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Ensuring hydrometric data are fit-for-purpose through a national Service Level Agreement

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Abstract Globally, access to hydrometric data of adequate quality, consistency and coverage to answer pressing research questions and manage operational freshwater systems remains a major issue. Despite recent advances, many datasets remain inaccessible or have limited utility due to data accuracy and completeness issues. In light of such problems, a Service Level Agreement (SLA) was introduced in 2002 to control the provision of data to the UK national hydrometric archive. Central to this framework is a set of quantifiable indicators of data quality, completeness and provision. The paper presents the results from the first 11 years of the SLA and discusses the experiences in applying the system to a diverse gauging station network maintained by multiple data providers. The improvements shown in data quality and consistency demonstrate that such systems can help to ensure hydrological databases provide high quality information to meet water management needs both today and into the future.

Key words hydrometric information; data management; monitoring; gauging station networks; river flow data; UK

INTRODUCTION

Quantitative measurements of river flow and other hydrometric variables are of fundamental importance in informing water management. Records of the current and historical state of freshwater fluxes form the foundations of research, policy and operational management in areas such as: flood risk management, water resources provision and protection of aquatic ecosystems. As a result, where the utility of such records is reduced through limited availability or poor data quality, the impact on our ability to understand, manage and mitigate the risks posed by the freshwater environment can be severe.

Within the UK, measurement of river flows is devolved to a regional level with four hydrometric measuring authorities maintaining 12 regional monitoring networks totalling around 1150 primary gauging stations. To ensure consistency across regions, provide a single coherent source of national data, and aid assessment of UK-wide water resources, the UK National River Flow Archive (NRFA) is maintained as a publicly-funded national focal centre for hydrometric information. The NRFA collates, quality controls, analyses and disseminates river flow data and associated information to a wide range of users, including freshwater regulators, scientific researchers, educational users, government bodies and international organizations. One important role for the NRFA is the provision of data to international data sharing initiatives such as the FRIEND European Water Archive and WMO Global Runoff Data Centre. Comprehensive descriptions of the NRFA, its remit, scope of work and operating practices are given in Dixon (2010) and Dixon *et al.* (2013).

SERVICE LEVEL AGREEMENT

In addition to the installation and maintenance of the UK hydrometric monitoring network, flow gauging and data collection, the regional measuring authorities have primary responsibility for data processing and initial quality control. Once a year, these validated river flow records from all primary gauging stations are transferred to the NRFA, where they undergo further quality checking before being combined with auxiliary information and added to the national database for long-term storage and dissemination. This additional level of data validation, completed by experienced NRFA staff, provides an independent appraisal of the daily flow data provided to the national archive. Through the use of custom-built visualisation and data handling software, quality control procedures place a strong emphasis on the final utility of data, by focusing on maximising data quality, reducing gaps in records, and ensuring comprehensive user guidance is maintained.

To control the provision of data to the national archive and provide a framework for targeting improvements to data availability, completeness and quality, a Service Level Agreement (SLA) was developed between the UK regional measuring authorities and the NRFA. Implemented in 2002, the SLA now covers all major NRFA data providers and comprises two key elements. Firstly, an agreement between the network operators and the archive ensures that when there are proposed closures or operational changes affecting a core set of gauging stations, both the national level strategic requirements and local operational needs are considered. The UK gauging network grew rapidly in the 1960s/1970s but by the late 1990s, a reduction in the number of new stations being established and growing pressure to rationalise monitoring programmes led to a decline in the operational hydrometric network (Fig. 1). The SLA agreement, which covers around 60% (currently 715 stations) of the network, was designed to promote stability in monitoring and ensure that valuable long-term records are maintained into the future. A similar aim of maintaining a core, stable, network of gauges is central to the US National Streamflow Information Programme, developed in response to concerns about declining hydrometric networks (Norris, 2009).

