IHE DELFT Institute for Water Education

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Importance of groundwater monitoring in IWRM

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Learning objectives

- Understand groundwater's role in IWRM
- Why and how to monitor groundwater levels, abstraction and quality?
- What are the different objectives of monitoring?
- What are the basic components to consider while designing a monitoring plan?

Different paradigms for addressing water challenges

Integrated water resources management (IWRM)	Water security	Eco-cities, sponge cities, and smart cities
Resilience and Adaptation	Integrated disaster risk management	Water governance
Integrated groundwater management (IGM)	Nexus based approaches (eg. WFE, WFEE)	… and others.

- Different paradigms have their strengths and limitations.
- Combining their advantages and minimizing conflicts can support better outcomes.
- When tailored to context, they can promote sustainable water management.

Paradigm shift over time

Water resources development (1960s-1970s)

- Dominant paradigm: water is a resource to be exploited
- The engineering approach of "predict and provide"
- Emphasis on infrastructure
- Individual projects

Water resources management (1980s-1990s)

- Recognition that water can be 'overexploited'
- Accounting for ecological and social constraints
- Regional and national planning instead of a project approach
- Demand-side measures come into focus

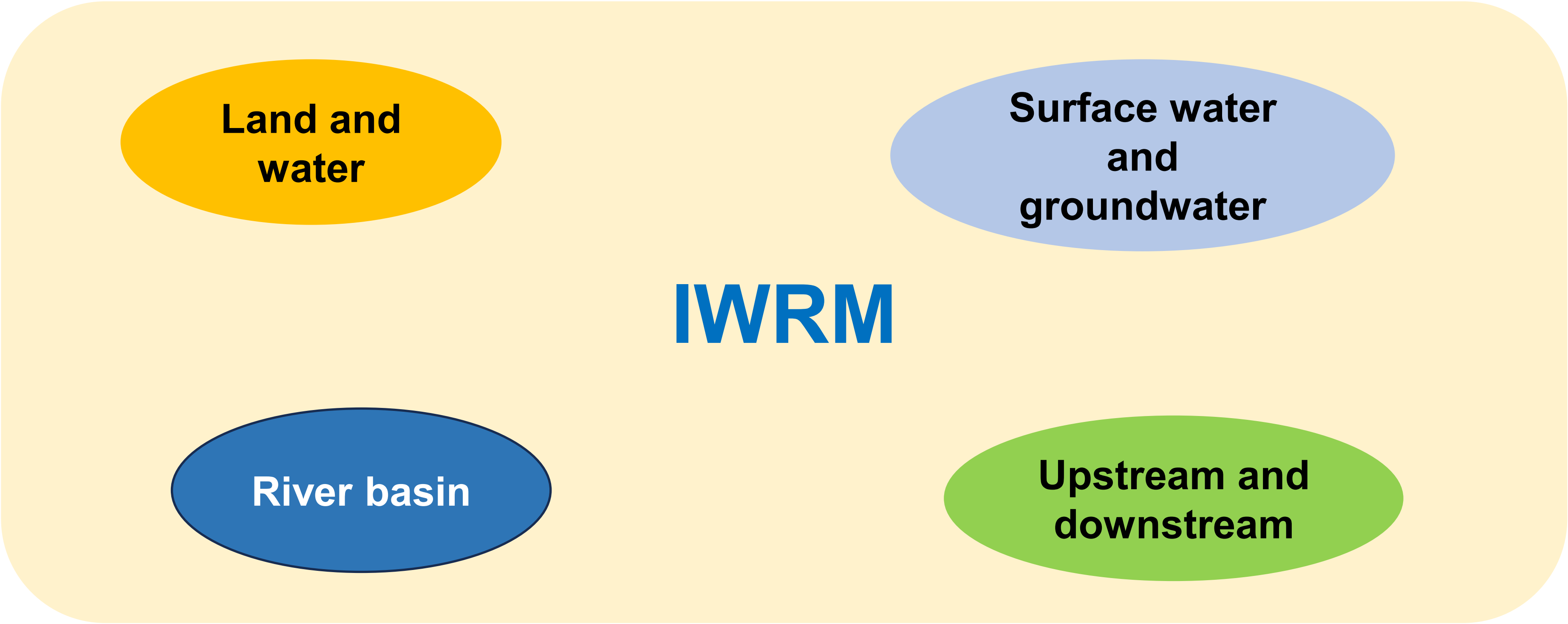
Integrated water resources management (1990s-present)

- Water management embedded in an overall policy for socio-economic development, physical planning and environmental protection
- Public participation
- Focus on sustainability

van der Zaag and Savenije (2014)

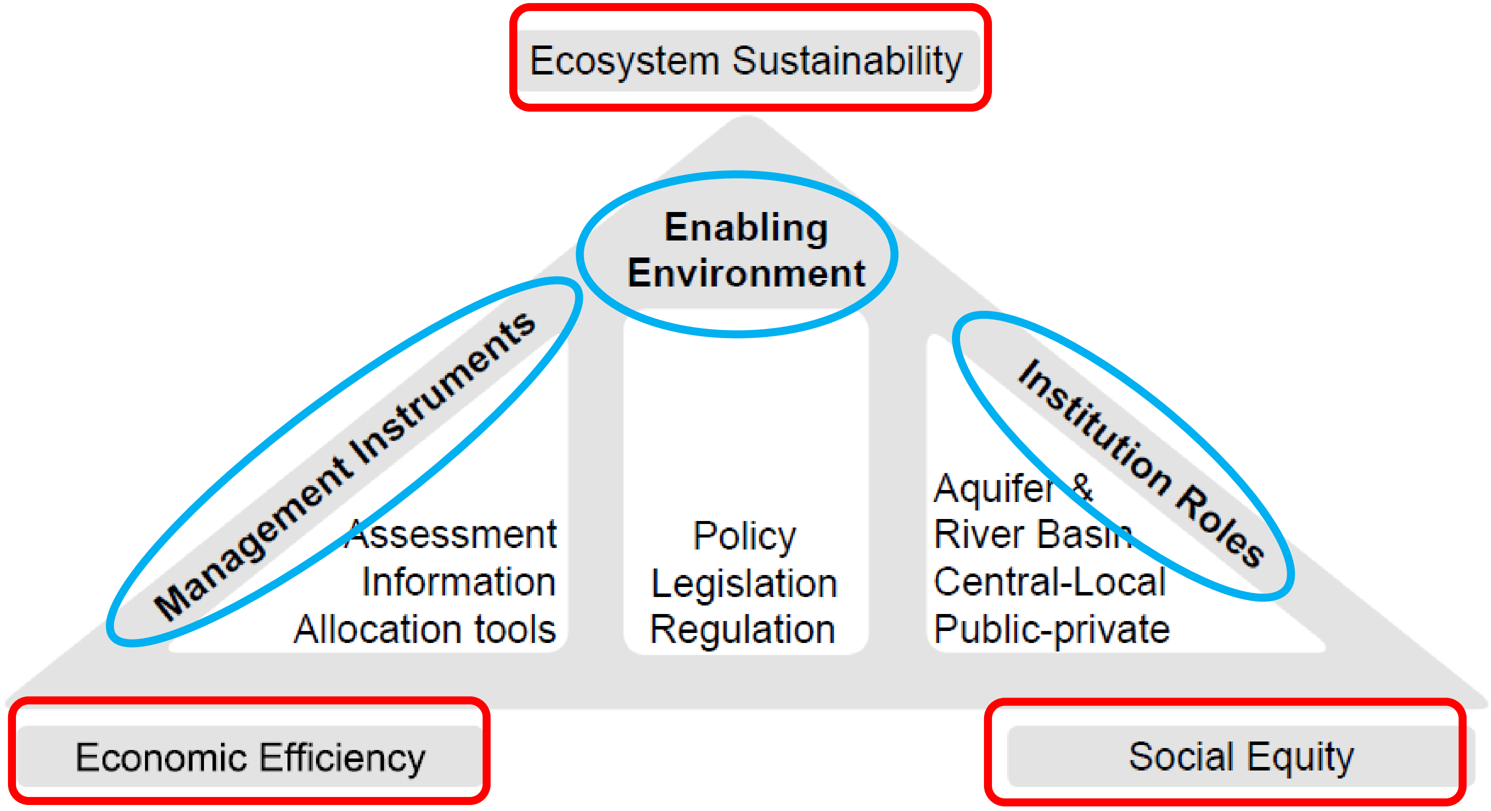
What is IWRM?

- Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment.



IWRM principles and framework

- Three key ‘pillars’ for IWRM implementation
- Three key ‘areas for’ IWRM reforms



GWP: Integrated Water Resources Management Toolbox

- IWRM Tool Box: Change Areas (http://www.gwp.org/en/ToolBox/ or https://iwrmactionhub.org/)

Enabling environment	Institutional roles	Management instruments
• Policies • Legislative framework • Financing and incentive structures	• Creating an organizational framework • Institutional capacity building	• Water resources assessment • Plans for IWRM • Demand management • Social change instruments • Conflict resolution • Regulatory instruments • Economic instruments • Information management and exchange

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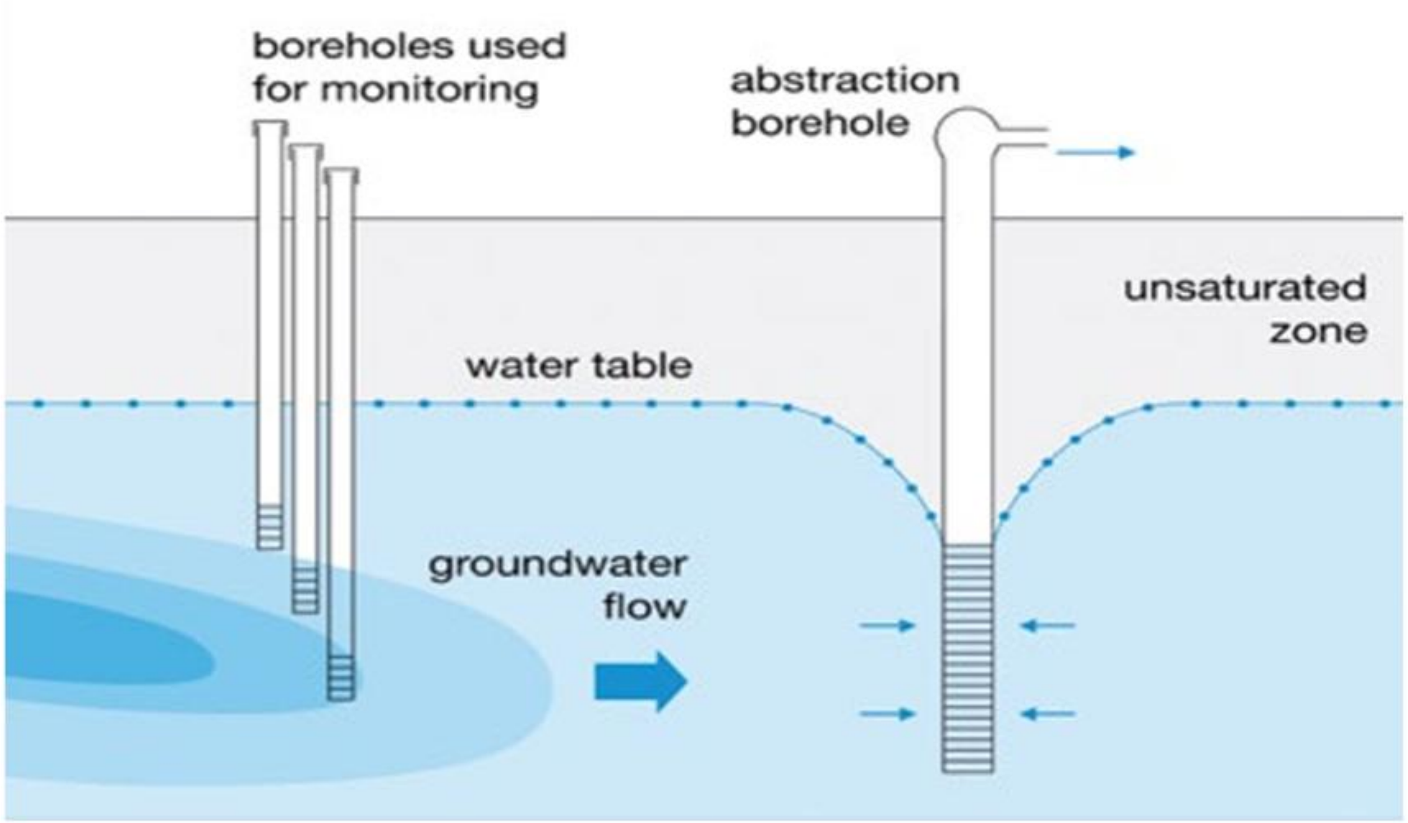
Groundwater Monitoring

- Which are the typical cases in your basin where dedicated groundwater monitoring including quality is needed?



Schematic representation of groundwater quality monitoring for specific management objectives

Groundwater monitoring : first step to Management

- Why?
- What?
- Where?
- When?
- How?

Groundwater Monitoring: Why?

- Groundwater overdraft
  - Continuous decline of groundwater levels leads to aquifer depletion
  - Increase of groundwater abstraction
  - Decrease of groundwater recharge by surface water diversion
  - Climate variability
  - North China Plain, drop of water level 1 to 5 m per year, total 30 to 90 m
  - High Plain Aquifer in USA, drop of water table up to 70m
- Groundwater pollution
  - Deterioration of groundwater quality
  - Saltwater intrusion
  - Groundwater pollution from point and diffusive sources
  - Nitrate and pesticides are found in shallow groundwater beneath agricultural land in the world
- Impacts on environment
  - Desertification
  - Degradation of groundwater dependent ecosystems
  - Land subsidence

Dry well

Increased demand

Over-exploitation

Groundwater Monitoring: Why?

