Off-stream Reservoir: A Tool for Improving Yield & Water Quality Reliability

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Utilities depending on surface water sources are often faced with the challenges of a limited supply and a growing demand. Many surface waters are being regulated to maintain minimum flows in streams to mimic natural regimes, limiting the water available for withdrawal. To compound the problem, in some cases the water quality of the supply water is gradually being degraded by increased anthropogenic activities, while at the same time, the treatment standards for drinking water have become more stringent. Thus, utilities must plan for meeting challenges of both water quality and quantity when evaluating their supplies.

This article discusses off-stream reservoirs as a tool to increase a system's reliability in meeting water demand and improving raw water quality. During a survey of utilities in the U.S.(1), about 80 percent responded that they used both water quality and quantity issues as triggers for making reservoir operational decisions. While they monitored both quantity and quality data in the reservoir, water quality data were used only half the time in making operational decisions.

In this article, we investigate the use of an off-stream reservoir to mitigate water quality and quantity concerns and present a mass balance approach to determine reservoir reliability by combining water quality and quantity data to regulate the use of reservoir water. The article also discusses a case study illustrating the use of the reservoir reliability model for the Water Supply Master Plan for the city of Punta Gorda, Florida.

Mass Balance Approach to Predict Reliability & Regulate Reservoir Operation

Reliability Evaluation

A mass balance approach was used to predict system reliability and regulate reservoir operation. Reliability is defined as the percent of days that the utility can supply water to meet the total demand of the service area. This definition of reliability and the reliability criteria chosen for planning can be modified, based on the established practices of the utility. Since both water quality and water quantity are used for operational control, three reliability measures are calculated in this model:

1) Quality Reliability—The percent of days when the finished water quality parameter is below a specified target level, regardless of quantity considerations.
2) Quantity Reliability—The percent of days when the utility can supply water to meet the total demand of the service area, regardless of quality considerations.
3) Combined Reliability—The percent of days when the finished water meets both the quantity and quality reliability criteria.

Model Technical Approach

Since the reservoir, river flow, aquifer storage and recovery (ASR) wells, and water treatment plant are treated as a system, the model was created to simulate the system operation based on various input parameters such as river flow, river water quality, system demand, storage parameters, and target water quality parameters. The model simulates the system operation over the days of record to determine the reliability of the system as defined above for various operational scenarios. The model allows the user to input historic river flow and water quality data and regulates the use of the reservoir according to the flow available and/or the quality of water available.

Model Assumptions

The reservoir model operates with the following assumptions:

- Historical flow records are representative of future hydrologic conditions.
- Precipitation is approximately equal to evaporation (no net gain or loss in stored water volume).
- Losses in storage volume due to seepage are negligible
- Minimum reservoir level for the off-stream reservoir is 10 percent of the total storage volume (water quality impacts are unknown at present).
- Raw water diversion pump station capacity is not a limiting factor.
- Off-stream storage is assumed half full at the beginning of each model simulation.

Model Configurations

Two model configurations were developed to address different water supply and operational control concerns. In the first configuration, water supply to meet system demand was used as the controlling parameter for reservoir operation. The off-stream reservoir and ASR wells were used to store raw water, and the model was used to predict reliability in meeting different system demands using various storage volumes.

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The user can select the percent of the water injected into ASR wells that is recoverable, based on historical operation. The user also selects the storage zone volume associated with ASR wells and the injection and recovery flow capacities to and from the ASR wells, based on the site specific conditions of the utility.

In the second model configuration, the utility is assumed to be limited by water quality constraints in the raw water source. The model was modified to simulate conditions in which water from the ASR wells and/or the off-stream reservoir is used to blend with the raw water to meet a selected water quality criterion, such as total dissolved solids (TDS). To address this scenario, the mass balance model was modified to allow recharge of the ASR wells and the off-stream reservoir only during specific months based on raw water quality.

The stored water can then be used to either supply water in the absence of flow in the surface water source or to blend with poorer-quality raw water. By recharging with only high-quality water and using the stored water to blend, the reliability of achieving the water quality target, such as TDS, improves; however, the reliability of meeting the system demand (yield) decreases if water quality constraints are imposed.

For the various iterations of the model, a set of defined boundary conditions was utilized to calculate the daily reservoir level, based on the volume of raw water diverted to the water treatment plant or off-stream storage.

Model Applications

One of the primary strengths of the model is that it can determine reliability in meeting water demands if the utility is limited by water quality constraints in the raw water source. The utility can establish target levels for various water quality parameters and use these to regulate the reservoir operation.

