Towards a new definition of DWF

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Introduction

As a concept, Dry Weather Flow has existed for over 30 years. In the context of sewage treatment its intended use, in conjunction with quality parameters, is to define the load that can be assimilated by the receiving environment. By defining the base load, it is also a yardstick by which population growth in a catchment can be identified. It is a key parameter used by the Environment Agency in the setting of consents to discharge, and with recent improvements in flow measurement within the industry is likely to attract increased Regulator attention for the foreseeable future.

It is therefore important that DWF can be robustly, reliably and consistently measured. Unfortunately this is not currently the case. This paper details the work carried out under UKWIR project WW21/D to develop an alternative measure of DWF. In addition, the paper will summarise the regulatory progress that is being made towards adoption of the new measure, and will highlight other flow-related research needs that have recently been identified.

Background

The current definition of DWF was first published in the Institute of Water Pollution Control Glossary in 1970, and is quoted here from the Environment Agency (EA) standard consent conditions:

> *"the average daily flow to the treatment works during seven consecutive days without rain (excluding a period which includes public holidays) following seven days during which the rainfall did not exceed 0.25 millimetres on any one day"*

To date, there has been no systematic EA assessment of DWF compliance due to the generally poor availability of validated flow data. Recently imposed requirements for flow monitoring and reporting mean that these data are now becoming available, and EA assessment and reporting of flow compliance is anticipated from 2006.

DWF is used in the setting and enforcement of effluent discharge consents, for wastewater treatment works design, and to determine the 'base flow' for use in sewerage modelling.

In consent setting and enforcement, DWF is used alongside quality limits as a means of controlling the pollutant load discharged to the watercourse. It is also used in determining the flow at which discharges to storm tanks will be permitted by the consent (Flow to Full Treatment, FFT).

In wastewater treatment works design, the main considerations are the incoming BOD load, and the mean and peak flows to treatment. DWF may still be used in the estimation of the latter flow parameters, but this would ideally be within the context of a more complete characterisation of wastewater flow and quality.

In sewerage modelling, DWF is used to determine the base flow of domestic and industrial wastewater to be applied at model nodes. Best practice requires the separate estimation of the individual DWF components, with infiltration being estimated either from infiltration surveys and/or detailed analysis of long term outfall flow records.

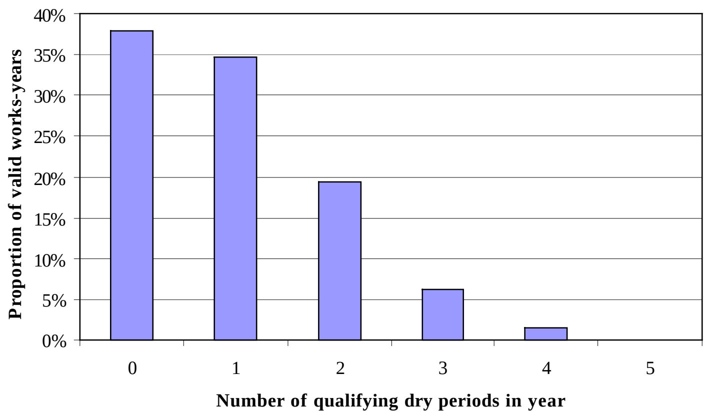
Problems with Current Definition

There are a number of problems with the current definition of DWF, which can be summarised as follows:

- The opportunities for measuring DWF are limited by the rarity of suitable dry periods in the UK, as illustrated in Figure 1. Analysis of rainfall data collected within the UKWIR project indicated that only around 62% of works-years contain a qualifying period for calculation of DWF.

- Seasonal variations in DWF occur, particularly where infiltration is significant. It is of particular concern that DWF values derived from winter dry periods can lead to spurious consent failures where the consented DWF has been set on the basis of summer river needs.

Figure 1 – Frequency of occurrence of qualifying dry periods



- Representative rainfall data is not available for all sewage works. In addition, for large catchments, spatial variations can mean that no single rain gauge is representative of the catchment.

- The current method of determining DWF compliance does not take into account the inherent uncertainties in either the measurement or calculation processes.

- The definition does not provide reliable information regarding the statistical distribution of flows for use in consent setting calculations.

- The current definition makes no specific provision for unusual catchments that have high seasonal variations, for example due to tourism or food processing industries.

- There is no theoretical link between the current definition and the design formula, PG + I + E. This formula will continue to be important in forecasting future flows for design and strategic planning purposes.

Selection Criteria

To provide a structured approach to evaluating alternative definitions of DWF, the following selection criteria were agreed by the UKWIR group:

- **Applicability** – The method should be such that it can be calculated for a high proportion of (or preferably all) assessment periods and works.

