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3.4 Quantitative Stresses and Monitoring Obligations

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3.4.1 INTRODUCTION

The role and behaviour of aquifers depend on climate, relief and geological conditions. In the temperate climates of Central and Northern Europe, in flat and low relief areas, the dominant shallow permeable formations are normally full of water which discharges into the more or less permanent surface water stream network. Losses by phreatic and phreatophyte evaporation are relatively small, and wetlands easily form in depressions and lowlands. Groundwater abstraction is often a small fraction of recharge, dominantly for human supply in urban and rural environments, so the groundwater flow pattern does not

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suffer significant changes. Groundwater quality problems, both natural and man–induced, represent a major concern, as well as the quality of groundwater–related surface water and habitats. This corresponds with the orientation and emphasis on water quality of the European Water Framework Directive (WFD, 2000/60/CE Directive to establish a community framework for action in water policy), and the recent Groundwater Daughter Directive (GWD, 2006/118/EC Directive on protection of groundwater against pollution and deterioration).

In arid and semiarid areas, such as those found in Southern Europe, around the Mediterranean Region, and especially in Central, Eastern and Southern Spain, groundwater plays important environmental roles and its dominant use is not for town and industrial supply, but to attend the important agricultural demand for irrigation of crops (EUWI, 2007). In some cases this amounts to more than 80% of total groundwater abstraction. This abstraction is a large fraction of the recharge, and in some areas may approach and even exceed annual mean recharge (MMA, 2000). In many areas this intensive development of aquifers (Llamas and Custodio, 2003; Custodio *et al.*, 2005a, Sahuquillo *et al.*, 2005; Llamas and Martínez–Santos, 2005) is more the rule than the exception, and this may involve serious ecological and water quality impacts, in addition to the problems of sustainability of groundwater abstractions and serious seawater intrusion in coastal groundwater bodies (Custodio, 2005b). Under intensive development, groundwater body quality problems and their ecological consequences continue to be important, but groundwater quantity issues are also important, and water scarcity becomes dominant in the mind of water users and society in many areas of the country. This is the case in most south-eastern and central areas of Spain. Only in areas of Catalonia and the humid NW human supply is the dominant concern. In any case quantity and quality issues are closely linked, although not always recognized by water administrators and society in general. When exploitation of water resources is high, agricultural return flows significantly increase water salinity and concentrations of non-desirable chemicals in aquifers. In water scarce areas, changes in groundwater bodies are already significant and restoration to background levels prior to intensive exploitation may be unrealistic in many cases. However, there are also other dependencies on groundwater including habitats and river systems (Box 3.4.1) that have to be taken into account, the more the more arid is the climate. They deserve protection, both in quantity and in quality, and at the same time taking into account their value and the social benefits from groundwater development (Box 3.4.2).

BOX 3.4.1 Role of groundwater

In Nature

- Contributing water and solutes to:
  - River base-flow
  - Springs and seeps
  - Groundwater dependent-wetlands
  - Phreatophyte areas

  - Coastal habitats depending on groundwater
  - Shore marine habitats
- Conditioning geotechnical properties of the ground
- Affecting the external and internal geodynamic behaviour of the Earth
- Influencing
  - salinity and solute distribution in the ground
  - mobilization of solutes (some of them may be noxious)

To supply human needs

- A reliable fresh water resource for:
  - Drinking purposes
  - Urban and rural supply
  - Irrigated agriculture
  - Animal raising
  - Industry
- A strategic water resource in:
  - Droughts
  - Failures in supply systems
  - Emergencies
  - Criminal actions
  - Conflict situations

A source of services

- from groundwater-dependent habitats
- stabilizing rural settlements and landscape preservation

BOX 3.4.2 Social benefits from groundwater development

Groundwater has proved its effectiveness to:

- Alleviate poverty in depressed areas
- Provide safe drinking water (in spite of some problems and failures)
- Dramatically improve population health
- Help developing an area
- Provide smooth social transition in developing poor areas
- Increase food production
- Improve employment and stabilizing population
- Increase security against droughts

- Guarantee water supply in extreme situations
- Reduce funds misuse and corruption

These social benefits are related to:

- Adequate quantity and quality
- Resilience to seasonality and inter-annual variation
- Easy location and distributed accessibility
- Readiness for use
- Low technical and administrative requirements

3.4.2 GROUNDWATER QUANTITY AND GOOD QUANTITATIVE STATUS

Groundwater quantity may be measured by the water storage in the ground when referring to reserves, and to recharge when referring to renewable flux. In a long-term stationary groundwater system under natural conditions average discharge equals average recharge. Discharge is produced in streams and springs as base–flow and part of it is evaporated in lakes, wetlands and phreatophyte areas, or transferred to other adjacent groundwater bodies.