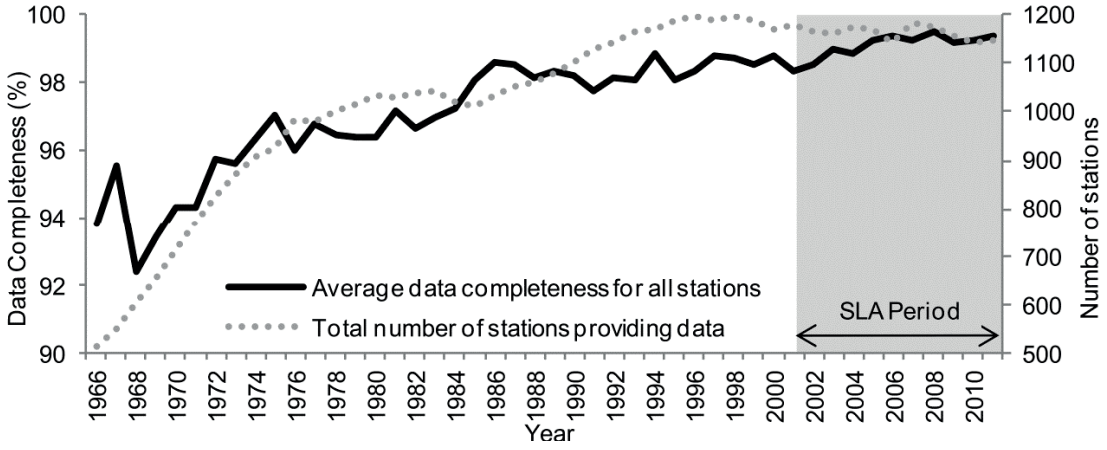

Fig. 1 Annual average data completeness for all UK gauging stations providing data to the NRFA.

In tandem with this network stability objective, a second key element of the SLA is a set of quantitative indices of data utility which are used to assess data from the core network on their transfer to the NRFA. Objective scoring mechanisms measure both the completeness and timeliness of annual data submissions to the archive, as well as the proportion of records where data quality issues are found. The results from the first 11 years of applying these performance metrics form the focus of the remainder of this paper.

In addition to data quality, the focus on data completeness and provision to the archive were agreed in response to concerns about data availability and recognition of the impact that small periods of missing data can have on the overall utility of a time-series. Short segments of missing data in gauged daily flow series can have considerable impact for the calculation of widely used derived series (e.g. 7-day minima). While average data completeness from UK gauging stations increased gradually between the 1960s/1970s and 1990, thereafter it remained around 98% (Fig. 1) – indicating that poorly performing stations result in around a week of flow data missing per station, on average, each year. SLA metrics assessing data completeness were therefore instigated in order to drive further improvements by encouraging the adoption of more resilient data collection systems and promoting the use of data infilling methodologies for estimating missing data (Harvey *et al*., 2012).

SLA SCORING METHODOLOGY

The SLA performance metrics for data completeness and timeliness are calculated for data provided to the NRFA at the point of submission (point 1 in Fig. 2). During the secondary quality

control conducted by the NRFA, where potentially anomalous flows are identified, these are queried with data providers using auditable enquiry logs. Data providers are given a set period of time in which to investigate queried data and respond to the NRFA to confirm their validity or provide alternate back-up, corrected or estimated data. These responses form the basis of the data quality and query timeliness indicators which apply where problems in the measurement or processing of flows are confirmed (point 2 in Fig. 2).