Information for

- Sustainable development
    - Master plan
    - Integrated water resources management
- Control of groundwater hazards
    - Groundwater pollution
    - Waterlogging and salinity
    - Overdraft
    - Land subsidence
- Protection of environment
    - Desertification
    - Degradation of eco-systems
- Research
- Support of other hydrogeological activities

Groundwater Monitoring: Why?

Four basic objectives:

- Resource monitoring
    - Increase understanding of groundwater system in a basin
    - Ex. recharge, discharge etc
- Compliance monitoring
    - Obtain information on the effectives of management measures
    - Measuring groundwater use

Well field management
Source: www.pbc.gov

Groundwater Monitoring: Why?

Four basic objectives:

- Protection monitoring
    - Identify potential impacts on specific groundwater infrastructure or aquifer(s)
    - Ex. Well fields for public water supply against depletion and quality hazards
    - Urban infrastructure against land subsidence
    - Archaeological sites against rising water tables

- Pollution containment monitoring
    - Provide early warning information on impacts of potential pollution hazards
    - Ex. Intensive agricultural land use
    - Specific industrial sites
    - Solid waste landfills
    - Land reclamation areas
    - Quarries and mines

Groundwater Monitoring: What?

- Groundwater heads
- Natural/artificial recharges
- Natural/artificial discharges
- Temperature
- Hydrochemical constituents
- Pollutants

Groundwater Monitoring: What?

Types of data required for groundwater management

Type of data	Static data (from archives)	Dynamic data (from field stations)
Groundwater occurrence and aquifer properties	• Well records (borehole logs, initial groundwater levels and quality) • Pumping test information	• Groundwater level monitoring • Groundwater quality monitoring
Groundwater use	• Pump installation details • Water use inventories • Population registers and forecasts • Energy consumption for irrigation	• Well abstraction monitoring (direct or indirect) • Groundwater level variations at well
Supporting information	• Climatic data • Land use inventories • Geological maps/ cross sections	• River flow gauging • Meteorological observations • Satellite land use observations

Groundwater Monitoring: Where?

- Geographic scope
  - National : whole country
  - Regional : groundwater basin (transboundary aquifers)
  - Local : aquifers
- Locations of observation wells
- Number of observation wells

→ Network density

Groundwater Monitoring: When?

- Time scope
  - Long-term
  - Short-term
  - Temporal

- Number of observations

- Time of collection

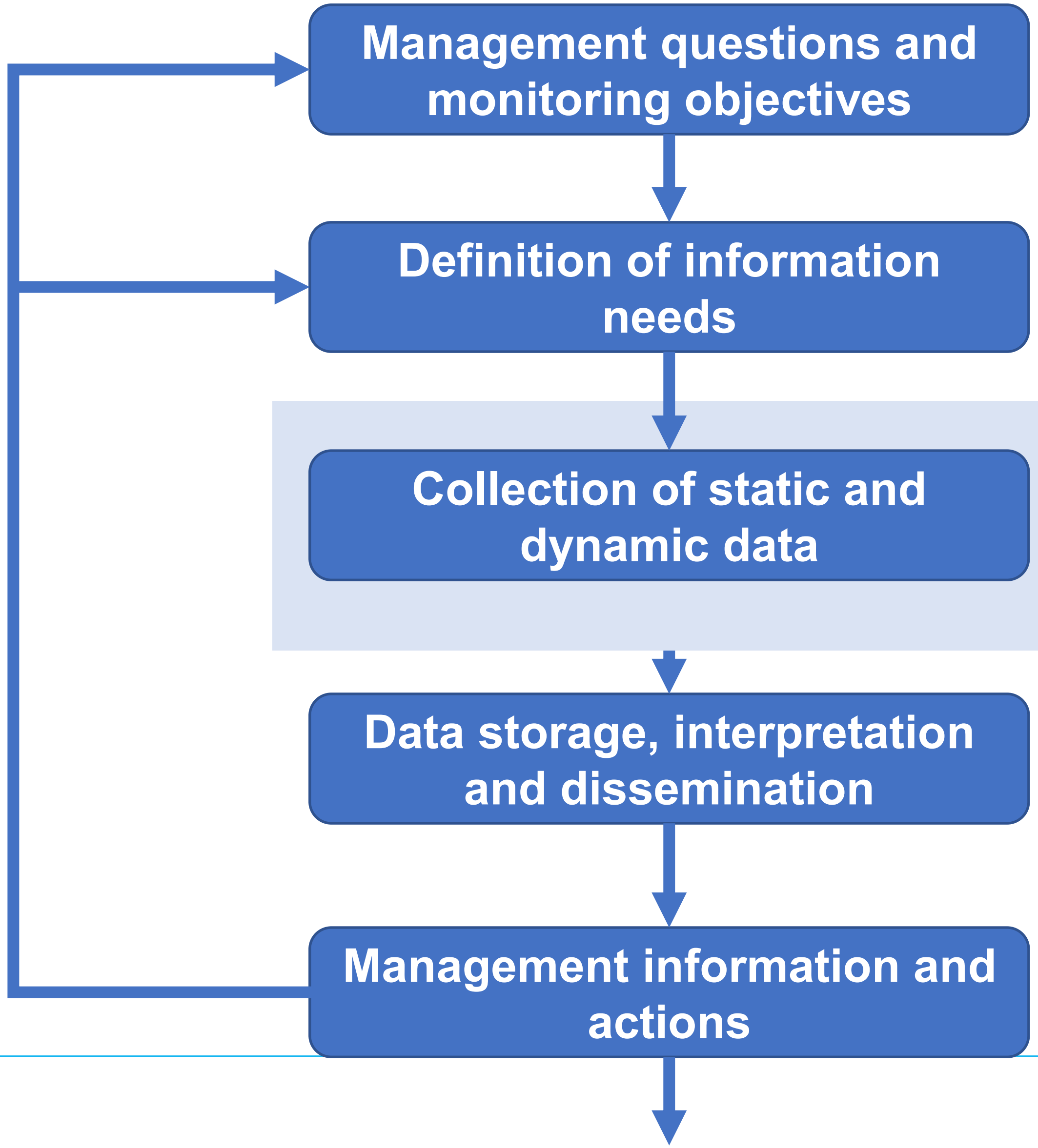
Number of observations and Time of collection → Sampling frequency

Groundwater Monitoring: When?

Network classification

Factors	Primary (basic)	Secondary (specific)	Temporary
Intended use of data	Planning Management	Operation control	Research
Geographical scope	National Regional	Regional Project-based	Project-based
Period of observation	Long-term	Short-term	Temporal
Variables (parameters)	Quantity Quality	Quantity Quality	Quantity Quality

Groundwater Monitoring: How?

