BS 7843-1:2012

BSI Standards Publication

Acquisition and management of meteorological precipitation data from a raingauge network

Part 1: Guide for the design, development and review of a raingauge network

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ISBN 978 0 580 71309 5

ICS 07.060

The following BSI references relate to the work on this standard:
Committee reference CPI/113
Draft for comment 11/30219641 DC

Publication history

BS 7843-1.1 first published July 1996
BS 7843-1.2 first published September 1996
BS 7843-2.1 first published September 1996
BS 7843-3.1 first published November 1999
BS 7843-3.2 first published January 2005
BS 7843-1 first published December 2011

Amendments issued since publication

Date	Text affected

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to ii, pages 1 to 32, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 7843 is published by BSI and came into effect on 31 December 2011. It was prepared by Technical Committee CPI/113, *Hydrometry*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

BS 7843-1:2012, together with BS 7843-4:2012, supersedes BS 7843-1.1:1996 and BS 7843-1.2:1996, which will be withdrawn on the publication of BS 7843-4:2012.[1)]

Together with BS 7843-2:2012, BS 7843-1:2012 supersedes BS 7843-2.1:1996, which is withdrawn.

Together with BS 7843-3:2012, it supersedes BS 7843-3.1:1999 and BS 7843-3.2:2005, which will be withdrawn on the publication of BS 7843-3:2012.[1)]

Relationship with other publications

BS 7843, *Acquisition and management of meteorological precipitation data from a raingauge network*, comprises four parts.

- *Part 1: Guide for design, development and review of a raingauge network.*
- *Part 2: Code of practice for operating raingauges and managing precipitation data.*
- *Part 3: Code of practice for the design and manufacture of storage and automatic collecting raingauges.*[1)]
- *Part 4: Guide for the estimation of areal rainfall.*[1)]

Information about this document

This is a full revision of the standard.

As a guide, this part of BS 7843 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of BS 7843 is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

[1)] In preparation. Publication expected early in 2012.

Introduction

Precipitation totals and intensities are measured at frequencies ranging from seconds to months, and the data are required on timescales ranging from the immediate to several weeks in arrears. The requirements for precipitation data are numerous and varied, and measurements are made by many different organizations and individuals using a variety of instruments and techniques. Individual instruments might be operated for a dedicated purpose at specific locations, or larger numbers might be arranged into networks covering wide areas. Radar has made a major impact on the estimation of areal precipitation totals and intensities by detailing precipitation events at high resolution in space and time. However, the techniques for converting radar measurement to an estimate of areal precipitation are subject to uncertainties that might be particularly large in certain meteorological or topographical situations. Measurements from raingauges complement radar measurements and play a central role in providing precipitation data.

Many different types, shapes and sizes of raingauge are acceptable for the measurement of rainfall, each reflecting a specific requirement. Most consist of a circular collecting device, delineating the fixed area of the sample, and a funnel leading into a storage reservoir and/or measuring system. Some types of automatic gauge do not require a funnel.

Raingauge networks are of particular importance at a time of actual, or anticipated, change in rainfall patterns or characteristics. Identifying and quantifying any such changes is a strategic imperative with direct relevance across a broad range of applications. A national raingauge network providing data for a national archive is essential to meet these and other requirements. The national archive holds precipitation data collected by many different regional and local network operators, each of which may hold its own archive locally. The methods of implementing and operating such a system described in this British Standard ought to result in the generation and storage of precipitation data of known quality.

1 Scope

This part of BS 7843 gives guidance on the design, development and review of UK networks of collecting raingauges that meet user requirements in the most cost-effective way. It is applicable to raingauges deployed at ground level or close to the ground for the purpose of measuring precipitation in mm of water equivalent.

Remote sensing raingauges, devices that detect the presence of precipitation particles and weather radars are not covered by this standard.

This part does not give guidance on the installation or maintenance of individual collecting raingauges. Recommendations for these are given in BS 7843-2.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 7843-2:2012, *Acquisition and management of meteorological precipitation data from a raingauge network – Part 2: Code of practice for operating raingauges and managing precipitation data*

BS EN ISO 772:2001, *Hydrometric determinations – Vocabulary and symbols*

3 Terms and definitions

For the purposes of this part of BS 7843, the terms and definitions given in BS EN ISO 772:2001 and the following apply.

3.1 areal precipitation

value of precipitation within a specified time interval averaged over a specified area

3.2 calibration

process which establishes, under specified conditions, the relationship between the values indicated by a raingauge and the corresponding known values indicated by a measurement standard with associated measurement uncertainties

3.3 daily precipitation

total precipitation that accumulates over 24 h ending at 0900 UTC

NOTE Some newspapers and websites attribute the 24 h accumulation measured at 0900 UTC to the previous day.

3.4 data flag

indicator relating to the quality and characteristics of a precipitation value

3.5 exposure

extent of shelter or protection from the weather

3.6 inspection

review of the suitability and effectiveness of all aspects of the site, the equipment and the processes that impact on the quality of precipitation data from the site

3.7 maintenance

process that ensures that the site and equipment continue to function correctly for the measurement of precipitation

3.8 manual reading

measurement of precipitation made by an observer using a storage raingauge and a rain measure

3.9 monthly precipitation

total precipitation from 0900 UTC on the first day of the month to 0900 UTC on the first day of the following month

3.10 observer

person who takes manual readings

3.11 observing system

equipment and processes at the site employed for the measurement of precipitation and the logging and processing of precipitation data

3.12 operational (adj)

undertaken regularly, on a permanent basis and according to well-defined methods

3.13 operational performance monitoring

process for identifying possible problems or incidents with the production of precipitation data on short timescales

NOTE Generally less than 24 h.

3.14 precipitation

water or ice derived from the atmosphere and deposited at ground level

NOTE Measured in terms of the depth in mm of its liquid equivalent.

3.15 precipitation metadata

records relating to the site, the equipment and the operating practices that specify the circumstances under which precipitation measurements are made

3.16 production system

equipment and processes employed for the operational production of precipitation data

3.17 quality control

process for identifying measurements of precipitation which are erroneous to the extent that they lie outside the range of values that might be reasonably expected

NOTE The quality control process includes the provision of best estimates of the true values of erroneous data.

3.18 rainfall

total liquid component of precipitation, including condensation from the atmosphere, collected and measured by a raingauge

3.19 rain measure

graduated measuring cylinder made of clear glass or plastic used by the observer for measuring the volume of collected liquid and melted solid precipitation

3.20 raingauge

3.20.1 automatic raingauge

collecting raingauge that measures rainfall by automatic means

NOTE Also known as a recording raingauge. This may include data processing and logging capability.

3.20.2 collecting raingauge

instrument that collects precipitation falling through an orifice of known cross-sectional area for the measurement of its water equivalent volume, mass or weight accumulated over a measured period

3.20.3 storage raingauge

collecting raingauge that accumulates rainfall and melted solid precipitation in a collecting vessel for manual measurement of its volume

3.21 real-time data

data obtained while the precipitation event to which it relates is occurring

3.22 site

area of ground where a raingauge is deployed for measurement or has been deployed in the past

NOTE Other instruments for measuring the environment may also be deployed at the site.

3.23 UTC

Coordinated Universal Time

4 Data requirements

4.1 Application areas

4.1.1 General

Different organizations require precipitation data for varying applications, and these are described in **4.1.2** to **4.1.15**. The design, function, siting, etc., of a raingauge network depends upon these requirements.

NOTE A summary of typical user requirements is given in Annex A.

4.1.2 Flood forecasting and warnings

High temporal and spatial resolution rainfall data are required in real time for rainfall run-off models used for fluvial and pluvial flood warnings. Combined with radar rainfall data they are used for monitoring rainfall events to identify when predetermined thresholds have been exceeded. In non real time, rainfall data are required for developing run-off models and generating statistics that put forecasts into context (e.g. return periods).

4.1.3 Weather forecasting

High temporal and spatial resolution rainfall data are required in real time for numerical weather prediction models and general weather forecasting. Combined with radar rainfall data they are used for monitoring weather events and informing decisions on forecasts and warnings. In non real time, rainfall data are required for validating models and generating statistics that put forecasts or events into context.

