DWF – An Inlet Works Perspective

Denys A. Wickens

Haswell Consulting Engineers

WaPUG Spring Meeting, Coventry 2004

Introduction

This paper was initially conceived in response to the default DWF profile in Hydroworks™. That profile seemed atypical compared with data previously collected by the author as part of flow and load surveys using treatment works' flowmeters. The study was then expanded to a wider range of works as data was put in order and patterns began to emerge.

The underlying structure of this paper is thus to address the following questions:

- Is Dry Weather Flow a valid concept at any or all sites?
    - Its Theoretical Definition
    - Its Empirical Definition
    - It must be reproducible
- What is the impact of catchment size?
- Is it predictable from theoretical populations?

Definitions

The theoretical definition of Dry Weather Flow (DWF) is that it is the sum of all flows except those caused by rainfall. Thus:

$$DWF = I + E + ?PG$$

Where
I is infiltration (in daily flow units)
E is Trade Flow (in daily flow units)
P is population
G is flow per head per day.

The summation symbol for PG has been used because various categories can be applied to populations (residents, campers, day visitors, etc.) and each typically has a distinct value for G. The value of DWF is conventionally expressed as a daily average. There is an expectation that infiltration under winter conditions may differ from summer conditions where winter weather is sufficiently wet to raise groundwater levels from below most sewer pipes to above them.

To ease calculations by lumping population flow and infiltration into a single assumption, this equation is often reworked into the following form:

$$DWF = P_{res}(G + I) + ?P_{nr}G + E$$

Where
I is infiltration (as flow per head per day)
P_{res} is the resident population (usually including overnight visitors in hotels, etc.)
P_{nr} is the non-resident population (campers, day visitors, etc.)
G and E have unchanged meaning.

These definitions of DWF underly the calculations in catchment flow modeling, with the added refinements that diurnal flow profiles may be specified for PG flows, and trade flows.

The empirical definition typically used by the Environment Agency in England and Wales is that Dry Weather starts once seven days without rain have been completed, and that measurements of DWF should average at least seven consecutive days data with no more than 0.2 mm of rainfall/day that all follow that start of Dry Weather. Trade flows should be typical.

Infiltration is often estimated as the overnight low flow under Dry Weather conditions, although technically this is only the upper bound for the value.

Results

Calculations

Flow data was obtained in raw form at 15 minute resolution and averaged to hourly resolution. This hourly data was then averaged for periods of Dry Weather Flow, each of at least 7 days duration. All data is presented using GMT times of day: some overnight low flows may thus appear to differ by an hour depending on whether local time was GMT or British Summer Time.

Infiltration was estimated as the minimum hourly flow for catchments with smooth flow profiles. At other catchments a judgment was made of what period (typically 3 hours) over which to average to get a representative flow.

Peaking ratios were then derived from the maximum hourly flow ratio'd to the daily average flow.

Theoretical populations were taken from address counts and populations per dwelling in the range 2.25-2.50, depending on the source of the data. No corrections were made for trade flows.

Limitations and Bias

The data from sewage works flowmeters gives an inlet works perspective of flow. This means the flow measurement is of generally good quality, with meters typically traceable to an appropriate British Standard. There is routinely 18 months-worth of data available, and sometimes several years-worth. There is thus usually at least one period of EA-definition Dry Weather available for study, and there may be several.

On the negative side, inlet works data is, however, of only modest resolution by modeling standards (15 minutely is typical) and is averaged over that time period. Individual pumping events are thus poorly detected. Peak flows are rarely available since most meters are downstream of overflows. Non-catchment hydraulic peculiarities can also be introduced into the data by the operation of upstream screens and (on effluent flowmeters) dosing siphons.

The rainfall data used here is sourced from the EA. It is typically at daily resolution from a gauge within 10 km of the works. It is subject to occasional undetected failures, but in general is of satisfactory quality.

The geographical spread of the data may bias the results towards catchments that do not display pronounced seasonal infiltration. Most catchments lie in a broad band from Gloucester to Whitby with a few outliers further west into the Potteries and Wales.

Works with known trade flows over 30% of the population flow have been excluded.

Detailed examination of a limited number of catchment drawings that showed address counts implied that there was a degree of both over- and under-counting of dwellings. Maximum errors due to incorrect counting appeared to be under 10%.

Definition Checking – Effects of Rainfall

Short Term

In terms of checking the empirical definition, Figures 1 and 2 address the issue of whether 7 days is a long enough period without rain for directly rainfall-related flows to have reduced to zero. At Site 1 it appears that 5 days is enough (this is the usual case). At Site 2, which has very high infiltration, a month was not enough following prolonged wet weather. Overall, the EA empirical definition of Dry Weather appears to be a good one and does not need to be treated with much caution, despite the inevitable exceptions.

