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Optimizing water delivery system storage and its influence on air pollutant emission reduction

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ABSTRACT

This paper presents a quantitative approach to estimating the carbon dioxide (CO_2) emission reduction by optimizing water storage operations in water delivery systems. This approach uses hydraulic models of water delivery systems to perform pumping energy optimization analyses with equalization water storage and identifies marginal electrical generation types based on locational marginal price (LMP) data available in open electrical markets. The marginal pollutant emission reduction has been evaluated based on pumping energy optimization, hourly marginal generation types and pollutant emission rates for different types of generation. An example is presented that applied the proposed approach to a large water delivery system in the Metro Detroit area, Michigan. The analysis results showed a daily CO_2 emission reduction of 11.7 tonnes, which accounted for approximately 3% of the total CO_2 emission produced by the electricity consumption for pumping water under the maximum day demand condition of 2012.

1. Introduction

The accumulation of carbon dioxide (CO_2) in the atmosphere is recognized as a major contributor to the global warming problem. Reducing carbon and other air pollutants emissions is an immense issue for protecting our environment. In 2011, the total U.S. emission of CO_2 was 5420 million tonnes, the second largest CO_2 emitter country in the world. The U.S. emission of CO_2 by the electricity generation section in 2011 was 2166 million tonnes, or about 40% of total U.S. CO_2 emissions [1]. Potable water delivery in the U.S. accounts for 3% of the nation's electricity consumption, which generates an annual CO_2 emission of approximately 64 million tonnes [2].

Various energy resources have been used for electricity generation including nuclear, coal, natural gas, fuel oil and renewable fuels like hydroelectric, geothermal, solar, and biomass. Nuclear and renewable generators do not discharge air pollutants. The other fossil fuel based types of power plants emit air pollutants and are normally less environmental-friendly.

Power plants are classified as base plants and peaking plants based on their operational status to meet the diurnal variation of energy demand in a region. Base plants produce electricity at a constant rate and are operated year-round to meet some or all of the given region's continuous demand. They usually use coal, nuclear or renewable fuels. Peaking plants operate primarily when power use is at its peak and are often powered by natural gas or fuel oil.

Water utilities pay an electrical demand charge in addition to a usage fee. The electrical usage is the energy that a water utility consumes and is measured in kilowatt-hours (kWh). The electric demand represents the highest rate of electrical current during a billing period and is measured in kilowatts (kW).

The electrical demand charge will be a large part of the energy bill if a water utility operates its pumping facilities to directly serve water demands without storage. During peak water demand hours many utilities use stored water to serve part of the on-peak demands to reduce the on-peak pumping requirements. This allows the pumping facilities to operate at a constant or less variable pumping rate to reduce peak electric demand.

Numerous water storage optimization studies have been performed with a focus on minimizing pumping energy use and costs [3,4]. However, little consideration has been given to the environmental effects of optimizing water storage operations even though it is generally assumed that a reduction of energy consumption results in reduction of air pollutant emissions. To assess the environmental effects of optimizing storage operations in water delivery systems, appropriate methodologies are required to evaluate the pollutant emission reduction.

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Table 1
LMP ranges for marginal generation.

Marginal generator type	Upper bound LMP ($)
Nuclear/renewable	19.25
Coal	78.88
Combined cycle natural gas	128.58
Other natural gas	140.28
Residual fuel oil	202.2
Simple cycle natural gas	277.11
Distillate fuel oil	>277.11

Many water distribution systems do not own enough storage capacity to supplement their peak-demand water delivery. Instead, they adjust pumping to roughly match the water system demand variations. Under this operation mode, more water is pumped during peak hour periods and less water is pumped during off-peak hours. Consequently, adding more water storage would help these utilities reduce energy costs. Water is pumped to storage during off-peak hours and storage is used to serve the demands during peak hours so that water utilities are able to run their pumps at constant or near constant rates for both on-peak and off-peak periods.

Peaking plants powered by natural gas and fuel oil produce higher pollutant emissions. Therefore, shifting on-peak electrical demands to off-peak hours by using water storage would reduce air pollutant emissions. This paper presents a quantitative approach that estimates the potential CO_2 emission with water delivery system model simulation and the available locational marginal price (LMP) data in electricity markets.

2. Approach

To evaluate storage capacity and pumping optimization in a water delivery system and its influence on air pollutant emissions, a calibrated hydraulic computer model is required. If the existing storage facilities are unable to meet water delivery requirements, necessary cyber storages are added to the hydraulic model to meet the requirements.

