ABSTRACT

The Edwards Aquifer is located in south central Texas and serves as the sole source of water to the region, which includes the City of San Antonio. Recent declines in spring flows fed by the aquifer that water the habitat of several endangered species triggered a court ruling that led to the issuance of groundwater pumping permits for the Edwards Aquifer in the late 1990's. If the level in a monitor well drops below a certain elevation, municipal and industrial users of the aquifer are cut back a proportion of their monthly allocation until the water level rises above the trigger elevation. This project provides a framework for analyzing short-term alternatives for obtaining temporary pumping permits to assist the San Antonio Water System municipality (SAWS) in countering possible cutbacks.

In this report, a hydrologic simulation model is developed to predict the monthly aquifer levels into the future. The probabilities of encountering cutbacks of different quantities in the short-term are determined from the simulation results and are used to calculate the non-pecuniary expected costs of shortfalls in meeting demands. This project follows a policy of minimizing the total expected cost to SAWS for any scenario; that is, the sum of non-pecuniary expected costs of shortfalls plus pecuniary costs of obtaining temporary water rights. Based on any aquifer level in December, the total expected costs during the next twelve months of 1) doing nothing, 2) leasing, and 3) optioning water are compared to determine the most appropriate course of action for SAWS to cover possible cutbacks in its withdrawals from the Edwards Aquifer.

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Chapter 1

Introduction

Motivation

Prior to 1990, the State of Texas did not regulate the usage of groundwater. Following the English common law rule of 'absolute ownership', groundwater was considered to be the property of the owner of the land above it. No restrictions were placed on the amount of water that each owner could pump as long as the water was put to beneficial use. However, environmental concerns over the potential loss of endangered species triggered a Texas Supreme Court ruling that led to the issuance of groundwater pumping permits for the Edwards Aquifer: the first ever regulation of groundwater pumping in Texas. All users of the aquifer now have annual pumping permits that limit their allocation of Edwards Aquifer water.

In order to preserve the flow from springs that are fed by the aquifer, municipalities and industries are cut back a proportion of their monthly allocation if the aquifer level drops below a certain trigger elevation until the water level rises above it again. Now the municipalities must prepare for these possible cutbacks in order to continue pumping water to meet their customers' demands. This project examines the trading of water permits in the existing Edwards Aquifer water market as a means of providing the municipalities with additional, temporary permits to counteract the possible cutbacks.

Background

The Edwards Aquifer (EA) is located in south central Texas, stretching East to West for 175 miles. Its waters serve agricultural, municipal, industrial, commercial, recreational and ecological purposes. The greater San Antonio region, which is located in the southeastern section of the aquifer, takes virtually all of its municipal and industrial water from this aquifer, served mainly by the San Antonio Water System municipality (SAWS). More than 1.5 million people and considerable economy is dependant on the Edwards Aquifer water supply (Keplinger 1998).

The aquifer has a fractured limestone formation. It recharges quickly from rainfall and exhibits rapid water movement and pressure transmission compared to other aquifers. Most of the recharge occurs in the west. Water flows generally eastward, up to 145 miles/year (about half a mile per day) at some locations (Jensen 1988).

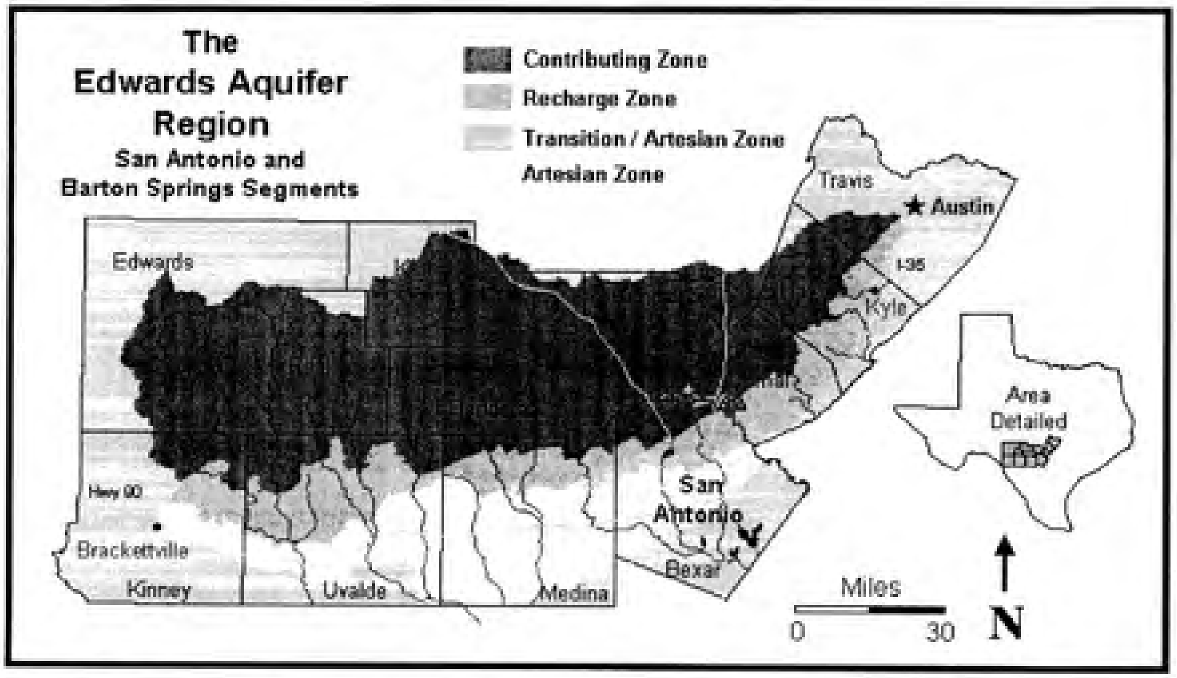

Fig. 1.1 The Edwards Aquifer Region

To the west of San Antonio, water is being pumped mainly for irrigation. The city itself pumps water for all its municipal and industrial needs from the EA, making the tenth largest city in the United States dependent on only one source of water supply (Pedersen 1997).

To the east of the city, the remaining water in the EA feeds artesian springs, the largest being Comal Springs and the San Marcos Springs. These springs serve recreational uses and supply between 30% and 70% of the Guadalupe River flow each year, feeding the habitat's several species. The U.S. Fish and Wildlife Service lists five of these species as threatened or endangered. The habitat quality has been linked to flows from springs, which are highly correlated with the aquifer elevation (Keplinger 1998).

By the early 1990s, high pumping rates and a few dry years caused the flow at Comal Springs and the San Marcos Springs to decline, negatively affecting the habitat of the endangered fish. Consequently, several interested parties, most notably the Sierra Club, filed lawsuits declaring that a minimum spring flow must be maintained to protect the endangered species. In 1993, the district federal court ordered that pumping limits must be imposed to maintain spring flow. This court order led the way to the passage of Texas Senate Bill 1477 in the same year (Edwards Aquifer Authority 1998).

The Texas Senate Bill 1477 (SB 1477) made several significant changes in the management of the Edwards Aquifer (Keplinger, McCarl and Chen 1998). It:

- established the Edwards Aquifer Authority (EAA) to manage the aquifer. Among other things, the EAA is charged with protecting terrestrial and aquatic life dependent on the Edwards Aquifer water.
- requires the EAA to promote a water market in the region by establishing water rights and by providing for water sales and leases by collecting fees, adjudicating, defining and monitoring individual pumping rights.
- requires the EAA to cap the annual pumping permits at 450,000 acre-feet (AF)[1], to be reduced to 400,000 AF by the year 2008 (Eckhardt 2002).

The Senate Bill was challenged in the courts, but in 1996, the Texas Supreme Court ruled that the bill was not unconstitutional. The EAA was officially established in that year and spent the next few years establishing tradable water permits. By 2001, all users of the aquifer were issued permits that restricted their yearly pumping rights to a specific allocation, and the permits were put into effect. Altogether, the EAA issued 532,000 AF of permits, intending to reduce these allocations to 450,000 AF shortly, and then to 400,000 AF by 2008. Of the 532,000 AF pumping rights, 227,000 AF were allocated to municipalities, 247,000 AF to agricultural users and 58,000 AF to industry (Durbin, 2002). While the allocation to the municipalities is smaller than their average yearly production, agricultural users were allocated about double their average yearly use. Between 1989 and 1998, total withdrawals from the aquifer averaged 435,000 AF, ranging between 327,000 AF and 542,000 AF. Total withdrawals exceeded 450,000 AF in four of those ten years, and exceeded 400,000 AF in all but two years.

In order to preserve spring flows that nurture the aquatic life that the EAA is charged to protect, the EAA is considering a policy of temporarily cutting back allocations when the aquifer level is low[2]. Following this policy, when the aquifer level drops to or below a predetermined trigger level at a specific monitor well, the monthly allocations for municipal, industrial and commercial users are cut back by a certain percentage. The cutbacks continue month after month until the aquifer level exceeds the trigger level again, after which the cutbacks are removed.

While this cutback policy does not affect agricultural and personal users of the aquifer, municipalities face the possibility of being cut back from their monthly allocations during dry years, when demand is usually highest. Since groundwater withdrawal was never before regulated prior to the recent Senate Bill, the residents of San Antonio and other towns are not accustomed to having their water usage rationed. However, a water market now exists for the Edwards Aquifer region. In order to offset the possible cutbacks and ensure that their supply of water to meet the demand of their customers is not affected, the San Antonio Water System (SAWS) and other municipalities can enter the water market as buyers to obtain additional, temporary water rights from agricultural users. While there are several municipal users on the Edwards Aquifer, SAWS is by far the largest, withdrawing about 70% of all municipal consumption from the aquifer, and it has the greatest financial and political capacity. Hence, in this research, it is assumed that only SAWS would be interested in entering the water market.

There are multiple alternatives available in the water market. Buying water permits permanently increases the purchaser's annual allocation while permanently decreases the seller's. Leasing transfers the right to withdraw the leased quantity of water

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[1] An acre-foot is 325,850 gallons. One acre-foot of water is approximately the annual consumption of two households.
[2] The EAA is still considering different policies and the final plan may differ from that described in this report.

(a portion of the seller's permitted allocation) from the seller to the purchaser from the date the lease is signed through December of that year. At the end of the year, the lease expires and the rights return to the seller. Buying and leasing water permits already exist in the water market for the Edwards Aquifer. In addition, options might be considered. An options contract transfers the right to withdraw up to the optioned quantity from the seller to the purchaser only after a specified exercise date. The purchaser pays the seller a fixed fee (contract cost) for the right to lease their water after the exercise date at a set exercise price. The purchaser then only pays for the quantity that is exercised (which could be less than the full optioned quantity). The contract cost is unique only to options. As with leasing, the options contract expires at the end of the calendar year and the rights return to the seller.

Given that the risk of facing cutbacks in the short term is uncertain, and given the different market alternatives with all the different cost structures, SAWS has a difficult task in planning a course of action to deal with the possibility of cutbacks. Throughout this report, it is assumed that SAWS is risk averse and opposed to water rationing.

Goal of this Study

The goal of this study is to provide SAWS with tools for setting policy on the appropriate course of action to cover forced cutbacks in their withdrawals from the Edwards Aquifer in the short term; the tools take the form of mathematical models.

This study is SAWS-oriented. It aims to assist SAWS in understanding how to analyze and then compare the different market alternatives to select the most appropriate one given the aquifer's current scenario. This report lays the framework for a procedure that SAWS could use repeatedly with updated data to predict future cutbacks and calculate its own expected cost for each market alternative, for any month of the year and given any current aquifer level. This report assumes that SAWS wants to minimize its expected costs in meeting customer demands.

Tasks

There are four tasks for achieving the goal of this study:

- *Task 1: Describe the Edwards Aquifer system.*

  This involves examining the aquifer's hydrology, its historical levels, recharge and withdrawal rates, the regulatory mechanisms for the EA, and the market alternatives.

- *Task 2: Develop a simulation model to predict the probabilities of facing cutbacks in the short term.*

  This involves creating a simulation program that can predict future aquifer levels given any starting water elevation in any starting month of the year. The program utilizes a regression model that relates aquifer level to the different components described in Task 1. The user of the model can vary certain inputs such as withdrawal rates, the start elevation, and the starting month in order to update the analysis continuously. The simulation model then predicts the future water elevations, each time using a different set of historical recharge data. After several simulations, the probability of the water elevation dropping below a trigger level during a specific simulation period can be estimated.

- *Task 3: Predict the water elevations and calculate the probabilities of facing different cutbacks for different scenarios.*

  Running the simulation model for several different scenarios, probability tables and charts can be produced to describe how the Edwards Aquifer is predicted to behave. These tables and charts provide insight to SAWS on how best and when to perform a cost analysis (Task 4) to produce the most accurate predictions that are used to compare the different market alternatives.

- *Task 4: Develop the outline for an expected cost analysis of the market alternatives and make recommendations on policy to SAWS.*

  By entering the water market, SAWS incurs pecuniary costs in obtaining additional water rights plus other costs due to forced cutbacks. Using the probability of facing cutbacks, the market mechanisms and estimated prices for the different alternatives, an expected cost analysis reveals the market alternative that yields the lowest total expected cost to SAWS. The framework for this analysis is described such that SAWS can repeat the analysis for any assumed set of conditions. A sensitivity analysis accounts for uncertainty in the estimated prices for each alternative.

The overall method of predicting future water elevations and performing an expected cost analysis can be repeated for any month and for any set of conditions SAWS is interested in exploring.

Chapter 2

The Edwards Aquifer System

The Edwards Aquifer supports a variety of purposes. In general, ground water flow is from West to East; most irrigation is in the west, and most municipal usage is in the east, primarily in San Antonio. As more water is pumped from the aquifer, less is discharged at the springs. Several times in the 1990s, spring flow at Comal Springs almost ceased (Keplinger, McCarl and Chen 1998).

Spring Discharge

Using data from the United States Geological Survey (USGS) and Edwards Aquifer Authority sources, Eckhardt (2002) compiled yearly records of spring discharges. Based on these yearly records, the average annual spring discharge between 1934 and 1998 was 365,000 AF, with a standard deviation of 125,000 AF; annual discharge ranged from 69,800 AF to 802,800 AF. Figure 2.1 shows the total spring discharge from 1934 to 1998. Although the springs never completely ceased to flow in the same year, the San Pedro, San Antonio and Comal Springs dried up separately at different years(EAA 2002).

Between 1989 and 1998, total spring discharge averaged at 402,000 AF, ranging from 212,000 to 802,800 AF. Thus, on average, spring discharge in recent years was not significantly different than in previous decades. However, the total spring discharge shows much more year-to-year variability in the past decade than in previous decades. Nonetheless, Comal Springs temporarily ceased to flow in 1956, and again almost dried up in the 1990s, threatening loss of wildlife habitat supported by these springs.

Fig. 2.1 Historical Total Spring Discharge from the Edwards Aquifer, 1934 - 1998

Recharge Rates

The USGS uses a water-balance model to estimate monthly recharge to the aquifer, based on readings of several gages located upstream and downstream of the aquifer. Precipitation records are used by USGS to estimate runoff and infiltration into the aquifer. Storm events are broken into two components: floodflow and increase in base flow, both of which are estimated by a technique using the upstream gages as described by USGS (Puente 1978). About 30% of the infiltration area is not gaged, but its infiltration per acre of land is assumed to be proportional to infiltration in the gaged areas. Recharge is calculated monthly as the sum of the flow through the upstream gages plus runoff/infiltration estimates, minus the flow through the downstream gages.

The USGS recognizes that the monthly recharge estimates are not entirely accurate. Errors in the estimates are due mainly to errors in estimating infiltration in the ungaged areas and to inaccuracies in streamflow measurements. Additional gages were installed in 1953, which seem to have improved recharge estimates after that year. Furthermore, USGS expects that long-term annual averages are more accurate than the monthly calculations for recharge.

Figure 2.2 shows the estimated annual recharge to the aquifer in thousands of acre-feet for all years with recorded recharge data. Table 2.1 shows historical data on recharge and spring discharge. Since 1989, the 10-year average annual recharge has been estimated at 945,000 AF, which is larger than the historic 64-year average. Between 1970 and 1994[1], the average monthly recharge was 75,500 AF, with a standard deviation of 6,000 AF. The monthly recharge in this period ranged from 6,200 AF to 996,000 AF.

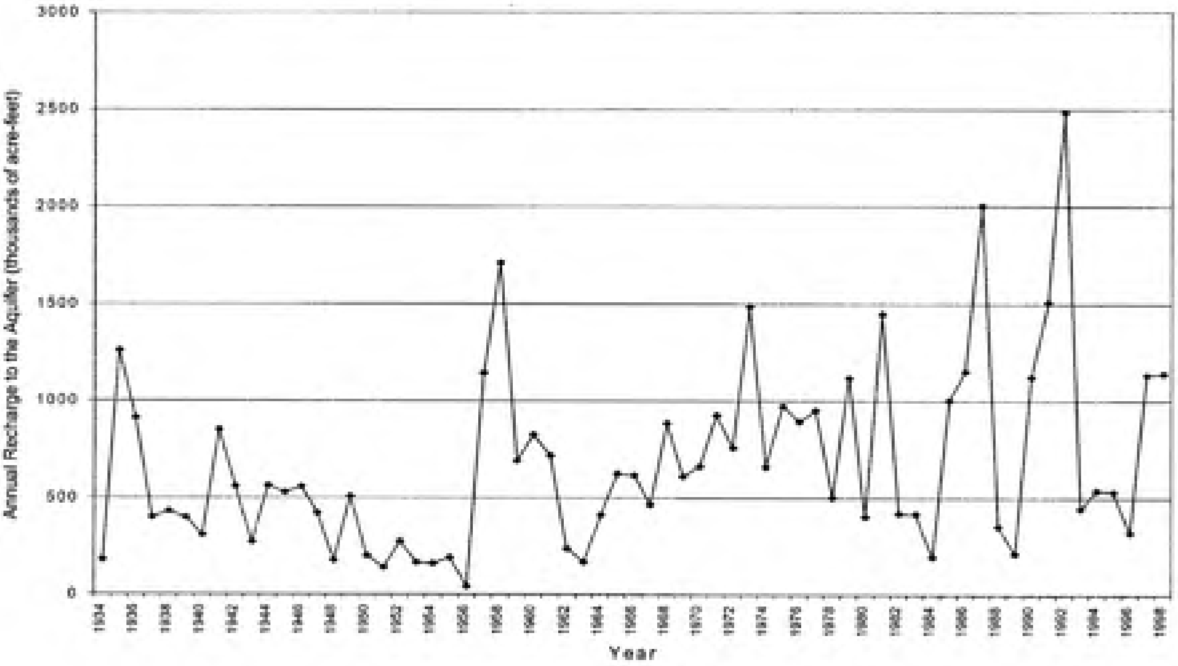

Fig. 2.2 Total Estimated Recharge to the Edwards Aquifer, 1934 - 1998

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[1] Due to the limited data available from other components of the Edwards Aquifer, 1970 – 1994 is the largest period for which there is accurate and consistent data from all components.

Table 2.1 Edwards Aquifer's Annual Recharge and Spring Discharge Data (in AF), 1934 – 1998

	Average (1934-1998)	Minimum	Maximum	Standard Deviation	Average (1989-1998)
Recharge	683,100	43,700	2,486,000	480,100	945,000
Spring Discharge	365,000	69,800	802,000	125,000	402,000

Withdrawal Rates

Eckhardt (2002) collected records of annual withdrawals from the various sectors served by the Edwards Aquifer from 1955 through 1998, and he classified the withdrawals according to the following uses: irrigation, municipal/military, domestic/livestock, and industrial/commercial. SAWS is only one of several users that are included in the municipal/military group, which also includes all other municipalities in and towns outside of San Antonio. The domestic/livestock group includes all the private individual wells owned by families, as well as livestock operations. In 1995, the USGS revised the method of estimating domestic/livestock withdrawals, significantly decreasing the reported withdrawals for this group for the years following 1994 (Eckhardt 2002). Thus, in order to use consistent data in evaluating withdrawals from the system, only records through 1994 are considered in estimating each sector's proportion of total withdrawals from the Aquifer. SAWS provided their records of monthly withdrawals from the aquifer since January 1970, which are used in developing the aquifer model in the next chapter.

Table 2.2 reports average annual withdrawals for the four sectors that use EA water (Eckhardt 2002). Figure 2.3 shows the yearly withdrawals and how they compare to each sector, as well as the total annual withdrawals.

Table 2.2 Annual Withdrawals from All Users of the Edwards Aquifer (in AF), 1970 – 1994

	Average (1970-1994)	**Minimum**	**Maximum**	**Standard Deviation**	**Ten-Year Average (1985-1994)**	**Proportion of 1985-1994 Withdrawals**
Irrigation	126,750	27,100	203,100	47,400	120,000	27 %
Municipal/Military	231,400	167,500	287,200	38,300	260,000	58 %
Domestic/Livestock	37,700	28,600	49,900	4,900	40,000	9 %
Industrial/Commercial	21,200	11,500	67,500	11,900	29,000	6 %
All Users	***417,050***	***310,400***	***542,500***	***70,100***	***449,000***	***100 %***

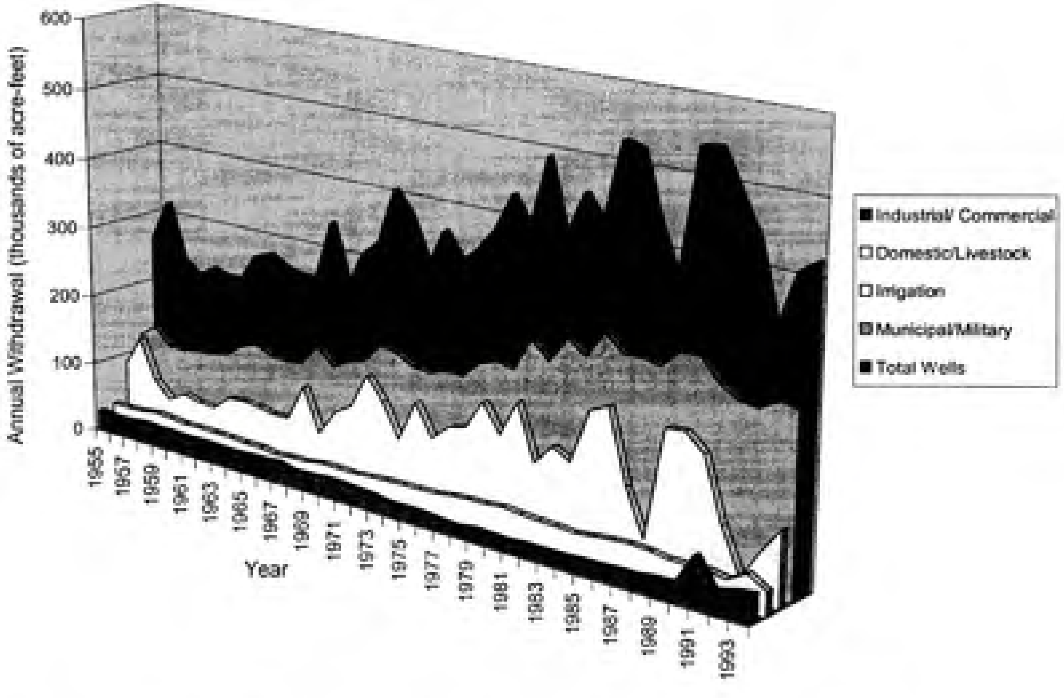

Fig. 2.3 Annual Withdrawals from the Edwards Aquifer by Sector, 1955 - 1994

As shown in Table 2.2 and Figure 2.3, municipalities withdraw the most water from the aquifer, but irrigation is also a large user. Municipal withdrawals increased from 1955 to about 1985, after which they have been fairly constant. Since 1985, municipal/military withdrawals have consistently averaged about 260,000 AF per year, which is 12% higher than the historic average reported in Table 2.2.

Agricultural withdrawals vary significantly from year to year, but the average has increased since 1970; the ten-year average from 1985 through 1994 is about 120,000 AF/year. Industrial, commercial, domestic and livestock withdrawals have not changed much over the years.

Overall, total annual withdrawals show an increasing trend between 1955 and 1994, and they have occasionally exceeded the 450,000 acre-feet total permitted level set by the Texas Supreme Court later. The ten-year average total well withdrawal between 1985 and 1994 is 449,000 AF.

Aquifer Levels at the J17 Well

The Edwards Aquifer Authority uses one well located in San Antonio, called the J17 well, to monitor and regulate the aquifer. Figure 2.4 shows the water elevation on the first day of every month between January 1933 (when monitoring started) and December 1999. The EAA (2002) reports daily records of water elevation at this well.

As shown by Figure 2.4, the water elevation at the start of each month historically varied between 615 and 700 feet above sea level. After the 1950's drought, the water elevation varied significantly but was usually above 650 feet. Nonetheless, it is evident that the aquifer level drops below 650 feet regularly, which is the trigger level that the

EAA uses in deciding cutbacks of municipal, commercial and industrial users from their monthly allocations.

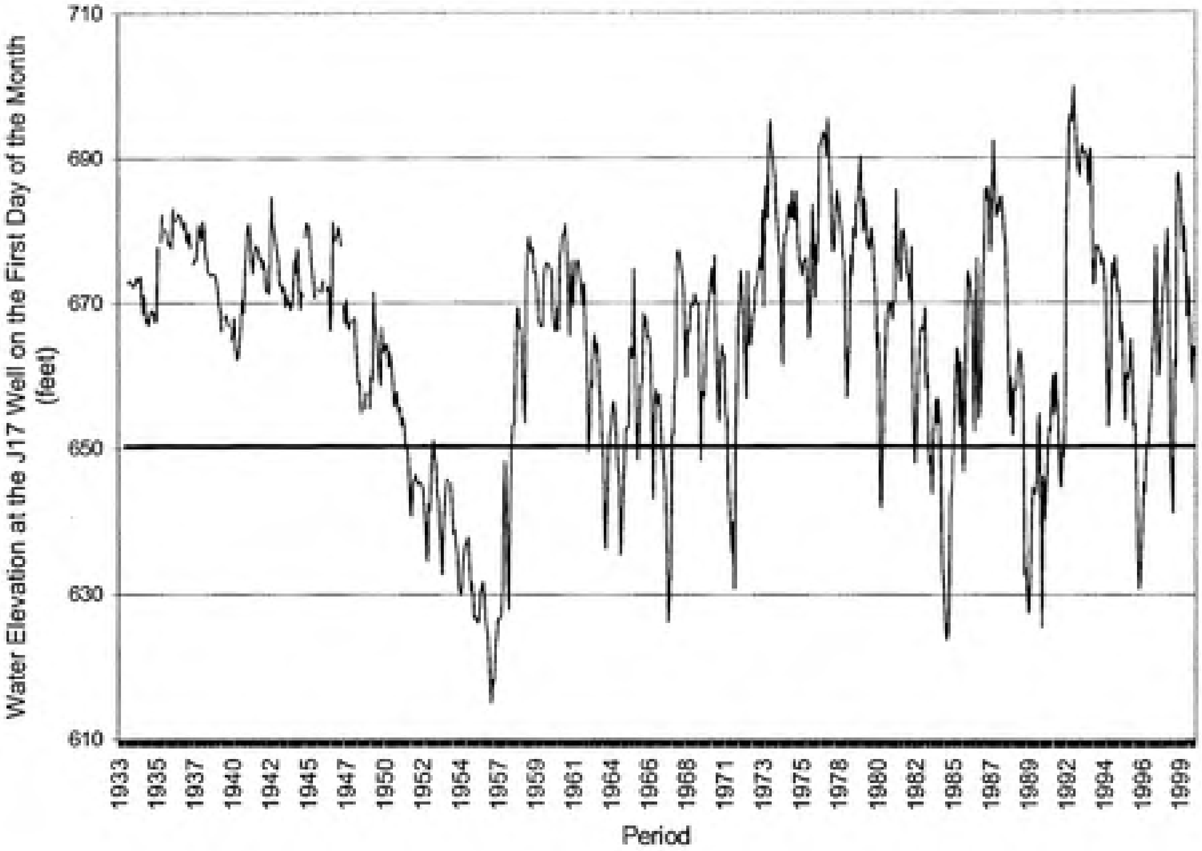

Fig. 2.4 Water Elevation at the J17 Well, 1933 - 1999

Figure 2.5 shows the five-year moving average of J17 water elevations from 1933 to 1999. The moving average shows no increasing or decreasing trend since 1985, ranging from 660 to 670 feet, which corresponds with the steadying municipal withdrawal rates since 1985. Table 2.3 reports statistics on the water elevation at the J17 well that was observed on the first day of each month for 1933-1999. As shown, the average water level was 665 feet.

