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Research paper

Upgrading a regional groundwater level monitoring network for Beijing Plain, China

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ABSTRACT

Monitoring of regional groundwater levels provides important information for quantifying groundwater depletion and assessing impacts on the environment. Historically, groundwater level monitoring wells in Beijing Plain, China, were installed for assessing groundwater resources and for monitoring the cone of depression. Monitoring wells are clustered around well fields and urban areas. There is urgent need to upgrade the existing monitoring wells to a regional groundwater level monitoring network to acquire information for integrated water resources management. A new method was proposed for designing a regional groundwater level monitoring network. The method is based on groundwater regime zone mapping. Groundwater regime zone map delineates distinct areas of possible different groundwater level variations and is useful for locating groundwater monitoring wells. This method was applied to Beijing Plain to upgrade a regional groundwater level monitoring network.

1. Introduction

Continuous decline of groundwater levels has been observed in many places of the world in the past half-century. It has indicated clearly the depletion of groundwater reserve in large scales (Konikow and Kendy, 2005). Groundwater depletion has been caused either by over-exploitation or reduction of groundwater recharge. The combination of these two causes has accelerated groundwater depletion in Beijing Plain, China. On one hand, groundwater abstraction continuously increases to meet demand for expanding industrial, agricultural and urban water supply. On the other hand, natural groundwater recharge has been affected due to the storage and diversion of inflowing rivers. Climate variability exerts extra pressure on the groundwater reserve. Significant decline of groundwater levels in the Beijing Plain has been observed since 1970's. Groundwater levels have decreased to historical low levels during the 8 consecutive dry years from 1999 to 2006. The total drop of groundwater levels amounts to more than 20 m since 1970's.

Quantification of the groundwater depletion provides very important information for effective groundwater resources management. Groundwater depletion can be assessed by integrating contour maps of groundwater level changes over the aquifer area or by using well calibrated groundwater models (McGuire et al., 2003). Both methods require long-term measurements of groundwater levels at regional scale. Regional groundwater depletion is rarely assessed because of the lack of these measurements. The regional monitoring network also provides important information required for water resources management (Van Bracht, 2001).

Historically, groundwater level monitoring in Beijing Plain started from monitoring water supply well fields and urban areas. Monitoring wells are clustered around well fields and the city. A regional groundwater level monitoring network does not exist. This paper reviewed the state of the art of regional groundwater level monitoring network design methods. A new method based on the delineation of groundwater regime zones was proposed. The method was applied to Beijing Plain to upgrade the existing monitoring wells into a regional groundwater level monitoring network.

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2. Overview of groundwater level monitoring network design

2.1. Types of groundwater level monitoring networks

Groundwater monitoring generally starts in small scale with local problems. It evolves into regional or national monitoring networks focusing on both of local and regional problems. Regional scale groundwater level monitoring is necessary since most groundwater basins are regional; impacts of intensive human activities on groundwater have extended to the whole basin; and integrated water resources management requires regional groundwater level information at basin scale. Three stages of groundwater monitoring network development may be distinguished (Jousma and Roelofsen, 2004): (1) temporal monitoring networks for groundwater investigation or identification of local problems; (2) local groundwater monitoring networks for systematic monitoring of impacts of intensive groundwater withdrawal; and (3) national or regional groundwater monitoring networks for providing sufficient information for integrated water resources planning and management.

Objectives of groundwater level monitoring and intended use of groundwater level data determine types of monitoring networks. Objectives of groundwater level monitoring have been defined by Heath (1976), WMO (1994) and UNESCO (1998). In summary, data from a long-term regional groundwater level monitoring network may be used: (1) to characterize groundwater systems; (2) to analyze groundwater quantitative status; (3) to identify changes in groundwater recharge, storage and discharge; (4) to detect effects of climate change on groundwater resources; (5) to assess impacts of groundwater development; (6) to calibrate groundwater flow models; (7) to assess effectiveness of groundwater management and protection measures.

There are various classifications of groundwater level monitoring networks (Heath, 1976; WMO, 1989; UNESCO, 1998; Jousma and Roelofsen, 2004). Two main types of groundwater level monitoring networks are usually distinguished: basic (background or primary) monitoring networks and specific (or secondary) monitoring networks.

