

**Technical Assistance  
(Implementation Support) and  
Management Consultancy**

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# **Groundwater Handbook: Groundwater Level**

May 2014

## Groundwater Handbook: Groundwater Level

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## Glossary

ADCP	Acoustic Doppler Current Profiler
ARG	Autographic Rain Gauge
AWS	Automatic Weather Station
BBMB	Bhakra-Beas Management Board
CGWB	Central Ground Water Board
CPCB	Central Pollution Control Board
CGWB	Central Water Commission
CWPRS	Central Water and Power Research Station
Div	Division
DPC	Data Processing Centre
DSC	Data Storage Centre
DWLR	Digital Water Level Recorder
e-GEMS	Web-based Groundwater Estimation and Management System (HPII)
eHYMOS	Web-based Hydrological Modelling System (HPII)
eSWDES	Web-based Surface water Data Entry System in e-SWIS (HPII)
e-SWIS	Web-based Surface water Information System (HPII)
FCS	Full Climate Station
GEMS	Groundwater Estimation and Management System (HPI)
GW	Groundwater
GWDES	Ground Water Data Entry System (HPI)
GWIS	Groundwater Information System (GPI)
HDUG	Hydrological Data User Group
HIS	Hydrological Information System
HP	Hydrology project (HPI Phase I, HPII Phase II)
HYMOS	Hydrological Modelling System (HPI)
IMD	India Meteorological Department
Lab	Laboratory
MoWR	Ministry of Water Resources
NIH	National Institute of Hydrology
SRG	Standard Rain Gauge
Stat	Station
Sub-Div	Sub-Division
SW	Surface water
SWDES	Surface water Data Entry System (HPI)
TBR	Tipping Bucket Raingauge
ToR	Terms of Reference
WISDOM	Water Information System Data Online Management (HPI)
WQ	Water Quality



# 1. Introduction

This Hydrology Project Phase II (HP II) Handbook provides guidance for the management of groundwater data. The data are managed within a Hydrological Information System (HIS) that provides information on the spatial and temporal characteristics of the quantity and quality of surface water and groundwater. The information is tuned to the requirements of the policy makers, designers and researchers to provide evidence to inform decisions on long-term planning, design and management of water resources and water use systems, and for related research activities. The Indian States and Central Agencies participating in the Hydrology Project are listed in Annex I. However, this Handbook is also relevant to non-HP States.

It is important to recognise that there are two separate issues involved in managing groundwater information. The first issue covers the general principles of understanding monitoring networks, of collecting, validating and archiving data, and of analysing, disseminating and publishing data. The second covers how to actually do these activities using the database systems and software available. Whilst these two issues are undeniably linked, it is the first – the general principles of data management - that is the primary concern. This is because improved data management practices will serve to raise the profile of Central/State hydrometric agencies in government and in the user community, highlight the importance of groundwater data for the design of water-related schemes and for water resource planning and management, and motivate staff, both those collecting the data and those in data centres.

This Handbook aims to help HIS users locate and understand documents relevant to groundwater in the library available through the Manuals page on the Hydrology Project website. The Handbook is a companion to the HIS Manuals. The Handbook makes reference to the six stages in the hydrometric information lifecycle (Figure 1.1), in which the different processes of data sensing, manipulation and use are stages in the development and flow of information. The cycle and associated HIS protocols are explored more fully in Section 2. Subsequent sections cover different stages of the cycle for different groundwater variables.

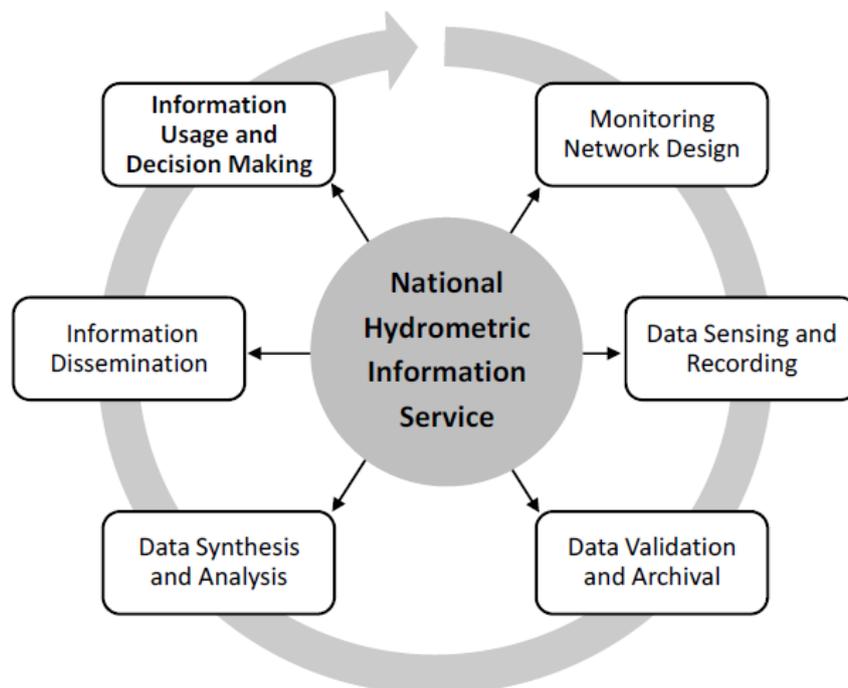


Figure 1.1 Hydrometric information lifecycle (after: Marsh, 2002)

## 1.1 HIS Manual

The primary reference source is the HIS Manual Groundwater (GW), one of many hundreds of documents generated during Hydrology Project Phase I (HPI) to assist staff working in observation networks, laboratories, data processing centres and data communication systems to collect, store, process and disseminate hydrometric data and related information. During HPI, special attention was paid to the standardisation of procedures for the observation of variables and the validation of information, so that it was of acceptable quality and compatible between different agencies and States, and to facilities for the proper storage, archival and dissemination of data for the system, so that it was sustainable in the long-term. Therefore, the majority of the documents produced under HPI, particularly those relating to fundamental principles, remain valid through and beyond HPII. Some parts of the guides, manuals and training material relating to HPI software systems (SWDES, HYMOS, WISDOM, GWDES, GEMS, GWIS) have been partially or wholly superseded as replacement Phase II systems (e-GEMS, e-SWIS) become active.

The HIS Manual GW describes the procedures to be used to arrive at a sound operation of the HIS in regard to groundwater quantity data. The HIS Manual GW consists of 10 volumes. Each volume contains one or more of the following manuals, depending on the topic:

- Design Manual (DM) - procedures for the design activities to be carried out for the implementation and further development of the HIS.
- Field Manual (FM) or Operation Manual (OM) – detailed instructions describing the activities to be carried out in the field (station operation, maintenance and calibration), at the laboratory (analysis), and at the Data Processing Centres (data entry, validation, processing, dissemination, etc). Each Field/Operation Manual is divided into a number of parts, where each part describes a distinct activity at a particular field station, laboratory or data processing centre.
- Reference Manual (RM) - additional or background information on topics dealt with or deliberately omitted in the Design, Field and Operation Manuals.

Those HIS Manual GW volumes relevant to groundwater level are:

**GW Volume 1: Hydrological Information System:** a general introduction to the HIS, its structure, HIS job descriptions, Hydrological Data User Group (HDUG) organisation and user data needs assessment.

- Design Manual
- Field Manual
  - Part II: Terms of Reference for HDUG
  - Part III: Data needs assessment

**GW Volume 2: Sampling Principles:** units, principles of sampling in time and space and sampling error theory.

- Design Manual

**GW Volume 4: Geo-Hydrology:** network design, implementation, operation and maintenance.

- Design Manual
- Field Manual
  - Part I: Network design and site selection
  - Part II: Drilling of litho-specific piezometers
  - Part III: Aquifer tests
  - Part IV: Testing and implementation of DWLR
  - Part V: Reduced levels of wells

- Part VI: Manual water level data collection from observation wells and piezometers
- Part VII: Digital water level data collection from piezometers
- Part VIII: Monitoring wells – inspection and maintenance
- Reference Manual

**GW Volume 5: Creation of GIS datasets:** a somewhat out-of-date introduction to the use of GIS for processing spatial data.

- Operation Manual

**GW Volume 8: Data processing and analysis:** specification of procedures for Data Processing Centres (DPCs).

- Operation Manual
  - Part I: Data collection, data entry and data validation – water level data
  - Part III: Data processing and analysis
  - Part IV: Groundwater resource assessment
  - Part V: Groundwater Year Book

**GW Volume 10: HIS activities – Groundwater domain:** outline of protocols for data collection, entry, validation and processing, communication, inter-agency validation, data storage and dissemination, HIS training and management.

- Operation Manual

In this Handbook, individual parts of the HIS Manual SW are referred to according to the nomenclature “GWvolume-manual(part)” e.g. Volume 4: “Geo-Hydrology” Field Manual Part IV: “Testing and implementation of DWLR” is referred to as GW4-FM(IV), and Volume 8: “Data processing and analysis” Operation Manual Part I: “Data collection, data entry and data validation” is referred to as GW8-OM(I).

A hard copy of the relevant manuals should be available for the locations listed in Annex II. For example, a hard copy of SW4-FM(IV) should be available at all piezometers where water level is measured with a DWLR. Similarly, SW8-OM(I) should be available at all Data Processing Centres where data entry and validation take place.

## 1.2 Other HPI documentation

Other HPI documents of relevance to groundwater include:

- The e-GEMS software manual, and the GWDES and GEMS software manuals - although GWDES and GEMS are being superseded by e-GEMS in HP11, to promote continuity, e-GEMS contains GWDES and GEMS functionality.
- “Groundwater O&M norms” – a maintenance guide for hydrogeology, hydro-meteorology and water quality instrumentation and equipment.
- “Groundwater Yearbook” – a template for a Groundwater Yearbook published at State level.
- Groundwater training modules – these relate primarily to DWLR groundwater data handling (see Table 1.1). Their contents have been largely incorporated into this Handbook as the underlying principles remain valid.

*Table 1.1 HPI groundwater training modules*

<b>Topic</b>	<b>Module</b>	<b>Title</b>
DWLR groundwater	01	Understanding Conventional and DWLR Assisted Water Level Monitoring
	01	Role of DWLR Data in Groundwater Resource Estimation
	03	Other Applications of DWLR Data
	04	How to Identify the Cycles using Harmonic Analysis
	05	Understanding the Concept of Optimal Monitoring Frequency of DWLR

## 2. The Data Management Lifecycle in HP II

Agencies and staff with responsibilities for hydrometric data have a pivotal role in the development of groundwater quantity information, through interacting with data providers, analysts and policy makers, both to maximise the utility of the datasets and to act as key feedback loops between data users and those responsible for data collection. It is important that these agencies and staff understand the key stages in the hydrometric information lifecycle (Figure 1.1), from monitoring network design and data measurement, to information dissemination and reporting. These later stages of information use also provide continuous feedback influencing the overall design and structure of the hydrometric system. While hydrometric systems may vary from country to country with respect to organisation set-ups, observation methods, data management and data dissemination policies, there are also many parallels in all stages of the cycle.