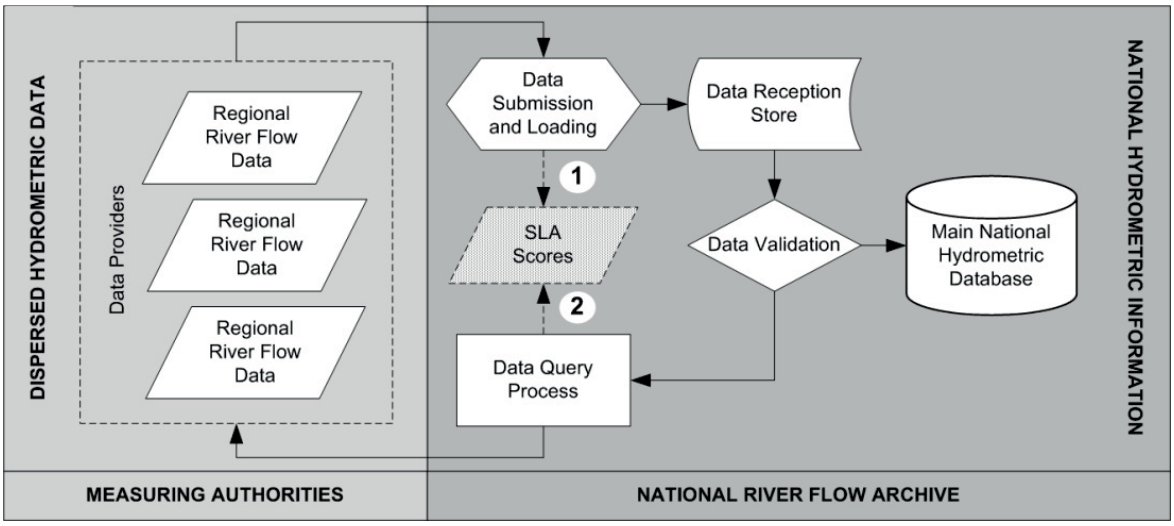

Fig. 2 Schematic representation of data provision to the NRFA and its subsequent validation prior to inclusion on the national archive (adapted from Dixon, 2010).

The SLA scores are first calculated for individual stations and then aggregated to assess the performance of particular regional data providers, certain categories of gauging stations (e.g. type of measurement technique, record length) or the network as a whole. Data are received in annual submissions, during the spring of the following calendar year. Performance scores are reported back to measuring authorities ahead of the following year's submission to encourage improvements and inform operational practice.

Two measures of "timeliness" are made, the first (*Data Timeliness)* assesses the initial provision of flow data to the NRFA while the second (*Query Timeliness*) measures the response to queries raised against anomalous data. Scaled between 0 and 10, a maximum *Data Timeliness* score is given where data are submitted on or before the 31 March deadline and the score is decreased for every day late, until a score of zero is given after 10 weeks. For *Query Timeliness*, a six-week time period is permitted for responses to queries, after which scores are decreased for every day late, with a score of zero given after 20 days.

Data completeness is assessed at the point of submission using a ratio between the amount of missing Daily Mean Flow (DMF) data and the total amount of flow data which are expected for each station (i.e. normally 365 or 366 p.a.). This *DMF Completeness* metric is then scaled from 0 to 10, so that data completeness of 90% or less receives a score of 0 and complete datasets are awarded 10. A second, aggregated, *Station Completeness* score is then calculated as the percentage of stations within the given region (or category) with complete data.

Data quality is assessed by calculating scores based on queries logged against anomalous data during the quality control process. Using a similar mechanism to data completeness, the *DMF Queries* score uses a ratio between the amount of Daily Mean Flow data where no valid queries are logged and the total amount of data for each station. Scaled from 0 to 10, the *DMF Queries* score is also reported as performance relative to an expected level of 90%. A *Station Queries* score is given for the percentage of stations within the region (or category) where no data issues are found.

RESULTS

Data provision and query timeliness

Designed to assess adherence to the annual data provision and validation timetable and encourage prompt data submission, the overall aim of the timeliness metrics is to ensure NRFA users are able to access contemporary data. Both timeliness scores have varied during the SLA period; however, excluding 2003 (where severe data system upgrade issues were widespread), on average all data have been submitted within 10 days of the given deadline. Over the last five years, 80% of data submissions have been on time. The *Query Timeliness* metric is used as a second performance management tool to assess data providers and, over the same period, results show that 68% of data query responses were submitted within the permitted six week window.