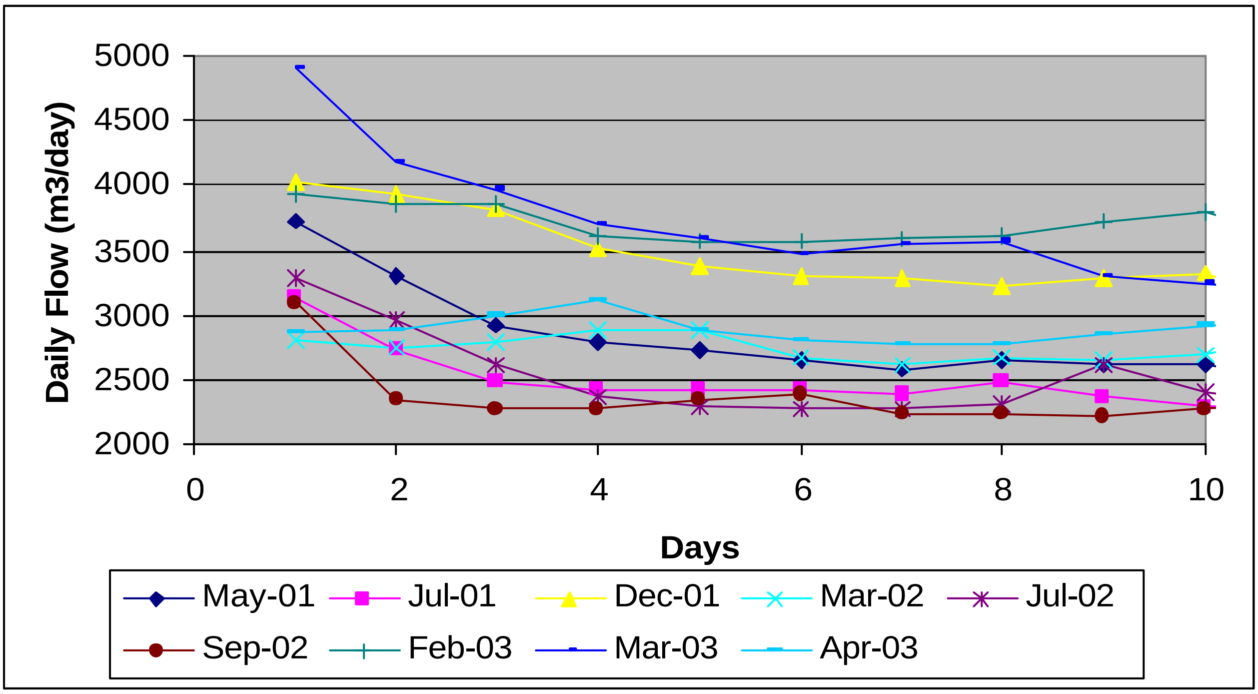


Fig. 1. Daily Flows at Site 1 on dry days following rainfall on day zero.

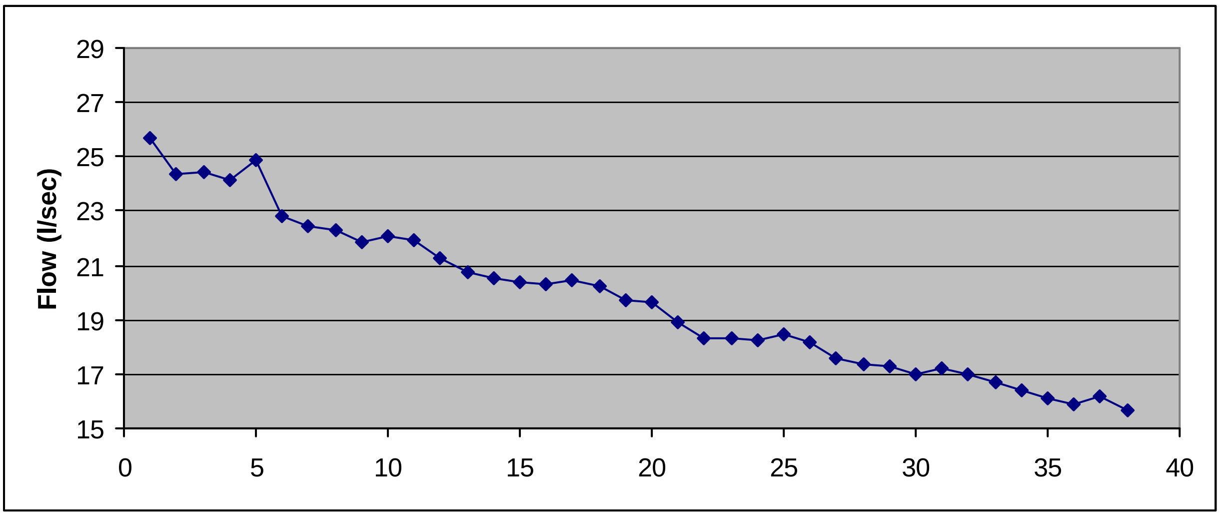


Fig. 2. Daily Flows at Site 2 on dry days following rainfall on day zero.

Long Term

Figure 3 shows data from an all-flows works where it can be seen that the effect of more prolonged wet weather took 3-6 months to die away to background levels.