### 2.1 Use of hydrogeological information in policy and decision-making

The objectives of water resource development and management in India, based on the National Water Policy and Central/State strategic plans, are: to protect human life and economic functions against flooding; to maintain ecologically-sound water systems; and to support water use functions (e.g. drinking water supply, energy production, fisheries, industrial water supply, irrigation, navigation, recreation, etc). These objectives are linked to the types of data that are needed from the HIS. GW1-DM Chapter 3.3 presents a table showing HIS data requirements for different use functions on page 17. In turn, these use functions lead to policy and decision-making uses of HIS data, such as: water policy, river basin planning, water allocation, conservation, demand management, water pricing, legislation and enforcement.

Hence, freshwater management and policy decisions across almost every sector of social, economic and environmental development are driven by the analysis of hydrometric information. Its wide-ranging utility, coupled with escalating analytical capabilities and information dissemination methods, have seen a rapid growth in the demand for hydrometric data and information over the first decades of the 21st century. Central/State hydrometric agencies and international data sharing initiatives are central to providing access to coherent, high quality hydrometric information to a wide and growing community of data users. Hydrological data users may include water managers or policymakers in Central/State government offices and departments, staff and students in academic and research institutes, NGOs and private sector organisations, and hydrology professionals. An essential feature of the HIS is that its output is demand-driven, that is, its output responds to the hydrological data needs of users.

GW1-FM(III) presents a questionnaire for use when carrying out a data needs assessment to gather information on the profile of data users, their current and proposed use of surface water, groundwater, hydro-meteorology and water quality data, their current data availability and requirements, and their future data requirements. Data users can, through Central/State hydrometric agencies, play a key role in improving hydrometric data, providing feedback highlighting important issues in relation to records, helping establish network requirements and adding to a centralised knowledge base regarding national data. By embracing this feedback from the end-user community, the overall information delivery of a system can be improved.

A key activity within HP II was a move towards greater use of the HIS data assembled under HPI. Two examples of the use of HIS data include the Purpose-Driven Studies (PDS) and the Decision Support Systems (DSS) components of HP II. See the Hydrology Project website for more information about DSS and PDS, and access to PDS reports.

The 38 PDS, which were designed, prepared and implemented by each of the Central/State

hydrometric agencies, are small applied research projects to investigate and address a wide range of real-world problems and cover surface water, groundwater, hydro-meteorology and water quality topics. Some examples of projects include urban groundwater hydrology and groundwater quality in and around Bangalore city in Karnataka (PDS number GW-KN-1), and an evaluation of downstream consequences of well pumping on the Verna Plateau and working out a water resource management strategy in Goa (PDS number GW-Goa-1). The PDS utilise hydrometric data and products developed under HPI, supplemented with new data collected during HPII.

Two separate DSS programmes were set up under HPII. One, for all participating implementing agencies, called DSS Planning (DSS-P), has established water resource allocation models for each State to assist them to manage their surface and groundwater resources more effectively. The other, called DSS Real-Time (DSS-RT) was specifically for the Bhakra-Beas Management Board (BBMB), although a similar DSS-RT study has also now been initiated on the Bhima River in Maharashtra. The DSS programmes have been able to utilise hydrological data assembled under the Hydrology Project to guide operational decisions for water resource management.

## **2.2 Hydrogeological monitoring network design and development**

Section 3.2 of this Handbook outlines the design and development of groundwater monitoring networks. Networks are planned, established, upgraded and evolved to meet a range of needs of data users and objectives, most commonly water resources assessment and hydrological hazard mitigation (e.g. flood forecasting). It is important to ensure that the hydro-meteorological, surface water, groundwater and water quality monitoring networks of different agencies are integrated as far as possible to avoid unnecessary duplication. In particular, a raingauge network should have sufficient spatial coverage that all groundwater monitoring stations are adequately covered. Integration of networks implies that networks are complimentary and that regular exchange of data takes place to produce high quality validated datasets. Responsibility for maintenance of Central/State hydrometric networks is frequently devolved to a regional (Divisional) or sub-regional (Sub-Divisional) level.

## **2.3 Data sensing and recording**

Sections 3.1 to 3.4 of this Handbook review groundwater monitoring stations and piezometers, maintenance requirements and measurement techniques. Responsibility for operation of Central/State groundwater monitoring stations is frequently devolved to a regional (Divisional) or sub-regional (Sub-Divisional) level. However, it is important that regular liaison is maintained between sub-regions and the Central/State agencies through a combination of field site visits, written guidance, collaborative projects and reporting, in order to ensure consistency in data collection and initial data processing methods across different sub-regions, maintain strong working relationships, provide feedback and influence day-to-day working practice. Hence, the Central/State agencies are constantly required to maintain a balance of knowledge between a broad-scale overview and regional/sub-region hydrogeological awareness. Operational procedures should be developed in line with appropriate national and international (e.g. Indian, ISO, WMO) standards (e.g. WMO Report 168 "Guide to Hydrological Practices").

For the Hydrology Project, field data from observational stations are required to be received at Sub-Divisional office level and entered onto the database by 7 days after return from the field (GW10-OM HIS activities – Groundwater domain).

## 2.4 Data validation and archival storage

The quality control and long-term archiving of groundwater quantity data represent a central function of Central/State hydrometric agencies. This should take a user-focused approach to improving the information content of datasets, placing strong emphasis on maximising the final utility of data e.g. through efforts to improve completeness and fitness-for-purpose of Centrally/State archived data. Section 3.5 of this Handbook summarises the stages in the processing of hydrometric data. Section 4 of this Handbook covers the process from data entry through primary and secondary validation, to analysis of groundwater level data (Section 2.5).

During all levels of validation, staff should be able to consult station metadata records detailing the history of the site and its hydrometric performance, along with hydrogeological and climate maps and previous quality control logs. Numerical and visual tools available at different phases of the data validation process, such as versatile groundwater level plotting and manipulation software to enable comparisons between different near-neighbour or analogue observation wells and assessment of time series statistics greatly facilitate validation. High-level appraisal by Central/State staff, examining the data in a broader spatial context, can provide significant benefits to final information products. It also enables evaluation of the performance of sub-regional data providers, individual stations or groups of stations, which can focus attention on underperforming sub-regions and encourage improvements in data quality.

A standardised data assessment and improvement procedure safeguards against reduced quality, unvalidated and/or unapproved data reaching the final data archive from where they can be disseminated. However, Marsh (2002) warns of the danger of data quality appraisal systems that operate too mechanistically, concentrating on the separate indices of data quality rather than the overall information delivery function.

For the Hydrology Project, the timetable for data processing is set out in GW10-OM HIS activities – Groundwater domain, and summarised in Table 2.1 of this Handbook. Data entry and primary validation of field data from observational stations is required to be completed at Sub-Divisional/Divisional office level by 7 days after return from the field, and 7 days after data entry, respectively, ready for secondary validation by State offices. Secondary validation should be completed within one month (initial) and four months (intermediate) of data collection, in State DPCs for State data, and CGWB local offices for CGWB data. Some secondary validation will not be possible until the end of the hydrological year when the entire year's data can be reviewed in a long-term context, and compared with CGWB data, so data should be regarded as provisional approved data until then (e.g. for June data by the end of the hydrological year plus 3 months), after which data should be formally approved and made available for dissemination to external users. At certain times of year (e.g. during the monsoon season), the data processing plan outlined above may need to be compressed, so that validated hydrometric data are available sooner.

## 2.5 Data synthesis and analysis

Central/State hydrometric agencies play a key role in the delivery of large-scale assessments of groundwater quantity data and other hydrological data. Through their long-term situation monitoring, they are often well placed to conduct or inform scientific analysis at a State, National or International level, and act as a source of advice on data use and guidance on interpretation of groundwater flow patterns. This is especially true in the active monitoring of the State or National situation or the assessment of conditions at times of extreme events (e.g. monsoonal rains, droughts) where agencies may be asked to provide input to scientific reports and research, as well as informing policy decisions, media briefings, and increasing public understanding of the state of the water environment. Section 4 of this Handbook covers analysis of groundwater level data, as well as the process from data entry through primary and secondary validation (Section 2.4).

**Table 2.1 Groundwater data processing timetable for data for month n**

<b>Activity</b>	<b>Responsibility</b>	<b>Deadline</b>
<b>Groundwater level data</b>		
Data receipt	Sub-Divisional office	7 days after return from field
Data entry	Sub-Divisional/Divisional office	7 days after return from field
Primary validation	Sub-Divisional/Divisional office	7 days after data entry
Secondary validation	State DPC	Initial – within 1 month of data collection
	State DPC	Intermediate – within 4 months of data collection
	State DPC	Final – end of hydrological year + 3 months
Analysis	State DPC	As required
Reporting	State DPC	At least annually
<b>Rainfall data</b>		
Data receipt	Sub-Divisional office	5 <sup>th</sup> working day of month n+1
Data entry	Sub-Divisional/Divisional office	10 <sup>th</sup> working day of month n+1
Primary validation	Sub-Divisional/Divisional office	10 <sup>th</sup> working day of month n+1
Secondary validation	State DPC	Initial - end of month n+1
	State DPC	Final – end of hydrological year + 3 months
Correction and completion	State DPC	Initial - end of month n+1
	State DPC	Final – end of hydrological year + 3 months
Compilation	State DPC	As required
Analysis	State DPC	As required
Reporting	State DPC	At least annually
<b>Data requests</b>	State DPC	95% - within 5 working days 5% - within 20 working days
<b>Interagency validation</b>	CGWB	At least 20% of State stations, on rolling programme, by end of hydrological year + 6 months

## 2.6 Data dissemination and publication

One of the primary functions of Central/State hydrometric agencies is to provide comprehensive access to information at a scale and resolution appropriate for a wide range of end-users. However, improved access to data should be balanced with a promotion of responsible data use by also maintaining end-user access to important contextual information. Thus, the dissemination of user guidance information, such as composite summaries that draw users' attention to key information and record caveats (e.g. monitoring limitations, high levels of uncertainty regarding specific flood event accuracy, major changes in hydrometric setup), is a key stewardship role for Central/State hydrometric agencies, as described in Section 6 of this Handbook.

