TECHNICAL REPORT

ECONOMIC AND HYDROLOGIC IMPLICATIONS OF PROPOSED EDWARDS AQUIFER MANAGEMENT PLANS

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Economic and Hydrologic Implications of Proposed Edwards Aquifer Management Plans

Executive Summary

The Edwards Aquifer underlies a large region in south central Texas extending from west of Uvalde to Austin. The karstic aquifer supports irrigated agriculture in the western part of the region, provides the sole source of water supply for San Antonio in the central portion and provides for spring flow-based recreation and municipal water supply in the eastern part of the region. In addition, spring flows and return flows from cities provide water supplies for downstream users and freshwater inflows to maintain productivity of bays and estuaries. The spring flows also support several threatened and endangered species unique to that ecosystem.

Despite the varied and growing demand on Edwards Aquifer water, pumpage is unregulated since, according to Texas water law, ground water is a property right vested with the land owner. Throughout at least the past two decades, attempts to negotiate voluntary management plans to restrict pumpage have been unsuccessful, even though demand is projected to exceed average recharge near the turn of the century.

A recent court ruling has increased the pressure for adoption of an Aquifer management plan. Acting on a suit brought to ensure spring flow and aquatic habitat protection under the Endangered Species Act, the court ruled that a management plan be developed and approved by the Texas Legislature by May 31, 1993. Should the Legislature fail, the court would implement its own plan.

In 1992, two management plans were drafted by the Texas Water Commission (TWC) but were not adopted. Since Texas Legislature is considering plans similar to the TWC plans, a study was undertaken to evaluate the hydrologic and economic implications of these TWC plans. Both plans propose imposition of pumping limits based on water elevation in a reference well located in San Antonio. Four variants of the plans were analyzed using an annual economic/hydrologic simulation model of the aquifer. The model simulates water use by the agricultural, industrial and municipal sectors while simultaneously forecasting annual spring flow and year-end water elevations. Model solutions depict optimum water allocations among sectors based on economic welfare maximization. The model also accounts for uncertainty in the incidence of elevation-triggered pumping limits and recharge amounts. When the value of water is optimized in an economic sense, the model predicts an annual loss in regional economic activity of between $6.26 and $19.58 per acre foot that pumpage is reduced.

Under a 1988 demand scenario, annual welfare is reduced between $0.73 and $1.57 million across the plans. The annual loss rises to between $2.38 and $6.60 million under estimated year 2000 demand conditions. Agricultural water use is the most pivotal: under year 2000 demands, irrigated acres decline by 32% to 84% while net agricultural income falls annually by $1 million (13%) to $2.5 million (36%). Simultaneously, the municipal and industrial sector welfare is reduced annually by between $0.8 million (2%) and $5.7 million (8%).

The benefits from all management plans are increased spring flows at Comal and San Marcos springs and higher ending aquifer levels. However, none of the proposed plans is forecast to guarantee flows at Comal springs given a repeat of the 1950's drought.

The model assumes that low valued users would allow higher valued users to displace their water use, a result that is unlikely in the absence of compensation. Thus, a rights structure was also examined where the irrigated agriculture sector (generally a low valued user) is guaranteed water usage at the 1988 level. The results demonstrate that while agricultural welfare is raised, municipal, industrial and total welfare is reduced by more than the agricultural gain. In other words, agricultural gains are achieved at the expense of municipal and industrial welfare. Equivalently, without an agricultural guarantee, the municipal and industrial gains are achieved at agriculture's expense. One set of results reveals a year 2000 agricultural use value equals about $19 per acre foot while non-agricultural values are about $109 per acre foot.

The results suggest the desirability of simultaneously implementing water market mechanisms to allow water use reallocation along with plan-induced pumpage restrictions. An unchanging allocation of pumping use causes growing disparity in sectoral water values as demand grows ($90 per acre foot in the above example). The simultaneous imposition of pumpage limits, water rights and water markets appears necessary to maintain economic efficiency. The results show that allowing water sales through a market mechanism could return as much as $11 million annually, while allowing both water sales and leasing is worth an additional $1 million. Markets would allow economic agents to seek out the highest valued uses of scarce aquifer water resources and provide compensation to those users reducing their usage.

Economic and Hydrologic Implications of

Proposed Edwards Aquifer Management Plans

The Edwards Aquifer (EA) near San Antonio, Texas is an important water source for agricultural, industrial, municipal and recreational uses. The San Antonio municipal area draws its water almost exclusively from the EA with recent (1988-90) municipal and industrial usage averaging close to 330,000 acre feet (af) per year. Recent use by the agricultural industry is near 190,000 af per year. The EA also supports springs at San Marcos and New Braunfels (Comal Springs) which provide habitat for endangered species (Longley), as well as spring flow supported recreation and downstream water usage. The EA is a fractured limestone formation which recharges very quickly. However, average recharge (637,000 af) is not a great deal larger than recent average use (518,000 af), leaving much less to support spring flow than the 50 year average (350,000 af).

There has been considerable concern regarding EA management. In recent years pumping has frequently exceeded recharge. As a consequence, spring flows have been felt to be in danger of cessation. Public action and concern regarding the Aquifer is manifest in the history of policy and private actions. In the late 1950s, the Edwards Underground Water District (EUWD) was formed to manage the Aquifer. In the late 1980s, the western agricultural counties seceded from the EUWD due to disagreements about drought management plans. In the early 1990s, lawsuits were filed requesting that the Aquifer be declared an underground river and that the endangered species in the springs be protected by insuring minimum levels of spring flow.

