CASE STUDY — STATISTICAL FORECASTING TECHNIQUES FOR EVALUATING AN INTERRUPTIBLE SUPPLY CONTRACT

Rachel J. Kullman[1]
Karen R. Rademacher[2]
Stephen W. Smith[3]

ABSTRACT

In Colorado, unprecedented changes are brought to bear on senior irrigation water rights, primarily due to drought and population growth. Changes have created both pressures and opportunities to the irrigators who hold these senior water rights. Changing administrative procedures, escalating water values, and curtailment of ground water pumping in Colorado necessitate irrigators make hard decisions about how they will preserve their water supply and agricultural operations for the long-term.

In response to these changes, some irrigators in Colorado have explored options for "interrupting" their irrigation supply to provide water to a municipality or power company in exchange for financial compensation. These arrangements are often called interruptible supply plans or contracts. These contracts typically include guarantees that an irrigator will provide some portion of their water supply to the contracting entity. Despite the opportunity for financial compensation, many irrigators chose not to enter into such contracts because interrupting water supply can be uncertain and risky.

The case study presented in this manuscript provides an example of one statistical methodology that can be used to determine the level of risk or uncertainty associated with entering into an interruptible water supply contract. Understanding the risk and uncertainty can help both contracting entities understand the implications of an interruptible supply contract. The methodology, known as Monte Carlo simulation, is widely applied across multiple disciplines. However, we are not aware of its use in previous interruptible supply analyses.

---

[1] Rachel Kullman is a project manager with Aqua Engineering, Inc. in Montrose, Colorado. rkullman@aquaengr.com
[2] Karen Rademacher is a project manager with Aqua Engineering, Inc. in Fort Collins, Colorado.
[3] Stephen Smith is chairman and vice president of Aqua Engineering, Inc. in Fort Collins, Colorado.

INTRODUCTION

The case study presented is based on work we conducted for the New Opportunity Ditch Company. This ditch company was approached by a neighboring power company wanting to enter into an interruptible supply contract whereby the ditch company would interrupt irrigation supply to provide water for the operational of a coal-fired power plant.

As the ditch company considered this contract they realized there were many unknowns and risks they could not quantify and therefore could not appropriately weigh. The ditch company asked us to quantify the level risk they would experience if they were to enter into a contract with the power company.

Because the terms and conditions of this contract are currently under negotiation, we have used fictitious names in this manuscript for both the ditch and power companies.

Description of Contracting Entities

The New Opportunity Ditch Company. The New Opportunity Ditch Company owns both direct flow water rights from the South Platte River and storage water rights in the New Opportunity Reservoir, which are used to irrigate approximately 10,000 acres.

Many shareholders in the ditch company also supplement company-owned water supplies with wells that pump alluvial ground water. These ground water wells are tributary to the South Platte and as such impact or deplete water supply in the river when pumped. To remedy these impacts, tributary wells are required to operate within a state and water court approved augmentation plan.[4] The New Opportunity Ditch Company manages the augmentation plan for shareholders that use ground water wells.

To augment river depletions caused by ground water wells, the New Opportunity Ditch Company places junior water rights they own into off-channel recharge ponds when those water rights are in priority. The ditch company operates and

[4] An augmentation plan provides a mechanism for junior water rights (e.g. ground water wells) to use water supplies out-of-priority in a way that protects senior water rights from the depletions caused by the junior pumping. Typically this will involve storing junior water when in priority and releasing that water when a call comes on; purchasing stored waters from other entities to release when a river call comes on; or purchasing senior irrigation water rights and changing the use of those rights to off-set the new users injury to the stream. (http://water.state.co.us/wateradmin/terms.asp#Augmentation%20plan:).

manages over 100 of these recharge ponds, most of which are located more than three miles from the South Platte River.

Water placed into these ponds seeps to the alluvial aquifer and travels towards the South Platte River. The aquifer attenuates these recharge events so that a steady stream of credits is generated at the South Platte River. One recharge event may provide a steady state of return each day for a period of several years or decades depending on its distance from the river and the aquifer properties.

The recharge credits generated by these ponds are used to offset the depletions at the river caused by ground water pumping. Based on the number of credits in any given year, the ditch company will issue a well pumping allocation to ground water users so as to best match ground water pumping to available recharge credits. New Opportunity's credits at the South Platte River typically exceed actual depletion caused by ground water wells.