For large parts of the 20th century the primary data dissemination route for hydrometric data was via annual hardcopy publications of data tables i.e. yearbooks. However, the last decade or so has seen a shift towards more dynamic web-based data dissemination to meet the requirement for shorter lag-time between observation and data publication and ease of data re-use. Like many countries, India now uses an online web-portal as a key dissemination route for hydrometric data and associated metadata which provides users with dynamic access to a wide range of information to allow selection of stations. At least 95% of data requests from users should be processed within 5 working days. More complex data requests should be processed within 20 working days.

## 2.7 Real-time data

During HPII many implementing agencies developed low cost real-time data acquisition systems, feeding into bespoke databases and available on agency websites. Such systems often utilise short time interval recording of data e.g. 5 minutes, 15 minutes, etc. As groundwater levels change relatively slowly, there is not an immediately obvious need for fast transmission of data to a Central/State agency. In some instances, agencies are taking advantage of the telemetry aspect of real-time systems as a cost-effective way of acquiring data from remote locations. However, for some operational purposes (e.g. real-time drought monitoring, seasonal planning of groundwater use, etc), real-time data is extremely valuable.

Real-time data should go through some automated, relatively simple data validation process before being input to real-time models e.g. checking that each incoming data value is within pre-set limits for the station, and that the change from preceding values is not too large. Where data fall outside of these limits, they should generally still be stored, but flagged as suspect, and a warning message displayed to the model operators. Where suspect data have been identified, a number of options are available to any real-time forecasting or decision support model being run, and the choice will depend upon the modelling requirements. Whilst suspect data could be accepted and the model run as normal, it is more common to treat suspect data as missing or to substitute them with some form of back-up, interpolated or extrapolated data. This is necessary for hydrometric agencies to undertake some of their day-to-day functions and, in such circumstances, all the data should be thoroughly validated as soon as possible, according to the same processing timetable and protocols as other groundwater data.

Real-time data should also be regularly transferred to the e-GEMS database system, through appropriate interfaces, in order to ensure that all hydrogeological data are stored in a single location and provide additional back-up for the real-time data, but also to provide access to the data validation tools available through e-GEMS.

### 3. Groundwater Monitoring Stations and Data

#### 3.1 Types of groundwater quantity monitoring station

Table 3.1 lists the relevant section in the HIS Manual GW for detailed information, with respect to groundwater level data, on design and installation, maintenance, measurement, data entry, primary and secondary validation, analysis of data, and reporting. References for rainfall data, important for estimating rainfall recharge, are also included, many of which (particularly those relating to processing and analysis of rainfall data) are in SW8-OM. See the Precipitation and Climate Handbook for more information about rainfall data management.

Groundwater wells types include the following:

- **Open dug wells** - constructed to tap mostly unconfined aquifers, in use for domestic or irrigation water supply. The term includes large diameter irrigation wells and collector wells.
- **Tubewells** - drilled in unconsolidated formations and having a well assembly for the entire depth and a screen at the end, usually fitted with a hand pump or power-driven pump for use for domestic or irrigation water supply.
- **Boreholes** - drilled in consolidated formations and having casing pipe only against collapsible formations with no well assembly, usually fitted with a hand pump or power-driven pump for use for domestic or irrigation water supply.
- **Piezometers** - purpose-built, small diameter wells for water level recording and water quality monitoring, although water levels and water samples can also be taken from the above well types. In unconsolidated formations, piezometers are provided with screens tapping the zone of interest whilst, in consolidated formations, they are left open ended (uncased). Water levels in piezometers are measured and recorded:
  - Manually using a calibrated steel tape or electrical dip tape
  - Automatically using a **DWLR** (Digital Water Level Recorder) containing a pressure transducer. The pressure at the sensor is directly proportional to the height of the water column above the sensor and atmospheric pressure. The sensor needs to be compensated for the atmospheric pressure when measurements are made. Vented DWLRs, most common in India, make a direct comparison between the water pressure and air pressure via a narrow air tube. Unvented transducers make measurements only of water pressure, and compensation for air pressure is calculated after data are collected using a separate barometer recording of air pressure.

All groundwater level monitoring programs depend on the design of the piezometer network. Ideally, the piezometers need to provide data representative of the different geology, lithology and groundwater development environments. The network density is determined by the monitoring objectives, the complexity of the aquifer system, and the magnitude and frequency of variations in groundwater level and piezometric head. In general, monitoring of a local unconfined aquifer will need a relatively dense network of piezometers, whilst for a deeper confined aquifer a less dense network will be required. The spatial distribution and depth of piezometers depend on the aquifer system and general groundwater flow, the lithology of the aquifer, and additional information on precipitation, surface water systems, and anthropogenic factors (e.g. abstractions, irrigation, etc). Water level monitoring in complex geological and lithological environments may require measurements of water levels in multiple piezometers (nested) constructed at different depths tapping different aquifer units representing different geological and lithological units.

*Table 3.1 Where to go in the HIS Manuals GW and SW for groundwater data management guidance: groundwater level and rainfall*

<b>Instrument / Variable</b>	<b>Design &amp; Installation</b>	<b>Maintenance</b>	<b>Measurement</b>	<b>Data entry</b>	<b>Primary Validation</b>	<b>Secondary Validation</b>	<b>Correction &amp; Completion</b>	<b>Compilation</b>	<b>Analysis</b>	<b>Reporting</b>
<b>DWLR</b>	GW4-DM 8.1 GW4-FM(II) GW4-FM(III) GW4-FM(IV) GW4-FM(V)	GW4-FM(VIII) GW10-OM	GW4-DM 5, 6 GW4-FM(VI) GW4-FM(VII)	GW8-OM(I) 3.1-3.2, 4.1- 4.2	GW8-OM(I) 4.3	GW8-OM(I) 4.4			GW8-OM(III) 3, 4 GW8-OM(IV) GW8-RM 1	GW8-OM(V)
<b>Rainfall</b> (see Precipitation and Climate Handbook)	GW3-DM 6.2.1-6.2.3, 8.2.2-8.2.4	GW3-FM(II) 1.3 GW3-FM(III) 2.3, 3.3 GW3-FM(V) 2.2, 3.2-3.4	GW3-FM(II) 1.2 GW3-FM(III) 2.2.2, 2.3.2	SW8-OM(I) 4.4-4.7	SW8-OM(I) 5	SW8-OM(II) 2	SW8-OM(II) 3	SW8-OM(II) 4	SW8-OM(III) 4	SW8-OM(III) 9

A set of specifications for groundwater equipment was compiled under HPI and updated under HPII. As such, the DWLR specification in GW4-RM has been superseded; however, GW4-RM also includes useful bid evaluation guidance and an acceptance protocol for DWLRs, and GW4-FM(IV) describes the DWLR commissioning procedure which should be used in conjunction with the specific installation instructions for the procured DWLR. The specifications, which are downloadable from the Hydrology Project website, provide a guideline for procurement (with examples of some procurement templates and documents also on the Hydrology Project website).

### 3.2 Groundwater monitoring networks

A groundwater monitoring network is a system of dedicated observation wells in a hydrogeological unit in which groundwater levels, and water quality, are measured at a pre-determined frequency. Groundwater monitoring networks may be required for assessment of groundwater resources, or for monitoring of saline water intrusion, of groundwater levels in irrigated areas, of groundwater levels in drought-prone areas, or monitoring artificial recharge. Whatever the purpose, monitoring networks should be considered to be dynamic entities and it is important that the current utility of well-established monitoring networks is periodically assessed to ensure that they continue to meet changing requirements and to optimise the information they deliver. Network reviews should be done in collaboration with other agencies. Improving the density of networks and upgrading of networks are continuous activities, replacing non-performing open wells with dedicated piezometers as well as constructing deep piezometers to cover aquifers that have not been previously monitored.

GW4-FM(I) describes the different types of groundwater monitoring networks and the design of networks for monitoring groundwater levels in aquifers. This is a multi-step process comprising:

1. Identification of hydrogeological data users and their data needs to understand what data are required and at what frequency. This informs the purposes and objectives of the network in order to fulfill the hydrogeological data need, and evaluation of the consequences of not meeting those targets, to inform a prioritisation of objectives in case of budget constraints. Purposes may include: monitoring the water levels and water quality of independent aquifers; understanding the relationship between different aquifers; understanding the hydraulic characteristics of different aquifers; evaluating groundwater regime characteristics; understanding the regional flow characteristics; and estimating groundwater resources availability.
2. Inventory of available information to understand the geological formations in the area and their hydraulic characteristics, the recharge and discharge mechanism which governs groundwater flow, and the factors that might influence natural groundwater flow. Geological and hydrogeological maps, lithological cross sections, structural maps, geomorphological maps, drilling data and geophysical survey reports are useful in this respect.
3. Evaluation and optimisation of the existing network to assess how well it meets the purposes and objectives, as well as the adequacy of existing equipment and operational procedures, and possible improvements to existing network. This step also includes identification of gaps (need for new stations) and over-design (redundancy) in the existing network e.g. locations where the States and CGWB, or two States, have wells very close together. GW4-FM(I) Chapter 1.5 presents some techniques to guide users through this step. These may involve the development of regionalisation and network optimisation techniques (e.g. Institute of Hydrology, 1999; Hannaford *et al.*, 2013).
4. Estimation of overall costs of installing, operating and maintaining the network, once the preliminary design or evaluation of the network has been completed. This step also includes evaluation of the network in relation to purposes and objectives, ideal network, available

budgets and overall benefits to assess sustainability which is of paramount importance. Achieving an optimum network design may involve an iterative process, repeating steps 4 and 5, until a satisfactory outcome is reached.

5. Preparation of phased implementation plan for optimum network that is prioritised, realistic and achievable in the time scales allowed.
6. Selection of appropriate sites for piezometers and site surveys. GW4-FM(I) devotes Chapter 1.8 to this topic, and GW4-FM(I) Annex 1 provides a useful checklist of all the factors that should be taken into consideration in selecting a piezometer to ensure long-term reliable data. A site survey comprises four phases: a desk study, a reconnaissance survey, a field survey and a data interpretation phase. The site survey, which should be carried out in collaboration with CGWB, may reveal that the desired location is unsuitable, and an alternative site or flow measurement technique may need to be considered.

The selected piezometer site should show no influence from any external sources (e.g. canal, tank, perennial river, irrigation return flows, etc), except in the cases that the piezometer is for studying the impact of these parameters on the groundwater system. The site should not fall within the radius of influence of a well, which is under pumping; but it should be capable of recording the effects of the pumping as a regional phenomenon. Ideally, the water quality at the site should not be influenced by local recharge/pollutant sources. There are also site-specific logistic considerations, including ownership, access, space, and security. Piezometers that represent different lithologies are called lithology-specific piezometers (also known as lithospecific piezometers).

7. Establishment of a framework for regular periodic maintenance to ensure optimum performance of the piezometers.
8. Establishment of a framework for regular network reviews (e.g. after 3 years or sooner if new data needs develop) i.e. starting this process again from step 1.

