Evaluation of the Safe Yield of Groundwater Production Derived from Wind Energy

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Abstract: Groundwater aquifers are key sources of water in arid and semiarid regions. Fossil fuels are commonly used to power water-well pumps. The adverse effects of greenhouse gas emissions from fossil fuel use have led to the search for alternative clean energy sources to extract groundwater. A key factor in assessing the viability of wind energy use in groundwater extraction is the safe yield of groundwater production that can be derived by using windmills to power water wells. This paper presents and tests simulation and optimization models developed to estimate the safe yield of groundwater production derivable from the joint application of wind energy to water extraction and water storage for irrigation. **DOI: 10.1061/(ASCE)EY.1943-7897.0000240.** *© 2014 American Society of Civil Engineers.*

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Introduction

Extraction of groundwater by powering water-well pumps with fossil-fuel energy is perhaps the most common method used to supply groundwater in many regions (Sterret 2007). Using fossil fuels leads to air pollution by the emission of greenhouse gases (Intergovernmental Panel on Climate Change 2014). Desire to avoid such pollution has focused attention on alternative clean energy sources (Loáiciga 2011). Wind energy is a clean, renewable energy source that has few adverse environmental effects and is available in many places. Although wind energy has been used for small-scale hydrologic applications, it is gaining popularity as a clean source of electricity generation to supply water for agricultural and other water-resource uses.

There have been a few studies conducted on the feasibility of using wind energy for water resources applications. Al Suleimani and Rao (2000), for example, investigated the amount of groundwater that can be extracted using wind turbines operating at various speeds. These authors claimed that existing wind resources were enough for groundwater extraction in several rural places in Oman. Valdés and Raniriharinosy (2001) designed three different simple wind pumps for use in Madagascar. Bakos (2002) investigated the feasibility of using a wind-driven water plant system for inexpensive electricity generation. The author concluded that using such system would be feasible and could reduce electrical energy consumption in several Greek islands. Bueno and Carta (2006) recommended wind-powered hydro storage systems in the Canary Islands. Garcia-González et al. (2008) suggested using wind energy in conjunction with hydro pumped-storage units in order to solve the problem of variable wind speed. Vieira and Ramos (2008) reported an optimization model that determines the best operation times of the day for a wind-energy system with pumped storage and defined water inflow and consumption. Vieira and Ramos (2009) reported an optimization model to optimize water supply efficiency. Their results indicate that using wind turbines to provide pumping energy needs would reduce costs significantly. Ramos et al. (2011) proposed three solutions to improve energy management and the efficiency of water supply systems, namely: (1) using water turbines in gravity pipes to control the pressure and electricity generation, (2) optimizing pumping operation rules giving consideration to electricity tariffs and water demand patterns, and (3) using renewable energy tools such as wind turbines in water pumping stations. According to their results, optimization of the operating rules of water supply and electricity production in renewable hybrid systems can minimize water-pumping costs and reduce CO_2 emissions. Sun et al. (2011) found out that wind-wheel and water-pump operations can be matched out at different wind speeds, and that the maximum water discharge can be achieved at different wind speeds if the torque specifications and wind-wheel power generation are matched out correctly and optimized. Notton et al. (2011) investigated the joint application of renewable energy with water storage. Protopapas and Papathanassiou (2012) reported that using hybrid (wind energy and diesel power) stations to provide dispatchable power leads to significant increase in wind energy production. Bekele and Tadesse (2012) studied the feasibility of a small-scale hydropower/photovoltaic/wind-based hybrid electric supply system for six sites. After optimizing the hybrid system, the cost of energy was determined to be less than \$0.16 per kWh.

Recently, many techniques have been developed and applied in all aspects of water resources systems such as reservoir operation (Bozorg Haddad et al. 2011a; Fallah-Mehdipour et al. 2011a, 2012a, 2013a), hydrology (Orouji et al. 2013), project management (Bozorg Haddad et al. 2010b; Fallah-Mehdipour et al. 2012b), cultivation rules (Bozorg Haddad et al. 2009; Noory et al. 2012; Fallah-Mehdipour et al. 2013b), pumping scheduling (Bozorg Haddad et al. 2011b), hydraulic structures (Bozorg Haddad et al. 2010a), water distribution networks (Bozorg Haddad et al. 2008; Fallah-Mehdipour et al. 2011b; Seifollahi-Aghmiuni et al. 2011, 2013), operation of aquifer systems (Bozorg Haddad and Mariño

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