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Integrated Water Resources Management Document Series

2. IWRM

Thematic Paper 2.6/2: Groundwater Monitoring and its Importance to IWRM

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中国水利 CHINA WATER

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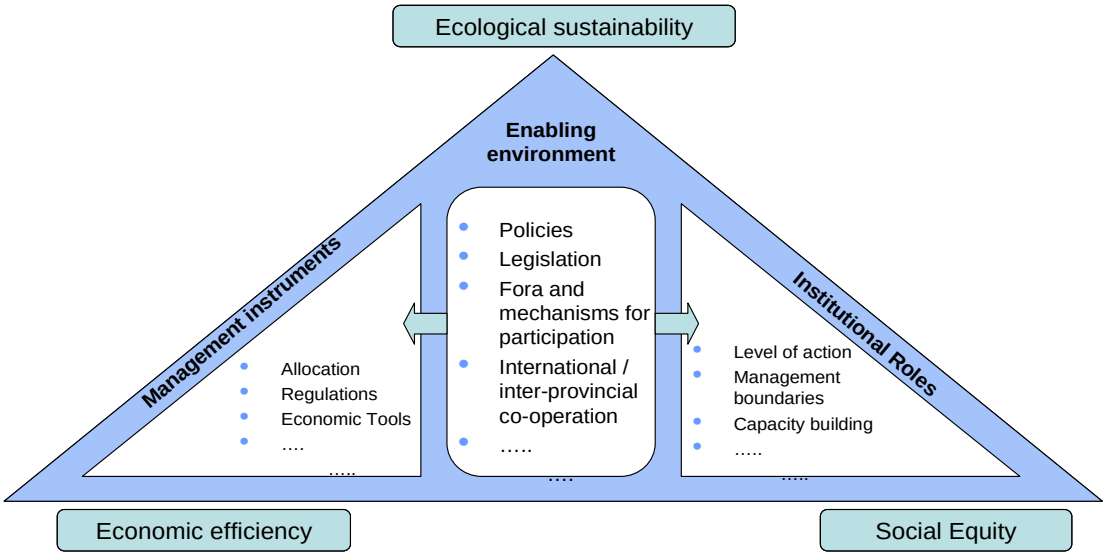
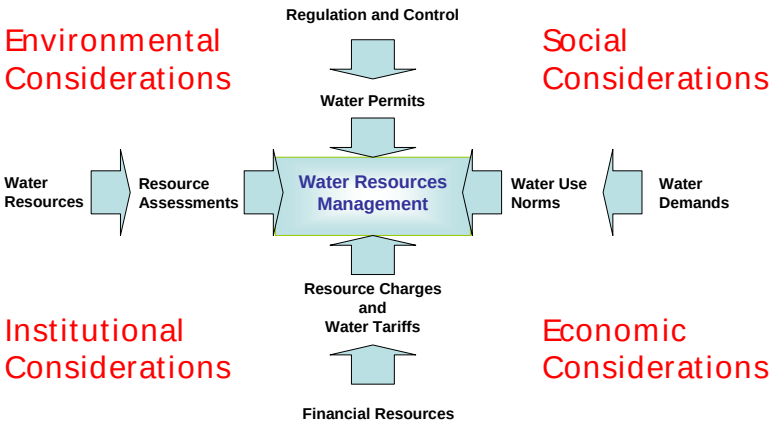
Integrated Water Resources Management (IWRM)

(Basics after Global Water Partnership)



Driving Elements of Integrated Water Resources Management



(Second figure after WRDMAP)

Summary: Groundwater monitoring is an important and essential component of the dynamic process of management of groundwater resources. In the context of IWRM, groundwater monitoring should be seen in the broad sense and not just be a technical issue. Successful monitoring depends equally on non-technical issues such as institutional and administrative strength, staff capacity and appropriate finance.

Groundwater monitoring should also be seen in the context of gaining understanding of the groundwater system and its interdependency with the surface system. For this reason it is not restricted to the monitoring of groundwater levels and groundwater quality. It should include all those time-variant parameters that exert an influence on groundwater behaviour.

The Paper comprises the following sections:

- Introduction
- Explanation of groundwater monitoring
- Data needs for each management level
- Recommendations for monitoring systems
- Institutional recommendations (especially data sharing and dissemination)

This document is one of a series covering topics on sustainable water resources planning, allocation and management. Details are given in the bibliography.

The Ministry of Water Resources have supported the Water Resources Demand Management Assistance Project (WRDMAP) to develop this series to support WRD/WAB at provincial, municipal and county levels in their efforts to achieve sustainable water use.

1 Introduction

The definition of Integrated Water Resources Management (IWRM) is as follows:

IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

'Integration' in IWRM relates to many aspects of the land and water system, such as:

- Land and water management
- Surface water and groundwater management
- Quantity and quality in water resources management
- Upstream and downstream water-related interests
- Water and wastewater management
- Integration of all stakeholders in planning & decision process
- The natural system and the HUMAN system:
  - mainstreaming water in the national economy
  - ensuring coordination between sectors
  - ensuring partnership between public and private sector management
  - involving everybody!

Groundwater is an integral part of a natural river basin system; in many river basins it plays an important part in economic and social activities. For

example, groundwater is abstracted for irrigation purposes in many basins and is thus an important contributor to the livelihoods of the rural farmers. Likewise, it frequently serves as an important source for public and industrial water supply, often for reasons of water quality. However, humans are not the only users of groundwater. The water needs of the natural environment can also place demands on the groundwater resource. Rivers can be reliant on groundwater to maintain flows, while wetland areas or certain terrestrial ecosystems rely on groundwater for their wellbeing. In desert oasis areas, shallow groundwater levels have maintained natural vegetation for centuries, thereby averting the encroachment of the desert. Groundwater for human use obviously competes with the requirements for the natural environment. Overuse through human consumption results in the lowering of the groundwater table. This can lead to severe environmental degradation and even the destruction of areas inhabited by humans.

Human activity also forms a threat to the quality of the groundwater resource. The use of fertilisers and pesticides/herbicides in agriculture forms a threat of diffuse pollution, which is particularly important when groundwater is used for human consumption. Industrial activity and accidental spillage of poisonous substances can be a severe source of point pollution and a clear threat to groundwater quality. If undetected, it can form a serious threat to human health, particularly when contaminated groundwater is used for human consumption. Once an aquifer is contaminated it is often either very expensive or impossible to re-instate good conditions.

Groundwater contamination: Arsenic

Groundwater is an important resource, especially for rural populations, yet there is now evidence that unsafe levels of arsenic are present in many Asian countries. The impacts cut across many sectors – from water supply, to irrigation, health, and education.

Bangladesh and West Bengal in India were the first countries where the discovery of arsenic triggered mitigation and research responses. In the meantime, due to increased testing, arsenic has also been found in Cambodia, Lao, Myanmar, Nepal, Pakistan, Vietnam, several provinces in China, and additional states in India. An estimated 65 million people in Asian countries are at risk of ingesting unsafe levels of arsenic through drinking water.

Arsenic contamination is a long-term issue and, with extended screening, more affected areas are likely to be found in the future. There are also other toxic trace elements – such as fluoride, manganese and boron – which are found in groundwater and require similar approaches. Interventions and actions by governments and their development partners will therefore be required at the local, national and global levels simultaneously.

There is clearly a need for balancing the needs of humans and the natural environment, and a need for sustainable management of the groundwater resource so that future generations as well as the environment don't suffer the consequences of uncontrolled use of groundwater.

Problems associated with overuse of limited groundwater resources are evident throughout the world. The realisation that sustainable use is a clear requirement has led to new legislation related to various aspects of

groundwater resources management. Such legislation places more and more emphasis on the protection of the natural environment and on the need to protect the groundwater resource from the threats of pollution.

There is also a growing realisation that groundwater resource challenges cannot be successfully overcome by the use of technical solutions only. The human element is equally important and needs to be given the appropriate attention and priority. Such human elements relate to institutional aspects as well as to communication and participation at different management levels. Furthermore, an important human component relates to education at all levels within society. There is thus a need for a holistic approach to groundwater management and this is embedded in the principles of IWRM. A holistic approach also means that groundwater management can not be undertaken in isolation. Addressing all different aspects of the land and water system, with groundwater forming a component, is essential.

The emphasis of IWRM on a co-ordinated and integrated approach clearly warrants a co-ordinated approach to the planning and execution of groundwater monitoring. Effective management of groundwater resources requires knowledge of the behaviour of groundwater systems (both in relation to quantity and quality) and the interaction with the surface environment. Such knowledge relies heavily on the availability of monitoring data, which provides direct evidence of the response of the groundwater system to changes in climatic conditions and human activities (such as for example groundwater abstraction). Emphasis and responsibilities will differ depending on the management level and on the significance of groundwater to humans and the environment. Monitoring is not just a technical issue and there is a clear need for integration of monitoring at the different management levels, with clear lines of communication, active participation and a pro-active approach to data dissemination and sharing. It is also important to consider groundwater monitoring in the context of financial constraints.

Consequences of groundwater overuse

In Minqin County, Gansu Province, shallow groundwater table conditions existed prior to the introduction of large scale groundwater abstraction for irrigation. This shallow groundwater table had for centuries supported extensive natural vegetation, including grasses, shrubs and trees. The over-use of groundwater as well as human interventions that have reduced recharge, have resulted in a significant decline in the groundwater table to the extent that it can no longer support the natural vegetation. The consequences have been the death of natural vegetation and a threat of serious desert encroachment.

Sand encroachment in Northern Minqin

2 What is Groundwater Monitoring?

The following has been extracted from GW•MATE Briefing Note No. 9 "Groundwater monitoring requirements for managing aquifer response and quality threats" published by the World Bank/Global Water Partnership:

- *Groundwater monitoring comprises the collection, analysis and storage of a range of time-variant data on a regular basis according to specific circumstances and objectives.*
- *The type and volume of data required will vary considerably with the management issue being addressed, but is also inevitably dependent upon available financial resources.*

Groundwater monitoring is a process and does not just involve the collection of data through measurements at monitoring facilities. To extend the words contained in the above quotes from Briefing Note No. 9, the process of groundwater monitoring includes the following:

- The development of an appropriate groundwater monitoring protocol, which includes the aspects of monitoring that are listed in the following bullets. The word appropriate is introduced to indicate that **monitoring serves a clearly defined purpose and known objectives,** all within the constraints of financial resources:
  - Establishment of monitoring facilities relating to all natural and anthropogenic influences on the behaviour of groundwater. **Account should be taken of the density of the monitoring network and the frequency of monitoring.**
  - Collection of information from the monitoring facilities that is according to **scientific rigor appropriate to the level and the detail of the monitoring.**
  - **Storage and retrieval of the collected data** in a manner that ensures that it is **easily retrievable and available for further analysis,** both in the immediate and longer-term future. This requires attention to the type of storage and retrieval systems (paper files and/or computer applications), and the methods used for storage and retrieval (this could include specific software applications such as database/GIS systems). The type of storage and retrieval systems would depend on the groundwater resource management level (explained below).
  - **Processing and analysis systems** that allow the data to be prepared for applications used in groundwater resource assessment, management and forecasting. Such systems could range from simple forecasting of hydrogeological trends to the application of complex integrated surface water and groundwater models, this again depending on the management level. Reference is made to Thematic Paper 1.2

'Groundwater Resource Quantity Assessment'.

