QUANTIFYING BASE INFILTRATION IN SEWERS

A Comparison of Methods and a Simple Empirical Solution

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ABSTRACT

This paper addresses three empirical methods used to determine degree of Base Infiltration (BI) in 45 isolated sewer basins throughout the Orange County Sanitation District (OCSD) collection system. These include a common estimation method called night-time "Wastewater Production", a second method called "Minimum Flow Factor", and a third empirical method employing the "Stevens-Schutzbach" equation. These empirical methods were tested against a chemical parameter verification method that involves regressing hourly concentrations of several common wastewater chemical analysis parameters (Chemical Oxygen Demand – COD, etc.) with hourly sewage flow rates. The chemical parameter method results were also compared to BI estimates based on potable water use records.

In addition the Wastewater Production and Stevens-Schutzbach methods were evaluated by comparing the BI predictions to the sewer flows during the Northeast Power Blackout of 2003.

Results to date indicate that the Stevens-Schutzbach equation provides a more accurate estimate of BI in basins yielding flows comprised of more than 20% BI.

KEY WORDS

Infiltration, Flow Monitoring, RDII, Sewer Capacity

INTRODUCTION

In 1999, the Orange County Sanitation District (OCSD) established criteria upon which their 24 member cities would receive matching grant funds for rehabilitation work to reduce seasonal groundwater infiltration or Base Infiltration (BI) from offending areas of their 4500 mile collection system. In order to identify areas of high BI, OCSD identified isolated sewer shed areas or "basins" that approached or exceeded BI contributions of 30% of the total Average Daily Flow (ADF) from that basin. This roughly equates to values of BI that exceed the published standard of 500 gpd/idm (gallons per day/ inch-diameter-mile) (ASCE, 1982). This created a strong need for a universally accepted means of determining degree of seasonal BI from specific basins to aid member cities and OCSD in qualifying applicants for the grant funds.

Historically, wastewater system managers have been interested in the degree to which BI enters their collection systems in order to understand its impact. At a minimum, BI is considered a nuisance cost to treat, but in more severe cases it can actually rob capacity needed to convey the wastewater component of ADF in some basins.

More recently, the expanding interest in modeling the performance of collection systems over extended periods created the need for more accurate estimates of BI contributions from various collection system basins. In the OCSD system, there appears to be a relationship between degree of BI in a basin and potential for that basin to generate high levels of Rainfall Dependent Inflow and Infiltration (RDII) (Mitchell, 2003 & 2005).

There is no clear-cut universally accepted method by which to determine or otherwise verify the degree of BI from collection system basins. This paper will help clarify the most appropriate method by presenting a comparison of various BI determination methods.

BASE INFILTRATION ESTIMATION METHODS

There are four common empirical methods used by practitioners to estimate BI based exclusively on sewer flow data and daily (or diurnal) patterns in areas of predominantly residential land use. They are listed below. To evaluate the accuracy of these methods, this paper includes the fifth, sixth, and seventh methods as verification methods.

<u>Empirical Methods</u>

1. Wastewater Production Method
2. Minimum Flow Factor Method
3. Stevens-Schutzbach Method
4. Fraction of Minimum Method

<u>Verification Methods</u>

5. Chemical Analysis Method
6. Potable Water Use Method
7. Dead-Low Flow Method

The following section discusses the first three of the empirical methods, each of which involves evaluating Average Daily Flow (ADF) and Minimum Daily Flow (MDF). The fourth method is considered crude since it assumes BI is a simple fraction of the MDF; therefore this fourth method is not evaluated herein. In this paper, both ADF and MDF are quantities measured during dry weather during which the flow is not experiencing the immediate effect of rainfall.

It is important to recognize that some basins (including many in the OCSD service area) will contain a considerable percentage of industrial and commercial land use zones that generate wastewater throughout the night and in irregular patterns. Consequently, in such areas, these empirical estimation methods for calculating BI would be less accurate by usually overestimating BI.

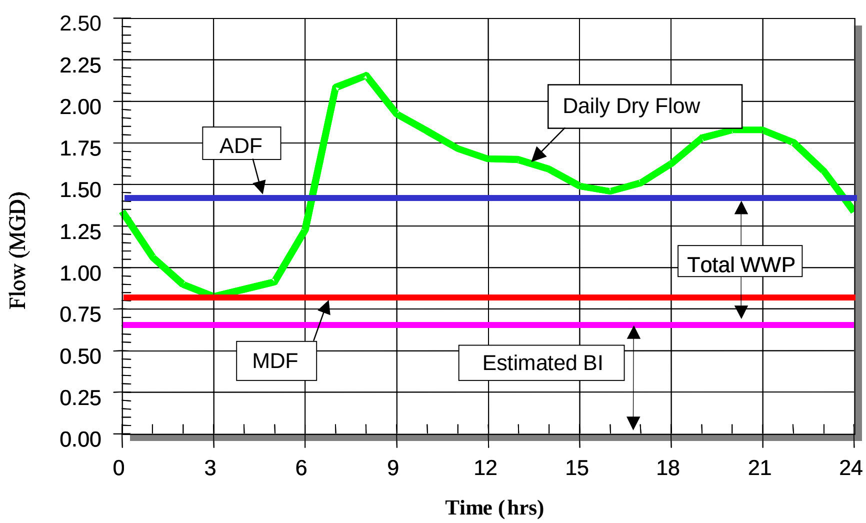
Following the discussion of the three empirical methods, this paper will compare each of the empirically-derived BI values in a case study. Additionally, the empirically derived BI values will be compared to BI "verification" values derived based on analyzing samples of common wastewater parameters [e.g. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand-(COD)] from selected basins. The values of BI derived using chemical parameter analyses will be compared to BI values generated based on analysis of water use records in two of the case study basins to evaluate the efficacy of this method. Each of the case study basins evaluated using the two verification methods are considered typical predominant residential land use (with some commercial zones). Finally, a very unique BI verification method is addressed herein called the Dead-Low Flow Method.

Wastewater Production Method

The two components of dry weather flows, or ADF, are defined as domestic Wastewater Production (WWP) and Base-Infiltration (BI). This method estimates the amount of flow that is attributed to domestic wastewater sources and derives BI by subtraction. The method is based on domestic water use studies wherein the minimum water use rate occurring in the early morning hours (typically 12:00 am to 6:00 am) is about 12% of the overall daily water use (Mayer, 1999; Harping, 1997; University of Wisconsin-Madison, 1978). Some consultants use this observation as a basis to estimate that 0.12 of the average daily wastewater production occurs during the minimum flow period overnight, leaving 0.88 as the fraction of wastewater produced by taking the difference of ADF and MDF. Some practitioners modify the 0.88 factor to achieve results more consistent with specific land use or basin size. This may include residential areas with a high percentage of nighttime water use fixtures such as water softeners. Then, if the total computed WWP is less than the actual ADF, BI is considered the culprit.

This can be restated to say that a factor, X, or 0.88 of the WWP equals the difference between ADF and MDF. Then, Base Infiltration (BI) is the flow that is left over after WWP is subtracted from ADF (See Figure 1).

Figure 1 – Diurnal Dry Weather Flow Components used to Calculate BI



The relationships used to estimate Base Infiltration (BI) are written in equations 1 and 2. Any consistent units of measure [e.g. million gallons/day (mgd) or liters/second (l/s)] can be used.