The existence of groundwater abstractions may modify recharge to some extent, but especially reduces discharges. This means that stream and spring base-flow, and wetland and phreatophyte area decrease or may even be wiped out. These environmental impacts are due to the quantity of groundwater available, and also to quality changes due to aquifer chemical modifications, entry of pollutants and decreased dilution (Box 3.4.3).

BOX 3.4.3 Main impacts from developing groundwater

On water quantity:

- Groundwater level drawdown. This may mean:
  - increased water cost
  - early need to substitute wells, pumps and associated facilities
- Depletion of discharge to springs, rivers, lakes and wetlands
- Reduction of phreatophyte areas
- Impairment of groundwater dependent habitats
- Longer surface stream tracts where water infiltrates into the ground

On water quality:

- Water quality may change as a consequence of:
  - Modifying the flow pattern
    - displacement of low quality water bodies
    - enhanced seawater encroachement in coastal aquifers
    - more easy infiltration of degraded surface water
    - penetration of shallow water into deep aquifers
    - mobilization of noxious substances
  - Changing the mixing of groundwater in wells, boreholes and springs
  - Enhanced chemical reactions in the ground by
    - altering the redox situation:
    - dewatering, reatuation, allowing aerated water
    - modifying flow velocity
    - increasing flow through formations containing leachable minerals

On land

- Land subsidence due to decreased water pressure in the ground:
  - more easy inundation
  - changes in habitats
- Increased collapse rate in
  - karstic areas
  - areas around poorly constructed wells and drains
- Habitat modification due to water quantity and quality changes
- Impairment of landscape and scenic values

The good quantitative status of a groundwater body is more difficult to define than good chemical status, because the latter relies on easily measurable mineral solutes, suspended matter and microorganisms in water, or extensive water properties such as electrical conductivity, pH, redox potential and temperature. Good quantitative status should reflect the ability of groundwater bodies to maintain at least a part of their essential environmental roles as water sources, such as preserving river and spring base–flow, and a depth to the water-table compatible with pheatophyte and wetland subsistence. Also discharges into lakes, streams and littoral tracts need the chemical and biochemical environment that depends on groundwater outflow. Maintaining water head distribution prevents excessive land subsidence in order not to impair land drainage and flooding frequency, and, in coastal areas, marine inundation.

For the assessment of quantitative status, information on groundwater levels is needed, in conjunction with estimates of recharge. Spring-flow gauging and river base-flow evaluation are the more reliable methods of integrated groundwater recharge assessment, when this is possible. As indicated in EC (2007), an understanding of groundwater relationships with surface waters and terrestrial ecosystems is necessary for the development of the needed conceptual model of the hydrogeological system to groundwater resource and the assessment of groundwater quantitative and chemical status.

Often aquifers are complex systems consisting of several layers more or less linked vertically through aquitards. Good quantitative status not only refers to the upper layer, which interacts with surface water and the environment, but to the other layers through the influence they may have in the upper layer or in discharge areas.

Groundwater is transferred form high areas to lower areas, with lateral movement and vertical exchanges among the different layers. Groundwater flow is essentially three-dimensional, and two-dimensional representations are only simplifications for more easy treatment. In many cases these simplifications are acceptable for analyzing flow components and mass transfer, as stresses are likely to have significant effects, mostly in the upper aquifer layers. However, in other cases, a 2-D conceptual model may be inappropriate and even may lead to erroneous results. Often, cases of inappropriate conceptual models are due to the lack of wells or boreholes deep enough to determine the vertical component of the water head gradient, or poor measurements of the water-table elevation when exploitation is mostly by deep wells. However, in many other cases this is due to inadequate analysis of existing data.