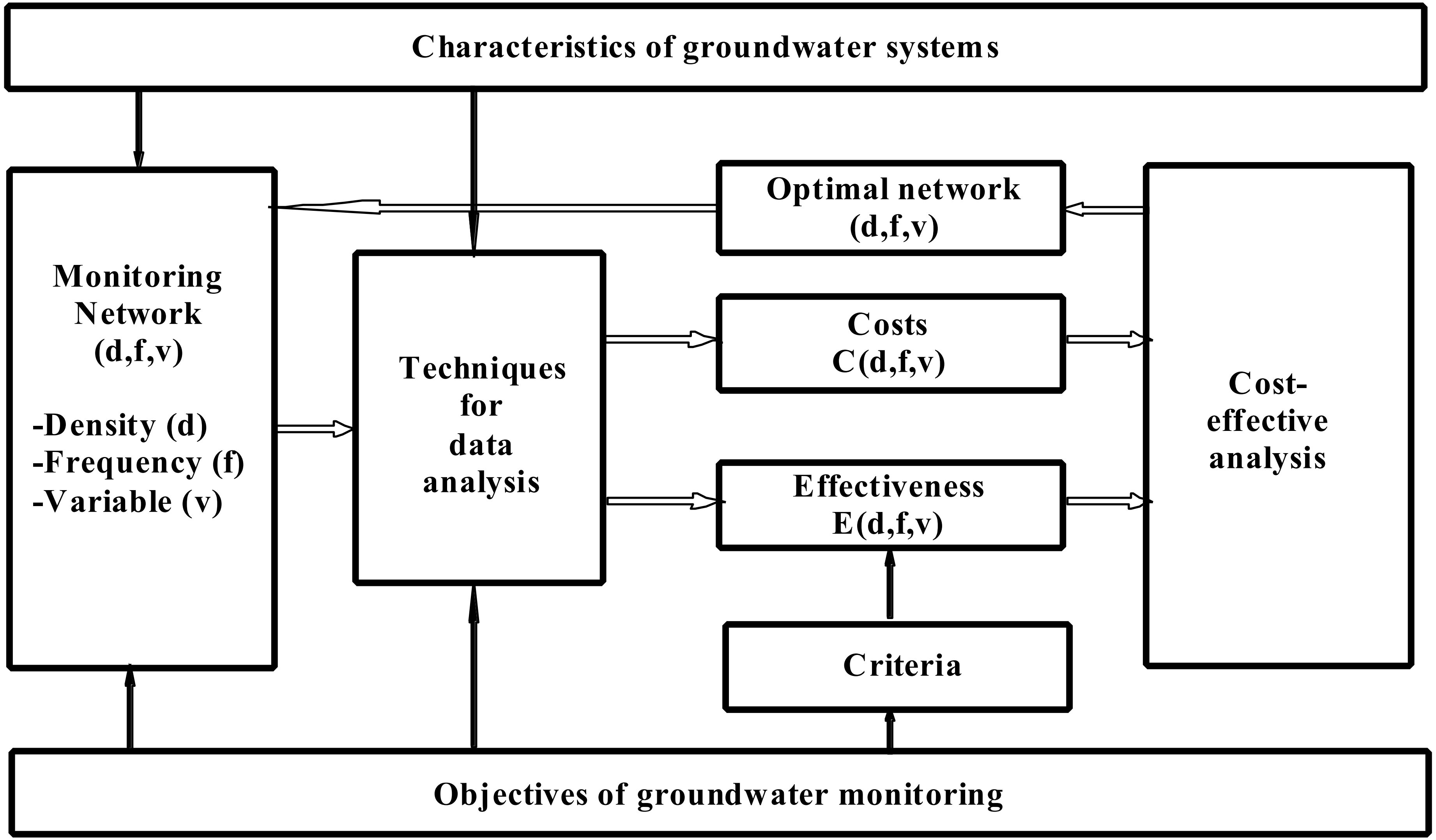


- Groundwater specific
- Water use
- Supporting data

Groundwater Monitoring: How?

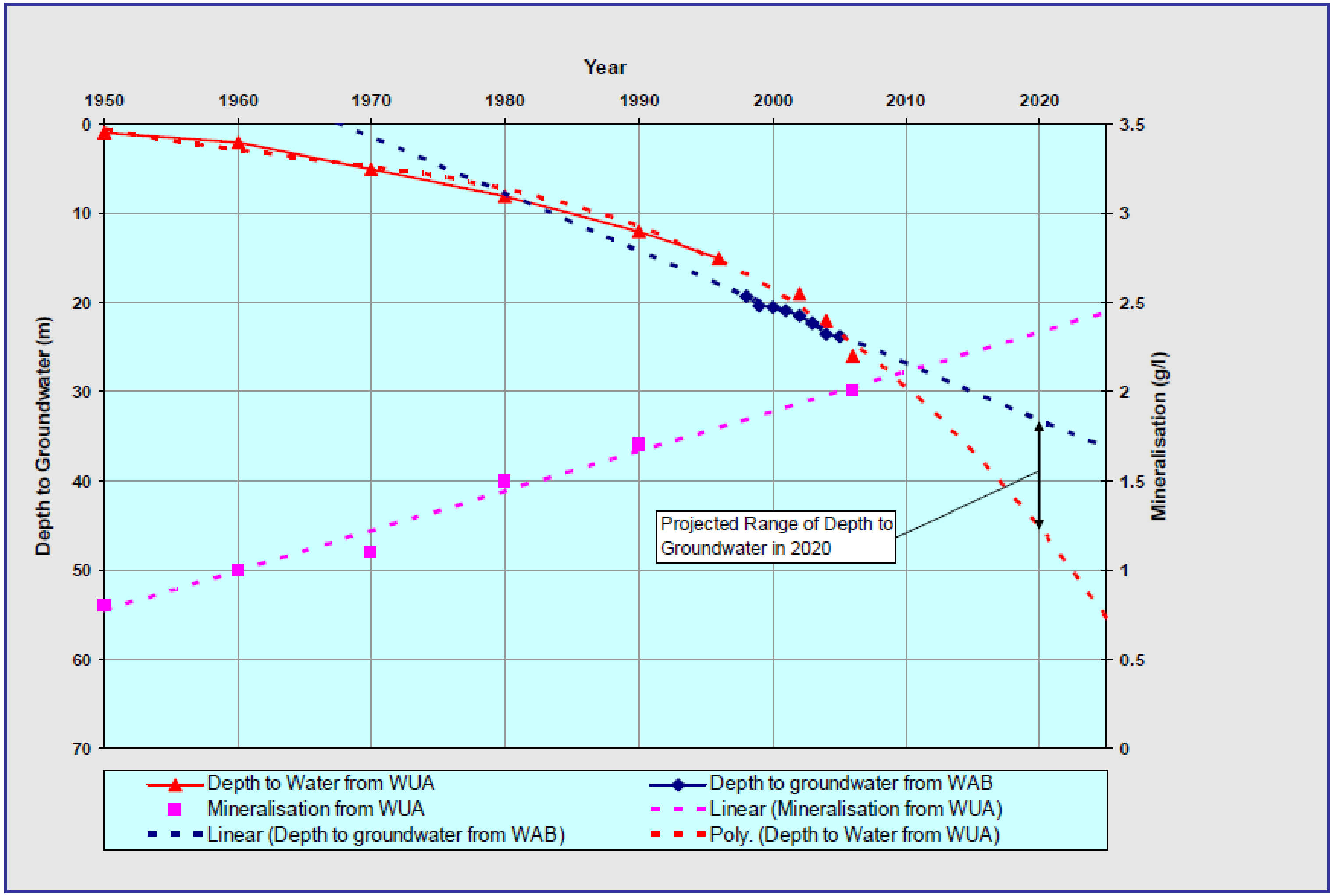
- Preliminary design
  - Groundwater studies (UNESCO, 1972)
  - Guide to hydrological practice (WMO, 1981)
  - Management of groundwater observation programmes (WMO, 1989)
- Quantitative analysis
  - Optimum design
  - Pragmatic approach