$$\mathbf{WWP = (ADF - MDF) / X} \quad (1)$$

$$\mathbf{BI = ADF - WWP} \quad (2)$$

Where,

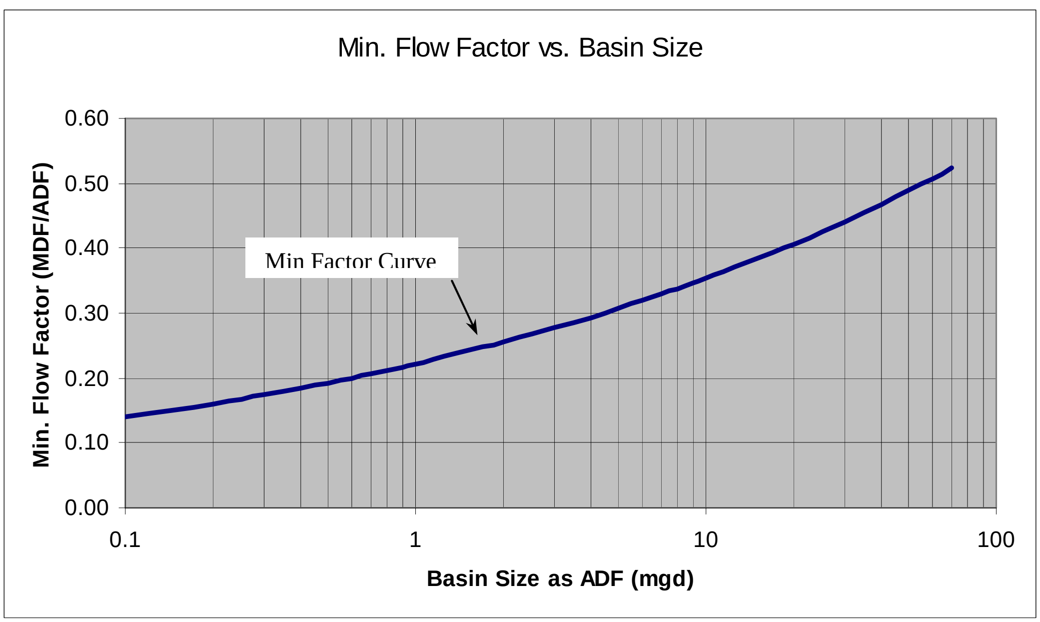
BI	= Base Infiltration
WWP	= Daily Average Total Wastewater Production
ADF	= Average Daily Flow rate
MDF	= Minimum Daily Flow rate
X	= fraction of WWP that accounts for non-zero nighttime wastewater production (0.88).

As BI varies over the year, the difference between average and minimum flow (and WWP) is expected to remain constant.

Minimum Flow Factor Method

This method uses the ADF to determine what the expected MDF would be for that size basin based on published minimum flow factors (ASCE, 1982). The Minimum Flow Factor (Min Factor) is defined as the fraction MDF/ADF. As expected, this factor becomes smaller with decreasing basin size as shown with the “Min Factor Curve” in Figure 2.

Figure 2 – Chart Showing Relationship of Basin Size vs. Expected Min Factor



This relationship of basin size and the Min Factor can be closely approximated using equation 3 where the (ADF – BI) term can initially be set to ADF. Then BI can be computed by taking the difference between measured actual MDF and the MDF based on the Min Factor as shown in equation 4, which is rewritten as equation 5. For a more exact solution to BI, one or more iterations back through equations 3 and 5 should be done. For equation 3 to be valid, ADF and BI flows must be in units of mgd (ASCE, 1982).

$$\textbf{Min Factor} = 0.222\,(\text{ADF} - \text{BI})^{\wedge}\,0.202 \tag{3}$$

$$\textbf{BI} = \text{MDF} - \text{Min Factor}\,(\text{ADF} - \text{BI}) \tag{4}$$

Which can be rewritten as:

$$\text{BI} = \frac{\text{MDF} - \text{Min Factor (ADF)}}{1 - \text{Min Factor}} \tag{5}$$

Stevens - Schutzbach Method

In 1999, Stevens and Schutzbach developed an empirical method to overcome apparent weaknesses in the Wastewater Production (WWP) method. It was observed that the WWP method appeared to overestimate BI from large basins (ADF >5 mgd) and underestimate BI from very small basins (ADF <0.1 mgd). The WWP method is strongly dependent on the minimum measured flow value in the depth and velocity regime with the greatest potential for measurement uncertainty. In some small basins the BI estimate using the WWP method was observed to generate negative values. The Stevens/Schutzbach (SS) equation uses a curve fitting technique to increase the reliability of the BI estimation at flow metering locations with very low or very high flows and in basins heavily influenced by pump station flow. Equation 6 is the empirically derived Stevens/Schutzbach equation that was used to estimate base infiltration in the OCSD basins. For equation 6 to be valid, units of mgd must be used for MDF and ADF values.

$$\text{BI} = \frac{0.4\ (\text{MDF})}{1 - 0.6\,(\text{MDF/ADF})^{\wedge}\,\text{ADF}^{0.7}} \tag{6}$$

Like equations 1 through 5, equation 6 is also dependent on average and minimum flows that occur in traditional residential flow patterns. However, like in the Min Factor method, equation 6 evaluates the relationship of the ratio of MDF/ADF vs. ADF (rather than the difference ADF–MDF vs. ADF as in the WWP method).

ADS looked at ADF and MDF data from approximately 2,000 basins nationwide and noted a fairly consistent relationship between ADF–MDF vs. ADF as shown in Figure 3. This observation suggests that determining BI by measuring departure from the best fit curve to the lowest data points would be difficult to do in a precise manner (as in the WWP method).

Assuming there is consistent relationship between ADF and the ratio MDF/ADF when very little to no BI is present (as in the Min Factor method, see Figure 2), a wide scatter of data using this relationship would be expected in basins experiencing a measurable degree of BI. Figure 4 is plot of ADF vs. MDF/ADF for the basins and confirms there is a significant departure from the Min Factor curve shown in Figure 2 (and re-plotted in Figure 4).

By regressing a curve to be below the lowest point in the large data set in Figure 4, setting a lower BI constraint of zero, and allowing the curve to adjust for different MDF/ADF ratios, various comparator "Min Curves" are generated (see Figure 4). For example, the lower (low BI) Min Curve shown in Figure 4 was determined by setting BI to 10% of the ADF in equation 6, then the MDF/ADF ratio was calculated for each value of ADF (or basin size). A different Min Curve is generated for each degree of BI. This method effectively disallows negative values of BI from being generated. The BI can be estimated from equation 6 for an apparent vast array of basin sizes (ranging from 0.05 mgd up to more than 10.0 mgd).