The Texas Water Commission (TWC) declared the Aquifer an underground river subject to surface water law during mid-1992, but this declaration was overturned by the courts during the fall of 1992. In early 1993, the district federal court upheld the endangered species lawsuit and ordered that pumping limits be imposed to protect EA spring flow with a plan for imposing the limits due to be put in place by May 31,1993 (Bunton). Another set of actions have involved the formation of drought management plans. The late 1980s saw one such plan proposed by the EUWD, while 1992 saw two draft plans released by the TWC. These plans restrict pumping under conditions of low aquifer elevation. Early 1993 legislative actions seem to favor imposition of a form of the TWC plans.

The various actions cited above indicate concern about the ability of the EA to meet the current and anticipated demands placed upon it, especially under drought conditions. These concerns are well founded for several reasons. Average recharge over the 1934-1991 period was 637,000 af and during this period annual pumping usage rose from a 1930s average of 113,000 af to a 1980s average of 462,000 af. Usage during 1988/90 averaged 518,000 af. Over the 50 year period, use increased annually by about 1.1% of average recharge. This usage expansion occurred both in the western agricultural areas (Uvalde, Kinney and Medina Counties), as well as in the eastern municipal and industrial use areas (Bexar, Hays and Comal counties). In addition, 1991 saw the introduction of a catfish operation which used at least 25,000 af annually (although operations are now suspended). Water demand is only expected to increase.

Accompanying this usage expansion have been trends indicating increased aquifer sensitivity. Spring flow per acre foot of recharge has fallen about 1% per year. The difference between the beginning water level and the observed annual low has increased. For example, during the 1940s and 1950s the beginning year water level and the yearly low level differed on average by 2 feet while during the 1980s this difference averaged 24 feet. A regression indicates this difference has expanded by 0.5 feet per year. Furthermore, the EA was largely able to sustain spring flow through a severe seven year drought in the 1950s,[1] but in the late 1980s the water level went from a record high to virtually a record low after only two moderately low recharge years. Simultaneously, the flow at Comal springs came very close to ceasing.

In such a setting some form of public action is almost inevitable. This paper reports the results of an economic evaluation of recently proposed TWC drought management plans and the associated imposition of water markets.

The Drought Management Plans

During 1992, the TWC proposed two alternative EA drought management plans. The first plan proposed sectoral cutbacks in water use (TWC, 1992a). The cutbacks would be triggered when aquifer water levels at the J-17 reference well in San Antonio declined to selected elevation levels. Under the variant of the plan studied in Thorkildsen and McElhaney, water usage would continue without restriction when the J-17 water level exceeds 649 feet above sea level. However, when elevation falls below 649 while remaining above 633 feet, then water use would be reduced by 30% in the agricultural sector and 15% in the non-

[1] Comal Springs did cease flowing for several months during 1957.

agricultural sector. More severe cuts are proposed when the water elevation falls below 633 feet with the agricultural use reduction being 50%, while the municipal and industrial use reduction is 30%.[2] In the present analysis this plan will be referred to as the sectoral specific plan, or sectoral plan for short.

Subsequently, in the late summer, the TWC issued a second plan (TWC 1992b) which restricts overall use without imposing sectoral specific cutbacks. The plan is again based on J-17 reference well elevation. In the second plan, when the J-17 aquifer water elevation falls below 666 feet total water pumped by all users would be restricted in the first 10 years of the plan to 450,000 af, compared to the current usage level of 518,000 af. After 10 years this water use limit falls to 400,000 af. In addition, the second plan calls for water use reductions to 350,000 af if the J-17 level falls below 625 feet. This plan will be called the total limit plan, while its components will be called the 450,000 af and the 400,000 af limits.

The Analytical Framework

The EA management plans were analyzed using an annual economically and hydrologically based aquifer activity simulation model (EDSIM). EDSIM is an extension of the mathematical programming model which was used by Dillon; Williams; and Dillon and McCarl. EDSIM encompasses use by the agricultural, industrial and municipal sectors while simultaneously calculating ending elevation and spring flow. EDSIM chooses the sectoral water use pattern as well as the amount of irrigated and dryland acreage that maximizes the overall regional economic value. Regional value encompasses farmer profits, assuming farmers

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[2] This plan also mentioned compensation to agriculture when water use was restricted, but this option was not included in this study.

in the region are price takers, plus municipal and industrial (M&I) welfare. M&I welfare is measured as consumers' surplus, which equals the area under the demand curve above the water price for consumers of M&I goods and services. This measure gives a result equivalent to income changes for water at the well head after pumping. The municipal demand elasticity is drawn from Griffin and Chang while the industrial demand elasticity is drawn from Renzetti. The quantity demanded by M&I and agriculture interests is dependent upon rainfall and climatic conditions.

There are several key characteristics of the EDSIM framework which merit discussion. First, EDSIM is an optimization model. Water is allocated to the highest and best use in terms of generating greatest net economic value for the region. Thus, EDSIM is not constrained to simulate current use, but rather simulates best use in an economic sense. However, when pumping limits are not imposed (the "base" case), the EDSIM water use solution does correspond closely to water use in the current unrestricted pumping environment. Thus, when EDSIM is executed with the pumping limit plans imposed, the results simulate the "best" economic outcome that could arise under that plan as well as a comparison with the existing situation. Note, however, that "best" is defined from a total regional viewpoint not from the viewpoint of any sector, so water may be moved among sectors in the solution.