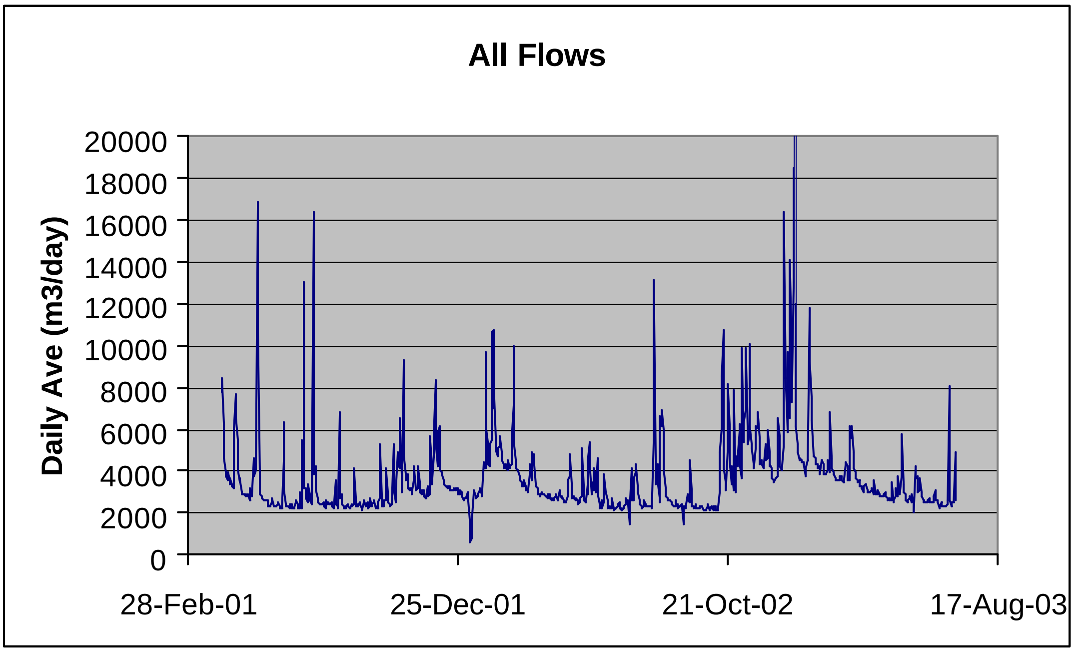


Fig 3. Works where infiltration takes 3-6 months to return to steady state

By contrast Figure 4 shows a works where at least 18 months was required for the same relaxation after wet weather.

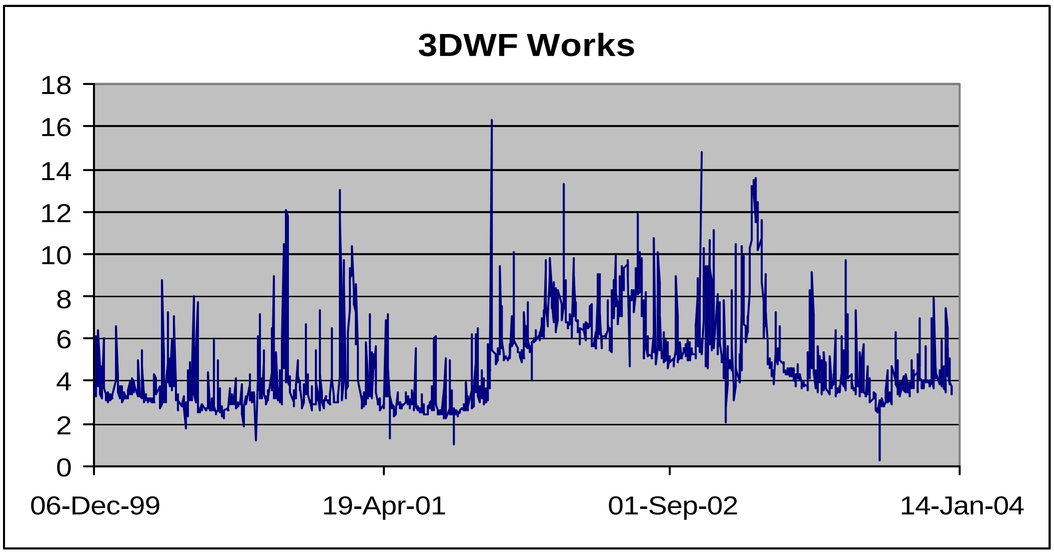


Fig. 4 A Works where infiltration takes 12-18 months to return to steady state

In essence this data seems to show that the classification of infiltration into “winter” and “summer” is too simplistic. A fuller model is that there is baseline weather-independent infiltration, which then has a rainfall-related element added to it with a catchment-specific decay-time added to it.

Reproducibility and Types of Flow Profile

The question of reproducibility between DWF periods is initially addressed (Figs 5-7) by showing data that was adequately reproducible over a range of catchment sizes. Smooth diurnal profiles with a large morning hump and a lesser evening hump are the norm, but at each scale of works it is possible for there to be a reproducible but irregular DWF profile, and examples of this are given. All of the catchments shown with an irregular profile had substantial terminal pumping, but other works with substantial or total terminal pumping did not give irregular profiles. Insufficient detail is known about these works to identify the causes of irregular profiles.