Figure 3 – Chart Showing Relationship of (ADF-MDF) vs. ADF

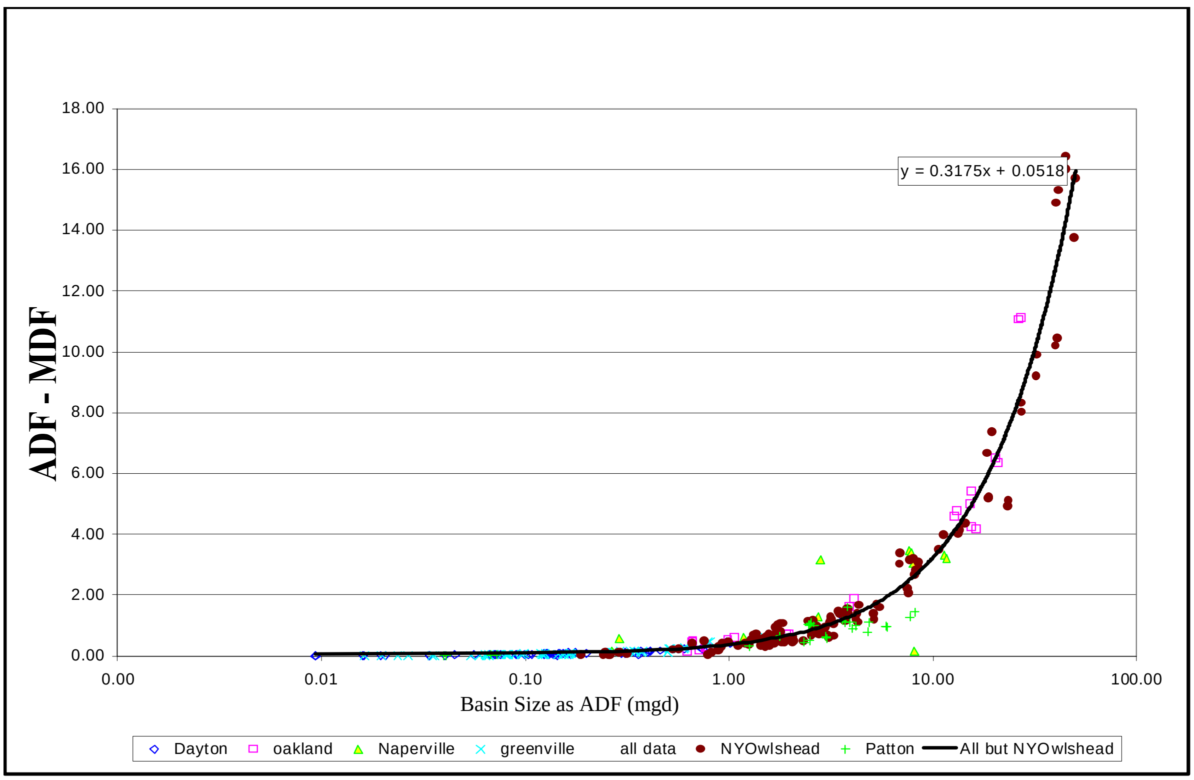


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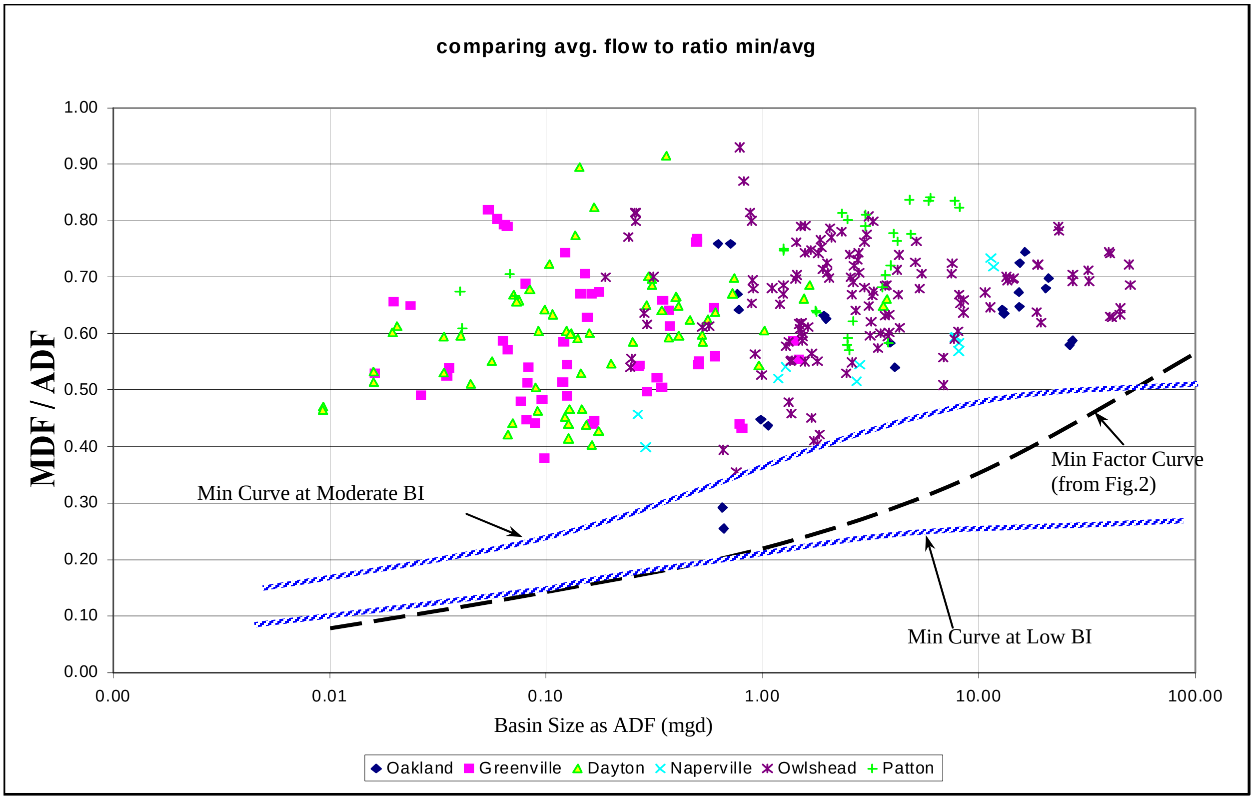
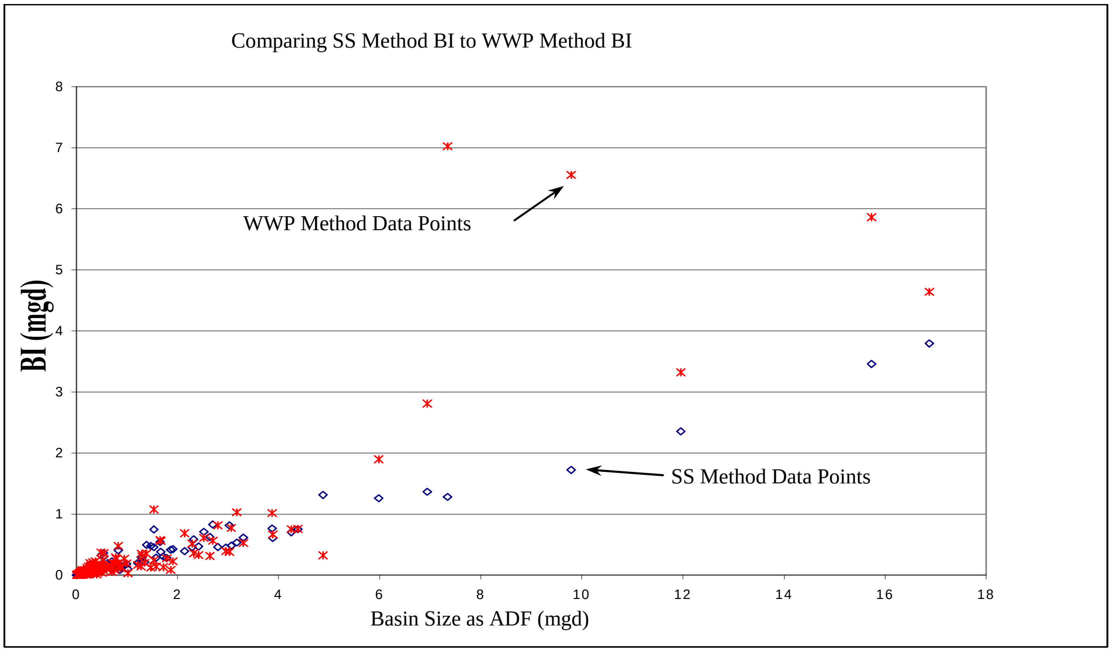
Figure 4 – Chart Showing Relationship of (MDF/ADF) vs. ADF and Variable Min Curve



Comparing the SS and Wastewater Production Methods

Figure 5 plots the estimated BI for the nationwide data set of basins displayed by basin size (ADF). It is seen that the SS Method in general produces a lower, more realistic and stable estimate of BI than does the Wastewater Production method in very large basins (i.e. at flows greater than 5 mgd).

Figure 5 – Chart Showing Relationship of WWP Method BI vs. SS Method BI



CASE STUDY BASINS IN OCSD SERVICE AREA

To supplement the grant program discussed in the Introduction, OCSD conducted a long-term flow monitoring study from Spring 2002 through Spring 2005. This study covered approximately 75% of its service area in an effort to better understand the relative contributions of RDII from up to 138 sewer-shed areas or basins. The basins ranged in size from 20,000 lineal feet (lf) to 150,000 lf. As originally planned, the top approximate 50% of the RDII-producing basins remained during the final season of the OCSD flow monitoring program (Winter 2004-2005), leaving 72 basins for evaluation. The OCSD service area experienced unusually heavy rainfall during this final season of the program with a season total rainfall of more than twice normal. RDII was largely sustained at much higher flows than observed in previous seasons exhibiting far less rainfall.

Of the 72 basins remaining in the final (heaviest) rain season, 45 were selected for rigorous evaluation of each of the above three BI empirical estimation methods. The 45 case study basins were chosen by eliminating those that were not hydraulically isolated (i.e. those requiring subtraction of an upstream flow meter), those producing ADF values less than 0.1 mgd, and those showing historically insignificant (i.e. less than 15% BI) since project inception with no increase into the recent heavy rain season.

The results of the BI determined for each of the 45 basins using each of the above three empirical BI estimation methods are shown in the graph as Figure 6. Note that the results of BI computed using chemical and potable water verification methods discussed later in this paper are also shown in Figure 6. The empirically derived BI values have been normalized in this chart by dividing computed BI flow rate by that basin's ADF to yield BI in units of %ADF. The chart is sorted according to average BI of the three empirical methods so as not to favor one over the other in the display. The BI estimates appear to trend reasonably well together, although some basins showed a much larger difference among the three methods while some basins showed very good agreement between the BI methods.