Second, EDSIM incorporates uncertainty. Two uncertain phenomena are modeled. One involves the chance that the J-17 water elevation will fall into an interval where pumping limits are imposed. The other involves the level of recharge. EDSIM maximizes the average value of the water supply considering that the total system will operate in each of the three J-17 elevation intervals a given percentage of the time while encountering events across the recharge distribution.[3] In dealing with uncertainty, the amount of agricultural irrigation equipment installed is restricted to be the same across all uncertain events. However, demand for water is conditional on the weather utilizing Griffin and Chang's weather elasticity for municipal usages and the Blaney-Criddle irrigation demand formula for the agricultural sector (see Dillon for details). Collectively, the model solution proscribes a level of optimum irrigation development and optimal sectoral water use which is dependent upon the pumping limit and recharge level.

Third, EDSIM incorporates hydrological information based upon a regression summary of the Texas Water Development Board's EA simulation model (Knowles, 1981). The regression results are used in determining pumping lift as well as in forecasting ending elevation and spring flow based on pumping, recharge and initial elevation (Dillon, McCarl, and Williams give details).

Fourth, EDSIM encompasses water use by the municipal, industrial and agricultural sectors. The agricultural submodel assumes farmers are profit maximizers choosing between dryland and irrigated production as well as establishing crop mix. The choice of irrigated acres depends on the weather situation (as given by the recharge scenario), water supply and installed irrigated acres. The M&I submodels derive an economic equilibrium given price dependent county level demand curves for those entities by intersecting the demand curve with the supply price. The supply price equals the pumping cost plus any water opportunity cost stimulated by pumping restrictions. Thus, EDSIM allocates water among sectors so that, to the extent

[3] The recharge distribution used herein is a 17 event representation of the recharge distribution observed from 1934-1990. Dillon discusses the development and statistical characteristics of the recharge distribution.

allowed by the pumping limit scenario, marginal productivity is equalized and the overall level of economic activity is maximized.

Most of the EDSIM data come from models formulated by Dillon and Williams, but the agricultural part was largely specified using data on the existing copping patterns from Pena and Jenson, while the agricultural impact multipliers were drawn from Jones and Wyse.

Fifth, EDSIM is run under both year 1988 and year 2000 demand conditions. The year 2000 conditions assume constant real prices with the municipal and industrial water demand expanding according to regional forecasts by the Texas Water Development Board.

Derivation of Probability for Various Water Levels

Thorkildsen and McElhaney conducted a hydrologic simulation analysis of the alternative trigger levels posed in the sectoral based drought management plans using the model in Knowles (1981). They calculated that 18% of the time the J-17 water elevation would be at 649 ft or above, 54% of the time it would be between 649 ft and 633 ft and 28% of the time it would be below 633 ft. Later, estimates were made for the 666 ft and 625 ft trigger levels in the total limit plan (Knowles, 1992). Those results indicate that 6.6% of the water levels would be above 666 ft, while 14% would be below 625 ft and 79.4% would fall between 625 ft and 666 ft. These latter probabilities are used in the present study.

Study Design

Several simulations were done to study the drought management plan implications. The first set dealt with the overall implications of drought management plan implementation. Two variants of the sectoral plan was imposed as were the 450,000 and 400,000 af limits suggested under the total limit plan. These simulations were done under both actual year 1988 and projected year 2000 demand. The variants of the sectoral plan involved two ways of imposing the agricultural limits: one reducing irrigated acreage and one reducing irrigation water use. The plans were only examined under the aquifer elevation triggers imposed in the total limit plan. Thus, we used the percentage water use reductions imposed by the sectoral plan, but the elevation triggers were 666 ft and 625 ft. Also, the sectoral plan appraisal was done assuming there is no compensation to any sector for restricted pumping.

Analyses were also done regarding the effect of a water rights allocation in the form of agricultural use guarantees under the 450,000 and 400,000 af limits. Here, agricultural use was guaranteed to equal recent average usage (~ 170,000 af). In turn, simulations were done relative to the reduction agriculture would take when water use is restricted to 350,000 af. The simulations involve a model determined "optimal" agricultural reduction and a proportional reduction where the agricultural reduction was equal in proportion to the total regional water use reduction. This analysis was done for both 450,000 and 400,000 af limits, but only under year 2000 demand.

Finally, a third analysis was done considering the potential for water markets.

Nature of EDSIM Output

The EDSIM results contain projections of welfare, water use, agricultural activity and hydrological activity. The welfare measures correspond to net agricultural income and M&I consumers' surplus as well as a total welfare sum across all sectors. The M&I consumers' surpluses are derived by computing the area under the demand curves less the water price times the quantity of water consumed. Changes in this surplus measure are interpretable as the change in income by these parties . Net agricultural income equals the sale value of agricultural products times the product yields less the cost of the inputs used including pumping cost. Total welfare is the M&I surplus measure plus the agricultural profits measure.