- **Sharing of data** between the different groundwater resources management levels and the publication of information for use by interested stakeholders. This requires **data/information enquiry systems** that allow for easy access.
- **Clear definition of roles and responsibilities** at the different management levels.

Groundwater monitoring plans thus encompass much more than just the collection of data. A monitoring protocol, which is encapsulated into a monitoring plan, should include the following:

- Establishment of monitoring facilities
- Collection of information from the monitoring facilities using accepted methods
- Development of effective data storage and retrieval facilities
- Development of data processing, analysis and visualisation systems for use in groundwater resource assessment, management and forecasting
- Establishment of effective and agreed data sharing and dissemination
- A clear definition of roles and responsibilities at the different management levels
- Ensuring the use of well-trained staff and the allocation of adequate financial resources

To emphasise again, monitoring should serve a clearly defined purpose and known objectives, all within the constraints of financial resources. It is also important that roles and responsibilities for monitoring are clearly defined for each management level.

Dead forest

3 How is Groundwater Data Used, What is Needed and Who by?

3.1 How is groundwater data used?

Groundwater data is used to serve a variety of purposes, depending on the management level and on what key issues need to be addressed in the river basin or parts thereof.

River basin level

The need for monitoring data at the river basin level is largely related to the management of water resources within the river basin as a whole and particularly the use of water resources simulation models.

Key needs for groundwater monitoring include:

- to enable accurate assessment of total available water resources;
- to understand interactions between surface and groundwater and therefore build a conceptual model of water resources interactions within the basin, as well as define potential pollutant pathways;
- to enable the development of reliable water resource management tools in order to achieve surface water and groundwater utilisation that ensures sustainable and equitable distribution and use of water for different purposes.

Good quality groundwater data is particularly important where simulation models are used as water resource management tools. The ability of a model to accurately predict future behaviour of a groundwater system under a variety of resource management scenarios depends to a large extent on the availability and accuracy of the above-mentioned data. Two categories of accurate data are required for model input:

1. data needed for the definition of inflow and outflow components, particularly recharge from distribution system losses and irrigation returns, and discharge, particularly groundwater abstraction, and

2. data needed for model calibration and thus data needed to compare simulated with observed groundwater behaviour. Such data includes in particular the spatially and time variant groundwater levels.

Other management levels have an important role to play in the provision of data required for use in water resource planning models. The feedback of the simulation results to those who have supplied the monitoring data is a responsibility for authorities involved with management at the river basin level.

County/Municipality level and WUA level

Groundwater management at County/ Municipality level and at the WUA level is more closely related to local issues. Groundwater monitoring thus has a different focus to that required for regional scale management, although the different levels of management should be seen as closely integrated rather than separate. Groundwater monitoring at County/ Municipality and WUA levels is particularly important in areas where groundwater is heavily utilised and where groundwater levels are falling and/or groundwater quality is deteriorating. In such areas, the need

for monitoring can be summarised as follows:

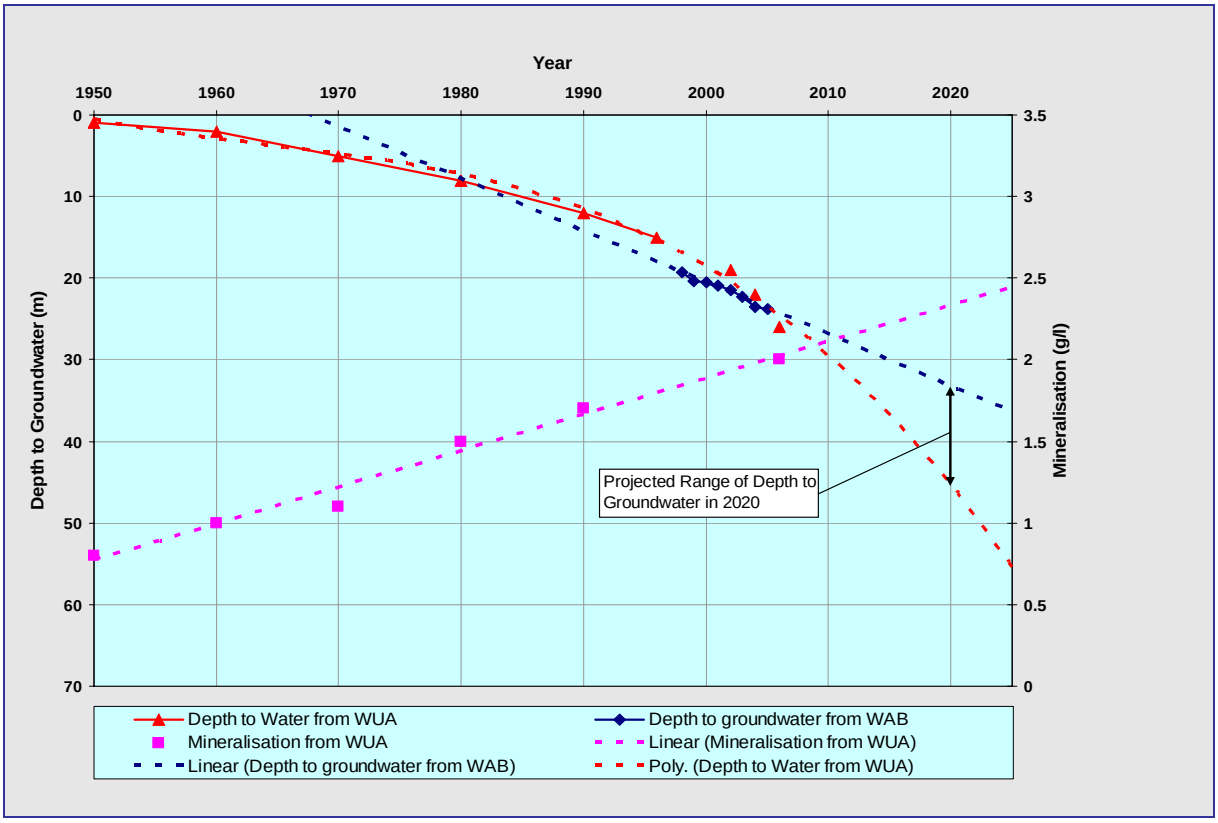
- To enable the analysis of groundwater levels to forecast trends and identify areas where groundwater levels are dropping rapidly. This information is important to farmers, because groundwater levels impact on their ability to abstract water at affordable cost. This type of monitoring can be undertaken at irrigation district level (by WMS/WAB) or at the WUA level. Figure 1 shows an example of how groundwater level and salinity data can be used for simpler forecasting.
- To enable the analysis of levels in urban areas for water supply wells and wellfields. Groundwater level monitoring and groundwater quality data is often even more critical in urban areas since any reduction in supply is less easily accommodated and can have disastrous implications. Good planning and continuous monitoring is thus essential.
- To forecast groundwater salinity trends. This is important for both water allocation within the river basin and for advising farmers on the need for alternative crop choices, with more focus on salt tolerant crops. This type of monitoring can be undertaken at irrigation district level (by WMS/WAB) or at WUA level.
- To identify groundwater water quality changes, this may impact on human health if groundwater is being used for domestic purposes.
- To verify abstraction returns supplied by permit holders and thus allow for better estimates of actual groundwater use.
- To allow higher level authorities to achieve optimum water allocation strategies. Data from both the primary network (administered at the higher level) and the secondary network (administered at the lower levels and possibly with less rigor) is of high value for this purpose

3.2 What groundwater data is needed for IWRM?

The components of a groundwater resource assessment are summarised in Table 1. Although this report is related to groundwater monitoring, it is clear from the column “Data requirements” that information on surface water, as well as climate, agriculture and industry, is also needed to fully understand groundwater behaviour. It is therefore important that those responsible for surface water and groundwater monitoring appreciate the inter-relationships between surface water and groundwater bodies and thus design monitoring systems in a way that ensures completeness in data collection.

Data required for a complete groundwater monitoring system must include all data that is directly or indirectly related to groundwater, but ultimately depends on the objectives for using the data. The following questions need to be asked: What data components are required to answer the questions that have been set? Is this data available? Is the data of sufficient frequency and spatial coverage? Is the data of adequate quality and accuracy?

Figure 1: Graph showing past and projected groundwater levels and mineralisation



The graphs above relate to groundwater level and salinity monitoring in Minqin County in Gansu Province. The data obtained from the WUA shows an accelerating trend in the depth to groundwater, while the graphs based on monitoring by the WAB shows a more linear trend. Both graphs clearly indicate a continuing downward trend in groundwater levels. The data for the period prior to 1970 indicate shallow groundwater table conditions and the beginning of the decline in groundwater level. The salinity graph is representative for areas where groundwater is over-abstracted. Most likely due to considerable re-circulation of groundwater, salt accumulate and cause a gradual increase in groundwater salinity. The trend shown here is linear, but this is likely to be a coincidence.

Typical monitoring components are:

- groundwater levels;
- groundwater quality;
- groundwater abstraction;
- meteorological data;
- water use (groundwater and surface water) in agriculture
- water use in other sectors, and
- land subsidence information when this is attributed to over-abstraction of groundwater.

Each of the above listed monitoring components is discussed briefly in the following sections. More detailed recommendations for monitoring these components are given in Advisory Note 2.6/1 ‘Groundwater Monitoring - River Basin to County Levels’, and in Advisory Note 2.6/2 ‘Groundwater Monitoring at Village Levels’. These advisory notes make reference to the technical standards for monitoring different components developed at the national level.

Groundwater levels

Groundwater levels are required to:

- obtain spatial and time variant distribution of groundwater levels (Figure 1);
- determine groundwater flow rate and flow direction;
- allow for identification of historical trends and thus for forecasting future levels, and
- be used as calibration targets in groundwater models.

For the regional assessment of groundwater resources, groundwater levels contribute significantly to the understanding of groundwater behaviour. However, as with all other components that describe the groundwater system (refer to Table 1), groundwater levels on their own are insufficient to fully describe groundwater behaviour. For example, understanding temporal changes in groundwater levels requires an understanding of groundwater recharge and discharge components and the geological/ hydrogeological characterisation of the groundwater system.

Groundwater quality

Groundwater quality can affect both crop production and human health.