The Stevens-Schutzbach method appears to produce the lowest estimates of BI in the basins producing higher levels of BI while each of the three empirical methods tended to converge moving to basins producing lower levels of BI. In fact the Min Factor method appears to approach zero as calculated BI decreases below 15% indicating this method becomes very sensitive when BI is low.

This prompted a sensitivity analysis of the methods to the minimum flows recorded by the flow meters, particularly since the potential for error in flow measurement is more prominent (on a percent flow basis) during minimum flows (Mitchell and Stevens, 2005; Den Herder, 1995). Testing sensitivity in a mid-size basin (ADF of 0.38 mgd) that produces moderate to high BI of about 40%, a potential error in MDF of 30% resulted in changes to computed BI values of 16%, 15%, and 11% for the Min Factor, Wastewater Production, and Stevens-Schutzbach methods, respectively. In fact, the Min Factor method produces negative values for BI in the event the measured MDF error exceeds -60% (lower than actual). In this same basin, the Wastewater Production method starts to produce negative BI values if the MDF error exceeds 75% low. This suggests that the Stevens-Schutzbach equation is better suited to basins that produce low MDF values or MDF values that are of lower confidence. Figure 7 depicts the relationship between MDF error vs. error in calculated BI for each of the three empirical methods.

There appears to be a good correlation between increasing basin size and increasing divergence in BI estimates among the three methods. Figure 8 depicts a plot of basin sizes vs. maximum divergence among the three methods. This chart indicates that the methods converge as basin size decreases below an ADF of 0.5 mgd. For basins with an ADF of 1.0 mgd or more, the three methods are divergent by generally around 15% to 20%.