Groundwater Monitoring: How?



What does monitored data tell us?

- Graph shows past and projected groundwater levels and mineralisation
- Groundwater level and salinity monitoring in Minqin County in Gansu Province, China



Network Design: Pragmatic Approach

Step 1 Determination of the objective

Step 2 Characterisation of monitoring area

Step 3 Assessment of the existing network

Step 4 Design of sub-optimal network

Network Design: Technical Objectives

- ***Technical objective***
  - monitoring status of groundwater systems
  - monitoring trend
- ***Surrogate objective***
  - estimation of mean
  - interpolation of groundwater state variables
  - detection of trend
  - identification of periodic fluctuations
- ***Surrogate criteria***
  - confidence internal for mean
  - standard deviation of interpolation error
  - trend detectability
  - Nyquist frequency

Characteristics of Monitoring Area

- Geographical scope of the monitoring area
- Topography and geomorphology
- Land use
- Climate and hydrology
- Geology and hydrogeology
- Conceptual hydrogeological system
- Social-economical activities
- Development of water resources

Assessment of Existing Monitoring Network

- Inventory of observation wells
- Assessment of spatial distributions
- Assessment of observation frequency
- Inspection of maintenance and management
- Inspection of data storage, analysis and information dissemination

Assessment of Existing Monitoring Network

- Assessment of spatial distributions
  - Locations of observation wells posted on hydrogeological map with contour lines
  - Coverage for quantitative status assessment
  - Contour map of Kriging interpolation error
- Assessment of observation frequency
  - Hydrograph of time series
  - Time series analysis

Design of a sub-optimal monitoring network

	Space	Time
Technical Objectives	• Interpolation • Global average	• Detect trend • Identify periodicity • Estimate mean
Criterion	• Accuracy of interpolation • Accuracy of estimating average	• Trend detectability • Accuracy of identifying periodic fluctuations • Accuracy of estimating mean
Minimum	Network density (d)	Sampling frequency (f)
Methods	• Statistical test • Kriging	• Statistical test • Time series analysis
Procedures	Simulation	Analytical

Spatial distribution: Guidelines

- Multiple aquifers
  - separate wells at each aquifer in the same location
- Coverage of spatial heterogeneity
  - each aquifer is divided into homogenous zones
  - at least one well at each homogenous zone
- Hydrogeological continuity
  - distance between wells < scale of heterogeneity
- Coverage of boundary conditions
  - pairs of observation wells perpendicular to boundaries
- Coverage of hydrological stresses
  - pairs of wells perpendicular to rivers
  - coverage of recharge and discharge locations

Spatial distribution: Guidelines

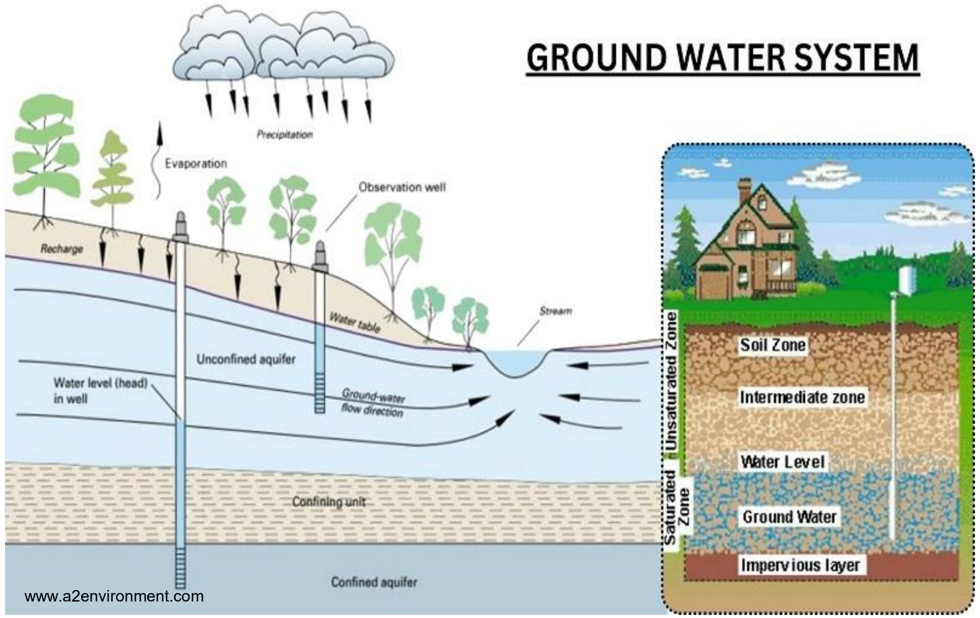
- Utilization of existing wells
  - production wells for water quality sampling, but not for measuring groundwater levels
  - exploration wells converted for observation wells
  - elevation of reference point and depth of filters
- Adherence to a geometric pattern
  - effective to detect spatial trend
  - convenient for numerical modelling
- Co-location of observation wells
  - same location for water level and quality measurement
- Elimination of short-term dynamic effects
- Accessibility

Sampling frequency: Guidelines

- Satisfaction of objectives
- Coverage of temporal variability
- Recording of principal fluctuations
- Convenience of data collection, storage, and processing
- Trade-off between frequency and density
- Budget limitations