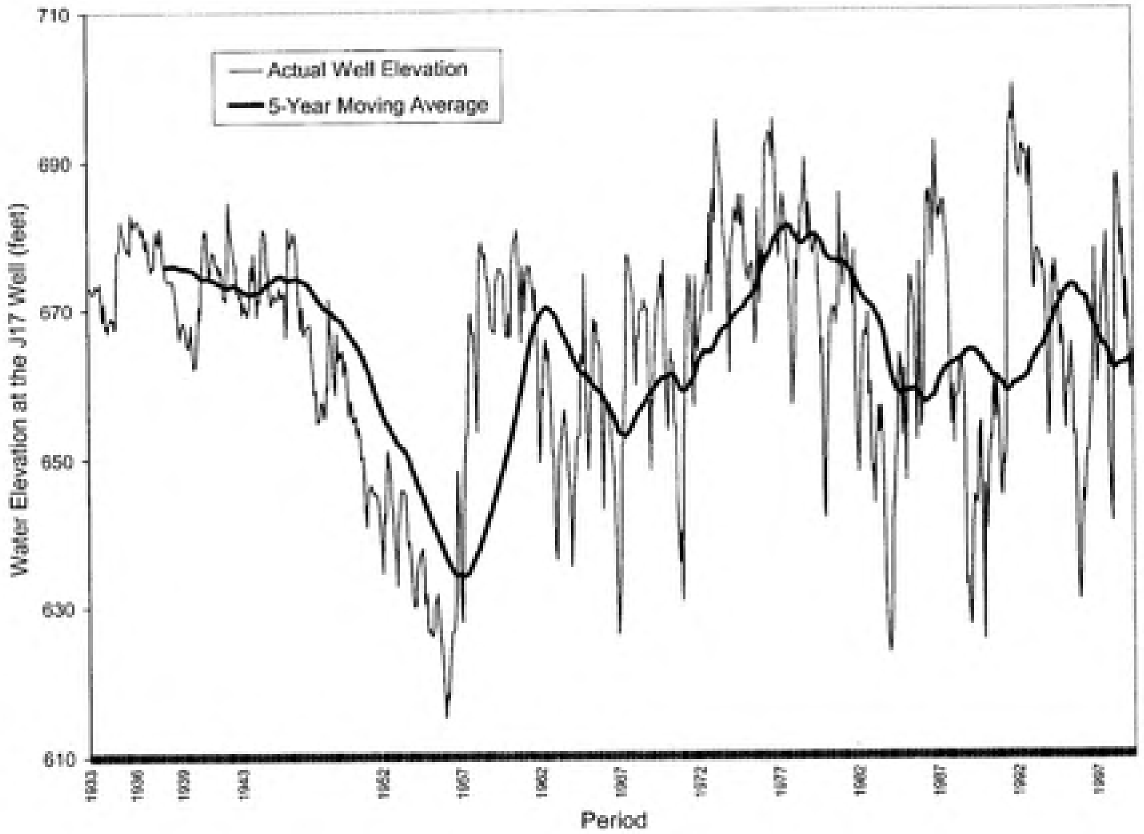

Fig. 2.5 The Five-Year Moving Average of J17 Water Elevation

Table 2.3 Water Elevation at the J17 Well (in feet), Based on Monthly Readings

	All Months (Jan 1933-Dec1999)	Post-Drought Years (Jan 1957-Dec1999)	Last Ten Years (Jan 1990-Dec1999)
Average Elevation	664	665	665
Standard Deviation	16.1	15.5	16.7
Minimum Elevation	615	624	625
Maximum Elevation	700	700	700

Regulatory Mechanisms

At the beginning of every month, the EAA checks the elevation at J17. If it is at or below 650 feet, the EAA imposes a "5% cutback" on all municipal, industrial and commercial withdrawals for that month (but not agricultural or domestic withdrawals). At the beginning of the next month, the J17 elevation is measured again, and the 5% cutback is removed if the water table elevation exceeds 650 feet; otherwise the cutback is continued. All municipal, industrial and commercial users are required to report to the EAA the historical proportion of their annual water withdrawal that occurred for each month of the year. These monthly proportions are kept on file at the EAA, as well as the permit levels for each user. The EAA multiplies these factors by the annual withdrawal cap set by the permit in order to calculate the approximate water withdrawal in every month for each user. From this estimated monthly withdrawal rate, the EAA calculates the "5% cutback" and informs all the municipal, industrial and commercial users that they are allowed to withdraw only up to 95% of their calculated monthly withdrawal.

The cutback levels are increased to 10% if the water elevation at J17 drops to 640 feet, and if the elevation drops to or below 630 feet, the cutback is increased to 15% of the monthly withdrawal rate. This cutback policy does not affect agricultural or domestic users of the aquifer; only municipal, industrial and commercial users are cut back, and they all are cut back at the same time. Table 2.4 lists the different cutback levels.

Table 2.4 J17 Elevations and the Corresponding Cutbacks

J17 Elevation (feet above sea level)	Percent Reduction in Monthly Permits for Municipal, Industrial and Commercial Users
≥651	0 %
650 – 641	5 %
640 – 631	10 %
≤630	15 %

Water Market

In order to alleviate some of the risk to the municipalities of not being able to supply enough water to their customers during dry months (usually May through August), a water market exists in which water permits can be bought and sold. Irrigators with greater allocations than they plan to use can sell some of their allocations to municipalities. Municipalities are also allowed to be sellers in the water market, but they are more likely to buy than sell. SAWS is the only large municipal user of the Edwards Aquifer, withdrawing about 70% of total municipal consumption. It is assumed in this analysis that SAWS is the only municipality that will enter the water market to obtain additional pumping rights.

Trading water permits can be permanent or temporary. Buying water permits permanently increases the purchaser's permitted withdrawals and permanently decreases the seller's. Buying water rights can presumably occur any day of the year and is immediately effective.

Leasing transfers the right to withdraw the agreed-on lease quantity from the seller to the purchaser for twelve months from the date the lease is signed. However, since my analysis focuses on one-year periods ending at end of a calendar year, it is assumed hereafter that lease contracts expire on December 31st. In addition to its permitted allocation, the purchaser has the right to withdraw up to the maximum lease quantity any time during the year, and the seller is forbidden to withdraw that amount, whether the purchaser uses its full lease quantity or not. At the end of the year, the lease expires and the rights return to the seller. Whatever portion of the lease quantity that was not used by the purchaser is not carried over to the next year, but is "lost". The purchaser must pay the seller an amount equal to the lease price times the full lease quantity, even if the purchaser does not use the full amount. For example, if SAWS leases 50 AF at $70/AF, but uses only 20 AF by December 31st, it must still pay $3,500 to the seller; 30 AF of water is "lost" for the year, without being used by either party.

Optioning water is another valid transaction, but it has not yet been exercised in the EA region. Options are similar to leases, but when the option contract is signed, the purchaser and seller agree on an "exercise date": the purchaser can start withdrawing on or after the exercise date, but not before. The exercise date can be the day the option contract is signed or any day thereafter in the calendar year. If the purchaser chooses to exercise, he informs the seller, who is then prohibited from withdrawing the quantity that is exercised. The purchaser may choose to exercise any quantity up to the full option quantity, and pays only for the quantity that is exercised. The seller must be prepared to yield the full option quantity at any time until December 31st, but may withdraw the difference between the full option quantity and the quantity that is exercised. At the end of the calendar year, the option contract expires and all rights return to the seller. Under optioning, the purchaser is required to pay a fixed fee (contract cost) plus the exercise price times the amount of water exercised. If the purchaser chooses not to exercise the option, he only plays the fixed fee. Both parties agree upon the exercise price in advance, when the option contract is signed.

For example, assume SAWS signs an options contract in February, setting the exercise date May 1. Both parties agree on the exercise price of $70/AF and an option quantity of up to 50 AF. Upon signing the contract, SAWS pays the seller the fixed fee (contract cost) of $1,000 up front, which is typically based on the option amount. After signing the contract, the seller must be prepared to yield up to 50 AF of its permit through the end of the calendar year. In July, SAWS chooses to exercise 20 AF of the option quantity, and does not exercise the remaining 30 AF through the rest of the year. SAWS thus pays the seller the exercise cost of 20 AF * $70/AF = $1,400, bringing its total cost to $2,400. Had SAWS chosen not to exercise the contract, it would have had to pay the seller only the $1,000 contract cost.

Leasing and optioning are alternatives for SAWS to cover unexpected cutbacks in the short term, whereas buying water permits deals with the long term. Table 2.5 compares the characteristics of the three alternatives described above.

Table 2.5 The Three Water Market Alternatives

Characteristic of the Contract	**Type of Contract**		
	Buying	**Leasing**	**Optioning**
Effective Date for Using Water	Upon execution	Upon execution	On or after the exercise date
Expiration Date	Indefinite	December 31st	December 31st
Amount of Paid Water	Full contract amount	Full contract amount	Exercised quantity
Additional Contract Cost	None	None	Fixed option fee

The Texas Water and Development Board (TWDB) explained that farmers using the aquifer irrigate mainly in the summer months: a single year's record of monthly agricultural withdrawals showed that 12% of the year's withdrawals occurred in April, 18% in each May and June, 13% in July and 10% in August, accounting for about 70% of the year's withdrawals between April and August. Agricultural withdrawal of water was very low in all other months of the year (up to but not greater than 6% for any one month). At the end of August, harvesting begins, and water consumption drops significantly as the farmers begin to plan for next year's crops. Farmers apparently invest in new equipment in January and February.

If SAWS is to enter the water market looking to trade for water pumping rights from the agricultural sector through lease or option contracts, it must be aware of how farmers value their water and enter when prices are low. Following the annual investing and growing cycle, the farmers' value of water is likely to increase near irrigation time, reach its peak during irrigation season, then drop in the autumn months of September through December, rising again in January as investments are made to prepare for the next year. It would be more beneficial to the farmers for SAWS to approach them for water permit trading in the months of September through December, such that they may agree on contracts and become fully aware of their water pumping limits well before they start investing in equipment or planning for the next year's crops. Some farmers may even wish to switch to dry-irrigation schemes for the year they trade away their water permits. At the same time, it would be more beneficial for SAWS to plan its strategy for the next year around the same time, since this is when the farmers' value of water is lowest and SAWS is likely to get the lowest price on its contract. However, because lease and option contracts expire in December, SAWS should probably sign contracts as early as January, after having negotiated the terms in November or December.

In order to accomplish this, however, SAWS must have the capacity to look several months into the future and to predict the probability of the J17 level dropping to 650 feet. Currently, SAWS does not have this capability and is therefore unable to enter the water market early to capture the low prices, or to evaluate the differences between lease and option contracts, or to decide how much water to lease or option. This report lays the foundation for such an analysis. The next chapter presents a model for predicting J17 elevations and the probability of facing cutbacks, given any starting elevation in J17, in any month of the year for any target withdrawal rate.

Chapter 3

Predicting the Probability of Cutbacks

SAWS needs to predict the probability of water level in J17 falling below 650 feet in order to evaluate the alternatives that are available to them in the water market. A simulation model is presented herein to simulate monthly water elevations in the future using historical aquifer recharge data, any assumed withdrawal rates, any initial J17 water elevation, the month of when the elevation is read, and the duration of the simulation period. The model then calculates the probability of the water table dropping below different trigger levels. Using the model of this chapter, SAWS can predict the probability and amounts of cutbacks they are likely to face in the coming year.

Model for the J17 Level

The Edwards Aquifer in many ways behaves like a reservoir. Based on inflows and outflows, the volume of water either increases or decreases from one month to the next, which is reflected in increasing and decreasing water elevations in well J17. The storage in reservoirs can be predicted using a simulation model based on a flow balance equation in the form:

$$S_{t+1} = S_t + I_t - Q_t \tag{3.1}$$

where S_t is the volume of water in the reservoir at the start of month t, I_t is the inflow during month t, and Q_t is the outflow in month t.

This equation can be modified to apply to an aquifer, where water elevation depends on the volume of water in the aquifer:

$$H_{t+1} = a + b H_t + g I_t - h Q_t \tag{3.2}$$

where H_t is the water elevation at the start of month t (say in well J17); a, b, g and h are regression constants.

In the case of the Edwards Aquifer, the inflow data (I_t) in Equation 3.2 are the recharge estimates to the aquifer provided by the USGS. Monthly recharge data are available for January 1934 through December 1998.

The outflows in Equation 3.2 (Q_t) include the withdrawals made by the municipal, agricultural, industrial, commercial, military, livestock and domestic users of the aquifer, for which Eckhardt (2002) provides yearly data. Spring discharge, however, is not included in the mode: it is analogous to spillovers from reservoirs. Similarly, if, after water flows through the Edwards Aquifer past all the withdrawal points there is water present at the end of the aquifer with sufficient head, it will flow out of the springs. Spring discharge is, therefore, correlated with the volume of water in the aquifer, and it is omitted from Equation 3.2.

The parameters in Equation 3.2 were estimated using linear regression analysis based on 25 years of monthly data. The elevation at J17 for the first day of each month was used in the regression analysis. SAWS was able to provide monthly records of withdrawals from January 1970 through November 1999. However, Eckhardt's records on withdrawals were all in annual terms. Monthly data could not be obtained for each of the water using sectors. Using estimates made by irrigators on their quarterly withdrawals for year 2000 and considering the primary crops grown in the region, the Texas Water

Board disaggregated the agricultural withdrawals of that year into monthly values. This could not be done for other years since there are no monthly or quarterly records of irrigation pumping. Using the disaggregated values, each month's proportion of the year's total withdrawal was estimated and is reported in Table 3.1 in the "percentage" columns. Table 3.1 also shows the ratio of each month's estimated withdrawal to the *average monthly* withdrawal rate, which are reported as fractions in the columns labeled "Monthly Multiplier." These fractions have units of AF/AF of average monthly withdrawal. For example, the agricultural sector withdraws 5.8% of its total annual usage in January, and the municipal sector withdraws 6.9% in January. Dividing by 1/12, 5.8% of annual withdrawals is equivalent to 69% of the average monthly withdrawal, which is shown in Table 3.1 (as a fraction, not percentage). By multiplying the average monthly withdrawal rate with the multiplier for a month estimates the month's withdrawals.

Table 3.1 The Proportion of Yearly Withdrawals and Multipliers by Month for the Agricultural and Municipal Sectors

	Agricultural Sector		Municipal Sector	
Month	Percentage of Total Annual Withdrawals	Monthly Multiplier	Percentage of Total Annual Withdrawals	Monthly Multiplier
January	5.8 %	0.69	6.9 %	0.83
February	5.8 %	0.69	6.4 %	0.77
March	5.8 %	0.69	7.5 %	0.90
April	12.2 %	1.46	8.0 %	0.96
May	18.3 %	2.20	8.4 %	1.01
June	18.3 %	2.20	9.2 %	1.10
July	13.1 %	1.58	11.1 %	1.33
August	10.2 %	1.23	11.2 %	1.34
September	5.8 %	0.70	8.9 %	1.07
October	1.6 %	0.19	8.3 %	1.00
November	1.6 %	0.19	7.1 %	0.85
December	1.6 %	0.19	7.1 %	0.85
Total	**100 %**	**12.0 (Avg: 1.0)**	**100 %**	**12.0 (Avg: 1.0)**

The values in Table 3.1 indicate high withdrawal rates for the agricultural sector in the summer when harvesting occurs and dry weather necessitates irrigation. It is assumed that these proportions represent each year's irrigation withdrawals, and hence they are used to generate monthly withdrawal data for the agricultural sector from 1970 through 1998. Similarly, using SAWS' monthly withdrawal data from 1970 through 1998, monthly multipliers were computed (see Table 3.1) and used to generate monthly withdrawals for the municipal sector. Figure 3.1 shows the monthly multipliers for the agricultural and municipal sectors.

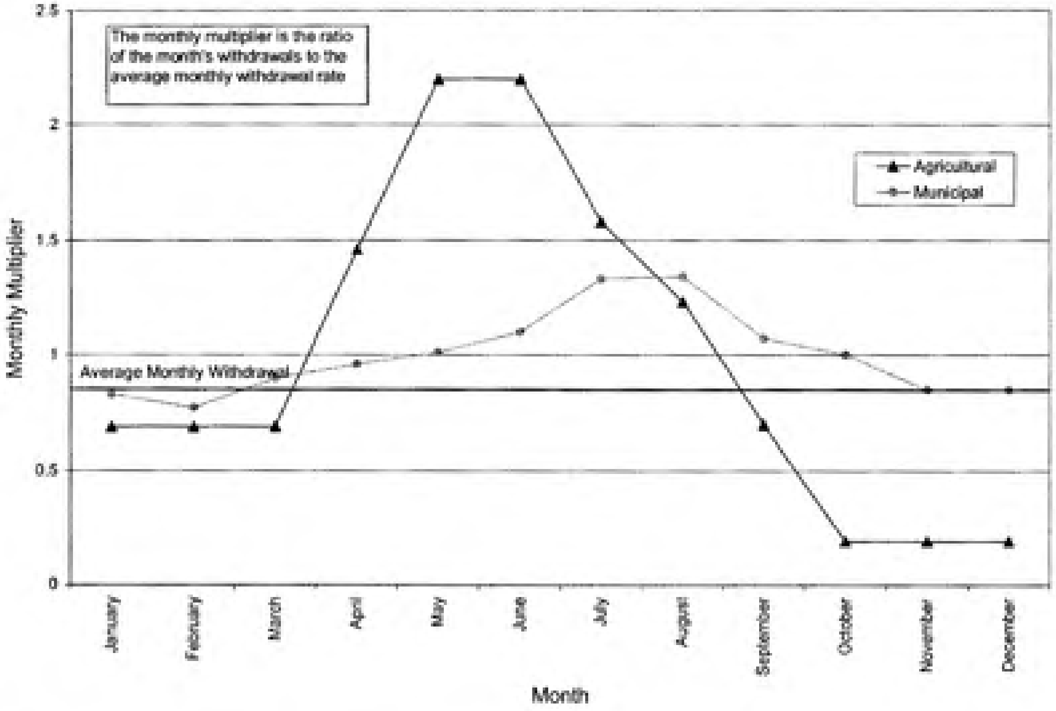

Fig. 3.1 Monthly Multipliers for the Agricultural and Municipal Sectors

As shown in Figure 3.1, the monthly variation in agricultural withdrawals is much higher than municipal withdrawals; it follows that municipal and agricultural withdrawals should be treated separately in Equation 3.2. Furthermore, since there were no monthly data available for industrial, commercial, military, livestock and domestic withdrawals, these had to be lumped with either municipal or agricultural withdrawals (depending on which of the two withdrawal patterns shown in Figure 3.1 most resembles the sector's monthly withdrawal pattern) in Equation 3.2. Thus two main withdrawal groups are formed for Equation 3.2: the municipal group and agricultural group, where all sectors in a group are assumed to have the same monthly multipliers. Table 3.2 lists the different sectors in each group. Industrial and commercial withdrawals do not vary much by season, and are thus put in the municipal group. In addition, Eckhardt lumps military with municipal withdrawals. Livestock operations use high amounts of water during the summer to feed and wash the animals, while domestic users own individual wells that are mostly used to water lawns or gardens in the summer months. Thus, livestock and domestic withdrawals are assumed to follow irrigation patterns and are grouped with the agricultural sector.

Table 3.2 Water Use Sectors Represented by Monthly Multipliers

Monthly Multiplier Group	**Sectors in the Group**
Agricultural	Agricultural, Livestock, Domestic
Municipal	Municipal, Industrial, Commercial, Military

The method of estimating withdrawals for certain sectors was changed by USGS in 1995. In order to use consistent data, only withdrawals from January 1970 through December 1994 were used to estimate the regression model. After Equation 3.2 was fitted to the data, the regression model that best describes the water elevation at the J17 well is:

$$H_{t+1} = \underset{(10.5)}{144.5} + \underset{(40.1)}{0.796\,H_t} + \underset{(9.27)}{0.000026\,I_t} - \underset{(-7.47)}{0.000218\,A_t} - \underset{(-5.96)}{0.000355\,M_t} \qquad (3.3)$$

$n = 300$, $R^2 = 0.91$. Numbers in parentheses are t-stats.

where H_t = water elevation at the J17 well at the start of month t (feet),
H_{t+1} = water elevation at the J17 well at the start of the next month (feet),
I_t = total aquifer recharge during month t (AF),
A_t = total agricultural, livestock and domestic withdrawals during month t (AF),
M_t = total municipal, industrial, commercial withdrawals during month t (AF).

As shown by the t-stats, each regressor is statistically significant at the 1% level, including the constant. The R-squared value for the regression model is high at 0.91. The residuals have a mean of 0 and a standard deviation of 4.9 feet. Figure 3.2 compares the historical start-of-month elevations at J17 with predicted elevations. The model was started with the historical elevation at J17 for January 1970 and run for 300 months using the historic recharge and withdrawal data to make the predictions shown in Figure 3.2. The predicted end-of-month elevation was used as the start-of-month elevation for the next month, which means that errors were allowed to propagate throughout the simulation; historic well elevations for H_t were not used. The resulting predictions were relatively close to the historical elevations: the residuals had a mean of 0.14 feet with a standard deviation of 9.5 feet.

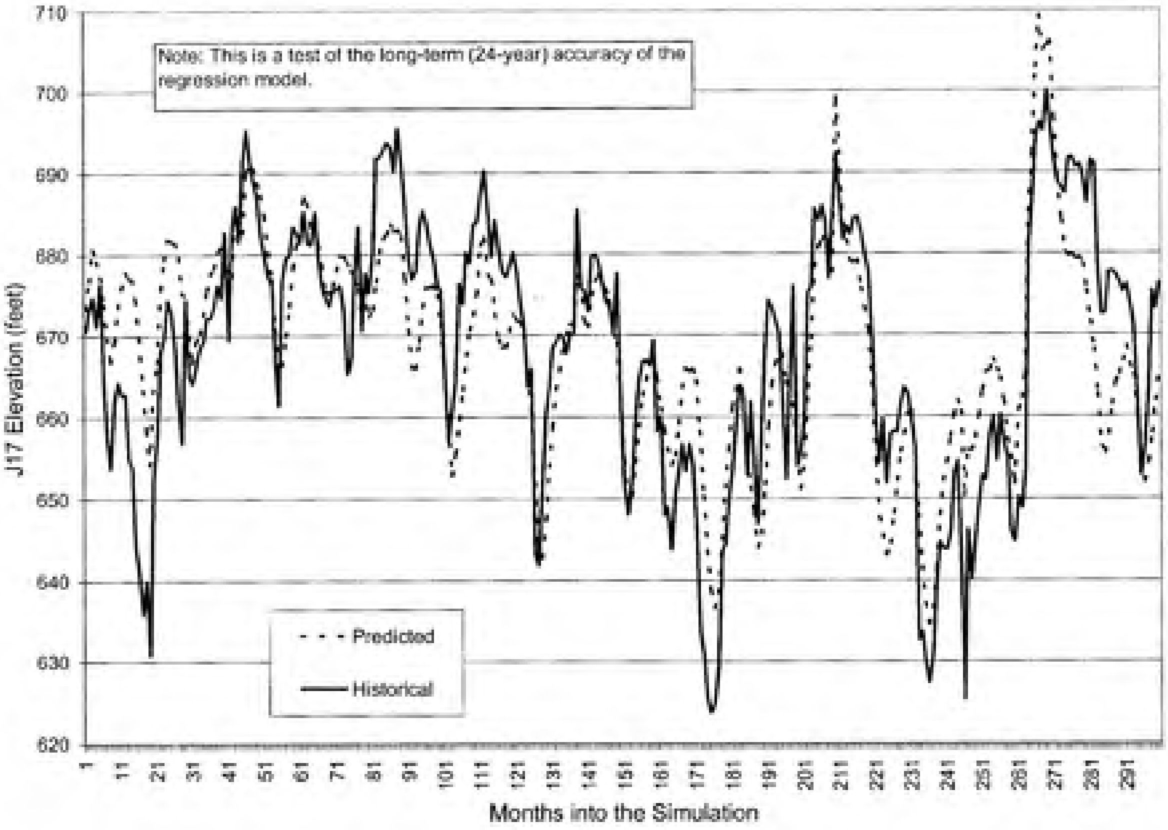

Fig. 3.2 Predicting J17 Elevations Allowing Errors to Propagate

Because this research is concerned primarily with short-term (annual) predictions, the simulation was run again, this time setting each January elevation to the historic J17 elevation, thus allowing errors to propagate for only 12 months. Figure 3.3 shows the predictions of water elevations compared to historic elevations given that the J17 elevation was reset to its historical value every 12 months. The residuals had a mean of 0.4 feet with a standard deviation of 8.1 feet. Table 3.3 lists the average residuals for each month when using the Equation 3.3 to predict the J17 elevations for one year starting with January's historic elevation. The residuals show that, on average, the predictions are too low between February and August, and too high through the rest of the year.

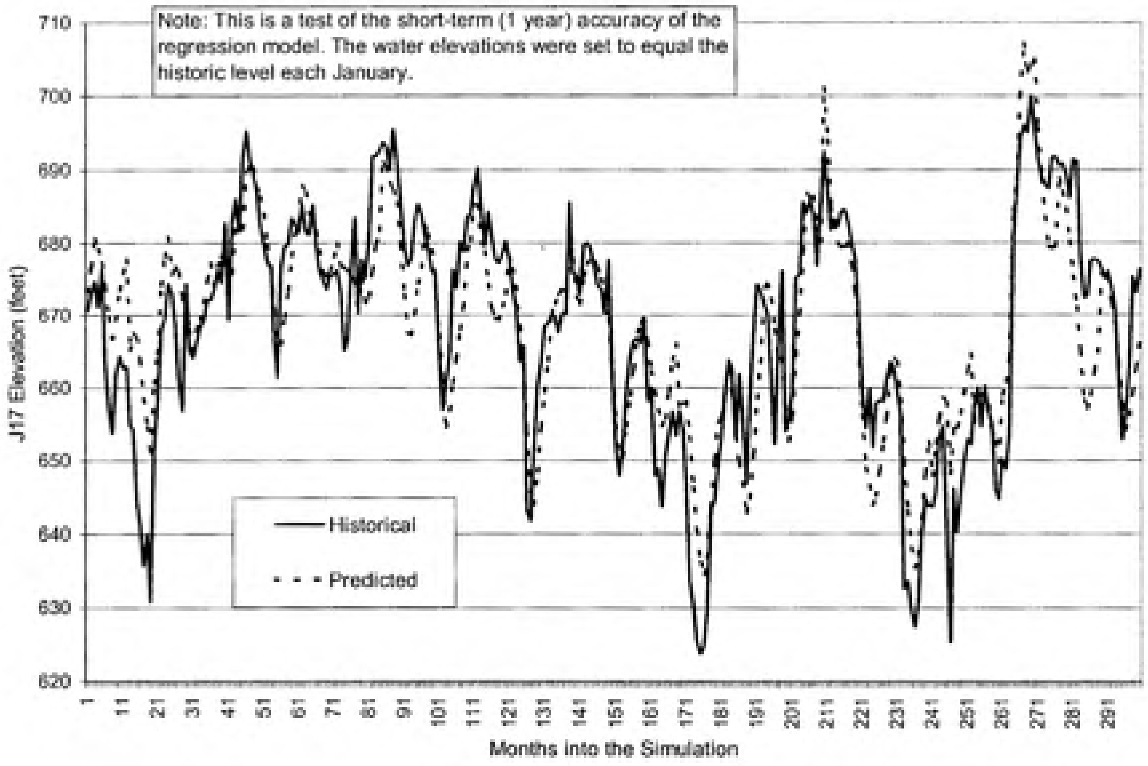

Fig. 3.3 Predicting Aquifer Elevations, Resetting J17 Each Year

Table 3.3 Average Monthly Residuals and Standard Deviations, Resetting J17 Each Year

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Avg. Residual (ft)	0.84	2.52	4.36	3.41	1.29	2.27	2.08	-0.16	-3.09	-4.34	-2.87	**0.42**
St. Dev. (ft)	2.94	4.30	6.27	8.07	8.80	9.87	8.25	7.85	8.28	8.79	8.66	**8.08**

Simulation Model for Edwards Aquifer

Using Equation 3.3, SAWS can predict monthly J17 water elevations for any future period, which in this illustration is assumed to be 12 months. A value for H_1 must be selected: the starting elevation of the starting month 1 of the simulation period. Then the user selects values for agricultural and municipal group withdrawals, A_t and M_t, for the next 12 months ($t = 1, 2, \ldots, 12$). Next, the recharge values from the first year of historical data are selected for I_t. The next step is to calculate H_2, the predicted elevation in J17 for month 2, after which Equation 3.3 is used recursively for predicting H_t for the rest of the year, $t = 3, 4, \ldots, 12$.