In order to understand quantitatively an aquifer system the first step is to establish a conceptual model considering its characteristics and behaviour, and then check and quantify this model, or improve it. This may require hydraulic, hydrochemical and environmental isotope studies to obtain the parameters and boundary conditions to be fed into the appropriate calculation or numerical model(s). These may consist of simple calculations or sophisticated 2-D and 3-D flow and transport models.

In the WFD, Article 4.1,b,ii, requires EU Member States to protect, enhance and restore all groundwater bodies and ensure the equilibrium between abstraction and recharge of these waters in order to achieve good status for groundwater. A strict interpretation may be too limitative and in extreme situations may be used as an argument to exclude any groundwater development in many aquifers that are not permanently recharged by perennial surface water streams. Often this cannot be applied in dry climate areas. The limit should be acceptable ecological and quality impacts, although these are poorly defined concepts that largely depend on what is considered acceptable. Acceptability has complex ecological, economic and social components, that may change with time, and has to be agreed by the society.

A first appraisal of quantitative status is the decrease (as a fraction) of ecologically sensitive outflow, of wetland and phreatophyte surface areas, and of water salinity and quality. Water-table and piezometric level evolution is a relevant indicator that has to be monitored for the different groundwater bodies, taking into account the three-dimensional nature of the problem. Experience through well-studied cases is needed.

3.4.3 IMPACT OF GROUNDWATER DEVELOPMENTS

Any groundwater artificial development has some impact on the water balance components and often on water quality. The seriousness of the impacts increase with the intensity of such development (Custodio, 2001).

Groundwater development has many positive benefits from the hydrological, water quality, economic and social points of view (Custodio, 2005a; Llamas and Custodio, 2003). The social benefits are the more relevant to the WFD. Groundwater development is needed in many developing countries to attain the Millennium Declaration Goals (MDG) and to solve poor quality and scarcity of water (Ragone *et al.*, 2007), as recognized by the United Nations and supported by the International Association of Hydrogeologists. Possible drawbacks from groundwater development and unsustainable situations can be easily identified by the impact on water quantity, water quality and effects on land. Most of these drawbacks are the subject of the WFD related regulations.

In general terms, groundwater development had only a small impact on aquifers and related water bodies until 30–80 years ago, depending on the country or region. Since then, groundwater development has been almost exponential, especially in the semi–arid and arid areas of Southern Europe (Central, Eastern and southern Spain, south of France, areas of Italy, Greece) and around the Mediterranean sea, as well as in central and western USA, Australia, Middle East, India and China, and in many small islands (see Box 3.4.4). A large part of this largely uncontrolled development has been carried out by individuals and small communities producing what can be called a silent revolution (Fornés *et al.*, 2005; Llamas, 2005; Giordano and Willholth, 2007), mostly to develop irrigated agriculture. This has been a characteristic of groundwater development in the last 20–50 years (depending on the area) and will probably continue in the early part of present century.

A common although difficult concept is that of overexploitation (Custodio, 2002; Hernández-Mora *et al.*, 2001). Overexploitation puts the accent on the negative aspects, and not necessarily on environmental issues. The concept may be misused, for example, to try to halt aquifer exploitation, thus losing the large potential benefits from using groundwater. Groundwater mining is directly forbidden in the WFD except if it is clearly demonstrated that this may be a sound activity under special circumstances and for a limited time. An adequate study of intensive groundwater use, case by case, will provide answers to quantitative questions, provided they are carried out by trained personnel who do not yield to external interests, political pressure, media influence and self-interest (Llamas and Custodio, 2003).

3.4.4 DEFINITIONS OF GROUNDWATER QUANTITY

Groundwater quantity is mainly defined by:

1. Storage in the different groundwater bodies, that is to say, in aquifers and aquitards. These values are the saturated volume multiplied by total porosity. Only a part of this water can be abstracted since a part is retained in the formation by capillary forces. The volume is a fixed one in the case of confined aquifers or variable when the upper boundary is the water-table.

