to hydrographs resulting from both hourly data, and hourly data distributed into 15-min data according to the protocol outlined above.

Comparisons of hydrographs for various sized tributary areas and storms were conducted using the RUNOFF block of SWMM. Based on the results of the comparisons, the 15-min distribution of hourly rainfall provides a much better representation than using observed hourly data as input to the GDRSS Model and compares well with actual 15-min data results. The 15-min synthetic data lead to more accurate representations of the peaks of the hydrograph than did the hourly data when compared to those generated using actual 15-min data. Therefore, the 15-min distribution of hourly data is recommended for simulations, whether event-specific or continuous, when actual 15-min data is not available.

Snowfall/Snowmelt

Hydrologic simulations require the development of a rainfall/snowmelt record. The development of a rainfall/snowmelt record requires the separation of precipitation into snowfall and rainfall. The snowfall record can be used to track the accumulation of snow on the ground, which is utilized to generate a snowmelt record. Meteorological records often include a complete record of snowfall and snow on the ground which can be utilized in combination with recorded rainfall to generate a rainfall plus snowmelt record. For example, the NCDC records daily climatological data at the Detroit Metropolitan Airport station. The climatological data collected includes maximum temperature (T_{max}), minimum temperature (T_{min}), daily precipitation (PRCP), daily snowfall (SNOW), snow depth (SNWD), and water equivalent of snow depth or snow on the ground (WTEQ).

If no snowfall occurs on a day, it is possible to calculate daily snowmelt if the WTEQ measurement is available. The total daily snowmelt would simply be equal to the WTEQ from the previous day minus the WTEQ of the current day, or:

$$TotalDailySnowmelt = WTEQ_{previousday} - WTEQ_{currentday} \quad (9.4)$$

Then the daily rainfall plus snowmelt would be equal to the recorded rainfall plus the observed snowmelt.

However, WTEQ was found to be missing for a considerable portion of the record. In the event that WTEQ data is unavailable, total daily snowmelt must be calculated. Research performed at the University of Michigan has demonstrated that the degree-day method in combination with calculated melt by rainfall can be used to estimate snowmelt in Michigan. Observed air temperature is a surrogate parameter which can be used to calculate snowmelt resulting from atmospheric heat and radiation, while a heat balance can be performed to calculate the amount of snowmelt from warm rainwater. The potential snowmelt due to temperature using SI units is given by:

$$M_1 = C(T_a - T_b) \quad (9.5)$$

where:

M_1 = potential snowmelt due to atmospheric heat and radiation,

C = degree-day factor,

T_a = average air temperature, and,

T_b = temperature base.

The air temperature is taken to be the average temperature for the day, or:

$$T_a = \frac{(T_{\max} + T_{\min})}{2} \quad (9.6)$$

with:

$T_{\max}$ = maximum daily temperature; and

$T_{\min}$ = minimum daily temperature.

A value of $C=0.05$ for the degree-day factor has been found to give good results in Michigan. The temperature base is based on an analysis comparing calculated WTEQ to observed WTEQ that resulted in a "best" temperature base of $T_b=34^\circ\text{F}$ (1°C). With these values, the above equation for potential snowmelt due to heat and radiation becomes:

$$M_1 = 0.05(T_a - 34^\circ) \quad (9.7)$$

If rain also occurs on this day, then the following equation is used to calculate the potential snowmelt due to rain using SI units:

$$M_2 = \frac{P(T_a - 32^\circ)}{144} \quad (9.8)$$

where:

M_2 = potential snowmelt due to rain,

P = depth of rain, and

T_a = average air temperature.

Based on the foregoing equations, the calculation for total potential snowmelt becomes:

$$PS_i = M_1 + M_2 = 0.05(T_a - 34^\circ) + \frac{P(T_a - 32^\circ)}{144} \quad (9.9)$$

where:

$$PS_i = \text{potential snowmelt}_{\text{currentday}}$$

To estimate the amount of snowmelt that would occur during a day, the potential snowmelt of the current day and the sum of the WTEQ for the previous day plus the WTEQ of snowfall occurring on that day should be compared. The smallest of either the potential snowmelt of the current day, or the sum of the WTEQ of the previous day plus the WTEQ of snowfall of the current day, should be taken as the estimate for total daily snowmelt. The following equations are used in this calculation of total daily snowmelt:

$$TDS = PS_i \quad (9.10)$$

where:

$$TDS = \text{total daily snowmelt}$$

or,

$$TDS = (WTEQ_{\text{previousday}} + WTEQ_{\text{snowfall}_{\text{currentday}}}) \quad (9.11)$$