- **Repeatability** – The method should show low variability between assessment periods at a given works where domestic and industrial flows have not changed significantly, ie there is little variability due to year-on-year variations in rainfall patterns and/or the occurrence and timing of dry periods.

- **Statistically based** – The method should be defined in statistical terms with reference to the distribution of flows over a defined period.

- **Continuity** – The method should give results that are close to the 'best' identified interpretation of the traditional method. This 'best' interpretation has been identified by assessing viable interpretations of the current method against the same selection criteria described here, and is referred to as 'the baseline method'.

- **Simplicity** – The method should be as simple as possible in concept and calculation.

- **Linkage to design formulae** – As far as practicable, the method should show reasonable agreement with the P.G + I + E formula, provided that an appropriate method for calculating the infiltration component is adopted.

- **Manageable implications** – The method should have manageable implications for other consented flow parameters (particularly FFT).

- **Additional information** – The method should provide additional statistical information to allow flows to be characterised more accurately in consent setting calculations. If this criterion is to be met, more than one output value will be required.

- **Ready for implementation** – The method should be ready for implementation without significant further development.

Alternative Definitions Investigated

The following alternative methods were selected for comparison with the current definition of DWF:

- various percentiles of the daily flows, with and without rainfall conditions
- various percentiles of a moving average of the daily flows, for various averaging periods
- the mean, mode and geometric mean of the daily flows
- methods involving fitting a distribution to the daily flows.

When evaluating the performance of the current definition of DWF, both an "all year" and a "summer only" condition have been evaluated.

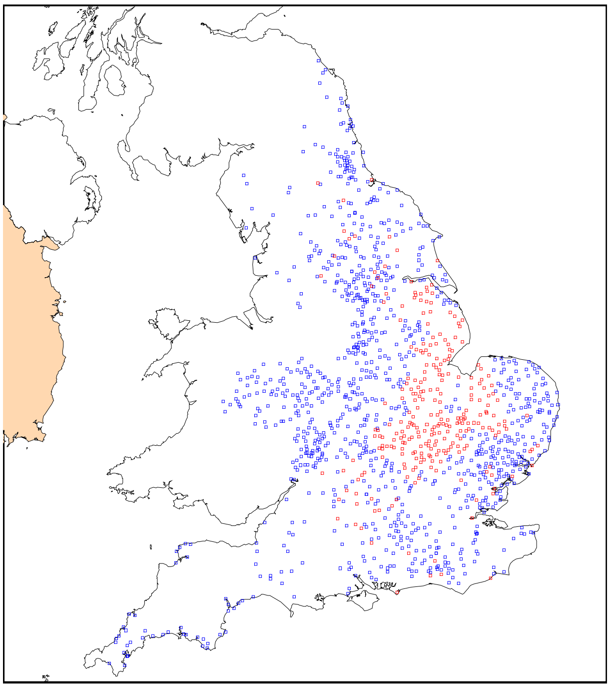
Data Availability

Flow and rainfall data were requested from the 11 water and sewerage companies participating in the UKWIR project, together with associated catchment information.

4,447 works-years of flow data and 3,123 works-years of associated rainfall data were received from nine water and sewerage companies (Figure 2). After subjecting both flow and rainfall data to a range of validation tests (described in the following section) complete works-years of data with in excess of 75% of values complying with all validation tests (3,266 works-years of flow data and 1,803 works-years of associated rainfall data) were passed forward for use in the analysis.

Table 1 provides additional details, with '1 year' denoting any continuous 12-month period. Works with less than 12 months of continuous flow data were not included.

Figure 2 – Geographical distribution of flow and rainfall data used in analysis



Key
= Works with at least one 12-month period of combined flow and rainfall data used in the analysis.
= Works with at least one 12-month period of flow data used in analysis, but no 12-month period of combined flow and rainfall data.

Table 1 – Summary of data volumes used in analysis

Number of works-years' flow data	Total	With matching rainfall data
= 1 year	1,302	1,002
= 2 years	786	436
= 3 years	607	191
= 4 years	416	103
= 5 years	84	48
Total	3,266	1,803

Data Validation

The flow data received were subjected to the following validations:

- Negative, zero or missing daily flow values were identified and invalidated.
- Two tests were performed to identify periods of constant or near-constant flows due to meter or data transmission errors.
- Identification of erroneous low flow values, based on the ratio of mean flow to the 20th percentile of valid flows.
- Data were reviewed manually where outlier values were observed in the results of the various DWF methods, and data exhibiting unrealistic behaviour were invalidated.

Similarly, for rainfall data:

- Negative or missing daily rainfall values were identified and invalidated.
- Gauges which are subject to a significant proportion of missed readings were excluded.
- Long periods without rain were manually reviewed.
- Checks were carried out for missing values at the beginning or end of the data period.
- As for flow data, rainfall data were reviewed manually where outlier values were observed.
- Finally, all summer dry periods were manually reviewed.

