Estimating Groundwater Infiltration in Sewers

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Abstract

Infiltration and inflow (I/I) are common problems in sanitary sewer systems. While inflow typically gets most of the attention in wet weather, groundwater infiltration can also be a big problem in dry weather, silently stealing sewer capacity 24 hours per day, 7 days per week, 365 days per year. Groundwater infiltration cannot be measured directly but is often estimated from sewer flow monitor data using a variety of empirical methods.

The authors provide an overview and comparison of four methods, including the % Minimum Method, the Wastewater Production Method, the Stevens-Schutzbach Method, and the Mitchell Method. Examples of each method are provided using actual flow monitor data to further explore the performance of these methods and provide guidelines for proper application.

Introduction

Dry weather flow conditions are characterized by evaluating flow monitor data observed during normal conditions, excluding wet weather events and the periods associated with the recovery from these events. The resulting dry day patterns are identified as diurnal patterns and result from the collective residential, commercial, industrial, and institutional sewer use from a given area. An example of the diurnal patterns observed in a residential area are shown in Figure 1, and the distinctive patterns of Weekday and Weekend residential flows are readily apparent (Enfinger, 2006). Diurnal patterns are often described in terms of minimum, average, and maximum flow rates (Q_{min}, Q_{avg}, and Q_{max}) for both Weekday and Weekends Day Groups.

Observed dry weather flows are comprised of two components, including Wastewater Production (Q_{WW}) and Groundwater Infiltration (Q_{GWI}). These components are related to the average flow rate as shown in Equation (1),

$$Q_{avg} = Q_{WW} + Q_{GWI} \quad (1)$$

While Q_{GWI} is often of interest to wastewater professionals, it is not measured directly by flow monitors. Rather, it is generally assumed that $0 \leq Q_{GWI} \leq Q_{min}$ and is *estimated* using a variety of empirical methods, including the % Minimum Method, the Wastewater Production Method, the

Stevens-Schutzbach Method, and the Mitchell Method. An overview and comparison of these methods is provided in the following sections.

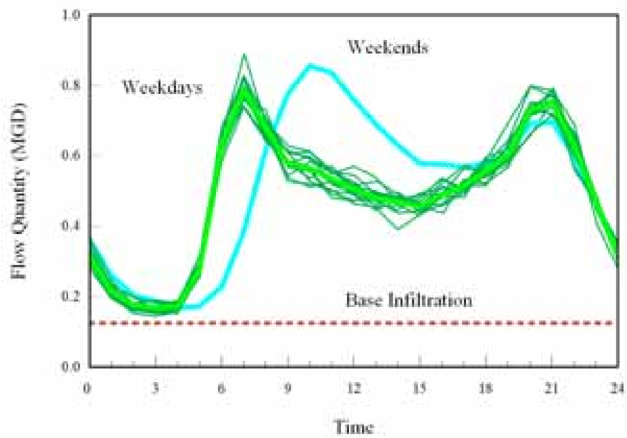

FIGURE 1: Weekday and Weekend Diurnal Patterns

% Minimum Method

The *% Minimum Method* estimates groundwater infiltration as a percentage of the minimum flow rate as shown in Equation (2). This method is simple to use and intuitive to understand; as a result, it is widely used in practice (Vallabhaneni, 2007).

$$Q_{GWI} = xQ_{min} \quad (2)$$

Mathematically, the percentage attributed to groundwater infiltration (x) can vary from 0% to 100% of the minimum flow rate. If the percentage is set to 0%, then none of the minimum flow rate is assumed to be groundwater infiltration, and $Q_{GWI} = 0$. If the percentage is set to 100%, then all of the minimum flow rate is assumed to be groundwater infiltration, and $Q_{GWI} = Q_{min}$. Values of x ranging from 50% to 90% are generally used in actual practice, with values of 80% and 90% most common.