For crop production it is the groundwater salinity that is of main concern. Groundwater salinity can increase over time as a consequence of the continuous re-circulation of water during the irrigation process, leaving salts behind on the land surface and within the upper soil profile. The process of salinity increase is slow because of the large volume of the groundwater reservoir, yet steady because of the continuous influx of salts. Not only will high groundwater salinity impact on the crop growth and consequently the crop yield, it will also require additional irrigation water for leaching of soils.

For human health, it is not only groundwater salinity that is relevant, but other chemical constituents as well. Pollution incidents such as chemical spills and diffuse pollution from agriculture can cause unwanted chemical constituents to enter groundwater. Appropriate monitoring protocols are required to enable identify the occurrence of chemical constituents that are harmful to human life.

Ideally, groundwater quality should comply with Chinese water quality standards.

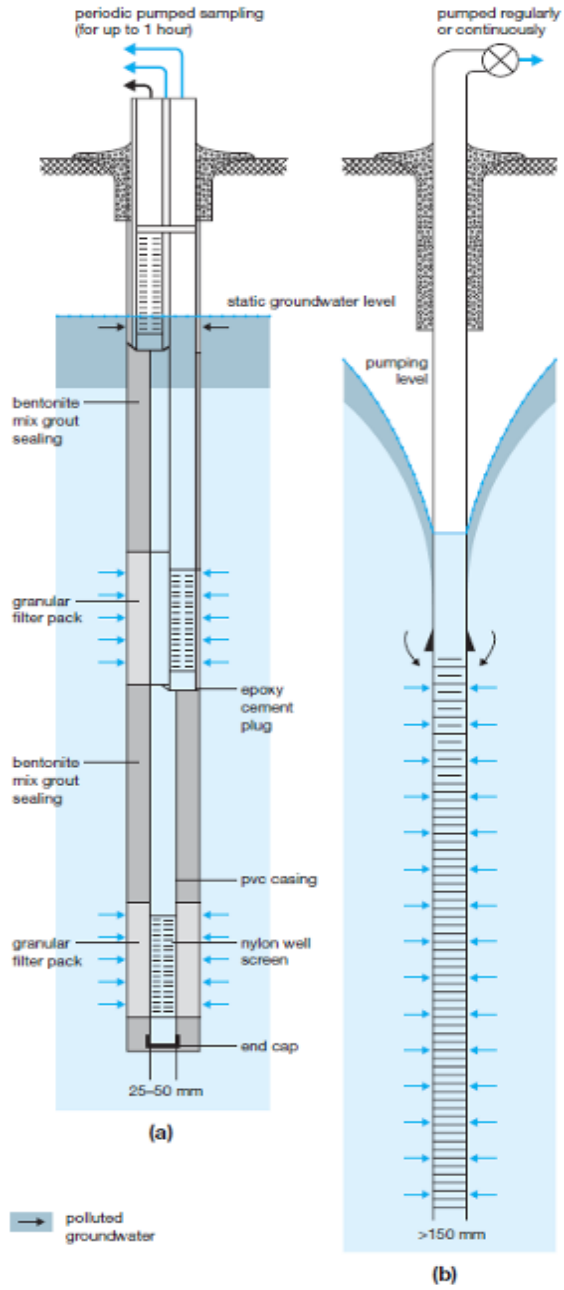
In general, groundwater quality changes slowly over time and so the frequency of measurement need not be the same as for groundwater levels (an exception may relate to point pollution incidents).

IC card control box in Minqin County

Table 1: Components of groundwater resource assessment

Water balance/ resource component		Data requirements (monitoring data shown in bold)
Lateral flow across aquifer boundaries		• Elevations on base of layers • **Groundwater levels for layers** (spatial and temporal distribution) • Aquifer transmissivity
Leakage flows between aquifers		• Thickness of layers • **Groundwater levels for layers** (spatial and temporal distribution) • Vertical permeability
Storage changes		• Storage coefficients (unconfined & confined) • Groundwater levels for layers (spatial and temporal distribution)
Recharge	Natural (rainfall)	• Mapping of non-irrigated areas • Spatial and temporal distribution of **rainfall** • Soil classification and parameters (to assess soil moisture balance of root zone) • **Evapotranspiration** • Data from reports, climate stations and modelling studies
	Urban	• **Gross potable supply to urban areas** • "Return flow" factor (factor defining proportion of gross supply returning to groundwater)
	Irrigation	• **Gross irrigation supply and canal flows** • **Irrigated areas** • Irrigation efficiency factors including field application and distribution efficiencies
Surface water – ground water interaction	River/canal aquifer interaction	• **Groundwater levels** • **River levels** (together with groundwater this enables determination of surface water and groundwater interaction). • **River flows** at key gauging points • **Diversions** (together with river flows this enables carrying out a water balance for river reaches and determining whether the river is "gaining" or "loosing" water from/to the aquifer) • River surface area (could be time variant) • River bed conductance (together with river surface area enables estimation of possible seepage to the aquifer using analytical techniques)
	Reservoir aquifer interaction	• **Reservoir levels** • Surface water area (often directly related to reservoir level) • **Groundwater levels**
Discharge	Abstraction	• Well permit records • History of number and types of well • **Average daily abstraction** for irrigation, industry and domestic use • Irrigated areas, cropping calendar, crop demands, crop quotas and irrigation efficiency
	Capillary losses (only in shallow water table areas)	• Ground surface elevations • Soil types and their physical parameters • Rooting depths for various crops • **Groundwater levels**
Groundwater and Surface Water Salinity		• **Historical groundwater salinity data** • **Salinity of recharge components** • **Salinity of abstracted groundwater**

Figure 2 Comparison of monitoring well with an abstraction well



The advanced monitoring well allows capture of vertical groundwater level differences and water quality variation with depth.
The abstraction well gives mixed values for groundwater level and water quality and measurements are influenced by abstraction

Groundwater abstraction

Accurate knowledge of the quantities of groundwater extracted for agricultural, forestry, domestic and industrial use is essential for the effective management of water resources at a basin level and is important to the accuracy of groundwater resources simulation models.

If there are a large number of abstraction wells in the basin, estimating total groundwater abstraction can be a difficult task and estimates are often derived from indirect methods and thus subject to uncertainty.

Direct measurement of abstraction using flow meters is very accurate but expensive. Indirect methods for abstraction estimation include: measurement of pump operation hours, measurement of motor electrical consumption and, if the groundwater is used for irrigation, measurement of cropped areas, crop types and irrigation norms provides an alternative estimate.

It is furthermore important to undertake monitoring of net groundwater use and thus determine the proportion of gross abstraction returning to the groundwater system in the form of recharge (often referred to as urban recharge in the major towns where piped distribution systems are present, or irrigation return flow in irrigated areas).

Meteorological data

The main climatic parameters are rainfall and the climate factors that determine evapotranspiration of crops and other vegetation.

Rainfall data is important in determining the rainfall contribution to crop water use and to groundwater recharge. Temperature, humidity, wind speed and sunshine hours are used in the

calculation of reference crop evapotranspiration, which determines the water needs for crops and other vegetation (including planted forest) during different stages of their development.

Water use in agriculture

Water use in agriculture is from three sources; natural precipitation, surface water and groundwater. In northern China, the contribution of natural precipitation to total water use is normally small and irrigation supply from surface water and/or groundwater is the major part.

In irrigated rural areas, groundwater recharge largely occurs through the return flow to the groundwater table of surplus water. The amount of recharge is not known with any precision, although it is an important input component to groundwater models. It can be estimated by taking into account the actual crop consumptive use of different crops, the total quantity of water applied to the cropped areas (the sum of water derived from rainfall and diverted from irrigation canals) and the gross quantity of groundwater used for irrigation. It also includes losses from water distribution systems.

The increase in irrigation efficiency will generally result in a reduction in the gross water use. It will, however, also reduce the recharge to groundwater and thus net savings of the resource may be marginal. Reductions in net water use for agriculture can be achieved through changes in cropping patterns with more extensive use of crops that require less water. However, if water savings are used for more irrigation overall, recharge can be reduced.

Water use in other sectors

Groundwater is widely used for public water supply and for industrial water supply for reasons of accessibility, quality and reliability of supply. It is important to monitor gross groundwater abstraction and also the supply from surface water sources (if any). Also important is the information required to calculate return flows to groundwater in the form of loss from water supply distribution and drainage networks.

3.3 Who uses groundwater data?

Groundwater data is important to all management levels, from water user groups who use groundwater for irrigation, to basin level authorities who are responsible for allocating water across the basin and water resources management.

Given that an important part of IWRM is to actively involve all stakeholders in the water monitoring and management process, it is clear that all management levels should have responsibilities for collecting and analysing data.

The emphasis of IWRM on a co-ordinated and integrated approach clearly warrants a co-ordinated approach to the planning and execution of monitoring. So, although the emphasis of the monitoring will differ depending on the management level, integration of monitoring at the different levels is needed. This should involve clear lines of communication and a pro-active approach to data dissemination and sharing. The overall focus at the different management levels should not be seen as separate, but as being closely inter-related as well as complimentary.

River basin level

At the river basin level there is need for both collection of data that feeds into the river basin management tools (the simulation models in particular) as well as supplying data/information (for example outputs from the simulation models) required by the County/Municipality for sub-regional and local scale resource evaluation, planning and management.

Technical aspects of monitoring at the river basin level are contained in the Advisory Note 2.6/1 'Groundwater Monitoring - River Basin to County Levels'.

County level

The management at County level is usually undertaken by the Water Affairs Bureau (WAB). The groundwater management at County/Municipality level is more closely related to local issues, and the focus is thus different from the management of groundwater resources at a river basin scale.

The WAB is responsible for the monitoring and processing of surface water allocation, groundwater use, groundwater levels and water quality data, including that obtained from the WUAs. The WAB is also responsible for permit administration and associated monitoring.

At County level there is need for both collection of data that feeds into the river basin level management system as well as data used for County and local scale resource evaluation, planning and management. Processed information should therefore be passed on to the river basin level for use in their management tools as well as disseminated to other management levels and to stakeholders.

Technical aspects of monitoring at County level are contained in the Advisory Note 2.6/1 on 'Groundwater Monitoring - River Basin to County Levels'. Reference to National Standards (referred to in the bibliography) and provincial/local instructions should also be made.

WUA level

Management at WUA level relates to local scale use of water and land resources. Monitoring at this scale will be of direct benefit to the communities. It will also benefit the higher management levels, particularly once monitoring systems are in place in all WUAs. Table 2 outlines the responsibilities that could be given to WUAs for the monitoring of relevant groundwater data for their needs.

Monitoring is an essential component of effective self-management of water resources at the WUA level. This is particularly important when there are potential water shortages and there is a need for adjustment of cropping patterns so that less water demanding crops are favoured. Monitoring of water use and recording of cropping patterns (crop types and related areas) by the WUA allows for annual evaluation and thus for judgement of the success of implementation of changes in water use and cropping. Learning from experience, and communication of this experience within the WUA and preferably amongst different WUAs will lead to ability to face the challenges of coping with reduced amounts of water.