This procedure predicts J17 elevations using only the first historic year's recharge data. The procedure is then repeated for all 65 years of data, each time using a different historic year's recharge to select values for I_t. The values for A_t, M_t, and the starting elevation do not change from one run to the next. Therefore, in this model, the withdrawals do not increase for dry years or decrease for wet years. A more accurate, yet more complex, model would automatically adjust the withdrawals for each month, say by a specific percentage, depending on the degree of recharge modeled for the simulation run. However the automatic adjustments are not exact and would not eliminate the error in predicting monthly withdrawals in advance; thus, the simpler model of using the same A_t and M_t values for all simulation runs is used in this analysis. Following this method, the elevation for each month in the simulation period is determined several times, once for each simulation run. The probability of the elevation for any selected month dropping to or below a trigger level can then be calculated. This approach is shown schematically in Figure 3.4; a simulation program was written to perform this procedure. The macro is included in Appendix B.

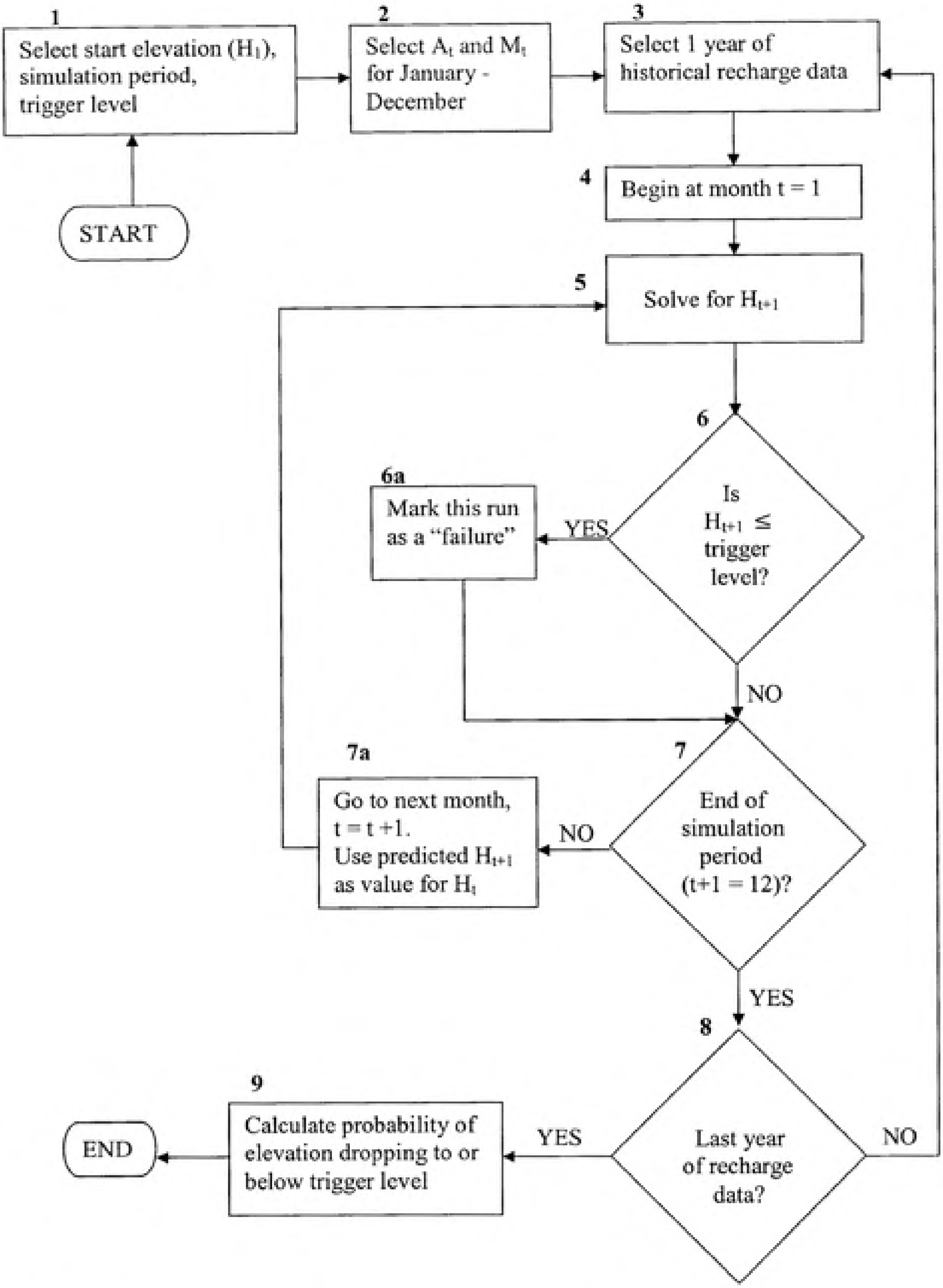

Fig. 3.4 Model for Predicting the Probability of Drawing J17 Elevation Below a Trigger Level

In box 1, the user specifies the starting month, inputs the start elevation H_1, the simulation period ($t = 1, \ldots, 12$), the average monthly withdrawal rates for municipal and agricultural groups, and selects a trigger level (650, 640 or 630 feet). In box 2, average monthly withdrawal rates are converted to specific monthly withdrawals using the monthly multipliers of Table 3.1. The first historic year's recharge data are selected in box 3. For the starting month (box 4), its recharge value I_1, starting elevation H_1, and withdrawals A_1 and M_1 are read into the model. Equation 3.3 is then used in box 5 to predict H_{t+1} for the next month. If the predicted elevation is equal to or lower than the selected trigger level (box 6), the simulation run is marked as a "failure" (box 6a), indicating that for the selected year of recharge data, the J17 level was drawn down to or below the trigger level.

If month t is not the last one of the simulation period (box 7), the next month is selected (box 7a) and the process is repeated in boxes 5 – 7 for each month (using the *predicted* H_{t+1} value for next month's H_t value) until the end of the simulation period is reached, which marks completion of one "simulation run". Once this occurs, the next historical year's recharge data are selected (box 3), and a new simulation run is repeated until all the recharge data have been used for making simulations (box 8). For each simulation run, the model predicts a new elevation for every month in the simulation period, H_2, H_3, H_4, … H_{12}. Each run represents one possible scenario that the Edwards Aquifer might face given the specified withdrawal rates, start elevation, and trace of recharge data. With 65 years of recharge data, 65 runs for a simulation period of one year can be made.

Once all the historic years of recharge data have been used to produce all the simulation runs, the probability of the J17 elevations dropping to or below the selected trigger level is calculated in box 9 as follows:

$$P = \text{Sum of runs recording a failure / Total number of runs} \tag{3.4}$$

Conversely, the probability of *not* drawing down the J17 level to the trigger level is

$$P' = 1 - P \tag{3.5}$$

For example, if 30 out of the total 65 runs recorded a failure, the probability is 46% (30/65) that the J17 level will drop below the trigger level sometime during the 12 months. The simulation model also enables estimation of the probability that J17 will drop to a trigger level *in a specific month*.

$$P_t = \text{Sum of runs recording a failure for month t / Total number of runs} \tag{3.6}$$

Knowing each run's predicted monthly elevations allows the user to study when the J17 level reaches the trigger level and how many months it takes for the J17 level to recover. This allows the user to calculate probabilities that describe the duration for which the J17 level is below the trigger. For a simulation period of 12 months, there are many combinations of months that could fail. Breaking down the year into all such possibilities, the J17 level may drop below a trigger level for any single month, any combination of 2 months (eg: January and February; January and August, etc.), any combination of 3 months (e.g.: January, February, and March; January, August and November, etc.), and so on for combinations of 4, 5, …, 11 months, or for all 12 months, or not for any month. Therefore, for a 12-month simulation period, there are 4,096 (2^{12}) different combinations of months that may fail. Moreover, for each month that fails, whether separately or in combination with other months, the elevation may drop to any one of three different trigger levels. This produces thousands more combinations that may fail, and the simulation model enables estimation of probabilities of failures for each of these mutually exclusive possibilities. The sum of all these probabilities equals P from Equation 3.4.

Since SAWS and other municipal, industrial and commercial users are cut back from their monthly allocations by a percentage if the J17 level reaches or drops below specific trigger levels (Table 2.4), the trigger levels used for the simulation model should be either 650, 640 or 630 feet. Then, the probabilities calculated by Equations 3.4 and 3.6 also indicate the probabilities that the corresponding cutback may occur. In the above example, if the trigger level was selected to be 650 feet, then the probability of these water-using sectors being cut back at least 5% of their monthly allocations sometime during the simulation period is 46%.

Current withdrawal rates and different start elevations and scenarios were investigated using the simulation model, which are discussed in the next chapter.

Chapter 4

How the Edwards Aquifer System Behaves

This chapter includes tables and charts of probabilities produced from different runs of the simulation model in Chapter 3. The results are analyzed to describe the mechanics of the Edwards Aquifer and to point out key considerations in using the model for policy decisions.

Predicting the Next Twelve Months with Average Withdrawal Rates

Table 4.1 shows the probability of the J17 level dropping to or below 650 feet any time during the next 12 months based on different start elevations in J17 at any month of the year. The predictions are based on the current average withdrawals of 24,135 AF/month by the municipal group and 13,360 AF/month by the agricultural group (see Table 3.2), totaling to 450,000 AF of yearly withdrawals from the aquifer. The higher the start elevation, the less likely the water level will reach the 650 feet. For example, if at the beginning of January the water elevation is 610 feet, there is a 100% probability that for the selected withdrawals, the J17 level will drop to or below 650 feet at least once during the next 12 months. However, if the start elevation in January is 660 feet, the probability of J17 reading an elevation of 650 feet or below in the next twelve months is only 63%, and with an elevation of 660 feet in April, the probability of reaching the trigger by the following March is 77%.

Table 4.1 Probability of J17 Elevation Dropping To or Below 650 Feet in Next 12 Months, Based on Average Withdrawal Rates

Starting Month	Start Elevation 610	620	630	640	650	660	670	680	690	700
January	100	100	100	98	72	63	37	25	2	0
February	100	100	98	97	77	69	41	22	0	0
March	100	100	100	97	83	73	44	8	0	0
April	100	100	100	100	86	77	41	0	0	0
May	100	100	100	100	91	77	22	0	0	0
June	100	100	98	97	91	58	0	0	0	0
July	100	100	100	100	94	0	0	0	0	0
August	100	100	100	100	92	27	17	5	2	0
September	100	100	100	98	58	42	33	31	25	22
October	100	100	100	95	58	45	31	25	22	9
November	100	100	100	98	61	48	31	25	17	2
December	100	100	98	97	70	56	34	25	8	0

Table 4.1 shows the probability that SAWS will be cut back in the next 12 months. Using the results from Table 4.1, Figure 4.1 shows the probability of not facing a cutback (P' from Equation 3.5). Consider a J17 elevation of 670 feet at the beginning of February: Figure 4.1 indicates that the chance is about 60% that the J17 level will stay above 650 feet for the next 12 months.

Tracing the chart horizontally, one can determine the elevation necessary for any starting month that is required to maintain a specific probability of not facing a cutback. For example, a J17 elevation of 670 feet in January has a probability of about 63% of not falling to 650 feet in the next 12 months. However, by February, the J17 elevation must exceed 670 feet for the probability to remain unchanged, and in March it must be even higher. However, by May, the J17 elevation can be well below 670 feet to have a 63% chance of not drawing the aquifer level down to 650 feet in the next 12 months.

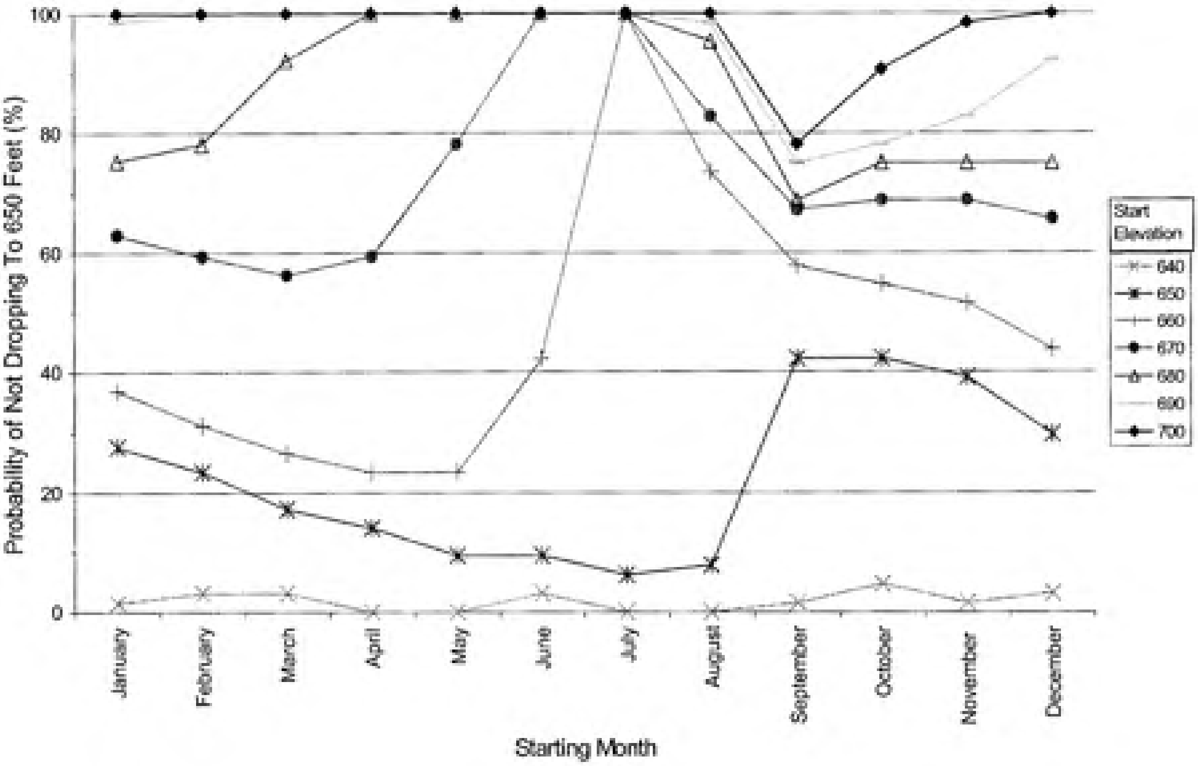

Fig. 4.1 Probability of J17 Level Not Dropping To or Below 650 Feet in Next 12 Months, Based on Average Monthly Withdrawals

As shown in Figure 4.1, there is no general pattern to the iso-elevation curves. For example, considering the curve for a starting elevation of 680 feet, the probability of not dropping to 650 feet increases from January through March, whereas the curve for a starting elevation of 670 feet decreases during the same period. This means that there is no general trend that describes how the Edwards Aquifer must behave from month to month in order to maintain a target reliability of avoiding cutbacks for the region. Consequently, this shows that if SAWS is interested in adopting policies centered around reliability levels, it must not create a policy that simply reacts to whether the water table is rising or falling, as this has different effects on the probability of facing a cutback depending on the elevation and month of year.

Figure 4.1 shows how short-term predictions might be affected by the choice of month in which the J17 elevation is used as a basis for deciding whether to obtain more water through the market. An error in reading (or inputting) the J17 level in different months affects the accuracy of the calculated probabilities by varying degrees. For example, if in June the J17 level was actually 650 feet but recorded as 660 feet, the model would estimate a 42% probability that SAWS will not face a cutback, whereas the more accurate value is around 9%. However, if the same error were repeated for the month of April instead of June, the user would calculate 23% probability of not facing a cutback instead of the more accurate 15%. The same error yielded a much more inaccurate prediction when the error occurred in June than when it occurred in April, indicating a greater sensitivity of the model predictions to the start elevation in June than in April. The sensitivity of the calculated probabilities to the elevations in different starting months is depicted in Figure 4.1. As shown, for J17 elevations of 650 - 680 feet, the calculated probabilities are most sensitive to the elevation readings between May and August, whereas September shows the least sensitivity. Thus, SAWS might choose to read the J17 level in September and run the simulation model then to minimize inaccuracies in the predictions due to errors in J17 readings.

Predicting the Next Twelve Months with Different Withdrawal Rates

Figures 4.2 and 4.3 compare the probabilities of the water table not dropping to or below 650 feet within 12 months, assuming low, average and high withdrawal rates. Table 4.2 shows the withdrawal rates for each category. The low and high withdrawal rates are a 5% decrease and a 5% increase in the average withdrawal rates respectively.

Table 4.2 Withdrawal Rates for the Municipal and Agricultural Groups

	Municipal Group (AF/month)	Agricultural Group (AF/month)	Total Annual Withdrawals (AF)
Low Withdrawals	22,928	12,692	427,440
Average Withdrawals	24,135	13,360	449,940
High Withdrawals	25,342	14,028	472,440

Figure 4.2 shows the results for when the simulation begins with an initial elevation of 660 feet, whereas Figure 4.3 shows the results for when the simulation begins with an initial elevation of 670 feet. As shown, increasing and decreasing the withdrawal rate by only 5% produces a considerable change in the probabilities of triggering cutbacks. The change is more significant at the higher start elevation shown in Figure 4.3 than in Figure 4.2. In Figure 4.2, the marginal change in the probabilities of not facing a cutback was between 10-40% for low and high withdrawal rates. Figure 4.3 shows a marginal change of about 30% in the probability of not facing a cutback for low and high withdrawals. Based on this level of sensitivity, conservation techniques in the Edwards Aquifer region can have a major impact in managing the short-term future of the aquifer. Conversely, there is little room left to increase overall water usage from the aquifer without significantly increasing the possibility of facing cutbacks.

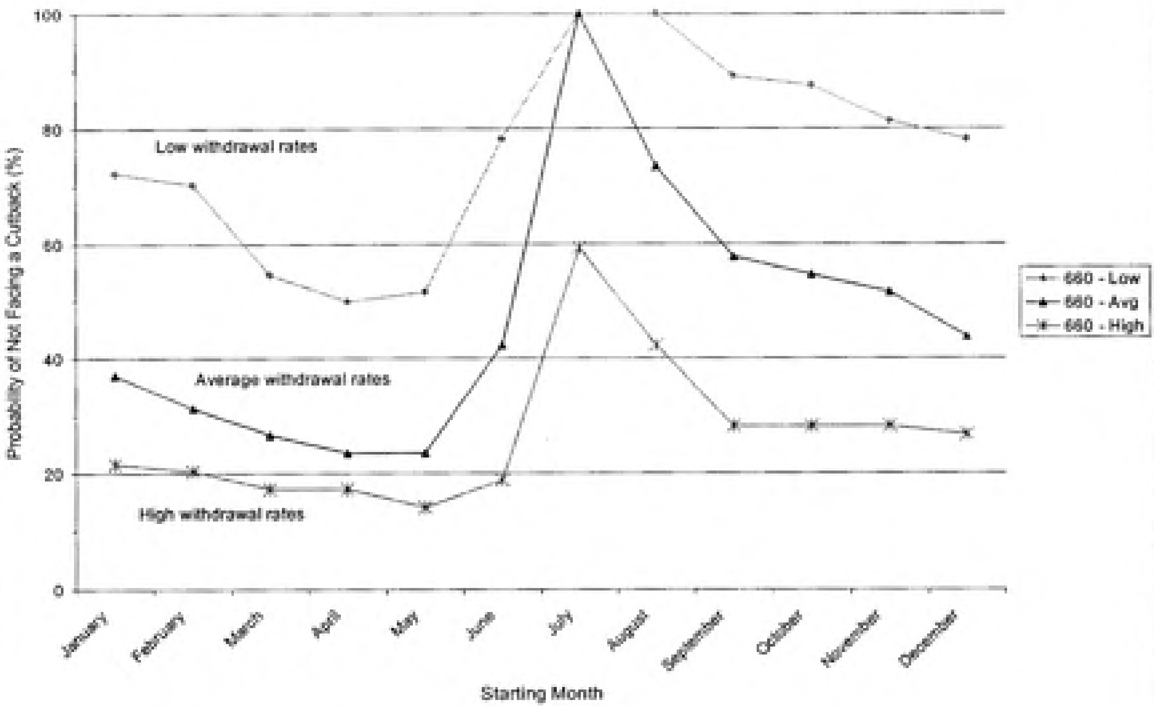

Fig. 4.2 Probability of J17 Level Not Dropping To or Below 650 Feet in the Next 12 Months, Based on a Start Elevation of 660 Feet and Various Withdrawal Rates

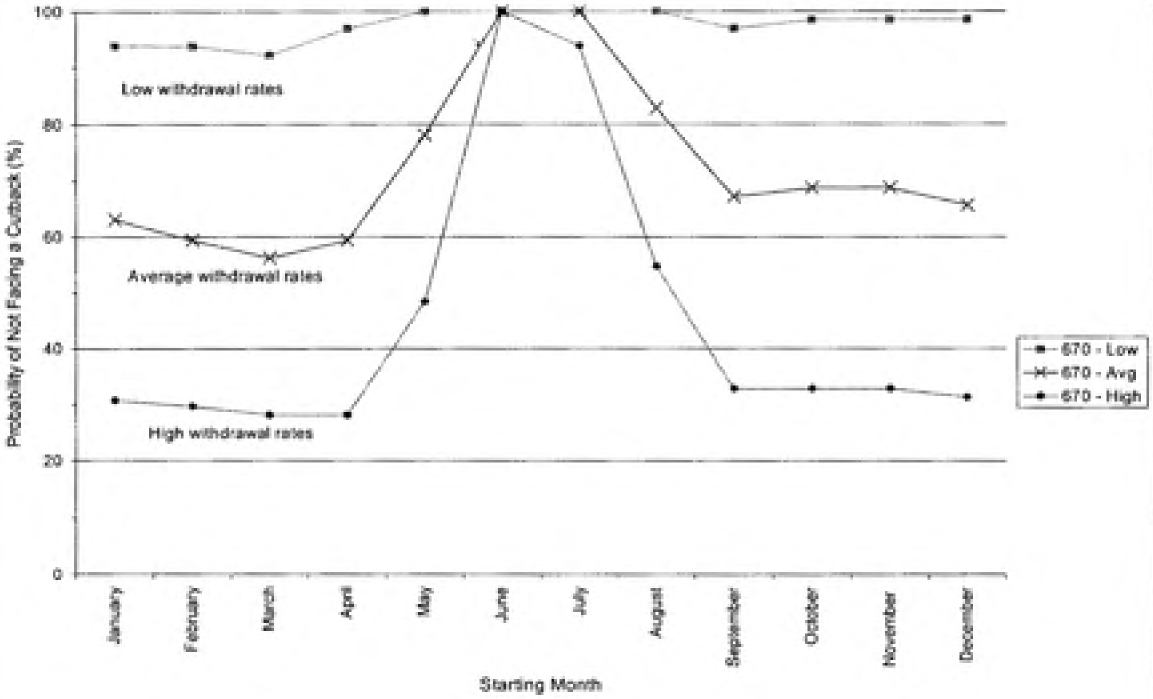

Fig. 4.3 Probability of J17 Level Not Dropping To or Below 650 Feet in the Next 12 Months, Based on a Start Elevation of 670 Feet and Various Withdrawal Rates

Predicting the J17 Levels for Different Simulation Periods

Figures 4.4 and 4.5 compare the probabilities of not triggering cutbacks within 12, 24, 36, 48, and 60 months, assuming average withdrawal rates. Figure 4.4 shows the results for when the simulation begins with a start elevation of 660 feet, and Figure 4.5 shows the results for a start elevation of 670 feet.

Figures 4.4 and 4.5 both show that as the simulation period increases, the probability of not facing a cutback decreases. The most significant reductions come from increasing the simulation period from 12 to 24 months. Figure 4.4 shows that, for a start elevation of 660 feet, the probability of not triggering a cutback drops by 10-55% for every month if a two-year simulation period is used instead of one-year. For Figure 4.5, the corresponding reduction in the probability is about 30-50%. For all months except July, the decrease in probabilities is more significant when the start elevation is 670 feet (Figure 4.5) than when it is 660 feet (Figure 4.4). As the simulation period is increased even further, the probability drops by only 3-10% for every 12 months added to the simulation period. Therefore, for short-term planning, SAWS must choose whether to plan for the next year only or for the next two years since the choice significantly affects the probability of facing a cutback. Planning for longer than 2 years should not be necessary since the probability values do not differ significantly from those for the 24-month simulation period.