Once groundwater infiltration is estimated using Equation (2), wastewater production is estimated using Equation (3) by subtracting groundwater infiltration from the average dry weather flow rate.

$$Q_{WW} = Q_{avg} - Q_{BI} \quad (3)$$

The application of the % Minimum Method is demonstrated in the following example:

EXAMPLE Flow monitor data are obtained from a given sewer basin, and dry weather flow conditions are characterized for both Weekday and Weekend Day Groups. Weekday Q_{min}, Q_{avg}, and Q_{max} are 0.103 MGD, 0.428 MGD, and 0.726 MGD, respectively. Weekend Q_{min}, Q_{avg}, and Q_{max} are 0.109 MGD, 0.459 MGD, and 0.873 MGD, respectively.

Use the % Minimum Method to estimate Q_{GWI} and Q_{WW}. Assume that x = 80%.

(a) Calculate Q_{GWI} for the Weekday Day Group using Equation (2).

$Q_{GWI} = xQ_{min} = (0.80)(0.103) = 0.082$ MGD

(b) Do the same for the Weekend Day Group. $Q_{GWI} = 0.087$ MGD

(c) Identify the Day Group with the minimum Q_{GWI}. This is the Weekday Day Group. Then, set Q_{GWI} equal to this value for both Day Groups. Therefore, Q_{GWI} is set equal to 0.082 MGD for both the Weekday and Weekend Day Groups.

(d) Calculate Q_{WW} for the Weekday Day Group using Equation (3).

$Q_{WW} = Q_{avg} - Q_{GWI} = 0.428 - 0.082 = 0.346$ MGD

(e) Do the same for the Weekend Day Group. $Q_{WW} = 0.377$ MGD

Note that the groundwater infiltration estimate for weekdays shown in Step (a) is different than the groundwater estimate for weekends shown in Step (b). However, common sense suggests that groundwater infiltration should be the same for both weekdays and weekends. This concern is resolved by identifying the minimum groundwater infiltration estimate, assigning it to *both* weekdays and weekends, and calculating wastewater production for weekdays and weekends, respectively, using this common value. This approach is also applied to the Wastewater Production Method, the Steven-Schutzbach Method, and the Mitchell Method in subsequent sections.

Wastewater Production Method

The *Wastewater Production Method* assumes that the difference between the average and minimum flow rates is attributed to a percentage (x) of wastewater production, as shown in Equation (4).

$$Q_{WW} = \frac{(Q_{avg} - Q_{min})}{x} \tag{4}$$

Values of 88% and 90% are commonly used, and values of 70% and 75% have also been proposed (DeCoite, 1981 and Mitchell, 2007). Once wastewater production is estimated using Equation (4), groundwater infiltration is estimated using Equation (5) by subtracting wastewater production from the average dry weather flow rate.

$$Q_{GWI} = Q_{avg} - Q_{WW} \tag{5}$$

Substituting Equation (4) into Equation (5) provides groundwater infiltration in one step as shown in Equation (6).

$$Q_{GWI} = Q_{avg} - \frac{(Q_{avg} - Q_{min})}{x} \quad (6)$$

The general assumption that $0 \leq Q_{GWI} \leq Q_{min}$ governs the allowable range of x, and this range is determined by solving Equation (6) for x when $Q_{GWI} = 0$ and $Q_{GWI} = Q_{min}$. Based on these assumptions, $1 - (Q_{min}/Q_{avg}) \leq x \leq 1$. The application of the Wastewater Production Method is demonstrated in the following example:

EXAMPLE Flow monitor data are obtained from a given sewer basin, and dry weather flow conditions are characterized for both Weekday and Weekend Day Groups. Weekday Q_{min}, Q_{avg}, and Q_{max} are 0.103 MGD, 0.428 MGD, and 0.726 MGD, respectively. Weekend Q_{min}, Q_{avg}, and Q_{max} are 0.109 MGD, 0.459 MGD, and 0.873 MGD, respectively.

Use the Wastewater Production Method to estimate Q_{GWI} and Q_{WW}. Assume that $x = 88\%$.

Solution

(a) Calculate Q_{GWI} for the Weekday Day Group using Equation (6).

$$Q_{GWI} = Q_{avg} - \frac{(Q_{avg} - Q_{min})}{x} = 0.428 - \frac{(0.428 - 0.103)}{0.88} = 0.059 \text{ MGD}$$

(b) Do the same for the Weekend Day Group. $Q_{GWI} = 0.061$ MGD

(e) Identify the Day Group with the minimum Q_{GWI}. This is the Weekday Day Group. Then, set Q_{GWI} equal to this value for both Day Groups. Therefore, Q_{GWI} is set equal to 0.059 MGD for both the Weekday and Weekend Day Groups.