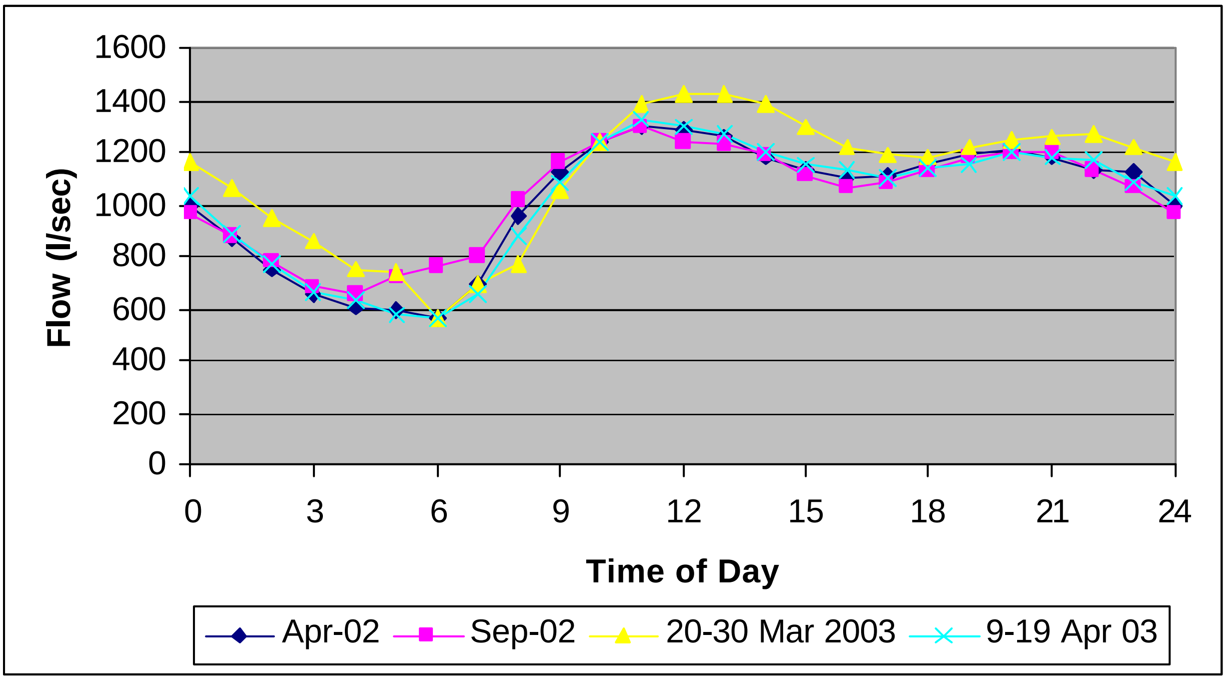


Fig 5. Reproducible DWF at a Large Works

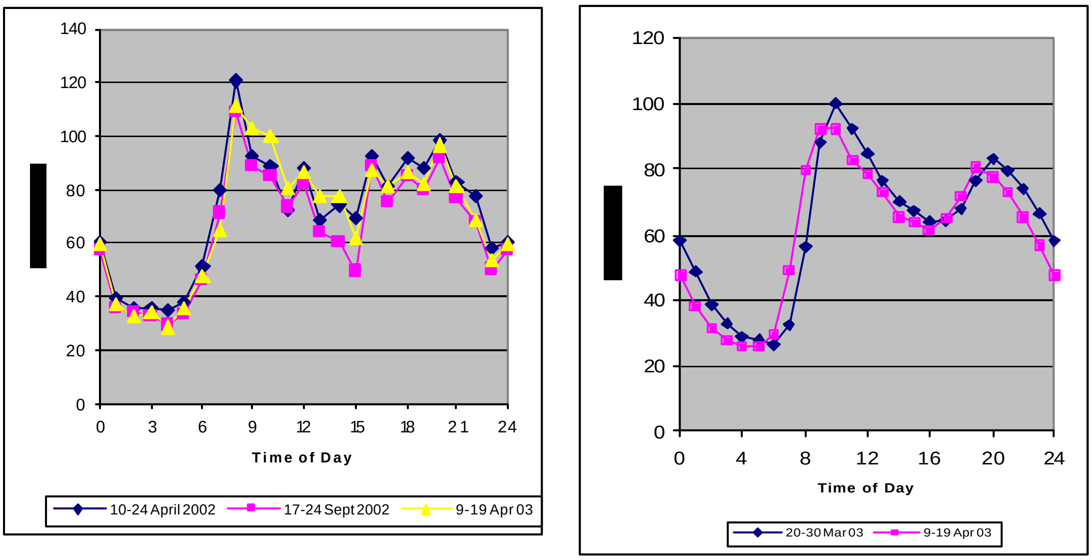


Fig. 6 Reproducible DWF at Moderate Works

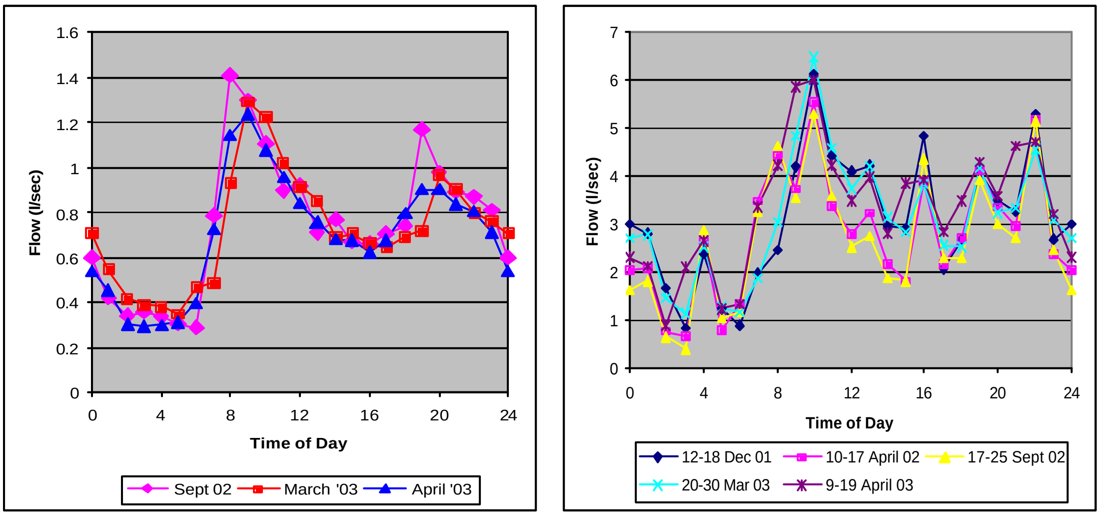


Fig. 7 Reproducible DWF at Small Works

Different "winter" and "summer" infiltration as a concept is shown to be valid, at least for some sites, by Fig 8. The flows net of the overnight low flow are reproducible, but the overnight low flow is not. Careful examination of the dates in Figs 5-7 will show that