<u>The Watt Power Company</u>. The Watt Power Company operates a coal-fired power plant on the South Platte River a few miles downstream of the New Opportunity Ditch service area. Like most coal-fired power plants, the Watt power plant requires a firm year-round water supply to cool operating equipment. The Watt Power Company approached the New Opportunity Ditch Company about entering into a contract that would supply their coal-fired power plant with between 3,000 and 5,000 acre-feet of water per year for the next 30 years.

The opportunity to enter into this type of contract is desirable to the New Opportunity Ditch because at many times of the year their recharge projects generate extra water or credits at the South Platte River. These credits could be used directly from the river by the power company to meet their needs. A contract to supply this excess water to the power company would provide for financial compensation that may not have otherwise been available.

Entering into this type of contract is also risky for the New Opportunity Ditch Company. At times, the ditch company may not have enough recharge credit at the river to meet the power company's needs. If the ditch company is unable to meet the terms of the contract using its recharge credits, they would have to guarantee delivery either by reducing their own augmentation needs (reduce ground water pumping) or, in a worst case, by using New Opportunity's senior storage water rights.

Monte Carlo Methodology

<u>Applicability of Methodology</u>. We determined that Monte Carlo simulations would best address the questions and concerns of the ditch company in this study. The Monte Carlo methodology presents results for a particular scenario in terms

of a full range of risks. More commonly used methods provide limited answers to a particular scenario in terms of fixed assumptions like average or worst-case.

By using Monte Carlo simulations, we were able to decisively address the following questions posed by the New Opportunity Ditch Company:

- How likely is it that the ditch company recharge project will generate excess credits at the river to meet Watt Power's needs?
- How likely is it the ditch company will have to reduce their pumping allocation to well owners to meet the contract obligations?
- How likely is it that the ditch company will have to release water from their reservoir to meet the contract obligations?
- How does this likelihood change if New Opportunity Ditch enters into a contract level of 3,000 acre-feet per year as opposed to 4,000 or 5,000 acre-feet per year?

<u>Methodology Concepts</u>. Monte Carlo simulations are "stochastic techniques – meaning they are based on the use of random numbers and probability statistics to investigate problems" (Woller, 1996). Simulations that randomly generate thousands of values for uncertain variables will reveal a range of outcomes, not just one outcome. The range of outcomes can be interpreted in terms of probability. In other words, which outcomes are most or least likely to occur.

In this study, the outcomes using Monte Carlo simulations can be interpreted and framed not as distinct numbers but instead in terms like:

- "recharge projects are sufficient to meet Watt Power's needs in four years out of ten," or
- "in three out of ten years, it will be necessary to reduce well pumping allocation by 0.5 acre-feet per acre of land," or
- "in two out ten years, it will be necessary to release water from the New Opportunity Reservoir to meet the contract obligation."

Results in this form are more meaningful than just simply stating the average or worst case scenario one can expect.

Decisioneering's Crystal Ball 7 software was used to run the Monte Carlo simulations in this study. This software is essentially an "add-on" to Microsoft's Excel spreadsheet program. Although the model cannot run without Crystal Ball, the spreadsheets can be opened and viewed with Microsoft Excel alone.

The New Opportunity model relies heavily on calculations that can be computed directly using Excel functions. Crystal Ball is added to these existing calculations in the form of what are called "assumptions" and "forecasts".

Excel cells that serve as a "variable" to a particular calculation can be made an "assumption" in Crystal Ball. An assumption is a set of data that are distributed in some manner like normal, uniform or lognormal distribution. An assumption basically defines a variable in Excel as a range of values instead of just one value. Using Crystal Ball, a calculation set up in Excel can be run thousands of times, all the while picking (at random) a number from the distribution to serve as the variable in the calculation.

Similarly, the results or answer cells in Excel can be designated as "forecast" cells using Crystal Ball. A forecast is used to display the probability of obtaining particular outcomes or results. The forecast essentially stores the results of the thousands of trials that are drawn from the "assumptions." These outcomes can be interpreted in terms of risk or uncertainty.

EVALUATION OF INTERRUPTIBLE SUPPLY CONTRACT

Model Input

The general approach to the New Opportunity Ditch Company project was to determine **when** and in **what amount** water is likely to be available to the recharge ponds over the contract period since this is the preferred water source for fulfilling a contract obligation. This supply is preferred because credits are consistently generated at the South Platte River – credits not used by the ditch company for augmentation would otherwise be left in the river and not used.