2. Recharge from outside the groundwater body. Under common circumstances most of the recharge comes from rainfall infiltration in the aquifer outcrops. In dry climates and mountaineous areas stream water infiltration may be significant and in some cases dominant. Also infiltration of snow-melt may be an important contribution to recharge. In shallow aquifers, especially in flat areas in dry climates, part of recharge goes back to the atmosphere through phreatic and phreatophyte area evaporation. What remains is net recharge.
3. Interaquifer leackage. Under many circumstances a groundwater body may receive groundwater from an adjacent (at the side, above, or below) water body. The outflow can be regarded as negative recharge. In this respect aquitards may play a very significant role.

BOX 3.4.4 Intensive exploitation of aquifers in southeastern Spain

South–eastern Spain is a semiarid area with a large water demand for irrigating high value crops that has induced a very intense exploitation of the region's aquifers. Often groundwater abstraction exceeds aquifer recharge, producing sustained water level drawdown and the drying of springs and of some wetlands. In other cases water salinity increases by seawater or saline water intrusion. Although in some cases groundwater exploitation has to be decreased or even abandoned, many aquifers continue providing valuable water resources at a relatively low cost.

Some of the more important aquifers have been modelled and different exploitation strategies have been simulated to foresee their future behaviour (Figure 3.4.1). The Guadalentín aquifer, with a surface area of 800 km^2 and a total recharge of 26×10^6 m^3/a, supports abstraction higher than 100×10^6 m^3/a, with a depletion of 3×10^9 m^3 in the last 30 years. From the aquifers of Jumilla–Villena (340 km^2; recharge of 7×10^6 m^3/a) and Ascoy–Sopalmo (420 km^2; recharge of 1.5×10^6 m^3/a) more than 50×10^6 m^3/a are pumped with a depletion of 1.5×10^9 m^3 in each of them. In some areas groundwater drawdown exceeds 160 m, but the average value is around 60 m to 80 m. In the Cingla–Cuchillos aquifer, with an average recharge of about 8.5×10^6 m^3/a, current pumpage is 28×10^6 m^3/a or a cumulative withdrawal since 1975 that exceeds recharge by 450×10^6 m^3. See the figure below.

Model simulations provide some interesting conclusions. If pumping is reduced to zero groundwater levels will still not recover to their original values within the next 30 or 40 years at current recharge rates. Former springs in Jumilla–Villena and Ascoy–Sopalmo areas will remain dry, and the former wetland in the Guadalentin valley will remain well above the aquifer water levels.

If pumping continues at current levels, sustained groundwater level drawdown will continue and in some areas wells will dry up during the next 10 to 15 years. This means that a further reduction in pumping will be needed. There will be no further environmental damage except some water salinity increase in the Guadalentin aquifer. This aquifer already contains high salinity water. It seems that these aquifers cannot be environmentally recovered from an economic and social point of view.

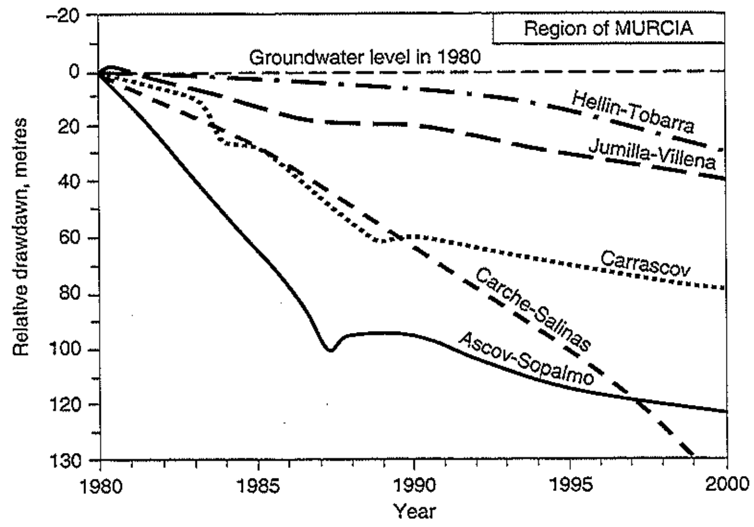


Figure 3.4.1 Aquifer modelling in the region of Murcia, Spain.