Monitoring of groundwater levels in conjunction will also enable the WUA to judge the changes in the groundwater table over time. Knowledge of such changes are useful to the WUA in determining what measures are required to avoid wells running dry or performing poorly. The aim in the longer

term is to halt and/or reverse falling trends in groundwater levels. If this is not the case, then the WUA can pro-actively communicate with the WAB (and via the WAB with higher level authorities) and report the situation. Such feedback is important for the successful management of water resources at the river basin level.

Other organisations

Other organisations that undertake monitoring are affiliated with other ministries (MLR and (EPB) MEP). It is important that data collected by such organisations is available for use in the development of groundwater assessment tools. It is thus important that data sharing arrangements between organisations are established and that such arrangements are made effective. Monitoring duties of these organisations should be seen in the context of their overall duties, as explained in the following two bullets:

- **The Ministry of Land Resources (MLR)** - manages hydrogeological surveys and assessments; undertakes geotechnical and geo-environmental assessments; monitors and regulates groundwater abstraction; and protects groundwater from over-abstraction and pollution.
- **The Ministry of Environmental Protection (MEP)** - is responsible for protection of the environment from pollution and for environmental regulation.

Example: Management levels in Shiyang River Basin

Within the Shiyang River Basin three management levels have been identified which have responsibility for groundwater monitoring:

	Scale	Management Level
1	River basin	Shiyang River Basin Management Bureau (SRBMB)
2a	County / Municipality	Water Affairs Bureau (WAB)
2b	Irrigation district	Water Management Station / District (WMS/WMD)
3	Local	Water User Association (WUA)

Although the roles and responsibilities will differ for the three management levels, a clearly defined integrated approach to monitoring is required. An integrated monitoring plan has been developed with sub-components included for each management level.

Table 2 Monitoring components and responsibilities at WUA level

Monitoring Component		Type of Record	Monitoring Unit	Responsibility
Irrigation Water Use	Groundwater	Electricity use or direct readings/ measurements	Production group	Production group leaders
	Surface water	WMS records and timings of irrigation	Production group	WMS representatives/ production group leaders
Cropping		Areas for individual crops	Production group	Production group leaders
Groundwater levels		Depth to water measurement	Selected wells (possibly one for each production group)	Production group leaders

4 Recommendations for Groundwater Monitoring Systems

4.1 Groundwater monitoring facilities and techniques

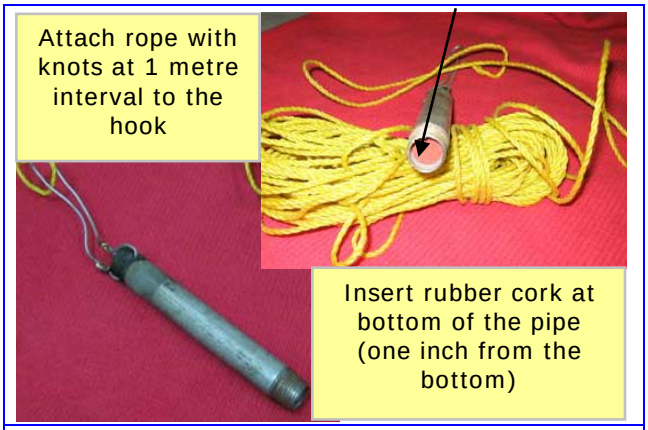
Recommendations for setting up monitoring facilities and specific techniques for actual monitoring of different parameters are outlined in the following documents:

- SL 183-2005 – Technical standards for groundwater monitoring
- Advisory Note 2.6/1 – Groundwater Monitoring - River Basin to County Levels
- Advisory Note 2.6/2 – Groundwater Monitoring at Village Levels

4.2 Monitoring equipment

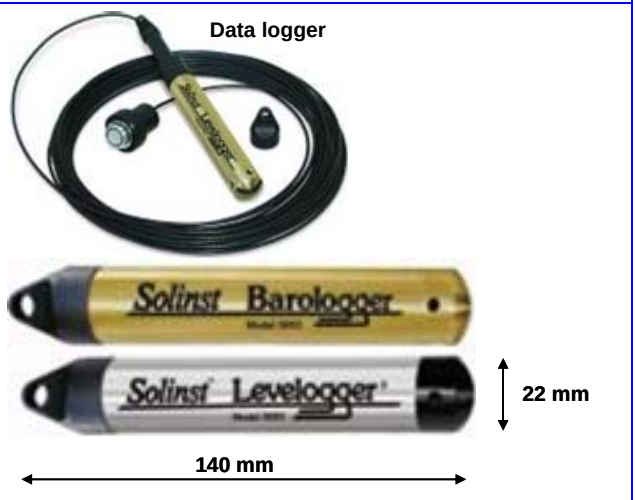
Monitoring equipment is closely related to the monitoring components. Equipment can range from very simple and low cost, to very advanced and high cost. The choice of equipment depends on criteria such as those listed in the following:

- The purpose of monitoring and associated level of accuracy.
- Simple methods are not necessary less accurate than very advanced methods. For example manual dipping of groundwater levels, if done with care, can be as accurate as levels obtained using data loggers.
- Cost plays an important part in the choice of equipment. One has to balance the use of simple equipment (cheap) combined with the cost of labour (could be high), and the use of advanced equipment (expensive) and less labour cost (automation). In this context one also needs to consider the cost of storage and maintenance of equipment, transport cost, etc.



Basic groundwater level monitoring device

Standard groundwater level monitoring device



Advanced groundwater level monitoring device

4.3 Data analysis and visualisation

The type of data analysis carried out will depend on the use of the data for the various management functions. It should be noted that data analysis and visualisation go hand in hand and are therefore mutually supportive.

In the following sections the use of analysed groundwater monitoring data for specific purposes is discussed in more detail.

Use of data in water resources assessment and modelling

Data items for groundwater resource assessment are indicated back in Table 1. The data listed in this table is required for direct or indirect incorporation into groundwater models as well as for normal hydrogeological analysis. The items listed in bold refer to monitoring data.

Monitoring data, particularly historical groundwater levels, which describe the spatial and temporal distribution of groundwater levels, are needed in the model calibration process. Groundwater level monitoring data can also be used for determination of aquifer properties as shown in Figure 3.

Use of data for abstraction permit management

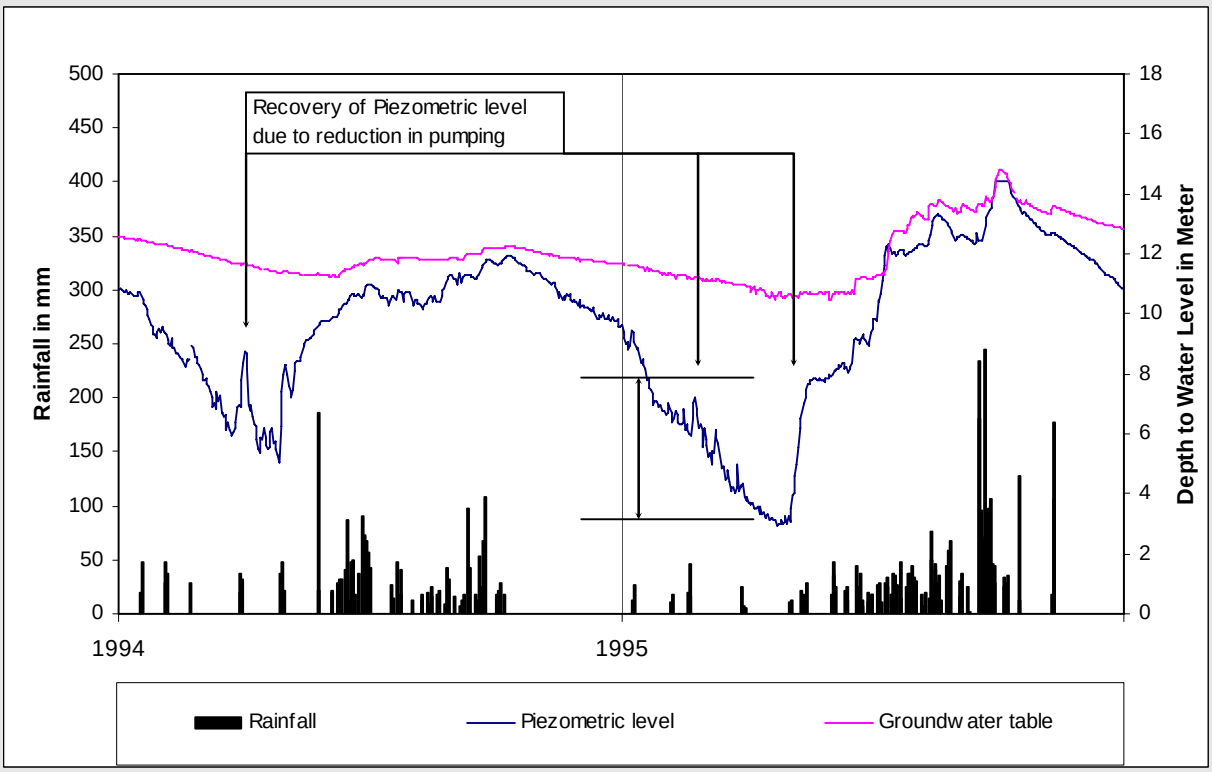
Abstraction permit management will include a number of components all of which will require specific monitoring. The components include:

- Identification of unregistered wells (wells without a permit).
- Monitoring of abstraction data, particularly if based on electricity consumption and pumping rate, will allow for checking of annual groundwater abstraction against the permitted amount. Demand management requires the checking of actual abstractions to avoid overuse of groundwater.
- Groundwater level and water quality monitoring will provide time series that can be extrapolated into the future. This will enable the WAB to assess the criticality of the groundwater situation and provide advice to farmers and close wells if necessary.
- Monitoring data that feeds into the resource assessment models. Feedback from these models, when operated in predictive mode, will enable the WAB to take rational decisions about the reduction of the number of registered wells.

Use of data in water management

The use of groundwater level and quality monitoring at the WAB and WUA management levels will, as already mentioned before, enable the forecasting of groundwater levels and salinity based on historical trends. Such forecasts will allow for the planning of actions, which could include: reduction in water use through changes in cropping patterns, informing the higher level authorities about the criticality of groundwater conditions in certain areas, informing the WUAs about the possible need for deepening of wells or pump setting, and, possibly as a final resort, taking wells out of production. However, deepening of wells must be critically and cautiously investigated since it could just aggregate the resource over-use.

Figure 3 Example of using groundwater levels for determination of aquifer properties, in Bangladesh



Determination of Vertical Permeability of the Upper Clays

Abstraction reduction occurs when significant rainfall occurs and can satisfy crop demand.