4.1.4 Water resources operation

For river regulation and reservoir operations purposes rainfall data might be required in real time for inputs to rainfall run-off and reservoir flow routing models. These help to inform abstraction and compensation-flow decision making during drought and flood events. For groundwater and soil moisture models, daily rainfall data are normally sufficient.

4.1.5 Water resources planning

Resource planning decisions, often with the aid of simulation models, require daily, weekly or monthly interval data for both rainfall and aquifer recharge estimates held in long-term archives. Sometimes this involves simulating critical droughts with the use of low monthly rainfall and reservoir inflow time-series sequences combined with high soil moisture deficits.

4.1.6 General climatology

High spatial resolution rainfall data are needed to define the general climatology as part of the public weather service provided for the national benefit. The data are analysed to generate a wide range of products, including gridded averages, extremes and return periods.

NOTE The methodology used for creating gridded data is described in BS 7843-4.

4.1.7 Detecting climatic variability and change

Long-term trends and multi-decadal cycles in the patterns and intensity of rainfall are significant in relation to a wide range of user needs, and are of particular importance for the development of climate change adaptation strategies. The detection of changes in average and extreme rainfall patterns requires long historical records from a selection of sites where, over time, there have been few changes to the conditions under which the measurements have been made. The exceptionally demanding requirements for minimizing measurement uncertainty have led to the publication of WMO GCOS Climate Monitoring Principles 1-10 [1].

4.1.8 Flood risk management

Extreme storm and flood frequency analysis requires long-term statistical analysis of rainfall depth durations and their probability of occurrence expressed in terms of a return period.

Long-term records for both daily storage and recording raingauges are used:

a) to compile these statistics which are routinely used with incoming intensity data for estimating the return period of recent storm and flooding events; and

b) as the basis for producing design flood hydrographs in flood alleviation schemes generated from rainfall run-off models in combination with hydrodynamic flow routing models, or reservoir routing models for reservoir safety planning.

Intensity data are used in real time from radar and raingauge networks, often a combination of both, for input into rainfall and/or flood forecasting models, and when issuing flood warnings.

4.1.9 Environmental protection and improvement

Point rainfall intensities are required for urban drainage improvement design studies for reducing sewer flooding or pollution of watercourses or bathing beaches, e.g. from combined sewer overflow (CSO) spills. This normally requires data to be collected for short-term surveys of between 1 and 6 months for input into sewer drainage design models. Increasingly, intensity data are required in real time from both recording raingauges and radar for monitoring sewer and CSO performance, and for alerting sewer maintenance teams.

4.1.10 Ecosystem management

The use of rainfall data to estimate river flows and water storage is key to meeting the requirements of the European Water Framework Directive [2]. The Directive promotes ecological status as the fundamental environmental objective. This requires consideration of the quantity and dynamics of river flows that drive hydro-morphological processes and the creation of floodplain habitats. Flow data are also used by regulating bodies to license activities that have potential to degrade ecological status such as water abstraction, effluent discharge, river impoundment and engineering activities. Rainfall inputs are also used to understand site hydrology for effective wetland conservation and impact assessment. Typical applications include quantifying recharge sources (rainfall verses groundwater), site sensitivity and recovery times.

4.1.11 Waste water treatment

The performance of waste water treatment works can be impacted by high intensity precipitation. High temporal resolution rainfall data covering sub-catchments is required for real-time operational purposes.

4.1.12 Agriculture

Agricultural uses of rainfall data include drainage design, crop growth modelling, irrigation operations and the prediction of the spread of certain crop and animal diseases.

4.1.13 Commerce and industry

Rain and snow events can have a large impact on many areas of commerce and industry, e.g. disrupting transport or a construction programme, and can lead to costly insurance claims. Retail sales of some products are significantly correlated with rainfall. For many commercial companies point rainfall data are used in both the operations and planning sides of the business.

4.1.14 Radar adjustment

The UK radar product that provides values of precipitation intensity on grids of 1 km, 2 km and 5 km resolution is used for flood forecasting, weather forecasting and for many other applications. Radar measurements are subject to systematic bias which can be reduced by the use of raingauge data. Real-time precipitation data from sites in the vicinity of each radar are required for this purpose.

4.1.15 Research

A very wide range of precipitation data are required for research purposes. Where past data acquired for other applications do not meet a specific research requirement, a small dedicated network should be established, normally for a limited period, to generate the relevant data. Measurements of other environmental parameters might also be required.

4.2 Aspects of precipitation data requirements

Requirements for precipitation data should take into account both the liquid and solid phases, including the amount of rain in a stated period; the amount of solid precipitation in a stated period and the amount of accumulated solid precipitation lying on the ground at a stated time. An assessment of requirements should take into account a number of factors including the following.

a) *Spatial density*. Many different application areas have a requirement for precipitation data from a number of sites, which is usually best expressed in terms of the spatial density of raingauges. The required density could be greater in some areas than others.

b) *Specific locations*. For example, collocation with other environmental networks already in place.

c) *Time resolution*. High time resolution intensity data are required to capture the detail of extreme rainfall events.

d) *Length and continuity of record*. Some applications require long-term series of data where there is consistency of measurement over time. Other requirements can be met by a temporary monitoring programme.

e) *Uncertainty of measurement*. Upper bounds for uncertainty should differentiate between systematic and random errors. Where data are required to generate areal estimates, the degree to which measurements are representative of the local area should be taken into account.

NOTE See Annex B for further information on uncertainty.

f) *Timeliness*. Operational activities generally require data in real time, while planning and research activities often make use of data long after the event.

g) *Reliability and completeness of data record*. Gaps in the data record could be a serious problem for some applications.

h) *Instrument performance for frozen precipitation and in freezing conditions*.

i) *Quality control*. Timeliness and scope of the quality control process might be important.

j) *Precipitation metadata*. Current and historical metadata required to understand the characteristics of the precipitation measurements.

k) *Format and delivery*. Requirements for digitized historical data should be considered.

l) *Archiving and access to data*.

4.3 Statement of data requirements

An analysis of requirements for precipitation data should be undertaken at regular planned intervals. Representatives of data users from each relevant application area (see **4.1**) should be consulted for their assessment of the data requirements listed in **4.1** and **4.2**. Records of this statement of requirements should be maintained.

The statement of requirements should:

a) be technology-free wherever possible;

b) address present and future requirements;

c) identify whether requirements are for operational or long-term applications; and

d) give an indication of the value of the data and their dependence on the degree to which the requirements might be met.

For most applications, there is usually no abrupt transition in the utility of data as changes are made to meet specific requirements. For this reason it is helpful to express requirements for each application area at three different levels:

1) a minimum level that has to be met to ensure the data are useful;

2) a maximum level, beyond which further improvement in observing capability delivers little significant additional benefit; and

3) an optimum level, between the minimum and the maximum, which delivers the greatest benefit for a given cost.

5 Objectives of a precipitation data acquisition system

The requirements for precipitation data covering the applications outlined in **4.1** can be met by various networks of sites and systems for the processing and storage of data. For many applications the development and support of a national archive of precipitation data is an important objective. The national archive should:

a) include current and historical precipitation measurements from as many sites as possible;

b) provide a complete set of precipitation metadata;

c) provide assurance of the quality of the measurements, including data flags; and

d) provide ease of access to the data.

A procedure should be undertaken at regular intervals to determine which raingauges contribute to the national archive. Selection should be based on the suitability of the site and the quality of the precipitation data, taking into consideration inspectors' reports, quality control results and other relevant information.