An understanding of the geometry of the groundwater body is needed to determine groundwater storage. However this is not always well known, and in many cases the lower limit (base) of the groundwater body may be quite speculative. Geological studies, drilling and geophysical surveys are the most commonly used means to gain knowledge. Total and drainable porosity (the part of porosity with water free to move under gravity) are also the result of studies and measurements.

Recharge is a key value required to evaluate quantitative status, and consequently to understand chemical status and its evolution, and make judgements on overexploitation and on the consequences of intensive use. However, recharge is one of the most difficult hydrogeological parameters to calculate. Numerous methods are available to make evaluations. Most of them refer to recharge by rainfall. They include soil water balance methods, which include evaluation of actual evapotranspiration by means of meteorological, runoff and plant effect calculations, measurement of flow in the unsaturated zone, chloride (or other conservative ion) balance in the soil, chemical and environmental isotope ground profiling and modelling (Lerner *et al*., 1990; Simmers, 1988; Custodio *et al*., 1997). Changes in water-table levels may be used, under favourable circumstances, to calculate and calibrate recharge. Recent studies include direct soil evaporation and phreatophyte evapotranspiration, in order to improve estimates in dry climates. Atmospheric chloride deposition on land and chloride balance in the soil is a fast, reliable method to estimate long-term average recharge under steady state conditions (Alcalá and Custodio, 2007; Custodio, 2009). Recharge varies with time and depends on location. Thus, the recent introduction of geographical information systems (GIS) allows more accurate evaluations provided that the significant parameters are known or can be calibrated. Advances are being made to consider the impact of land use activities and development on recharge. Additionally efforts are also being made to consider future climate and man-made land use change scenarios.

In situations where there is concentrated recharge through fissures, soil discontinuities and areas of runoff concentration evaluation of recharge is even more complex and uncertain. Recharge from surface waters, snow-melt and especially floods, which involve large volumes over a short timescale, irregular spatial and temporal patterns is still a subject of research, as well as recharge through fractured rocks,

Discharge is the result of recharge, after being smoothed and delayed by the effect of the large water storage in the aquifer system. It can be used as an averaged indicator of integrated recharge and to calibrate evaluation methods. This can be done by simple calculations or through aquifer system modelling.

However discharge is also prone to large uncertainties. Base-flow to streams has to be derived from hydrographs and/or chemical balances. However river hydrographs can be modified by aquifer abstraction and water intakes or inflows from other rivers. Evaporation from lakes and wetlands needs measurement stations and environmental correction factors.

Artificial abstraction can be determined using calibrated flow measuring devices. However these are often rare at sites where groundwater is used for irrigation. In these cases the irrigated surface area and the applied water depth have to be used as proxies. In many cases they are poorly known and even the number of operating wells and how they are pumped may be highly uncertain. Water intakes from rivers, directly or through canals, are also not always known and very often they are not metered. Similar quantitative uncertainties exist in water inflow to surface water from reservoirs, tributaries or other inputs. In dry climates fresh water is scarce and often attains high market values, so uncontrolled exploitation is often more the rule than the exception. Flows from artificial drainage of infrastructures and buildings in urban areas may be also highly uncertain.

Interaquifer flow has to be evaluated by hydraulic calculations and by means of hydrogeochemical and environmental isotope studies, and thus they may be also highly uncertain.

All the terms/parameters defining the aquifer system's quantitative behaviour must be used to calculate a water balance. Water balance calculation methods range from simple calculations to sophisticated methods employing numerical modelling of flow that can be reinforced by mass transport modelling when water chemistry is known with enough spatial and temporal detail. Long data series may greatly reduce uncertainty. This includes measuring chemical atmospheric deposition.