The results are also summarized in terms of

a) water use, including average water used by each party and water use by aquifer elevation level,

b) agricultural characteristics, including irrigated acreage developed, irrigated land use (which counts double cropping), dryland use, agricultural water use both on average and by elevation level, agricultural income on average and by elevation level, agricultural income standard deviation and an estimate of the induced income effects.[4] The regional induced economic impacts of changes in agricultural activity were calculated with multipliers from an input-output model (Jones and Wyse). These induced economic effects give an estimate of the change in regional economic activity due to alterations in agricultural activity but are not included in the overall welfare calculation as they would be offset by effects elsewhere (Stoevenor and Kraynick).

c) hydrological characteristics, where annual average and minimum spring flow at Comal and San Marcos springs as well as J-17 well ending elevation level are reported based on equations developed in a regression study (Dillon, McCarl

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[4] Neither of the last two items are valid welfare measures, so they are included in the agricultural characteristics section of the data.

and Williams) summarizing results from the Aquifer simulation model used by the Texas Water Development Board (Knowles, 1981)[5].

Analysis of the Drought Plans

The results of the drought management plan analyses are summarized in Tables 1 through 5. Table 1 contains welfare projections indicating that under 1988 demand, the total limit plans have smaller effects on the regional economy than the sectoral specific plans. In particular, the total limit plans reduce total welfare by 1.89% and 3.02%, whereas the sector limits cause 3.78% and 4.07% welfare losses. As demand grows to projected year 2000 levels, the plans become more restrictive, with the total limit plans cause a 4.81% to 6.96% reduction in welfare, while the sectoral limits cause reductions between 13.56% and 13.79%.

The plans have differing implications for the municipal, industrial and agricultural sectors. The 1988 municipal welfare reductions are minor, in the largest amounting to a 1.52% change. The largest welfare reduction for the industrial sector amounts to 2.66%. The notable result is that the most pivotal sector across the analyses is agriculture. The agricultural sector loses between 7.39% and 15.27% of its annual income with the loss rising to as much as 36.03% under year 2000 demand. Table 2 presents additional information on the agricultural

[5] The regression results should be interpreted with caution as it was found by the authors that the GWBSIM4 version used yielded results quite different from the current monthly version that was used Thorkildsen and McElhaney to derive their probabilities. Nevertheless, this information is presented to give an indication of the hydrological benefits of the water use limits.

impacts which shows that the drought management plans cause agriculture to rely more heavily on dryland production with irrigated acreage shifting under the 1988 demand scenario from as much as 91,200 acres to as little as 51,920 acres. This causes a reduction in net income of up to 15%, and an increase in the instability of agricultural income (as measured by the income standard deviation). The agricultural consequences are more severe as demand increases to year 2000 levels and irrigated acreage falls to as little as 14,970 acres.

EDSIM also generates data on the induced effects of the changes in agricultural income on the regional economy. However, before discussing these results a caveat is necessary. The induced income effect reported only considers the implications of changes in agricultural activity. Clearly, any reallocation to or reduction in M&I water use would cause changes in M&I gross income which would cause other induced income changes.[6] The increased spring flow would also cause gains to occur to those benefiting from spring flow. Thus the induced impact information presented here is biased. It is presented since a regional shift is implied with the agriculturally induced losses occurring largely in the western part of the region and the M&I changes and spring flow gains occurring in the central and eastern parts. The results show substantial reductions in agricultural induced income totaling as much as 22.59% and 55.83% for 1988 and 2000, respectively.

The results may also be examined in terms of welfare change per acre foot of water. Table 3 presents two types of marginal values. The first "computed" value, reports the change in sectoral welfare from the base model to that in the scenario being analyzed divided by the

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[6] The M&I induced income effects would, based on Jones findings, be larger per af than the agricultural effects; however, we did not have data to analyze them.

change in water use between those scenarios. The shadow price values are the average linear programming dual variables from the EDSIM constraints and are interpretable as the marginal change in total welfare due to a small alteration in water supply. These values are reported for the average of all recharge states under: a) the average situation with respect to elevation triggers; b) the cases where the elevation falls in the interval between 666 and 625; and c) the case where elevation falls below 625. The data show the average 1988 shadow value of agricultural water ranges between $12.28 and $21.42, while non-agricultural values range from $12.28 to $19.09. The associated average computed marginal values of water range from $13.32 to $19.58 in agriculture and $6.26 to $11.55 in M&I sectors. All values rise in the year 2000 scenario. These values can be interpreted as the minimum level of benefits that must accrue to those benefiting from the water use limits. Thus, on the margin, the annual benefits accruing from the water saved by the pumping limits must be at least $12.28 /af and that by year 2000, the opportunity cost of these restrictions rises to at least $26.51.

The sectoral limits show one other interesting result. Note that in Table 3, the value of agricultural water is approximately constant under the sectoral limits for both the 1988 and 2000 scenarios. However, note the value of water for M&I uses rises between 3- and 5-fold. This indicates that a water use plan which permanently allocates a given amount of water to the individual sectors causes a discrepancy in water use values as the municipal and industrial demand grows.

The water use implications of the four plans are shown in Table 4. Total water use is reduced most by the sectoral limits and the 400,000 af total limit. The largest water use adjustments under 1988 demand occur in agriculture. This reduction in water usage comes about through a substantial drop in irrigated acreage (Table 2), with between 32.23% and 33.46% less irrigated acreage under the sectoral cuts, while reductions of 20.94% and 44.54% occur under the total limit plans. Furthermore, agricultural water use is more severely reduced as regional demand grows to the year 2000 levels.