These uncertain variables were the driving force behind our statistical model – they were the Crystal Ball "assumptions" or data distributions that allowed us to test thousands of possible outcomes. We then evaluated these outcomes relative to the three proposed contract levels (3,000 acre-feet, 4,000 acre-feet, and 5,000 acre-feet) so the New Opportunity Ditch could contemplate what level of risk they were willing to accept, if any at all.

Water Availability to Recharge Projects. The recharge ponds that contribute to New Opportunity's pool of recharge credits are relatively new – the earliest were constructed in the mid- to late-1970's. Construction has continued until the present, with additional sites yet to be constructed.

Reliable records of water delivery to the ponds are available starting in 1985 and have continued through the present. Using this short period of record as a study period for the purpose of projecting future water supplies for the next 30 years (30 years being the term of the proposed interruptible supply contract) would yield potentially misleading results. Furthermore, this period coincided with rather extreme weather patterns for northeastern Colorado. The 1980's and 1990's were years of relatively plentiful rainfall, snowpack and streamflow. These years were then followed by the intense drought of 2002 through 2004 and again in 2006.

Considering these limitations in the delivery record, we determined the most useful predictor of recharge water availability would be the historical river call records. These records have been maintained consistently by the State Engineer for over 75 years. These records indicate which water rights were "calling" for water on a daily basis and also which days all water users were satisfied ("free river"). It is during these historical "free river" periods that water would have likely been available to New Opportunity's recharge sites, most of which have relatively junior water rights.

For example, Figure 1 shows the distribution of free river days in the month of July for the 75-year call record. This distribution shows that the most likely outcome in July is to have no days of free river (close to 50% of the time the number of free river days equals zero).

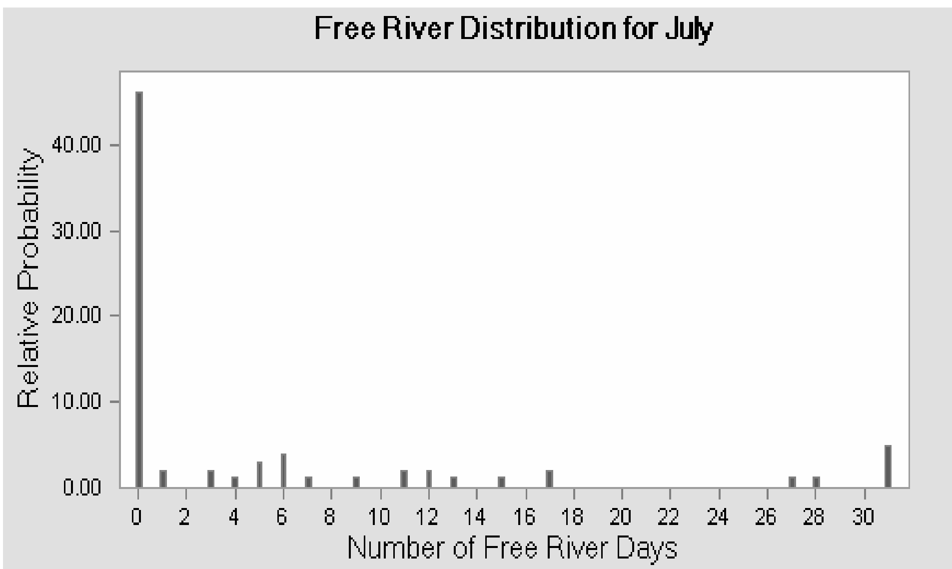

Figure 1. Distribution of free river days for the month of July from historical river call data set. Nearly 50% of the time (relative probability on y-axis), the number of days in July the South Platte River is "free," is zero.

July is the peak water demand period on the South Platte River because that is when irrigated agriculture uses the most water. It is therefore reasonable to expect that free river conditions are not as likely to occur during this month as river calls. This information helped us to understand the extent to which free water would have been available to New Opportunity's recharge projects. For example, over the next 30 years, New Opportunity Ditch might expect only half of the month of July to be free river and thus have water available to recharge projects.

Each month of the historical call record was modeled as an "assumption" in Crystal Ball. In essence, we put 75 years worth of "free river" periods into a hat and drew them at random to form 30-year sequences of recharge opportunities (or free river periods) the ditch company can likely expect in the future.

Quantity of Water Available to Recharge Projects. Once we determined **when** water would be available to the recharge ponds in the future, the next step was to model the **amount** of water available for delivery to recharge structures.

Rather than making uninformed guesses about the amount of water that would have been available over the 75-year period of call record, we tabulated actual deliveries into the New Opportunity recharge areas since 1985 by month, and limited our simulation to these actual historical deliveries. In other words, we assumed that future recharge would be no more and no less intensive than the recharge that has occurred historically.