6 Network design

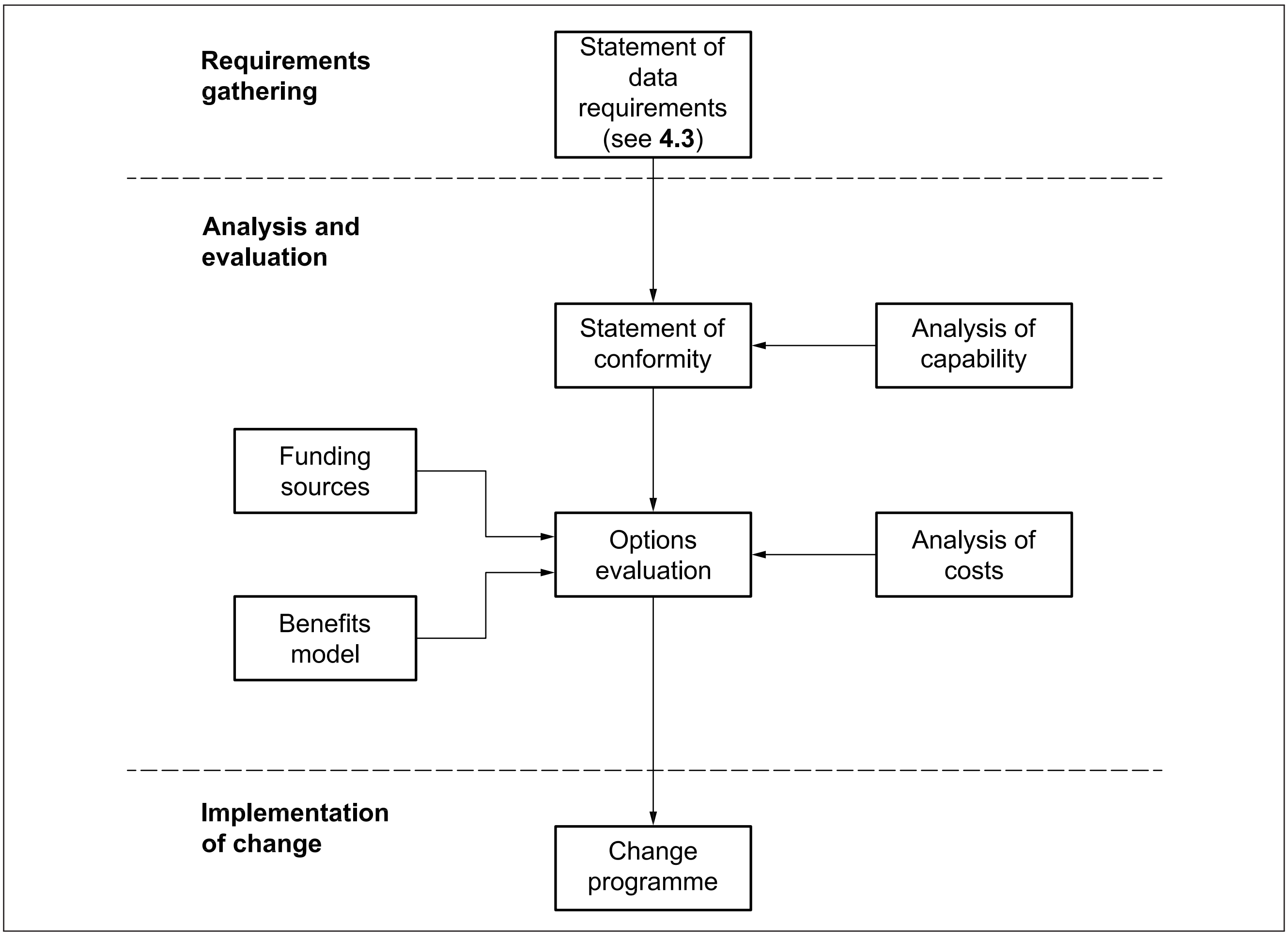
6.1 Change programme

Network design is a process that, taking as its input the statement of requirements for precipitation data, identifies a programme of change that meets the data requirements in the most cost-effective way. The stages of design are shown in Figure 1 which follows the procedure defined by WMO No. 544, Part II, Requirements for observational data [3]. For a country such as the UK with well-established raingauge networks that have evolved over a great many years, a change programme usually builds on existing infrastructure, but small networks may be created to fill significant gaps. Development of the capability of weather radars is out of scope of the change programme, but the ability of radar to meet many aspects of the user requirements should be taken into account at all stages of the network design process.

NOTE See Annex C for characteristics of precipitation estimates from radar.

Many applications require raingauge data to estimate areal accumulations on a local or a national scale. Guidance on raingauge densities that allow areal estimates to be calculated to a target accuracy are a valuable aid to network design. For the purpose of calculating areal estimates of precipitation (see BS 7843-4), measurements should capture geographical variability and be spatially and temporally representative of the actual precipitation over the extent of the network.

Figure 1 **A process for network design**



6.2 Analysis of capability

An analysis of the capability of the current precipitation networks should be undertaken to establish a baseline against which future changes should be assessed. The analysis should determine the degree to which the requirements in **4.2** are met. It should focus on existing raingauge networks while taking into account weather radars and other sources of precipitation data that might not be widely available. Accuracy of measurement may be assessed by reference to raingauge trials, quality control flags and inspectors' reports (see BS 7843-2:2012, **6.1** and **12.1**).

6.3 Statement of conformity

The statement of conformity is a direct comparison between the statement of requirements for each application area and the capability of the existing networks identified in **6.2**. It should identify:

a) gaps in the existing raingauge networks;

b) requirements for new networks;

c) sites not contributing significantly to the requirements; and

d) sites, equipment or practices that ought to be improved to ensure that precipitation data meet requirements.

6.4 Cost-benefit analysis

The costs of the raingauge network should be analysed to a level of detail sufficiently accurate to estimate the additional cost of changes to existing capability. Capital costs should be distinguished from operational running costs. Costs of all processes for the production and ownership of precipitation data should be analysed, including:

a) site ownership, including rent and power;

b) raingauges and other equipment;

c) installation;

d) maintenance, repair and inspection;

e) observers, if applicable;

f) network management;

g) telecommunications;

h) quality control and archiving; and

i) dissemination of quality controlled data.

A benefits model, or benefit scoring system, should be established to quantify the total benefit achieved by any incremental change to the end-to-end system for the production of precipitation data. Wherever possible, benefits should be quantified in monetary terms. A benefits model should take into account:

1) the potential value of each existing or proposed site in the network, taking into account its location and the availability of other data in the locality;

2) the actual performance of each existing site in the network;

3) a relative weight attributed to each of the stated requirements; and

4) a relative weight attributed to each application area.

The statement of conformity (see **6.3**) provides information on the degree to which benefits have been realized, or might be realized, after a change to the production system.

Network design aims to identify where changes could be made to the raingauge network and the end-to-end system for the production of precipitation data, which improve the way user requirements are met with the funding available. Possible options for change should be identified by considering all relevant factors, including:

i) shortcomings identified by the statement of conformity;

ii) changes driven by reduced sources of funding;

iii) cost saving that could be achieved by automation or changes in operational practices; and

iv) benefits achieved by collaboration.

A cost-benefit analysis should be undertaken of all realistic options by considering all relevant factors, including:

- the benefits of the option, monetary and otherwise, derived from the benefits model;
- the full lifetime cost of the option using data from the cost analysis and other sources where appropriate; and
- the funding available to implement the change and meet long-term operating costs.