The reliability model developed in this project can also be used for various other

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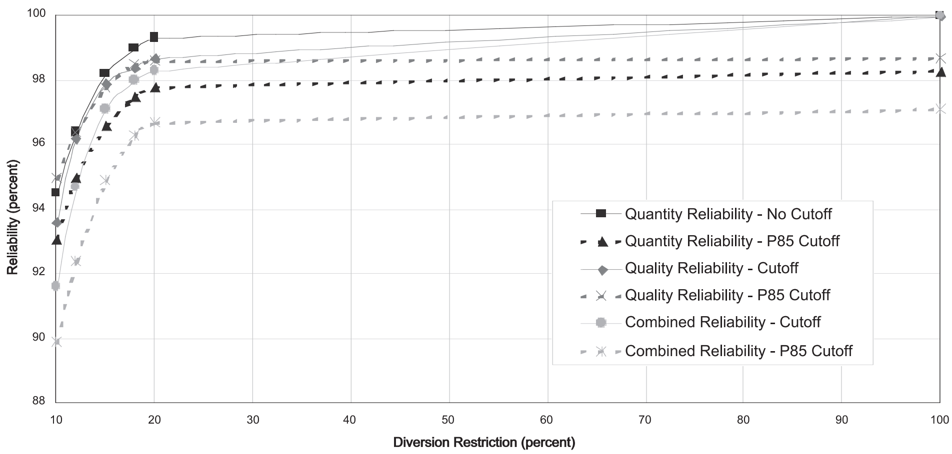
Figure 1
Quality, Quantity, and Combined Reliability as a Function of Allowable Diversion Restriction



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applications. The model has built-in flexibility to address source water withdrawal restrictions to evaluate impact of any *existing* or *potential* new regulations. It can be used to predict the reliability of a system if an existing reservoir is used to maintain acceptable raw water quality in addition to providing raw water storage, or it can be used to size a potential new reservoir that must be used for improving both yield and water quality. Finally, it can be used to evaluate the impact of different storage components such as ASR wells. This mass balance approach allows flexibility to utilities and facilitates planning activities for sizing of new reservoirs.

Case Study for the City of Punta Gorda

The model was used in developing the Water Supply Master Plan for the city of Punta Gorda, which uses water from Shell Creek for its water supply. Raw water is withdrawn from an in-stream reservoir on Shell Creek and is treated at the city's 10-million-gallon-per-day (mgd) Shell Creek Water Treatment Plant. The city is currently permitted to withdraw 5.358 mgd on an annual average basis. It also currently owns and operates two 1-mgd ASR wells.

Shell Creek Water Supply Challenges

Shell Creek is scheduled to be regulated for minimum flows and levels (MFLs) by the Southwest Florida Water Management District in 2007. The impact of various potential MFLs on the city's water supply was evaluated as part of the Master Plan. MFL restrictions on Shell Creek could involve a downstream minimum flow cutoff and/or a "percent of flow" diversion restriction on the amount of withdrawal permitted. The various potential MFL restrictions simulated in the model are:

1) Minimum downstream flow—The minimum downstream flow regulation seeks to maintain some specific flow at all times downstream of the in-stream reservoir.
2) *Low flow cutoff*—A low-flow cutoff regulation would allow withdrawal from Shell Creek only during periods when the flow in the creek is above a certain value (the cutoff). It would prevent withdrawals during dry periods when flow over the in-stream dam is below the cutoff value. A statistical flow measure termed P85 flow was used as the low-flow cutoff for modeling analyses and is defined as the 15th percentile flow (flow is greater than P85 value on 85 percent of days).
3) Diversion restriction—A diversion restriction entails withdrawing only a fixed amount of water from the creek, based on a percent of the total flow. The withdrawal allowed would be based on a percent of the flow in the creek on the previous day.

There is also a water quality concern associated with Shell Creek due to elevated levels of chlorides and other dissolved solids in the creek. The water management district has published the "Shell Creek and Prairie Creek Watersheds Management Plan Reasonable Assurance Documentation" to restore and maintain the water quality conditions in Shell Creek. The plan was initiated in 2004 with the objective of improving surface water quality in the Shell Creek and Prairie Creek watersheds to consistently meet Class I standards by 2014.

The mass balance reliability model was used to address both the raw water quantity and quality concerns in Shell Creek.

The model also accounted for changes in future ASR regulations by allowing the flexibility to incorporate the use of ASR wells into the model as desired. Currently, ASR wells are permitted and regulated through the Florida Department of Environmental Protection's Underground Injection Control Program. Results of future regulations may affect the permitting and regulatory constraints for ASR wells, which could influence the use of these systems for the city.

Model Applications for the City of Punta Gorda

The city uses the existing in-stream reservoir on Shell Creek for potable water supply. The reservoir model was used to determine the required size of a new off-stream reservoir to be constructed by the city based on various MFL restriction scenarios. It was also used to simulate the effect of raw water quality and the potential to regulate reservoir operation to improve finished water quality.

The model was used to predict reliability in meeting the city's projected water demands under different MFL restrictions. Figure 1 shows the quality, quantity, and combined reliabilities in meeting the city's predicted 8-mgd annual average build-out demand using a 1-billion-gallon off-stream reservoir and two 1-mgd ASR wells under various potential MFL restrictions.

Stored water was used to blend raw water to achieve a target TDS of 450 mg/L in this scenario. Similar analyses were conducted to evaluate the reliability using different reservoir volumes with and without the use of ASR storage to meet various target TDS concentrations.