several of those catchments do not display variable infiltration during the same dry periods as in Fig. 8. The adjacent catchment to Fig 8 (1.5 km away) did not display marked changes in infiltration for the same periods.

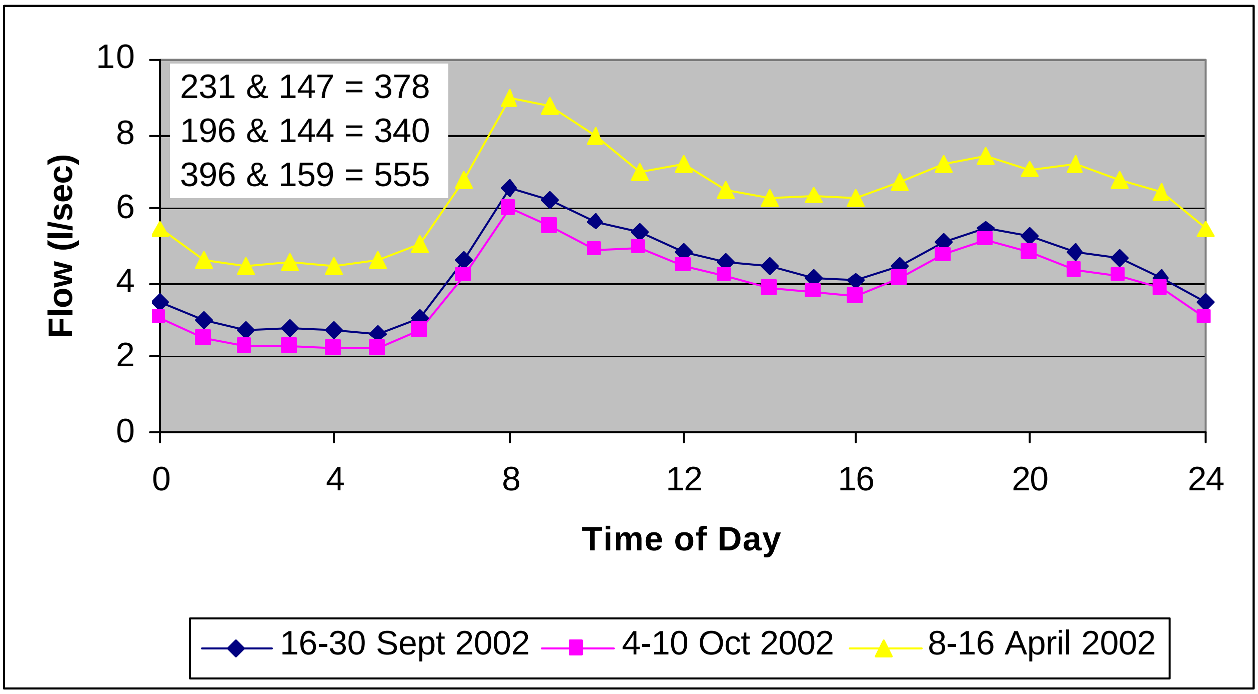


Fig. 8 Only the PG Element of DWF Reproducible

Some cautionary data is given in Figs 9 and 10 to show that not all works give reproducible data for DWF. At one the catchment includes a barracks (Fig 9); for the other (Fig 10) there is no known cause.