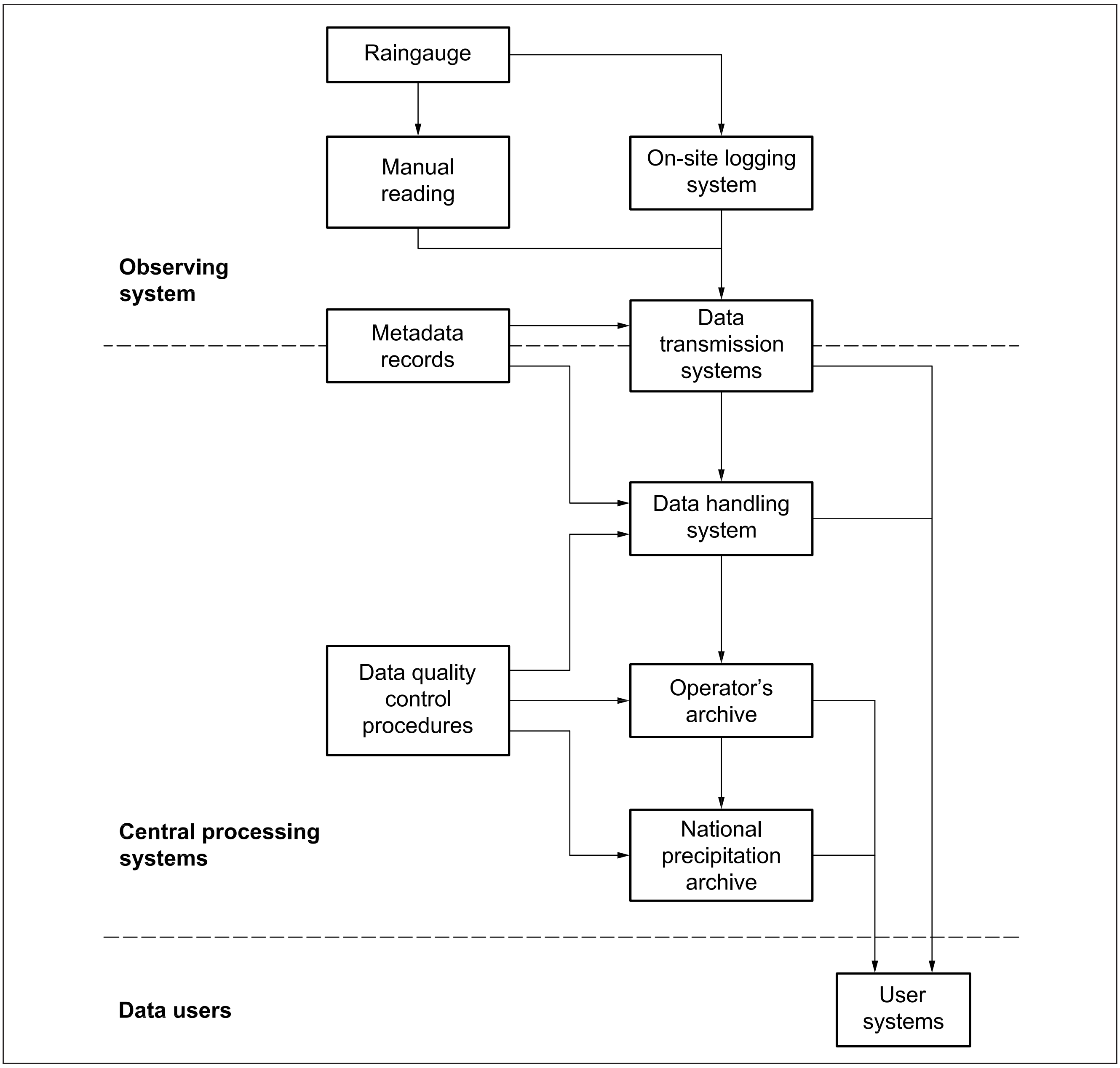
The most beneficial options, if any, should be selected for implementation.

7 Implementation of change

7.1 General

A schematic diagram showing all components of a typical production system for precipitation data is shown in Figure 2. Arrows indicate the flow of data. Change activity could apply to any aspect of the whole system.

Figure 1 **Typical production system showing flow of precipitation data**



7.2 Raingauge sites

Many requirements for precipitation data may be met by networks of raingauges of approximately uniform density, complemented by local networks of a higher density. Change programmes are often required to develop new networks, fill gaps in existing networks or to replace sites which are due to close. The design of a raingauge network is influenced by the availability and reliability of radar coverage. Radar provides spatial and temporal detail of precipitation events but estimates of intensity are often subject to large errors (see Annex C), while raingauges provide a calibrated point measurement at much coarser resolution. The two types of measurement complement each other, a factor that should be taken into account in network design.

The main issues to consider when selecting sites for raingauges are as follows.

a) The representativeness of the site

   The measurement of precipitation is highly dependent on the altitude of the site and the topography in the locality. Coastal and orographic effects are often large. Where the site is required for estimates of areal precipitation, it should be representative of the local area defined by the typical separation of precipitation sites within the network. In particular, the altitude should not be greatly different from the average for the local area. Urban environments pose severe problems for the accurate measurement of precipitation. Urban structures near the raingauge usually have a large unpredictable impact on the collection of precipitation by a raingauge and security considerations often greatly limit the choice of site.

b) The degree of shelter from the wind

   The largest errors in the measurement of precipitation are usually caused by wind in the immediate surroundings of the raingauge (see Annex B). BS 7843-2:2012, **4.2.2**, gives recommendations for wind-exposed raingauge sites.

c) The need to meet a specific user requirement

   Funding for precipitation measurements might be linked to sites chosen to meet the requirements of specific customers, often closely linked to areas of high population or specific river basins. Dense local networks provide an increased understanding of how local topography or the urban environment influences rainfall distribution, how the rainfall is translated into river or sewer flows or groundwater recharge, and how changing rainfall patterns could impact on society.

d) Collocation with other environmental measurements

   Precipitation measurements are related to other environmental parameters, such as river flow, air temperature and humidity. Collocation of measurements at one site is often desirable for reasons of operational efficiency and consistency of interpretation of the data.

e) The existence of a long historical record

   Where a contraction of an existing network of sites is sought, consideration should be given to maintaining measurement capability at sites with a long record of precipitation data. Such sites are required to put precipitation variability observed today into a historical context. In areas where there are few long period sites in operation, the reinstatement of closed sites with a long historical record should be considered.

f) The long-term viability of the site

As new sites can be very costly to establish, only sites which can be secured for long periods should be selected for gauges. Where a site is leased, long-term agreements with the owners should be established wherever possible.

g) The availability of power and telecommunications

If the raingauge requires mains power or connection to the telephone system, the distance from the nearest possible linkage points is an important factor in the final choice of site. The availability of other telemetry links such as Global System for Mobile Communications (GSM)/General Packet Radio Service (GPRS) or satellite communications could be affected by local conditions, e.g. the local topography, and the proximity of buildings, power lines or other interference sources. Low-power telemetry outstations may be installed, powered by battery trickle-charged, where necessary, by wind turbine or solar panel charging.

h) Security

The risk of animals or malicious persons breaking into the site should be assessed, together with the cost of security measures.

i) Availability of observers

Where a storage gauge is deployed, the availability of observers and the accessibility of the site are important considerations, particularly where daily manual readings are taken.

7.3 Field instrumentation

7.3.1 Raingauge

Manually-read storage raingauges can be used where there is a requirement for daily or longer period readings, but the full cost of the manual process should be considered. For sites requiring an intensity raingauge capable of resolving the temporal detail of rainfall events, the range of suitable instruments is wide (see BS 7843-3 for more information on raingauge design). The choice of raingauge should be based on the following.

a) Measurement uncertainty

The main sources of error in the raingauge measurement include wind, wetting, evaporation, and splash-in and out and problems in snow and freezing conditions. The uncertainty of measurements of precipitation has been established under various conditions by undertaking field trials. Results of national and international raingauge intercomparisons should be used to inform the choice of raingauge and calibration practice (see BS 7843-3 for descriptions of class A and class B automatic raingauges). It might be necessary for ground level or flush raingauges to be installed at some sites in order to minimize systematic errors of measurement. Even on sites with exposure conditions in accordance with those outlined in BS 7843-2:2012, **4.2**, the difference from ground level measurements can be of the order of 2% to 10%. See Annex B for discussion of measurement uncertainty.

b) Performance in freezing conditions

From consideration of the location and the altitude range of the area to be covered by the network, it is possible to determine whether specific provision needs to be made for snow measurement and the effects of prolonged sub-zero temperatures.

c) Expected precipitation rates and amounts

The raingauge should be designed to measure the maximum precipitation amounts or intensities likely to be experienced at the site.

d) Measurement resolution

A requirement to measure small amounts of precipitation will have a bearing on the choice of raingauge. For example, a tipping bucket raingauge having a bucket capacity of 0.2 mm will not be able to detect some light precipitation events.

e) Robustness

The type of raingauge chosen should be sufficiently robust to withstand the conditions under which it will be operating over a long period of time.

f) Compatibility with other raingauges

Wherever possible the type of raingauge should be harmonized across the network to give advantages in maintenance, training, data acquisition and processing. Problems of compatibility of precipitation measurements could arise where different raingauge types are used within a network or the same raingauge type is deployed in different ways.

g) Timeliness of data receipt

The ability to meet requirements for real-time precipitation data should be balanced against the cost of installing and operating the appropriate means of communication.

h) Non-standard raingauges

Informal measurements from raingauges not designed in accordance with BS 7843-3 and operated in accordance with BS 7843-2 may be used to supplement data from the formal network as long as the data quality flags clearly indicate that there could be high uncertainty in the quality of this data.

i) Availability of observers

Where a storage gauge is deployed, the availability of observers and the accessibility of the site are important considerations, particularly where daily manual readings are taken.