The recovery of piezometric level to reduction in pumping follows from the Darcy equation as follows:

$$q = k * delh / D$$

where

q - reduction in gross abstraction (in mm/d/unit gross area)

k - vertical permeability of upper clays (mm/d)

delh - recovery in piezometric level (m)

D - saturated thickness of the upper clays (m)

If gross abstraction is equal to 7 mm/d and the total cropped area is 50% of gross area, then the reduction in gross abstraction will be 3.5 mm/d/unit gross area. The saturated thickness of the aquitard is about 10 m while the recovery is about 2.7 m. Using this information a permeability value of about 13 mm/d is derived.

If one applies a similar analysis to the rapid recovery after the irrigation season in 1995, and assumes that gross abstraction reduction per unit gross area is 4.5 mm/d, one derives a value for the permeability of about 10 mm/d (for a recovery of about 4.6 m)

Although not exact, the estimates for the vertical permeability provide valuable feedback to the model.

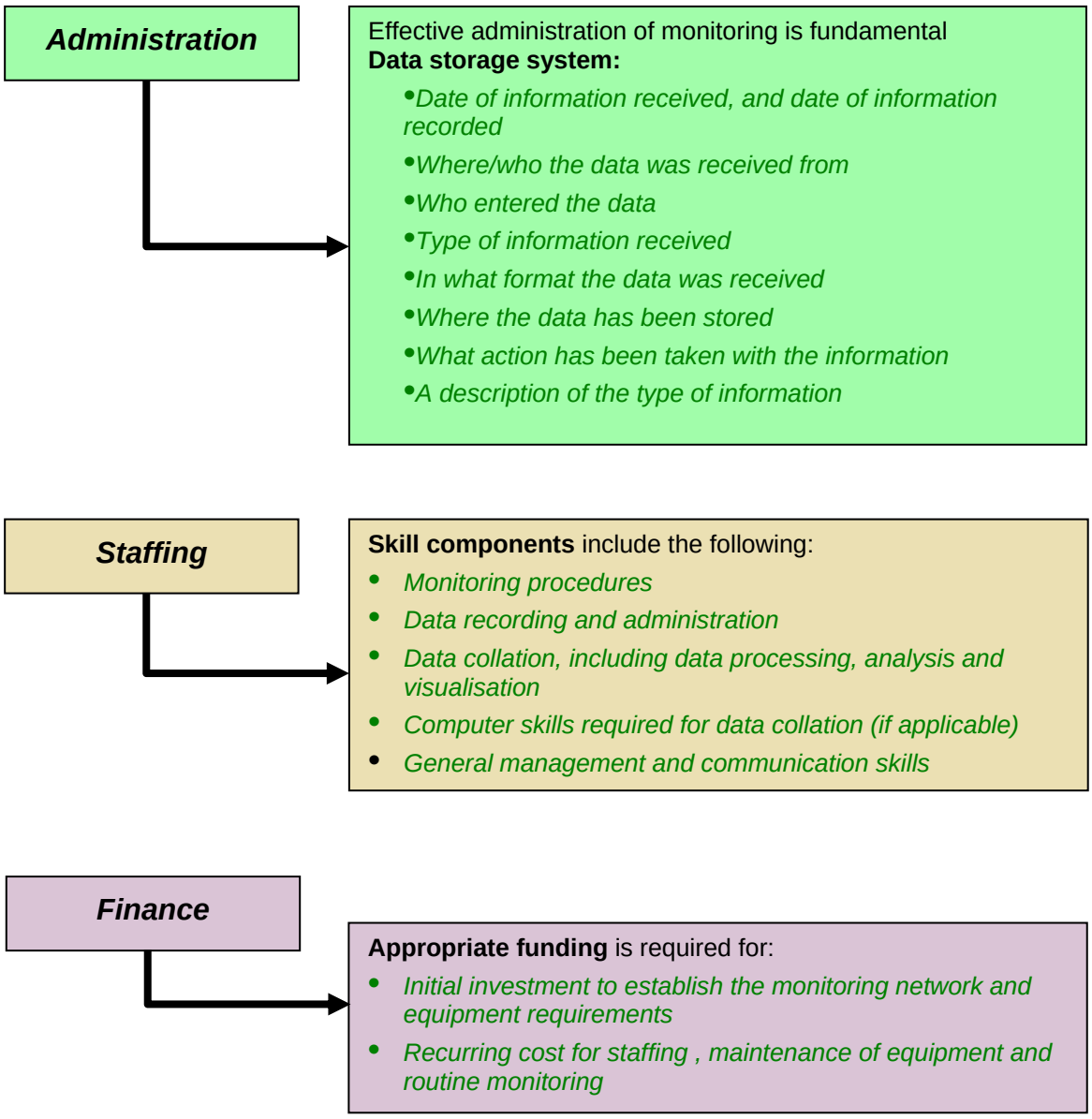
Uncertainties relate in particular to the gross abstraction estimate.

5 Institutional Recommendations

5.1 Administration – Recording, storage and processing of data

Effective administration of groundwater monitoring is a fundamental component of a monitoring plan and will ensure its beneficial impact on integrated water resources management. Aspects of administration, staff skills and finance are summarised in Figure 4.

Figure 4: Organisational aspects of monitoring



When data is recorded and received from any source, then the receipt of this data should be recorded in an appropriate data storage system. For the higher management levels this would be a computerised system, while for the WUA level it would comprise a paper filing system. The data storage system should at least record the following information:

- Date of information received, and date of when information was recorded (if applicable)
- Where/who the data was received from (e.g. Minqin County WAB)
- Who entered the data
- Type of information received (e.g. groundwater level, GIS data, report, etc.)
- In what format the data was received (e.g. electronic, paper, etc.)
- Where the data has been stored (e.g. filing cabinet 1, link to file on C:\ drive, etc.)
- What action has been taken with the information (e.g. none, filed, transferred from paper to electronic form, etc.)
- A description of the type of information (e.g. 30 groundwater levels for Minqin County, number of well readings taken from, etc.)

This recording process is known as Quality Assurance (QA). It allows data to be easily stored, located and retrieved. It is also a comprehensive record of what information is available and can allow data, which may have been forgotten about, to be relocated. Similarly, a record of what information has been disseminated should be kept, recording where and what was sent. This record will allow for checks to be made in case any information is lost or misplaced and data can then easily be retrieved and re-sent.

Transfer of data in paper format from the WUA to the WAB should be followed by entry of such data into computerised storage and processing facilities, after which they can be made available to the river basin management level.

To allow for a fully integrated monitoring system, there should be consistency between the river basin management and the WAB management levels in the types of storage and processing facilities used so that data transfer can easily be facilitated.

5.2 Staff and capacity building

It is important that sufficient staff are available with the necessary administrative and technical skills to effectively and efficiently undertake the monitoring tasks for which they have responsibility.

Skill components include the following:

- understanding of hydrogeology and hydrology
- monitoring procedures;
- data recording and administration;
- data collation, including data processing, analysis and visualisation;
- computer skills required for data collation (if applicable), and
- general management and communication skills.

It is usually necessary to undertake a training needs assessment to identify the type of training required and to estimate the cost of training of staff.

It is also necessary to assess the adequacy of computer hardware and software and identify necessary computer upgrades and costs. Software used for storage, processing and analysis generally includes Excel, database software (for example Microsoft Access) and GIS.

5.3 Finance

Appropriate funding is required for undertaking all monitoring tasks and should cover two aspects:

- An initial investment is required to establish the monitoring network, and to cover equipment requirements (including computer hardware and software facilities), office facilities and training needs.
- Finance to cover recurring annual costs for staffing, maintenance of equipment and routine monitoring. The determination of this cost will be a function of the frequency and type of monitoring required.

5.4 Data sharing and dissemination

Groundwater monitoring data must be part of a water resources database. Such a database should include all monitoring data (as listed in Table 1) required for resource assessment and modelling.

Information sharing, and the communication that is closely linked with it, is one of the cornerstones of IWRM.

Amongst the different management levels and the stakeholders there is an increased acknowledgement that sharing of information and data and the dissemination of results from data analysis and modelling is essential to the effective management of water resources. There is also a clear understanding that data/information sharing relates to all resource management levels and that it applies to both within and between management levels.

The dissemination of information should be proactive; it is important that the higher level river basin authorities are not just seen as ‘receivers’ of information but also as ‘givers’. It is important that a data sharing and dissemination strategy is developed, which outlines the communication channels and the format of disseminated data, and also identifies stakeholders and their data needs.

The following sections provide advice on how effective data/information sharing and information dissemination can be achieved. To become successful and effective, it does require active participation and commitment at all management levels.

Cost effectiveness of monitoring

Effective groundwater monitoring is characterised by two key requirements (according to Global Water Partnership):

- It should be driven by specific objectives - monitoring for its own sake often leads to inefficient use of manpower and budgets.
- The data collected should be systematically stored for future use - there are far too many cases of monitoring data being ‘lost along the way’.

When considering how detailed monitoring should be, one has to consider the following:

- the added value to accurate resource assessment;

- the cost of additional monitoring facilities - equipment, personnel, transport etc; and
- possible opportunities for provision of data at limited cost (for example, through annual abstraction returns and involvement of water users in monitoring).

Options for data sharing

Data sharing relates mainly to processed data and is used to inform the different management levels and stakeholders. It can, however, also include the sharing of raw data if this is required for specific analysis for specific purposes.

Recommendations for data sharing include:

- Exchange of data and knowledge within management levels requires easy access to data/information. Within WUAs information could be kept at the Village Committee office and at the WUA office (if this exists). Such information would include the monitoring data collected by the WUAs as well as information dispatched by the other management levels. Such information could also usefully include details about data/knowledge/experience from other WUAs. Information held at these offices should be freely available to community members and should be actively disseminated to community members.
- Data collected at WUA level should be transferred to the WAB, where it can be incorporated into a storage and retrieval system. It should be subjected to quality checks and be corrected if needed. Analysis of data could take place as well. It should be the duty of the WAB to share this checked and analysed data with other WABs and the other management levels. Feedback to the WUAs is particularly important.
- The WAB and WUA have an important role in the monitoring of data required for water resource models. The raw data should be subjected to checking and processing before it is passed on to the river basin management level.
- The management at the river basin scale is the responsibility of the river basin management bureau (if one exists). In some cases the responsibility for the monitoring of groundwater levels and quality is contracted out to a Hydrology Bureau, or a similar organisation. If this is the case, clear procedures for data sharing and information dissemination need to be established. One option would be to establish a website which would be accessible by the different management levels and by relevant stakeholders.
- The groundwater monitoring needs of the river basin management bureau (RBMB) are not limited to groundwater levels and quality and include data required for inclusion in water resources management models. This data is normally collected by the WAB and WUA management levels. The data should be processed by the RBMB and models run to assess future water resources planning and management scenarios. It is very important that such analysed data and model results are shared with the other management levels. In practice this would involve dissemination to the WAB and

subsequent dissemination by the WAB to the WUA.