To ensure that the calculation of snowmelt was accurate, the calculated daily snowmelt was compared to observed snowmelt where it was available throughout the record. In addition, the observed WTEQ was compared with the WTEQ for the previous day and the precipitation occurring on the current day. A comparison with the snow depth on the ground also gave an indication of the accuracy of the WTEQ and calculated daily snowmelt. Other elements besides WTEQ could also have missing data. Therefore each element was queried for missing data. For instance, the maximum and minimum temperatures were found to have missing data. To estimate the average temperature for these days, the average temperature from the preceding day and the subsequent day were averaged to obtain an estimate of the average temperature for that day.

Total daily snowmelt was then applied to the 15-min rainfall record. Research has shown that if the total daily rainfall is less than or equal to 0.2 in (5.1 mm), then the daily snowmelt should be distributed uniformly between 10:00 am to 4:00 p.m., which are typically the warmest six hours of the day. However, if total daily rainfall was greater than 0.2 in (5.1 mm) over the day, then the total daily snowmelt was applied proportionally to the synthetic 15-min rainfall intensities. The 15-min rainfall and the 15-min snowmelt records were combined into a single 15-min rainfall/snowmelt record.

Spatially Non-Uniform Precipitation

The Southeast Michigan Council of Governments (SEMCOG) has maintained records of precipitation data from a large network of gauges throughout Southeast Michigan. Many of these gauges are located in close proximity to the Detroit Tunnel and Dearborn Tunnel tributary areas. Because of the distribution of these gauges in Southeast Michigan, SEMCOG precipitation data can provide information regarding the spatial distribution of precipitation over a large area during a single event or a long period of record.

Precipitation data from various SEMCOG gauges was examined over the same 36-y period as the data from the NCDC at Detroit Metropolitan Airport. As part of this investigation, it was necessary to examine data from SEMCOG gauges located within or adjacent to the tributary areas of the Detroit and Dearborn Tunnels. In addition, it was necessary to seek out the SEMCOG gauges that provided the most comprehensive period of record and most

Figure 9.6 Locations of local SEMCOG gages within the tributary areas of the Dearborn and Detroit Tunnels.

successful precipitation catch. After examination, it was determined that SEMCOG gauges W-09, W-16, W-25, and W-27 provided the best information for the Detroit Tunnel tributary area, and SEMCOG gauges W-08, W-22, W-23, and W-36 provided the best information for the Dearborn Tunnel tributary area.

Figure 9.6 is a map of the tributary area to the Dearborn and Detroit tunnels, along with the locations of these eight local precipitation gauges. All GSRSS model sub-areas in the Detroit and Dearborn Tunnel tributary areas were assigned a SEMCOG gauge according to the Thiessen Polygon Method.

Hourly rainfall data from each of the SEMCOG gauges was then distributed into 15-min rainfall data according to the same methods used on the NCDC hourly data. In addition, snowfall/snowmelt was calculated from the NCDC gauge, and applied in the same manner as described above. Rainfall and snowmelt were then combined into one record for each of the eight local precipitation gauges for incorporation into GDRSS simulations.

Monthly Infiltration

Sherrill and Brater’s research at the University of Michigan included examination of seasonal variation of infiltration capacities in Southeast Michigan (EPA-670/2-75-046). In their research, Sherrill and Brater developed a set of monthly average infiltration capacities which, when incorporated into the SWMM framework, provide a better representation of the variation in soil infiltration capacity over a typical calendar year. Figure 9.7 illustrates the monthly variation in infiltration parameters that was incorporated into RUNOFF for use in the GDRSS continuous model.

Figure 9.7 Average monthly values for soil infiltration capacities.

In the modified GDRSS RUNOFF coding, a maximum and minimum infiltration is designated for each month, corresponding to the constants (f_o and f_c) used in Horton's equation.

$$f = f_c + (f_o - f_c)e^{-kt} \quad (9.12)$$

The f_o and f_c are set to represent the corresponding monthly infiltration rate. A constant decay coefficient (k) is used over the simulation.

9.4 Results of Improvements

Components of the improved precipitation and infiltration records affect the wet weather runoff simulated by the RUNOFF block, and consequently affect the overflow volume and frequency simulated by the TRANSPORT block within the continuous simulations. The following is a discussion of the impacts that these improvements have on the overflows from the Detroit Tunnel alone.