Figure 6 – Chart Comparing BI Methods in OCSD System Basins

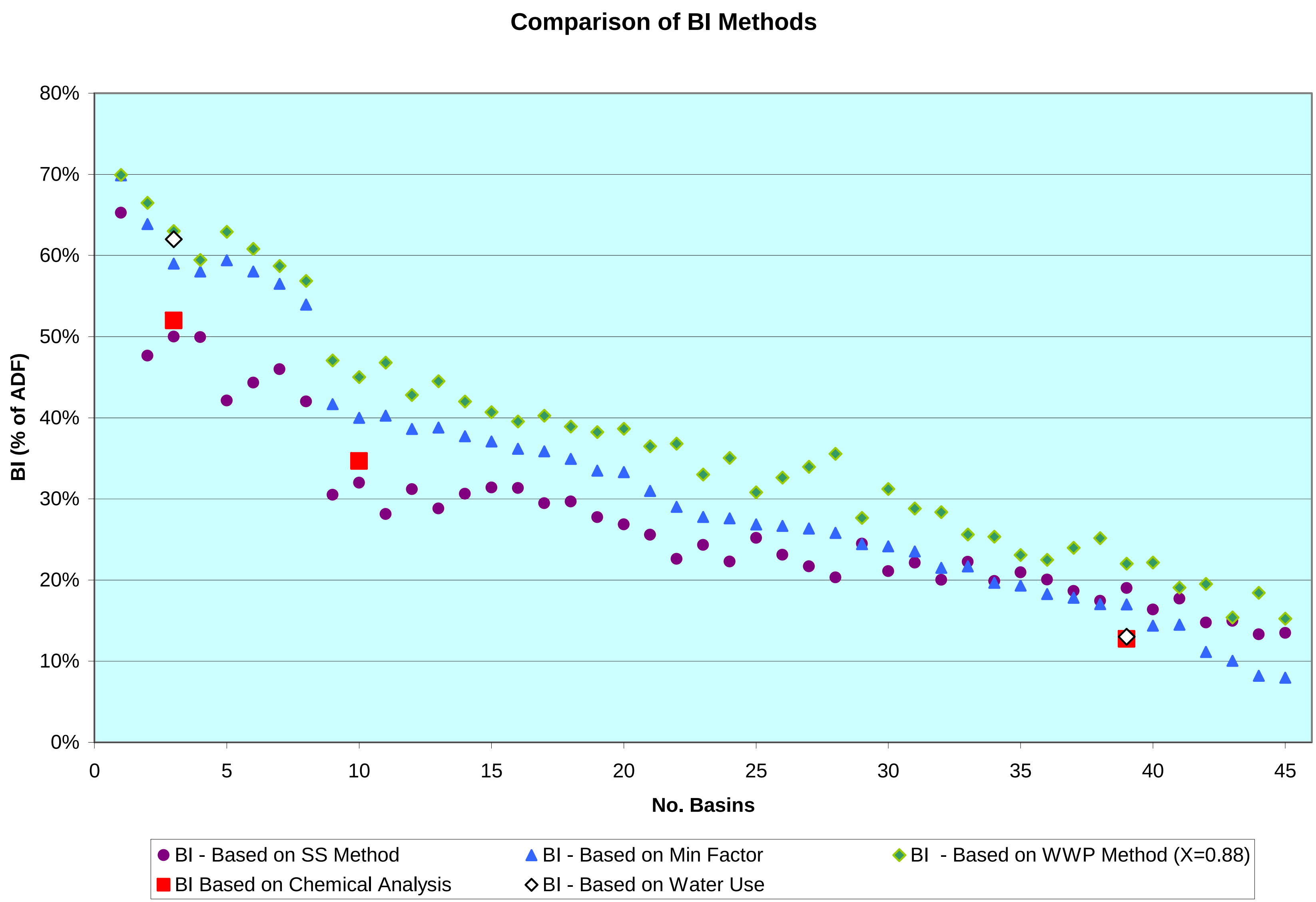


Figure 7 – Chart Showing Relationship of MDF Error vs. BI Resulting Error

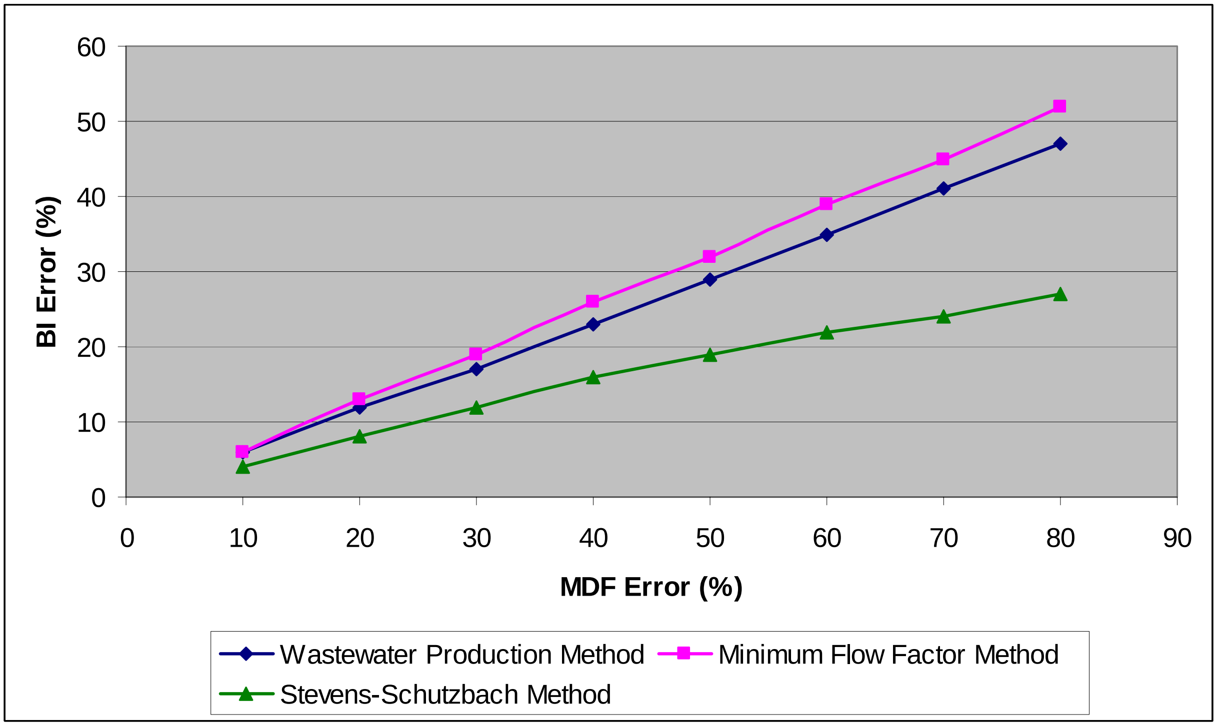
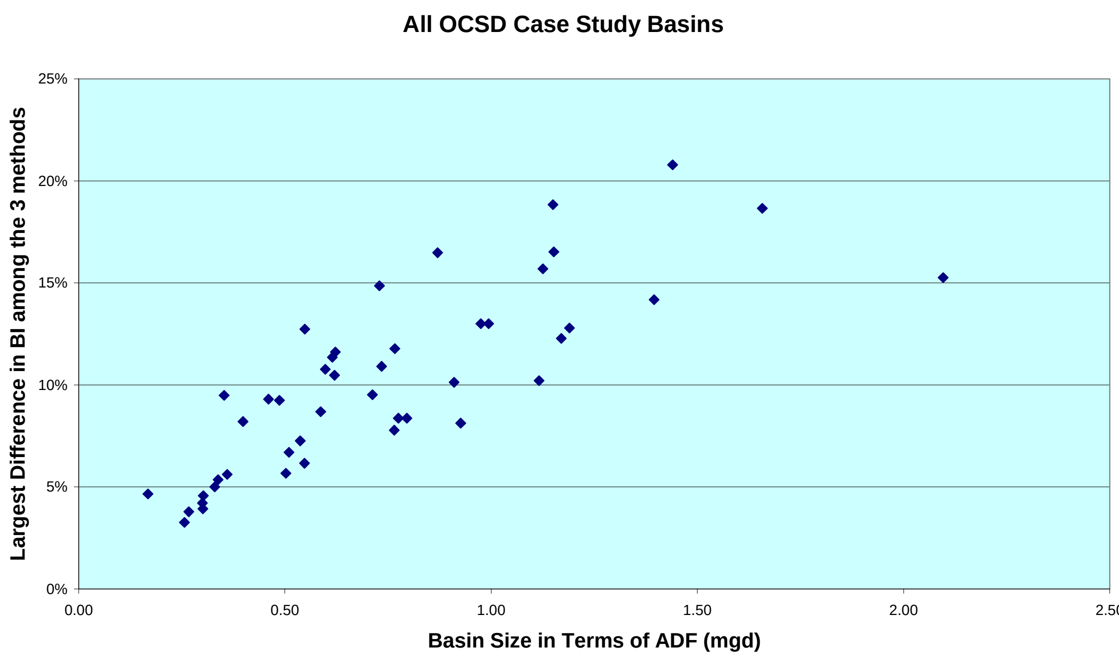
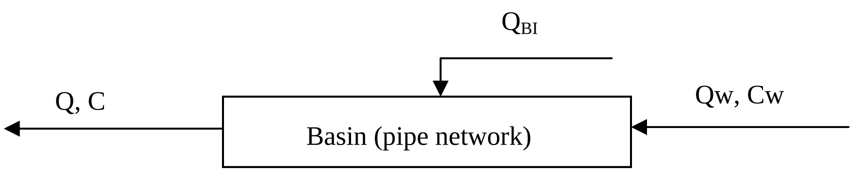


Figure 8 – Chart Showing Relationship of Basin Size and BI Method Agreement



Chemical Analysis Method of Verifying BI

The above empirical method comparison provides relative performance among the methods. However, a verification method was needed to help determine which of the empirical methods produced BI estimates that were closest to actual BI. The primary method used for this verification relies on comparing typical wastewater parameter concentrations in selected basin outlets versus flow rate. This verification method relies on the theory that, for a given fixed intrusion rate of infiltrating groundwater, the percentage of actual wastewater out of the basin will be at its lowest during the minimum night-time flow period (i.e. when little wastewater is produced, leaving a higher fraction of groundwater in the sewer). Conversely, as wastewater production rises during the day, its fraction of the overall flow will increase. The simple mathematical model of this relationship is depicted below. Any consistent units of flow and concentration can be used in the following relationship.



Where,

C	=	wastewater parameter concentration out of basin
Q	=	ADF or flow rate as measured at basin outlet
Q_{BI}	=	BI or flow rate of infiltrating water
Qw	=	WWP or wastewater flow rate before dilution with infiltrating water
Cw	=	wastewater parameter concentration before dilution with infiltrating water

A mass balance of this model produces the relationship shown in equation 7.

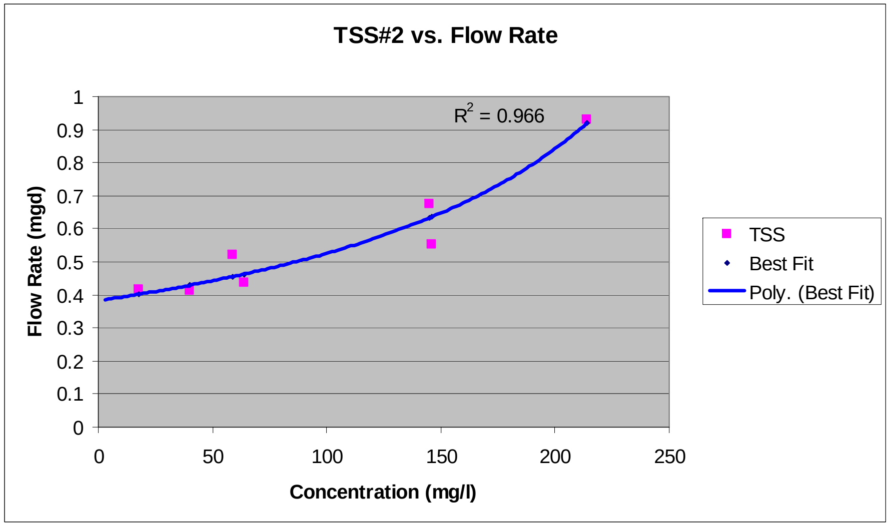
$$\mathbf{Q = Cw\,(Q_{BI}) / (Cw - C)} \qquad (7)$$

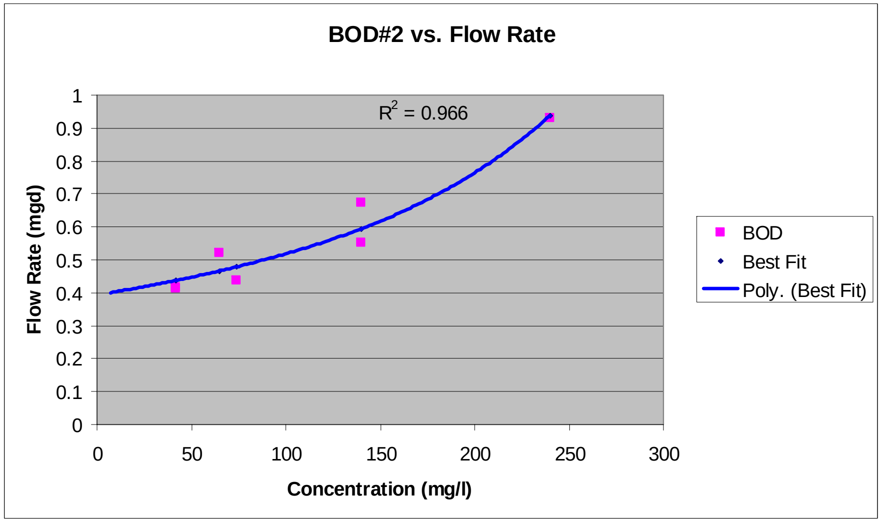
By measuring values of Q and C directly and plotting, a regression curve can be generated using the solver functionality within Microsoft Excel©. This arrives at a best fit curve by simultaneously adjusting Cw and Q_{BI} in order to minimize the difference between measured values of Q and values of Q computed using equation 7.