Multiplying the number of free river days and available flow gives the total quantity of recharge water available in a particular month. For example, Figure 2 shows the distribution of flow available to recharge projects for the month of November. As shown, flow availability in November has been highly variable; it has been as low as 7.5 cubic-feet per second and as high as 98.6 cubic-feet per second.

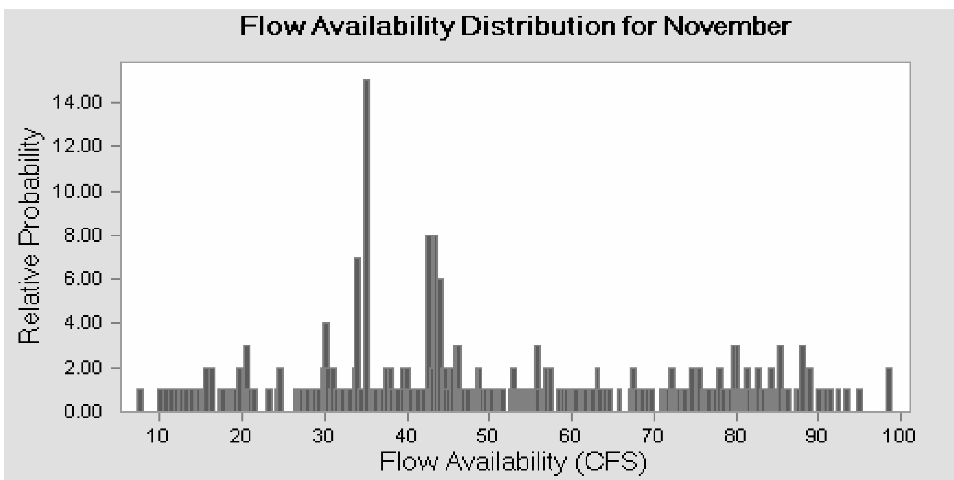

Figure 2. Distribution of daily flow available to recharge for November from actual delivery records to recharge ponds. Flow availability is highly variable.

Similar to the range of free river days, flow availability was also modeled as an "assumption" or range of variables in Crystal Ball.

Study Results

Assessing the Level of Risk. In assessing the risk associated with entering into a contract with the power company, the ditch company had to consider the tradeoff between financial compensation for entering into a contract and the amount of water that would likely be available to meet their irrigation needs. A higher contract amount may not be desirable if it will require the ditch company to regularly decrease the amount of ground water pumping allocated to well owners.

It may be even less desirable if the ditch company has to regularly forgo some portion of their senior reservoir water rights to meet contract obligations.

Figure 3 shows the results of the Crystal Ball model in the form of a "forecast" trend chart for the month of September assuming the ditch company enters into a contract to supply 3,000 acre-feet per year. September is presented because our model shows this to be the most critical month of the year for the ditch company because river credits from recharge are typically at their lowest level.

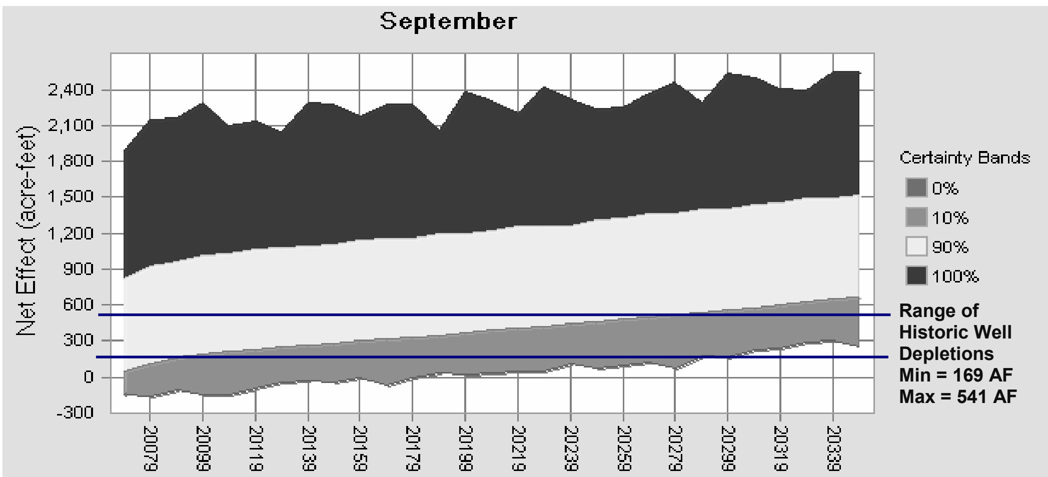

Figure 3. Forecast trend chart for 3,000 acre-feet contract level with Watt Power. Net effect represents the recharge credits available at the South Platte River after the contract obligation has been met.

