WATER SYSTEM RELIABILITY ASSESSMENT

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Quantifying Water Infrastructure Risks using Monte Carlo Simulation

Utilizing a state-of-the-art statistical approach such as Monte Carlo simulation programmed in Carollo's Blue Plan-it® (BPI) Decision Support System, computer simulation can now assist regulators, utilities, and design engineers to account for water system reliability through quantitative analysis for decision making. During planning and design, this may mean quantifying vulnerability reduction or reliability enhancement to prioritize infrastructure improvement projects. For existing facility operation, it could be focusing on reduction of risks through planned maintenance activities and data collection, as well as proactive asset management. The application of this tool includes qualitative microbial risk assessment for drinking water or direct potable reuse systems (see QMRA fact sheet), water infrastructure resilience to natural disasters such as earthquakes or hurricanes, in-stream flow projection for main rivers under climate change conditions, water supply facility planning for various economic growth scenarios, etc.

Monte Carlo Simulation

This fact sheet introduces a function of Carollo's BPI Decision Support System, which utilizes repeated random sampling to obtain numerical results and to solve complex problems that might be deterministic in principle. Refer to other BPI fact sheets for more information on BPI.

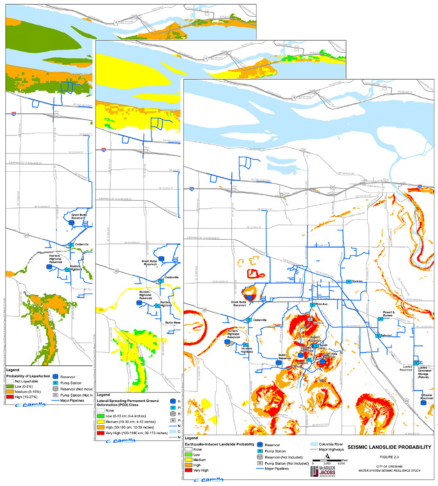
Probability distributions are a much more realistic way of describing uncertainty in variables of a water system risk analysis. During a Monte Carlo simulation, input values are sampled at random from the input probability distributions. BPI repeats simulation thousands of times, generating a probability distribution of possible outcomes. This provides a much more comprehensive view of what may happen, representing a number of advantages over deterministic or "single-point estimate" analysis.

- First, the probabilistic results represent not only what could happen, but how likely it is to happen.
- Second, combined with statistical analysis software such as JMP, R, or Minitab, BPI can create graphs of different outcomes with their chances of occurrence to communicate findings to stakeholders in a simple but profound way.
- Third, with just a few cases, deterministic analysis makes it difficult to see which variables impact the outcome the most, and what combinations of inputs drive certain outcomes. In a Monte Carlo simulation, it's easy to see which inputs had the biggest effect on the bottom-line results and what synergism may exist.

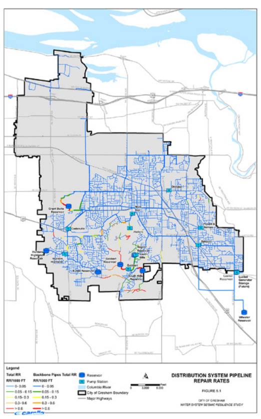
Water Infrastructure Resilience

Communities in the Pacific Northwest are becoming increasingly aware of the major threat that a catastrophic seismic event will have on them. Recent seismological research provided compelling evidence that earthquakes represent the most eminent seismic hazard in these regions. When such disasters occur, significant damage to the urban water infrastructure will disrupt daily life and the local economy. For many states, documents such as the Water System Seismic Resilience Plan, provide goals for utilities to improve their resilience. BPI provides a comprehensive reliability assessment tool for utilities to evaluate their current and proposed reservoirs, pump stations, treatment facilities, and distribution systems. It can generate cost estimates for recommended improvements, and rank various projects based on their effectiveness in improving reliability.

The initial step is to identify seismic hazards for the study area by reviewing GIS data for site conditions, ground motions, ground deformations, and other hazards associated with seismic events with a given magnitude. Site reconnaissance will then be conducted at several facilities located on or near relatively steep slopes or mapped landslides. This effort helps to observe the site conditions with respect to the hazard maps, and confirm slope-sliding hazards. Using the available geologic hazard data and site assessments, a series of GIS layers and hazard maps can be prepared, providing the basis of analysis to determine the susceptibility of failure caused by a seismic event.