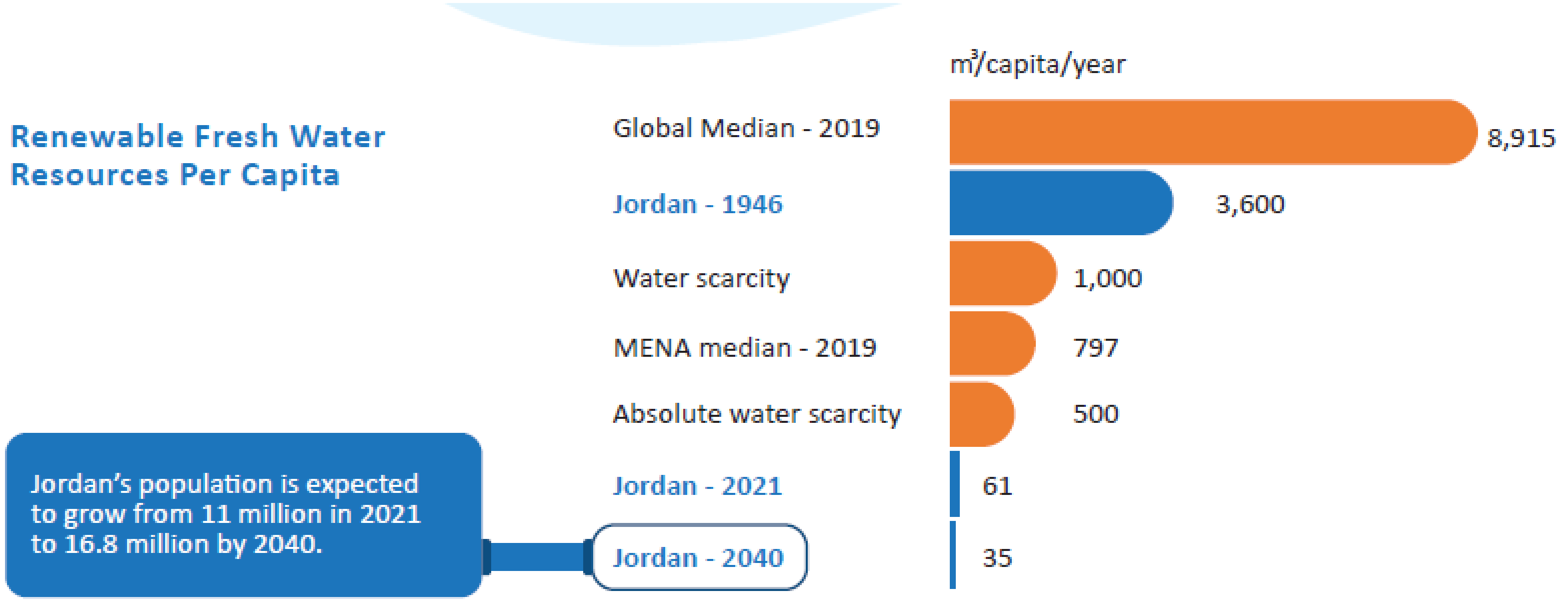
Exercise

- Time invested: 15 -20 minutes.
- Participants to work individually or in groups. Each group to work with one of the topics below:
    1. Monitoring a dune infiltration system to protect a drinking water well field against seawater intrusion
    2. Monitoring plan for an industrial site to prevent spreading of possible contaminants through the groundwater
    3. Monitoring system for trend monitoring in a sedimentary shallow aquifer in river basin
- Activities:
    - Define the monitoring objectives and basic design parameters.
    - What are the main benefits and who are the main beneficiaries of the monitoring?
    - Suggestions to make the monitoring plan cost effective.
    - How to assure sustainable financing?
    - Who will implement the monitoring and how is the monitoring information handled to address the management objectives?
- Report your discussions in 5 minutes.



Jordan- current status of groundwater

- Groundwater is being pumped at double the safe yield of aquifers
- Aquifers are shrinking, groundwater levels are dropping, and water quality is deteriorating
- Around a quarter of Jordan's renewable freshwater from aquifers and rivers originate from neighborhood countries
- Jordan uses 1,093 MCM (2021) of water per year at the cost of severe over-pumping of groundwater



National Water Strategy, 2023

Jordan – water laws

- Jordan's water laws - primarily defined by the Law on the Water Authority No. 18 of 1988. Established state ownership of all water resources and the Water Authority of Jordan (WAJ), and the Ministry of Water and Irrigation (MWI)
- Groundwater By-Law No. 85 of 2002, which affirmed state ownership of underground water and set rules for its use.
- National Water Strategy (2023-2040) published in 2023.

IWRM and environmental protection

Goal 1

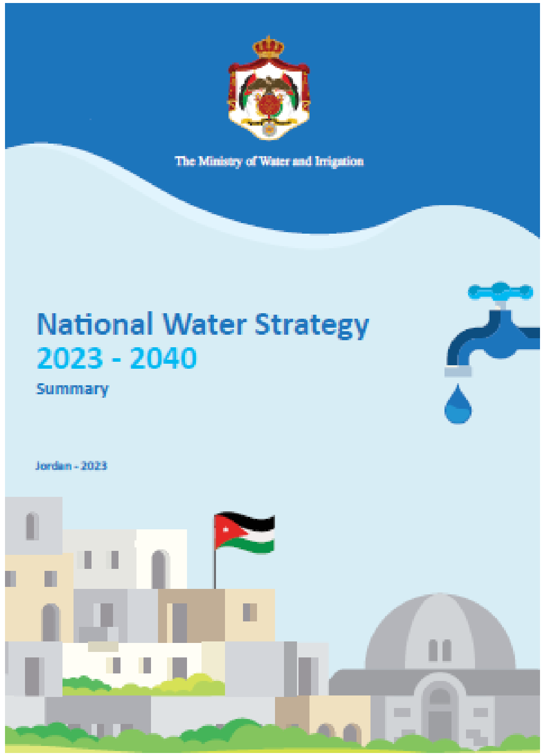
Sustainably manage groundwater resources to restore safe yield levels and protect Jordan's aquifers

Target

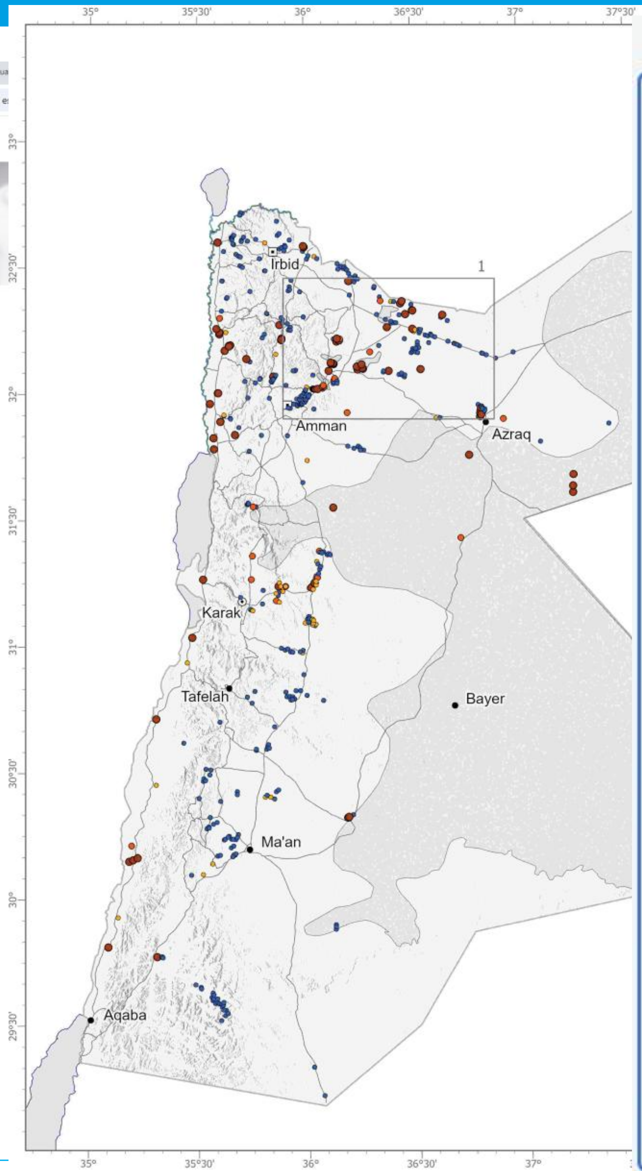
Annual abstraction reaches and sustains safe yield levels from 2035