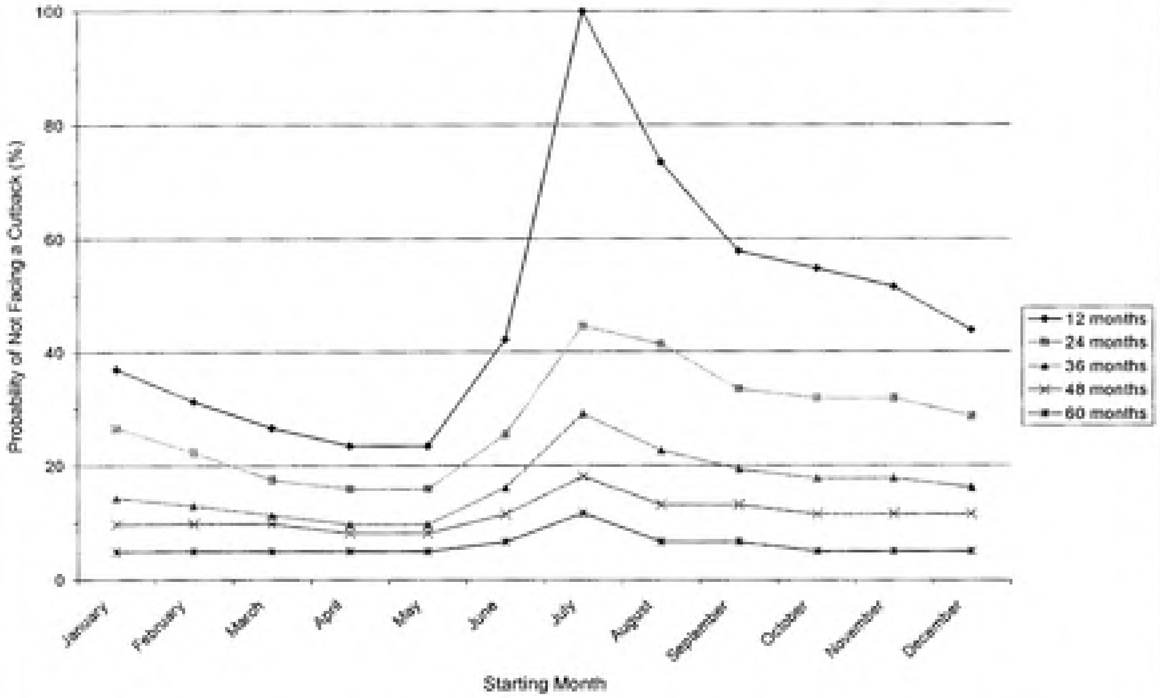

Fig. 4.4 Probability of J17 Level Not Dropping To or Below 650 Feet Within 12, 24, 36, 48 and 60 Months, Based on Average Withdrawal Rates and a Start Elevation of 660 Feet

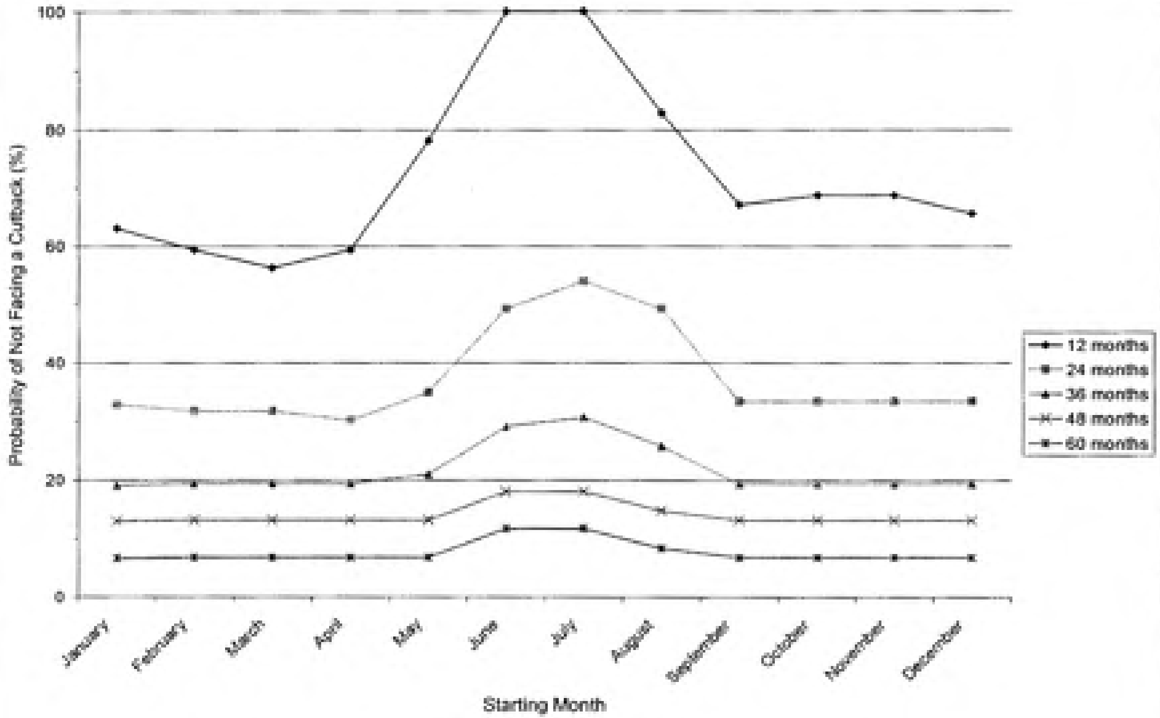

Fig. 4.5 Probabilility of J17 Level Not Dropping To or Below 650 Feet Within 12, 24, 36, 48 and 60 Months, Based on Average Withdrawal Rates and a Start Elevation of 670 Feet

The observations made from running the simulation model to investigate different scenarios provide valuable insights about how and when to use the simulation model to predict future elevations and calculate the probability of drawing the aquifer level below a trigger level. In the next chapter, these insights are used for designing a policy to plan for possible cutbacks.

Chapter 5

Cost Analysis

SAWS has different alternatives for dealing with the possibility of cutbacks, including: 1) buying, 2) leasing, 3) optioning water rights, or 4) doing nothing. Using the simulation model to predict the probability of cutbacks, an expected cost analysis was performed to compare the different alternatives. The total expected cost of an alternative is a combination of its pecuniary cost (e.g.: leasing) plus the non-pecuniary cost of not providing enough water for meeting customers' demands. The total expected cost of an alternative can therefore be calculated as:

$$E\,(\text{Alternative}) = (R * P_R) + \sum_i (P(Q_i) * Q_i * C_i) \qquad (5.1)$$

where E (Alternative) is the total expected cost of the alternative, R and P_R are the quantity and price of purchasing additional water rights, $P(Q_i)$ is the probability of a shortfall of quantity Q for month i, and C_i is the unit price of the shortfall for month i in meeting customer demand. The non-pecuniary cost of not meeting customer demand is summed over all months i in the simulation period.

Equation 5.1 shows that in order to calculate the expected cost of an alternative, the (pecuniary) prices of obtaining water rights by buying, leasing or option must first be determined, as well as the possible cutback amounts that may occur in the year and the probabilities of these cutbacks occurring, which can be determined using the simulation model. The amount of water rights to be obtained by SAWS can then be treated as a variable that is increased or decreased to minimize the total expected cost for SAWS given a specific scenario.

In effect, the amount of water rights leased or optioned by SAWS are reserved for when EAA mandates cutbacks so that SAWS can continue meeting customer demand without curtailing its production. For instance, assume SAWS leases or options an additional 1,000 AF of water rights for next year. If SAWS originally had 175,000 AF in permanent water rights, SAWS can then pump as much as 176,000 AF for the year. Through the year, SAWS pumps water according to its permanent water allocation, but in June, the water table drops below 650 feet and the EAA mandates a 5% cutback for the month of June, which amounts to 700 AF. In order to avoid a 700 AF shortfall, SAWS can claim that 700 AF of the 1,000 AF of water rights it has leased or optioned are allocated to the month of June, and the remaining 300 AF are reserved for the future. Thus, SAWS could continue to pump at its regular June production levels.

It is to SAWS' advantage to lease or option additional water rights as early as possible in the calendar year in order to reserve water through the rest of the year in case of cutbacks that may occur. Temporary water rights expire at the end of December. Also, the earlier contractual agreements are made between SAWS and the agricultural suppliers, the lower the price of water will be for SAWS. As described in Chapter 2, the price of water will rise as summer harvest months are approached. It is preferable for SAWS to plan for next year as early as the previous autumn. While it was noted in Chapter 4 that September might be an appropriate month to start the simulation model, December was chosen in this research for running the simulation model because water elevations in December yield more conservative predictions of next year's cutbacks: as shown in Figure 4.1, J17 elevations of 650 – 670 feet in December produce lower probabilities of not drawing the aquifer level down to trigger levels than September

The ability to update the simulation model's predictions annually allows SAWS to adopt a one-year planning horizon. The alternatives for a one-year planning period are: 1) leasing, 2) optioning, or 3) doing nothing. Buying water rights is ignored in this analysis since the benefits accrue over several years.

When the EAA initially issued pumping permits, the municipal sector got about 43,000 AF short of its average production (Durbin, 2002). In this research, it is assumed that SAWS and other users of the aquifer have purchased long term rights to cover this deficit and thus are capable of withdrawing at their average rates. That is, the short term analysis of this research is not affected by the long-term need SAWS had of covering its initial deficit.

For the analysis herein, average withdrawal rates were assumed for a one-year planning period. The simulation was run by inputting the J17 elevation at the beginning of December, and monthly predictions were made from January through December of the next year, noting when the elevation drops to the trigger levels of 650, 640 and 630 feet. If the water elevation drops to these levels in any month, the municipalities are cutback 5%, 10% and 15% respectively of their allocation for the month. For this analysis, different start elevations in December were used ranging from 610 feet to 700 feet.

The "Do Nothing" Alternative

Under this alternative, SAWS is assumed to be willing to risk cutbacks without obtaining temporary water rights. There are no pecuniary costs of obtaining water rights, but there are (expected) non-pecuniary costs.

Using the simulation model starting with different water elevations in December and predicting the elevations for January through December, the probability of facing a cutback in each month was estimated by Equation 3.6. By repeating the simulation using the different trigger levels, these probabilities were disaggregated into the probability of facing a 5%, 10% or 15% cutback in each month. Table 5.1 shows these probabilities, as well as the aggregated probability of cutbacks (in the shaded area). The aggregated probabilities differ by ± 1% from the reported values in Table 5.1 due to rounding errors.

For example, Table 5.1 shows that if the water level in December is 630 feet, there is a 20% probability that SAWS will be cut back 5% of its allocation in January, and a 58% probability that its allocation in October will be cut back by 5%. The different cutback levels and their associated probabilities are mutually exclusive. For example, the 72% probability of facing a 5% cutback in September if the aquifer elevation is 610 feet in December is completely independent of the 14% chance of a 10% cutback in September. Therefore, the values in Table 5.1 should be read as "if the December elevation is 610 feet, the probability is 72% that SAWS will be cut back 5% of its allocation in September, 14% that it will be cut back 10% in September, and 0% that it will be cut back 15%." Overall, there is a 72 + 14 + 0 = 86% chance that SAWS' allocation will be cut back in September by some amount, which is shown in the shaded bottom panel of Table 5.1 labeled "any".

Table 5.1 Probability of Facing Cutbacks for Each Month of the Year Given the Water Elevation in December

		Probability of Facing a Cutback of Specified Magnitude During the Month of ...											
% Cutback level	J17 level in December	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5%	700	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5%	690	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%
5%	680	0%	0%	0%	0%	0%	0%	0%	0%	25%	2%	0%	0%
5%	670	0%	0%	0%	0%	0%	0%	0%	6%	34%	16%	0%	0%
5%	660	0%	0%	0%	0%	0%	0%	0%	28%	53%	23%	0%	0%
5%	650	0%	0%	0%	0%	0%	0%	5%	45%	66%	38%	0%	0%
5%	640	97%	0%	0%	0%	0%	0%	31%	66%	69%	48%	2%	0%
5%	630	20%	97%	23%	0%	0%	23%	48%	73%	75%	58%	14%	0%
5%	620	2%	27%	92%	47%	33%	52%	70%	78%	80%	67%	19%	0%
5%	610	2%	2%	69%	88%	73%	78%	80%	77%	72%	72%	25%	0%
10%	700	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	690	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	680	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	670	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	660	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	650	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	640	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	630	78%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10%	620	98%	72%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%
10%	610	2%	97%	30%	0%	0%	0%	0%	5%	14%	0%	0%	0%
15%	700	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	690	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	680	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	670	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	660	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	650	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	640	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	630	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	620	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15%	610	97%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Any	700	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Any	690	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%
Any	680	0%	0%	0%	0%	0%	0%	0%	0%	25%	2%	0%	0%
Any	670	0%	0%	0%	0%	0%	0%	0%	6%	34%	16%	0%	0%
Any	660	0%	0%	0%	0%	0%	0%	0%	28%	53%	23%	0%	0%
Any	650	0%	0%	0%	0%	0%	0%	5%	45%	66%	38%	0%	0%
Any	640	97%	0%	0%	0%	0%	0%	31%	66%	69%	48%	2%	0%
Any	630	98%	97%	23%	0%	0%	23%	48%	73%	75%	58%	14%	0%
Any	620	100%	98%	92%	47%	33%	52%	70%	78%	81%	67%	19%	0%
Any	610	100%	98%	98%	88%	73%	78%	80%	81%	86%	72%	25%	0%

Knowing SAWS' monthly withdrawal rates, the 5%, 10% and 15% cutbacks can be expressed as quantities, which are shown in Table 5.2.

Table 5.2 Estimated SAWS' Monthly Withdrawals and Cutback Quantities (in AF)

SAWS withdrawals & cutbacks (AF)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Average Withdrawal	12119	11243	13141	14017	14747	16061	19419	19565	15623	14601	12411	12411	**175357**
5% Cutback	606	562	657	701	737	803	971	978	781	730	621	621	**8768**
10% Cutback	1212	1124	1314	1402	1475	1606	1942	1957	1562	1460	1241	1241	**17536**
15% Cutback	1818	1686	1971	2103	2212	2409	2913	2935	2343	2190	1862	1862	**26304**

With the information from Tables 5.1 and 5.2, Equation 5.1 can be modified for the alternative of doing nothing as follows:

$$\text{E (Do Nothing)} = \sum_i \sum_j (P_{ij}) * (Q_{ij}) * C \qquad (5.2)$$

where P_{ij} is the probability of facing a cutback of magnitude j (5%, 10% or 15%) in month i from Table 5.1, Q_{ij} is the corresponding cutback quantity from Table 5.2, and C is the price of the shortfall in $/AF, which is assumed to be constant for all months.

It is difficult to assess the unit value of water that cannot be supplied to meet demand. Assuming SAWS is risk averse, the unit cost C of a shortfall would be much greater than the price of leasing or optioning water, which can be up to as much as $100/AF. Furthermore, a study by McCarl (1997) claimed that "[o]ften … water in urban usages, in terms of tap prices, is valued somewhere in the neighborhood of $500 per acre foot." Thus, a shortfall value of $500/AF for C is assumed, and for simplicity, the shortfall price is treated as a constant. Using a constant price for C assumes that the marginal cost of shortfalls is constant, whereas in reality the marginal cost may increase as the shortfall increases.

Summing each month's expected costs of cutbacks, the total expected cost for SAWS for a one year simulation period is shown in Table 5.3 and Figure 5.1, which ranges from $0 to over $ 4 million. The expected costs are proportional to C; thus, halving its value to $250/AF would produce expected costs ranging from $0 to over $ 2 million. As the results indicate in Table 5.3, even with a high start elevation of 690 feet, there are expected costs of tens of thousands of dollars due to possible cutbacks.

Table 5.3 The Total Expected Cost of the "Do Nothing" Alternative for SAWS

J17 Elevation in December (feet)	Total Expected Cost for Next Year
700	$ 0
690	$ 30,513
680	$ 103,347
670	$ 221,866
660	$ 430,614
650	$ 637,594
640	$ 1,216,385
630	$ 2,120,275
620	$ 3,225,384
610	$ 4,293,363

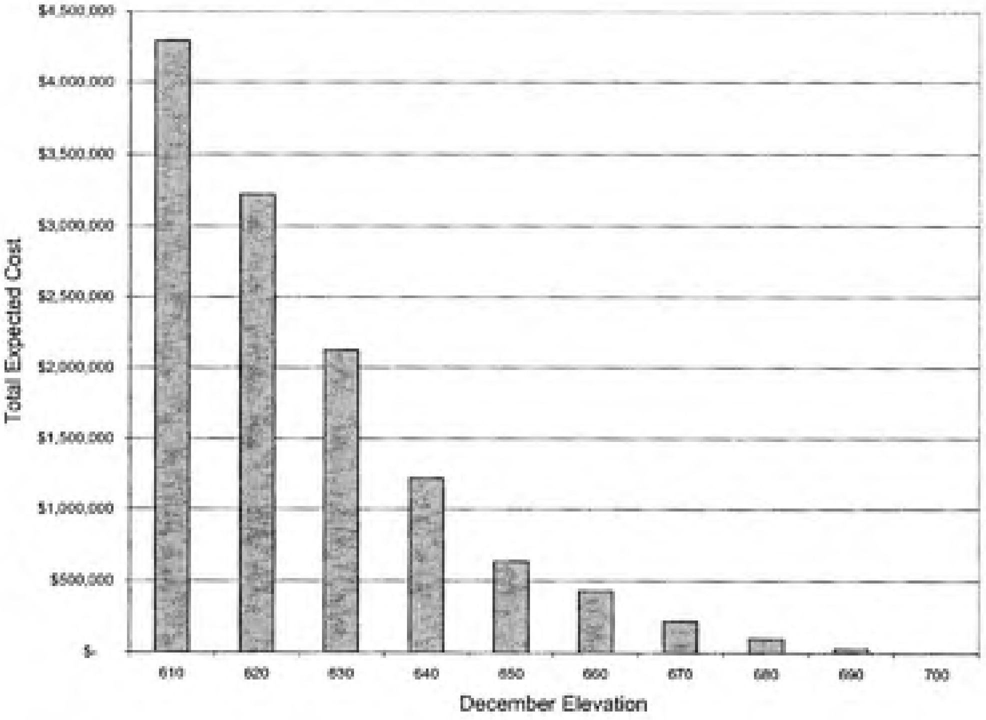

Fig. 5.1 The Total Expected Cost of the "Do Nothing" Alternative for SAWS

The Lease Alternative

When SAWS leases water, it can lease a small quantity and risk cutbacks that cannot be completely covered, or it can lease a large quantity, pay more, but lower the risk of a shortfall. Depending on the elevation in December, one choice might produce a lower total expected cost than the other.

Using the simulation model to predict monthly elevations, all the combinations of possible cutbacks were identified for each December elevation. The probability of facing each of these "total" cutbacks for the year was also calculated. Thus, knowing the elevation in December, the probability of facing cutbacks totaling a specific amount for the year was read into a lookup table (see Appendix C-2). The "total" cutback quantities and their related probabilities are mutually exclusive. For example, for the December elevation of 680 feet, there is a 2% probability of a cutback of 1,511 AF in the next year, 23% chance of a 781 AF cutback, and 75% chance of no cutback. These are the only possible scenarios of cutbacks for next year, hence the probabilities sum to 100%.

Using this information, Equation 5.1 for the lease alternative is:

$$E(\text{Lease}) = (L * P_L) + \sum_x P(Q_x) * S * C \tag{5.3}$$

where

$$S = \begin{cases} Q_x - L, & Q_x > L \\ 0, & Q_x \leq L \end{cases} \tag{5.4}$$

where L is the quantity of water leased for the year in AF, P_L is the price of leasing water in \$/AF, $P(Q_x)$ is the probability of facing a cutback of quantity Q_x, C is the non-pecuniary price of shortfalls in \$/AF, and $Q_x - L$ is the shortfall that occurs when the cutback quantity exceeds the lease quantity ($Q_x > L$). The term S cannot be negative since the expected cost to SAWS does not decrease is there is a surplus of leased water, i.e.: if $L > Q_x$. Therefore S (shortfalls) takes on a value of zero when $L \geq Q_x$. The values of Q_x and their corresponding probabilities $P(Q_x)$ are shown in Appendix C-2.

Assuming that SAWS leases water in January, it will negotiate a lease price with the farmers in January or the previous December. While the actual lease price is not known, Durbin (2002) calculated that the lease price (following slightly different lease contract rules) early in the agricultural cycle year would be around \$50/AF. The assumed shortfall cost is \$500/AF. By setting a value for L, thus indicating the quantity of water to be leased for the year, the total expected cost could be calculated for the given December elevation. The optimum lease quantity L^* can thus be solved for by minimizing the total expected cost for SAWS using Solver, an optimization program. As a result, the *minimum* total expected cost for SAWS for the year is calculated for each December elevation, and the optimum lease quantity is determined. The results are shown in Table 5.4.

Table 5.4 SAWS' Minimum Total Expected Cost of Leasing and the Optimal Lease Quantity by J17 Elevation in December

J17 Elevation in December (feet)	Optimum Lease Quantity, L^* (AF)	Probability of Cutbacks Exceeding L^*	Lease Contract Pecuniary Cost	Non-pecuniary Cost of Additional Shortfalls	Minimum Total Expected Cost for Next Year
700	**0**	0 %	$ 0	$ 0	**$ 0**
690	**0**	8 %	$ 0	$ 30,514	**$ 30,514**
680	**781**	2 %	$ 39,058	$ 5,703	**$ 44,761**
670	**1,511**	6 %	$ 75,560	$ 19,164	**$ 94,724**
660	**2,489**	0 %	$ 124,473	$ 0	**$ 124,473**
650	**2,489**	5 %	$ 124,473	$ 22,757	**$ 147,230**
640	**4,066**	2 %	$ 203,318	$ 4,848	**$ 208,166**
630	**6,694**	9 %	$ 334,727	$ 29,088	**$ 363,815**
620	**9,315**	2 %	$ 465,770	$ 6,103	**$ 471,873**
610	**10,739**	8 %	$ 536,950	$ 47,168	**$ 584,118**

Table 5.4 shows that in the worst-case scenario with a December elevation of 610 feet, SAWS will have to lease about 10,739 AF, which is equivalent to 6% of its current allocation[1]. In most cases, the lowest total expected cost is achieved by leasing a quantity less than the maximum possible cutback quantity for the year, thus running the small risk of facing cutbacks that exceed the optimum lease quantity. This risk ranges from 0% to 9% as shown in Table 5.4.

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[1] From the simulations, it was found that SAWS might be cut back by a maximum of 12,337 AF from its allocations in one year, assuming an annual allocation of 175,200 AF.

By changing the lease quantity L in Equation 5.3, the second-lowest total expected cost and the corresponding lease quantity were determined for different December elevations. Table 5.5 shows the second-best lease quantities and total expected costs. Figure 5.2 shows the comparison between the second-best solutions with the optimal solutions shown in Table 5.4.

Table 5.5 The Second-Best Lease Quantities and Total Expected Costs

J17 Elevation in December (feet)	Second-Best Total Expected Cost	Marginal Increase in Minimum Total Expected Cost	Second-Best Lease Quantity (AF)	Marginal Difference in Lease Quantity (AF)
700	N/A	N/A	N/A	N/A
690	$ 39,058	+ $ 8,544	781	+ 781
680	$ 75,560	+ $ 30,799	1,511	+ 703
670	$ 99,378	+ $ 4,654	1,759	+ 248
660	$ 156,413	+ $ 31,940	1,759	- 730
650	$ 173,021	+ $ 25,791	3,460	+ 971
640	$ 234,345	+ $ 26,179	4,687	+ 621
630	$ 365,412	+ $ 1,597	6,658	- 36
620	$ 494,174	+ $ 22,301	8,694	- 621
610	$ 584,574	+ $ 456	10,701	- 36

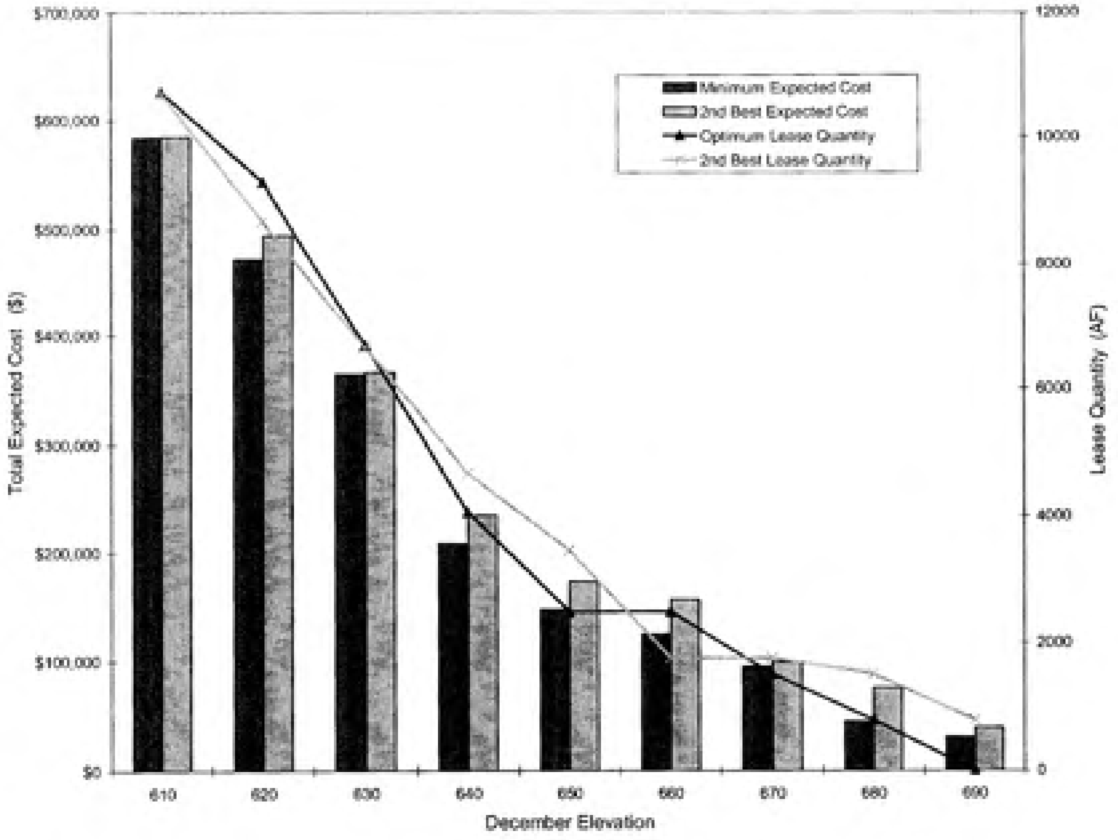

Fig. 5.2 The Optimum and Second-Best Lease Quantities and Total Expected Costs

Table 5.5 and Figure 5.2 show that for some start elevations, the difference between the optimum and second-best solution is large, while for the others it is small. The marginal increase in expected cost ranged from a few hundred dollars to over $30,000; some second-best solutions require leasing more water rights than the optimum. These findings imply that SAWS should perform the expected cost analysis and seek out the optimum and second-best solutions before presuming it does or does not have flexibility in the lease quantity they should target for the year, as the flexibility depends on the December elevation.

The Options Alternative

As with the lease alternative, SAWS can either option a large or a small quantity of water, balancing purchase costs against expected costs of shortfalls. Optimization is used to identify the optimum exercise month, optimum quantity of water to option and the minimum total expected cost.

The option exercise date can be set much later than the date when the contract is signed. For example, SAWS might contract with farmers in January, but the exercise date could be July, which means that SAWS could not use any of the option quantity before July (any cutbacks that occur between January and July could not be met through the options contract). The options alternative must therefore identify the best exercise month as well as the optimum quantity to option.

The simulation model is used to: predict monthly elevations for next year, identify all possible cutbacks quantities that can occur in the year and the probability of each. Assuming that SAWS contracts in January, the exercise month can be any month of the year. If January is the exercise month, then SAWS can presumably option enough water to counter all cutbacks throughout the year, whereas if February is the exercise month, SAWS can only counter all the cutbacks that occur after February. The simulation model was used to identify all the different cutbacks that might occur from every possible exercise month through December, with their corresponding probabilities. Knowing the elevation in December, the probability of facing cutbacks totaling a specific quantity *from a specific month through the remainder of the year* were read into a lookup table, a sample of which is shown in Appendix C-3.

Using this information, Equation 5.1 for the options alternative is:

$$E\,(\text{Options})_y = (O * C_O) + \sum_{i=1}^{y-1} \sum_j (P_{ij}) * (Q_{ij}) * C + Z \tag{5.5}$$

where

$$Z = \begin{cases} \sum_x P(Q_x)_y * Q_x * C_E \;, & Q_x \leq O \\ \sum_x [P(Q_x)_y * O * C_E + P(Q_x)_y * (Q_x - O) * C] \;, & Q_x > O \end{cases} \tag{5.6}$$

where I denoted the months, j denoted the 5%, 10% and 15% cutback levels, y is the exercise month, E (Options)$_y$ is the total expected cost for options with exercise month y, O is the quantity of water purchased in options contracts in AF, C_O is the price of options contracts in \$/AF, C_E is the exercise price in \$/AF, C is the cost of shortfalls in \$/AF, $P(Q_x)_y$ is the probability of facing cutbacks totaling to quantity Q_x from exercise month y through the remainder of the year, and where Q_x is measured in AF.