9.4.1 15-Minute Rainfall

Using 15-min instead of hourly rainfall data leads to a difference in estimated overflow volume and frequency. Using data from the 15-min rainfall distribution leads to a slight increase (approximately 5%) in both frequency of overflow and in annual overflow volume from the Detroit Tunnel over hourly data. The increase in tunnel overflow frequency and volume when using the hourly rainfall data distributed into 15-min data is a direct result of the improved representation of the runoff hydrograph when this 15-min data is used in the place of the original hourly data set.

9.4.2 Snowfall/Snowmelt

It is expected that including allowances for snowmelt in the continuous simulation will increase the overflow volume from the Detroit tunnel during the winter months. When examining the overflow volume of overflow events during winter months using a precipitation record both with and without allowances for snowmelt, the results indicate that using snowfall/snowmelt calculations does affect the estimated overflow volume from the Detroit Tunnel. The results of the continuous model for the months of October through May indicate that including a calculation for snowmelt increases annual overflow volume from the Detroit Tunnel by 4% during these winter months.

For purposes of this discussion, June through September are considered summer, while October through May is considered winter.

9.4.3 Spatially Non-Uniform Precipitation

Comparing simulations performed using spatially non-uniform precipitation data with those performed using a single precipitation record assuming uniform precipitation over the area, it is evident that incorporating spatially non-uniform precipitation data has distinct effects on the performance evaluation results. Using spatially non-uniform precipitation data from the SEMCOG precipitation gauges led to greater than a 20% decrease in both overflow frequency and volume from the Detroit Tunnel when compared to the results from the simulation using uniform precipitation data from the NCDC Detroit Metropolitan Airport Gauge.

Using non-uniform precipitation data in a tunnel performance evaluation will affect the estimates of overflow frequency and volume occurring from a CSO facility. The true benefit of a CSO project like a tunnel or basin that have large tributary areas can be determined by incorporating spatially non-uniform precipitation into the performance evaluation. When using a spatially non-uniform precipitation record in a simulation, it is possible that for a significant number of the precipitation events, intense precipitation may in reality only occur over a portion of the tributary area. In the event that only a portion of the tributary area experiences significant precipitation, the entire tunnel remains available for storage of wet weather from an event that is only occurring over only a portion of the area.

This potential for spatial non-uniformity of precipitation over an area increases as the size of the tributary area in question increases. Therefore, spatial non-uniformity of precipitation may have a greater effect on the computed performance of the combined regional tunnel, which has a greater tributary area than the Detroit Tunnel alone.

9.4.4 Improved Infiltration Record

Seasonal variation in infiltration capacities leads to better representation of winter events because the values of the parameters used in the winter season better represent the infiltration capacities of the soils under various ground conditions. Variation in infiltration parameters over the calendar year leads to better representation of winter events, especially snowmelt events, when the real infiltration capacity of the soil is quite low, due to frozen ground conditions.

When comparing 36-y simulations using 15-min precipitation (rainfall plus snowmelt and snowfall) data with and without monthly variation of infiltration capacities, an overall increase in overflow event frequency and volume occurred from the Detroit Tunnel during the winter months when these varying infiltration capacities were used. Both overflow frequency and overflow volume increased drastically during the months of October through May. This increase in computed overflow events during the winter months is representative of the frequency and volume of actual wet weather events witnessed by operations and maintenance staff at existing CSO facilities throughout the GDRSS.

9.5 Application of Improvements to the Performance Evaluation of the Proposed Regional Tunnel

Model simulations were first performed using the 36 y of 15-min rainfall plus snowfall and snowmelt data based on precipitation data from the NCDC at the Detroit Metropolitan Airport, assuming uniform precipitation over the tributary areas and monthly-varying infiltration parameters. However, to truly quantify the potential benefit of a combined regional tunnel project, it is necessary to incorporate the spatial non-uniformity of precipitation into the model simulations. Model simulations were then performed using the 15-min rainfall and snowfall/snowmelt data based originally on precipitation data from the SEMCOG gauges located throughout the area tributary to the Dearborn and Detroit Tunnels, along with monthly variation in infiltration capacity parameters.