7.3.2 On-site logging system

Automatic raingauges require a means of processing and storing data before onward transmission, referred to as the on-site logging system. In some cases this may be integral to the raingauge; in others it may be a separate data logger or remote telemetry unit. It should have some or all of the following functionality.

a) Data processing and formatting.

b) Real-time quality control checks (see BS 7843-2:2012, Clause **12**).

c) Data storage for the maximum likely period between data retrievals from the site, taking into account possible data outages due to line failures.

d) Remote access facility for system interrogation by maintenance engineers.

7.4 Data transmission systems

The choice of the method of data transmission from the raingauge to the data handling system should be based on user requirements and the efficiency of data collection. For flood forecasting, weather forecasting or other applications where data are required in real time, electronic transmission is necessary. For applications where sub-daily values are required, but not in real time, the options are widened to include local data logging or manual collection.

a) Real time

A wide variety of electronic transmission methods are available. These include dedicated line links or via the public telephone network, the internet, mobile telephone technology, radio telemetry, either direct or via satellite, and meteor burst techniques. Factors affecting the choice of method include the need for one-way or two-way communication, compatibility with other existing or proposed transmission and data-handling systems, the type of terrain and the proximity of sites to existing communication links.

b) Data logging

Where there is no requirement for the data to be transmitted in real time, local data logging is an option. A wide variety of solid state logging systems are available, many of which can be preprogrammed to carry out some initial processing of the data prior to storage in memory for subsequent retrieval.

c) Manual readings

Manual readings may be recorded on cards for later transfer to electronic format (see BS 7843-2:2012, Annex A). Alternatively, direct entry of precipitation data via remote database interfaces might be preferable.

7.5 Data handling system

Data from all the sites of a rainfall network need to be delivered to a variety of destinations according to user requirements, which themselves could continually change. Control of this data flow is best achieved by a central data-handling system through which all data pass for onward transfer. The functionality of the system should include some or all of the following items.

a) Maintenance of up-to-date data transfer schedules.

b) Timely delivery of data according the schedules.

c) Operational performance monitoring of data delivery and system status indicators.

d) Automatic retrieval of non-transmitted data following line or system outages.

e) Data validation.

f) Data processing.

g) Data reformatting.

h) Backup systems with automatic cut-over to ensure end-to-end resilience.

7.6 Metadata, quality control and archiving

The utility of precipitation data is maximized through the use of effective data management practices and maintenance of accurate metadata. This is true for both real-time and historical data records. In designing a raingauge network, consideration should be given to how the data will be managed after capture from the raingauge to final storage in an archive or user system. Specific areas of consideration should include:

a) data storage and security;

b) data formats;

c) precipitation metadata standards;

d) quality control procedures;

e) long-term archival arrangements; and

f) access and ease of retrieval.

Quality control of the data should be performed in a way that does not bias the incidence of extreme events. Recommendations for the operational processes for data handling and archiving are given in BS 7843-2:2012, Clauses **9** to **14**.

7.7 Commissioning changes

All changes to the system for acquiring precipitation data should be thoroughly tested before data are released for use. Acceptance of a new or modified system should be dependent on passing agreed acceptance tests based on completeness, repeatability and accuracy of the data. Recommended commissioning procedures include:

a) testing of all new or replacement equipment prior to installation;

b) calibrating new or replacement raingauges under controlled conditions;

c) inspecting and testing all equipment on site after installation;

d) testing data transmission methods site by site;

e) testing changes to databases offline;

f) end-to-end testing of the whole production system; and

g) critical scrutiny of all data.

Consistency, reliability and accuracy tests indicate only that the network is performing as designed. They do not necessarily mean that the network design is meeting the users’ requirements.

8 Network monitoring and review

8.1 General

User requirements change over time and network performance should be monitored and reviewed at agreed intervals to assess effectiveness and efficiency as described in **6.2**. The process can be used to structure systematic monitoring and review of the acquisition and management system to inform users and management whether their requirements are being met as planned.

8.2 Continuous performance monitoring

Performance monitoring should be based on measures agreed with the data users. Performance measures should include:

a) data volume;

b) data completeness;

c) data accuracy;

d) data timeliness;

e) timeliness of the quality control process; and

f) network costs.

When developing measures of data accuracy, consideration should be given to the degree to which the observed data capture the true precipitation patterns over the network area. Measures could include checks of the onset time of precipitation at individual raingauges, volume distribution patterns across the network and areal precipitation estimates. Typical methodologies used in assessing network accuracy embrace the assessment of inter-raingauge relationships (e.g. double mass analysis), comparisons with other precipitation records (e.g. radar products), and analysis of the water balance of catchments using hydrometric data. The observed precipitation characteristics should be compared to the assumptions made during the network design phase regarding probable gradients relating to altitude, geographical location and exposure.

The results of operational monitoring should be considered alongside the established user requirements to establish the case for any modification of the system. Modification may involve changes to the network design (Clause **7**) and/or operational practices (see BS 7843-2:2012, Clause **14**).

8.3 Network review

At planned intervals, an analysis of precipitation data requirements should be undertaken in accordance with **4.2** and **4.3**. The relevance of the application areas should be reviewed and, where necessary, updated. The actual and potential suitability of the existing system for meeting the requirements should be reviewed and options for change costed and their benefits assessed (in accordance with Clauses **6** and **7**).

The value of a network is best indexed by the utility, and breadth of application, of the information it yields. During a review of the network, consideration should be given to both long-term requirements and operational applications outlined in **4.1** and precipitation data objectives in Clause **5**. The requirements of existing and potential future data users should be taken into account. Where appropriate this should include primary, local, data users and secondary, indirect, users which may access data through national or international archives. The following areas assume particular importance when reviewing an existing network.

a) Length of existing record.

b) Data quality (both precipitation records and metadata).

c) Time series homogeneity.

d) Site representativeness.

e) Integrated monitoring benefits (collocation with other environmental measurements).

f) Utility of the deliverables.

g) Data availability.

h) Operation and maintenance costs.

Annex A (informative) Summary of typical user requirements for precipitation data

Table A.1 **Summary of typical user requirements for precipitation data** *(1 of 2)*

Application area	Spatial resolution	Temporal resolution	Timeliness	Comments
Flood forecasting and warnings	High	SH	RT	Use in rainfall run-off models. Alarm state raised if intensity criteria exceeded. Used in various other operational activities.
Flood forecasting and warnings	High	SH	STQ	Development of rainfall run-off models
Weather forecasting	High	H	RT	Required as input for numerical weather prediction models
Weather forecasting	High	H	STQ	Development and validation of numerical weather prediction models
Weather forecasting	Medium	H	RT	Used to inform decisions on issue of heavy rainfall warnings
Water resources operation	Medium	D	NRT	Include input for rainfall run-off, soil, groundwater and reservoir flow routing models. Inform decisions on river regulation and reservoir operations.
Water resources planning	High	D	STQ	Daily, monthly annual data for planning and investigations. Long period records used for design.
General climatology	High	D	STQ	Long period daily, monthly and annual periods to create gridded data and site statistics. Quality control ought not to bias frequency of extreme events.
Detecting climate variability and change	Medium	D	STQ	Long period homogeneous data records. Low uncertainty of measurement essential.
Flood risk management	High	SH	STQ	Long period records to estimate frequency and return periods. Quality control ought not to bias frequency of extreme events.
Environmental protection and improvement	High	SH	NRT	Compliance assessment for river and bathing water, including wet weather waivers. Warning of intermittent discharges from CSOs into watercourses or bathing waters
Environmental protection and improvement	SS	SH	STQ	Sites in urban locations and very short period accumulations for sewer design studies. Investigation of pollution incidents.
Ecosystem management	High	D	STQ	Short and long period records for non urban design studies. Decisions on licences for ecologically sensitive activities.
Waste water treatment	High	SH	RT	For management of water treatment activities.