Table 5 reports the hydrological implications of these plans. Notice that under 1988 demand, the pumping limits increase spring flow at Comal Springs between 11.39% and 36.02%, while at San Marcos spring flow increases by 1.26% to 2.06%. Simultaneously, J-17 ending aquifer elevation increases by 0.46% to 0.89% (about 3 to 5 feet). The results show Minimum Comal Springs flow is zero while Minimum San Marcos spring flow increases by approximately nine percent. Thus, the model suggests that the restrictions are not severe enough to keep Comal Springs flowing year round if the severe drought events observed in the past recur.[7]

The hydrology results differ somewhat under year 2000 demand. The spring flow gains are larger due to the greater pumping use (over 100,000 af more in 2000). Simultaneously, spring flow is marginally smaller under the total limit plans between the 1988 and 2000 demand scenarios. This decline occurs since the year 2000 total limit scenario results exhibit slightly larger average water use than in the corresponding 1988 results.

Agricultural Water Use Guarantees

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[7] This is not a surprising result as an Edwards related Committee indicated that usage reductions to 250,000 af or below would be needed to maintain spring flow in the face of the 1950's drought. (Special Committee on the Edwards Aquifer)

The results described in the preceding sections arise from the EDSIM optimization model which allocates limited EA water so as to maximize total regional welfare. The EDSIM structure assumes that low valued users would forego use to allow higher valued users access to water. In practice, such an event would be unlikely without compensation. In this section we explore the implications of a rights structure where agriculture is guaranteed an amount of water greater than the EDSIM optimum level. In these analyses, agricultural water use for the 666/625 ft case is constrained to equal the 1988 unrestricted level of usage for that case (as in the "1988 base" columns of the above tables). Simultaneously, when the initial water level falls below 625 ft, agriculture is simulated as taking either the EDSIM determined "optimum" water use reduction or a reduction proportional to the reduction in the water use limit (i.e., reducing water use by the proportion 350/450 or 350/400 depending on the total limit imposed).

Table 6 presents the welfare and water use implications with the agricultural guarantee for the total usage limit scenarios and the year 2000 demand. The No Guarantee plan gives the EDSIM optimal results when agricultural water use is not restricted. The next two columns give the implications of the agricultural use guarantee under the 666/625 ft case and either a proportional or an optimal usage reduction when the 625 ft trigger is activated. The market column will be discussed in the next section.

The results demonstrate water use and economic welfare tradeoffs between the agricultural and non-agricultural sectors. Under guarantees, average agricultural welfare is $1.53 million (28%) higher under the 450,000 af limit, while it is about 58% higher under the 400,000 af limit. These welfare gains occur due to considerably higher agricultural water use associated with the guarantee. On the other hand, M&I total welfare is reduced by more than the agricultural gain. Thus, total welfare is reduced with the agricultural gains achieved at the expense of M&I, or equivalently, without an agricultural guarantee, the gains in the M&I sector would be achieved at agriculture's expense.

Table 6 also presents data on the value of water under the year 2000 scenario. These data are computed by dividing the welfare change from the No Guarantee model by the change in water use for each sector at the various aquifer trigger levels. The results show a large discrepancy in water use value between sectors which grows over time. For example, under the proportional share and 400,000 af limit, agricultural income rises from $4.53 million to $7.17 million while agricultural water use increases to 166,000 af as opposed to 26,620 af. This amounts to a welfare gain of $18.89 per af. Simultaneously, non-agricultural welfare is reduced from $40.61 million to $26.19 million or $108.64 per af. Thus, water values differ by $89.75 per af. A comparable calculation for 1988 conditions yields $39 per af. This growing difference in water value raises the possibility of M&I interests buying agricultural water through a water market thereby increasing the welfare of both sectors.

Water Markets

The above results raise the issue of water markets. Since EDSIM is an optimization model which does not consider the costs involved in transferring water, it is by nature a simulation of water use after an idealistic, no transaction cost, water market has acted. In order to examine the effects of a water market we need to impose water use distortions on EDSIM and, by comparison with the base model, evaluate the economic implications of removing these distortions.

Some combination of two market forms among several parties are relevant in such a setting. These forms are temporary (lease) and permanent (sale) markets. The parties that could be involved are: 1) spring flow interests; 2) agricultural interests; and 3) M&I interests. The costs of initiating a transfer to the parties representing the spring flow interests are dependent on the management plan. In particular, when one of the above EA management plans is imposed, the traditional pumped water users are forced to reduce their water use and therefore their welfare. Under those circumstances, the Table 3 average water values give the amount of money that would need to be transferred annually on a per acre foot basis ($6.26 to $19.58) to keep the existing water users at least as well off as they would be without the pumping restrictions. Data in Table 1 illustrate the total regional cost of restricting use. This amounts to an annual welfare loss (under 1988 demand) of between $0.73 and $1.57 million with the annual loss rising under year 2000 conditions to between $2.38 and $6.69 million. These results estimate the price or total compensation needed if water rights were established for existing users and that, in turn, the spring flow interests had to buy sufficient rights to reduce usage to the levels implied by the pumping limit plans.