- Data sharing with stakeholders should be pro-active, for example through the establishment of a web-based data repository, or through the preparation of annual yearbooks send out to the stakeholders. It should also be reactive in response to stakeholders' requests for data. Issues that need to be considered include:
  - Is the information specific to the information/data request?
  - Could a charge be levied for supply of information/data?
  - Are there confidentiality issues?
- The process of data sharing should become part of a communication and dissemination strategy which is adhered to by all management levels and relevant organisations/stakeholders.
  - The communication and dissemination strategy should include exchange and communication protocols and a clear understanding and appreciation of the roles and responsibilities at the different management levels.
  - The process of formulating a communication and dissemination strategy should involve a discussion between all stakeholders to establish the most efficient method for data transfer, involving timescales for certain data requirements, e.g. weekly, monthly transfers, etc.
  - There should be a mutual agreement on the strategy between all interested parties as ultimately every stakeholder is working towards the same goal. A memorandum of understanding between the various stakeholders should be prepared, and this should be signed in order to ensure that data sharing is not just a token gesture but will become a reality.

Example of Stakeholder Composition	
Minqin WAB	Primary
Minqin Water Management Stations	
Case Study Areas WUAs	
Case Study Areas Communities	
Gansu Hydrology Bureau	
Gansu PPMO	
Lanzhou Water Affairs Bureau	
Wuwei Water Affairs Bureau	
Shiyang River Basin Management Bureau	
Bureau of Education	Secondary
Women's Federation	
Bureau of Agriculture	
Bureau of Electric Power	
Bureau of Forestry	
Civil Affairs Bureau	
Environmental Protection Bureau	
Land Resources Bureau	
Poverty Alleviation Bureau	
Statistics Bureau	
Water Supply Company	

Dissemination audiences

The dissemination audiences include the different management levels and organisations associated with those management levels (such as for example the hydrology bureaus with the river basin management bureau). They also include the primary and secondary stakeholders if not already included under the different management levels.

Important secondary stakeholders will include organisations that have direct or indirect links with water resources, such as for example the Environmental Protection Bureau, the Land Resources Bureau and the Animal Husbandry Bureau. Such organisations hold information with links to water resources, such as groundwater quality data and land use data.

In terms of reactive dissemination, the number of organisations could be many and involve Government bodies, universities or even members of the public.

Data enquiry procedures

As far as possible, data sharing should become a normal day-to-day practice that does not require any prompting and is built into a communication action plan.

Regarding data enquiry procedures, clear protocols need to be established. Questions that may arise include those related to confidentiality of certain data items and the openness in terms of access to the web-based data repository. It is likely that access restrictions need to be employed, which provide different levels of access and password control. Open access to data and information should be ensured for the different management levels, although access to unchecked/ unverified data may require restriction until checking/verifying has been undertaken.

Cost of data

Access to historical data is often constrained by the need for payment for the data. There is no real reason for not charging for the supply of data and it is common practice in other countries (such as the United Kingdom) to do so. However, difficulties do arise when no clear protocol for charging for data has been established and when no clear cost rates for data provision have been established.

To avoid the risk of not using data for cost reasons and the resulting lack of accuracy of water resources evaluation or poor water resources management, the following needs to be considered:

- There needs to be clarity about who should pay for data. It would be counter-productive if data exchange between the three management levels would be subjected to payment.
- Provision of data/information to stakeholder organisations could be subjected to the payment of a fee. It should be clear what the charging structure is and above all, it should be affordable.

With provision of data/information at a cost, the ownership of the data needs to be clarified. This means that organisations that buy the data have no right to use the data beyond the purpose it was bought for. Such organisations would not be entitled to provide or sell the data to other organisations.

Appendix A

International experience: Groundwater monitoring examples

International Experience –Groundwater monitoring in the Netherlands

Groundwater monitoring in the Netherlands has a similar setup as in England and Wales (see below). It is the responsibility of both NITG-TNO, the country's geoscientific information and research centre, and the water companies. NITG-TNO manages the monitoring of groundwater levels and groundwater quality using a network of purpose-built monitoring facilities. The data is processed in a central database.

Water companies also undertake monitoring and collected data is copied to NITG-TNO for inclusion in their database.

Traditionally data would be collected by data collectors, these being volunteers or paid staff. Groundwater levels collected by water companies were taken on a two-weekly basis, as part of a licensing agreement issued by provinces. Data was then submitted digitally or in writing to NITG-TNO.

Given the cost of data collection, there has been a shift towards the use of autographic recorders (mainly Diver data loggers). These have the added advantage that they only need to be downloaded every three months, which allows for flexibility in monitoring frequency.

International Experience – Use of monitoring data in the United Kingdom

Regional integrated groundwater and surface water models have been developed for major aquifer systems in the United Kingdom. These models are used by the regulator (the Environment Agency) to address planning and management issues related to groundwater use, to reduce risks of over-abstraction and water quality deterioration thus maintaining good quality for public water supply, and for assessing the impacts of climate and groundwater use on the wellbeing of the eco environment.

The models are complex and require considerable data. Part of the data is obtained from regular monitoring and includes:

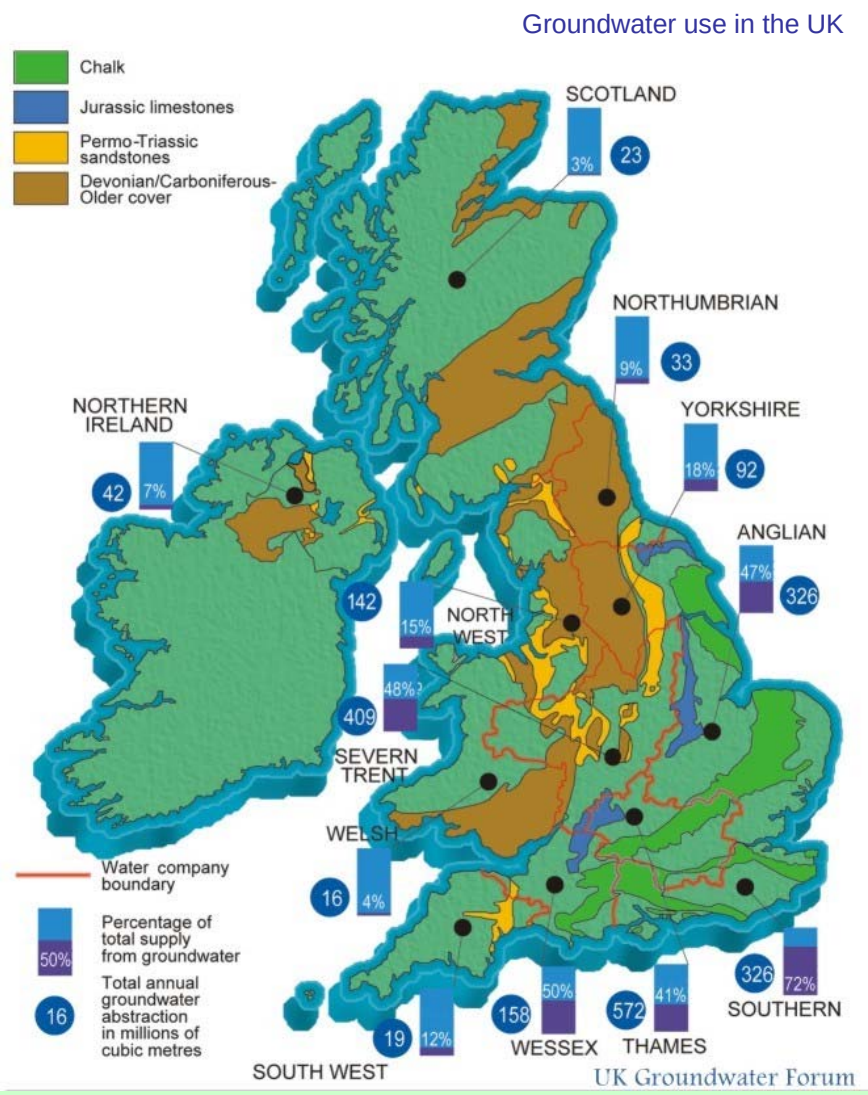
- Rainfall and evapotranspiration data, which is monitored by and obtained from the Meteorological office. This data contributes to recharge derivation
- Land use data, which is transient over the long time periods employed in the models. This data is also required for recharge derivation.
- Groundwater level monitoring data is used during model calibration and allows for judgement of the adequacy of model simulated groundwater levels.
- River flows at gauging stations and river flow accretion profiles (obtained from spot flow gauging campaigns using current metering). Such data is also used during model calibration and compared with model simulated flows and accretions.
- Groundwater abstraction (and possible artificial recharge), abstraction of surface water (for example from rivers) and discharge to rivers or infiltration ponds (generally treated sewage effluent).

International Experience – Monitoring in England and Wales

Groundwater in the United Kingdom is of major importance to securing public water supply. A high proportion of total water use is derived in parts of the United Kingdom underlain by major aquifer (see the image below).

The Environment Agency (EA) is the main regulator for water, air, land and the environment. In this role it undertakes extensive monitoring of the integrated surface water and groundwater environment. Monitoring groundwater levels and groundwater quality is undertaken on a routine basis for a network of monitoring wells spread across England and Wales. The density of the monitoring network depends on the importance of groundwater to public water supply, to other water users and to the environment. The latter plays a role of growing importance, with direction originating from the various directives issues by the European Union (EU).

Groundwater use in the UK



Routine monitoring of groundwater levels is generally on a monthly basis (sometimes twice a month) with responsibility of the telemetry team within the EA. Where monitoring used to be manual, there is now a gradual shift to more cost-effective use of autographic recorders.

Special monitoring that is site specific and at a local scale is also undertaken by the EA. It relates to special studies undertaken to satisfy the requirements of the EU Habitats Directive, which requires that good ecological status is achieved in location identified to be of European importance. The monitoring relates to detailed investigations of the hydrogeology of such locations and involves detailed monitoring using piezometers with screens set at different depths. Such monitoring may be of relatively short duration (several years), although some of the monitoring points may be incorporated into the routine monitoring network. Such detailed monitoring is most often done on a frequency of one day and uses data loggers for this purpose. Special monitoring may also be undertaken by the EA during pollution incidents.

Routine monitoring data is in the public domain, while data related to special areas is available to resource assessment studies undertaken by others.

Groundwater level and water quality monitoring is also undertaken by water companies and involves their own strategic monitoring network. Local scale monitoring is also undertaken by water companies when they require undertaking field investigation and monitoring work related to the EA programme for restoring sustainable abstraction (RSAP). The monitoring is closely related to sites of special scientific interest (SSSI) that are classified as wetlands or groundwater dependent terrestrial ecosystems (GWDTE). Monitoring can be at high frequency (one day) and is generally undertaken during the implementation of projects.