Table A.1 **Summary of typical user requirements for precipitation data** *(2 of 2)*

Agriculture	SS	D	RT	Inform local decisions
Commerce and industry	SS	H/D	NRT	Site locations biased towards urban areas
Radar adjustment	Medium	H	RT	Sites representative of area around each radar
Research	High	SH/H/D	STQ	Many unrelated applications.

Key

High	5 km – 20 km spacing
Medium	20 km – 50 km spacing
SS	site specific
SH	sub-hourly (e.g. tip times, 1 min or 10 min)
H	hourly
D	daily
RT	real time (less than 1 h after end of measurement period)
NRT	near real time (less than 1 day after end of measurement period)
STQ	slow time quality controlled (more than 1 day after end of measurement period with quality control flags and estimates for erroneous or missing data)

Annex B (informative) Analysis of the uncertainty of precipitation measurement

B.1 Treatment of uncertainty

Imperfections in the measurements of precipitation give rise to errors which are defined as differences between the true values and the measured values. Errors are viewed as having two components: a systematic component and a random component. The value of the error for any measurement cannot be determined as the true value is unknown; rather its uncertainty is expressed in terms of estimates of the mean (*m*) and standard deviation(*s*) of all the errors that might be made:

$$m = \sum_{n}^{1} \frac{x_i}{n}$$

$$s = \sqrt{\sum_{1}^{n} \frac{1}{n-1}(x_i - m)^2}$$

where:

x_i is the value of each error;

n is the number of measurements in the sample.

The standard deviation *s* is referred to as the experimental standard deviation and is a measure of the uncertainty associated with random errors. Its square s^2 is an unbiased estimate of the population variance. The mean *m* is an unbiased estimate of the population mean, or, equivalently, the systematic error. Systematic errors can be eliminated by applying a correction of opposite sign to each measured value.

Following WMO No. 8 [4] the general equation for corrected precipitation accumulations takes the form:

$$P_k = kP_c = k\left(P_g + \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4\right)$$

where:

k the correction factor to account for the wind field deformation (collection efficiency);

P_c the amount of precipitation caught by the raingauge;

P_g the measured amount of precipitation in the raingauge; and

ΔP_{1-4} the corrections for wetting, evaporation, splashing of rain and blowing of snow.

For rainfall intensity raingauges the correction factor k may be intensity dependent. Each of these components of the systematic error are discussed in **B.2.1**.

B.2 Systematic instrument errors

B.2.1 Raingauge collection efficiency

The largest source of error in the measurement of precipitation often arises from the effects of wind around the orifice of the raingauge. Eddies in the vicinity of the raingauge counteract the effects of falling precipitation particles leading to a systematic underestimation of precipitation amount. This systematic error depends on wind speed and precipitation particle size: the greater the wind speed and the smaller the precipitation particles, the greater the degree of underestimation (see also **B.2.5**). Where the raingauge is well sheltered by shrubs, trees or buildings in its immediate vicinity, the wind speed at the height of the orifice will be substantially reduced, accompanied by a reduction in the systematic error by the similar proportion. Because vertical motion in the atmosphere falls to zero at ground level, a raingauge deployed in a pit with its orifice level with the ground is widely used for reference measurements. Differences between measurements made in a pit and those made by a similar instrument deployed above the ground are assumed to provide reliable estimates of the systematic error in the raingauge collection. The construction of such a reference raingauge pit is specified in BS EN 13798. Few measurements have been made routinely in the UK using reference pits, but turf walls (see BS 7843-2:2012, **4.2.3**) are deployed widely at windy sites. The design of a turf wall reduces, but does not exclude, eddies around the raingauge.

The most comprehensive trial of the effects of wind on the collection efficiency of raingauges is described by Sevruk and Hamon (1984) [5]. Differences between national raingauges, deployed according to national practices and reference pit measurements were made at over 50 locations worldwide. The results show a mean underestimation of precipitation amount of 3% with considerable range from 0% to 20%. Much of the variability might be attributed to difference in raingauge design and more especially to differences in windiness and drop size distribution at each of the sites. Unfortunately, there was no contribution to this trial from the UK, but results from other trials undertaken in the UK have been published elsewhere. Essery and Wilcock (1991) [6] report a trial conducted at an exposed site in Northern Ireland over a 12-year period, which shows that the Met Office Mk 2 raingauge deployed on open ground systematically underestimates precipitation by 2% relative to a raingauge in a turf wall, and by 5% relative to a ground level raingauge in a pit. Other trials with the Mk 2 raingauge deployed on open ground report systematic errors relative to ground level measurements of 3% (Green, 1970 [7]) and 7% (Rodda and Smith, 1986 [8]).

B.2.2 Raingauge wetting

The wetting loss depends on the amount of exposed surface of the raingauge relative to its collecting area and the adhesion characteristics of the surface material. Generally, older instruments lose their polished surfaces and suffer greater wetting loss. Sevruk (1990) [9] reports typical upper bound on wetting loss of 0.2 mm per rainfall event with a further upper bound of 0.1 mm on the wetting loss of any measuring container. Static calibrations of the buckets of tipping bucket raingauges are normally undertaken in their wet state, reducing the possibility of any further systematic errors.

B.2.3 Evaporation

The enclosed design of raingauges used in the UK reduces the loss of collected precipitation by evaporation. Losses are higher in summer when temperatures are higher but, even so, they are unlikely to exceed 0.05 mm.

B.2.4 Splash-in and out

Many of the raingauges used in the UK are designed and deployed in such a way as to minimize any error due to splash-in and out of rain. Where the orifice height is at least 300 mm above ground level and the surrounding surface is short-cropped grass, amounts of rain splashing in are very small. The design of a raingauge collector that minimizes splash-out is described in WMO No. 8, part 6 [4]. It has a deep vertical wall leading to a funnel with a sufficiently steep slope.

B.2.5 Snow and freezing conditions

The collection efficiency of a raingauge is far less for light snow flakes than for rain droplets, resulting in larger systematic errors than those described in **B.2.1**. Losses of up to 50% have been attributed to the deformation of the wind field around the rim of the raingauge in snow conditions. Wind shields that minimize the effects of the wind-field are particularly effective in snow, but they are not used widely in the UK. Even allowing for lower collection efficiency, few sites in the UK are capable of accurate measurement of frozen precipitation and this needs to be borne in mind when analysing precipitation data. Where storage raingauges are in use, the manual measurement of the water equivalent of snow that has fallen (see BS 7843-2:2012, **8.3**) requires time and patience, not always applied by the time-pressured observer. Most automatic raingauges used in the UK are of the tipping bucket type, designed to measure the mass of collected liquid precipitation. With few exceptions, the raingauges are unheated allowing falling snow to build up on the funnel, overtopping the raingauge in heavy falls and windy conditions. Snow that has accumulated in the funnel only melts when the ambient temperature rises above freezing, perhaps hours or days after the precipitation has ceased.

NOTE A more detailed discussion of the measurement of snow and its uncertainty may be found in WMO-No. 749, part II [10].

B.2.6 Heavy rain

The WMO field intercomparison of 25 different designs of rainfall intensity raingauges (Vuerich et al., 2009 [11]) quantified systematic and random errors in measurements at various rainfall intensities. Systematic errors from weighing raingauges were generally within a 5% tolerance limit, while some tipping bucket raingauges subjected to Class B calibration (see BS 7843-3) showed under-recording of between 5% and15% at high rainfall intensities (typically greater than 50 mm/h). The reason for the poor performance of the tipping bucket lies in its relatively slow response in heavy rain events when the bucket overfills before tipping and emptying. Dynamic calibrations for Class A tipping bucket raingauges (see BS 7843-3) under laboratory conditions using a constant flow pump can establish the magnitude of the under recording at various precipitation intensities.