The $\sum_{i=1}^{y-1} \sum_j (P_{i,j}) * (Q_{i,j}) * C$ term is similar to the "do nothing" expected cost in Equation 5.2, summing the expected non-pecuniary costs of all cutbacks that may occur from January (i=1) through the month prior to the exercise month (y-1), for all cutback levels j.

When the option quantity exceeds the cutbacks that may occur on or after the exercise month ($Q_x \leq O$), Equation 5.6 calculates the expected pecuniary cost of exercising the option using the quantity Q_x and the probability of the total cutback $P(Q_x)_y$

occurring. No shortfalls occur, thus no non-pecuniary costs associated with shortfalls are included. However, when the possible cutbacks exceed the optioned quantity of water ($Q_x > O$), the expected cost of the surplus shortfall $Q_x - O$ is calculated as well as the expected cost of exercising the option using the quantity O (i.e.: exercising the maximum amount of the option quantity) in Equation 5.6.

Using different options contract rules, Durbin (2002) calculated the price of an options contract C_O to be around \$20/AF. The actual price may vary from this value due to the different characteristics of options contracts; however, relative to the other market prices, \$20/AF is also a good estimate for C_O for options contracts described in this report. Since the contract is signed in January, the exercise price C_E is assumed to be the same as the lease price C_L set in January, since the outlook for the farmers supplying the water rights does not change whether they lease or option their water. Thus, the exercise price C_E is assumed to be \$50/AF. As the exercise price is agreed on at the time the options contract is signed, the price is constant throughout the year, regardless of the exercise date.

For each December elevation, an option quantity O is chosen and the total expected cost for SAWS is calculated from Equation 5.5 twelve times, once for each possible exercise month. The lowest of these twelve total expected costs indicates the lowest expected cost for SAWS for that December elevation and option quantity O. Using Solver, the total expected cost is minimized by changing the option quantity O and exercise month y to identify the optimum quantity of water to option O^* and the optimum exercise month y^*.

Optimizing for all December elevations, Table 5.6 and Figure 5.3 show the minimum total expected costs for SAWS and the optimum exercise month and optimum option quantity for each elevation in December. Table 5.6 shows that the optimum option quantities range from 0 through 12,337 AF, which is the expected maximum cutback SAWS could face in a year. If the elevation in December is below 650 feet, the exercise month should be set for January. However, for higher elevations, the exercise month can be any month between January and the end of the summer, as shown in Table 5.6, without increasing the total expected cost for SAWS. This implies that SAWS has the advantage of being able to delay the exercise month if it helps in negotiating options contracts with the farmers. By setting January as the exercise month, an option acts almost identical to a lease, yet with an additional option contract cost (C_O times the option quantity). However, since SAWS does not necessarily have to pay for the full option quantity, SAWS might have lower total expected cost for an option contract with a January exercise month than for a lease contract, even with the additional option contract cost. In fact, this advantage may also allow SAWS to option a greater quantity than the optimum lease quantity and still have lower total expected cost using an options contract.

Table 5.6 SAWS' Minimum Total Expected Cost of Optioning Water and the Optimal Option Quantity and Exercise Month(s) by December Elevation

J17 Elevation in Dec. (feet)	Optimum Option Quantity, O^* (AF)	Optimal Exercise Month(s), y^*	Options Contract and Expected Exercise Pecuniary Costs	Non-pecuniary Costs of Additional Shortfalls	Minimum Total Expected Cost for Next Year
700	**0**	None	$ 0	$ 0	**$ 0**
690	**781**	January – September	$ 18,674	$ 0	**$ 18,674**
680	**781**	January – September	$ 24,777	$ 6,314	**$ 31,091**
670	**1,759**	January – August	$ 53,485	$ 14,156	**$ 67,641**
660	**2,489**	January – August	$ 92,851	$ 0	**$ 92,851**
650	**3,460**	January – July	$ 132,968	$ 0	**$ 132,968**
640	**4,066**	January	$ 199,304	$ 8,025	**$ 207,329**
630	**7,315**	January	$ 358,329	$ 0	**$ 358,329**
620	**9,315**	January	$ 500,959	$ 13,380	**$ 514,339**
610	**12,337**	January	$ 676,092	$ 0	**$ 676,092**

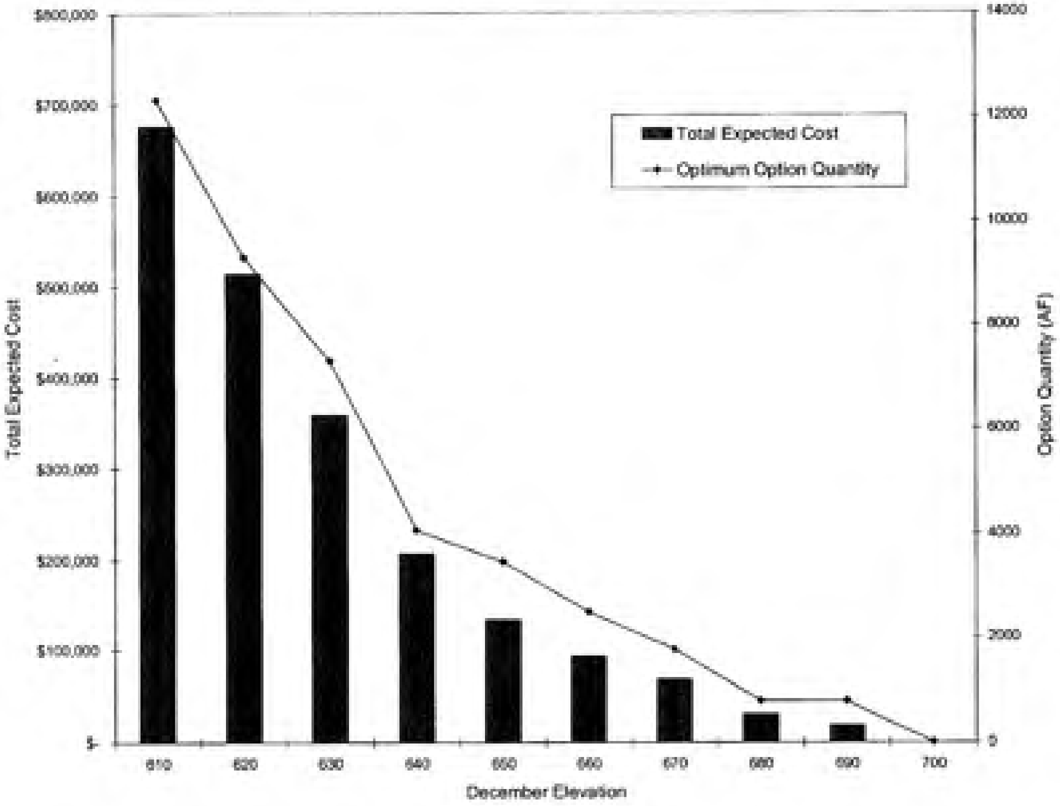

Fig. 5.3 Minimum Total Expected Cost of Optioning Water and Optimum Quantity

Comparing the Three Alternatives

With the analysis of the three alternatives for obtaining temporary water rights, SAWS can compare them to decide which one is best; the results are in Table 5.7 and Figure 5.4.

Table 5.7 Comparison of Alternatives

		Do Nothing	Lease		Options		
J17 Elevation in Dec. (feet)		Total Expected Cost	Minimum Expected Cost	Optimum Lease Quantity (AF)	Minimum Expected Cost	Optimum Option Quantity (AF)	Best Alternative
700	Pec Non-Pec	$0 $0 $ -	$0 $0 $ -	0	$0 $0 $ -	0	Do Nothing
690	Pec Non-Pec	$0 $30,514 $ 30,514	$0 $30,514 $ 30,514	0	$18,674 $0 **$ 18,674**	781	Options
680	Pec Non-Pec	$0 $103,347 $ 103,347	$39,058 $5,703 $ 44,761	781	$24,777 $6,314 **$ 31,091**	781	Options
670	Pec Non-Pec	$0 $221,866 $ 221,866	$75,560 $19,164 $ 94,724	1511	$53,485 $14,156 **$ 67,641**	1759	Options
660	Pec Non-Pec	$0 $430,614 $ 430,614	$124,473 $0 $ 124,473	2489	$92,851 $0 **$ 92,851**	2489	Options
650	Pec Non-Pec	$0 $637,594 $ 637,594	$124,473 $22,757 $ 147,230	2489	$132,968 $0 **$ 132,968**	3460	Options
640	Pec Non-Pec	$0 $1,216,385 $ 1,216,385	$203,318 $4,848 **$ 208,166**	4066	$199,304 $8,025 **$ 207,329**	4066	Options or Lease
630	Pec Non-Pec	$0 $2,120,275 $ 2,120,275	$334,727 $29,088 **$ 363,815**	6695	$358,329 $0 **$ 358,329**	7315	Options or Lease
620	Pec Non-Pec	$0 $3,225,384 $ 3,225,384	$465,770 $6,103 **$ 471,873**	9315	$500,959 $13,380 $ 514,339	9315	Lease
610	Pec Non-Pec	$0 $4,293,363 $ 4,293,363	$536,950 $47,168 **$ 584,118**	10739	$676,092 $0 $ 676,092	12338	Lease

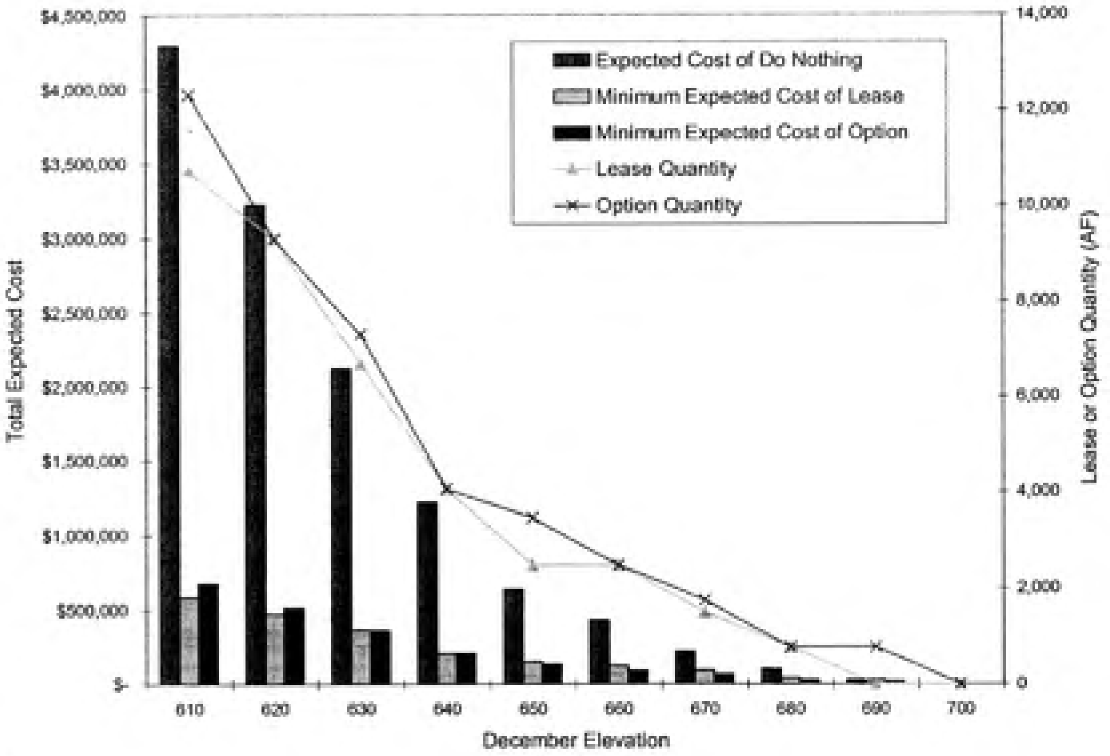

Fig 5.4 Comparison of Alternatives

Figure 5.4 shows that the total expected cost to SAWS of doing nothing can be greatly reduced by either leasing or optioning water whenever the December elevation is below 700 feet. Table 5.7 shows that in minimizing total expected cost, SAWS should option water if in December the water elevation is between 650 – 690 feet, and lease water if the elevation is 620 feet or lower. Between December elevations of 630 and 640 feet, the total expected costs of leasing and optioning water are about the same. Note that the pecuniary costs of leasing water when the December elevation is 630 feet is about $24,000 lower than the pecuniary costs of optioning water, hence SAWS might choose to lease water if the J17 elevation in December reaches 630 feet. Figure 5.4 shows that the optimum option and lease quantities are very similar, but optimum option quantities are usually slightly higher than optimum lease quantities (by up to about 1,600 AF).

Table 5.7 shows that the (expected) pecuniary costs of options are sometimes smaller than the pecuniary costs of leases, even though the optimal option quantity is greater than the lease quantity. For example, for a December elevation of 670 feet, the expected pecuniary cost of optioning is $53,485 for an option quantity of 1,759 AF. At the same elevation, the pecuniary cost of leasing is $75,560 for a lease quantity of 1,511 AF. This is because the probability of facing large cutbacks is very small, thus the probability of exercising the entire option quantity is small, whereas for leasing, SAWS must pay for the entire lease quantity regardless of the probability of exercising it.

This analysis and Table 5.7 show that the total expected cost to SAWS ranges from $ 0 to $ 584,118 based on the assumed prices. The next section includes an analysis to test the sensitivity of optimal results to different prices.

Sensitivity Analysis

The price of shortfalls was assumed to be $500/AF, but this value depends on SAWS' aversion to risk of a shortfall. The analysis was repeated using shortfall prices of $100/AF - $700/AF, holding all else unchanged. Figure 5.5 shows the minimum expected cost alternative for each value of shortfall price.

As shown in Figure 5.5, as the price of shortfalls increases, options become the optimal policy for more scenarios. As the shortfall price increases, the expected cost of the large cutback amounts increase. Optioning becomes the lowest expected cost alternative by providing SAWS with an opportunity to option large quantities and not pay for them unless the small probabilities of facing these large cutbacks occur.

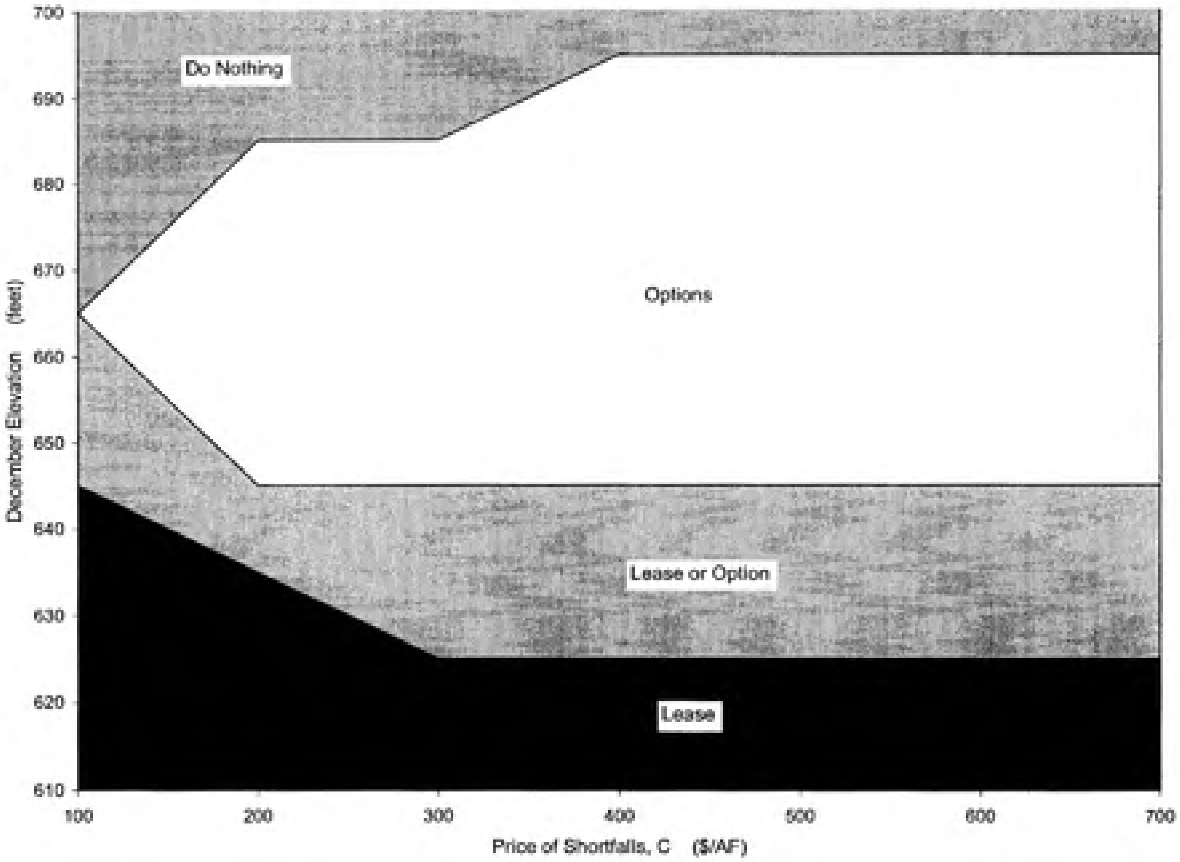

Fig. 5.5 Best Alternative for Different Shortfall Prices

Figure 5.5 also shows that the results of the policy analysis do not change significantly if the price of shortfalls is $300/AF or more. However, if SAWS does not place a high value on supplying its customers with sufficient water to meet their demands (i.e.: less than $300/AF), then the policy will depend on how SAWS values shortfalls. Assuming that SAWS is averse to the risk of a shortfall, a shortfall price of $500/AF is suitable for the policy analysis.

Using a shortfall price (C) of \$500/AF and an options contract price (C_O) of \$20/AF, the sensitivity of the optimal policies to the lease price and options exercise price is examined. Assuming that SAWS signs lease and options contracts in January, the lease price C_L and options exercise price C_E are set to equal each other. The prices ranged from \$10/AF to \$100/AF in the sensitivity analysis to cover the economically efficient range of lease and options exercise prices (Durbin 2002). Figure 5.6 shows the minimum expected cost alternative for each lease and options exercise price.

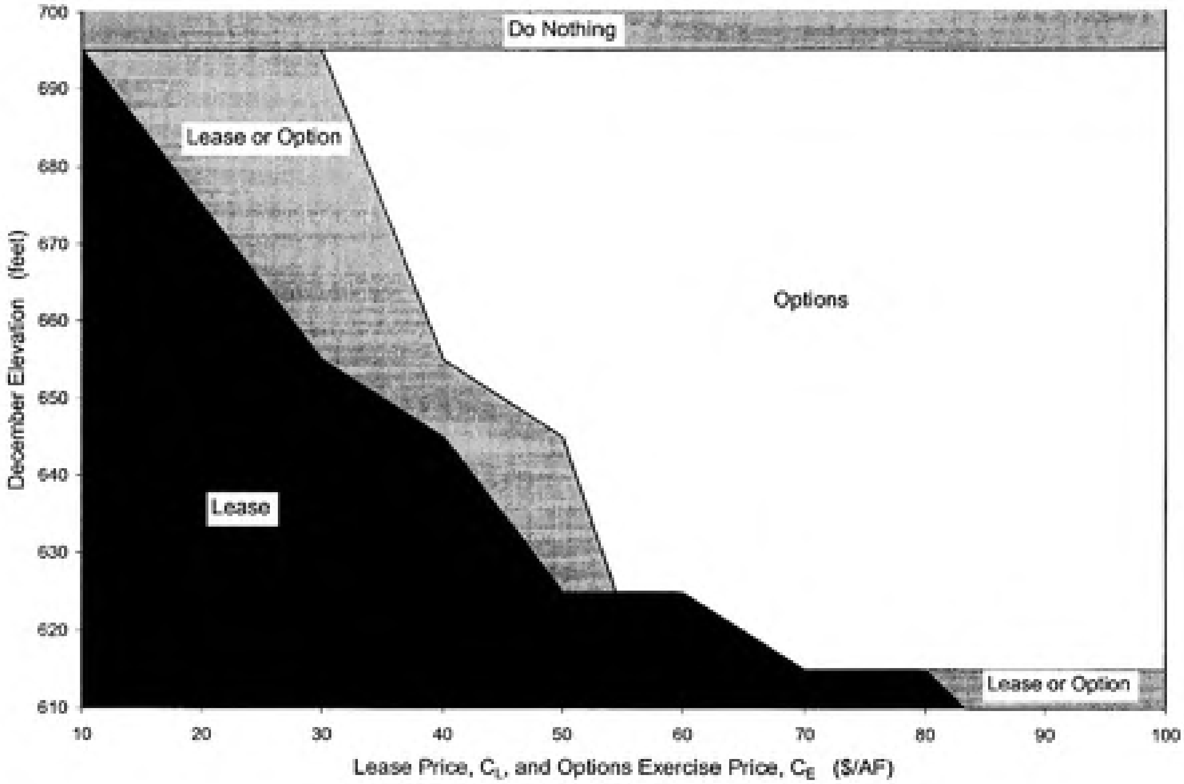

Fig. 5.6 Best Alternative for Different Lease and Options Exercise Prices

Figure 5.6 shows that as the prices increase, options become more (and lease contracts become less) attractive to SAWS, and when the prices exceed $80/AF, leasing becomes a poor alternative for SAWS regardless of the elevation in December. This is because SAWS only pays for the exercised quantity in options and not the full quantity, as is the case with leasing. Conversely, at very low prices, leasing water is superior to optioning it, which is due to the lack of a fixed fee on lease contracts. Figure 5.6 shows that the policy recommendations are sensitive to the lease and options exercise prices. However, substituting real prices from the water market would produce accurate results. The $50/AF price value for C_L and C_E used in this analysis provides a mid-range perspective on the water market alternatives.

Chapter 6

Summary and Conclusions

The goal of this project is to provide SAWS with guidance for setting policy on the appropriate course of action to cover forced cutbacks in their withdrawals from the Edwards Aquifer in the short term. More generally, this project aims to outline a procedure for analyzing different alternatives for obtaining temporary water rights from a market to cover cutbacks that may result from drawing the aquifer down to specific trigger levels. This study analyzes the total expected cost of each alternative, and following a policy of minimizing total expected costs, it identifies the alternative and the amount of water rights that SAWS must secure for the next year.

A simulation model is developed in this report to predict the water elevations at the J17 well for the next several months using historical recharge data and an initial J17 well reading to predict when the aquifer level might drop below a trigger level and the probability of this happening. December is chosen as the month in which the simulation is run in order to predict the next year's aquifer levels as accurately as possible. The predictions from the simulation model are used to calculate the different quantities that SAWS could be cut back in the next year, the probability of each of these cutbacks occurring, and the expected cost of the shortfalls.

Using the water market annually to obtain temporary water rights to counter possible cutbacks, SAWS can 1) do nothing, 2) lease or 3) option water rights from suppliers in the market. Optimization is used in this analysis to minimize the total expected costs of leasing and optioning water and determining the optimum lease and option quantities for the different elevations in December, as well as the optimum exercise month for options contracts. The results show that the optimum options exercise month is always January, but for water elevations in December greater than 650 feet, the options exercise date could be anytime until the end of the summer (July, August or September depending on elevation) without affecting total expected cost.

A comparison of alternatives 1, 2 and 3 shows that SAWS can significantly lower the expected cost of doing nothing by leasing or optioning water if the aquifer level in December is lower than 700 feet. For a lease and options exercise price of $50/AF and an assumed (non-pecuniary) price of shortfalls of $500/AF, SAWS can minimize its total expected costs by optioning water when the aquifer level is between 650 – 690 feet in December and by leasing water when the aquifer level is 620 feet or below; if the water elevation is 630 – 640 feet, leasing and optioning perform about the same. These results do not change significantly if the price of shortfalls is $300/AF or higher. The optimum lease quantities are always equal to or less than the optimum option quantities, and the maximum lease or option quantity for any December elevation is 12,337 AF. As the lease and options exercise prices increase, options become the minimum expected cost alternative for a wider range of water elevations because SAWS only pays for the exercised quantity in options and not the full quantity, as is the case with leasing. Lease contracts stop being the minimum expected cost alternative for any elevation at a price greater than $80/AF. Leasing, however, is the best alternative at low prices since there are no fixed fees for lease contracts. The user of the model would presumably enter the real price of lease and options contracts, as determined in the water market, in order to avoid the sensitivity of the results.

The minimum total expected cost for SAWS, using the aforementioned prices, ranges from $0 to $584,118, depending on elevation in December. Since SAWS has about 300,000 customers (nearly a million people), the total expected costs of optimally optioning or leasing water translate to an increase in each customer's yearly water bill of $0 to $1.95; the maximum expected cost of doing nothing is equivalent to a $14.30 increase. While the comparison is significant in percentage terms (options and leases produce expected cost savings of 0% - 700% compared to doing nothing), the overall cost to SAWS customers of optioning or leasing is very low. Therefore, the impact of optioning or leasing quantities that are non-optimal on consumer prices is small. This suggests that SAWS has some flexibility on obtaining water through options or leases without being overly concerned about obtaining exactly the optimal quantity as long as the quantity leased or optioned is not significantly different from the optimal quantity.

With the low consumer prices in the Edwards Aquifer region, SAWS could opt to buy out irrigated lands with their corresponding water permits. A study by Keplinger, McCarl and Chen (1998) reports that a land purchase program would cost SAWS about $105 - $140 per year per acre of land at a 7% interest rate. With an average of 1.5 AF of water used to irrigate an acre of land, this is equivalent to $70 - $93 per acre-foot of water per year. If SAWS buys out land to cover the maximum 12,337 AF of cutbacks it could face in a year (according to the simulation results), the plan would increase each customer's water bill by less than $4 per year. However, there is an important advantage to optioning and leasing water besides reducing the total expected costs from doing nothing or from buying irrigated lands. By following a policy of optioning and leasing, the permanent water rights remain with the irrigators. This is important both politically and regionally. Municipalities have historically been reluctant to sell water rights to irrigators in existing water markets, thus, during dry years, farmers who do not have sufficient water rights may not be able to obtain additional water through the water market. Therefore, the longer the permanent water rights remain with the irrigators, the greater protection the farmers will have against dry years, while leasing and optioning water still protect municipalities from cutbacks.

Although the numeric results in this report are specific to starting the simulation in December with aquifer levels of 610 – 700 feet, the analysis can be repeated using any starting month and any elevations. This would allow SAWS to use the simulation model to begin planning for next year as early as the summer, make a one-year preliminary plan in November or December, and then update the simulation monthly to monitor the probabilities of cutbacks through the remainder of the year to make certain there is sufficient leased or optioned water reserved for the rest of the year.

Recommendations for Future Work

The simulation model treats the monthly withdrawals deterministically, ignoring uncertainty in the withdrawals. A stochastic approach in incorporating withdrawals into the simulation model would increase confidence in the calculated probabilities of cutbacks. This could be done in the same way that uncertainty in recharge was managed: by repeating the simulation several times, using many different withdrawal estimates for every month, close to the average withdrawal rate. Another approach would be to use Monte Carlo simulation, treating withdrawals and recharge stochastically. These approaches were not chosen for this project, as it was necessary to keep the size of the simulation model small in order to examine each run's monthly predictions to determine all the different total cutback quantities possible.

Since option contracts incur a separate fixed fee but have the same exercise price as lease price, it may be determined that the total expected costs could be further reduced at low water elevations, where probabilities of cutbacks are very high, by leasing a small quantity of water and optioning another quantity to reserve in case the cutbacks exceed the lease quantity. Therefore, a fourth alternative might be a portfolio of leasing and optioning in the same year. Further analysis would be necessary to verify the expected cost savings of this alternative at very low water elevations. At least one project has studied water rights portfolios for the municipalities in the Edwards Aquifer region (Durbin 2002).