Responsibility for groundwater level and water quality monitoring also lies with private organisation responsible for landfill management or private organisations (often property developers), particularly when contaminated land is an issue.

Data collected by water companies and above-mentioned organisations is not in the public domain. Availability to groundwater resource planners and management, and consultants who work on behalf of the EA and undertake water resources projects, such data is made available for use on such projects. Permission would be required by the owners of the data if this would be needed for other projects.

Appendix B

Guidance on groundwater monitoring: Water Framework Directive

Guidance on groundwater monitoring – Water Framework Directive (1)

Guidance Document No.15 related to the "Common Implementation Strategy for the Water Framework Directive" (2000/60/EC) provides detailed guidance on groundwater monitoring in terms of qualitative, quantitative and protected area monitoring.

This important document states that conceptual models are the basis for monitoring. A conceptual model is a representation of the current understanding of the groundwater system and its inter-relationship with the surface/surface water environment. It describes, within a spatial and time-variant context, the dynamic behaviour of a groundwater system, both in term of quantitative aspects (groundwater flow direction, magnitude, storage, etc) and in qualitative terms (for example the occurrence and movement of chemical constituents in the groundwater). It furthermore identifies the important aspects of potential threats to groundwater quality (point and diffuse pollution) and equally the threats from groundwater to surface systems (such as rivers, wetlands, etc). Figures B1 and B2 are reproduced from the guidance document and show the link between the conceptual model and monitoring (source: CIS WG 2.7 Monitoring Guidance).

The document also stresses the need to consider conceptual understanding at both the region and local scale. At the regional scale, the monitoring needs to be appropriate to verify and improve the conceptual understanding of the regional groundwater system. At the local scale, specific issues will be more prominent and may relate to local pollution incidents or to groundwater dependent terrestrial ecosystem (GWDTE). At the local scale as well, monitoring will be more detailed, both in terms of spatial coverage and in the frequency of monitoring. Such local-scale monitoring is sometimes over a relatively short period (several years) compared with regional scale modelling, which continues over many years.

The Guidance Document, in realising the potential very high cost of monitoring, aims at establishing cost-effective and targeted groundwater monitoring across Europe that enables objectives to be met. It states that the purpose of monitoring must be used to:

- establish the chemical and quantitative status of groundwater bodies (including an assessment of the available groundwater resource);
- assist in further characterisation of groundwater bodies;
- validate the risk assessments carried out under Article 5;
- estimate the direction and rate of flow in groundwater bodies that cross Member States' boundaries;
- assist in the design of programmes of measures;
- evaluate the effectiveness of programmes of measures;
- demonstrate compliance with DWPA and other protected area objectives;
- characterise the natural quality of groundwater including natural trends (baseline); and
- identify anthropogenic induced trends in pollutant concentrations and their reversal.

Guidance on groundwater monitoring – Water Framework Directive (2)

The Guidance Document highlights the consideration of different aquifer types and how these may impact on type and frequency of monitoring (Figures B3 and B4). It also promotes integrated monitoring so that an understanding of the linkages between groundwater and the surface/surface water environment can be obtained.

The Guidance clearly indicates that selection of monitoring facilities should be guided by the conceptual understanding of the integrated groundwater and surface water system at regional and local scales. Site selection factors must thus be assessed on a site by site basis. The same applies to the frequency of monitoring and its selection should therefore not be limited by constraints contained in existing guidance. The amount and frequency of monitoring will thus be determined by the data needed to determine risk and status, and where necessary the design and assessment of a programme of measures.

The Guidance pays significant attention to ensuring quality of monitoring data. The quality depends on the purpose but must be defined for each step of the monitoring process, which include the following:

- conceptual modelling
- monitoring design
- field sampling and measurements
- laboratory analysis
- transfer, storage, modelling
- interpretation of data
- result reporting

Quality should be based on defined sets of verifiable quality requirements for each step in the process. It is further important that, during the monitoring process, the achievements of the quality requirements shall itself be monitored and, if not met, be re-evaluated and if required, improved and repeated.

The process is cyclical and in this way there will be a continuous improvement in the conceptual understanding and the efficiency/effectiveness of the monitoring process. The guidance illustrates this through Figure B2

Range of hydrogeological settings and aquifer types

- major alluvial and coastal plain sediments where the relations with surface water systems might be complex;
- intermontane colluvial systems, discharging mainly to springs and/or directly to the base flow of rivers
- consolidated sedimentary aquifers – limestone, chalk and sandstone
- karstic (mountain or plain) areas with or without external inflow
- marls and clays with local aquifers made of limestone or sand
- recent coastal calcareous formations and islands
- glacial and associated small alluvial formations
- extensive volcanic terrains
- weathered and fresh crystalline basement (including metamorphic rocks such as gneiss and schist)

Figure B1 Link between the conceptual model understanding and monitoring

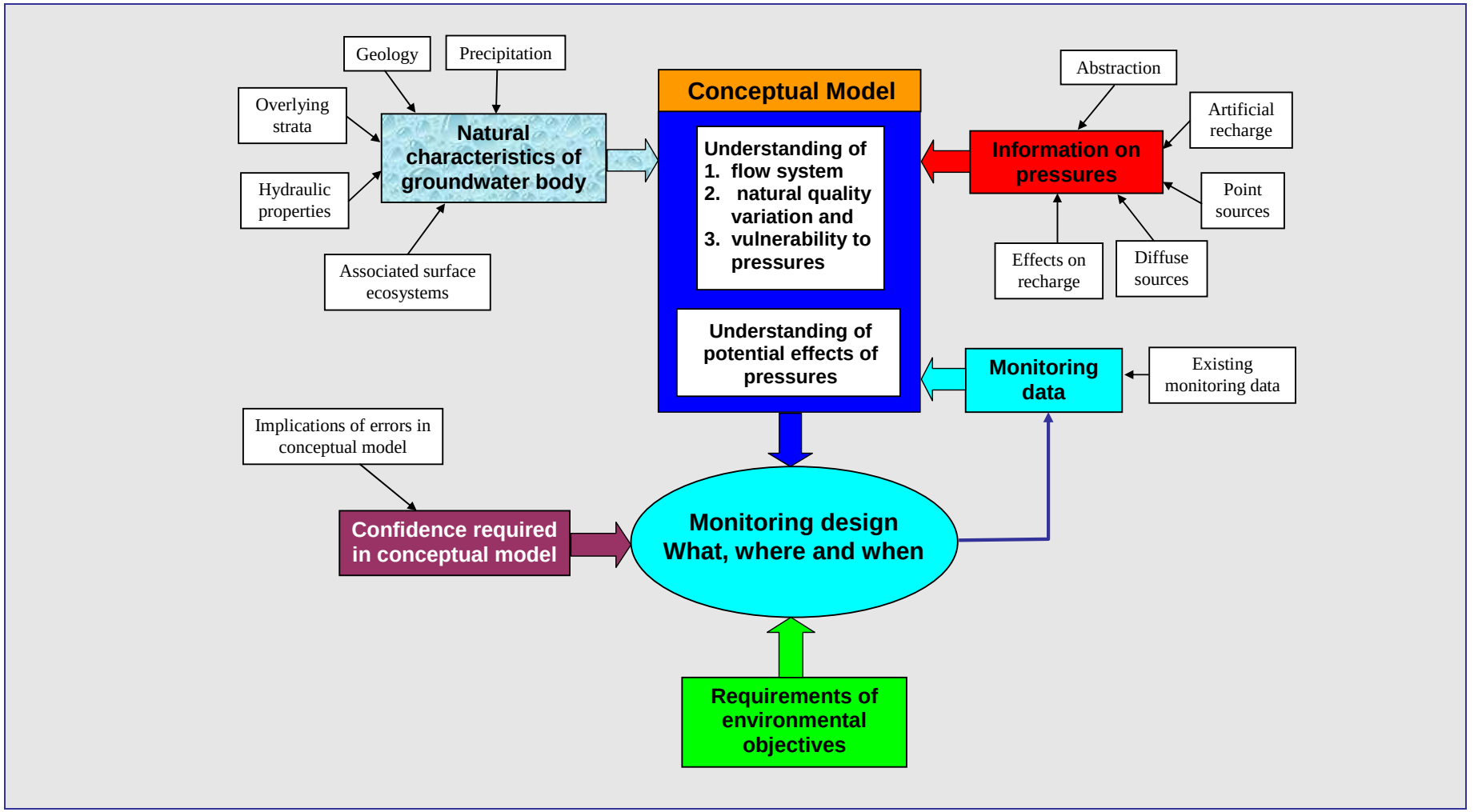


Figure B2 Iterative control of the conceptual model against set quality requirements