Basic monitoring networks are large scale regional or national monitoring networks designed for groundwater resources assessment and monitoring of regional groundwater regime and overall impacts. The basic network covers an independent groundwater basins or a complete country. Observation wells are installed in major aquifers at relatively large distances. Observations are taken with fixed low frequency for infinite long-term period.

Specific monitoring networks are local scale monitoring networks designed for monitoring of operations of groundwater systems for water supply or other specific purposes. The specific network focuses on local problems, for example, monitoring water table decline around pumping well fields, monitoring effects of irrigation schemes, and monitoring the groundwater levels in nature conservation areas. Network density should be sufficiently high to quantify effects and observation frequency should be sufficiently high to identify short-term variations.

Basic and specific monitoring networks are usually combined to form an integrated monitoring network. In this integrated monitoring network, basic monitoring wells provide reference conditions to assess local impacts observed by specific monitoring network. Regional low density basic wells serve the overall objectives while superimposed local high density wells focus on specific objectives. The classification of basic and specific networks may also be useful to divide the responsibility for monitoring between governmental organizations responsible for overall water management, and organizations with operation of specific water systems.

2.2. Design methods of groundwater level monitoring networks

In contrast to a growing large number of publications for designing groundwater quality monitoring networks (Loaiciga et al., 1991; ASCE, 2003), there are considerably less publications for designing groundwater level monitoring networks. From published references, methods for groundwater level monitoring network design can be classified into: (1) hydrogeological approach, (2) geostatistical approach, and (3) modeling approach.

Hydrogeological approach refers to principles and guidelines for groundwater level monitoring network design based on conceptual understanding of hydrogeological systems. Groundwater studies (UNESCO, 1972) provided an example of designing an observation well network to determine groundwater balance components in an experimental river basin. Peters (1972) proposed criteria for determining density of observation wells and record length for various intensities of hydrogeological investigations. Heath (1976) classified groundwater level observation wells into 3 networks: (1) hydrological network, (2) water management network, and (3) baseline network. Guidelines for required observation well density and observation frequency were proposed for these three networks. WMO (1989) issued a guideline for management of groundwater observation programmes. The groundwater observation networks were divided into a basic network, a specific network and a temporal network. Guidelines for choices of observation sites and frequency were provided for the design of a basic network. A guiding document was published by UNESCO (1998) on monitoring for groundwater management in (semi-)arid regions. Groundwater monitoring was classified into background monitoring and specific monitoring. The objective of a background groundwater quantity monitoring network was defined to provide time-varying information to characterize the initial stages of the development of a groundwater system. A new guideline on groundwater monitoring for general reference purposes was compiled by IGRAC (2006). A general reference groundwater monitoring programme is established for the reconnaissance of the groundwater system and the early stage of groundwater development and management. The objectives of the monitoring programme were defined to characterize regional groundwater systems, to detect trends in relation to groundwater use, to estimate potential for further groundwater development, and to provide historical reference data sets. Guideline and options for the design of groundwater monitoring networks for shallow and deep groundwater systems were provided.

Geostatistical techniques were not widely used for the design of groundwater level monitoring networks since it requires large number of measurements to estimate the spatial correlation structure, and a measure of network efficiency is difficult to define for multiple purposes of a groundwater level monitoring network (Taylor and Alley, 2001). Nevertheless, the variance of estimation errors for interpolating groundwater levels could be used as surrogate criteria for evaluating network efficiency. Kriging is a logical choice since it is not only the best interpolator, but also-provides the variance of interpolation error. Sophocleous et al. (1982) applied universal Kriging to analyze a groundwater level monitoring network for Northwest Kansas. Olea (1984) proposed to use the average standard error and the maximum standard error as two indices for measuring the global performance of sampling networks for spatial functions. A case study of the Equus Beds aquifer in the central Kansas was used to demonstrate the use of the method. Kriging method was also applied to redesign of groundwater level monitoring networks for the province of Gelderlands in The Netherlands (Van Bracht and Romijn, 1985).

In principle, numerical groundwater modeling could be used to identify key locations to measure groundwater levels to improve the model calibration. The integration of a numerical groundwater