While the simulation model could be used to simulate several years of monthly elevations, this project focuses on a one-year simulation. Expanding the analysis to multi-year plans would allow for comparison of the benefits of buying water rights to the benefits of annual leases and options studied in this report.

A long-term analysis of using different market alternatives is necessary to determine the most effective way of covering the difference between SAWS' historical sales and its current permitted allocation. This analysis could be further expanded to consider non-market solutions, such as developing new water sources outside the Edwards Aquifer.

Addendum

It was assumed in this analysis that SAWS is averse to risking any possible cutback in the next twelve months. However, SAWS may be averse only to high-level cutbacks, and it might choose not to lease or option water that would counter low-level cutbacks. As shown in Table 5.1, most cutbacks would be at the 5% level. If SAWS is not unduly concerned about the risk of 5% cutbacks, and chooses to act only on the possibility of 10% and 15% cutbacks, it can reduce its total expected costs significantly. These high-level cutbacks occur only when the December elevation is 630 feet or below, and leasing is the optimum alternative. Table 6.1 shows the minimum total expected costs of doing nothing versus leasing if SAWS assumes no cost would be incurred by a 5% cutback.

Table 6.1 Comparing Minimum Total Expected Costs for Countering All Cutbacks Versus Only the 10% and 15% Cutbacks

		Minimum Total Expected Cost		
December Elevation (feet)	Averse To . . .	Do Nothing	Lease	Optimum Lease Quantity (AF)
630	All Cutbacks	$ 2,120,275	$ 363,815	6,695
	Only 10% & 15%	$ 236,695	$ 30,297	606
	Reduction	*89%*	*92%*	*91%*
620	All Cutbacks	$ 3,225,384	$ 471,873	9,315
	Only 10% & 15%	$ 506,356	$ 64,507	1,168
	Reduction	*84%*	*86%*	*87%*
610	All Cutbacks	$ 4,293,363	$ 584,118	10,739
	Only 10% & 15%	$ 1,039,405	$ 183,539	3,212
	Reduction	*76%*	*69%*	*70%*

At December elevations greater than 630 feet, the total expected cost of doing nothing is $0 if SAWS is not averse to the possibility of a 5% cutback, or as large as $207,329 if SAWS is averse to 5% cutbacks. Therefore, if SAWS chooses not to counter the 5% cutbacks, it will reduce its total expected cost by up $207,329 for elevations greater than 630 feet. Table 6.1 shows that for elevations below 630 feet in December, the minimum total expected cost of leasing if SAWS is concerned only about 10% and 15% cutbacks ranges from $30,297 to $183,539, which is a 70% - 92% reduction in the minimum total expected cost of leasing when countering for all cutback levels. In fact, even the optimum lease quantities are lowered by 70% - 91% if SAWS chooses not to act on the risk of 5% cutbacks. Therefore, if SAWS is not averse to 5% cutbacks, its minimum total expected costs and optimum lease quantities reduce significantly (by up to $400,000 and 8,000 AF) which is the expected cost of SAWS' aversion to 5% cutbacks.

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Appendix A

Edwards Aquifer Data and Regression Analysis

A-1: Withdrawals
A-2: Recharge
A-3: Regression Analysis

Appendix A-1

Estimated Annual Withdrawals from the Aquifer by Sector, 1955 – 1998

Data in 1000s of AF

Year	Irrigation	Municipal/ Military	Domestic/Stock	Industrial/ Commercial	Total
1955	85.2	120.5	30.1	25.1	**261**
1956	127.2	138.3	28.9	22.4	**317**
1957	68.8	116.1	29.8	22.6	**237**
1958	47.2	113.7	33.4	25.1	**219**
1959	60	118.9	31.5	24.2	**235**
1960	54.9	121.1	29.1	23.3	**228**
1961	52.1	124.5	29.6	22.2	**228**
1962	72.7	143.7	28.8	22.8	**268**
1963	75.4	151.8	27.8	21.8	**277**
1964	72.6	140.2	26.3	21.7	**261**
1965	68	138.8	27	22.3	**256**
1966	68.2	141.8	23.3	22.6	**256**
1967	119.4	171	25.1	25.8	**341**
1968	59.3	146.9	25.5	20	**252**
1969	95.2	162	29.2	21.1	**308**
1970	110.1	167.5	29.3	22.5	**329**
1971	159.4	196.2	28.6	22.6	**407**
1972	128.8	190.5	30.8	21.1	**371**
1973	82.2	177.1	32.3	18.8	**310**
1974	140.4	174.6	33.5	15.1	**364**
1975	96.4	182.5	33.6	15.3	**328**
1976	118.2	182.1	34.6	14.7	**350**
1977	124.2	205.3	38.1	13	**381**
1978	165.8	214.2	40.3	11.5	**432**
1979	126.8	208.9	40.7	15.2	**392**
1980	177.9	256.2	43.3	13.7	**491**
1981	101.8	231.8	40.9	12.6	**387**
1982	130	268.6	39.5	15	**453**
1983	115.9	249.2	38.8	14.7	**419**
1984	191.2	287.2	36.2	15.2	**530**
1985	203.1	263.7	39.2	16.5	**523**
1986	104.2	266.3	42	16.8	**429**
1987	40.9	260.9	43.5	18.7	**364**
1988	193.1	286.2	41.9	18.8	**540**
1989	196.2	285.2	38.2	22.9	**543**
1990	172.9	254.9	37.9	23.7	**489**
1991	88.5	240.5	39.5	67.5	**436**
1992	27.1	236.5	34.8	29	**327**
1993	69.3	252	49.9	36.1	**407**
1994	104.5	247	33.9	39.3	**425**
1995	95.6	255	*11.6	37.3	**400**
1996	181.3	261.3	*12.3	38.8	**494**
1997	77.4 a/b	253	12.3	34.4	**377**
1998	131.9 a	266.5	13.4	41.7 b	**454**
Average	***108.7***	***201.6***	***32.2***	***23.3***	**366**

Data source: USGS and Edwards Aquifer Authority, 1999.

"a" Includes estimates from Atascosa County discharge by Edwards Aquifer users.

"b" Includes estimates from Guadalupe County discharge by Edwards Aquifer users.

* In 1995 the USGS revised the method of calculating domestic/livestock pumpage, which significantly decreased the estimate for 1995 and 1996

Appendix A-2

Estimated Recharge in the Edwards Aquifer, 1934 – 1998

Data in 1000s of AF

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1934	18.5	15.4	21.9	37.8	24.3	10.0	11.5	7.6	5.6	9.7	8.3	9.0	**179.6**
1935	10.3	18.3	9.7	13.1	142.5	546.2	124.3	77.5	129.2	67.9	54.9	64.2	**1258.1**
1936	44.2	34.2	35.6	32.2	55.4	77.8	66.0	32.4	253.3	125.1	86.8	66.5	**909.6**
1937	54.4	41.5	53.8	42.0	26.7	52.8	23.1	15.8	13.4	18.6	15.9	42.6	**400.6**
1938	71.5	62.5	43.7	62.1	68.9	29.9	30.1	16.9	13.1	11.2	10.8	11.9	**432.7**
1939	16.9	14.5	14.4	12.2	10.7	8.8	151.2	37.3	18.0	65.7	21.3	28.0	**399.0**
1940	15.6	21.0	20.4	32.8	38.7	41.7	33.4	14.9	11.5	8.2	17.4	53.1	**308.8**
1941	26.1	87.0	93.8	106.3	159.9	87.3	56.3	41.8	51.3	65.3	43.6	31.9	**850.8**
1942	25.9	23.3	23.8	56.8	63.9	26.1	25.5	31.9	94.9	91.6	52.4	41.5	**557.8**
1943	32.3	21.3	23.2	32.5	26.6	34.6	29.9	13.8	18.6	14.2	11.4	14.6	**273.1**
1944	24.3	43.9	66.9	45.0	87.1	65.6	27.8	37.7	51.6	34.1	23.8	52.9	**560.9**
1945	83.3	69.4	81.3	74.8	51.4	29.8	17.6	12.4	21.5	38.7	17.9	29.7	**527.8**
1946	33.1	40.9	45.7	35.0	62.6	34.7	17.8	12.6	42.6	80.4	86.1	64.9	**556.1**
1947	93.1	58.4	51.9	37.4	38.0	41.1	28.2	25.7	12.5	9.7	13.9	12.7	**422.6**
1948	14.8	14.9	15.2	12.9	14.3	35.3	22.7	5.4	11.4	14.9	9.0	7.5	**178.3**
1949	15.6	84.7	54.2	75.5	75.1	52.9	21.8	39.3	26.0	24.6	18.0	20.2	**508.1**
1950	14.9	20.9	16.0	14.8	31.2	29.8	27.1	11.3	9.3	5.9	8.3	10.8	**200.2**
1951	7.8	14.7	18.3	19.6	29.6	19.0	6.3	4.1	7.1	5.4	3.6	4.5	**139.9**
1952	4.8	4.5	8.1	22.0	35.2	22.1	8.2	4.2	129.5	8.5	10.3	18.0	**275.5**
1953	21.8	16.2	13.5	11.6	8.2	4.7	4.8	9.4	32.7	18.4	14.0	12.5	**167.6**
1954	12.3	7.7	6.8	8.1	48.0	25.3	22.6	7.4	5.9	7.3	6.0	4.6	**162.1**
1955	4.5	8.1	5.9	5.3	13.2	5.5	17.3	7.9	88.0	17.2	12.6	6.3	**192.0**
1956	5.3	5.3	5.0	4.0	3.6	1.9	4.1	2.5	1.7	4.0	3.6	3.0	**43.8**
1957	1.8	5.0	31.4	268.0	252.0	190.0	22.9	14.6	78.0	134.4	84.5	60.1	**1142.7**
1958	84.8	143.1	170.8	75.0	226.3	277.3	95.2	43.1	213.8	169.1	133.6	79.0	**1711.3**
1959	44.4	42.9	38.0	51.8	41.5	95.6	82.7	35.7	35.9	127.0	50.9	43.9	**690.3**
1960	54.0	46.1	44.4	44.3	36.6	31.2	53.8	144.2	50.2	127.7	90.7	101.7	**825.0**
1961	77.9	113.3	73.7	51.5	34.8	105.9	81.2	46.1	31.4	43.4	30.4	27.5	**717.1**
1962	24.2	20.1	19.2	20.6	17.6	30.9	12.9	8.4	12.2	37.4	18.3	17.7	**239.4**
1963	16.3	17.1	15.2	25.5	35.9	12.4	7.6	6.7	6.0	7.2	9.4	11.4	**170.7**
1964	15.0	22.2	28.3	21.8	16.1	22.9	7.6	12.7	139.1	59.6	44.6	23.3	**413.2**
1965	25.5	75.2	34.9	46.4	111.1	108.4	37.6	16.8	25.0	47.9	25.1	69.8	**623.5**
1966	35.4	32.8	28.0	55.4	48.9	25.9	26.1	158.3	118.0	41.2	24.4	20.8	**615.2**
1967	18.2	15.9	16.8	17.1	11.1	7.7	15.4	12.1	79.2	100.7	113.3	58.9	**466.4**
1968	150.6	121.0	114.4	86.2	126.8	66.9	88.6	32.0	27.3	23.3	20.0	27.8	**884.7**
1969	21.4	25.4	27.4	64.4	60.1	28.4	16.5	17.8	18.2	179.4	60.1	91.3	**610.6**
1970	46.3	57.5	116.9	47.0	101.2	72.4	26.9	17.2	85.1	44.1	24.4	22.5	**661.7**
1971	19.7	17.8	20.0	15.1	13.1	29.2	23.5	304.5	89.9	235.4	87.7	69.5	**925.3**
1972	48.6	37.6	33.8	28.6	158.3	63.9	32.6	165.8	73.6	47.0	36.6	30.1	**756.4**
1973	32.4	62.0	58.1	71.6	50.6	178.7	420.3	97.7	63.4	309.5	89.3	52.9	**1486.5**
1974	44.1	29.3	30.8	23.8	110.2	35.8	20.3	69.3	79.3	55.3	93.9	66.3	**658.4**
1975	57.1	217.0	76.5	55.2	212.3	104.6	92.8	42.4	25.9	38.1	26.9	24.4	**973.1**
1976	19.2	17.1	16.7	56.2	147.8	44.6	285.5	54.3	41.3	56.9	98.3	56.3	**894.1**
1977	78.5	89.3	60.0	156.1	221.8	93.7	41.2	26.1	19.2	59.7	73.0	33.2	**952.0**
1978	26.0	24.0	21.8	27.9	15.4	33.5	11.1	140.8	69.3	33.5	46.8	52.3	**502.6**
1979	66.1	79.6	248.8	191.2	98.9	253.0	62.6	37.0	23.2	21.2	17.3	19.0	**1117.8**

continued on next page

Appendix A-2

cont.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1980	20.3	18.8	20.0	20.2	59.7	27.7	13.5	16.5	70.9	70.1	31.1	37.7	**406.5**
1981	25.9	24.9	73.6	146.0	194.8	406.9	222.3	56.8	43.0	149.6	71.4	33.2	**1448.4**
1982	29.0	25.3	25.3	21.4	180.0	36.3	21.3	16.3	16.5	14.7	15.7	20.5	**422.3**
1983	20.3	26.6	37.0	26.7	50.1	72.8	30.4	20.3	22.8	38.5	48.8	25.8	**420.1**
1984	24.5	19.0	16.9	13.0	18.1	10.8	7.2	6.5	6.2	19.0	35.5	21.2	**197.9**
1985	184.5	71.9	128.6	58.8	68.2	118.5	63.7	34.4	15.3	58.3	122.1	78.9	**1003.3**
1986	44.7	39.1	27.5	20.9	64.4	160.9	43.7	21.1	88.3	206.3	143.0	293.8	**1153.7**
1987	159.5	77.1	138.4	69.4	130.3	996.1	143.3	86.8	89.8	40.7	34.5	37.7	**2003.6**
1988	28.5	23.4	24.4	20.7	25.9	55.0	68.6	32.0	26.8	18.0	16.1	16.1	**355.4**
1989	28.2	28.9	25.6	18.5	23.8	13.0	9.2	7.8	6.8	15.4	23.5	13.9	**214.4**
1990	13.7	37.1	44.0	148.6	233.1	29.5	334.0	151.8	54.3	29.1	25.7	22.3	**1123.2**
1991	37.5	50.2	25.7	68.4	82.0	52.1	49.0	13.9	274.9	64.6	62.6	727.5	**1508.4**
1992	347.4	522.5	479.0	163.7	360.6	376.2	76.3	43.7	24.7	21.6	33.1	37.0	**2485.7**
1993	58.3	57.3	60.1	41.7	64.0	49.3	26.9	14.5	19.9	25.8	15.9	13.9	**447.6**
1994	20.2	21.6	70.1	31.4	136.6	36.8	50.7	19.7	29.5	29.1	34.4	58.0	**538.1**
1995	43.6	23.8	62.7	36.4	70.5	64.7	32.6	14.2	91.8	30.6	40.1	20.4	**531.3**
1996	17.3	15.3	14.9	13.1	10.0	9.6	7.3	8.3	83.1	45.8	59.3	40.4	**324.3**
1997	23.9	42.9	97.1	177.2	109.0	405.9	119.3	45.3	29.6	40.6	21.2	22.6	**1134.6**
1998	45.9	64.9	142.7	64.1	27.6	26.3	13.6	182.3	69.4	336.1	117.0	52.4	**1142.3**

Data source: USGS

Appendix A-3

Regression Analysis on the Monthly Aquifer Level at J17

Portion of the data table

Year	Month	Recharge I_t (AF)	Agricultural group withdrawals A_t (AF)	Municipal group withdrawals M_t (AF)	Aquifer level H_t (ft)	Aquifer level H_{t+1} (ft)
1970	1	46348	8029	11764	669.92	670.65
	2	57546	8029	10669	670.65	673.14
	3	116875	8029	12079	673.14	674.78
	4	47001	16993	13910	674.78	671.19
	5	101194	25510	14898	671.19	676.5
	6	72374	25510	17746	676.5	663.6
	7	26934	18317	23345	663.6	657.16
...	...	and so on				
1994	5	136558	25327	23358	673.96	671.17
	6	36779	25327	26546	671.17	661.98
	7	50681	18186	36360	661.98	652.83
	8	19688	14144	32120	652.83	656.4
	9	29493	8083	23546	656.4	663.36
	10	29088	2187	22856	663.36	675.35
	11	34381	2187	20441	675.35	673.14
	12	58030	2187	20326	673.14	676.3

Regression Analysis

1970-1994

Regression Statistics	
Multiple R	0.953422793
R Square	0.909015022
Adjusted R2	0.907781328
Standard Error	4.932328447
Observations	300

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	71701.35478	17925.339	736.823371	3.79E-152
Residual	295	7176.719854	24.327864		
Total	299	78878.07463			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	144.5220419	13.77954175	10.48816024	4.41312E-22	117.40339	171.640695	117.403388	171.6406954
Ht	0.796486703	0.01985169	40.1218593	1.6793E-121	0.7574178	0.83555557	0.75741784	0.835555571
It	2.60581E-05	2.81028E-06	9.27242521	3.9909E-18	2.053E-05	3.1589E-05	2.0527E-05	3.15889E-05
At	-0.00021798	2.91864E-05	-7.468568891	9.21978E-13	-0.000275	-0.0001605	-0.00027542	-0.000160541
Mt	-0.00035521	5.96117E-05	-5.958744177	7.23377E-09	-0.000473	-0.0002379	-0.00047253	-0.000237893

all variables are statisically significant

Appendix B

Simulation Model Macro

```
Sub Edwards_Aquifer_macro_1()
'
' Edwards_Aquifer_macro_1 Macro
' Macro recorded February 2002 by Shadi Eskaf
'
' [illegible]yboard Shortcut: Ctrl+e
'
' Clears contents of output sheet
With ActiveWorkbook
Sheets("output").Range("G3:H67").Value = Null
Sheets("output").Range("C2:C8").Value = Null
Sheets("output").Range("C9:C10").Value = Null
Sheets("output").Range("B15:C26").Value = Null
Sheets("output").Range("B29:C40").Value = Null
Sheets("output").Range("I2:M67").Value = Null
Sheets("output").Range("I69:M69").Value = Null
Sheets("calculations").Range("C5:BW69").Value = Null
Sheets("calculations").Range("A5:A69").Value = Null
Sheets("calculations").Range("D72:BW72").Value = Null
Sheets("calculations").Range("D75:BW75").Value = Null
Sheets("how long").Range("C5:I5").Value = Null
Sheets("how long").Range("A9:A73").Value = Null
Sheets("how long").Range("C9:I73").Value = Null
Sheets("probability table").Range("C9:AB9").Value = Null
Sheets("probability table").Range("C10:AB21").Value = Null
Sheets("calculations 2").Range("G3:G67").Value = Null
Sheets("calculations 2").Range("C2:C10").Value = Null
End With


' Reads input variables
With ActiveWorkbook
    Dim aginput As Variant
    Dim sawsinput As Variant
    Dim domstock As Variant
    Dim a(12)                        'ag + domestic + stock
    Dim w(12)                        'SAWS + municipal + industrial + commercial
    Dim s As Variant
    Dim y As Variant
    Dim f As Variant               'degrees of freedom (total number of cycles)
    Dim m As Variant
    Dim mtwo As Variant
    Dim l As Variant
    Dim optionendsingle As Variant
    Dim optionendmulti As Variant
    aginput = Sheets("input").Cells(4, 2).Value  'average agricultural withdrawals
    sawsinput = Sheets("input").Cells(5, 2).Value  'average SAWS withdrawals
    domstock = sawsinput * 0.23
    a(0) = aginput + domstock       'average monthly ag + domestic + stock
    w(0) = 1.653 * sawsinput        'average all municipal + industrial + commercial
    s = Sheets("input").Cells(7, 2).Value  'starting month of one-case scenario
    y = Sheets("input").Cells(9, 2).Value  'number of years in a cycle
    m = 12 * y                             'ending month label (12, 24, 36, 48, or 60)
    mtwo = s + m - 1                'ending month label for continuous cycles (non-December)
    Dim h(65, 73)                  'j17 heights as matrix, 65 cycles max, 72 months max
    l = Sheets("input").Cells(14, 2).Value   'trigger elevation
    optionendsingle = Sheets("input").Cells(33, 2).Value   'ending option for single case
    optionendmulti = Sheets("input").Cells(34, 2).Value    'ending option for multi starts

    'The model first calculates the single scenario, then does the various
    'elevations and table later

    'Calculates the monthly withdrawals of ag. and mun.
    Dim n As Variant
```

```
    Dim ta As Variant
    Dim tw As Variant
    For n = 1 To 12
        If IsEmpty(Sheets("input").Cells(n + 18, 3)) Then   'ag multipliers
            ta = Sheets("input").Cells(n + 18, 4).Value
            Else
            ta = Sheets("input").Cells(n + 18, 3).Value
        End If
        If IsEmpty(Sheets("input").Cells(n + 18, 5)) Then   'mun multipliers
            tw = Sheets("input").Cells(n + 18, 6).Value
            Else
            tw = Sheets("input").Cells(n + 18, 5).Value
        End If

        a(n) = a(0) * ta                                 'ag withdrawals
        Sheets("output").Cells(n + 14, 2).Value = a(n)
        Sheets("output").Cells(n + 14, 3).Value = ta
        w(n) = w(0) * tw                                 'mun withdrawals
        Sheets("output").Cells(n + 28, 2).Value = w(n)
        Sheets("output").Cells(n + 28, 3).Value = tw
        ta = 1                                          'as safeguard for when
        tw = 1                                          'historical multipliers are deleted
too
    Next n

        ' Calculating heights
        Dim c As Variant
        Dim r As Variant
        Dim j As Variant
        Dim qmon As Variant
        Dim zmon As Variant
        qmon = 0
        zmon = 0

        If optionendsingle = 1 Then                     'FOR THE END OF DECEMBER OPTION
            f = 66 - y                  'degrees of freedom
            For c = 1 To f
            For n = s To m
                If n <= 12 Then
                    j = n
                    ElseIf n > 12 And n <= 24 Then
                    j = n - 12
                    ElseIf n > 24 And n <= 36 Then
                    j = n - 24
                    ElseIf n > 36 And n <= 48 Then
                    j = n - 36
                    ElseIf n > 48 And n <= 60 Then
                    j = n - 48
                    Else: Sheets("output").Cells(1, 2) = "ERROR"
                End If
                h(c, s - 1) = Sheets("input").Cells(6, 2).Value         'initial height
                r = Sheets("data").Cells(c + 7, n + 2).Value         'recharge for that one
month
                h(c, n) = 144.522041945018 + (0.796486703142895 * h(c, n - 1)) + (2.60581232
741073E-05 * r) - (2.179806005167E-04 * a(j)) - (3.55210989191012E-04 * w(j))
                Sheets("calculations").Cells(c + 4, n + 3).Value = h(c, n)
                If h(c, n) <= 1 Then
                    Sheets("cutput").Cells(c + 2, 7).Value = 1
                    If IsEmpty(Sheets("output").Cells(c + 2, 8)) Then
                        Sheets("output").Cells(c + 2, 8).Value = n
                    End If
                    qmon = 1
                    zmon = zmon + qmon
                    qmon = 0
```

```
                End If
                If n = 12 Then
                    Sheets("output").Cells(c + 2, 9).Value = zmon
                    zmon = 0
                Else: End If
                If n = 24 Then
                    Sheets("output").Cells(c + 2, 10).Value = zmon
                    zmon = 0
                Else: End If
                If n = 36 Then
                    Sheets("output").Cells(c + 2, 11).Value = zmon
                    zmon = 0
                Else: End If
                If n = 48 Then
                    Sheets("output").Cells(c + 2, 12).Value = zmon
                    zmon = 0
                Else: End If
                If n = 60 Then
                    Sheets("output").Cells(c + 2, 13).Value = zmon
                    zmon = 0
                Else: End If
            Next n
                Sheets("calculations").Cells(c + 4, s + 2).Value = h(c, s - 1)
                Sheets("calculations").Cells(c + 4, 1).Value = c
            Next c

        ElseIf optionendsingle = 2 Then                 ' NOT ENDING IN DECEMBER
            If s = 1 Then
               f = 66 - y
               Else: f = 65 - y
            End If
            For c = 1 To f
            For n = s To mtwo
                If n <= 12 Then
                    j = n
                    ElseIf n > 12 And n <= 24 Then
                    j = n - 12
                    ElseIf n > 24 And n <= 36 Then
                    j = n - 24
                    ElseIf n > 36 And n <= 48 Then
                    j = n - 36
                    ElseIf n > 48 And n <= 60 Then
                    j = n - 48
                    ElseIf n > 60 And n <= 72 Then
                    j = n - 60
                    Else: Sheets("output").Cells(1, 2) = "ERROR"
                End If
                h(c, s - 1) = Sheets("input").Cells(6, 2).Value         'initial height
                r = Sheets("data").Cells(c + 7, n + 2).Value         'recharge for that one
month
                h(c, n) = 144.522041945018 + (0.796486703142895 * h(c, n - 1)) + (2.60581232
741073E-05 * r) - (2.179806005167E-04 * a(j)) - (3.55210989191012E-04 * w(j))
                Sheets("calculations").Cells(c + 4, n + 3).Value = h(c, n)
                If h(c, n) <= 1 Then
                    Sheets("output").Cells(c + 2, 7).Value = 1
                    If IsEmpty(Sheets("output").Cells(c + 2, 8)) Then
                        Sheets("output").Cells(c + 2, 8).Value = n
                    End If
                    qmon = 1
                    zmon = zmon + qmon
                    qmon = 0
                End If
                If n = s + 12 - 1 Then
                    Sheets("output").Cells(c + 2, 9).Value = zmon
```

```
                zmon = 0
            Else: End If
            If n = s + 24 - 1 Then
                Sheets("output").Cells(c + 2, 10).Value = zmon
                zmon = 0
            Else: End If
            If n = s + 36 - 1 Then
                Sheets("output").Cells(c + 2, 11).Value = zmon
                zmon = 0
            Else: End If
            If n = s + 48 - 1 Then
                Sheets("output").Cells(c + 2, 12).Value = zmon
                zmon = 0
            Else: End If
            If n = s + 60 - 1 Then
                Sheets("output").Cells(c + 2, 13).Value = zmon
                zmon = 0
            Else: End If
        Next n
            Sheets("calculations").Cells(c + 4, s + 2).Value = h(c, s - 1)
            Sheets("calculations").Cells(c + 4, 1).Value = c
        Next c

    Else: Sheets("output").Cells(1, 2) = "ERROR IN SELECTING ENDING OPTION"
    End If

        Dim x As Variant
        Dim yearfaillabel As Variant
        Dim yearfail As Variant
        Dim yearfailprob As Variant
        yearfail = 0
        For yearfaillabel = 1 To y
            Sheets("output").Cells(2, 8 + yearfaillabel).Value = yearfaillabel
            For x = 3 To 67
                If Sheets("output").Cells(x, 8 + yearfaillabel).Value > 0 Then
                yearfail = yearfail + 1
                End If
            Next x
            yearfailprob = 100 * (yearfail / f)
            Sheets("output").Cells(69, 8 + yearfaillabel).Value = yearfailprob
            yearfail = 0
        Next yearfaillabel

    'Calculating probability
    Dim z As Variant             'number of cycles that failed at least once
    Dim q As Variant
    Dim p As Variant             ' probability of success for the entire period
    z = 0
    For x = 3 To 67
        q = Sheets("output").Cells(x, 7).Value
        z = z + q
        q = 0
    Next x
    p = 100 * (1 - z / f)
    Sheets("output").Cells(2, 3).Value = s
    Sheets("output").Cells(3, 3).Value = h(1, s - 1)
    Sheets("output").Cells(4, 3).Value = p
    Sheets("output").Cells(5, 3).Value = a(0)
    Sheets("output").Cells(6, 3).Value = w(0)
    Sheets("output").Cells(7, 3).Value = y
    Sheets("output").Cells(8, 3).Value = optionendsingle
    Sheets("output").Cells(9, 3).Value = f
    Sheets("output").Cells(10, 3).Value = z
```

```
    'Calculating duration of failures
    Dim howend1 As Variant
    If optionendsingle = 1 Then
        howend1 = m
        ElseIf optionendsingle = 2 Then
        howend1 = mtwo
        Else: Sheets("how long").Cells(6, 1) = "ERROR IN SELECTING ENDING OPTION"
    End If

    Dim dur As Variant
    Dim prevcount As Variant
    prevcount = 0
    For c = 1 To f
        dur = 0
        For n = s To howend1 - 1
            If h(c, n) <= 1 Then
                dur = dur + 1
            End If
            If h(c, n) <= 1 And h(c, n + 1) > 1 And dur > 6 And IsEmpty(Sheets("how long").C
ells(c + 8, 9)) Then
                    Sheets("how long").Cells(c + 8, 9).Value = 1
                    dur = 0
                ElseIf h(c, n) <= 1 And h(c, n + 1) > 1 And dur > 6 And Not IsEmpty(Sheets("
how long").Cells(c + 8, 9)) Then
                    prevcount = Sheets("how long").Cells(c + 8, 9)
                    Sheets("how long").Cells(c + 8, 9) = prevcount + 1
                    dur = 0
                ElseIf h(c, n) <= 1 And h(c, n + 1) > 1 And dur <= 6 And IsEmpty(Sheets("how
 long").Cells(c + 8, dur + 2)) Then
                    Sheets("how long").Cells(c + 8, dur + 2).Value = 1
                    dur = 0
                ElseIf h(c, n) <= 1 And h(c, n + 1) > 1 And dur <= 6 And Not IsEmpty(Sheets(
"how long").Cells(c + 8, dur + 2)) Then
                    prevcount = Sheets("how long").Cells(c + 8, dur + 2)
                    Sheets("how long").Cells(c + 8, dur + 2) = prevcount + 1
                    dur = 0
                Else:
            End If
        Next n
        n = howend1
        If h(c, n) <= 1 Then
            dur = dur + 1
        End If
        If h(c, n) <= 1 And dur > 6 And IsEmpty(Sheets("how long").Cells(c + 8, 9)) Then
                    Sheets("how long").Cells(c + 8, 9).Value = 1
                    dur = 0
                ElseIf h(c, n) <= 1 And dur > 6 And Not IsEmpty(Sheets("how long").Cells(c +
 8, 9)) Then
                    prevcount = Sheets("how long").Cells(c + 8, 9)
                    Sheets("how long").Cells(c + 8, 9) = prevcount + 1
                    dur = 0
                ElseIf h(c, n) <= 1 And dur <= 6 And IsEmpty(Sheets("how long").Cells(c + 8,
 dur + 2)) Then
                    Sheets("how long").Cells(c + 8, dur + 2).Value = 1
                    dur = 0
                ElseIf h(c, n) <= 1 And dur <= 6 And Not IsEmpty(Sheets("how long").Cells(c
+ 8, dur + 2)) Then
                    prevcount = Sheets("how long").Cells(c + 8, dur + 2)
                    Sheets("how long").Cells(c + 8, dur + 2) = prevcount + 1
                    dur = 0
                Else:
        End If
        dur = 0
        Sheets("how long").Cells(c + 8, 1) = c
```

```
    Next c

    'Calculating probability of failure for each month
   Dim monfail As Variant
   Dim monprob As Variant
   monfail = 0
    For n = s To howend1
        For c = 1 To f
            If Sheets("calculations").Cells(c + 4, n + 3) <= 1 Then
                monfail = monfail + 1
            End If
        Next c
        monprob = 100 * monfail / f
        Sheets("calculations").Cells(72, n + 3) = monfail
        Sheets("calculations").Cells(75, n + 3) = monprob
        monprob = 0
        monfail = 0
    Next n

    'Now the model will calculate the various elevations' scenarios and construct the table

    Dim e(26)                       'various elevations as array. Max of 26.
    Dim o As Variant
    Dim howend As Variant
    For o = 1 To 26
      If Not IsEmpty(Sheets("input").Cells(11, o + 1)) Then
        e(o) = Sheets("input").Cells(11, o + 1).Value
            For s = 1 To 12
                If optionendmulti = 1 Then
                    f = 66 - y
                    howend = m
                ElseIf optionendmulti = 2 And s = 1 Then
                    f = 66 - y
                    howend = s + m - 1
                ElseIf optionendmulti = 2 And s > 1 Then
                    f = 65 - y
                    howend = s + m - 1
                Else: Sheets("probability table").Cells(23, 1) = "ERROR IN SELECTING ENDING
OPTION"
                End If

                For c = 1 To f
                    For n = s To howend
                        If n <= 12 Then
                            j = n
                            ElseIf n > 12 And n <= 24 Then
                            j = n - 12
                            ElseIf n > 24 And n <= 36 Then
                            j = n - 24
                            ElseIf n > 36 And n <= 48 Then
                            j = n - 36
                            ElseIf n > 48 And n <= 60 Then
                            j = n - 48
                            ElseIf n > 60 And n <= 72 Then
                            j = n - 60
                            Else: Sheets("output").Cells(1, 2) = "ERROR"
                        End If
                        h(c, s - 1) = e(o)                 'initial height
                        r = Sheets("data").Cells(c + 7, n + 2).Value 'recharge for that one
month
                        h(c, n) = 144.522041945018 + (0.796486703142895 * h(c, n - 1)) + (2.
60581232741073E-05 * r) - (2.179806005167E-04 * a(j)) - (3.55210989191012E-04 * w(j))
                    If h(c, n) <= 1 Then
                        Sheets("calculations 2").Cells(c + 2, 7).Value = 1
```

```
                    End If
                    Next n
                Next c

                'Calculating probability
                z = 0
                q = 0
                For x = 3 To 67
                    q = Sheets("calculations 2").Cells(x, 7).Value
                    z = z + q
                    q = 0
                Next x
                p = 100 * (1 - z / f)
                Sheets("calculations 2").Cells(4, 3).Value = p
                Sheets("calculations 2").Cells(10, 3).Value = z
                Sheets("calculations 2").Range("G3:G67").Value = Null

                ' Inputing the Probability of Success Table's Entries
                Sheets("probability table").Cells(s + 9, o + 2).Value = p
            Next s
        Sheets("probability table").Cells(9, o + 2).Value = e(o)
        Sheets("calculations 2").Cells(9, 3).Value = f
      End If
    Next o
   Sheets("calculations 2").Cells(2, 3) = "varies"
   Sheets("calculations 2").Cells(3, 3) = "varies"
End With

End Sub
```