The agricultural guarantee results, as well as the declining trend in "optimal" agricultural water use as demand increases, suggests a water market is needed to facilitate transfers between existing agricultural and M&I water users. The analyses with agricultural guarantees show that the water use value discrepancy can be as high as $89.75 per af per year ($108.64 minus $18.89). A market could correct such a discrepancy by providing for short term or permanent water transfers. EDSIM is structured to simulate each type of market. Comparison of the solutions for the Agricultural Guarantee and No Guarantee scenarios give a simulation of a lease market where water is allowed to be transferred when needed. The water sale market is simulated under the assumption that a senior water right is transferred and therefore that an equal amount of water use is transferred under all recharge and elevation events. Thus, EDSIM transfers an equal amount of water in all cases under this "permanent sale" scenario. The solution to the sale scenarios for year 2000 demand appears in Table 6 under the Market column.

The market results illustrate two significant features: first, annual total regional welfare under the leasing model is $46.14 million, as opposed to $45.29 million under the sale scenario (a $0.85 million difference). Thus, it is worth about $0.85 million annually to allow water leasing under agricultural guarantees in addition to a permanent transfer water market. Second, under the 450/350 plan in the presence of the agricultural guarantee, the water markets raise total welfare from around $41 million to $45 to $46 million while under the 400/350 plan this rise is from about $34 million to $44 to $45 million. Such increases in annual welfare mean that from 4 to 10 million dollars could be exchanged annually between the sectors and for contracting expenses with regional welfare increases.

The differences in use values (Table 6) also give room for market operations. The extreme difference in use values arises in the year 2000 400/350 case where the annual average value of $108.64 per af arises for non-agricultural usage, while the agricultural usage value is $18.89 per af. Thus, there is a differential of approximately $90 per year in use values per acre foot which market transactions could correct with the potential for gains to both sectors. This value discrepancy grows with demand being more than twice the same differential as computed under 1988 demand ($39). The TWC sectoral limit plan also shows dramatic changes in use values over time.

The results also suggest there may be a need for compensation of western rural communities for lost income. Under either of the water market structures, the agricultural induced income which largely occurs in the Western area falls in the neighborhood of 20% when agricultural activity is curtailed by the transfer of water out of agriculture to the non-agricultural sectors. This would be offset by induced income gains in the Eastern non-agricultural part of the region (Jones).

Conclusions

The economic impacts of the 1992 drought management plans posed by the TWC were investigated using an economic-hydrologic simulation model. The results indicate that the sectoral specific plans have larger near term consequences than the 450,000 af total limit plan. However, as the use limit transitions to 400,000 af and/or demand grows to levels anticipated for the year 2000, the model shows that agricultural sector use is the most pivotal. The "optimally structured" drought management plans reduce agricultural water use, transitioning a considerable amount of acreage back to dryland. This reduces annual agricultural income under year 2000 demand by between $1 million (13%) and $2.5 million (35%) depending on the plan imposed. Simultaneously, the plans decrease the municipal and industrial sector welfare by between $0.8 million (2%) and $5.7 million (8%) depending on the plan.

The benefits from the drought plans arise in terms of increased spring flows at Comal and San Marcos Springs and higher ending aquifer elevation. However, none of the proposed plans guarantee positive Comal Spring flow given a repeat of historical weather. Furthermore, these benefits come at a cost. The simulations show at least $6 of welfare is foregone per acre foot that pumping is restricted with the annual effect rising to as large as $6.7 million by the year 2000.

The results also indicate that it would be desirable to institute water marketing mechanisms to facilitate water use reallocation over time along with pumping limits. The study results show that as demand grows and the regional economy changes, that maintaining an unchanging sectoral allocation of pumping usage causes considerable disparity in use values. For example, when agriculture is guaranteed late 1980's usage, but the San Antonio region grows from 1988 to 2000 levels, the disparity in water use value is predicted to rise by more than two-fold. Similar results arise under the TWC sectoral limits plans. The simultaneous imposition of usage limits, water rights and water markets should be considered. Markets could allow economic agents to seek out the highest and best usages of scarce EA water resources allowing high valued water users to buy or lease water from lower valued users.

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Table 1. Comparison of Annual Welfare Effects of Alternative Water Management Plans[a]

	1988 Demand					2000 Demand				
	Base[b]	Land	Water	450/350	400/350	Base	Land	Water	450/350	400/350
Average Ag Income	7.14	6.05	6.16	6.61	6.15	7.09	6.05	6.16	5.55	4.53
change		-1.09	-0.98	-0.53	-0.99		-1.04	-0.93	-1.84	-2.55
percent change		-15.27	-13.68	-7.39	-13.86		-14.65	-13.05	-21.68	-36.03
Average Mun Surplus	30.85	30.38	30.38	30.66	30.69	40.35	35.36	35.36	39.59	39.61
change		-0.47	-0.47	-0.19	-0.16		-4.98	-4.99	-0.76	-0.74
percent change		-1.52	-1.52	-0.60	-0.53		-12.35	-12.36	-1.88	-1.82
Average Ind Surplus	0.62	0.61	0.61	0.60	0.61	1.08	0.41	0.41	0.99	0.99
change		-0.61	-0.01	-0.02	-0.02		-0.67	-0.67	-0.07	-0.09
percent change		-2.06	-2.06	-2.66	-2.46		-61.67	-61.67	-8.00	-7.93
Average Total Surplus	38.61	37.04	37.15	37.88	37.44	48.52	41.83	41.94	46.14	45.14
change		-1.57	-1.46	-0.73	-1.17		-6.69	-6.58	-2.38	-3.37
percent change		-4.07	-3.78	-1.89	-3.02		-13.79	-13.56	-4.81	-6.96