Analysis Tools

All flow data, rainfall data and catchment explanatory factors were imported into a relational database. This database was accessed by bespoke software capable of calculating DWF values using a wide range of alternative methods.

A wide range of method variations were calculated by the software and returned to the database for analysis. Each method was applied to each data set that had passed the validation criteria defined above. Appropriate analysis techniques were applied to these results in order to assess the performance of each method. These included the following:

- Review of scatter plots to compare DWF results from two selected methods. These plots highlighted biases related to works size, and whether a method persistently under-estimates DWF compared to another method.
- Review of histograms of DWF results
- Review of correlation matrices to identify biases in method results and performance between works with different numeric attributes.
- ANOVA analyses were undertaken to identify biases in method results and performance between works with different non-metric (ie categorical) attributes.
- Statistical hypothesis tests to identify biases in method results and performance between works in different binary categories.

Further bespoke software was used to calculate various ‘performance indicators’ from the method results, to provide quantitative means of assessing and comparing the performance of the many method variants considered. These included:

- a measure of the success rate of a method, that is the proportion of data sets for which a result could be obtained (termed “Success Rate”)
- a measure of the agreement between the results of a method and those of an identified “baseline” method (usually the current definition used in consents) (termed “GeoMean Ratio”)
- a measure of the variation in method results between years at the same works (termed “Temporal Variability”).

Results of Analysis

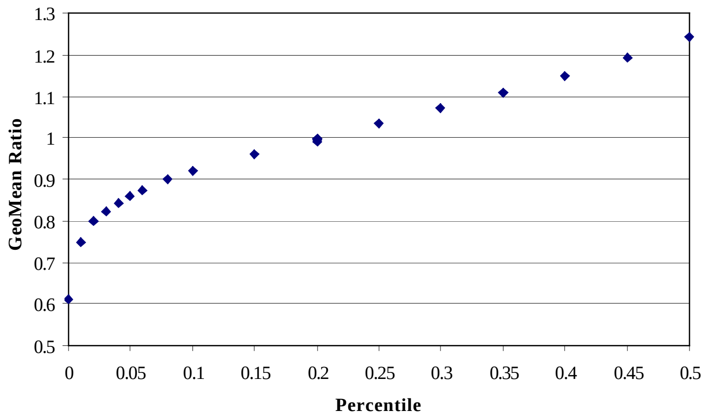
Full details of all the results from the analysis are contained within the UKWIR report. However, the principal conclusions can be summarised as follows:

- The current DWF definition cannot be calculated for a large proportion of data sets. The current method also gives results with high year-on-year variability when using dry periods from any month of the year. If restricted to summer dry periods only this variability is significantly reduced.

- By relaxing the stringent rainfall conditions imposed in the current method, a variant can be developed which can be calculated for almost all (90%) of data sets and has only a slightly increased (+2.3%) mean. However, 45% of the data sets available for use in the analysis had no corresponding rainfall data.

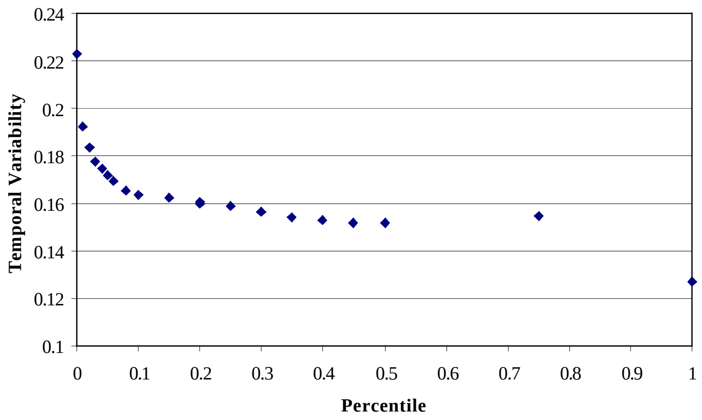
- A wide range of methods have been tested which do not require rainfall data, of which the 20th percentile flow (Q_{80}) gives the best overall performance against the selection criteria. It can be calculated easily for all reasonable data sets without use of rainfall data, agrees well on average with the summer DWF calculated by the existing method (Figure 3), and exhibits significantly reduced year-on-year variability.

Figure 3 – Use of GeoMean Ratio to assess agreement with baseline definition for rainfall independent percentile methods



- The 5th percentile of daily flows (Q_{95}), which was previously a favoured statistic, gave results which were on average 14% lower than the summer DWF calculated by the existing method (and Q_{80}). Q_{95} has somewhat higher year-on-year variability than Q_{80} (Figure 4), but in other respects has similar characteristics.