The operation of actual and cyber water storages in the water delivery system is subjected to an optimization analysis with the computer model. The location, type and size of the cyber storages can be adjusted to optimize the hourly energy requirements. This is done by: (1) shifting part of the peak hour pumping requirements to the off-peak period to reduce the electrical demand for the water delivery and (2) minimizing the total energy use for pumping water.

To optimize pollutant emissions based on energy consumption, diurnal variation data of the on-duty generator types is required because the emission rates are different for each type of generation.

Using the LMP's available in electricity markets to distinguish diurnal variations of marginal generation type is proposed [5]. According to the generation data collected for the power grids of the Midwest Independent Transmission System Operator (MISO), the relationship between LMPs and marginal generation types was developed and is summarized in Table 1.

Finally, the pollution emission rates for different types of electric generation are required to quantify the amount of emissions that can be reduced by utilizing water storage and shifting on-peak pumping requirements in a water delivery system. The emission rates for certain key pollutants, including CO_2, are available in USEIA (U.S. Energy Information Administration) [6]. The CO_2 emission rates for different types of generation are presented in Table 2.

3. Example of application

To assess environmental effects by optimizing storage use for water delivery, the water delivery system in the Metro Detroit area has been studied. The Metro Detroit area is the metropolitan area located in Southeast Michigan, having a population of approximately 4 million that makes up about 40% of Michigan's population. The water demand for the majority of the people in the Metro Detroit area is served by the Detroit Water and Sewerage Department (DWSD) water transmission system.

Table 2
CO_2 emission rates for different generation.

Marginal generator type	CO_2 (lbs/kWh)
Nuclear/renewable	0
Coal	2.14
Natural gas	1.22
Distillate oil (No. 2)	1.68
Residual oil (No. 6)	1.81

3.1. Water system overview

DWSD's water system is one of the largest systems in the nation, which serves the City of Detroit and 127 whole-sale customer communities located in eight counties throughout the Metro Detroit area. DWSD delivers water to the communities' water distribution systems or its retail customers via its 21 pumping stations and 3840 miles of transmission and distribution mains. DWSD's water network is supplied by five water treatment plants [7]. In 2012, the five water treatment plants delivered a total of 203 billion gallons of water to the customers. That represents a daily average water delivery of 556 MGD. A schematic of DWSD water system is shown in Fig. 1.

Currently, DWSD does not operate any elevated storage tanks. Instead, it uses 20 at-grade storage reservoirs with a total capacity

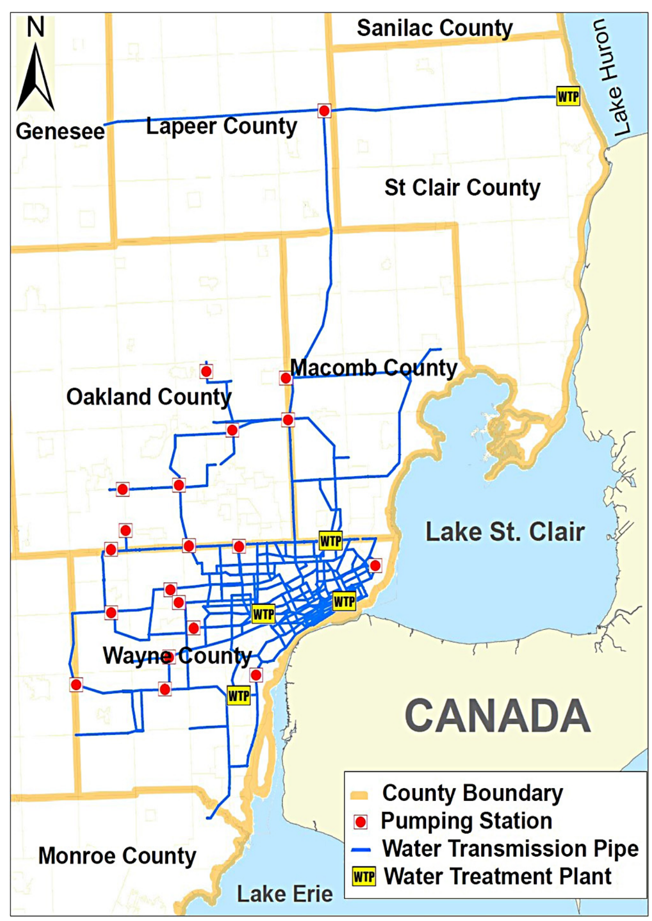

Fig. 1. Schematic of DWSD water system.