Example GIS layers prepared from geologic hazard data include liquefaction hazard, landslide susceptibility, peak ground acceleration and velocity, probability of liquefaction, liquefaction-induced lateral spread displacement, etc.

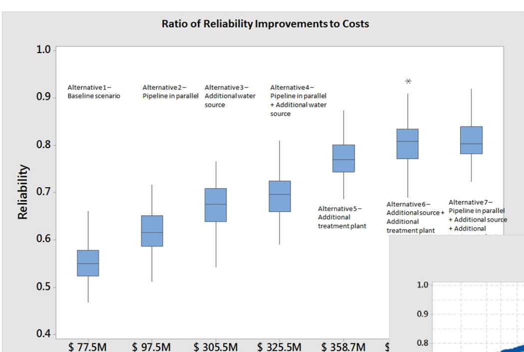


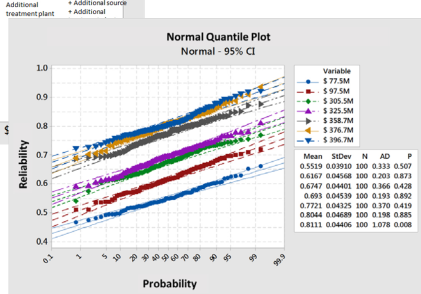
Reservoirs and Pump Station Reliability

Carollo's reliability tools evaluate reservoirs and pump stations using the Federal Emergency Management Agency (FEMA) Hazus Technical Manual methodology given the seismic hazard identification for each site. It takes into account the year of construction and any existing seismic design deficiencies.

Distribution System Reliability

The piping system evaluation typically uses the American Lifelines Alliance (ALA) method or similar methods to determine seismic fragility of water systems. The first step is to assign fragility constants based on pipe material, joint type, diameter, length, and date of installation. Once each pipe segment has been assigned fragility constants and seismic hazard data, failure rates for each pipe segment and an expected number of repairs on a given length of pipe can be calculated. Key areas with the most expected leaks and breaks in the distribution system can be identified by combining results of this analysis with the geological hazard data in GIS.

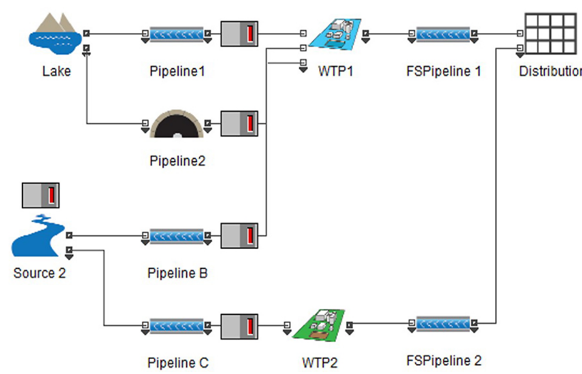




Example results generated using BPI to demonstrate reliability improvements to cost ratio, with normal quantile plot corresponding to 95% confidence intervals.

Treatment Facility and System Reliability

Water treatment plant reliability can be assessed using Monte Carlo simulation to represent the probability of a water treatment facility meeting its treatment goals under various normal and emergency conditions. Using its graphical interface, BPI provides an ideal platform for tracking flow mass balance, water quality, capital and O&M costs, as well as risks. By modeling the components and subcomponents in detail, the tool can be used to evaluate the optimal configuration of water treatment trains, i.e., parallel versus series, ideal numbers and location of duty versus standby equipment, to maximize reliability at the lowest cost, and project treatment facility performance under design and peak loadings. Combined with other tools, BPI can also provide insights to optimize the maintainability and availability of a repairable system, considering corrective and preventative maintenance, crew schedule, and spare part pools.



BPI evaluates water system reliability, prioritizing the need of backup sources, pipeline, and treatment facilities.

The reliability of the water system consisting of a lot of components can be analyzed using techniques such as reliability block diagram and fault tree. For example, water system reliability can be improved by adding a redundant water source, parallel pipeline, or alternative treatment facilities. Using BPI, such improvements can be quantified for a static system, as well as a time dependent system, to guide decisions on which project to invest in.