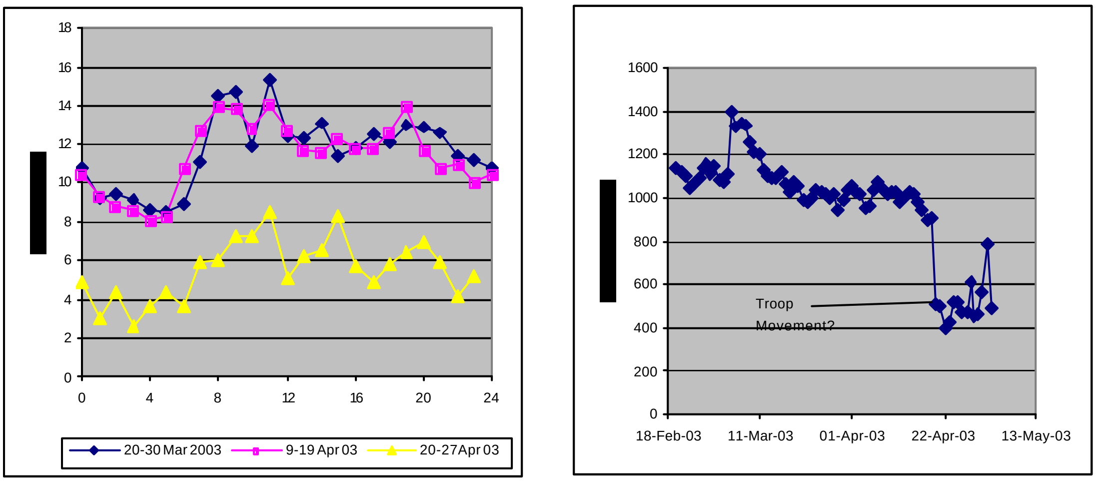


Fig. 9 DWF Not Reproducible For a Known Cause (a Barracks)

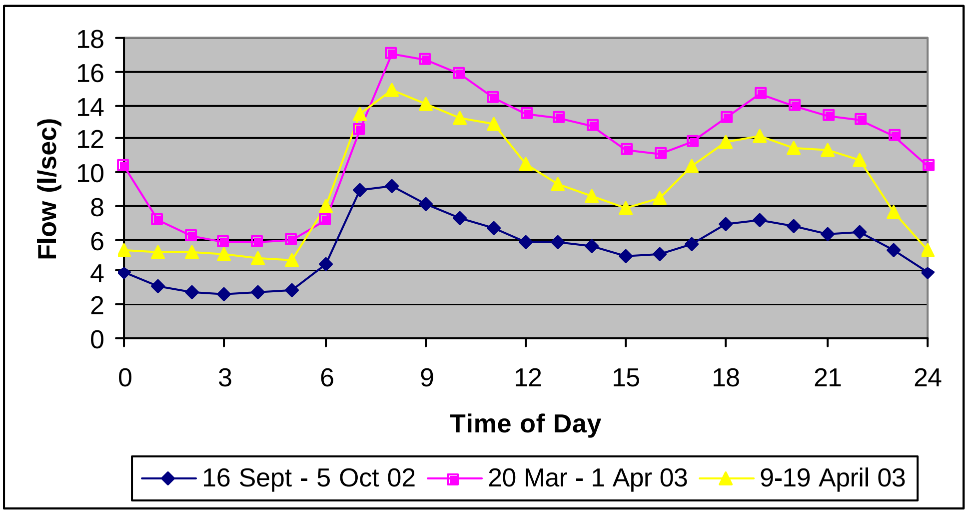


Fig. 10 DWF Not Reproducible (no Known Cause)

Peaking Ratios

There is an overall trend apparent in Figs 5-8 for the diurnal “peakiness” to increase as the catchments get small and more compact. This is followed through in Fig 11 which uses normalized flows to show that it is a real but very noisy trend: an 11,000 population works can be more peaky than a 350 population works.