B.3 Random instrument errors

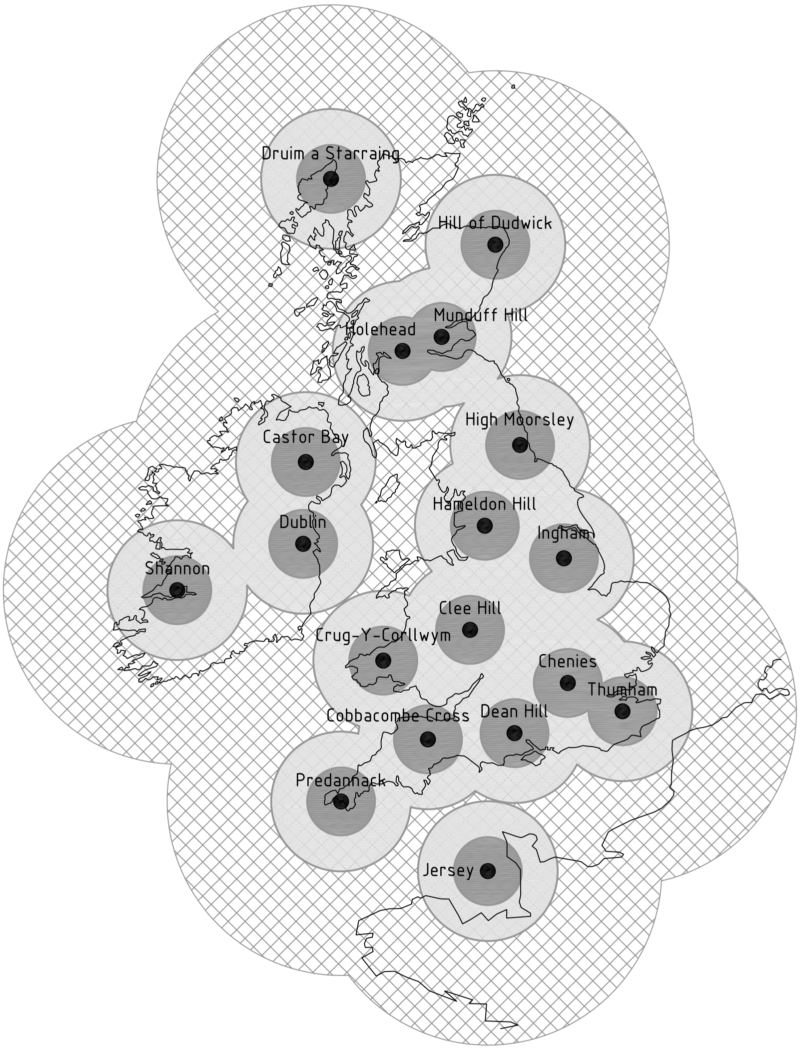
Sources of systematic error in the precipitation measurement described in **B.2**. may be removed by applying corrections based on intercomparison data. The corrected measurement is nevertheless subject to random error caused by any number of effects that were particular to the occasion. The experimental standard deviation of monthly precipitation was recorded for all national sites participating in the trial reported by Sevruk and Hamon [5]. Values were found to lie between 1 mm and 5 mm for a large majority of sites (mean 3.5 mm). The magnitude of the random errors reported by Essery and Wilcock [6] lay in the same range.

Annex C (informative) Characteristics of precipitation estimates from radar

C.1 The radar measurement

The network of C-band (25 mm wavelength) weather radars, currently operated by the Met Office and the meteorological services of Ireland and Jersey, is shown in Figure C.1. Each radar emits pulses of microwave radiation and detects the return signals reflected by particles of precipitation, whether liquid or frozen. The strength of the return signal may be used to estimate precipitation intensity and its delay is a measure of distance from the radar site. The pulses are concentrated in a narrow beam (typically 1°) which scans through a full 360° at a number of low elevation angles (typically between 0.5° and 4° above the horizon). A scanning cycle takes 5 min providing measurements of reflectivity for each elevation at 1° azimuth resolution and in 600 m bands (referred to here as gates) extending out to 255 km from the radar. As the beam spreads out the size of the sampling volume increases. At a distance of 50 km from the radar the sampling volume is about 1 000 m × 600 m increasing to an elongated 5 000 m × 600 m at the full 255 km range. The nominal resolution of the radar measurement is therefore 1 km at distances up to 50 km from the radar, 2 km at distances up to 100 km and 5 km at the full 255 km range. The areas covered by each radar at the three different nominal resolutions are shown in three different shades in Figure C.1.

Figure C.1 **The radar network in 2010 giving coverage over the UK, Ireland and Jersey**



Key

▩ 1 km resolution

☐ 2 km resolution

▨ 5 km resolution

C.2 Methods of processing the raw data

C.2.1 General

Raw reflectivity data from the UK network of weather radars passes through a series of quality control, correction and conversion steps described in **C.2.2** to **C.2.11**, to generate quantitative estimates of the precipitation rate at the ground on a uniform grid.

NOTE 1 These precipitation estimates are based, not only on the measurements of radar reflectivity, but also on data from operational forecast models, satellites, surface weather reports and, indeed, raingauge measurements.

NOTE 2 The methods described here are only applied to data from the UK radar network. Other countries that operate radar networks apply different processing methods to generate estimates of precipitation.

C.2.2 Noise filtering

A tuneable threshold (defined in terms of a gradient and offset) is used to identify pixels which fall below the likely level of signal noise.

C.2.3 Clutter identification

Clutter is the unchanging signal caused by obstacles close to the radar, such as trees, buildings, etc. An approach, based largely on the pulse-to-pulse signal variability, is used to distinguish between clutter and precipitation.

C.2.4 Residual spurious echo identification

Infrared and visible channel data from the Meteosat weather satellite are used to diagnose the probability of precipitation (PoP). Echoes with an associated PoP lower than a specified threshold are identified as spurious.

C.2.5 Occultation identification

The difference in frequency of detection (FoD) for gates along a ray from a sector average FoD is used to identify individual rays or sectors which appear to be occluded by obstacles in the line of sight. Additionally, a definition of the radar horizon elevation is used to determine and compensate for the extent of any partial beam blocking.

C.2.6 Attenuation correction

Attenuation of the radar beam by air and cloud is small compared with the attenuation by rain drops. To correct for the impact of intervening rain, a cumulative gate-by-gate algorithm equivalent to $A = 0.0044R^{1.17}$ (where A is the attenuation in dB and R is the precipitation rate in mmh^{-1}) is applied to reflectivity data, with $Z = 200R^{1.6}$ used to convert between reflectivity and rain rate. This is capped at a maximum of a factor of two increase in rain rate to avoid instability.

C.2.7 Vertical variations of reflectivity

A physically-based correction scheme, in which an idealized vertical profile of reflectivity is diagnosed at each radar pixel, is used to account for variations in the vertical profile of reflectivity. The idealized profile incorporates simple parameterizations of the bright band (see **C.4.2** for explanation of this term) and orographic growth of precipitation over hills. Operational forecast models are used to define values for the wind, humidity and freezing level, while cloud top height is determined from satellite data.

C.2.8 Conversion of reflectivity to precipitation rate

The estimate of surface reflectivity (Z) is converted to precipitation rate (R) using the relationship, $Z = 200R^{1.6}$.

C.2.9 Antenna pointing

A correction to the azimuth offset is applied using the sun as a known target.

C.2.10 Raingauge based mean field bias adjustment

Systematic errors in the data from each radar are corrected by applying an adjustment factor based on recent hourly raingauge measurements. This adjustment factor is applied to the entire domain of a single radar and is updated hourly. The number of raingauges used varies between 8 and 40, depending on the radar site, and the time window can vary from the last hour to several days, depending on recent weather conditions.