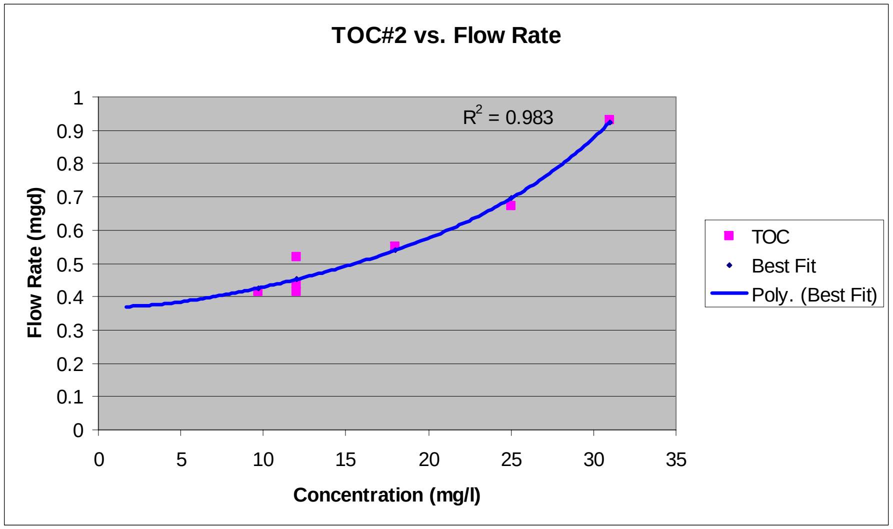
Three of the case study basins were evaluated using this verification method. The chemical parameters used in this evaluation were Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), and Chemical Oxygen Demand (COD). Plots of these parameters vs. flow rate (Q) for one of the three verification basins (OC134) are depicted in the series of graphs as Figure 9. In each case shown, a reasonably good regression coefficient is generated. The correlation coefficient for COD was lowest in this case.

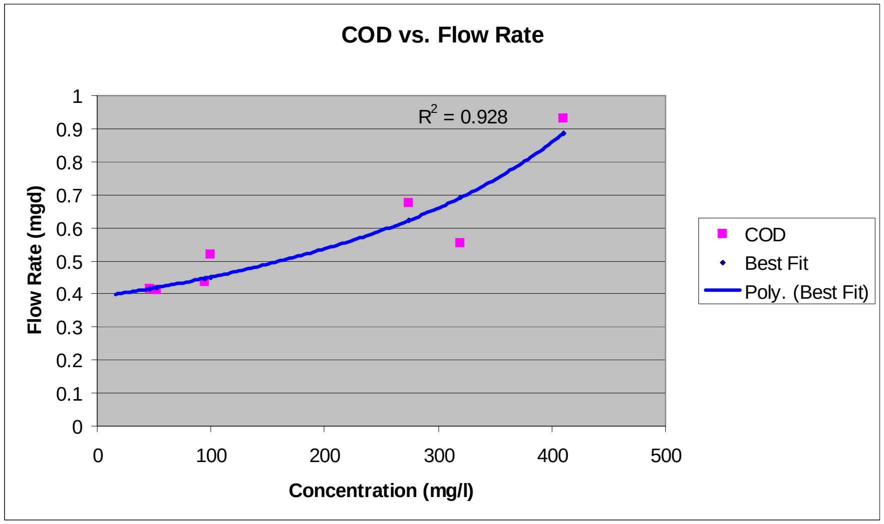
The result of the above regression method allows the determination of total Q_{BI} (the y-intercept of the curve), assuming no other sources of nighttime clear water flows. The Q_{BI} (or BI) is then divided by ADF of that basin to yield BI in units of %ADF.

Figure 9 – Plots of Parameter Concentration vs. Flow Rate for Basin OC134 showing Best Fit Curve Regression to Equation 7









Correction for Other Clear Water Sources

There are two possible additional sources of clear water flows that could occur continuously overnight in a residential basin. Those sources include water from recharge cycles from water softeners in hard water zones and leaking faucets. There is no known reasonable means by which to assume a typical production rate overnight from leaking faucets, so this contribution was not considered. However, it is possible to approximate the contribution from the water softener recharge source.

The area in which this BI case study was conducted is considered to be in a hard water zone. Water softener market saturation in such areas is thought to be between 20% and 40% with an expectation of toward the higher percentage in more affluent areas (Pipes, 2002). Typical recharge volumes from water softeners range between 30 and 80 gallons per cycle about 2 times per week (volumes and rates depending on whether the unit is older and using a simple timer or more recent using a recharge monitor) (Friedman, 2007 and Christopherson, 2007).

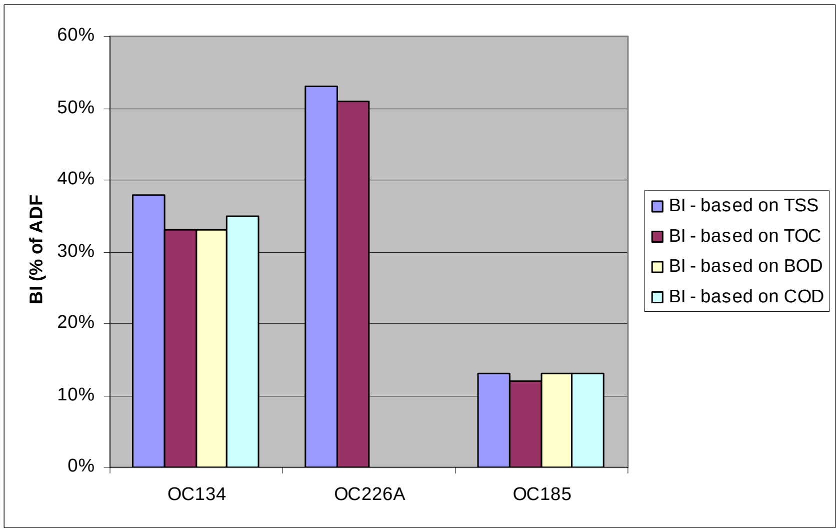
Assuming an average of about 100 gallons per week per household of recharge water is produced and assuming 30% of households in this study area use water softeners, the adjusted average clear water production from this source is 4.2 gallons per day per household.

Recharge cycles typically occur overnight between 2:00 and 5:00 am. Based on the water use records from basin OC226A, there are about 1316 dwellings in this area. That computes to about 5,520 gallons of clear water produced overnight between 2 and 5 am. OC226A is about 200 acres, so that is about 27.6 gallons/acre overnight. The overall wastewater flow from basin OC226A is about 44,000 gallons between 2:00 and 5:00 am (or about 9% of the ADF is during that time period), which is equal to 220 gallons/acre overnight. That means about 12.5% (27.6/220) of the flow overnight is likely from water softener recharge cycles.

Applying the same computations to basins OC134 and OC185, the portion of overnight flows that are potentially comprised of water softener recharge water is 18.4% and 47%, respectively. This illustrates that this source of clear water can be significant in basins yielding low BI as is the case in basin OC185.

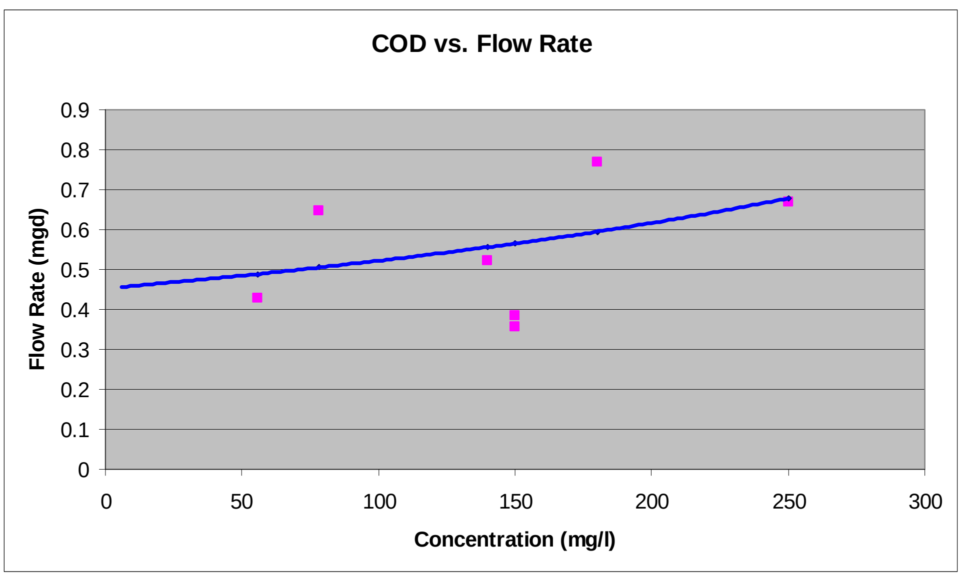
The BI values (y-intercept) from the above discussed chemical analyses were adjusted downward based on these clear water flows from water softeners. The resulting adjusted values of BI for the three basins, using each of the chemical parameters, is shown in Figure 10.