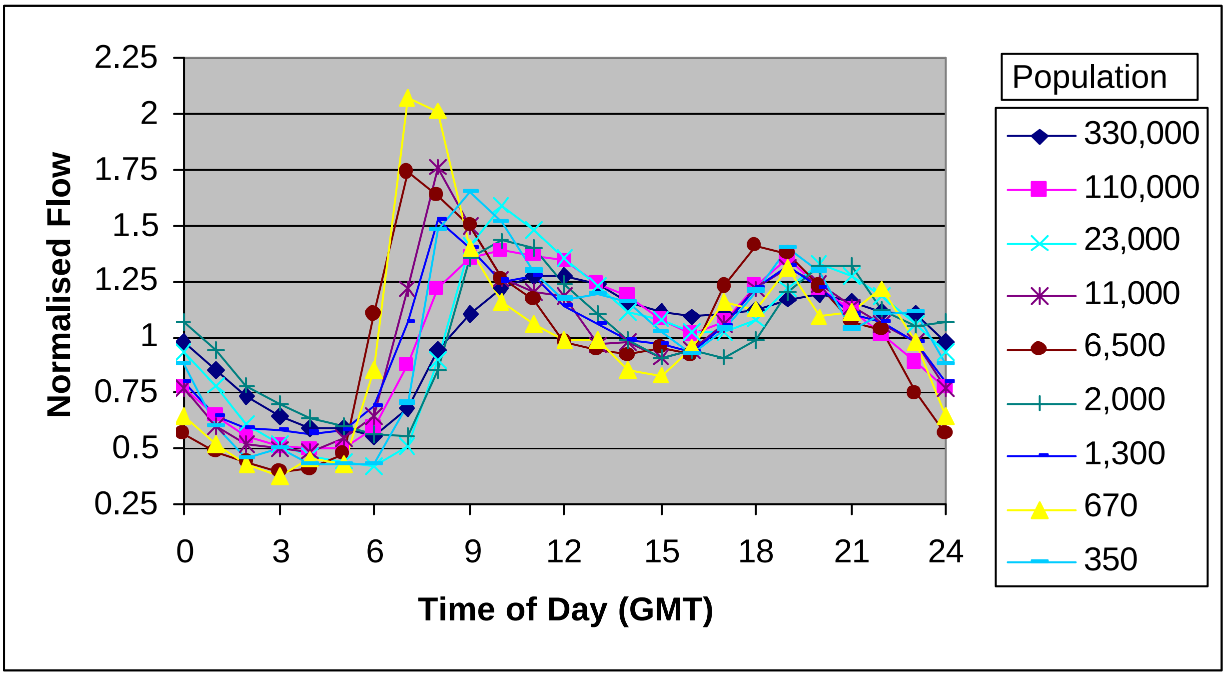


Fig 11. Normalised DWF Profiles over a range of catchment sizes

By contrast, the normalized flow data in Fig 12 shows two things: that large gravity catchments can give “overnight” low flow at late as noon despite the apparent universality of 3-6 am shown in Fig 11, and that pumping, even with large catchments, dramatically reduces the time it takes to get the flow to the works. The two catchments are about the same size physically and in terms of population (330,000 and 440,000 population). In both cases the works is off one edge of the main catchment population zone. The peakiness for the two works is also about the same despite the pumping reducing the system time lag, but two catchments is too few to generalize that this will be more universally true.

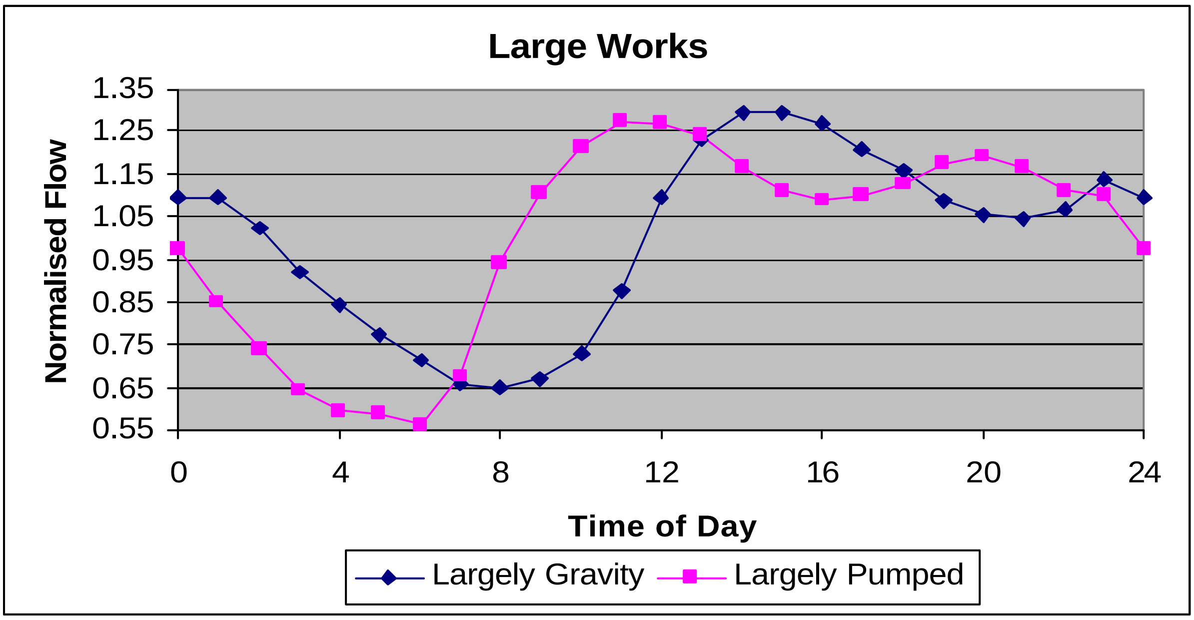
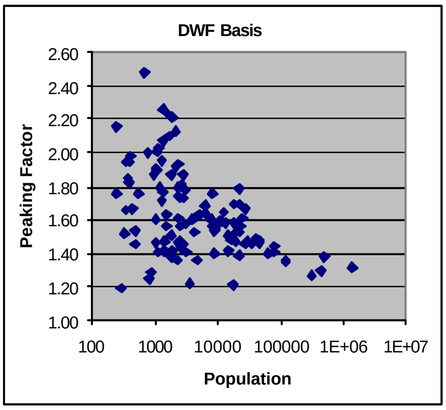


Fig. 12 Normalised Flow Data at Gravity and Pumped Large Catchments

The noise referred to in discussing Fig 11 appears best displayed in scatter plots to allow many more catchments to be included. Fig 13 shows an attempt to quantify peaking factors (the ratio of peak to average flow) both on unmanipulated data (“DWF Basis”), and on flows corrected for the overnight lows (“PG Basis”). The DWF Basis results show the observations above should actually be restated as showing that there is a normal range of variability of peakiness into which a catchment can fall, and that that range narrows as the catchments get larger.



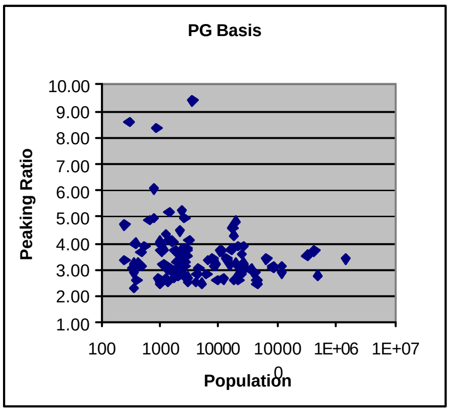


Fig. 13 Peaking Factors At Many Works

The PG Basis plot in Fig 13 probably shows more about the assumption that the overnight low flow is a good approximation of infiltration than it does about actual peaking. Up to about 5,000 population the range of peaking ratios appears constant at 2.3 to 5.5. Above about 5,000 the range decreases, implying the catchments are large enough that overnight low flow routinely contains some population flow. Two of the three outlying points have some question mark about the flowmeter (but not enough the discount the data); the third has infiltration known to be much higher than the population flows.