Data completeness

An overall rise in data completeness has been observed over the SLA period (Fig. 3) and annual completeness levels at submission are now generally above 99% (*DMF Completeness > 9*). Furthermore over 92% of stations commonly provide complete datasets (*Station Completeness > 92%)*. Where reduced levels of completeness have been observed (e.g. in 2002 and 2010) these are generally the result of particular, widespread, technical issues affecting submissions from one or more measuring authority. The relative scores for *DMF Completeness* and the *Station Completeness* allow assessment of the spread of missing data across the network. Scores since 2003 suggest that while the total amount of missing data is small (an average of 1% of data is missing in any one year), the gaps are generally spread over 4–10% of the SLA network. Such a pattern indicates the prevalence of short gaps in multiple flow records. The regular reporting of the SLA completeness metrics encourages the use of data estimation techniques to infill short gaps in records where backup data collection systems are unable to resolve issues. Furthermore, recent research by the NRFA (Harvey *et al.*, 2012) and revised data processing policies amongst UK measuring authorities now place a greater emphasis on infilling missing data sequences before data are submitted to the archive, particularly where they occur during stable flow recessions or where data transfer from nearby or analogue sites is possible.

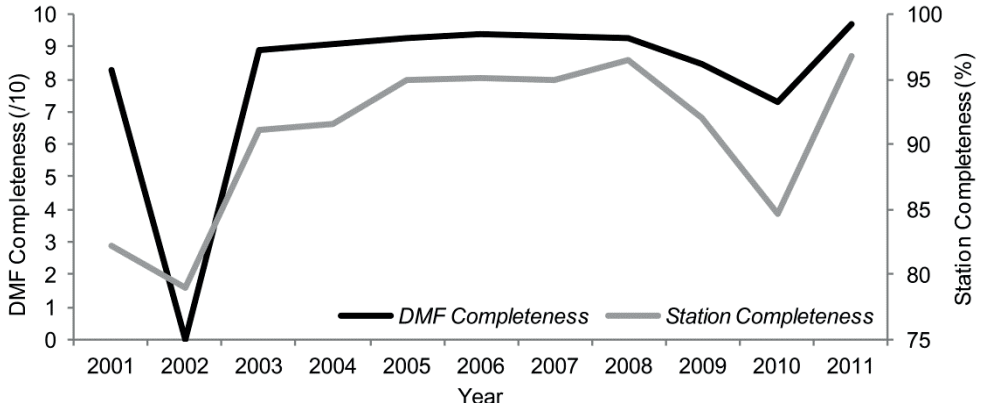

Fig. 3 Annual average DMF Completeness and Station Completeness scores for all SLA stations.

The UK hydrometric monitoring network expanded dramatically in the 1960s, when increased water resource demands and legislative changes led to a rapid expansion of the gauging station network (Fig. 1). The SLA network focuses on a core set of strategically important sites, including many of those with longer records which are of high utility in assessing hydrological change. Maintenance of complete records at such stations is normally seen as a high priority, with more resilient data collection systems, regular site visits and routine infilling of missing records. Such prioritisation is reflected in the SLA scores when categorised by the length of record at each station (Fig. 4). The average *Station Completeness* score increases with record length, with the higher data completeness in records over 40 and 50 years in length.

One key benefit of the SLA metrics lies in the subsequent improvements made to time-series after initial submission to the NRFA but before data are added to the national database. Flows highlighted by the SLA scores as missing from data submissions are often infilled by the data provider or NRFA before records are added to the national archive, resulting in more complete, higher utility data being available to users. As a result, the impact of introduction of the SLA on data completeness on the UK network as a whole has been to stabilise and further reduce the amount of missing flow records, with an average daily mean flow completeness of over 99% maintained for the last seven years (Fig. 1).