Another application of the model was to

Figure 2
Timeline for Construction of Off-stream Reservoir for City's Build-out Population

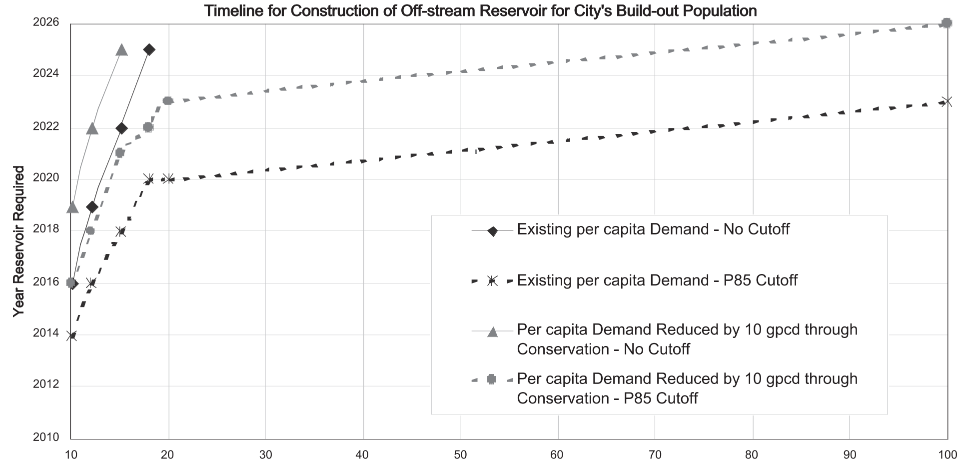
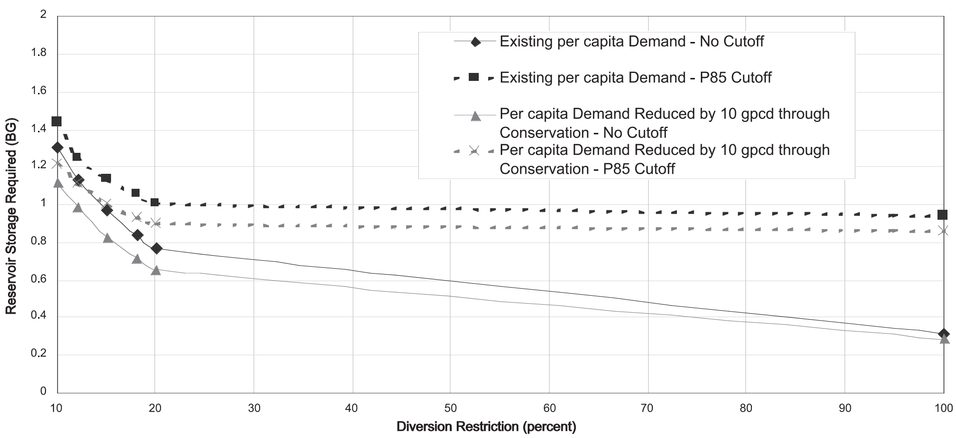


Figure 3
Size of Reservoir Needed when Using Reservoir for Blending to 450 mg/L TDS - Without ASR Wells



determine the trigger points for the off-stream reservoir construction, based on reliability requirements and system water demand. Figure 2 shows the timeframe required for the construction of the new off-stream reservoir for two different water-demand patterns for the city for different MFL restrictions. Figure 2 could be used to illustrate the benefit of less stringent MFLs or increasing conservation efforts to reduce demand, since it shows a direct correlation between these factors and the need for construction of an off-stream reservoir.

The final type of analysis conducted using the mass balance model was to determine the size of the off-stream reservoir needed to achieve a 95-percent benchmark reliability criteria under different MFL considerations, with and without the use of ASR wells. Various scenarios were modeled incorporating future uncertainties, such as the operation of ASR wells and the need for raw water blending, and the results were presented graphically.

Figure 3 presents the results for one such scenario, assuming that the city's current water-demand pattern continues in the future, that the stored water will need to be used for blending to improve raw water quality, and that the use of ASR wells may become questionable in the future such that all storage must be provided using the off-stream reservoir only. By modifying these assumptions, the reservoir sizes needed under various scenarios can be determined.

Using these analyses, a decision tree was prepared as part of the city's master plan. It incorporated figures similar to the ones described previously to provide a multi-path tool that can be used by the city, based on the outcome of various future uncertainties or future decisions made by the city.

Summary & Conclusions

Reservoirs can be powerful tools to increase quality and quantity reliability of surface water sources. A mass balance model is useful for evaluating the impact of various reservoir sizes and other factors that may impact a water system, including the use of ASR wells, minimum flows and levels, raw water quality, and demand shifts. Simulating various scenarios in the model provides utilities the flexibility to incorporate future uncertainties into their current planning efforts.

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(1) AwwaRF Project 3037, Reservoir Operations Survey, 2005