C.2.11 Generation of the network composite

Having undertaken processing steps in **C.2.2** to **C.2.10** for each of the radars, the data from the available radars are combined to produce network composite products. The weather radar network over the UK is sufficiently dense to provide significant overlap in the coverages provided by the radars. This provides resilience in the event that data from any one radar are unavailable. It also provides an opportunity to generate a composite that optimizes the estimate of precipitation at any given point on a Cartesian grid at 1 km, 2 km and 5 km resolution.

The UK composite quantitative estimate of precipitation is derived by selecting data from the radar with the lowest usable scan. Usable in this context refers to data that have not been identified as suspect as a result of the processing steps outlined above. The composite products are produced on the Cartesian grid. The conversion from the polar to the Cartesian grid is performed as part of the compositing process. The method used weights the contribution from each polar cell or bin by a function that has a Gaussian dependence on its distance from the Cartesian pixel centre.

C.3 Sources of error arising from the radar and radar site

C.3.1 Radar site, ground clutter and occultation

Ideally, the radar is sited on a tower that provides an unobstructed beam path in all azimuth directions over distant hills and, more locally, over trees, buildings and other obstacles. Greater errors in the estimates of precipitation occur where this is not achieved. Most strong persistent echoes from nearby targets, referred to as ground clutter, are removed during processing, but in some cases screening is effective enough to cause occultation of the whole beam in a ray or sector extending beyond the obstacle. Beams at higher elevations may be used to clear the top of hills, but the greater beam height will lead to larger errors of the type described in **C.4.3**.

C.3.2 Radome attenuation

The radar antenna is usually protected by a radome which attenuates the beam by an amount that increases when it is wet or covered by snow.

C.3.3 Radar hardware

Modern radar transmitters are usually able to maintain a stable output, but receivers are likely to be less stable. Regular maintenance of radar hardware is essential for reliable performance.

C.3.4 Spurious echoes

Radar beams are refracted on passing through air of varying density. Under certain atmospheric conditions (e.g. anticyclonic conditions where strong temperature and water vapour gradients are found at an inversion capping the boundary layer) anomalous refraction of the radar beam (referred to as anaprop) will result in strong echoes returned from the ground or sea surface. These are usually easily identified but there are some cases when it is difficult to distinguish between the precipitation and non-precipitation echoes.

Other spurious echoes commonly encountered include those from aircraft, ships at sea and flocks of birds.

C.3.5 Sampling and averaging

Random noise in the return signal caused by inhomogeneities in the atmosphere along the beam path is reduced by averaging a number of measurements. The sampling and averaging methods might also mask real short period detail in the precipitation rate.

C.4 Sources of error arising from meteorological causes

C.4.1 Variability of precipitation particle size distribution

Different meteorological processes give rise to precipitation particles of widely varying sizes; convective rain is usually associated with the largest raindrop sizes, while warm, shallow cloud might often produce small drizzle droplets. Because the reflectivity (*Z*) varies as the sixth power of the particle diameter, the relationship between *Z* and the precipitation rate (*R*) is strongly dependent on the precipitation particle size distribution. Various published studies show quite different *Z*-*R* relationships for drizzle, stratiform rain, thunderstorms and snowflakes. Uncertainty in the *Z*-*R* relationship used in the data processing step (**C.2.7**) will lead to uncertainties in the estimates of surface precipitation rates. Small drizzle droplets are often undetected except close to the radar.

C.4.2 Variability of reflectivity in the vertical

Some of the greatest errors in precipitation estimates arise from the large variability of reflectivity (*Z*) within a rain producing cloud. Moving downwards from the cloud top, *Z* increases steadily through the snow and ice crystal layer until the freezing level is reached. Here, melting snow particles appear as giant raindrops to the radar beam, causing a sharp spike in the *Z* profile known as the bright band. Values of *Z* are lower again in the rain that falls from the freezing level to the ground. In convective cloud a quite different profile of *Z* with height is observed. The level at which the radar beam intersects the rain cloud depends on its distance of the radar from the cloud; at large distances the radar will be measuring the reflectivity of snow particles near the cloud top, while at closer distances measurements are likely to be in the bright band or in the rain below the freezing level. The method described in **C.2.6** is an attempt to model the cloud physics to account for these effects, but there are many uncertainties associated with the assumptions made, particularly with respect to the bright band.

C.4.3 Effects on precipitation below the beam

Even at their lowest elevation of 0.5° above the horizon, the curvature of the earth causes the radar beams from the UK network to be at least 1 km above the ground in the majority of locations and to reach 4 km to 5 km above the ground towards the limits of the radar range. At greater distances the beam might pass over the top of some precipitating clouds and it is possible for large areas of rain to be missed altogether. Other undetected processes occurring below the radar beam include the evaporation of falling precipitation particles and low-level orographic enhancement of rainfall over hills. Smaller, but nevertheless significant errors might be caused by wind drift: the advection of precipitation particles by the wind from the position where they meet the radar beam to the point where they fall on the ground.

C.5 Radar/raingauge comparisons

Comparisons of raingauge measurements with collocated precipitation estimates from radar have been made for many years, the results reflecting long-term trends influenced by changes to the radar network and data processing methods. Figure C.2 shows values of the root-mean-square factor (RMSF), defined as:

$$RMSF = exp\sqrt{\frac{1}{N}\sum_{1}^{N}\left(\ln\frac{R_i}{G_i}\right)^2}$$

for R_i and $G_i \geq T$ where:

N is the number of events;

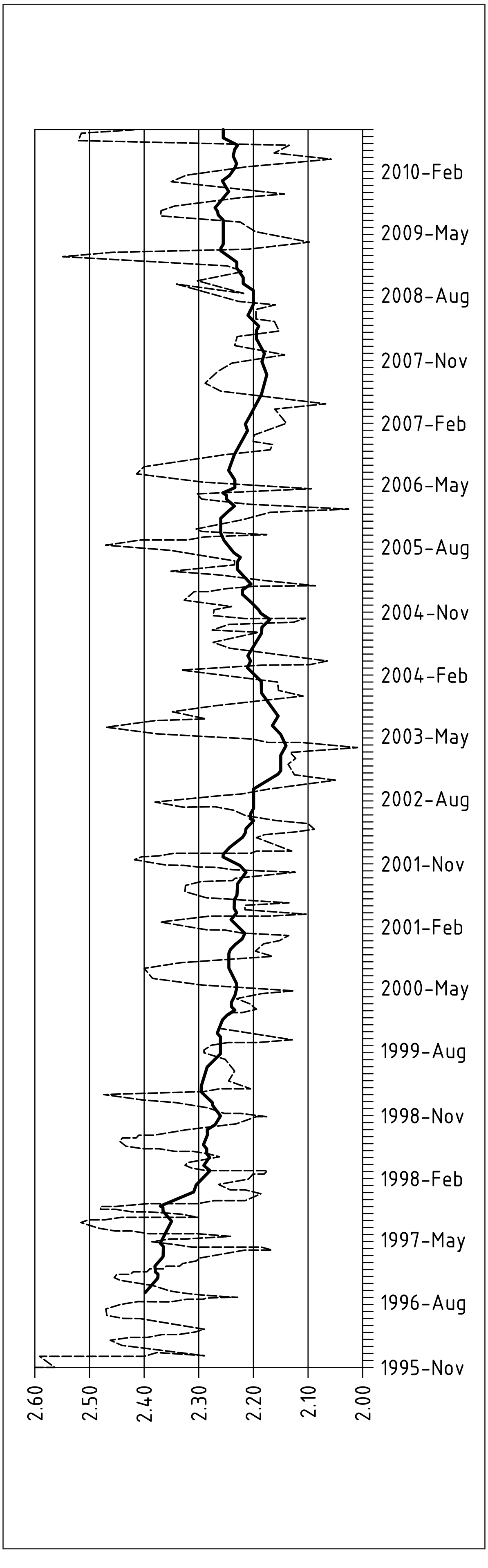
G is the raingauge measurement of hourly accumulation;

R is the collocated radar estimate; and

T is a selected threshold value.

This commonly-used measure for comparing rainfall values is favoured because it shows no strong dependence on precipitation rate. Typically, there is a factor of 2 (or 0.5) between the radar and raingauge measurements.

Figure C.2 **15 year time series of RMSF with a 0.2 mm hr^{-1} threshold**



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