Once sites have been selected, piezometer construction should follow standard procedures with the incorporation of site-specific elements. Steps in the construction of piezometers are outlined in GW4-FM(II), including site preparation, drilling and completion. Normally pumping tests are carried out soon after completion to estimate aquifer parameters such as transmissivity, storage coefficient and leakage factor. Aquifer pumping tests are described in GW4-FM(III), which provides a aquifer test data sheet in Annex 1. After completion, the height of the measuring point above ground level, used for all water level measurements, must be levelled in, connected to mean sea level (MSL), as described in GW8-FM(IV). The measuring point is usually the top of the casing for tubewells or boreholes, and the top of the cement/stone lining for open wells.

### 3.3 Site inspections, audits and maintenance

The optimum performance of groundwater monitoring networks should be ensured through well-defined operation and maintenance practices, supported with adequate budgets and trained manpower. Regular maintenance of equipment, together with periodic inspections and audits, ensures collection of good quality data and provides information that may assist in future data validation queries. Table 3.1 lists the relevant section in the HIS Manual GW for maintenance of groundwater monitoring stations. Information is summarised in the document "Groundwater O&M norms" which is a maintenance guide for hydrogeology, hydro-meteorology and water quality instrumentation and equipment.

A supply of appropriate spare parts should be kept on site and/or taken on station visits in case they are needed (see checklist in GW4-FM(VIII) Chapter 4.2.5). Whilst inspections will be carried

out every day that somebody is on site, piezometers and both manual measuring equipment (e.g. tapes) and DWLRs should be inspected and certified annually, and before the onset of the monsoon. Activities may include: checking the performance of and motivating the field staff; identifying existing or potential problems with the site, instruments, equipment and observation procedures at an early stage so they can be rectified; and undertaking independent measurement checks. GW4-FM(VIII), which provides a comprehensive guide for regular inspection and maintenance of groundwater monitoring stations and instruments, includes an annual operation and maintenance inspection report form on pages 11-12, as well as details of follow-up field investigations should any issues be identified. Any maintenance requirements and recommendations should be implemented before the onset of the monsoon.

### 3.4 Data sensing and recording

Table 3.1 lists the relevant section in the HIS Manual GW for operational instructions on the measurement of groundwater level in observation wells. Water levels in piezometers are measured and recorded:

- Manually using a calibrated steel tape or electrical dip tape
- Automatically using a **DWLR** (Digital Water Level Recorder) containing a pressure transducer

Measurements are made relative to a fixed reference point above ground level - usually the top of the casing for tubewells or boreholes, and the top of the cement/stone lining for open wells – which is levelled in, connected to mean sea level (MSL).

The measuring frequency depends on diurnal variations, short recharge and discharge events, seasonal variations (i.e. in wet and dry periods), and variations caused by anthropogenic factors. The groundwater level data should fully characterise the hydrogeological behaviour of the aquifer, and discriminate between short-term and seasonal groundwater fluctuations and long-term hydrogeological changes. Depending on the purpose of the network, it may be important to use groundwater level data to identify:

- Peaks and troughs of the groundwater levels
- Time of shallow groundwater level i.e. time during which the water level rises above a specified threshold level
- Time of deep groundwater level i.e. time during which the water level falls below a specified threshold level
- Rate of rise or decline in groundwater levels
- Response time of groundwater levels after a rainfall event

Under the Hydrology Project, all piezometers, including observation wells without DWLR, should be monitored for a minimum of four times a year. All observation wells with DWLR should have a minimum of 6-hourly monitoring in normal areas, and hourly monitoring in critical areas, with monthly downloading frequency.

Increasingly, DWLRs are generating high frequency groundwater level data which are more suited to many analytical techniques, and can produce more rational and credible results, as described in Groundwater Training Module 01 “Understanding conventional and DWLR assisted water level monitoring” (Section 4.4). High frequency DWLR data have a particularly important role to play in groundwater resource estimation by improving understanding of the rainfall recharge process (Section 4.4.5), and by permitting a more realistic groundwater balance and more accurate assessment of recharge (Section 4.4.6). Other uses include conjunctive use planning, identification of over-exploited areas, scheduling of pumping, calibration of aquifer response models and identification of cycles (Section 4.4.7). For more information, see Groundwater Training Module 03 “Other application of DWLR data”. Strategies for arriving at the optimal

monitoring frequency are presented in Groundwater Training Module 05 “Understanding the concept of optimal monitoring frequency of DWLR”.

Another issue in groundwater monitoring is the length of data collection. Only short-term data may be required for some types of groundwater investigations e.g. tests to determine the hydraulic properties of wells or aquifers. Long-term data are fundamental to the resolution of many of the most complex problems dealing with groundwater availability and sustainability, and significant periods of time from years to decades are typically required to collect data needed to assess the effects of climate variability, to monitor the effects of regional aquifer development, or to obtain data sufficient for analysis of water-level trends. Many of the applications of long-term groundwater level data involve the use of analytical and numerical (computer) groundwater models, where the water level measurements serve as primary data for calibration and testing. The enhanced understanding of the groundwater systems and data limitations identified by model calibration provides insights into the most critical needs for collection of future groundwater level data.

When making groundwater level measurements, the observer should always note any occurrences which may influence the groundwater level as observed by the instruments. These may include: damage to the equipment for a specified reason. The observer should also note any maintenance activities carried out at the monitoring site (e.g. change batteries, clean sensor, etc).

The observer should double-check that any manual reading is taken correctly, and transcribed correctly (e.g. decimal point in right place). If the reading is later transferred to another document (e.g. hand copied or typed in, or abstracted from a chart), the observer should always check that this has been done correctly. An experienced and suitably qualified observer should compare measurements with equivalent ones from earlier that day or from the day before, if available, as an additional form of checking. However, the observer should not, under any circumstances, retrospectively alter earlier readings or adjust current readings, but should simply add an appropriate comment.

Data collected in the field are delivered to a Data Processing Centre (DPC) on a variety of media, including handwritten forms and notebooks, and digital data.

### 3.5 Data processing

The processing of groundwater level data starts with preliminary checking in the field, as described in Section 3.4 of this Handbook, through receipt of raw field data at a DPC, through successively higher levels of validation in State and Central DPCs, before data are fully validated and approved in the National database. Validation ensures that the data stored are as complete and of the highest quality as possible by: identifying errors and sources of errors to mitigate them occurring again, correcting errors where possible, and assessing the reliability of data. It is important for staff to be aware of the different errors that may occur as described in GW4-MM Chapter 6.3.

Data validation is split into two principal stages: primary and secondary, with an optional tertiary stage. Validation is very much a two-way process, where each step feeds back to the previous step any comments or queries relating to the data provided. The data processing steps comprise:

1. Receipt of data according to prescribed target dates. Rapid and reliable transfer of data is essential, using the optimal method based on factors such as volume, frequency, speed of transfer/transmission and cost. Maintenance of a strict time schedule is important because it gives timely feedback to monitoring sites, it encourages regular exchanges between field staff, Sub-Divisional offices, State and Central agencies, it creates continuity of processing activities at different offices, and it ensures timely availability of final (approved) data for use in policy and decision-making.

2. Entry of data to computer, using the e-GEMS, is primarily done at a Sub-Divisional office level where staff are in close contact to field staff who have made the observations and/or collected the digital data. Historical data, previously only available in hardcopy form, may also be entered this way. Each Central/State agency should have a programme of historical data entry.
3. Primary data validation which should be carried out in State DPCs for State data and CGWB local offices for CGWB data, as soon as possible after the observations are made or data downloaded from loggers, using e-GEMS. This ensures that any obvious problems (e.g. indicating an instrument malfunction, observer error, etc) are spotted at the earliest opportunity and resolved. Other problems may not become apparent until more data have been collected, and data can be viewed in a longer temporal context during secondary validation.
4. Secondary data validation which should be carried out in State DPCs for State data and CGWB local offices for CGWB data, to take advantage of the information available from a large area by focusing on comparisons with the same variable at other good quality, nearby monitoring sites (analogue stations) which are expected to exhibit similar hydrogeological behaviours, uses e-GEMS. States should have access to CGWB data during secondary validation, and may receive support from CGWB in this activity.
5. Tertiary data validation which focuses on advanced techniques for the analysis and validation of spatial and temporal data, using tools like statistical analysis and spatial overlays. This stage of validation is time-consuming and is applied selectively.
6. Data storage. The e-GEMS HIS database, of both approved data and unapproved data undergoing primary and secondary validation, is backed up automatically. Therefore, there is no need to make regular back-ups, unless any data are stored outside the HIS database, for instance in Excel files or other formats awaiting data entry, or in stand-alone real-time databases – such files should be securely backed up, ideally onto an external back-up device and/or backed up network server, so that there is no risk of data loss. All PCs should have up-to-date anti-virus software.

Raw field data, in the form of handwritten forms and notebooks, and charts should also be stored in a secure manner after database entry to ensure that original field data remain available should any problems be identified during validation and analysis. Such hardcopy data should ultimately be securely archived, in the State DPC for State data or CGWB local office for CGWB data, possibly by scanning documents and storing them digitally.

7. Interagency data validation by CGWB – CGWB should aim to validate at least 20% of current and historic data from State groundwater monitoring stations every year, on a rolling programme, so that CGWB has independently validated the data from every State well at least once every 5 years. Interagency validation is a 2-way process and CGWB should discuss any identified issues and agree final datasets with State DPCs through a 2-way consultative process, to build capacity for data validation within the States.

For groundwater level data, Section 4 of this Handbook covers the process from data entry through primary and secondary validation, to analysis of data.

## 4. Groundwater Level Data Processing and Analysis

### 4.1 Data entry

#### 4.1.1 Overview

Entry of data to computer is primarily done at a Sub-Divisional office level where staff are in close contact to field staff who have made the observations and/or collected the manual or digital data. Data entry is carried out using e-GEMS. Prior to entry to computer, two manual activities are essential: registration of receipt of the data, and manual inspection of the groundwater level forms and notebooks from the field, for complete information and obvious errors. Data entry (see Table 3.1) and primary validation of field data from observational stations are required to be completed at Sub-Divisional/Divisional office level by 7 days after return from the field, and 7 days after days entry, respectively, ready for secondary validation by State offices.

#### 4.1.2 Manual inspection of field records

Prior to data entry to computer an initial inspection of field records is required. This is done in conjunction with notes received from the observation station on equipment problems and faults, missing records or exceptional levels. Groundwater level sheets and charts are inspected for the following:

- Is the station name and code and month and year recorded?
- Is the station coordinates and altitude (relative to mean sea level MSL) recorded?
- Is the height of the measuring point above ground level recorded?
- Are there some missing values or dry wells?
- Is the record written clearly and with no ambiguity in digits or decimal points?
- Do digital records downloaded from the data loggers have valid station/instrument identification, dates and timings, etc.