Appendix C

Simulation Results

Example of the simulation model predictions of J17 elevations

The numbers are the predicted start of month elevations (feet).

Simulation Parameters:

Starting month: December
Start Elevation: 620 feet
Trigger Level: 650 feet (cutbacks of at least 5%)
Number of months to predict: 12
Withdrawal rates: Average withdrawals

PREDICTED ELEVATIONS

Run	Year of recharge data	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1934	620	630.7	638	644.6	648.5	648.9	650	660.6	657.9	655.5	658.8	661.9	665.3
2	1935	620	632.2	640.1	646.6	650.7	651.2	649.6	648.1	646.4	645.2	653.8	659.4	664.1
3	1936	620	632.2	640.4	647.1	651.6	652.1	649.5	647.4	644.8	643.4	646.1	650.5	655.2
4	1937	620	631.6	640.3	647.6	651.7	652.7	651.1	648.1	645.5	644	646.6	650.7	655.2
5	1938	620	630.8	638.3	644.7	648.6	649	646.7	644	645.4	644.5	647.1	652.5	656.9
6	1939	620	631.2	638.6	645.1	649.1	649.9	648.1	646	643.9	642.7	645.5	649.8	654.7
7	1940	620	631.9	639.4	647.4	652.9	654.8	655.2	652.8	649.9	648.2	650.9	655.6	660
8	1941	620	631.3	638.9	645.4	649.5	650.8	649.5	646.7	644.3	643.4	648.3	654.1	659
9	1942	620	631.6	639.3	645.7	649.7	650.3	648.1	645.8	643.7	642.5	645.5	649.9	654.6
10	1943	620	630.9	638.5	645.6	650.8	651.5	650.7	648.7	645.9	644.9	648.3	652.6	657.1
11	1944	620	631.9	640.9	648.2	653.2	654.2	651.9	648.7	645.6	644	646.8	651.6	656.1
12	1945	620	631.3	639.1	646	650.5	651.1	649.7	647	644.3	643	646.6	652.5	658.6
13	1946	620	632.2	641.4	648.3	652.5	652.7	650.3	647.7	645.2	644	646.6	650.6	655.3
14	1947	620	630.8	638.2	644.6	648.6	649	646.8	644.7	642.6	641.4	644.5	649.1	653.9
15	1948	620	630.7	638.1	646.4	651.1	652.6	651.2	648.7	645.8	644.8	647.6	651.8	656.3
16	1949	620	631	638.4	644.9	648.9	649.3	647.4	645.1	643	641.9	644.8	649.2	653.9
17	1950	620	630.8	638	644.5	648.6	649.1	647.3	644.7	642.2	641.1	644.1	648.5	653.3
18	1951	620	630.6	637.8	644	648	648.7	647.1	644.6	642.2	641.1	647.3	651.2	655.6
19	1952	620	631	638.5	644.9	648.8	649.1	646.7	643.9	641.5	640.6	644.4	649.1	654.1
20	1953	620	630.8	638.2	644.4	648.2	648.6	647.3	644.9	642.8	641.6	644.5	648.9	653.7
21	1954	620	630.6	637.8	644.1	648	648.3	646.2	643.5	641.5	640.6	645.8	650.2	654.9
22	1955	620	630.7	637.9	644.1	647.9	648.2	645.8	643.1	640.9	640	643.1	647.7	652.7
23	1956	620	630.6	637.7	644	648.5	655.6	658.2	657.9	653.1	650	653.1	659.1	663.8
24	1957	620	632.1	641	650.2	657.1	657.4	659	660.8	657.3	654.1	659.9	665.4	670.1
25	1958	620	632.6	640.4	647.1	651.2	652.1	649.9	648.8	647.4	646.1	648.8	655.5	660.1
26	1959	620	631.6	639.9	646.8	651.1	651.8	649.6	646.9	645.1	647.1	650	656.4	661.9
27	1960	620	633.2	641.7	650	654.4	654.6	651.8	650.6	648.8	647.4	649.8	654.1	658.4
28	1961	620	631.2	638.8	645.2	649.2	649.7	647.4	645.1	642.7	641.6	644.6	649.8	654.7
29	1962	620	631	638.4	644.8	648.8	649.5	647.7	644.9	642.3	641.3	644.2	648.7	653.6
30	1963	620	630.8	638.2	644.8	649.1	649.6	647.3	644.8	642.3	641.4	647.8	652.9	657.9
31	1964	620	631.1	638.7	646.6	650.7	651.5	651.3	650.3	647.4	645.6	648.1	652.9	657.3
32	1965	620	632.3	640	646.5	650.4	651.6	649.7	646.8	644.4	646.8	651.6	655.4	659.4
33	1966	620	631	638.5	644.9	648.9	649.3	646.9	644.1	642	641.1	646	652.5	659.4
34	1967	620	632	642.7	651	656.3	657	656.1	653	650.9	648.7	650.7	654.3	658.3
35	1968	620	631.2	638.7	645.3	649.5	651	649.6	646.8	644.1	642.9	645.9	654.5	659.6
36	1969	620	632.9	640.7	647.7	653.7	654	653	650.6	647.5	645.6	649.7	654.1	658.3
37	1970	620	631.1	638.6	645	649	649.4	647	644.8	642.7	649.3	652.8	661.5	665.8
38	1971	620	632.3	640.3	646.9	650.9	651.2	652.3	649.9	647	649.1	652.2	656.1	660.2
39	1972	620	631.3	639.1	646.5	651.3	652.6	650.6	651.5	658.4	656.4	657.8	667.4	670.6
40	1973	620	631.9	639.8	646.3	650.4	650.7	650.6	647.8	645	645	649.1	653.8	659.9
41	1974	620	632.2	640.4	651.7	655.8	655.8	657.4	655	652.6	650.4	652	655.7	659.6
42	1975	620	631.1	638.6	645	649	650.4	651.3	648.6	652.6	650.6	652.6	656.7	662.3
43	1976	620	632	640.8	648.6	653	656.2	657.9	655.1	651.4	649	650.7	655.2	660.5
44	1977	620	631.4	639	645.5	649.5	650.1	647.6	645.4	642.8	645.1	649	653.2	658.1
45	1978	620	631.9	640.4	648.1	657.4	660.7	658.3	659.6	655.5	652.5	653.6	656.6	660.1
46	1979	620	631	638.5	645	649	649.5	648.3	645.8	643.2	642.2	646.7	652.3	657

cont.

Run	*Year of recharge data*	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
47	*1980*	620	631.5	639	645.5	650.9	654.3	655.6	661.5	661.2	657.6	658.2	663.5	667
48	*1981*	620	631.4	639	645.5	649.6	650	651.9	648.8	645.9	644.3	646.9	651	655.6
49	*1982*	620	631	638.5	645.2	649.7	650.2	648.6	647.2	644.8	643.6	646.5	651.3	656.7
50	*1983*	620	631.2	638.8	645.2	649.1	649.4	647.2	644.4	642	640.9	644	648.8	654.4
51	*1984*	620	631.1	642.8	649.8	655.7	655.8	653.6	652.4	649.8	647.9	649.7	654.4	661.1
52	*1985*	620	632.6	640.4	647	650.8	651	649.6	650.3	647.6	645.8	650	658.5	664.9
53	*1986*	620	638.2	647.8	653.9	659.2	658.9	657.7	678.5	672.7	667.5	667.3	667.9	669.6
54	*1987*	620	631.5	639.1	645.6	649.6	650	647.8	646.1	644.9	644	646.9	651.1	655.7
55	*1988*	620	630.9	638.7	645.3	649.5	649.8	647.7	644.9	642.4	641.3	644.3	649	654.2
56	*1989*	620	630.9	638.2	645.2	649.9	653.5	656	652	656.5	656.3	657.5	659.8	662.9
57	*1990*	620	631.1	639	646.2	650.2	651.7	650.6	648.3	646.1	644.5	653.8	657.8	662.2
58	*1991*	620	649.5	661.7	676.6	686.2	682.8	682.7	682.3	673.9	667.4	665.5	666	668
59	*1992*	620	631.5	639.9	647.1	651.7	652.2	650.6	648.2	645.5	644	646.7	651.2	655.8
60	*1993*	620	630.9	638.4	645	650.3	650.8	651.4	648.5	646.3	644.8	647.6	652	656.9
61	*1994*	620	632	639.9	646.2	651.1	651.6	650.3	648.3	645.7	644.2	648.8	652.9	657.8
62	*1995*	620	631	638.5	644.8	648.8	649.1	646.7	644.1	641.7	640.8	645.8	651	656.7
63	*1996*	620	631.6	639	646	651.9	655.9	654.7	660.7	657.9	654.6	655.5	658.5	661.7
64	*1997*	620	631.1	639.3	646.8	653.7	654.3	651.3	648.2	645.1	648	651.3	662.9	667.7

Example of analysis performed on the results of the simulation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MIN	630.6	637.7	644.0	647.9	648.2	645.8	643.1	640.9	640.0	643.1	647.7	652.7
MAX	649.5	661.7	676.6	686.2	682.8	682.7	682.3	673.9	667.5	667.3	667.9	670.6
AVG	631.8	639.8	646.8	651.4	652.3	651.1	649.8	647.5	646.3	649.5	654.4	659.0

Number of failures for that month

64	63	59	30	21	33	45	50	52	43	12	0

Probability of failure for that month (trigger level of 650 feet)

100%	98%	92%	47%	33%	52%	70%	78%	81%	67%	19%	0%

Cutback quantities (for SAWS) by month and trigger level:

Trigg. Level	Proportion	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
650	5%	1002	929.2	1086	1158	1219	1327	1605	1617	1291	1207	1026	1026
640	10%	2003	1858	2172	2317	2438	2655	3210	3234	2582	2413	2051	2051
630	15%	3005	2787	3258	3475	3656	3982	4815	4851	3873	3620	3077	3077

Track of cutbacks for every month for each simulation run

Run	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**TOTAL**
1	2003	1858	1086	1158	1219	1327	0	0	0	0	0	0	**8652**
2	2003	929	1086	0	0	1327	1605	1617	1291	0	0	0	**9859**
3	2003	929	1086	0	0	1327	1605	1617	1291	1207	0	0	**11065**
4	2003	929	1086	0	0	0	1605	1617	1291	1207	0	0	**9738**
5	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
6	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
7	2003	1858	1086	0	0	0	0	1617	1291	0	0	0	**7856**
8	2003	1858	1086	1158	0	1327	1605	1617	1291	1207	0	0	**13153**
9	2003	1858	1086	1158	0	1327	1605	1617	1291	1207	1026	0	**14179**
10	2003	1858	1086	0	0	0	1605	1617	1291	1207	0	0	**10667**
11	2003	929	1086	0	0	0	1605	1617	1291	1207	0	0	**9738**
12	2003	1858	1086	0	0	1327	1605	1617	1291	1207	0	0	**11994**
13	2003	929	1086	0	0	0	1605	1617	1291	1207	0	0	**9738**

cont.

Run	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**TOTAL**

14	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
15	2003	1858	1086	0	0	0	1605	1617	1291	1207	0	0	**10667**
16	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
17	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
18	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
19	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
20	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
21	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
22	2003	1858	1086	1158	1219	1327	1605	1617	2582	1207	1026	0	**16689**
23	2003	1858	1086	1158	0	0	0	0	0	0	0	0	**6106**
24	2003	929	0	0	0	0	0	0	0	0	0	0	**2932**
25	2003	929	1086	0	0	1327	1605	1617	1291	1207	0	0	**11065**
26	2003	1858	1086	0	0	1327	1605	1617	1291	1207	0	0	**11994**
27	2003	929	1086	0	0	0	0	1617	1291	1207	0	0	**8133**
28	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
29	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
30	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
31	2003	1858	1086	0	0	0	0	1617	1291	1207	0	0	**9062**
32	2003	1858	1086	0	0	1327	1605	1617	1291	0	0	0	**10788**
33	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
34	2003	929	0	0	0	0	0	0	1291	0	0	0	**4223**
35	2003	1858	1086	1158	0	1327	1605	1617	1291	1207	0	0	**13153**
36	2003	929	1086	0	0	0	0	1617	1291	1207	0	0	**8133**
37	2003	1858	1086	1158	1219	1327	1605	1617	1291	0	0	0	**13165**
38	2003	929	1086	0	0	0	1605	1617	1291	0	0	0	**8531**
39	2003	1858	1086	0	0	0	0	0	0	0	0	0	**4947**
40	2003	1858	1086	0	0	0	1605	1617	1291	1207	0	0	**10667**
41	2003	929	0	0	0	0	0	0	0	0	0	0	**2932**
42	2003	1858	1086	1158	0	0	1605	0	0	0	0	0	**7711**
43	2003	929	1086	0	0	0	0	0	1291	0	0	0	**5309**
44	2003	1858	1086	1158	0	1327	1605	1617	1291	1207	0	0	**13153**
45	2003	929	1086	0	0	0	0	0	0	0	0	0	**4018**
46	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
47	2003	1858	1086	0	0	0	0	0	0	0	0	0	**4947**
48	2003	1858	1086	1158	0	0	1605	1617	1291	1207	0	0	**11826**
49	2003	1858	1086	1158	0	1327	1605	1617	1291	1207	0	0	**13153**
50	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
51	2003	929	1086	0	0	0	0	1617	1291	1207	0	0	**8133**
52	2003	929	1086	0	0	1327	0	1617	1291	1207	0	0	**9460**
53	2003	929	0	0	0	0	0	0	0	0	0	0	**2932**
54	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
55	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	1026	0	**15397**
56	2003	1858	1086	1158	0	0	0	0	0	0	0	0	**6106**
57	2003	1858	1086	0	0	0	1605	1617	1291	0	0	0	**9460**
58	1002	0	0	0	0	0	0	0	0	0	0	0	**1002**
59	2003	1858	1086	0	0	0	1605	1617	1291	1207	0	0	**10667**
60	2003	1858	1086	0	0	0	1605	1617	1291	1207	0	0	**10667**
61	2003	1858	1086	0	0	0	1605	1617	1291	1207	0	0	**10667**
62	2003	1858	1086	1158	1219	1327	1605	1617	1291	1207	0	0	**14372**
63	2003	1858	1086	0	0	0	0	0	0	0	0	0	**4947**
64	2003	1858	1086	0	0	0	1605	1617	1291	0	0	0	**9460**
MIN	1002	0	0	0	0	0	0	0	0	0	0	0	**1002**
MAX	2003	1858	1086	1158	1219	1327	1605	1617	2582	1207	1026	0	**16689**
AVG	1987	1582	1001	543	400	684	1128	1263	1069	811	192	0	**10662**

Appendix C-2

Probabilities of all cutback amounts from January through December

All possible cutback quantities that may occur between **January - December**, given the J17 elevation in the previous December, as calculated from the simulation results. For each December elevation, all cutback quantities are **mutually exclusive.** For example, if the J17 elevation is 670 feet, SAWS faces only five possible scenarios between January and December: face cutback quantities of 0, 781, 1511, 1759, or 2489 AF throughout the year.

This lookup table provides the Q_x and $P(Q_x)$ values for Equations 5.3 and 5.4 (Lease Alternative)

J17 elevation in December	Total cutback quantity, Q_x	Probability of occurrance, $P(Q_x)$	Probability of all cutbacks quantities
700	no failures	no failures	no failures
690	781	8%	100%
	TOTAL:	***8%***	***100%***
680	781	23%	94%
680	1511	2%	6%
	TOTAL:	***25%***	***100%***
670	781	16%	45%
670	1511	13%	36%
670	1759	3%	9%
670	2489	3%	9%
	TOTAL:	***34%***	***100%***
660	781	23%	42%
660	978	3%	6%
660	1511	5%	8%
660	1759	6%	11%
660	2489	19%	33%
	TOTAL:	***56%***	***100%***
650	781	19%	27%
650	978	5%	7%
650	1511	6%	9%
650	1759	9%	13%
650	2489	27%	38%
650	3460	5%	7%
	TOTAL:	***70%***	***100%***
640	606	25%	26%
640	1387	6%	6%
640	1584	2%	2%
640	2365	13%	13%
640	2555	2%	2%
640	3095	20%	21%
640	3336	2%	2%
640	4066	27%	27%
640	4687	2%	2%
	TOTAL:	***97%***	***100%***

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cont.

Appendix C-2

J17 elevation in December	Total cutback quantity, Q_x	Probability of occurrance, $P(Q_x)$	Probability of all cutbacks quantities
630	606	2%	2%
630	1168	5%	5%
630	1774	11%	11%
630	1949	2%	2%
630	2146	2%	2%
630	2431	3%	3%
630	2555	3%	3%
630	2927	5%	5%
630	3533	3%	3%
630	3658	2%	2%
630	3898	2%	2%
630	4263	14%	14%
630	4504	3%	3%
630	4526	2%	2%
630	4629	3%	3%
630	5234	14%	14%
630	5855	2%	2%
630	6037	2%	2%
630	6512	2%	2%
630	6658	2%	2%
630	6695	9%	10%
630	7315	9%	10%
	TOTAL:	***98%***	***100%***
620	606	2%	2%
620	1774	5%	5%
620	2431	2%	2%
620	2555	2%	2%
620	2993	5%	5%
620	3212	2%	2%
620	3694	3%	3%
620	4665	2%	2%
620	4753	2%	2%
620	4921	5%	5%
620	5161	2%	2%
620	5234	2%	2%
620	5483	2%	2%
620	5724	5%	5%
620	5891	5%	5%
620	5964	2%	2%
620	6454	9%	9%
620	6527	2%	2%
620	6695	3%	3%
620	7154	2%	2%
620	7257	3%	3%
620	7958	6%	6%

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cont.

Appendix C-2

J17 elevation in December	Total cutback quantity, Q_x	Probability of occurrance, $P(Q_x)$	Probability of all cutbacks quantities
620	7965	2%	2%
620	8578	2%	2%
620	8695	13%	13%
620	9315	16%	16%
620	10097	2%	2%
	TOTAL:	***100%***	***100%***
610	606	2%	2%
610	2431	2%	2%
610	3599	3%	3%
610	4300	3%	3%
610	4380	2%	2%
610	5271	2%	2%
610	5738	2%	2%
610	6089	3%	3%
610	6497	2%	2%
610	6789	3%	3%
610	6811	2%	2%
610	7760	2%	2%
610	7833	2%	2%
610	7863	2%	2%
610	8250	2%	2%
610	8563	2%	2%
610	8571	6%	6%
610	9228	2%	2%
610	9301	25%	25%
610	9921	11%	11%
610	9958	6%	6%
610	10578	5%	5%
610	10702	2%	2%
610	10739	5%	5%
610	11360	3%	3%
610	12338	5%	5%
	TOTAL:	***100%***	***100%***

SAMPLE: Probabilities of all cutback amounts from any month y to December

This sample shows all the possible cutback quantities that may occur between **February - December**, and **October - December**, much like the January - December table in Appendix C-2. Lookup tables like these are calculated for month y through December, where y is month January, February, March ..., December.
For each December elevation, all cutback quantities are **mutually exclusive.**

These lookup tables provide the Q_x and $P(Q_x)_y$ values for Equations 5.5 and 5.6 (Options Alt.)

Sample 1: February - December

J17 elevation in December	Total cutback quantity, Q_x	Probability of occurrance, $P(Q_x)_y$	Probability of all cutbacks quantities
700	None	None	None
690	781	8%	100%
	TOTAL:	***8%***	***100%***
680	781	23%	94%
680	1511	2%	6%
	TOTAL:	***25%***	***100%***
670	781	16%	45%
670	1511	13%	36%
670	1759	3%	9%
670	2489	3%	9%
	TOTAL:	***34%***	***100%***
660	781	23%	42%
660	978	3%	6%
660	1511	5%	8%
660	1759	6%	11%
660	2489	19%	33%
	TOTAL:	***56%***	***100%***
650	781	19%	27%
650	978	5%	7%
650	1511	6%	9%
650	1759	9%	13%
650	2489	27%	38%
650	3460	5%	7%
	TOTAL:	***70%***	***100%***
640	781	6%	9%
640	978	2%	2%
640	1759	13%	17%
640	1949	2%	2%
640	2489	20%	28%
640	2730	2%	2%
640	3460	27%	37%
640	4081	2%	2%
	TOTAL:	***72%***	***100%***
630	562	16%	16%
630	1219	3%	3%
630	1343	5%	5%
630	1540	2%	2%
630	2322	8%	8%

continued on next page

cont.