The x-axis in Figure 3 represents the entire length of the contract period (30 years) or from year 2006 to year 2035[5]. The y-axis represents the net effect or the amount of recharge credits (in acre-feet) available at the South Platte River after contract needs are fulfilled. The net effect is the recharge water available to the ditch company for the issuance of pumping allocation for their augmentation plan. When net effect is positive, the ditch company has excess credits and may issue well owners full pumping allocation. When net effect is negative, the ditch company may have a deficit of recharge credits and may have to curtail pumping or in the worst case release water from their reservoir just to meet their obligation to the power company.

The color-differentiated certainty bands in Figure 3 display the distribution of outcomes or "forecasts" from the thousands of model runs in Crystal Ball. Each outcome falls within one of these bands. The bottom limit of the bands represents the lower limit for all outcomes. The top and bottom bands each represent the

[5] The x-axis label in Figure 3 includes the year and month. The year is stated first as four digits, the month is stated last as one digit. For September 2013, the label is 20139.

range of results that might be expected 10% of the time or 1 in 10 years for example. The bottom band represents the lower 10% of outcomes; the top band represents the upper 10% of outcomes. Combined, these two bands comprise a 20% frequency of outcome. The middle band displays the range of results that will be expected 80% of the time or 8 in 10 years.

At the 3,000 acre-feet contract level, no trial runs in the model produced a negative "net effect" after the year 2018. In other words, until the year 2018 (where bottom limit line moves above zero on the y-axis), the ditch company is at some level of risk of having a negative net effect at the river (i.e. they will have not generated enough recharge credits to meet their contract obligation with the power company). This risk is small at 10% or less until 2018.

Figure 3 also shows the range of historic ground water depletion from pumping that is expected during the month of September by New Opportunity well owners (between 169 acre-feet and 541 acre-feet). The certainty of having to reduce well depletions below the minimum historic pumping level exceeds 10% until year 2008 (where minimum pumping line intersects lower and middle certainty bands).

Figure 4 shows the forecast trend chart for a 4,000 acre-feet contract level. At this contract level, the ditch company is at a 10% risk of having a net negative effect at the river until the year 2026 (8 years longer than the 3,000 acre-feet contract level). The chance of having to reduce well depletions below the minimum historic level exceeds 20% until 2008, which is also greater than the 3,000 acre-feet contract level.

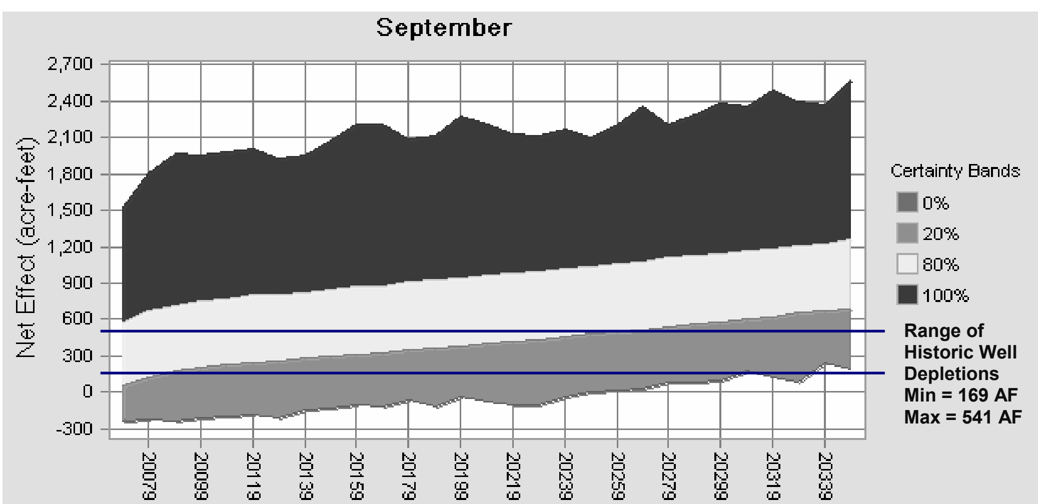

Figure 4. Forecast trend chart for 4,000 acre-feet contract level with Watt Power. Net effect represents the recharge credits available at the South Platte River after the contract obligation has been met.