Any queries arising from such inspection should be communicated to the observer to confirm ambiguous data before data entry. Any unresolved problems should be noted and the information sent forward with the digital data to Divisional/State offices to assist in initial secondary validation. Any equipment failure or observer problem should be communicated to the supervising field officer for rectification.

#### 4.1.3 Entry of manual groundwater level data

Groundwater level data may be entered manually. Using e-GEMS, the user selects the correct station and groundwater level series. The screen for entry (or editing) of groundwater level is displayed. The user enters the data and time of the measurement, the height of the measuring point above ground level, and the depth to groundwater level. Non-numerical entries are automatically rejected. The software also calculates the groundwater level reduced to MSL as the user enters the data.

**Dry wells** When the well is dry, the depth to groundwater level is left blank (not the depth of the well as the actual groundwater level is below the bottom of the well and is not known) and a comment entered against that day or time.

**Missing data** When data are missing, the corresponding depth to groundwater level is left as -999 (not zero) and a comment entered against that day or time.

Entered data should undergo entry checks and be viewed graphically to identify potentially suspect data not apparent in tabular form, which may reflect an error in data entry:

- A value cannot be saved unless all the required details are entered.
- A value cannot be saved when it is at the same date and time as another value i.e. no duplicates may be present.
- A value is flagged as suspect when a depth to groundwater level is entered that is more than the depth of the well.

For any missing or potentially suspect values, the user should refer back to the field documents to see if there was some error in entering the data. Any mismatch remaining after thorough checking of the field documents must be due to incorrect field computations by the observer and should be communicated to the supervising field officer.

#### **4.1.4 Import/entry of digital data**

Digital data from DWLRs take the form of groundwater levels at pre-set time intervals (e.g. 1 hour, 15 minutes, etc). DWLR data can be imported directly should an appropriate import interface be available (bespoke to each type of data logger) and , ideally, an import report will be automatically generated with the number of records offered, the number of records imported and the number of records rejected. Imported data should undergo entry checks and be viewed graphically as described in Section 4.1.3.

## **4.2 Primary validation**

### **4.2.1 Overview**

Primary validation is primarily done at a Sub-Divisional office level where staff are in close contact to field staff who have made the observations and/or collected the manual or digital data. Primary validation is carried out using e-GEMS. Primary validation (see Table 3.1) of field data from observational stations is required to be completed at Sub-Divisional/Divisional office level by 7 days after data entry, ready for secondary validation by State offices. This time schedule ensures that any obvious problems (e.g. indicating an instrument malfunction, observer error, etc) are spotted at the earliest opportunity and resolved. Other problems may not become apparent until more data have been collected, and data can be viewed in a longer-term context during secondary validation.

Primary validation of groundwater level data focuses on validation within a single data series by making comparisons between individual observations and physical limits, and between two measurements of groundwater level at a single station (e.g. a DWLR groundwater level and a manually-read check of depth to groundwater level).

### **4.2.2 Typical errors**

Staff should be aware of typical errors in groundwater level measurement, listed in Table 4.1, and these should be considered when interpreting data and possible discrepancies.

### **4.2.3 Comparison with physical limits**

Single station validation against data limits and expected hydrological behaviour is carried out by the inspection of the data using a combination of graphical and tabular displays. Groundwater levels which are below the bottom of the well or above the top of the well plus, say, 0.25 m, should be flagged as erroneous.

**Table 4.1 Measurement errors for groundwater level data**

<p><b>Manual depth to groundwater level measurement errors</b></p> <ul style="list-style-type: none"> <li>• Observer reads water depth incorrectly</li> <li>• Observer enters water depth incorrectly in the field sheet (e.g. misplacement of decimal point in the range 0.01 to 0.10, writing 4.9 m instead of 4.09 m)</li> <li>• Observer enters groundwater level to the wrong day or time</li> <li>• Observer fabricates readings, indicated by sudden changes in levels or extended periods of uniform mathematical sequences of observations</li> <li>• Observer uses incorrect measurement point</li> <li>• Observer enters depth of well for dry well</li> <li>• Depth of well is greater than length of measuring tape</li> </ul>
<p><b>DWLR measurement errors</b></p> <ul style="list-style-type: none"> <li>• Failure of electronics due to lightning strike etc. (though lightning protection usually provided)</li> <li>• Incorrect set up of measurement parameters by the observer or field supervisor</li> </ul>

Visual checking of groundwater level data is often a more efficient technique for detecting data anomalies than numerical checking. The plot of groundwater levels should cover a representative period of time (depending on the frequency of measurement) to reveal any discontinuities e.g. for daily data at least 2 months, for hourly data one month, etc. The scale of the hydrograph should be selected such that the variation of the groundwater level data is neither very flat nor very steep. Trend lines for pre-monsoon, post-monsoon and the whole time period, and 3D viewing, may also be utilised to aid interpretation. The main purpose of graphical inspection is to identify any abrupt discontinuities in the data or the existence of positive or negative spikes which do not conform to expected hydrogeological behaviour. These may be caused by an incorrect reading (often by 0.5 m or 1.0 m), a change in height of the measuring point, or assigning the reading to the wrong well. Suspect groundwater levels should be flagged for comparison with other groundwater levels measured in the same area during secondary validation.

#### **4.2.4 Comparison of manual and digital data**

For stations with a DWLR, periodic manual readings should be made once a month – before data download - using a calibrated measuring tape, to check correct operation of the DWLR. Comparison of manual and DWLR groundwater level data can be best carried out in graphical form, where the two water level series should correspond. If there is a systematic but constant difference between the manual and DWLR levels, it is possible that the DWLR has been set up at the wrong depth and the DWLR data may need adjusting.

Where a doubtful or incorrect groundwater level is identified, and there is any uncertainty as to the correct action, this should be marked with an appropriate flag to indicate that it is suspect. The data flagged as suspect are reviewed at the time of secondary validation.

### **4.3 Secondary validation**

#### **4.3.1 Overview**

Secondary validation of groundwater level data is primarily carried out at State DPCs, to take advantage of the information available from a larger area. Secondary validation is carried out using e-GEMS. Data may also be exported to Excel for secondary validation. For the Hydrology Project, secondary validation should be completed within one month (initial) and four months (intermediate) of data collection (see Table 3.1). Some secondary validation (including comparison with CGWB data) will not be possible until the end of the hydrological year when the entire year's data can be reviewed in a long-term context, so data should be regarded as provisional approved

data until then (e.g. for June data by the end of the hydrological year plus 3 months), after which data should be formally approved and made available for dissemination to external users.

Data entering secondary validation have already received primary validation on the basis of knowledge of the station and instrumentation and field documents. Data may have been flagged as missing or suspect. Secondary validation focuses on further investigation of data from the well, including comparison between groundwater level and incident rainfall (initial), and comparisons with neighbouring wells to identify suspect values (intermediate). Data processing staff should continue to be aware of field practice and instrumentation and the associated errors which can arise in data.

#### **4.3.2 Combined groundwater level and rainfall plots**

The addition of rainfall (Section 5) to the water level plots in Section 4.2.3, and to the comparison plots in Section 4.3.3, provides a means of validating water level data (see example in Figure 4.1a). Comparison may be made using an areal rainfall determined using Thiessen polygons or other methods over the entire basin, or for the intervening sub-basin corresponding to various gauging stations (Precipitation and Climate Handbook, Section 4.5.3). Where the basin is small or the number of raingauges limited, individual rainfall records may be plotted.

In general, a rise in groundwater level must be preceded by a rainfall event in the basin and, conversely, it is expected that rainfall over the basin will be followed by rise in water level. There must be a time lag between the occurrence of rainfall and the rise in water level. Where these conditions are violated, an error in rainfall or in the water level data may be suspected. However, the above conditions do not apply universally and the assumption of an error is not always justified, especially for isolated storms in arid areas:

- An isolated storm recorded at a single raingauge may be unrepresentative and much higher than the basin rainfall. The resulting recharge may be negligible or even absent
- Where storm rainfall is spatially variable, it may be heavy and widespread but miss all the raingauges, thus resulting in a rise in groundwater level without preceding measured rainfall

The use of comparative plots of rainfall and groundwater level is, therefore, qualitative but it provides valuable ancillary information when used with the multiple hydrograph plots. Trend lines for pre-monsoon, post-monsoon and the whole time period, and 3D viewing, may also be utilised to aid interpretation.

See also Section 4.4.5 for use of combined groundwater level and rainfall plots in understanding the rainfall-recharge relationship.

#### **4.3.3 Statistical methods**

Some simple statistical methods are available to check groundwater level measurements:

- Deviation from the mean or the median - check for values which differ more than three times the standard deviation from the mean or median (preferred as it is less affected by values of individual measurements and represents better the centre of the dataset). Ideally, the time series should contain at least 50 measurements.
- Frequency analysis - calculate the frequency of the measurements in order to identify values, which appear more often than normally expected. Such values may result from measurements affected by a casing joint or from overflowing or siltation of the well. The consistent rounding of measurements to a near value also may cause such values.

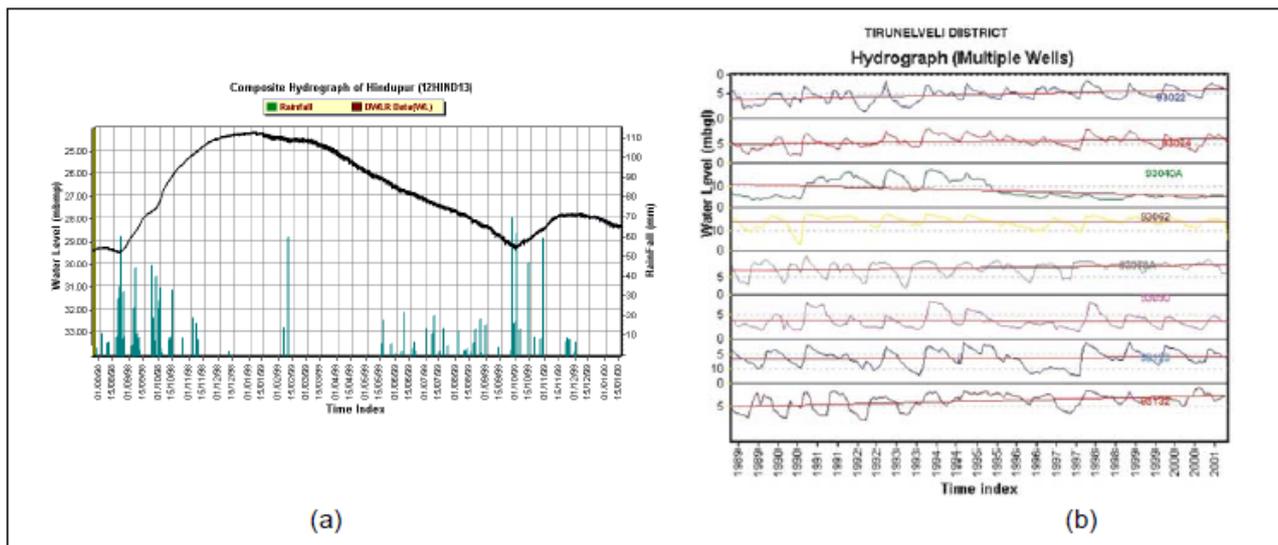


Figure 4.1 Examples of secondary validation techniques

#### 4.3.4 Multiple station comparison plots

Comparative time series plots are an effective visual method for identifying potential anomalies between wells data (see example in Figure 4.1b). Where only two wells are involved in the comparison, the identification of an anomaly does not necessarily indicate which well is at fault. For multiple time series plots, select a set of wells, ideally in the same area and with the same hydrogeological characteristics. Plot the groundwater level series as hydrographs, preferably in different colours for each well. For routine monthly validation, the plot should include the time series of at least the previous month to ensure that there are no discontinuities between one batch of data received from the station and the next. There will be differences in the plots depending on differing rainfall over the basins and differing recharge response to rainfall but, in general, fluctuations and trends are expected to be replicated at several wells and gross differences between plots may be identified. Trend lines for pre-monsoon, post-monsoon and the whole time period, and 3D viewing, may also be utilised to aid interpretation.