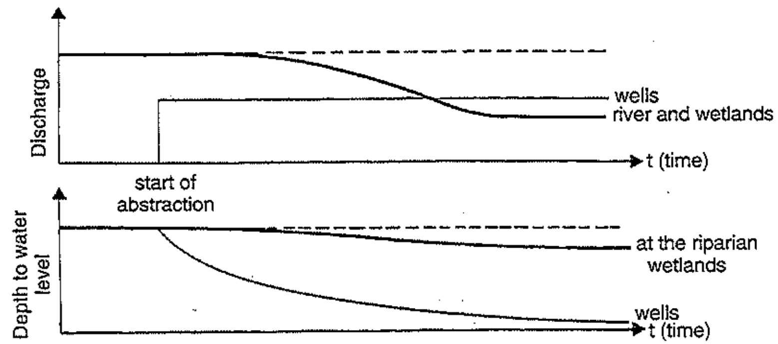
3.4.5 DELAYED EFFECTS IN AQUIFERS

The large storage associated with groundwater bodies with respect to annual flow introduces long delayed responses to external stresses, be they natural or artificial. This means that the impact produced by development at a given moment produces slow quantitative and chemical responses that may only diminish after years, decades and even millennia. Some large unconfined aquifers are still evolving after the large climatic changes at the end of last glacial period (16,000 to 10,000 years ago).

In a very simplified manner, aquifer response depends on the 'α parameter' where $\alpha = \beta L^2 S/T$. Parameter L is the aquifer size, S the storage coefficient, T the hydraulic transmissivity of a given aquifer and β a coefficient that depends on boundary conditions, but whose value is often between 1.5 a 2.5. While small, highly transmissive confined aquifers establish new steady state head conditions within days or weeks after a quantity perturbation, a large, unconfined low transmissivity aquifer may need millennia. This has important implications for defining the quantitative status of a groundwater body since the observed status may not be stationary but an evolving one. Thus the same observed groundwater levels may represent different situations, depending on the moment in time. Climatic variability can also affect simultaneously the aquifer, leading to delayed responses that need an adequate interpretation (see Box 3.4.5).

BOX 3.4.5 Time evolution of ground water. A simple example

Let us consider a hypothetical, oversimplified case of an unconfined groundwater body limited by impervious side and bottom boundaries and discharging into a river, thus contributing to base-flow and riparian habitats. Recharge is produced only on the aquifer outcrop. In a given moment diffuse exploitation is introduced, equivalent to a fraction of the recharge rate. The figure shows the shape of the time evolution of the depth to the water-table and the decrease of aquifer outflow to the river. The length of the time axis is decades to many hundreds of years in typical cases.



At the beginning the effect of abstraction seems to proceed at a very slow rate, but after some years it increases continuously and does not fade out until a long time (years to centuries). Consequently river base-flow and riparian habitats seem initially little affected, but afterwards they deteriorate fast, even when the groundwater body exploitation has not been changed for years. This may be improperly taken as overexploitation, when actually abstraction is less than recharge, but producing delayed groundwater level drawdown, decreased river discharge and riparian habitat deterioration.

These quantitative delayed effects may have a greater significance for the water quality status since groundwater moves slowly. Assuming piston flow in the aquifer (incoming groundwater fully displaces existing groundwater) the water velocity is given by the Darcy's law, $v = k \cdot i/m$, in which v is intergranular groundwater velocity, k is aquifer permeability (hydraulic conductivity) and m is dynamic porosity (close to total porosity in homogeneous sedimentary formations). Water and non-retarded solute movement in most cases varies from a fraction of a metre to a few hundreds of metres per year. This is much slower than changes in head and flow.

The result of a stress causing an impact may often be manifested in monitoring data after a considerable delay. For example, pesticide application to a wide area of land over a groundwater body may lead to increased concentrations in the groundwater many years after it was released. Practices to reduce nitrate inputs to groundwater in agricultural areas, will not be apparent years or decades later in deep parts of aquifers used for domestic supply. The movement (and temporal retention, and eventually the decay) of chemical changes in the unsaturated zone goes on unnoticed by normal monitoring, and the effects may be long delayed, and even appear after the stress has been suppressed.

3.4.6 MONITORING OF GROUNDWATER QUANTITATIVE STATUS

The key values to define groundwater body quantitative status – although not the only ones – are piezometric levels, both in space (in three dimensions) and along time. Information on groundwater levels and estimates of recharge should be used for the assessment of the quantitative status in conjunction with spring flows and the estimation of base-flow in rivers, when this is possible. Groundwater body parameters are not the subject of monitoring, but of studies. Such studies should be completed and extended every few years, especially if impacts are of concern.