[a] All units are million dollars (excepting the percent changes)
[b] The scenario definitions are:
1) Base is an unrestricted pumpage scenario;
2) Land defines the sectoral limit scenario of the TWC February plan with irrigated land limited;
3) Water defines the sectoral limit scenario of the TWC February plan with irrigation water limited;
4) 450/350 defines the total limit scenario of the TWC August plan with total use limited to 450,000 and 350,000 af under the elevation triggers; and
5) 400/350 defines the total limit scenario of the TWC August plan with total use limited to 400,000 and 350,000 af under the elevation triggers.

Table 2. Comparison of Agricultural Effects of Alternative Water Management Plans

	1988 Demand					2000 Demand				
	Base[c]	Land	Water	450/350	400/350	Base	Land	Water	450/350	400/350
Irrigation Developed[a]	86.07	74.97	77.83	76.49	53.14	86.07	74.97	77.83	53.14	22.37
percent change		-12.90	-9.58	-11.13	-38.26		-12.90	-9.58	38.26	-74.01
Irrigated Acres[a]	91.20	59.29	62.09	72.89	51.92	91.02	59.29	62.09	38.12	14.97
percent change		-35.00	-31.92	-20.08	-43.07		-34.86	-31.78	-57.38	-83.55
Dry Land Usage		10.40	7.72	8.97	30.84		10.40	7.72	30.84	58.04
Income[b]	7.14	6.05	6.16	6.61	6.15	7.09	6.05	6.16	5.55	4.53
percent change		-15.27	-13.68	-7.39	-13.86		-14.65	-13.05	-21.68	-36.03
Inc. Std. Dev.[b]	0.58	0.47	0.75	0.98	1.16	0.59	0.47	0.75	0.85	1.19
percent change		-18.87	29.81	68.63	100.01		-20.14	27.78	45.26	102.67
Ag-Induced Income[b]	77.41	65.55	66.41	69.79	59.75	76.73	65.55	66.41	54.13	33.89
change		-11.63	-10.77	-7.39	-17.43		-11.18	-10.33	-22.61	-42.84
percent change		-15.07	-13.96	-9.57	-22.59		-14.57	-13.46	-29.46	-55.83

[a] Reported in thousands of acres.
[b] Reported in millions of dollars.
[c] The scenarios are as defined in Table 1.

Table 3. Dollars of Welfare Foregone per acre foot for Agricultural, Municipal and Industrial Sectors Under Alternative Plans[a]

	Average[d]		Elevation 625-666[e]		Elevation < 625[f]	
	Agricultural	Municipal & Industrial	Agricultural	Municipal & Industrial	Agricultural	Municipal & Industrial
Computed Marginal Water Value						
1988 Demand						
Sector Limit - land[c]	19.58	11.53	19.52	6.83	20.21	23.39
Sector Limit - water	18.19	11.55	17.96	6.84	19.33	23.38
Total Limit 450/350 af	15.11	7.69	12.93	6.10	18.72	11.93
Total Limit 400/350 af	13.32	6.26	13.12	5.47	13.80	9.48
2000 Demand						
Sector Limit - land	18.81	37.55	18.56	33.80	19.59	58.09
Sector Limit - water	17.43	37.55	16.96	33.80	18.71	58.08
Total Limit 450/350 af	15.49	12.82	14.77	9.38	18.63	23.58
Total Limit 400/350 af	18.29	11.95	18.25	10.24	17.95	18.99
Shadow Price Value of Water						
1988 Demand						
Sector Limit - land	--[b]	19.09	--[b]	15.05	--[b]	51.01
Sector Limit - water	21.42	19.09	22.44	15.05	25.73	51.01
Total Limit 450,000 af	12.28	12.28	10.52	10.52	28.03	28.03
Total Limit 400,000 af	13.15	13.15	12.48	12.48	23.15	23.15
2000 Demand						
Sector Limit - land	--[b]	95.93	--[b]	89.43	--[b]	178.00
Sector Limit - water	21.10	95.93	22.04	89.43	25.73	178.00
Total Limit 450,000 af	26.51	26.51	22.96	22.96	59.13	59.13
Total Limit 400,000 af	27.36	27.36	26.13	26.13	47.21	47.21

[a] All units are reported in dollars per acre foot.
[b] Shadow prices for water are not obtained when land is limited.
[c] The four scenarios correspond to those defined in Table 1.
[d] Data in this column report the average across all pumping limit and recharge events.
[e] This data column contains averages across recharge events where the pumping limit triggered by elevations between 625 ft and 666 ft occurs.
[f] This data column contains averages across recharge events where the pumping limit triggered by elevations below 625 ft.

Table 4. Comparison of Effects of Alternative Management on Sectoral Water Use Under Alternative Management Plans.