(d) Calculate Q_{WW} for the Weekday Day Group using Equation (3).

$$Q_{WW} = Q_{avg} - Q_{GWI} = 0.428 - 0.059 = 0.369 \text{ MGD}$$

Do the same for the Weekend Day Group. $Q_{WW} = 0.400$ MGD

Stevens-Schutzbach Method

The *Stevens-Schutzbach Method* estimates groundwater infiltration based on the minimum and average flow rates using the relationship shown in Equation (7) (Mitchell, 2007).

$$Q_{GWI} = \frac{0.4Q_{min}}{1 - 0.6\left(\frac{Q_{min}}{Q_{avg}}\right)^{(Q_{avg})^{0.7}}} \quad (7)$$

Once groundwater infiltration is estimated using Equation (7), wastewater production is estimated using Equation (3) by subtracting groundwater infiltration from the average dry weather flow rate. The application of the Stevens-Schutzbach Method is demonstrated in the following example:

EXAMPLE Flow monitor data are obtained from a given sewer basin, and dry weather flow conditions are characterized for both Weekday and Weekend Day Groups. Weekday Q_{min}, Q_{avg}, and Q_{max} are 0.103 MGD, 0.428 MGD, and 0.726 MGD, respectively. Weekend Q_{min}, Q_{avg}, and Q_{max} are 0.109 MGD, 0.459 MGD, and 0.873 MGD, respectively.

Use the Stevens-Schutzbach Method to estimate Q_{GWI} and Q_{WW}.

Solution

(a) Calculate Q_{GWI} for the Weekday Day Group using Equation (7).

$$Q_{GWI} = \frac{0.4Q_{min}}{1-0.6\left(\frac{Q_{min}}{Q_{avg}}\right)^{(Q_{avg})^{0.7}}} = \frac{0.4(0.103)}{1-0.6\left(\frac{0.103}{0.428}\right)^{(0.428)^{0.7}}} = 0.057 \text{ MGD}$$

(b) Do the same for the Weekend Day Group. $Q_{GWI} = 0.059$ MGD

(c) Identify the Day Group with the minimum Q_{GWI}. This is the Weekday Day Group. Then, set Q_{GWI} equal to this value for both Day Groups. Therefore, Q_{GWI} is set equal to 0.057 MGD for both the Weekday and Weekend Day Groups.

(d) Calculate Q_{WW} for the Weekday Day Group using Equation (3).

$$Q_{WW} = Q_{avg} - Q_{GWI} = 0.428 - 0.057 = 0.371 \text{ MGD}$$

(e) Do the same for the Weekend Day Group. $Q_{WW} = 0.402$ MGD

Mitchell Method

The Mitchell Method uses the average flow rate and a minimum factor (MF) to determine an expected minimum flow (Q_{MF}). Actual and expected minimum flow rates are then used to estimate groundwater infiltration using an iterative solution as shown in Figure 2 (Mitchell, 2007).

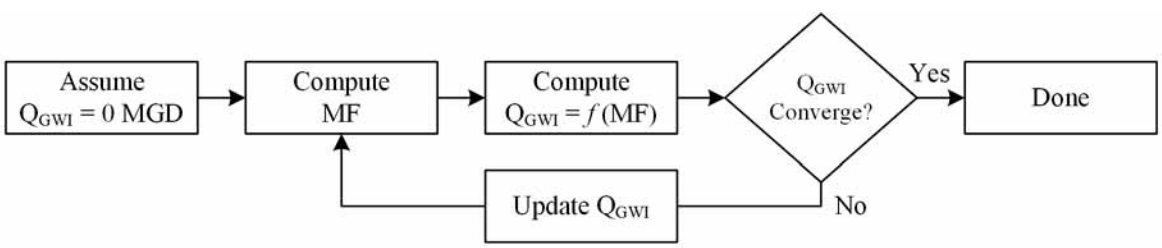

FIGURE 2: Iterative Solution for the Mitchell Method

The minimum factor is initially computed with Equation (8) assuming no groundwater, and groundwater infiltration is updated using Equation (9). Convergence is often achieved in no more than three iterations.