Figure 4 – Assessment of Temporal Variability for rainfall independent percentile methods

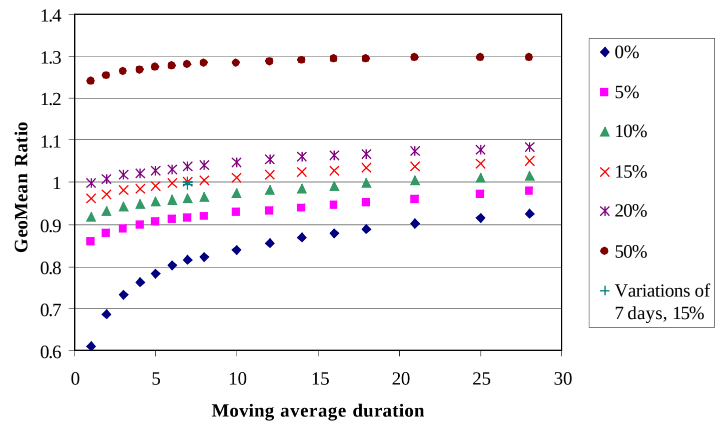


- Moving average methods can be developed that give similar performance to Q_{80} (Figure 5), but these are more sensitive to missing or invalid data and are more complex to understand and apply.

- Distribution fitting methods require a more complex calculation algorithm, but have the potential to provide a more effective check on whether effluent flows are exceeding the assumptions made when setting consents. However, these require further development and have more far-reaching implications for current practice.

Regulatory Overview

Figure 5 – Use of GeoMean Ratio to assess agreement with baseline definition for moving average methods



From the analysis of results, based on the agreed selection criteria, the measure that emerged as the most appropriate replacement for DWF was the 20th percentile (Q_{80}). This is in the process of being discussed formally at a national level between Water Companies and the Environment Agency, and will form the basis of a replacement for assessing DWF compliance. It is expected that an agreement will be reached on the regulatory principles before the year end.

Key to completing this transition successfully are a number of issues:

- **Changes needed to DWF values in current consents** – Previous experience in the early 1990's with the national consent translation programme revealed problems that would arise if there needed to be wholesale changes in numeric values in consents. As the 20th percentile has close agreement with DWF values that would be generated by the current methodology, current consents can be treated as if DWF had been set as 20th percentiles.

- **The compliance testing window** – It is expected that flow compliance testing will take place on an annual basis, either on a calendar or rolling year basis.

- **Incorporation of uncertainty into the compliance testing approach** – Unlike compliance testing of quality parameters, compliance testing of flow is currently on a pass/fail basis. To create the equivalent of a confidence interval, it is intended that annual compliance would be assessed on the basis of a 10th percentile basis, ie a works would be deemed to fail if the 10th percentile flow exceeded the consented DWF in any given year.

- **Strategy for works that fail consent** – The analyses carried out showed that currently nearly one third of works-years fail their DWF consent. Whilst this is reduced by use of the 20th percentile, there are still a significant proportion of works that would fail even the new measure. As part of the ongoing national discussion, an appropriate approach is being developed which will include identifying whether such breaches are trivial or would lead to breach of environmental standards, and tying in associated improvements to investment cycles. This will also involve developing an agreed change procedure with OFWAT, as well as the Water Companies and the Environment Agency.

Future Developments

Now that a revised and more robust definition of DWF is imminent, it paradoxically means that the rationale behind other flow based issues requires re-examination. These will be the focus of a number of UKWIR projects next year.

This includes:

- Examination of the concept of Flow to Full Treatment (FFT), including the relationship between DWF and FFT, the environmental basis for FFT, and its use as a works design parameter.
- The relationship between theoretical and measured values of DWF. In the field of natural hydrology, such “low flow” links have already been made for over 20 years.
- How flow values, and particularly flow distributions, are used in the modelling of discharges for consent setting, including the evaluation of “no deterioration”.
- How flow records are used to identify changes in catchment characteristics, particularly infiltration and populations.

Conclusions

The UKWIR project on assessment of alternative measures of sewage works dry weather flow has confirmed a number of fundamental problems in using the current rainfall-dependent definition of DWF to test consent compliance.

A viable alternative has been established, based on use of the 20^{th} percentile of daily flows, and is likely to be adopted as a replacement measure in the near future.

A number of associated issues of implementation are being finalized between Water Companies and the Environment Agency, but both parties are confident that a complete package around flow compliance will be agreed in the near future.

As issues around DWF become resolved, so other long-standing flow issues will be pushed to the fore, for future investigation and resolution.

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This paper has been produced with the permission of the Directors of Yorkshire Water and Tynemarch Systems Engineering Ltd. The views expressed in the paper are those of the authors and not necessarily the views of these organisations.

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