Figure 10 – BI Verification Results based on Chemical Parameter Regression Analysis



The relationship between flow rate and BOD, as well as COD, in basin OC226A was very poor as exemplified in the COD plot in Figure 11. Yet, the correlations using TSS and TOC parameters were good at 0.98 and 0.91, respectively. This is one of the few basins that is located on the coastline, therefore producing BI that is likely predominantly comprised of highly saline water from the Pacific Ocean or Newport Bay. The BOD and COD indirectly measures waste constituent concentrations based on laboratory measured Oxygen demand. It is possible that some constituents of the infiltrating salt water may be creating some instability in measured Oxygen demand at the laboratory.

Figure 11 – Plot of COD Concentration vs. Flow Rate for Basin OC226A



The BI verification results based on an average of the available results from each of the three test basins are posted on Figure 6 for reference. It appears that the verification values matched most closely to the Stevens-Schutzbach methods for the two basins yielding more than 30% BI. In the third basin producing much lower BI (13%), the chemical verification value was lower than all three empirical methods, but matched more closely to the Stevens-Schutzbach and Min Factor methods.

Potable Water Use Method of Verifying BI

The source of wastewater produced and deposited into a sanitary sewer system is invariably a potable water source from a domestic water provider. Hence, it is possible to compare volumetric water use in a particular basin to wastewater delivered from that basin via the sewer system to determine if additional flows must be present from other sources such as BI.

This method of determining BI relies on three important assumptions: 1) potable water use is metered at each point of use and is reliable and accurate; 2) the only source of wastewater generation is from a metered potable water distribution system (i.e. no water wells or other un-accounted sources of water); and 3) the percentage of indoor water use (i.e. percent of water returned to the sewer as wastewater) can be reasonably estimated. Unfortunately, the last assumption regarding percentage of potable water returned to the sewer as wastewater varies widely in literature, from 40% to 85% (ASCE, 1982; Viessman & Hammer, 1985; Metcalf & Eddy, 1991). Data from two large cities proximate to the OCSD system in Southern California, Los Angeles and Santa Monica, reported potable water to sewage conversions of 47% and 69%, respectively (ASCE, 1982). Metcalf & Eddy reports that values from 60% to 85% can be expected in residential areas, with the lower values representing semi-arid regions of the southwestern U.S (Metcalf & Eddy, 1991).

Water use data were collected from the highest and lowest BI-producing basins of the three case study test basins discussed above, OC226A and OC185, respectively. Complete water use data were not available for end-users in test basin OC134 due to non-existent or incomplete records from the four various size water agencies serving this basin area. The average daily water use data for the two evaluated basins were compared to the average daily wastewater flows measured in the sewer from each of the basins. The water used vs. wastewater generated is summarized in Table 1. Assuming a water-to-wastewater conversion factor of 60% (i.e. the low end of the Metcalf & Eddy estimate), the theoretical contribution from BI sources was determined and listed in Table 1 and compared to BI based on the chemical verification analyses from above.

Table 1 – Summary of Water Use and BI Estimates in Two Case Study Basins

Basin	Average Daily Water Use (mgd)	Water Use To Sewer (mgd)	Metered Sewer ADF (mgd)	Difference as BI (mgd)	BI	BI from Chemical Verification
OC226A	0.353	0.212	0.550	0.338	62%	52%
OC185	0.507	0.304	0.350	0.046	13%	13%

The BI results from the water use analysis compare favorably to the BI estimated previously with the WWP method in the basin producing a high degree of BI (OC226A). However, the BI estimate from water use data in the lower BI basin, OC185, was much lower than previous empirical estimates. These water use-based BI results are plotted on Figure 6.

Dead- Low Flow Method

As shown in this paper, it is difficult to find a direct way to separate sewer flow into the components of wastewater and base infiltration. Probably the perfect, yet most difficult, way for measuring BI is the Dead-Low Flow (DLF) method. This method involves stopping all generation of wastewater in a sewer shed and measuring what is left – the Dead-Low Flow. This method would clearly be unacceptable to dwellers in the sewer shed so it is never done intentionally. The Northeast Power Blackout on 14 August 2003 provides us with an opportunity to directly measure base infiltration by finding sewer sheds in which all water service has ceased during the blackout. The DLF method may be clouded by the presence of elevated storage tanks and backup power will allow waste water production to continue during the blackout.

Several flow metering sites were discovered in Oakland County, Michigan in a community that had neither backup power nor elevated storage tanks. The community was connected to a highly-reliable potable water system that operated at a high pressure. Pressure regulators replaced elevated tanks as the pressure-control method. The sewer flow meters confirm that flow dropped very quickly after the power failure and remained at the DLF rate for several hours.

Figure 12 displays the hydrograph of meter site 4840, which measures flow from a sewer shed that has neither elevated storage nor standby power on its potable water source. The drop in flow can clearly be seen on 14 August 2003. The spike in flow late on the 15th is the result of a rain and an upstream pump station coming online.

Figure 12 – Flow Drops on 15 August During the Northeast Power Blackout

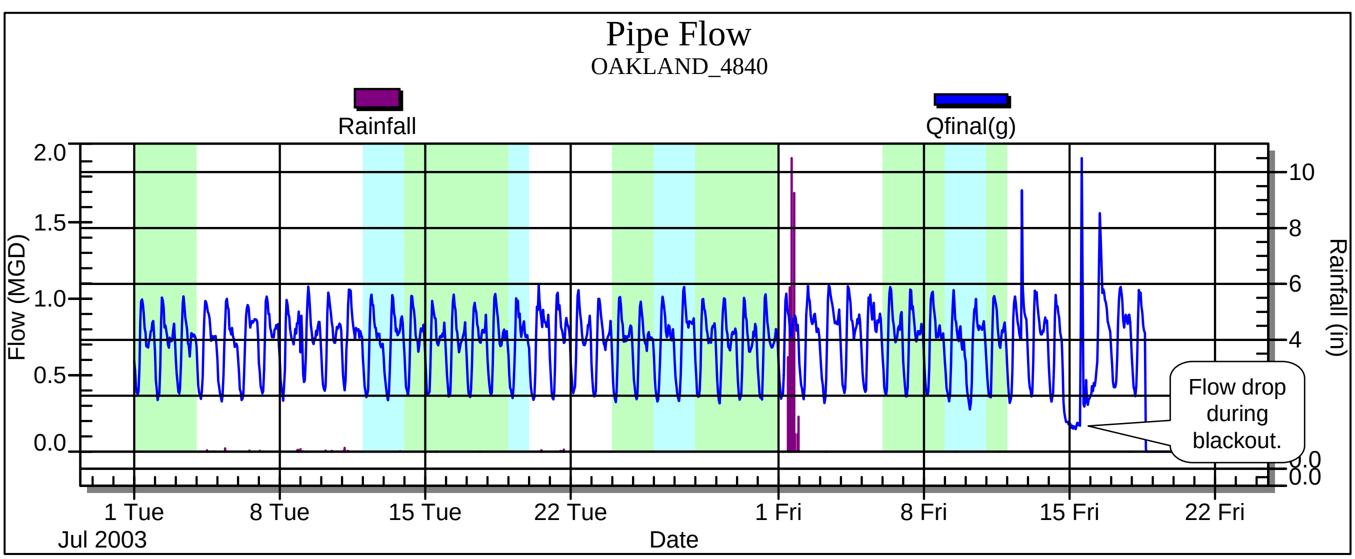
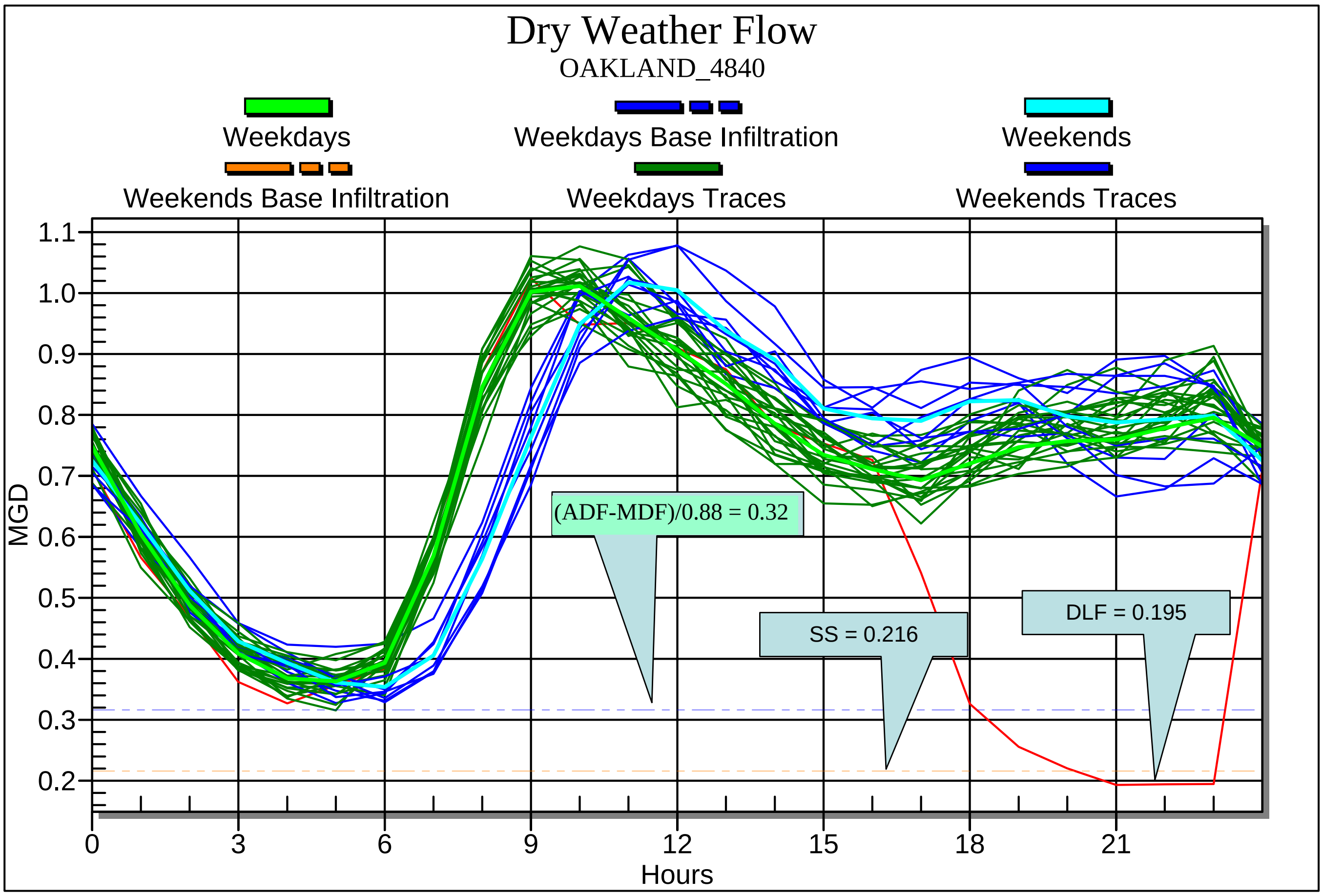