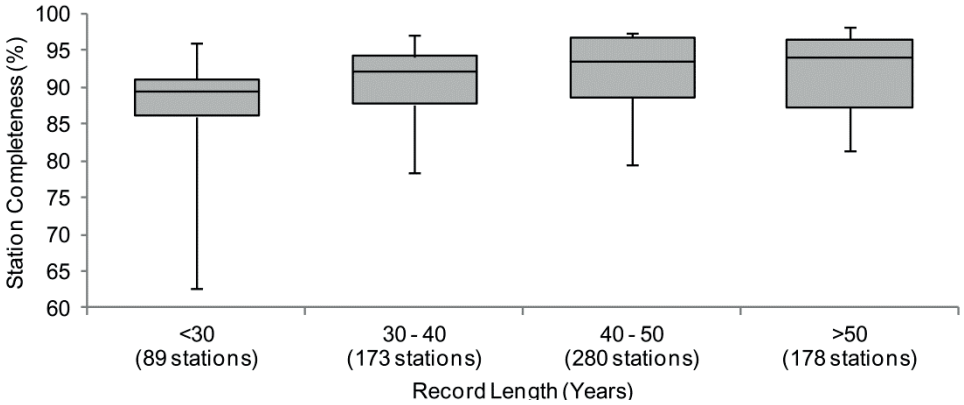

Fig. 4 *Station Completeness* scores for the 11 years of the SLA aggregated according to flow record length.

Data quality

Results assessing the quality of data submissions to the NRFA confirm that the UK hydrometric network generally performs well (Fig. 5). In each of the years the SLA has been operating, over 98.5% of all data submitted to the archive was found to have no valid data quality issues (*DMF Queries* > *8.5*). As the indicator is scaled to use 90% as a benchmark for non-queried data, marked fluctuations are seen in some years (e.g. in 2010) where significant/long-lasting issues affected a small number of sites (for example, channel stability issues which lead to marked alterations in the rating for a site and hence, at least temporary, loss of data). A more stable measure has proved to be the percentage of stations where no valid queries are issued (*Station Queries*), where a gradual increase has been observed over the SLA period (Fig. 5).

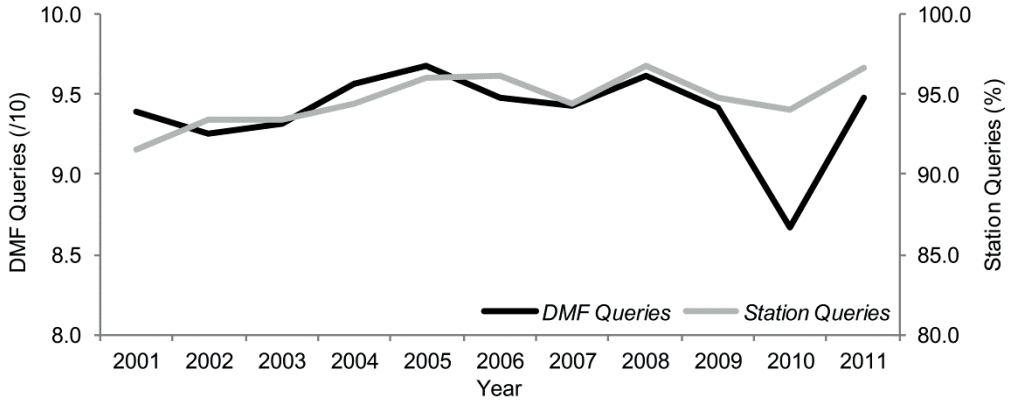

Fig. 5 Annual average *DMF Queries* and *Station Queries* scores for all SLA stations.

The SLA gauging station network is currently comprised of a majority of open-channel section (35% of stations) and purpose-built gauging structures (e.g. weirs, flumes; 58%), with the

remainder employing ultrasonic or electromagnetic flow measurement methods. In addition to assessing the performance of a certain data provider, the SLA framework can be used to assess the quality or completeness of data from different types of gauging stations. Taken together, the *DMF Queries* scores for all SLA years (2001–2011, Fig. 6) suggest that the extensive network of gauging structures in the UK produce data with relatively few data quality issues (average *DMF Queries* = 9.5, showing that issues are found in 0.5% of data).