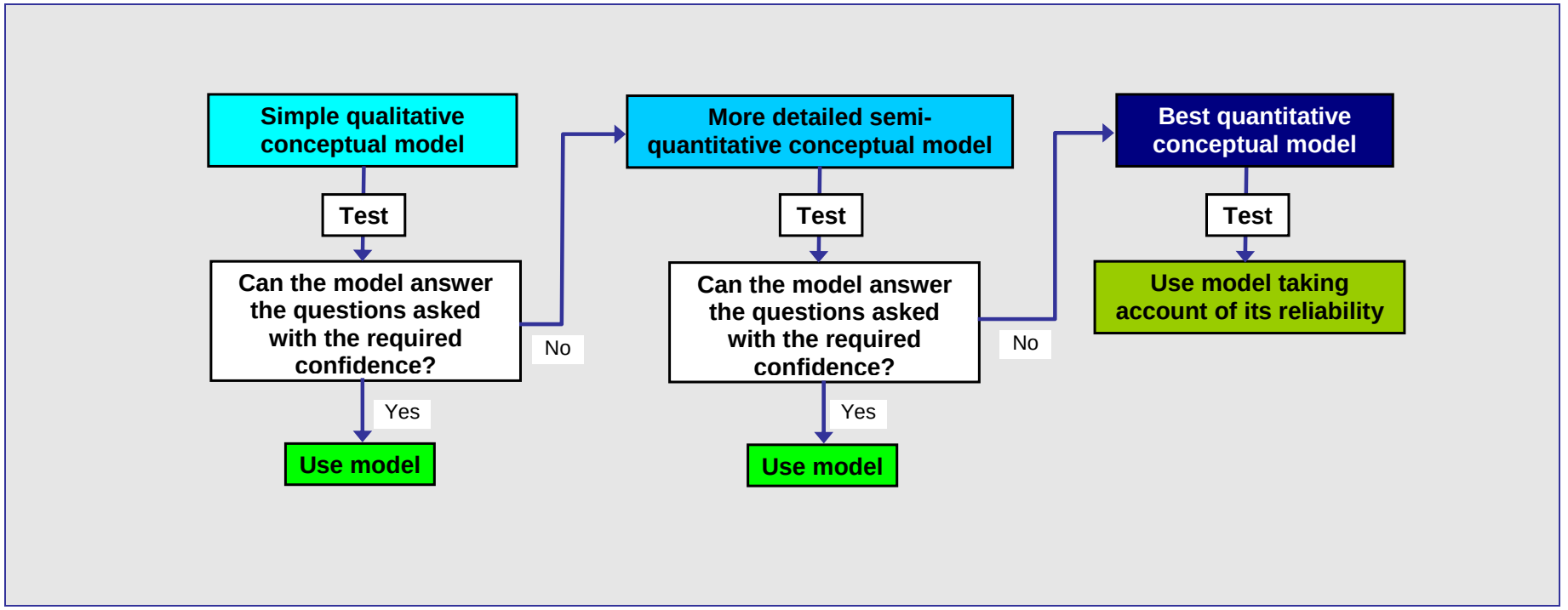
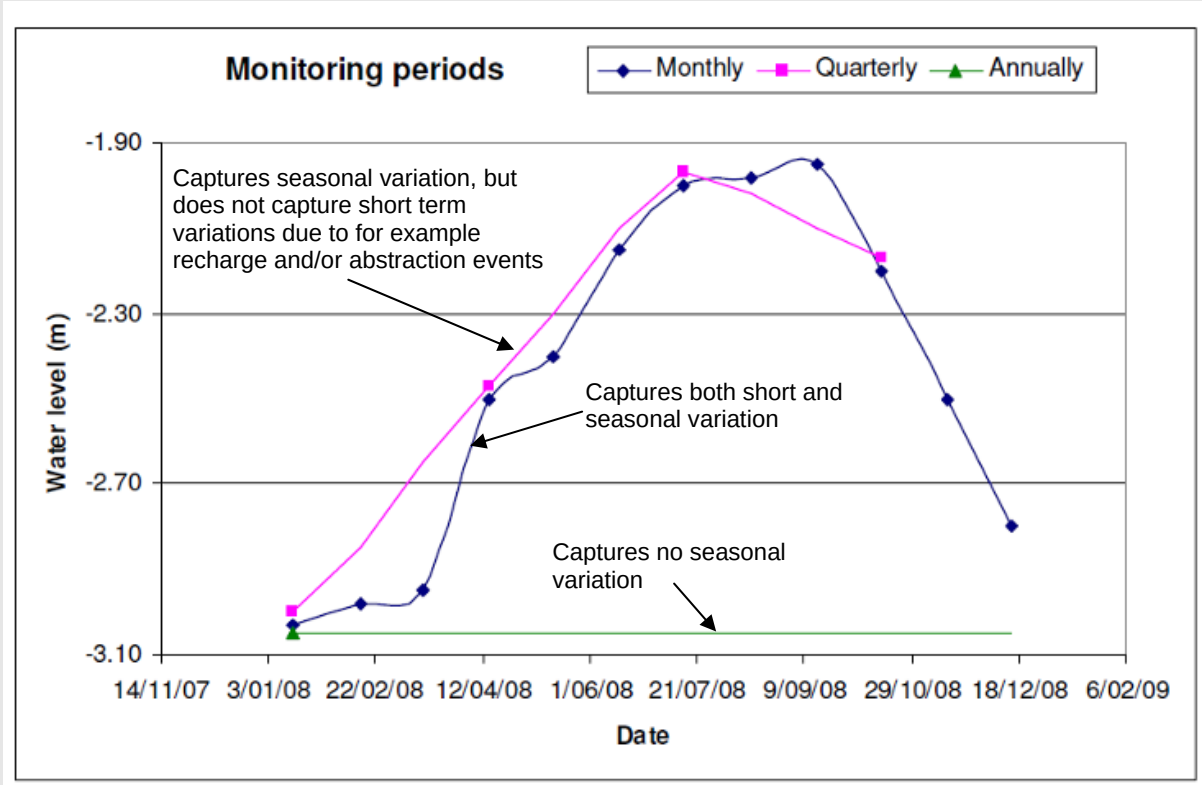
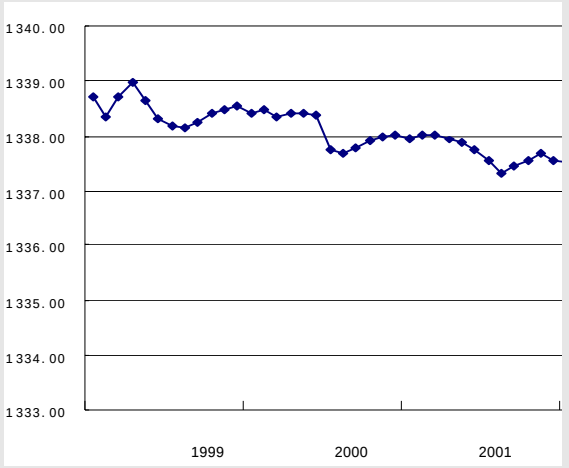
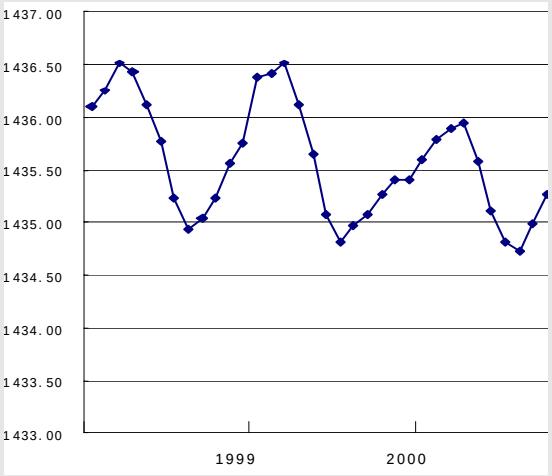


Figure B3: Example of different groundwater level monitoring frequencies

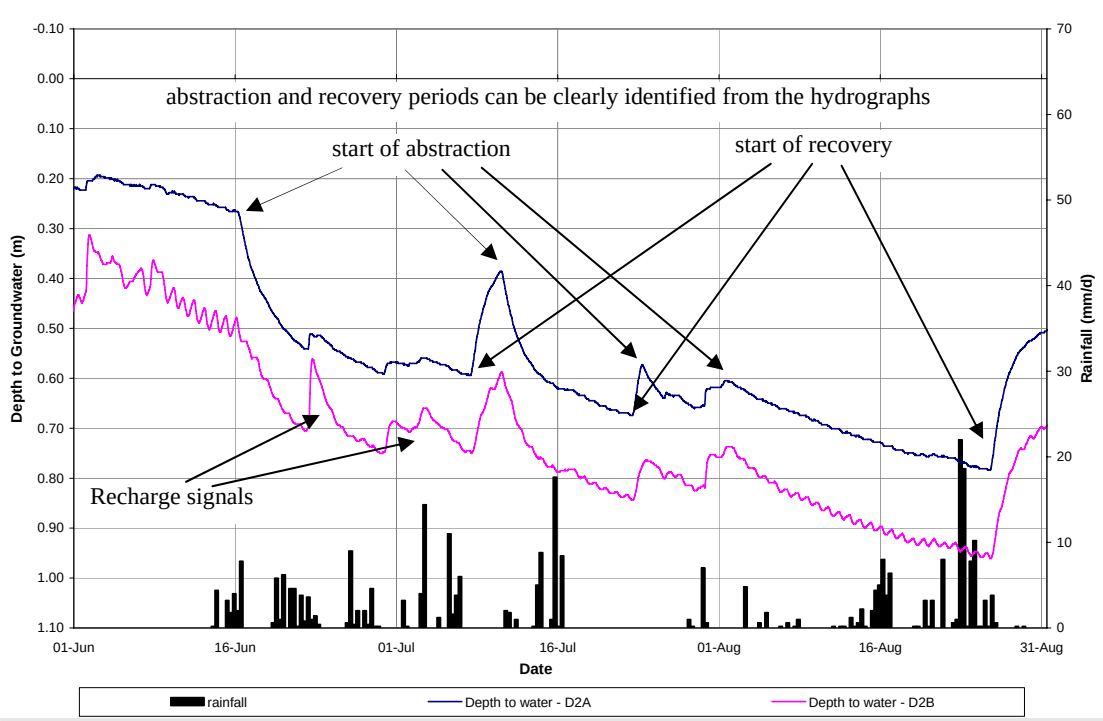






Monthly groundwater level measurements are adequate for capturing the seasonal variability as well as longer-term trends (the figures relate to groundwater level monitoring in the Shiyang River Basin)

Figure B4: Example of high frequency ground level monitoring



The graph shows groundwater levels in a deep (dark blue) and a shallow (pink) observation borehole. The boreholes were fitted with dataloggers that captured levels every 15 minutes. The graph also shows daily rainfall data. The data relates to a study of a nature reserve near Cambridge in England, where vegetation is dependent on shallow groundwater table conditions. The study was undertaken for a local water company to assess the impact of abstraction from nearby wells on groundwater levels in the nature reserve.

The graph clearly shows the impact of abstraction and also the response of groundwater levels to rainfall. The short measurement interval even allows for observation of diurnal fluctuations in the groundwater table caused by diurnal variation in evapotranspiration.

Document Reference Sheet

Glossary:

WAB	Water Affairs Bureau
WUA	Water Use Association
MLR	Ministry of Land Resources
MEP	Ministry of Environmental Protection
RBMB	River Basin Management Bureau

Bibliography:

SL 183-2005	Technical standard for groundwater monitoring
GW•MATE Briefing Note No. 9	Groundwater monitoring requirements for managing aquifer response and quality threats, published by the World Bank/ Global Water Partnership

Guidance Document No.15 related to the "Common Implementation Strategy for the Water Framework Directive" (2000/60/EC)

Related materials from the MWR IWRM Document Series:

Advisory Note 2.6/1	Groundwater Monitoring - River Basin to County Levels
Advisory Note 2.6/2	Groundwater Monitoring at Village Levels
Thematic Paper 1.1	Groundwater Flow Modelling
Thematic Paper 1.2	Groundwater Resources Quantity Assessment
Thematic Paper 2.6/1	Groundwater Management

Where to find more information on IWRM – recommended websites:

Ministry of Water Resources:	**www.mwr.gov.cn**
Global Water Partnership:	**www.gwpforum.org**
WRDMAP Project Website:	**www.wrdmap.com**

China – UK, WRDMAP

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Examples

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Advisory Services by : Mott MacDonald (UK) leading a consultancy team comprising DHI (Water and Environment), HTSPE (UK), IWHR, IECCO (Comprehensive Bureau), CIAD (China Agricultural University), Tsinghua University, CAAS-IEDA, CAS-CWRR, Gansu WRHB and Liaoning WRHB.

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