Figure 13 displays the weekday and weekend diurnal hydrographs for meter site 4840 along with the hydrograph of 14 August (shown in red) and the associated Dead Lowest Flow (DLF) of 0.195 mgd. The Stevens-Schutzbach method predicts a Base Infiltration of 0.216 mgd, which is very close to the actual DLF. The WWP method predicts a base infiltration of 0.32 mgd using the common factor (**x**) of 0.88. Using of a factor of 0.70 in the WWP method produces a base infiltration that equals the Stevens-Schutzbach method of 0.216 mgd.

Figure 13 – Weekday Diurnal Hydrograph Showing the Flow Drop During the 15 August Power Blackout. The Dead Lowest Flow (DLF) should be Base Infiltration.



DISCUSSION

Since the Wastewater Production method appears to be the most widely used method of estimating BI, some additional discussion is warranted. This method consistently produced the highest BI estimates of all methods in all the case study basins, so an evaluation was done to determine if a more suitable factor (**x**) should be used in equation 1. In order to adjust the BI downward to match the chemical verification results for the two basins producing BI >40%, the wastewater production factor (**x**) would have to be reduced from the originally assumed 0.88 down to 0.69 and 0.75 for basins OC226A and OC138, respectively. The above Oakland County data suggests a value for (**x**) of 0.70 should be used. The authors propose a factor in the range of 0.70 to 0.75 for (**x**) be adopted as a new default value for any BI studies conducted where the Wastewater Production method is to be used and BI is expected to be greater than 20%. Even though it appears that the Wastewater Production method can be adjusted this way to produce more accurate results, the authors recognize that a single value for (**x**) may not be realistic for all basin sizes for the same reason assuming a single value for a Min Factor is not realistic for all basin sizes (see Figure 2).

SUMMARY AND CONCLUSIONS

Results to date allow the following conclusions to be made:

- The Stevens/ Schutzbach empirical method provides good estimations of BI in basins yielding BI flows of more than 20% and is also far more stable in such basins (i.e. less sensitive to errors in minimum night-time flow measurements). In very large basins (5 mgd or more), the Stevens-Schutzbach method is recommended since the alternative methods appear to produce unrealistically high estimates of BI. This method was also verified to be the most accurate using the DLF method and flow data during the Northeast Power Blackout.

- If the Wastewater Production method is to be used to estimate BI, a revised factor (**x**) of no more than 0.75 (rather than 0.88) should be used as a conservative default value in the associated equation in cases where BI is greater than 20% of the ADF for basin sizes ranging from 0.2 to 2.0 mgd. Caution is warranted in using this factor for basins outside of this size range. Caution is similarly warranted in using this method to compare/ rank vastly different size basins in terms of BI performance.

- When using the chemical verification method described herein to estimate BI, the BOD and COD parameters are not recommended for use in cases where the sewer system under evaluation is suspected of experiencing infiltration from saline or brackish environments. In addition, in hard water areas, corrections should be made for contributions from water softener recharging cycles.

- The Water Use Analysis method of estimating BI can produce reasonable BI estimates. However, extreme caution is warranted regarding the accuracy of such data. Also, appropriate fraction of water use returned to sewer would need to be chosen based on climate and land use.

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REFERENCES

Mitchell, P.S., Koester, P.A. (2003). "OCSD's Strategy for Reduction of I/I." UIATC Technical Conference, Washington D.C., 2003.

Mitchell, P.S. (2005). "Annual Infiltration/ Inflow Report, Orange County Sanitation District", Winter 2005.

Mitchell, P.S., Stevens, P.L (2005). "How to Assure Success of a Flow Monitoring Program", UIMC Technical Conference, Washington D.C., 2005.

Den Herder, J.L. (1995). "Accuracy Limitations in Open Channel Flow Monitoring", National Conference on Sanitary Sewer Overflows, Washington D.C. EPA Seminar Publication 625/R-96/007.

Mayer, P.W., DeOreo, W.B., Opitz, E.M., Kiefer, J.C., Davis, W.Y., Dziegielewski, B., and Nelson, J.O. (1999). "Residential End Uses of Water", Report to AWWA Research Foundation, Denver, CO.

Harping, J.S. (1997). "Nature of Indoor Residential Water Use". MS Thesis, Dept. of Civil, Environmental, and Architectural Engineering. University of Colorado. Boulder, CO.

University of Wisconsin-Madison (1978). "Management of Small Wastewater Flows" EPA-600/7-78-173. U.S. Environmental Protection Agency, Office of Research and Development, Municipal Environmental Research Laboratory (MERL) Cincinnati, OH.

ASCE Manual of Practice No.60 (1982). "Gravity Sanitary Sewer Design and Construction".

Pipes, Anthony (2002). "Method and Apparatus for Parallel Desalting", US Patent Application #6863822. US Patent Office www.uspatentserver.com

Friedman, Daniel (2007). "The Home Inspection and Construction Information Website", discussion on reducing impacts of water softeners on septic systems www.inspect-ny.com/septic/watersoft.htm

Christopherson, Sarah and Olson, Ken (2007). "The Problems with High Efficiency Furnaces, Water Softeners and Iron Filters Discharging into Onsite Sewage Treatment Systems", University of Minnesota Water Resources Center http://septic.umn.edu/homeowner/factsheets/furnacessoftnersironfilters.html

Viessman, W., Hammer, M.J. (1985). "Water Supply and Pollution Control", 4th Edition. Harper & Row, New York.

Metcalf & Eddy, Inc. (1991). "Wastewater Engineering", 3RD Edition. McGraw-Hill, Inc., New York.