The number of gauging stations in the UK employing ultrasonic, and more recently acoustic doppler, techniques as the main method of flow measurement is growing – reflecting their relatively cheap installation/operating costs and non-intrusive nature. While the proportion of data where quality issues are identified remains small, gauging stations which rely on such technologies have been subject to a relatively higher number of valid queries. Generally spread over 10–15% of stations of this type, issues have been found to affect up to 3.5% of all data submitted in some years. Data quality SLA metrics are based on the amount of data where issues are identified relative to the total amount of data submitted to the NRFA for any station type. The comparatively small number of acoustic stations means the measure is susceptible to the influence of individual hydrometric issues. Despite this, the results suggest that such stations may not prove as reliable as open channel sites or flow measurement structures over extended periods of operation.

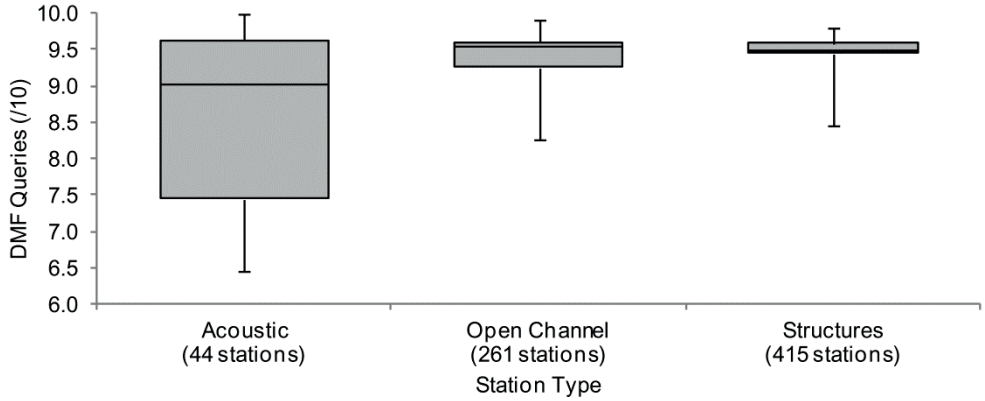

Fig. 6 *DMF Queries* scores for the 11 years of the SLA aggregated according to station type.

CONCLUSIONS

Application of an SLA framework for the provision of hydrometric data to the UK national hydrometric archive has provided the NRFA with a tool for quantitatively assessing the quality and completeness of submissions and their adherence to an agreed timetable. Through combining metrics with agreements aimed at stabilising a fluctuating network, the SLA has helped ensure long-term continuity in monitoring and promoted improvement to the utility of data available to users. Under the UK's collaborative model for delivering national hydrometric information, where separate organisations monitor, process and disseminate data, the SLA has provided a useful means of monitoring the network as a whole and performance of individual data providers.

The UK system relies on assessment of data quality by trained experts and has been designed to incorporate flexibility within the scoring systems (e.g. to take account of periods of unavoidable data loss). However, despite these considerations, data quality appraisal systems which operate mechanistically, concentrating on separate indices of data quality rather than the overall information delivery should be employed with caution. To mitigate against such issues, the SLA system is closely connected with other initiatives, such as close liaison with data provider's field teams and promotion of best practice through national and international standards, which aim to improve broader data utility (Dixon *et al.*, 2013).

Globally, there is a pressing need to improve the availability of high quality, easily accessible, hydrometric data. Such data and the national/regional databases that hold them, form the basis for both operational water management and research programmes such as FRIEND. Frameworks such

as the UK Service Level Agreement provide useful, transferable, tools for maintaining and improving the utility of such databases. The more widespread use of quantifiable data performance measures and expansion of data provision agreements would help maximise the hydrometric information available to researchers and water managers in an era of increasing resource pressures on networks around the globe.

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