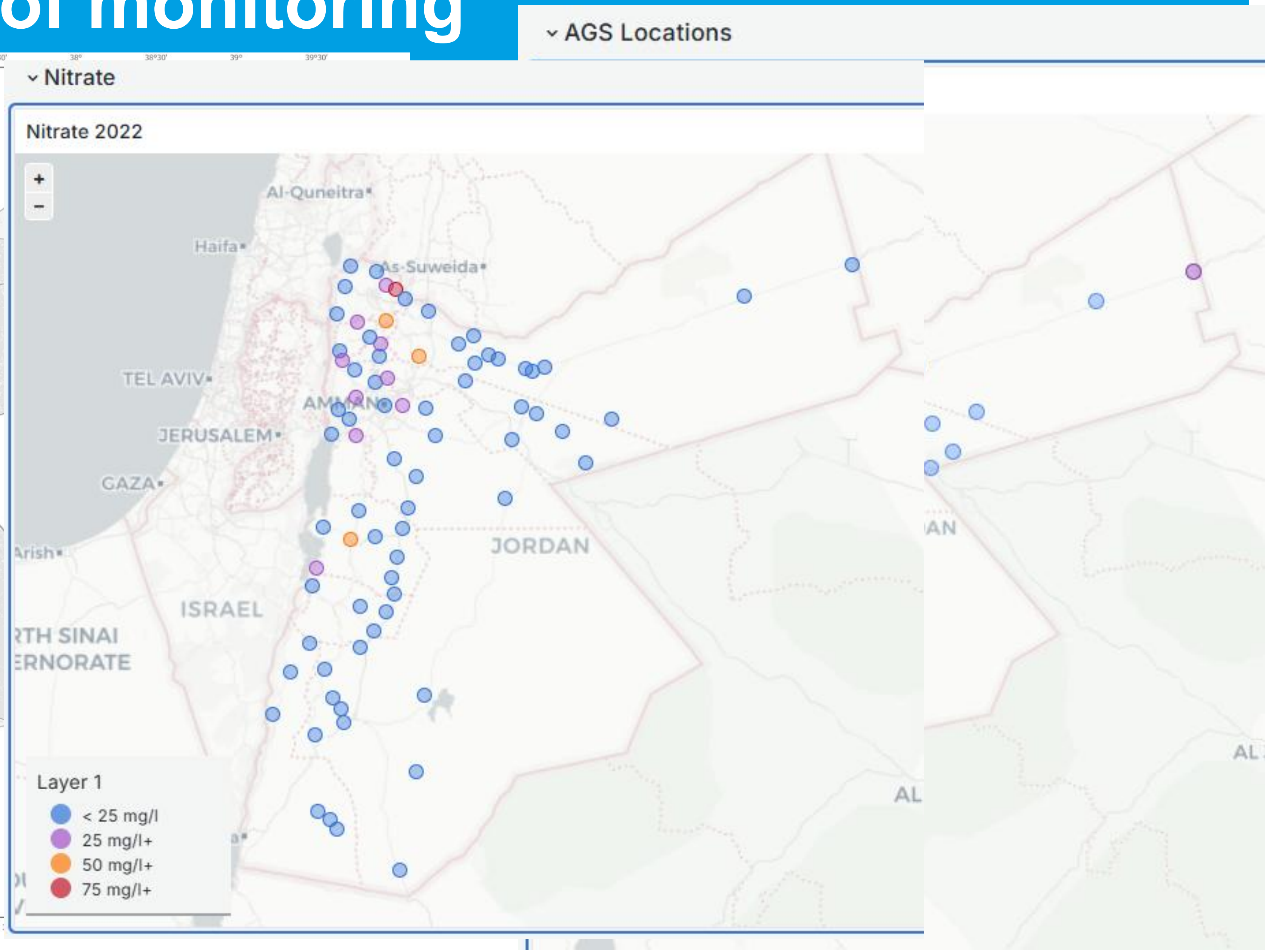
Key Objectives and Approaches

- Strengthen enforcement measures to reduce over-abstraction with reliable analysis of safe yield levels
- Link wells licensing limits and the water budget to safe yield levels
- Shift to groundwater conservation and aquifer recharge when desalination supplies are available
- Minimize pollution risks to protect groundwater quality