The monitoring programmes should be designed to provide the information needed to evaluate the risk posed by existing stresses and to establish the magnitude and spatial and temporal distribution of any impacts (Condesso de Melo *et al*., 2007), with a given strategy (Voigt *et al*., 2007). Risk assessments for groundwater should be based on a conceptual model of the groundwater system and how stresses interact with that system. The conceptual model is necessary to design monitoring programmes and also to interpret the data provided by them, and hence assess the achievement of the monitoring objectives. The level of detail in any conceptual model needs to be proportional to the difficulty in judging the effects of the stresses, although a simple, generalized sketch of the groundwater system may be good to start. Monitoring should provide the information needed to test model performance and, where necessary, improve them so that an appropriate level of confidence can be achieved in the prediction and assessment of groundwater behaviour. When very costly restoration or enhancement measures are need in the case of aquifers failing to achieve good status, relatively complex models are likely to be required.

In the case of limited existing monitoring networks it may be convenient to iteratively build or enlarge them to the extent needed to test or develop the needed conceptual models.

An understanding of groundwater relationships with surface waters and terrestrial ecosystems is necessary for the development of the conceptual model of the hydrogeological system, the determination of the available groundwater resources and the assessment of groundwater quantitative and chemical status (EC, 2007).

A given groundwater body may be not represented – and often it is not – by one monitoring point. This depends greatly on aquifer characteristics and shape, degree of development, density of links with surface water and the importance of groundwater-dependent ecological and water quality situations. The more spatially variable the groundwater flow system or the stresses on it, the greater the density of monitoring points needed. The amount of monitoring required also depends on the extent of existing information on water levels and on the groundwater flow system. Where this information is adequate and reliable, it may not be necessary to extend monitoring programmes. A guide could be to monitor sufficient points to validate the conceptual model. In case of having a consistent conceptual and validated model and an adequate knowledge of aquifer recharge and stresses, the monitoring network could even be reduced.

The measurement frequency should allow short-term and long-term level variations within the groundwater body to be detected, and to distinguish short and long-term variations in recharge from impacts of abstraction and discharges. For formations in which the natural temporal variability of groundwater level is high or in which the response to stresses is rapid, more frequent monitoring will be required than will be the case for groundwater bodies that respond slowly to short-term variations in precipitation or stresses. The number of points in the monitoring network can be reduced where measurements are made frequently, from weekly or fortnightly to every two months, but a more dense network is needed where data are taken more sparsely, once or twice per year. Installing some continuously recording devices is recommended in some cases, especially when groundwater body behaviour is being studied. In order to better use the technical and scientific capacity of the monitoring organization, the strategy of using more sparse monitoring networks between periods of simple monitoring of a particular groundwater body, and a denser network for periods of deeper analysis, allow a more efficient follow up of different groundwater bodies, which alternate in the strategy. Designing and operating integrated groundwater and surface water monitoring networks will also produce cost-effective monitoring information for assessing the achievement of the objectives of the WFD (EC, 2007) for groundwater bodies.

Groundwater level measurement points – piezometers – are not simply open holes in to the groundwater body, as is unfortunately the case in many situations. Although existing wells can be used – provided their characteristics, especially depth and length of the screen or open section are known – dynamic or residual pumping levels may impact on what is being monitored. Purpose-drilled piezometers are preferred. These should have relatively short screens at the appropriate depths, and be properly constructed. This means taking care during construction, for example by ensuring grouting, tube joints waterproofing and properly installed filter packs. Often several piezometers, clustered or nested, are needed at a given point to separately monitor the groundwater body in depth, including deep layers and aquitards. These may be expensive to construct and maintain, so a cost-benefit analysis should be carried out. The representativity of what is being monitored may also inform the need for investment. The design of a piezometric level monitoring network is a complex task that has to be carried out by trained hydrogeologists.