Discussion

Most of the data presented above confirms preconceptions, and is unsurprising in the extreme. It was a little surprising to find that some works have irregular DWF profiles, but less so when it was realized that this was associated with pumping.

The finding of prolonged times for infiltration to return to steady levels is a little more unexpected. No efforts yet have been made to model the results to provide a methodology for predicting long-term infiltration trends based on long-term rainfall data, but this is an obvious next step. Long-term data of this type will become readily available in the foreseeable future, because all UK sewage works over 50 m^3/day DWF will be fitted with BS-compliant flow metering by December 2004 to comply with the Urban Wastewater Treatment Directive; many already have this.

In terms of the impact of the findings in this paper, it should be recognised that Dry Weather Flow (DWF) seems typically to be of minor direct importance in catchment modeling related to designing sewers and intermittent discharges from them. Rainfall-related flows are typically so much greater than DWF that using assumed or generic values for DWF does not invalidate calculations on storm discharges.

However, particularly the data from small catchments is informative about some of the assumptions underlying the foul flows calculated by catchment models. One such assumption is that you can predict the foul flow from the number of dwellings and an assumption (usually derived from census data for the area) of population per dwelling. Typical assumptions made in sewage works design would be to use 140 l/head/day for the foul flow and, in the absence of data, 100 l/head/day for infiltration, giving a lumped (G+I) of 240 l/head/day.

Two possibilities exist for this to give incorrect predictions: either (G+I) could be wrong or use of housecounts to predict P_{res} could be wrong. Thus testing whether the overall model is correct could compare predicted populations calculated from DWF using 240 l/head/day, or it could derive (G+I) values from DWF and the theoretical population. The latter approach is used here.

Fig 14 shows that using this approach to derive foul flow is substantially invalid. The range of (G+I) values in small catchments covers a factor of ten, reducing to about a factor of two at catchments at about 30,000 population. Since (G+I) is lumped in this graph, the remarks above about the difficulty about determining infiltration do not apply.

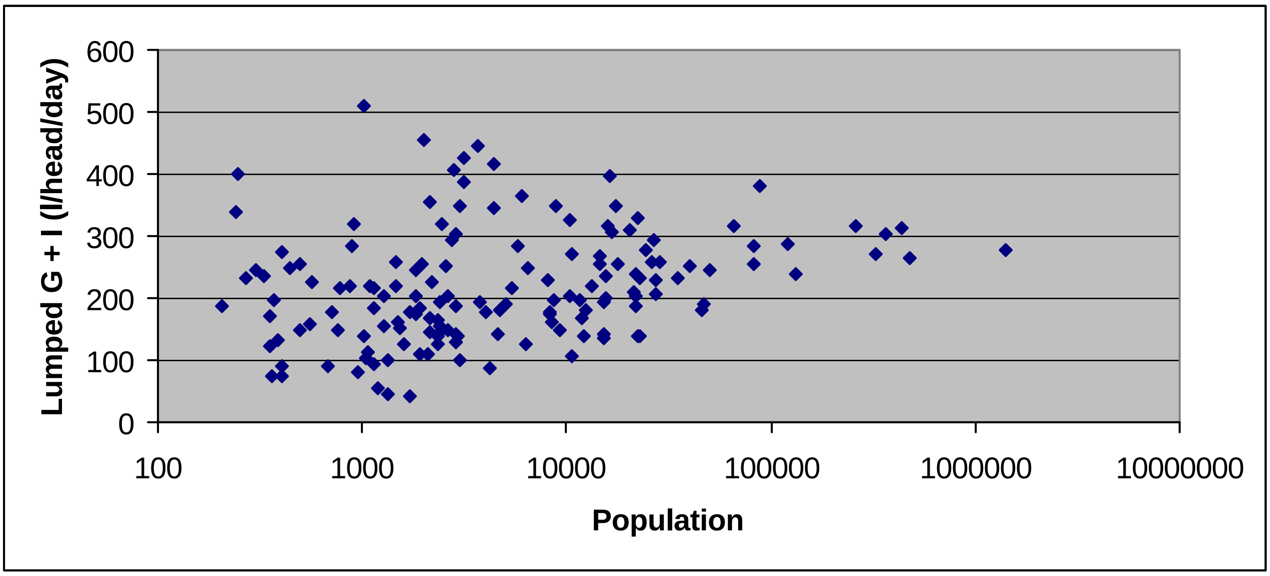


Fig 14 G+I Values Derived from DWF data and Address Counts

Summary and Conclusions.

Dry Weather Flow:

- Has a soundly based empirical definition
- Is usually reproducible
- Sometimes has seasonal differences in infiltration
- Has a unique profile influenced by both catchment size and pumping
- Cannot be predicted from address counts

Acknowledgements and Disclaimer

The data in the paper came from Severn Trent Water and Yorkshire Water whose permission to use it is gratefully acknowledged. The efforts of the following people were especially helpful: Hazel Edmonds, John Dickinson, Nick Madeley, Rachel Edgington, and Dan Timms.

The views expressed are those of the author, however.