$$MF = 0.222(Q_{avg} - Q_{GWI})^{0.202} \tag{8}$$

$$Q_{GWI} = \frac{Q_{min} - (MF)Q_{avg}}{1 - MF} \quad (9)$$

The minimum factor equation used here is the equation originally reported in the literature (Mitchell, 2007). However, other minimum factor equations have also been reported by various sources, and these equations are mathematically interchangeable. The application of the Mitchell Method is demonstrated in the following example:

EXAMPLE Flow monitor data are obtained from a given sewer basin, and dry weather flow conditions are characterized for both Weekday and Weekend Day Groups. Weekday Q_{min}, Q_{avg}, and Q_{max} are 0.103 MGD, 0.428 MGD, and 0.726 MGD, respectively. Weekend Q_{min}, Q_{avg}, and Q_{max} are 0.109 MGD, 0.459 MGD, and 0.873 MGD, respectively.

Use the Mitchell Method to estimate Q_{GWI} and Q_{WW}.

Solution

(a) Calculate Q_{BI} for the Weekday Day Group.

Apply iterative procedure shown in Figure 2.

			assume			calculate
Iteration	Q_{min}	Q_{avg}	Q_{GWI}	MF	$Q_{min\ MF}$	Q_{GWI}
	MGD	MGD	MGD		MGD	MGD
1	0.103	0.428	0.000	0.19	0.081	0.028
2	0.103	0.428	0.028	0.18	0.076	0.033
3	0.103	0.428	0.033	0.18	0.076	0.033

(b) Do the same for the Weekend Day Group. Q_{GWI} = 0.032 MGD

(c) Identify the Day Group with the minimum Q_{GWI}. This is the Weekend Day Group. Then, set Q_{GWI} equal to this value for both Day Groups. Therefore, Q_{GWI} is set equal to 0.032 MGD for both the Weekday and Weekend Day Groups.

(d) Calculate Q_{WW} for the Weekday Day Group using Equation (3).

$Q_{WW} = Q_{avg} - Q_{GWI} = 0.428 - 0.032 = 0.396$ MGD

Do the same for the Weekend Day Group. Q_{WW} = 0.427 MGD

A Note About Units

When applying these four methods, it is important to understand implications regarding units of measure. The % Minimum and the Wastewater Production Method can be used with various flow rate units of measure, provided that consistent units of measure are used. However, both the Stevens-Schutzbach Method and the Mitchell Method require that units of million gallons per day (MGD) be used for the minimum and average flow rate, and the resulting wastewater production and groundwater infiltration estimates are provided in the same units, as well.

Conclusion

The previous sections demonstrate *how* to use various methods to estimate groundwater infiltration in sewers using flow monitor data. However, they do not demonstrate *when* to select one method over another. The order in which these methods are presented reflects the historical timeline on which they were developed from the % Minimum Method and Wastewater Production Method in the 1970s to the Stevens-Schutzbach Method in the 1990s to the Mitchell Method in the 2000s, and the newer methods accommodate or resolve weaknesses of the older methods. Neither the % Minimum Method nor the Wastewater Production Method account for basin size. As basin size increases, flow attenuation occurs. This phenomenon is not acknowledged by these two methods, and as a result, they tend to overstate groundwater infiltration in larger basins. Both the Stevens-Schutzbach Method and the Mitchell Method accommodate flow attenuation and provide more realistic estimates of groundwater infiltration in larger basins. The Stevens-Schutzbach Method does this entirely on empirical grounds, while the Mitchell Method accomplishes this while rooted in established minimum factors familiar from sewer design. This paper provides details for wastewater professionals to use each of these methods, as well as appropriate details and caveats to consider along the way.

Acknowledgement

The authors acknowledge Ralph Petroff, Jim Schutzbach, and Paul Mitchell for their knowledge and expertise regarding groundwater infiltration at its estimation from sewer flow monitor data. They have provided many helpful discussions regarding the development and proper applications of these methods.

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