Not any variable of interest to define groundwater quantity status is for general purpose monitoring, although they may be needed to understand the aquifer behaviour or to help in model design and calibration. Such is the case of discharge quantity. This means gauging significant springs and river tracts to obtain base-flow. It should be considered that the needed points may not coincide – and often do not – with surface water quality monitoring needs.

Monitoring of abstraction is an easy task when wells, water galleries and drains have flow measuring and recording devices. But often this is not the case and then indirect means of measurement are needed, based on pumping energy consumption, well yield and hours of functioning, irrigated surface, served population, etc. This should be part of the monitoring operation, at the appropriate level.

Aquifer outflow through lakes, wetlands and phreatophyte areas should also be monitored by repeated surveys. Modern satellite and air-borne remote sensing devices are interesting monitoring tools for some variables, such as evapotranspiration and vegative cover, if properly calibrated. Advances are continuously being made to help in making these methods easily available to monitoring agencies.

3.4.7 AQUIFER MANAGEMENT AS A TOOL FOR GROUNDWATER QUANTITY STATUS COMPLIANCE

Aquifer management is one of the most challenging aspects of water resources management. Generally there are a large number of unrelated agencies and stakeholders often with a poor or non-existent understanding that the groundwater body is a common asset. This is more acute in dry areas, where irrigated agriculture is an important economic and social factor, even when in developed countries this accounts only for a small percentage of a region's total gross income. Generally, governments and regulating institutions have not been able to cope with this relatively new situation, and often they do not have the appropriate staff, economic resources, and understanding.

In dry areas irrigation and water supply consumes the whole groundwater recharge over large surfaces. This may lead to too intensive or excessive groundwater development. This development is difficult to control using classical means when the cost of water relative to crop value is low. Normally farmers will do all they can to get groundwater, even if they deplete it, as in a classical 'Tragedy of the Commons' situation. Only, with an understanding of the common asset will there be capability to establish the limits to development (López-Gunn and Martínez-Cortina, 2006). Efficient tools to engage and involve farmers in the management and collective stakeholder participation are needed (López-Gunn, 2007; Schlager and López-Gunn, 2006). To achieve this, groundwater quantity monitoring is a necessary tool, and where stakeholders are not able or prepared to carry it out the responsibility rests with public institutions, to do this subsidiarily at the beginning and to prepare and help users to carry out this jobs by themselves and to produce data and reports for the Water Authorities to be able to carry out general and management planning, but not the local tasks.

3.4.8 GROUNDWATER QUANTITY STATUS AND THE WFD – CONCLUDING REMARKS

The long history, high population density and concentration of activities in Europe have degraded and even wiped out many environmental assets and degraded water quality. This explains the programme for preservation and restoration of water-related environmental values in the European Union. These rely on quality parameters, but are closely linked to the quantitative situation.

For groundwater the concerns are:

- water-table depletion, which induce decay of wetlands, and reduction of phreatophyte areas and riparian tracts;
- stream base-flow and spring flow reduction;
- seawater contamination in coastal groundwater bodies;
- modification of lake functioning and even their disappearance;
- land subsidence in some areas, with increased risk of flooding, and modified inundation periods; and
- abstraction of poor quality groundwater that is later on disposed into the environment. This is mostly saline water, but also water with nitrates and pesticides from artificial contamination and some heavy metals, etc.

Often the actual situation is complex due to the specific characteristics of each aquifer, and their heterogeneity. A further complication is the long delayed behaviour of aquifer systems that produces non-steady situations of long duration, both in terms of quantity and quality. The chemical changes are often more important and difficult of identify. This means that the evaluation of an actual situation must be carried out in a dynamic context, and monitoring results should be interpreted in the same way. This may not be obvious, especially for non-specialists, and so well designed and continuously updated information is needed. This is not explicitly mentioned in the WFD, but must be considered.

Stakeholders have an important role as collaborators and partners with public institutions. This often has to be through their own representative bodies given the often very large number of stakeholders involved, especially when irrigated agriculture is important. They should contribute to monitoring in a given water body and any other related water bodies and use the results to draw their own conclusions after careful independent studies. It is not unusual that well informed stakeholders conclusions may be at odds with those of the public administration. An effective forum to resolve conflicts is a goal to be achieved, using common monitoring, and comparable evaluation tools.

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