A simulation was performed first with the Dearborn Tunnel and Detroit Tunnel represented separately, then another with the Dearborn and Detroit Tunnels connected to form a combined regional tunnel. This combined regional tunnel was represented in the model without the 30 MG proposed connection volume. Results from these 36-y simulations were tabulated into yearly overflow frequency and volume statistics. To compare the separate tunnel scenario to the combined tunnel scenario, the overflow volumes from the separate tunnels were added together, and the frequency of overflow was taken as the greater of the frequency of overflow from the Detroit Tunnel and the frequency of overflow from the Dearborn Tunnel.

It was determined that there is a net benefit in terms of both overflow frequency and volume in using a combined regional tunnel when taking into

account spatial non-uniformity of precipitation over a tributary area. Annual overflow volume decreased from 355.0 MG (1.34×10^8 L) per year to 256.2 MG (9.69×10^8 L) per year, and overflow frequency decreased from 2.7 events per year to 1.5 events per year between the separate and combined tunnel options. This corresponds to a 27.8% reduction in overflow volume, and a 44.4% reduction in overflow frequency over the 36-y period. These results indicate the benefit of a combined regional tunnel, where the entire combined tunnel storage volume could be utilized for a storm event occurring over only a portion of the tributary area to the combined tunnel. That is, combining the two tunnel projects into one usable volume maximizes use of the composite storage volume for spatially non-uniform precipitation events.

To complete the analysis, it is necessary to determine the impact on performance for various existing and proposed tunnel layouts under these spatially non-uniform precipitation conditions. The separate Detroit and Dearborn Tunnels, the Combined Detroit and Dearborn Tunnels at no connection volume, and the Combined Detroit and Dearborn Tunnels at 30 MG (1.13×10^8 L) connection volume are all compared in Figure 9.8, which contains the estimated net benefit of first combining the tunnel projects, and then also the benefit of the 30 MG proposed connection. It is especially important to note that by representing the 30 MG connection, the estimated annual overflow frequency is less than one event per year.

The incorporation of spatially non-uniform precipitation records has made possible a quantification of the effects of this phenomenon on tunnel option performance, and the determination of the true benefit of a combined tunnel

Figure 9.8 Impact of non-uniform rainfall plus snowfall and snowmelt on Combined Regional Tunnel performance.

project. The results of this performance evaluation have become the primary rationale behind a full-scale feasibility evaluation of a joint tunnel project for the Cities of Detroit and Dearborn, Michigan.

9.6 Conclusions and Recommendations

In this discussion, steps have been taken to quantify the effects of incorporating precipitation and infiltration improvements into the performance evaluation of various tunnel options .

Using precipitation data from a longer period of record incorporates long-term and historical variability in a precipitation record into the performance evaluation. The longer the record of observed precipitation used, the better chance there will be of the performance evaluation being indicative of a true historical pattern.

Much variability in precipitation intensity occurs in any hour of any precipitation event. However, using hourly precipitation data assumes temporal uniformity throughout the hour, which is not indicative of real precipitation patterns. 15-min precipitation data has the advantage over hourly data, in that a peak 15-min period can be represented by the data. This is especially important for typical summer events of short duration and high intensity.

Using precipitation data strictly from precipitation gauges only incorporates rainfall and any snowfall registering as precipitation into the performance evaluation. This may be acceptable for determining the performance during the summer months. However, because snowmelt as a result of either warmer temperatures or rainfall can have a significant affect on CSO volume and frequency in winter and spring months, it is important to incorporate this snowmelt into the performance evaluation for the entire year.

Also important for winter and early spring wet weather events is a correct representation of the effects of ground conditions on soil infiltration capacities. Frozen ground conditions can significantly reduce the infiltration capacity of soil. Conversely, dry soil conditions can lead to increased soil infiltration capacity, most common of the summer months of July, August, and September. Incorporation of monthly-varying infiltration parameters into this performance evaluation has led to an improved representation of wet weather events throughout the year.

Lastly, an effort was made to incorporate non-uniform precipitation records typical over such a large tributary area. By using the spatially non-uniform precipitation record, the true benefit of a combined regional tunnel can

be seen for events that are not uniform across the large tributary area.

It is anticipated that this improved precipitation and infiltration record will be included in future performance evaluations of CSO projects for the GDRSS, as it is currently the best tool available for determining the long-term impact of any future project. Results from this and other performance evaluations will be used to quantify the potential impact that abatement projects will have in reducing CSO and thereby increasing water quality in the receiving waters of Southeast Michigan.

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