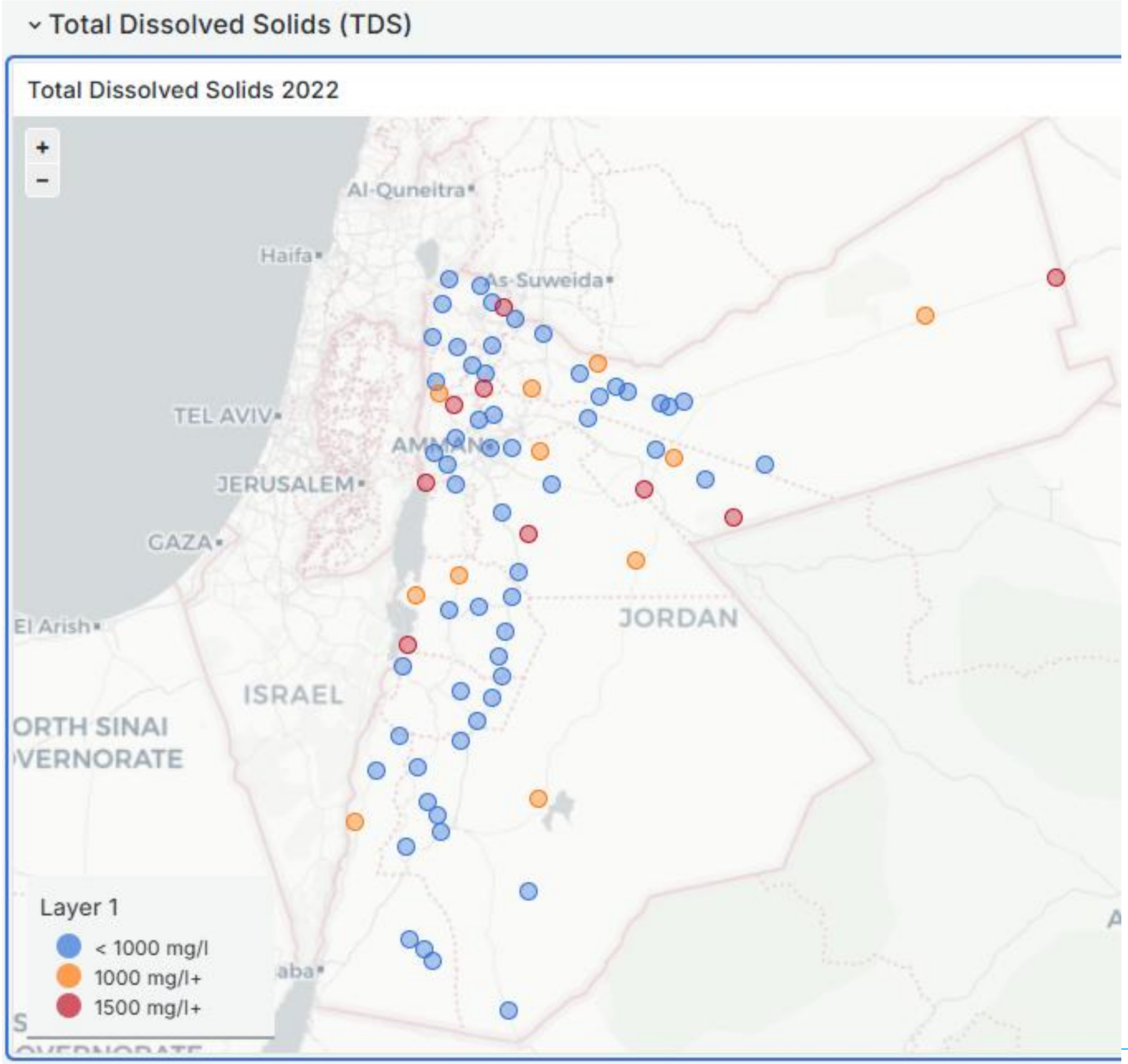
Current status of monitoring

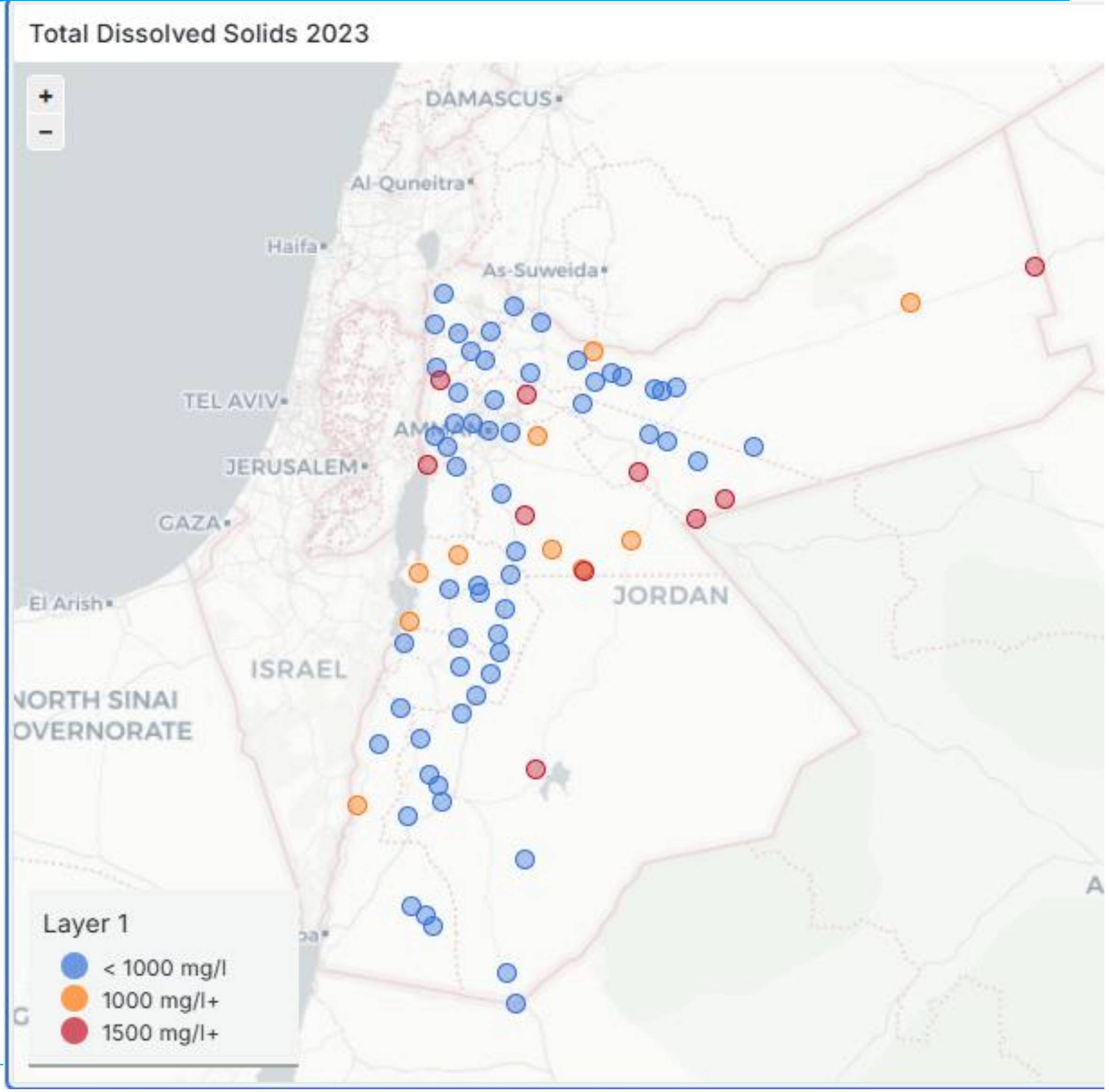




All data from the Groundwater Quality of Jordan Website ": https://eservices.mwi.gov.jo/groundwaterinformation/

Current status of GWQ monitoring





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Practical takeaways

- **Key requirements and provisions that affect monitoring practice**
  - Quantity & quality monitoring required→ Track both water levels & hydrochemistry regularly.
  - Licensing & abstraction control→ Data used to check compliance with permits & limits.
  - Protection zones & vulnerability mapping→ Monitoring prioritised around wellfields & sensitive aquifers.
  - Environmental Protection Law (2017)→ Prohibits pollution; EIAs & licensing include monitoring.
  - National baseline datasets (MWI/WAJ)→ Provide reference points & guide future monitoring design.
- Observed gaps and challenges: over abstraction and falling water levels; data fragmentation