Comparison of groundwater level series may permit the acceptance of values flagged as suspect because they fell outside the warning ranges, when viewed as water level or when validated as a single station. When two or more stations display the same behaviour there is strong evidence to suggest that the values are correct. Comparison plots provide a simple means of identifying anomalies but not of correcting them.

## 4.4 Analysis

### 4.4.1 Overview

Analysis of groundwater data (see Table 3.1) provides information on the past, present and future condition of the available groundwater resources, but may produce misleading results with insufficient knowledge of the groundwater level data and its quality. It is important to have an understanding of the completeness of the groundwater level data, and the quantity and potential significance of missing data, of the representativeness of the measured groundwater levels of the actual situation, and of the possibilities and limitations in the use of the groundwater level data. The completeness of the data is important with respect to the analysis of time-dependent data because some techniques (e.g. statistical analysis) may not yield results unless the dataset is continuous dataset. Understanding the limitations is particularly important with respect to spatial

analysis where, for instance, there may be an insufficient density of data points to represent the groundwater level, when preparing for a contour map using GIS.

GIS has a critical role to play in the interpretation of point groundwater level data for understanding surface water-groundwater interactions, water quality changes, groundwater resource availability, etc across an area. For improved understanding of the hydrological/hydrogeological system and for refining water resource estimates, additional spatial data on surface drainage, land use, geomorphology, slope, soils, geology and structures, and man-made (anthropogenic) features are required. GIS enables integration of different layers of point data and spatial information, including digital maps, generated from the topographic sheets, and thematic data interpreted from satellite images. GW5-DM provides a somewhat out-of-date introduction to the use of GIS for processing spatial data. See the e-GEMS manual for details about which GIS tools are available.

#### 4.4.2 Contour maps

Contour maps show the spatial distribution of groundwater level measurements, or of a value derived from the measurements. However, such a map will not be realistic when effects of physical features between monitoring stations are not accounted for e.g. a river. Additional information has to be incorporated to produce a meaningful map, which may necessitate manual editing of contours after combining the generated contours with other map layers e.g. topography. Figure 4.2 illustrates how the presence of a river influences contours. GW8-OM(III) Chapter 3 presents an example of preparing a contour map from groundwater level data in Andhra Pradesh.

Contours of groundwater level, and of other related spatially varying quantities like groundwater quality parameters, aquifer characteristics, rainfall, etc, are required for a variety of computations aimed at the quantitative estimation of groundwater resources and groundwater quality (contaminant transport). Contouring may be accomplished by a manual procedure or by a software-assisted automatic procedure based on a pre-selected algorithm. GW8-RM Chapter 1 presents the relative merits/demerits of the two procedures. The optimum approach combines the two procedures such that the software produces the contours according to the user specifications (e.g. grid spacing, contour interval, contouring algorithm) and an experienced hydrogeologist manipulates them manually to incorporate existing hydrogeological features. There are many contouring algorithms available, but the principle ones, discussed in detail in GW8-RM Chapters 1.2 to 1.5, are:

- Trend surface analysis (polynomial approximation)
- Kriging (including Universal Kriging)
- Spline functions

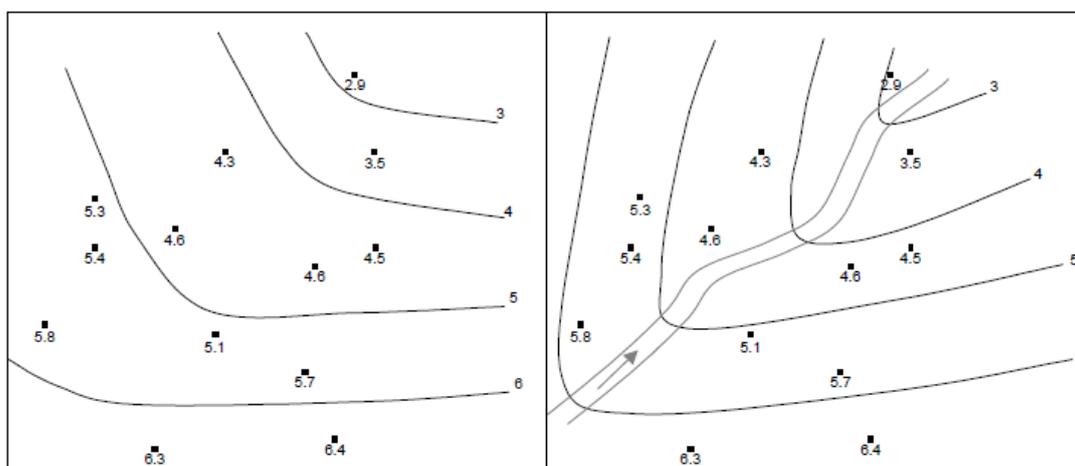


Figure 4.2 Contour map modified to account for a river

GW8-OM(III) Chapter 4 considers the choice of algorithm for a variety of contouring uses, including:

- Water table/piezometric elevation contouring – required for estimating lateral flow directions and rates
- Water depth contouring – produced for routine analysis aimed at evaluation, planning and management of groundwater resources.
- Water level fluctuation contouring – contours of water level fluctuation in a given period (e.g. monsoon and dry seasons) combined with contours of specific yield permit an estimation of the storage fluctuations, necessary for performing a lumped water balance. These may also be useful for calibrating a distributed aquifer response model.
- Computation of velocity field – contouring algorithms permit estimation of gradients of the attribute (i.e. the particular data e.g. groundwater levels) at any specified point, from which raster data (Section 4.4.3) of hydraulic gradients may be generated. Raster data of hydraulic gradient and hydraulic conductivity may be used for estimating the velocity distribution, in accordance with Darcy's law (GW4-DM Chapter 2.7.1).
- Groundwater level data validation – contouring algorithms permit identification of outliers i.e. data points that are statistically inconsistent with the dataset. This may be visualised as a high concentration of contours around the location of the well which may indicate a potentially erroneous value, though it is necessary to check the groundwater level plot of the well to determine whether the value really is in error. Figure 4.3 illustrates the effect of a low (4.4) measured value that should be followed-up to check its authenticity. A technique known as jack-knifing, suitable for use with kriging and universal kriging algorithms, may be adopted for detecting outliers.

#### 4.4.3 Raster maps

As indicated in Section 4.4.2, contour maps are usually processed to perform a variety of tasks like gridding/interpolation, integration (spatial averaging, storage estimation) and differentiation (velocity calculation). Raster maps are created from contour maps and contain values for a grid

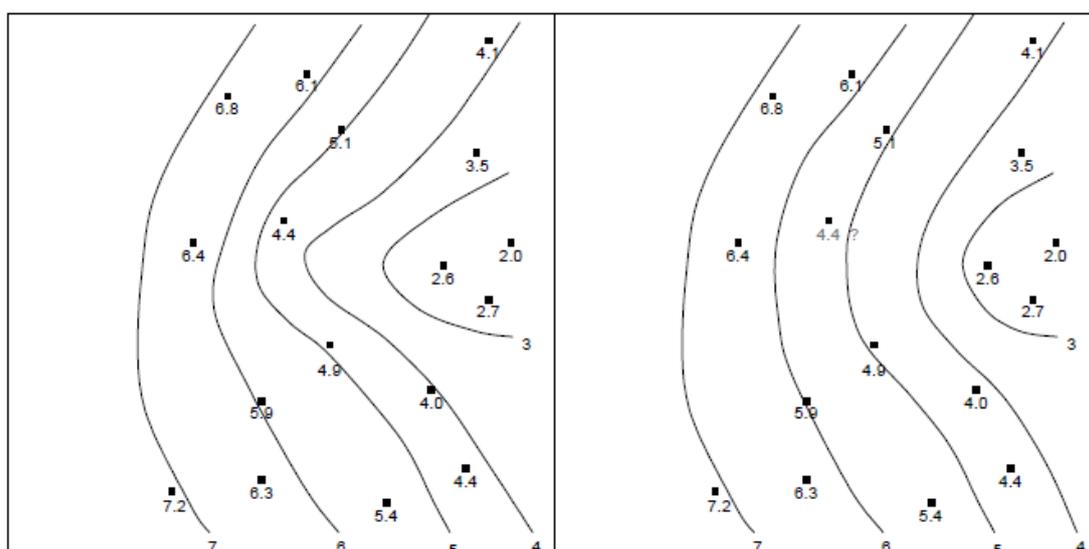


Figure 4.3 Contour map showing influence of suspect value

with uniformly distributed points. To facilitate visualisation, the derived values are classified by value, with each class assigned a separate symbol and/or colour.

Raster maps may be used for spatial calculations e.g. the difference in groundwater level between pre-monsoon (one raster map) and post-monsoon (another raster map), where subsequent multiplication of the derived raster map of the difference by the area of the raster cells and the specific yield of the aquifer (another raster map) will give the total groundwater volume increase during the monsoon period.

By overlaying different spatial layers, raster maps may be used in tertiary validation to ascertain whether any detected outliers are natural extremes or erroneous data values e.g. in a comparison of the results of aquifer pumping tests with a map of hydrogeological units, the values of the transmissivity and the storage coefficient derived from the pumping tests should conform to the values expected for the hydrogeological units on the map.