Appendix C-3

J17 elevation in December	Total cutback quantity, Q_x	Probability of occurrance, $P(Q_x)_y$	Probability of all cutbacks quantities
630	3052	16%	16%
630	3293	5%	5%
630	3314	2%	2%
630	4023	17%	18%
630	4643	2%	2%
630	4826	2%	2%
630	5300	2%	2%
630	5446	2%	2%
630	5483	9%	10%
630	6103	9%	10%
	TOTAL:	***97%***	***100%***
620	562	5%	5%
620	1219	2%	2%
620	1343	2%	2%
620	1781	5%	5%
620	2000	2%	2%
620	2482	3%	3%
620	3453	2%	2%
620	3541	2%	2%
620	3709	5%	5%
620	3950	2%	2%
620	4023	2%	2%
620	4271	2%	2%
620	4512	5%	5%
620	4680	5%	5%
620	4753	2%	2%
620	5242	9%	10%
620	5315	2%	2%
620	5483	3%	3%
620	5943	2%	2%
620	6045	3%	3%
620	6746	6%	6%
620	6753	2%	2%
620	7366	2%	2%
620	7483	13%	13%
620	8104	16%	16%
620	8885	2%	2%
	TOTAL:	***98%***	***100%***
610	1219	2%	2%
610	1781	3%	3%
610	2482	3%	3%
610	2562	2%	2%
610	3453	2%	2%
610	3920	2%	2%
610	4271	3%	3%
610	4680	2%	2%
610	4972	3%	3%
610	4994	2%	2%
610	5943	2%	2%
610	6016	2%	2%

continued on next page

cont.

J17 elevation in December	Total cutback quantity, Q_x	Probability of occurrance, $P(Q_x)_y$	Probability of all cutbacks quantities
610	6045	2%	2%
610	6432	2%	2%
610	6746	2%	2%
610	6753	6%	6%
610	7410	2%	2%
610	7483	25%	25%
610	8104	11%	11%
610	8140	6%	6%
610	8761	5%	5%
610	8885	2%	2%
610	8921	5%	5%
610	9542	3%	3%
610	10520	5%	5%
	TOTAL:	***98%***	***100%***

Sample 2: October - December

J17 elevation in December	Total cutback quantity, Q_x	Probability of occurrance, $P(Q_x)_y$	Probability of all cutbacks quantities
700	None	None	None
690	None	None	None
680	730	2%	100%
	TOTAL:	***2%***	***100%***
670	730	16%	100%
	TOTAL:	***16%***	***100%***
660	730	23%	100%
	TOTAL:	***23%***	***100%***
650	730	38%	100%
	TOTAL:	***38%***	***100%***
640	730	47%	97%
640	1351	2%	3%
	TOTAL:	***48%***	***100%***
630	730	44%	76%
630	1351	14%	24%
	TOTAL:	***58%***	***100%***
620	730	48%	72%
620	1351	19%	28%
	TOTAL:	***67%***	***100%***
610	730	47%	65%
610	1351	25%	35%
	TOTAL:	***72%***	***100%***

Appendix D

Examples of Expected Cost Analysis

Appendix D-1

Total Expected Cost to SAWS for the "Do Nothing" Alternative

Parameters

Simulation period: Jan - Dec
Starting month: December
Withdrawal rate: Average
Price of Shortfalls, C: $ 500/AF

Equation used: Equation 5.2
Tables used: Tables 5.1, 5.2

J17 elevation in Dec	Expected Cost of Shortfalls for Month (5%, 10%, 15% cutbacks aggregated)												TOTAL
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
700	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
690	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 30,514	$ -	$ -	$ -	$ 30,514
680	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 97,644	$ 5,703	$ -	$ -	$ 103,347
670	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 30,571	$ 134,260	$ 57,035	$ -	$ -	$ 221,866
660	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 137,568	$ 207,493	$ 85,552	$ -	$ -	$ 430,614
650	$ -	$ -	$ -	$ -	$ -	$ -	$ 22,757	$ 221,638	$ 256,315	$ 136,884	$ -	$ -	$ 637,594
640	$ 293,502	$ -	$ -	$ -	$ -	$ -	$ 151,713	$ 320,993	$ 268,521	$ 176,808	$ 4,848	$ -	$ 1,216,385
630	$ 534,931	$ 272,285	$ 76,997	$ -	$ -	$ 94,108	$ 235,155	$ 359,206	$ 292,932	$ 211,029	$ 43,632	$ -	$ 2,120,275
620	$ 601,205	$ 478,694	$ 302,856	$ 164,261	$ 120,971	$ 207,037	$ 341,354	$ 382,134	$ 323,445	$ 245,250	$ 58,176	$ -	$ 3,225,384
610	$ 894,707	$ 548,961	$ 420,918	$ 306,620	$ 270,745	$ 313,692	$ 386,868	$ 420,348	$ 390,575	$ 262,361	$ 77,568	$ -	$ 4,293,363

All expected costs in this table are non-pecuniary costs of shortfalls, as calculated by Equation 5.2, using Tables 5.1 and 5.2.

SAMPLE: Total Expected Cost to SAWS for the Lease Alternative (sample uses lease quantity of 2,489 AF)

Parameters:
Simulation period: Jan - Dec
Starting month: December
Withdrawal rate: Average
Shortfalls Price C: $ 500/AF

Contract details:
Lease price in Jan, P_L: $ 50/AF
Lease quantity, L (INPUT): 2489

Equations used: Equations 5.3 and 5.4
Table used: Lookup Table showing the Qx values (Appendix C-2).

		Expected Cost for Total Cutback Quantity Qx												
J17 Dec. elevation	Lease Cost	606	781	978	1168	1387	1511	1584	1759	1774	1949	2146	2365	2431
700	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
690	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
680	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
670	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
660	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
650	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
640	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
630	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
620	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
610	$ 124,473	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

	Expected Cost for Total Cutback Quantity Qx (... cont.)													
elevation	2489	2555	2927	2993	3095	3212	3336	3460	3533	3599	3658	3694	3898	4066
700	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
690	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
680	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
670	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
660	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
650	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 22,757	$ -	$ -	$ -	$ -	$ -	$ -
640	$ -	$ 513	$ -	$ -	$ 61,541	$ -	$ 6,616	$ -	$ -	$ -	$ -	$ -	$ -	$ 209,432
630	$ -	$ 1,027	$ 10,266	$ -	$ -	$ -	$ -	$ -	$ 16,312	$ -	$ 9,126	$ -	$ 11,008	$ -
620	$ -	$ 513	$ -	$ 11,806	$ -	$ 5,646	$ -	$ -	$ -	$ -	$ -	$ 18,822	$ -	$ -
610	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 17,339	$ -	$ -	$ -	$ -

cont.

	Expected Cost for Total Cutback Quantity Qx (... cont.)													
elevation	4263	4300	4380	4504	4526	4629	4665	4687	4753	4921	5161	5234	5271	5483
700	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
690	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
680	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
670	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
660	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
650	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
640	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 17,168	$ -	$ -	$ -	$ -	$ -	$ -
630	$ 124,735	$ -	$ -	$ 31,483	$ 15,913	$ 33,422	$ -	$ -	$ -	$ -	$ -	$ 193,006	$ -	$ -
620	$ -	$ -	$ -	$ -	$ -	$ -	$ 16,996	$ -	$ 17,681	$ 56,978	$ 20,875	$ 21,445	$ -	$ 23,384
610	$ -	$ 28,289	$ 14,772	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 21,730	$ -

	Expected Cost for Total Cutback Quantity Qx (... cont.)													
elevation	5724	5738	5855	5891	5964	6037	6089	6454	6497	6512	6527	6658	6695	6789
700	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
690	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
680	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
670	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
660	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
650	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
640	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
630	$ -	$ -	$ 26,293	$ -	$ -	$ 27,719	$ -	$ -	$ -	$ 31,426	$ -	$ 32,567	$ 197,113	$ -
620	$ 75,799	$ -	$ -	$ 79,735	$ 27,149	$ -	$ -	$ 185,820	$ -	$ -	$ 31,540	$ -	$ 65,704	$ -
610	$ -	$ 25,381	$ -	$ -	$ -	$ -	$ 56,236	$ -	$ 31,312	$ -	$ -	$ -	$ -	$ 67,187

	Expected Cost for Total Cutback Quantity Qx (... cont.)													
elevation	6811	7154	7257	7315	7760	7833	7863	7958	7965	8250	8563	8571	8578	8695
700	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
690	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
680	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
670	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
660	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
650	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
640	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
630	$ -	$ -	$ -	$ 226,201	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
620	$ -	$ 36,445	$ 74,488	$ -	$ -	$ -	$ -	$ 170,877	$ 42,776	$ -	$ -	$ -	$ 47,567	$ 387,838
610	$ 33,765	$ -	$ -	$ -	$ 41,179	$ 41,750	$ 41,978	$ -	$ -	$ 45,001	$ 47,453	$ 190,040	$ -	$ -

cont.

Appendix D-2

	Expected Cost for Total Cutback Quantity Qx (... cont.)											
elevation	9228	9301	9315	9921	9958	10097	10578	10702	10739	11360	12338	TOTAL
700	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 124,473
690	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 124,473
680	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 124,473
670	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 124,473
660	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 124,473
650	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 147,230
640	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 419,743
630	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,112,090
620	$ -	$ -	$ 533,277	$ -	$ -	$ 59,430	$ -	$ -	$ -	$ -	$ -	$ 2,137,066
610	$ 52,643	$ 851,418	$ -	$ 406,431	$ 233,387	$ -	$ 189,584	$ 64,164	$ 193,349	$ 138,595	$ 230,820	$ 3,188,277

All expected costs in this table, except in the Lease Cost column, are non-pecuniary costs of shortfalls that result from having cutbacks that exceed the lease quantity (which is 2,489 AF for this sample).

SAMPLE: Total Expected Cost to SAWS for the Options Alternative (sample uses option quantity of 2,489 AF)

Parameters:
Simulation period: Jan - Dec
Starting month: December
Withdrawal rate: Average
Shortfalls Price C: $ 500/AF

Contract details:
Options contact price, C_O: $ 20/AF
Options exercise price, C_E: $ 50/AF
Option quantity, Q (INPUT): 2489

Equations used: Equations 5.5 and 5.6
Tables used: Lookup Tables showing the Qx values (Appendix C-3).

SAMPLE: This sample only shows the calculations for exercise months February and October, but in actuality, all possible exercise months are analyzed (Jan, Feb, Mar, ... , Dec)

Exercise Month: **February:**

J17 Dec. elevation	Contract cost	Pre-exercise date shortfall costs	*Expected Cost for Total Cutback Quantity Q_x*						TOTAL
			562	781	978	1219	***and so on until..***	10520	
700	$ 49,789	$ -	$ -	$ -	$ -	$ -	...	$ -	$ 49,789
690	$ 49,789	$ -	$ -	$ 3,051	$ -	$ -	...	$ -	$ 52,841
680	$ 49,789	$ -	$ -	$ 9,154	$ -	$ -	...	$ -	$ 60,124
670	$ 49,789	$ -	$ -	$ 6,103	$ -	$ -	...	$ -	$ 71,976
660	$ 49,789	$ -	$ -	$ 9,154	$ 1,529	$ -	...	$ -	$ 92,851
650	$ 49,789	$ -	$ -	$ 7,323	$ 2,293	$ -	...	$ -	$ 134,030
640	$ 49,789	$ 293,502	$ -	$ 2,441	$ 764	$ -	...	$ -	$ 564,524
630	$ 49,789	$ 534,931	$ 4,392	$ -	$ -	$ 1,905	...	$ -	$ 1,274,946
620	$ 49,789	$ 601,205	$ 1,318	$ -	$ -	$ 952	...	$ -	$ 2,248,544
610	$ 49,789	$ 894,707	$ -	$ -	$ -	$ 952	...	$ 194,050	$ 3,259,392

Exercise Month: **October:**

J17 Dec. elevation	Contract cost	Pre-exercise date shortfall costs	*Expected Cost for Total Cutback Quantity Q_x*		TOTAL
			730	1351	
700	$ 49,789	$ -	$ -	$ -	$ 49,789
690	$ 49,789	$ 30,514	$ -	$ -	$ 80,303
680	$ 49,789	$ 97,644	$ 570	$ -	$ 148,003
670	$ 49,789	$ 164,831	$ 5,703	$ -	$ 220,324
660	$ 49,789	$ 345,061	$ 8,555	$ -	$ 403,406
650	$ 49,789	$ 500,710	$ 13,688	$ -	$ 564,188
640	$ 49,789	$ 1,034,728	$ 17,110	$ 1,055	$ 1,102,683
630	$ 49,789	$ 1,865,613	$ 15,970	$ 9,496	$ 1,940,869
620	$ 49,789	$ 2,921,958	$ 17,681	$ 12,662	$ 3,002,090
610	$ 49,789	$ 3,953,435	$ 17,110	$ 16,882	$ 4,037,217

Analysis continued on next page

After calculating the total expected cost for each possible exercise month, the total expected costs are compared and the minimum indicates the best exercise month. Optimization minimizes a cell in the column labelled "Minimum Expected Cost" by changing O

Comparing the total expected cost of every possible exercise month (note totals for February and October, calculated last page):

J17 Dec. Elevation	**Total Expected Cost to SAWS for options with exercise month of ...** January	February	March	April	May	June
700	$ 49,789	$ 49,789	$ 49,789	$ 49,789	$ 49,789	$ 49,789
690	$ 52,841	$ 52,841	$ 52,841	$ 52,841	$ 52,841	$ 52,841
680	$ 60,124	$ 60,124	$ 60,124	$ 60,124	$ 60,124	$ 60,124
670	$ 71,976	$ 71,976	$ 71,976	$ 71,976	$ 71,976	$ 71,976
660	$ 92,851	$ 92,851	$ 92,851	$ 92,851	$ 92,851	$ 92,851
650	$ 134,030	$ 134,030	$ 134,030	$ 134,030	$ 134,030	$ 134,030
640	$ 437,171	$ 564,524	$ 564,524	$ 564,524	$ 564,524	$ 564,524
630	$ 1,150,672	$ 1,274,946	$ 1,357,949	$ 1,367,188	$ 1,367,188	$ 1,367,188
620	$ 2,183,661	$ 2,248,544	$ 2,313,427	$ 2,356,751	$ 2,376,462	$ 2,381,646
610	$ 3,236,549	$ 3,259,392	$ 3,303,485	$ 3,344,653	$ 3,369,292	$ 3,379,507

J17 Dec. Elevation	**Total Expected Cost to SAWS for options with exercise month of ...** July	August	September	October	November	December
700	$ 49,789	$ 49,789	$ 49,789	$ 49,789	$ 49,789	$ 49,789
690	$ 52,841	$ 52,841	$ 52,841	$ 80,303	$ 80,303	$ 80,303
680	$ 60,124	$ 60,124	$ 60,124	$ 148,003	$ 153,137	$ 153,137
670	$ 71,976	$ 71,976	$ 99,489	$ 220,324	$ 271,655	$ 271,655
660	$ 92,851	$ 92,851	$ 216,662	$ 403,406	$ 480,403	$ 480,403
650	$ 134,030	$ 134,030	$ 333,504	$ 564,188	$ 687,383	$ 687,383
640	$ 564,524	$ 576,484	$ 881,015	$ 1,102,683	$ 1,261,811	$ 1,266,174
630	$ 1,370,987	$ 1,393,213	$ 1,677,230	$ 1,940,869	$ 2,130,795	$ 2,170,064
620	$ 2,387,293	$ 2,424,919	$ 2,713,966	$ 3,002,090	$ 3,222,815	$ 3,275,173
610	$ 3,395,985	$ 3,447,265	$ 3,703,563	$ 4,037,217	$ 4,273,342	$ 4,343,153

Therefore,

J17 Dec. Elevation	Minimum Expected Cost	Best exercise month(s)
700	[redacted]	Jan-Dec
690	[redacted]	Jan-Sep
680	[redacted]	Jan-Sep
670	[redacted]	Jan-Aug
660	[redacted]	Jan-Aug
650	[redacted]	Jan-Aug
640	[redacted]	Jan
630	[redacted]	Jan
620	[redacted]	Jan
610	[redacted]	Jan

Appendix D-4

Tables of Minimum Expected Cost and Optimum Amount of Water to Obtain or Each Alternative, Using Different Shortfall Prices, C ($100/AF - $700/AF)

These results were used in producing Figure 5.5 to test sensitivity of best solution to changes in C

C = $100/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 6,103	$ 6,103	$ 6,103	0	0
680	$ 20,669	$ 20,669	$ 20,669	0	0
670	$ 44,373	$ 44,373	$ 44,373	0	0
660	$ 86,123	$ 81,241	$ 79,776	781	781
650	$ 127,519	$ 111,344	$ 112,630	978	1759
640	$ 243,277	$ 183,424	$ 197,874	2662	3095
630	$ 424,055	$ 293,046	$ 336,252	4263	4629
620	$ 645,077	$ 420,656	$ 498,739	6454	7257
610	$ 858,673	$ 511,524	$ 638,594	9301	9301

C = $200/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 12,205	$ 12,205	$ 12,205	0	0
680	$ 41,339	$ 41,339	$ 27,669	0	781
670	$ 88,746	$ 74,100	$ 58,160	781	1511
660	$ 172,246	$ 115,347	$ 92,851	1582	2489
650	$ 255,038	$ 133,576	$ 120,376	2489	2489
640	$ 486,554	$ 205,257	$ 204,420	4066	4066
630	$ 848,110	$ 341,001	$ 354,645	5828	6695
620	$ 1,290,154	$ 458,515	$ 510,677	8695	9315
610	$ 1,717,345	$ 544,433	$ 658,221	9943	10702

C = $300/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 18,308	$ 18,308	$ 18,308	0	0
680	$ 62,008	$ 42,480	$ 28,809	781	781
670	$ 133,120	$ 87,058	$ 61,992	1511	1511
660	$ 258,368	$ 124,473	$ 92,851	2489	2489
650	$ 382,556	$ 138,127	$ 124,927	2489	2489
640	$ 729,831	$ 206,227	$ 205,390	4066	4066
630	$ 1,272,165	$ 352,179	$ 358,329	6695	7315
620	$ 1,935,230	$ 469,432	$ 511,898	9315	9315
610	$ 2,576,018	$ 563,825	$ 667,700	10578	10739

Appendix D-4

C = $400/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 24,411	$ 24,411	$ 18,674	0	781
680	$ 82,678	$ 43,620	$ 29,950	781	781
670	$ 177,493	$ 90,891	$ 65,360	1511	1759
660	$ 344,491	$ 124,473	$ 92,851	2489	2489
650	$ 510,075	$ 142,679	$ 129,478	2489	2489
640	$ 973,108	$ 207,197	$ 206,359	4066	4066
630	$ 1,696,220	$ 357,997	$ 358,329	6695	7315
620	$ 2,580,307	$ 470,652	$ 513,118	9315	9315
610	$ 3,434,691	$ 574,684	$ 672,577	10713	11360

C = $500/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 30,514	$ 30,514	$ 18,674	0	781
680	$ 103,347	$ 44,761	$ 31,091	781	781
670	$ 221,866	$ 94,724	$ 67,641	1511	1759
660	$ 430,614	$ 124,473	$ 92,851	2489	2489
650	$ 637,594	$ 147,230	$ 132,968	2489	3460
640	$ 1,216,385	$ 208,166	$ 207,329	4066	4066
630	$ 2,120,275	$ 363,815	$ 358,329	6695	7315
620	$ 3,225,384	$ 471,873	$ 514,339	9315	9315
610	$ 4,293,363	$ 584,118	$ 676,092	10739	12338

C = $600/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 36,616	$ 36,616	$ 18,674	0	781
680	$ 124,017	$ 45,902	$ 32,232	781	781
670	$ 266,239	$ 98,556	$ 69,923	1511	1759
660	$ 516,737	$ 124,473	$ 92,851	2489	2489
650	$ 765,113	$ 151,781	$ 132,968	2489	3460
640	$ 1,459,661	$ 209,136	$ 208,299	4066	4066
630	$ 2,544,329	$ 365,754	$ 358,329	7315	7315
620	$ 3,870,461	$ 473,094	$ 515,560	9315	9315
610	$ 5,152,036	$ 593,551	$ 676,092	10739	12338

Appendix D-4

C = $700/AF

	Minimum Expected Cost for ...				Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 42,719	$ 39,058	$ 18,674		781	781
680	$ 144,686	$ 47,042	$ 33,372		781	781
670	$ 310,612	$ 102,389	$ 71,976		1511	2489
660	$ 602,859	$ 124,473	$ 92,851		2489	2489
650	$ 892,631	$ 156,333	$ 132,968		2489	3460
640	$ 1,702,938	$ 210,105	$ 209,268		4066	4066
630	$ 2,968,384	$ 365,754	$ 358,329		7315	7315
620	$ 4,515,537	$ 474,314	$ 516,780		9315	9315
610	$ 6,010,709	$ 600,076	$ 676,092		11360	12338

Tables of Minimum Expected Cost and Optimum Amount of Water to Obtain or Each Alternative, Using Different Lease and Options Exercise Prices

These results were used in producing Figure 5.6 to test sensitivity of best solution to changes in P_L, C_E

Prices = $10/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 30,514	$ 7,812	$ 16,233	781	781
680	$ 103,347	$ 13,515	$ 23,279	781	781
670	$ 221,866	$ 24,895	$ 50,804	2489	1759
660	$ 430,614	$ 24,895	$ 58,402	2489	2489
650	$ 637,594	$ 34,604	$ 81,960	3460	3460
640	$ 1,216,385	$ 45,512	$ 110,406	4066	4066
630	$ 2,120,275	$ 73,151	$ 188,707	7315	7315
620	$ 3,225,384	$ 99,257	$ 256,796	9315	9315
610	$ 4,293,363	$ 123,378	$ 332,623	12338	12338

Prices = $20/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 30,514	$ 30,514	$ 16,844	0	781
680	$ 103,347	$ 21,327	$ 25,232	781	781
670	$ 221,866	$ 46,595	$ 55,014	1759	1759
660	$ 430,614	$ 49,789	$ 67,014	2489	2489
650	$ 637,594	$ 69,209	$ 94,712	3460	3460
640	$ 1,216,385	$ 86,175	$ 134,637	4066	4066
630	$ 2,120,275	$ 146,302	$ 231,112	7315	7315
620	$ 3,225,384	$ 192,411	$ 321,182	9315	9315
610	$ 4,293,363	$ 246,756	$ 418,491	12338	12338

Prices = $30/AF

	Minimum Expected Cost for ...			Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option	Lease	Option
700	$ -	$ -	$ -	0	0
690	$ 30,514	$ 23,435	$ 17,454	781	781
680	$ 103,347	$ 29,138	$ 27,185	781	781
670	$ 221,866	$ 64,189	$ 59,223	1759	1759
660	$ 430,614	$ 74,684	$ 75,626	2489	2489
650	$ 637,594	$ 97,441	$ 107,464	2489	3460
640	$ 1,216,385	$ 126,839	$ 158,867	4066	4066
630	$ 2,120,275	$ 219,452	$ 273,518	7315	7315
620	$ 3,225,384	$ 285,565	$ 385,568	9315	9315
610	$ 4,293,363	$ 363,714	$ 504,358	11360	12338

Appendix D-5

Prices = $40/AF

	Minimum Expected Cost for ...				Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 30,514	$ 30,514	$ 18,064		0	781
680	$ 103,347	$ 36,950	$ 29,138		781	781
670	$ 221,866	$ 79,612	$ 63,432		1511	1759
660	$ 430,614	$ 99,578	$ 84,238		2489	2489
650	$ 637,594	$ 122,335	$ 120,216		2489	3460
640	$ 1,216,385	$ 167,503	$ 183,098		4066	4066
630	$ 2,120,275	$ 292,603	$ 315,923		7315	7315
620	$ 3,225,384	$ 378,719	$ 449,953		9315	9315
610	$ 4,293,363	$ 476,728	$ 590,225		10739	12338

Prices = $50/AF

	Minimum Expected Cost for ...				Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 30,514	$ 30,514	$ 18,674		0	781
680	$ 103,347	$ 44,761	$ 31,091		781	781
670	$ 221,866	$ 94,724	$ 67,641		1511	1759
660	$ 430,614	$ 124,473	$ 92,851		2489	2489
650	$ 637,594	$ 147,230	$ 132,968		2489	3460
640	$ 1,216,385	$ 208,166	$ 207,329		4066	4066
630	$ 2,120,275	$ 363,815	$ 358,329		6695	7315
620	$ 3,225,384	$ 471,873	$ 514,339		9315	9315
610	$ 4,293,363	$ 584,118	$ 676,092		10739	12338

Prices = $60/AF

	Minimum Expected Cost for ...				Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 30,514	$ 30,514	$ 19,285		0	781
680	$ 103,347	$ 52,573	$ 33,044		781	781
670	$ 221,866	$ 109,836	$ 71,850		1511	1759
660	$ 430,614	$ 149,368	$ 101,463		2489	2489
650	$ 637,594	$ 172,125	$ 145,720		2489	3460
640	$ 1,216,385	$ 248,830	$ 231,560		4066	4066
630	$ 2,120,275	$ 430,760	$ 400,734		6695	7315
620	$ 3,225,384	$ 565,027	$ 578,725		9315	9315
610	$ 4,293,363	$ 691,508	$ 761,960		10739	12338

Appendix D-5

Prices = $70/AF

J17 Dec. Elevation	Minimum Expected Cost for ...				Optimum Amount to	
	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 30,514	$ 30,514	$ 19,895		0	781
680	$ 103,347	$ 60,384	$ 34,997		781	781
670	$ 221,866	$ 124,948	$ 76,060		1511	1759
660	$ 430,614	$ 174,262	$ 110,075		2489	2489
650	$ 637,594	$ 197,019	$ 158,472		2489	3460
640	$ 1,216,385	$ 289,493	$ 255,790		4066	4066
630	$ 2,120,275	$ 497,705	$ 443,140		6695	7315
620	$ 3,225,384	$ 658,181	$ 643,110		9315	9315
610	$ 4,293,363	$ 798,624	$ 847,827		10702	12338

Prices = $80/AF

J17 Dec. Elevation	Minimum Expected Cost for ...				Optimum Amount to	
	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 30,514	$ 30,514	$ 20,505		0	781
680	$ 103,347	$ 68,196	$ 36,950		781	781
670	$ 221,866	$ 140,060	$ 80,269		1511	1759
660	$ 430,614	$ 199,157	$ 118,687		2489	2489
650	$ 637,594	$ 221,914	$ 170,920		2489	2489
640	$ 1,216,385	$ 330,157	$ 280,021		4066	4066
630	$ 2,120,275	$ 564,651	$ 485,545		6695	7315
620	$ 3,225,384	$ 751,335	$ 707,496		9315	9315
610	$ 4,293,363	$ 904,447	$ 933,388		10578	11360

Prices = $90/AF

J17 Dec. Elevation	Minimum Expected Cost for ...				Optimum Amount to	
	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 30,514	$ 30,514	$ 21,115		0	781
680	$ 103,347	$ 76,007	$ 38,902		781	781
670	$ 221,866	$ 155,172	$ 84,478		1511	1759
660	$ 430,614	$ 224,052	$ 127,300		2489	2489
650	$ 637,594	$ 246,809	$ 183,217		2489	2489
640	$ 1,216,385	$ 370,821	$ 304,252		4066	4066
630	$ 2,120,275	$ 631,596	$ 527,951		6695	7315
620	$ 3,225,384	$ 841,968	$ 771,881		8695	9315
610	$ 4,293,363	$ 1,010,231	$ 1,018,797		10578	11360

Appendix D-5

Prices = $100/AF

	Minimum Expected Cost for ...				Optimum Amount to	
J17 Dec. Elevation	Do Nothing	Lease	Option		Lease	Option
700	$ -	$ -	$ -		0	0
690	$ 30,514	$ 30,514	$ 21,726		0	781
680	$ 103,347	$ 83,819	$ 40,855		781	781
670	$ 221,866	$ 165,721	$ 88,687		781	1759
660	$ 430,614	$ 244,383	$ 135,912		1759	2489
650	$ 637,594	$ 271,703	$ 195,514		2489	2489
640	$ 1,216,385	$ 411,484	$ 328,483		4066	4066
630	$ 2,120,275	$ 698,313	$ 570,356		6658	7315
620	$ 3,225,384	$ 928,917	$ 836,267		8695	9315
610	$ 4,293,363	$ 1,112,136	$ 1,104,206		9958	11360