	1988 Demand					2000 Demand				
	Base	Land	Water	450/350	400/350	Base	Land	Water	450/350	400/350
Average Water Use Across All Triggers										
Agricultural	166.87	111.04	113.14	131.94	92.55	166.24	111.04	113.14	66.98	26.62
percent change		-33.46	-32.23	-20.94	-44.54		-33.20	-31.94	-59.71	-83.99
Municipal	313.48	273.91	273.90	289.25	287.33	409.47	274.59	274.59	350.18	347.64
percent change		-12.62	-12.62	-7.73	-8.34		-32.94	-32.94	-14.48	-15.10
Industrial	18.31	16.21	16.21	16.28	16.11	31.87	16.26	16.26	25.29	25.01
percent change		-11.43	-11.43	-11.08	-12.01		-48.96	-48.96	-20.64	-21.52
Total Use	498.66	401.16	403.25	437.47	395.99	607.58	401.89	403.99	442.43	399.27
percent change		-19.55	-19.13	-12.27	-20.59		-33.85	-33.51	-27.18	-34.29
Use when elevation > 625 < 666										
Agricultural	166.24	112.28	114.53	140.02	95.53	166.24	112.28	114.53	70.90	27.17
Municipal	313.76	278.22	278.22	291.84	288.22	409.83	278.22	278.22	353.50	47.84
Industrial	18.33	16.48	16.48	16.49	16.18	31.91	16.48	16.48	25.60	25.00
Total Use	498.33	406.98	409.23	448.35	399.92	607.98	406.98	409.23	450.00	400.00
Use when elevation < 625										
Agricultural	166.24	83.92	83.42	74.38	67.34	166.24	83.92	83.42	28.89	13.88
Municipal	310.52	229.12	229.12	261.64	268.15	405.65	229.12	229.12	300.95	314.58
Industrial	18.05	13.57	13.57	13.98	14.50	31.43	13.57	13.57	20.19	21.54
Total Use	494.81	326.61	326.12	350.00	350.00	603.32	326.61	326.12	350.00	350.00

Note all units are in 1000 acre feet except the percentage changes. The scenarios are as defined in Table 1.

Table 5. Comparison of Hydrological Effects of Alternative Management Plans

	1988 Demand					2000 Demand				
	Base[c]	Land	Water	450/350	400/350	Base	Land	Water	450/350	400/350
Avg. Comal Spring flow[a]	45.53	61.93	61.34	50.72	52.13	41.98	61.90	61.31	50.43	51.98
percent change		36.02	34.72	11.39	14.48		47.46	46.06	20.14	23.84
Avg. San Marcos Spring flow[a]	106.43	108.56	108.55	107.77	108.62	104.18	108.54	108.54	107.68	108.56
percent change		2	1.99	1.26	2.06		4.19	4.19	2.00	1.99
Avg. Ending Elevation[b]	623.00	628.53	628.50	625.89	627.43	618.92	628.50	628.48	625.71	627.32
percent change		0.89	0.88	0.46	0.71		1.55	1.54	0.89	0.88
Min. Ending Elevation[b]	575.37	583.99	585.18	584.21	584.21	570.81	583.99	585.18	584.21	584.21
percent change		1.50	1.71	1.54	1.54		2.31	2.52	2.35	2.35
Min. Comal Spring flow[a]	0	0	0	0	0	0	0	0	0	0
percent change		0	0	0	0		0	0	0	0
Min. San Marcos Spring flow[a]	56.85	61.74	62.41	61.86	61.86	54.26	61.74	62.41	61.86	61.86
percent change		8.61	9.79	8.82	8.82		13.78	15.02	14.00	14.00

[a] In acre feet per year.
[b] In feet above sea level.
[c] The scenarios are as defined in Table 1.

Table 6. Results under Agricultural Guarantees and Water Markets under Year 2000 Conditions for Total Limit Plans

	450/350 Limitation				400/350 Limitation			
	No Guarantee (Leasing)	Guarantee w/ Proportional Share[d]	Guarantee w/ Optimal Share[a]	Permanent Sale Market	No Guarantee (Leasing)	Guarantee w/ Proportional Share[d]	Guarantee w/ Optimal Share[a]	Permanent Sale Market
Ag Welfare[a]	5.55	7.10	7.06	5.57	4.53	7.17	7.11	5.21
Ag Water Use - Avg[b]	66.98	163.76	159.87	80.56	26.62	166.00	163.37	66.82
Ag Water Value - Avg[c]	--	15.98	15.61	18.38	--	18.89	18.82	19.73
Elevation between 625 & 666[c]	--	15.57	15.59	17.98	--	18.97	18.97	19.61
Elevation below 625[c]	--	19.00	17.16	20.48	--	18.64	18.06	19.73
M&I Welfare[a]	40.59	33.23	34.27	39.72	40.61	26.19	27.15	38.58
M&I Water Use Avg[b]	375.47	281.86	285.75	361.36	372.65	239.92	242.55	334.38
M&I Water Value Avg[c]	--	78.55	70.32	81.63	--	108.64	103.40	131.24
Elevation between 625 & 666[c]	--	62.19	62.19	64.45	--	97.94	97.94	118.38
Elevation below 625[c]	--	162.97	129.41	189.90	--	175.14	146.71	219.90
Total Welfare[a]	46.14	40.33	41.28	45.29	45.14	33.36	34.26	43.80
Induced Income[a]	54.13	76.62	75.87	56.90	33.89	77.03	76.54	51.62

[a] In millions of dollars.
[b] In thousands of acre feet.
[c] In dollars per acre foot.
[d] Under these scenarios, agriculture is guaranteed rights to 1988 usage when the 625-666 case occurs.