#### 4.4.4 Computing basic statistics

Basic statistics are widely required for validation and reporting including:

- Annual mean water level:

$$\bar{X} = \frac{1}{N} \sum_{i=1}^N X_i$$

- Standard deviation - the root mean squared deviation  $S_x$ :

$$S_x = \sqrt{\frac{\sum (X_i - \bar{X})^2}{N-1}}$$

- Annual highest water level - the maximum value of a series X
- Annual lowest water level – the minimum value of a series X
- Monthly mean water level (also known as macro means) – the mean water level for each month

#### 4.4.5 Rainfall recharge understanding

At the beginning of a rainfall event, or indeed at the beginning of the monsoon season, when the soil may be dry, most of rainfall infiltrating into the ground may be held back in the soil and there may practically be no recharge. As the rainfall event builds up the soil moisture, the recharge process may be initiated. Thus, a certain depth of rainfall (RC) has to occur before a rainfall event starts producing recharge. Furthermore, since the water has to flow through the unsaturated zone before it appears as recharge at the water table, there is a time lag (Tg) between a rainfall event and the consequent recharge.

The rainfall recharge parameters RC and Tg need to be estimated for groundwater resource assessment. One of the ways of achieving this is to study the impact of the rainfall recharge on the water table, facilitated by high frequency DWLR data:

- First, superpose the hyetographs of all the rainfall events of a rainy season over the corresponding groundwater level hydrograph (Section 4.3.2).
- Examine the water level response following each rainfall event, starting from the beginning of the rainy season.
- Identify the first rainfall event (say X) which is followed by a conspicuous water table rise.
- Compute the cumulative rainfall preceding the X rainfall event. This provides an estimate of RC.

- Compare the time lags between the rainfall events (starting from X) and the following groundwater level rises and determine an average time lag. This provides an estimate of Tg.

For more information and an example, see Groundwater Training Module 02 “Role of DWLR data in groundwater resource estimation”.

#### 4.4.6 Groundwater modelling

Groundwater models simulate the hydrogeological conditions of an area in order to understand the hydrogeological processes taking place and to make estimations of future resources. There are different types of groundwater models. GW8-OM(III) Chapter 6 presents a simple model with horizontal layers, and GW8-OM(IV) describes a lumped water balance model in some detail.

A groundwater balance, usually applied to an unconfined aquifer, assumes that the difference between the net recharge volume (I) and net discharge volume (O) equals the change of groundwater storage ( $\Delta S$ ). I, O and  $\Delta S$  must be in respect of the same aquifer area and the time period:

$$I - O = \Delta S$$

When the study area is treated as a single entity, and flow across the boundary is estimated by Darcy’s law (GW4-DM Chapter 2.7.1), it is a lumped model. When the study area is divided into a finite number of cells, and flow between adjacent cells is estimated by Darcy’s law, it is a distributed model e.g. MODFLOW. Uses of lumped water balance models include:

- Estimation of groundwater resource – the model provides historical estimates of different components of recharge and discharge and may be used to estimate the status of the resource in a certain time span, essential for resource management.
- Validation – the model may be used to validate various adopted algorithms, norms, practices, parameter values, etc, by checking if independently estimated components of recharge, discharge and storage change satisfy the water balance equation:

$$I - O - \Delta S = \epsilon \Delta S$$

Where:  $\epsilon \Delta S$  is the residue term in the water balance equation i.e. the volumetric imbalance between the net recharge (that is, recharge minus discharge) and the storage fluctuation.

- Prioritisation of model components – the validation use above also leads to an understanding of the relative significance of the various component(s) of the model. The estimate of each component, expressed as a fraction of the storage fluctuation, provides an indication of the relative significance of the components. Larger effort should be put in to estimating the most significant components e.g. experimental field work to improve upon the estimates.
- Estimation of an unknown model component – a critical model component not amenable to rational estimation (e.g. rainfall recharge during the monsoon period) may be estimated by substituting the estimates of all other components and of the storage fluctuation into the water balance equation. If the residual term is assumed to be zero, the estimate of the unknown model component is reliably estimated, provided the estimates of all other components and of storage fluctuation are more or less error free

Groundwater balances benefit from the use of high frequency DWLR data. See GW8-OM(IV) and Groundwater Training Module 02 “Role of DWLR data in groundwater resource estimation” for more information.

#### 4.4.7 Time series analysis

Time series analysis may be used to test the variability, homogeneity or trend of a water level series, or to give an insight into the characteristics of the series as graphically displayed. For more information see GW8-OM(III) Chapter 5. See the e-GEMS manual for details about which time series analysis tools are available.

- **Dynamic equilibrium** – If the annual recharge to an aquifer equals the annual withdrawals from the aquifer, a volumetric balance exists and the groundwater level time series displays first order stationarity (GW8-RM Section 2.3). If the spatial and temporal distributions of the recharge, withdrawals and boundary conditions (e.g. stage of hydraulically connected streams in the vicinity) follow the same annual pattern over the years, the groundwater level time series displays second order stationarity. A time series displaying both first and second order stationarity is said to be in dynamic equilibrium i.e. the annual hydrographs over the years are from the same population.

In practice, a true dynamic equilibrium may never be reached, since there are always variations of recharge, withdrawals and boundary conditions from year to year. However, if these variations are small in comparison to the respective long-term mean, a near-dynamic equilibrium may be reached i.e. although there are some variations from year to year, there is no long-term rising/declining trend of the annual mean groundwater level and the shape of the groundwater level hydrograph is not undergoing any distortion.

- **Temporal trends** – If first order stationarity is violated, the annual mean groundwater level and other attributes of the hydrograph may display a rising or a falling trend. If this test holds but the test for second order stationarity is violated, the annual mean groundwater level may be devoid of a trend but one or more of the other attributes may be displaying a trend. Fit a regression line to a time series of the mean or other attribute and check if the slope coefficient is significantly different from zero i.e. whether there is any trend.
- **Regression analysis** - Regression analysis is a widely-used statistical technique in hydrology for: making estimates of dependent variable Y (i.e. the groundwater level at the test station) based on independent variables X (e.g. the groundwater level at an analogue station); for investigating the functional relationship between two or more variables; for infilling missing values in the test time series; and for validating the test time series. Regression relations may be obtained for annual, monthly or daily water level series. The most common model is based on the assumption of a linear relationship between two variables and has the general form:

$$Y_i = a X_i + c$$

In simple linear regression, the Y variable is regressed on one X variable. In multiple and stepwise linear regression, the Y variable is regressed on more than one X variable. In non-linear regression, the coefficients appear as a power:

$$Y_i = c X_i^a$$

The type of regression equation that is most suitable to describe the relation depends on the variables considered and, with respect to hydrology, on the physics of the processes driving the variables. Furthermore, it also depends on the range of the data of interest. Regression analysis may be used in tertiary validation to identify suspect data values.

- **Linear interdependencies** - Linear interdependence between two concurrent groundwater level series may be identified by estimating correlations (GW8-RM Section 2.2) between their respective time series. A significant correlation may indicate a close linear interdependence.
- **Lagged interdependencies** - Linear time-lagged interdependence between two concurrent groundwater level series may be identified by estimating correlations (GW8-RM Section 2.2) between their respective time series at different time lags. The lag at which the correlation is

highest may represent the lag between two series. If the highest correlation is significant, it may indicate a close linear interdependence.

- **Outliers** – Identification of the outliers (i.e. data points that are statistically inconsistent with the dataset) should start with a manual inspection of hydrographs (Section 4.3.4, also Section 4.4.2) followed up with statistical analysis. An outlier may represent some discrete or short-lived phenomenon. However, an outlier may also represent an erroneous data value. Outliers can be detected by statistical analysis of annual groundwater level data for a single well, by statistical analysis of trends of macro means, or by regression analysis between wells whose groundwater level data are linearly interdependent. The latter technique may be used in tertiary validation to ascertain whether any detected outliers are natural extremes or erroneous data values.
- **Cycles** - A plot of groundwater levels represents the consequences of a number of phenomena, many of which may be periodic (i.e. self repeating). These include: daily pumping and recovery; tidal effects; atmospheric pressure fluctuations; and seasonal rainfall, pumping and irrigation recharge. Each periodic phenomenon imparts a periodicity or cyclicity to the water level hydrograph. However, due to their superposition, all these cycles may not be visible, particularly in low frequency manual measurements. However, high frequency DWLR data present an opportunity to identify and infer the relative influence of different cycles on the groundwater system, and design fieldwork programmes accordingly.

Harmonic analysis (also known as spectral analysis) is a form of time series analysis used to separate a groundwater level time series into these hidden cycles. It is applicable only to stationary time series, devoid of any long-term trend (GW8-RM Section 2.3). For more information and an example, see GW8-RM Section 2.4 and Groundwater Training Module 04 "How to identify the cycles using harmonic analysis".

- **Analysis of hydrograph recession** – The recession of a groundwater level hydrograph predominantly resulting from the natural drainage, is related to the aquifer geometry and diffusivity. Analysis of the hydrograph recession can provide a preliminary estimate of the diffusivity, which in turn may lead to the estimation of the transmissivity or of the storage coefficient.

## 5. Rainfall Data Processing and Analysis

### 5.1 Rainfall in the Hydrology Project

Rainfall recharge is often the largest source of recharge to groundwater: a rise in groundwater level is usually preceded by a rainfall event in the basin. Hence, access to rainfall data is important in interpretation of groundwater level data, and for balancing recharge, discharge and storage of groundwater systems. GW3-DM, FM and RM describe the design, implementation, operation and maintenance of hydrometeorological networks, and rainfall data may be stored in e-GEMS. However, subsequent data processing and analysis of rainfall data are covered only in SW8-OM (see Table 3.1) and the surface water software e-SWIS has a wider range of validation and manipulation tools for rainfall data than e-GEMS. Therefore, it is recommended to carry out the majority of rainfall data processing and analysis in e-SWIS, and then export final datasets from e-SWIS, for import to e-GEMS. See the Precipitation and Climate Handbook for more information about rainfall data management.

## 6. Data Dissemination and Publication

### 6.1 Hydrogeological products

The traditional primary visible output of hydrogeological data archives is published reports, usually in the form of annual groundwater yearbooks. However, this is not generally the most convenient format of groundwater quantity data for data users who often require long-term records for a single station or a group of stations i.e. data by station rather than by year. For data users in the past, this necessitated the collation of data from a set of annual reports and the keying in of the data for the required analysis. In many countries, recent advances in IT, combined with well-established links between data suppliers and data users, mean that annual reports are no longer published in print, with the same information being provided online, and data requests met with a rapid and bespoke response.

