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Decentralized water reuse: regional water supply system resilience benefits

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Abstract

Resilience is related to the system functionality loss and the failure event duration (Bruneau et al. 2003). System redundancy and robustness affect the severity or functionality loss while the recovery time is largely related to the resource available and rapidity of the response. The purpose of this study is to investigate the resilience of a regional water supply system (RWSS) through a criticality analysis of five RWSS components. The relative importance was evaluated under two management/design conditions: (1) centralized versus decentralized wastewater treatment, and (2) decentralized wastewater plant location. For this study, the regional water supply system of a portion of the Tucson metropolitan area in Arizona was modeled. A Linear Programming (LP) flow allocation model determines the optimal flow allocation from multiple sources to users by minimizing the operational cost. The RWSS resilience was quantified by the failure, that is, the volume of water that was not delivered to users during the component failure of known duration.

Keywords: Resilience; centralized and decentralized wastewater treatment system; severity; unctionality

1. Introduction

As funding available for infrastructure becomes scarcer, systems are designed with less redundancy to provide the desired service but with less robustness and redundancy to ensure functionality under extreme or failure conditions. Developing resilient infrastructure systems continues to be a crucial task for providers of basic

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resources such as electricity and water. Clear definitions of robustness and resilience are not broadly accepted in the water resources field. Unlike water distribution networks, little effort has been focused on resilience of regional water supply systems (RWSS).

According to Bruneau et al. (2003), resilience is a function of the system functionality loss and the failure event duration. The system redundancy and robustness primarily affect the magnitude of functionality loss while recovery time is largely related to the system resourcefulness and response rapidity.

For this study, RWSS resilience was analyzed only considering system redundancy and robustness. . To assess resilience, a Linear Programming (LP) flow allocation model that was developed based on a portion of the Tucson metropolitan area in Arizona was used to compute the optimal flow allocation that minimizes operational costs.

The objective of this study was to investigate the resilience of a RWSS by adjusting the system configurations: (1) RWSS with centralized wastewater treatment system only, and (2) RWSS with centralized and decentralized wastewater reclamation. The resilience was quantified by utilizing two terms, functionality and severity, which are functions of volume of water that was not supplied to users due to a component failure and the failure duration.

2. Model

The LP model computes the optimal allocation of potable and non-potable water that minimizes the operational cost for a 41 year period on a monthly step (from 2010 to 2050). The details of the LP model will not be discussed in this paper, but the reader is referred to Hwang et al. (2013) to understand the system layout imbedded in the LP model.

The centralized system consists of water/wastewater treatment plants, recharge facilities, reservoirs, well fields, and arcs (pipes) that connect supply components and demand locations. This set of components serve potable and non-potable users in an area known as the RESIN study area that encompasses approximately 700 square kilometers. The area is divided into multiple pressure zones that stairstep at approximately 35 m elevation changes. The population growth is expected to predominantly occur in 7 pressure zones from the lowest pressure zone, Zone C, to Zone I. The population of the RESIN area is expected to increase from 41000 to as many as 76000 people over the study period. Furthermore, Central Arizona Project (CAP) water is the area's only potable water source. Approximately 490000 cubic meters of water per day can be delivered to the Tucson regions via the CAP canal.

The base model includes only a centralized wastewater treatment system and users in RESIN study area. To examine the effect of a decentralized wastewater (WW) treatment and reuse system on the RWSS resilience, an alternative model was developed. The base and alternative models' components and flow allocation mechanisms are identical except for the presence of the decentralized WW system in the alternative model. The alternative model includes a satellite plant (SP) and an indirect potable recharge (IPR) facility.

The role of the SP is to treat return flows from the users and transport the treated water to the IPR facility for infiltration to the aquifer and later extraction and distribution the water to potable and non-potable users. Decentralized WW systems can be installed within a number of pressure zones in the RESIN area to service the RESIN area. The economic benefit is the reduction of costs to treat and lift water from the centralized WW plant that is located over 30 km from and at an elevation approximately 100 m below the RESIN area. However, decentralized systems loss the economies of scale advantage in WW plant construction

3. Centralized and Decentralized Wastewater Treatment Systems

Since the 1800s, centralized facilities have played a primary role in wastewater systems. However, centralized wastewater systems can face capacity limitations, especially in some regions suffering from water scarcity, due to rapid urban expansion with increasing population growth. Therefore, from the sustainable water resources management perspective, a centralized facility may not be most appropriate for water-short areas. The decentralized wastewater treatment and reuse system can be a solution to ease the problem caused by centralized systems operating at or over capacity (Gikas and Tchobanoglous 2009).

From the construction cost perspective, decentralized wastewater treatment and reuse systems are unfavorable because decentralized systems can be more expensive to be constructed. However, decentralized systems can be more sufficient from the operational perspective. For example, Woods et al. (2013) conducted research for part of