Figure 5 shows the forecast trend chart for a 5,000 acre-feet contract level. At this contract level, the ditch company is at a 10% risk of having a net negative effect at the river until the year 2029 (only 3 years longer than the 4,000 acre-feet contract level). The chance of having to reduce well depletions below the minimum historic level exceeds 40% until 2007.

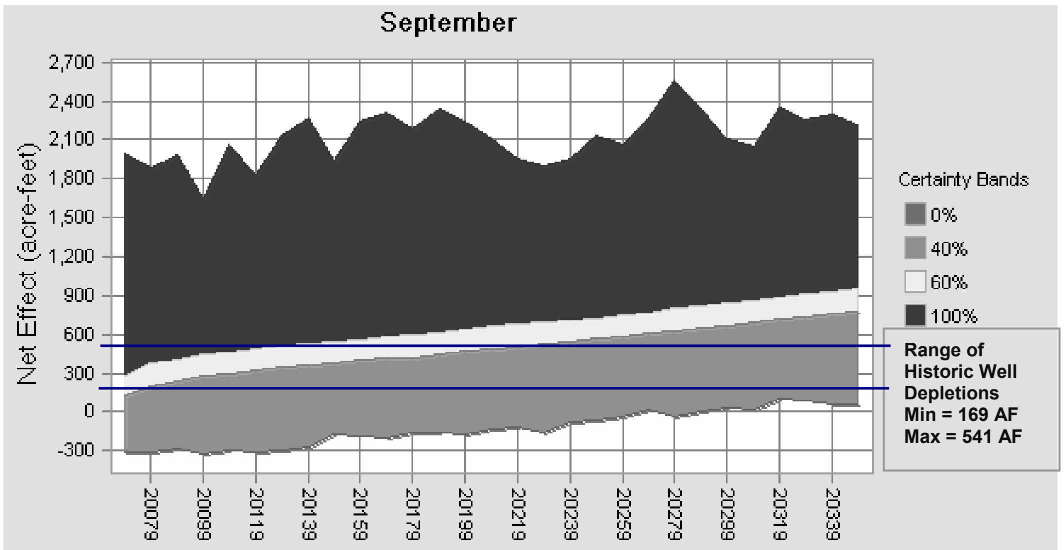

Figure 5. Forecast trend chart for 5,000 acre-feet contract level with Watt Power. Net effect represents the recharge credits available at the South Platte River after the contract obligation has been met.

In conclusion, the risk of having to release water from the New Opportunity Reservoir to meet contract obligations, at all contract levels, is less than 10% (likely to occur less than 1 in 10 years). At all contract levels, this risk goes to zero after some period of time – the higher the contract amount, the longer the period of risk.

Risk abates over the length of the study period as net effect or recharge credits increase. Because recharge ponds are located several miles from the river and because travel time is slow in the aquifer between the ponds and the river, many past recharge events have yet to accrue the river. Over the length of the contract term, New Opportunity expects a steady increase in these credits.

The risk of having to curtail ground water pumping allocation is highly variable between the three contract levels for the first several years of the contract. The risk of curtailment is four times greater at the 5,000 acre-feet contract level than the 3,000 acre-feet contract level.

SUMMARY

Risk was quantified using Monte Carlo simulations in Decisioneering's Crystal Ball Model. Using this model, we were able to substitute a full range of possibilities and test thousands of possible scenarios to determine which outcomes would be most likely for a proposed interruptible supply contract between a ditch company and power company. The intent was to provide risk levels to the ditch company so they could determine if and to what degree they wanted to interrupt their normal irrigation water supply to provide for the needs of the power company.

The results of this analysis are not as important as the methodology that was used and demonstrated in this manuscript. This methodology is not often used to evaluate risk in a water supply contract scenario. The intent of this paper was to demonstrate the applicability of this methodology for a multitude of applications and questions regarding risk and uncertainty.

REFERENCES

Colorado Division of Water Resources. http://water.state.co.us/wateradmin/terms.asp#Augmentation%20plan:

Decisioneering. Crystal Ball Version 7.1.2. Denver, Colorado. www.crystalball.com

Woller, J. (1996). The Basics of Monte Carlo Simulations. University of Nebraska-Lincoln. http://www.chem.unl.edu/zeng/joy/mclab/mcintro.html