A further consequence is that data suppliers have more time to focus on data analysis, periodic reports and short-term operational reports of interest to key data users e.g. reports on unusual flood events, groundwater level bulletins for water supply and irrigation sectors, real-time ground water level for drought monitoring, etc. A combination of digital and hardcopy hydrological products and online dissemination provide an effective means of demonstrating the capability of the HIS, in particular:

- Providing information on availability of data for use in planning and design, and making reporting and use of data more efficient by reducing the amount of published data and cost of annual reports
- Advertising the work of the HIS and its capability, and to create interest and awareness amongst potential data users
- Providing tangible evidence to policymakers of a return on substantial investment
- Providing feedback to data producers, and acknowledging the contribution of observers and co-operating agencies
- Providing a clear incentive to keep archives up to data and a focus for an annual hydrometric audit

Hence, the long-term goal of the HIS is web-based dissemination of user guidance and station metadata (additional datasets that include items that could assist users of the data to understand the data, their accuracy and any major influencing factor), which is usefully complemented by the publication of catalogues or registers of hydrometric stations (e.g. Marsh & Hannaford, 2008) and occasional reports, and by a dedicated enquiry and data retrieval service.

### 6.2 Annual reports

#### 6.2.1 Groundwater yearbooks

Groundwater yearbooks should report over the hydrological year from 1 June to 31 May. The hydrological year corresponds to a complete cycle of replenishment and depletion, so it is appropriate to report on that basis rather than over the calendar year. Annual groundwater levels, groundwater quality, rainfall and other climate data may be presented in a single combined report. The groundwater quantity elements of such reports incorporate a summary of information on the pattern of groundwater levels over the year, and information on groundwater resource availability and how the recent year compares with past statistics. Annual reports are produced at the State DPC and should be published within 12 months of the end of the hydrological year covered. GW8-OM(V) presents a detailed template and instruction for a groundwater yearbook published at State level. The following are typical contents:

- **Part I** - The first part of the yearbook, which may change little from year to year includes a preface and introduction, followed by information on drainage characteristics, geology and structures, soil types, sub-surface lithology, and typical groundwater issues of the area, and the administrative set-up in the groundwater agency.
- **Part II** – The yearbook should go on to describe the steps involved in the collection, data entry, processing, validation, analysis and storage of data, including any agencies contributing to the included data. The report should explain how the work is linked with other agencies collecting or using flow data including CGWB and operational departments in irrigation. It should also set out how data may be requested and under what terms and conditions they are supplied.

**Observational networks** – Maps, figures and tables should be used to summarise the salient features of the groundwater level and hydro-meteorological observational networks, including the objectives of the monitoring networks, the status of the networks, and a summary of data collection during the reporting year. Maps should also show major rivers and basin boundaries, as well as aquifer boundaries, and distinguish each site by symbol between operating agencies. Mapped stations should be numbered so that they can be related to information contained in tabular listings. Tables of current stations should include the latitude, longitude, altitude, responsible agency, the full period of observational record and the period of observation which is available in digital format. Information for each station should also include a summary description of the type of observation well and any notable features. All additions and closures of stations should be highlighted in the yearly report. Similarly, station upgrading and the nature of the upgrading should be reported.

- **Part III** – Next, the yearbook presents semi-static data (e.g. areas of crops irrigated by groundwater, crop water requirement, irrigation efficiency, irrigation return flow, etc) and dynamic data, starting with reviews of rainfall (and other climate) and of surface runoff during the reporting period, including graphs, tables and maps.

**Basic groundwater statistics** – This section forms the core of the report and should include a review of groundwater level changes and groundwater flow system characteristics for the reporting period. Maps, figures, graphs and tables should be used to summarise the salient points. This section should also include estimation of groundwater resource availability for the reporting year, and recommendations for sustainable development of groundwater.

- **Part IV Annexes** – These may include supplementary tables and information, such as a bibliography. Data users may be interested to know of other sources of hydrogeological data, including: concurrent annual reports from the HIS of other hydrogeological data, and previous annual flow reports (with dates) from the HIS or other agencies; any periodic reports of groundwater monitoring station metadata and time series statistics produced by the HIS or other agencies; and any special reports produced by the HIS or other agencies. A brief note on the administrative context of previous reports, methods of data compilation, and previous report formats may be helpful.

### 6.2.2 Annual hydrological reviews

Shorter than groundwater yearbooks, annual reviews of the hydrological year provide users with published assessments of the key elements of the hydrological cycle. Hence, the reports combine rainfall, snow (where relevant), climate, flow, reservoir stocks and groundwater, and possibly also water quality. Annual reviews are produced at the State DPC and should be published within 12 months of the end of the hydrological year covered. For an example, see [www.ceh.ac.uk/data/nrfa/nhmp/annual\\_review.html](http://www.ceh.ac.uk/data/nrfa/nhmp/annual_review.html).

## 6.3 Periodic reports

### 6.3.1 Metadata catalogues

Periodic reports of groundwater observation well metadata and time series statistics may be published by the State DPC at 5-year or 10-year intervals. The reports should incorporate temporal analysis and provide statistical summaries in tabular and graphical to make the information accessible and interesting to data users. The following are typical contents of such a periodic report:

- Introduction
- Data availability - maps and tabulations
- Descriptive account of annual groundwater levels since last periodic report
- Thematic maps e.g. contour maps of end of season groundwater levels
- Basic groundwater level statistics - monthly and annual means, maxima and minima: for the standard climate normal period (1961-90) where available; for the updated decade; and for the available period of record
- Analysis of periodicity and trend in groundwater level data

### 6.3.2 Monthly hydrological summaries

Routine monthly reports and statistics on the current state hydrological situation, including assessments of rainfall, snow (where relevant), evaporation, river flow, groundwater and reservoir stocks, provide users with a snapshot of the current situation and its historical context, and the future outlook. Such information may provide a vital input for planning domestic or industrial water supply, agricultural planning, hydropower and other water use sectors. Monthly summaries are produced at the State DPC and should be published within 10 working days of the month covered. For an example, see [www.ceh.ac.uk/data/NRFA/nhmp/monthly\\_hs.html](http://www.ceh.ac.uk/data/NRFA/nhmp/monthly_hs.html).

## 6.4 Special reports

Occasional special reports should also be published by the State DPC providing reactive analysis in the aftermath of monsoon rains and subsequent recharge. The reports are normally combined with reports of the resulting causative rainfall over the affected area. For an example, see [www.ceh.ac.uk/data/nrfa/nhmp/other\\_reports.html](http://www.ceh.ac.uk/data/nrfa/nhmp/other_reports.html).

## 6.5 Dissemination to hydrological data users

Final (approved) groundwater quantity datasets are provided by Central/State hydrometric agencies on a request basis. The online HIS data catalogue in e-GEMS, which shows the availability of fully validated (approved) data, supports hydrometric agencies in disseminating their data, and also helps hydrological data users to search available data and formulate their data requests and the formats required and direct them to the appropriate agency. The more comprehensive the information a data catalogue provides, the easier for users to identify the monitoring stations of interest to them, and be aware of any limitations to exploiting the data effectively. Users should be informed of the quality of any data supplied indicated by the data flag (e.g. observed, estimated, suspect, etc). There may be a charge for the data which is the product of significant investment in equipment and staff time. Data requests from users should be processed promptly: at least 95% of queries should be dealt with within 5 working days, and the remaining up to 5% of queries, which should be the more complex ones, within 20 working days.

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## Annex I States and Agencies participating in the Hydrology Project

Phase I (1996-2003)	Phase II (2006-2014)
<b>States</b>	<b>States</b>
Andhra Pradesh	Andhra Pradesh
Chhattisgarh	Chhattisgarh
	Goa
Gujurat	Gujurat
	Himachal Pradesh
Kerala	Kerala
Karnataka	Karnataka
Madhya Pradesh	Madhya Pradesh
Maharastra	Maharastra
Orissa	Orissa
	Pondicherry
	Punjab
Tamil Nadu	Tamil Nadu
<b>Agencies</b>	<b>Agencies</b>
Central Ground Water Board (CGWB)	Bhakra-Beas Management Board (BBMB)
	Central Ground Water Board (CGWB)
Central Water and Power Research Station (CWPRS)	Central Pollution Control Board (CPCB)
Central Water Commission (CGWB)	Central Water and Power Research Station (CWPRS)
Indian Meteorological Department (IMD)	Central Water Commission (CGWB)
Ministry of Water Resources (MoWR)	Indian Meteorological Department (IMD)
National Institute of Hydrology (NIH)	Ministry of Water Resources (MoWR)
	National Institute of Hydrology (NIH)

## Annex II Summary of Distribution of Hard Copy of HPI HIS Manual Groundwater

Volume	Manual	Part	Training	State DSC	State DPC	Div DPC	Sub-Div DPC	Station/ Lab
1 HIS	Design		+	+	+	+	+	
	Field	I Job description	+	+	+	+	+	
		II ToR for HDUG	+	+	+	+	+	
		III Data needs assessment	+	+	+	+	+	
Reference		+	+	+				
2 Sampling Principles	Design		+	+	+	+	+	
	Reference		+	+	+			
3 Hydro-meteorology	Design		+	+	+	+	+	
	Field	I Network design & site selection	+	+	+	+	+	
		II SRG operation & maintenance	+	+	+	+	+	1 SRG
		III ARG/TBR/SRG operation & maintenance	+	+	+	+	+	1 ARG
		IV FCS operation & maintenance	+	+	+	+	+	1 FCS
		V Field inspections, audits, maintenance & calibration	+	+	+	+	+	
Reference		+	+	+				
4 Geo-Hydrology	Design		+	+	+	+	+	
	Field	I Network design & site selection	+	+	+	+	+	
		II Drilling litho-specific piezometers	+	+	+	+	+	+
		III Aquifer tests	+	+	+	+	+	+
		IV DWLR testing	+	+	+	+	+	+
		V Reduced levels of wells	+	+	+	+	+	+
		VI Manual water level collection	+	+	+	+	+	+
		VII DWLR water level collection	+	+	+	+	+	+
		VIII Inspection & maintenance	+	+	+	+	+	+
Reference		+	+	+				
5 GIS	Operation		+	+	+	+	+	+
6 WQ Sampling	Design		+	+	+	+	+	
	Field		+	+	+	+	+	+
7 WQ Analysis	Design		+	+	+			+
	Operation		+	+	+			+
8 Data Processing & Analysis	Operation	I Data entry & data validation – water level	+	+	+	+	+	
		II Data entry and primary validation – water quality	+	+	+	+	+	+
		III Data processing & analysis	+	+	+	+	+	
		IV GW resource assessment	+	+	+	+	+	
		IV GW yearbook	+	+	+	+	+	
9 Data Transfer, Storage & Dissemination	Design		+	+	+			
	Operation		+	+	+			
10 HIS Activities - GW Domain	Operation		+	+	+	+	+	+