Climate Change and Texas Water Planning: an Economic Analysis of Inter-basin Water Transfers

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Climate change caused by increases in atmospheric concentration of green house gas has aroused attention from many governments and becomes a hot topic for researchers in examining physical science, production impact, adaptation, and mitigation strategies. In the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC 2007), projections appear that global surface temperature will increase between 3.2°F and 7.2°F with a likely range between 2.0°F and 11.5°F by 2100. One of the biggest impacts of climate change relating to water resource will be on regional water supply, water demand and water quality. Climate change is likely to affect many water-related aspects of human well-being, from agricultural productivity and energy use to flood control, municipal and industrial water supply, water quality and related human health.

In Texas, water scarcity is becoming a pervasive and persistent problem. Rapid population and economic growth are exacerbating problems in the drier areas and are causing emerging problems in wetter areas. The 2007 Texas Water Plan, a "comprehensive 50 year plan spanning from 2010 to 2060" proposes ways to deal with this involving 51 proposed inter-basin water transfer projects (Texas Water Development Board, 2006; see

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table 20). However, this plan almost neglects the climate change issue, where climate change is likely to make existing water scarcity problems even more severe and accelerate the need for water development investments and policy actions. In this paper, we explore the impact of climate change on water scarcity, water dependent economy, environmental in-stream flow and development of inter-basin water transfers.

Hydrological research on climate change involving water resource focuses on modeling runoffs based on yearly, monthly, or daily water balance model (here list a few: Kuczera 1982; Schaake and Liu 1989; Arnell 1992; Xu 2000). Precipitation is the major input, and other inputs include temperature and/or potential evaporation. Later on, factors such as soil and slope, influencing water filtration, is included in the water balance models. However, effect from human activity--water demand due to climate change is largely untouched.

Research from economic side has nicely taken into consideration of water related economic, hydrological, and environmental issues (Dillon 1991; McCarl et al. 1993; Keplinger et al. 1998; McCarl et al. 1999; Schiable et al. 2000; Watkins and McKinney 1999; Gillig, McCarl and Boadu 2001; Watkins et al. 2000; Rosegrant et al. 2000), but their models cover either only ground water, or possibly water management strategies, or in a very small scope. Recent studies from Cai and McCarl (2008a, 2008b, 2007) and Han (2008) have examined inter-basin water transfers on a state wide scope in Texas. Cai and McCarl (2007) take an initial step in developing an integrated economic, hydrologic and environmental model, TEXRIVERSIM, to evaluate those 51 inter-basin water transfers proposed in 2007 State Plan, then evaluate their impact on regional economy and environment in 2010. Han (2008) takes a second step examining inter-basin water transfers while maintain minimum in-stream requirement for environment. Cai and McCarl (2008a) expand TEXRIVERSIM using a dynamic approach covering future periods from 2010 to 2060, leading to more meaningful policy implications. Cai and McCarl (2008b) further incorporate the ground water component in Texas thus allowing the interaction between ground water and surface water through recharge, discharge, and ground water return flow to in-stream. However, all of these papers have ignored another important factor- climate change on water supply and demand. This article is motivated to fill this gap by integrating climate change impact on water supply, water demand, crop yield and its influence on inter-basin water transfers and regional economy.

Statistical approaches are used to estimate how climate influences in-stream water supply, municipal water demand, crop yields and irrigation water use. These results are then added into TEXRIVERSIM through the objective function and hydrological constraints. Finally, a climate change related scenario analysis based on four Global Circulation Models (GCMs) with three Special Report on Emissions Scenarios (SRES) A1B, B1, and A2 are used to compare the results from TEXRIVERSIM.

This article is organized as follows. In section 1, after a simple literature review, we lay out a panel model to evaluate climate change impact on surface water supply. In section 2, estimations from Bell and Griffin (2005) is used to quantify climate change impact on municipal water demand. In the next section, we develop another panel model to examine the relationship between climate and crop irrigated/dryland yield. Blaney-Criddle procedure (Doorenbos and Pruitt, 1977) and the Erosion-Productivity Impact Calculator (EPIC)

Model are used to estimate crop irrigation water requirement. Section 4 discusses climate change impact on water scarcity, environmental stream flow, regional welfare as well as inter-basin water transfers. The final section concludes.

Climate change impacts on surface water supply

Texas has very distinct characteristics in surface water supply. Surface water is almost entirely from rainfall with pronounced variation in annual rainfall across the state. Annual rainfall declines precipitously from east to west across the state, while no significant difference is found from north to south. Runoff is usually produced during and immediately after thunderstorm events. The frequency and intensity of storm events vary seasonally, with maxima in most areas of the state in spring and fall, causing runoff peaks in spring or fall.

Rush (2000) divides the state of Texas into 11 hydrologic regions and each region has a similar statistical equation for estimating mean annual and mean seasonal runoff for natural basins of Texas. The equations include contributing drainage area (defined as an area characterized by all runoff conveyed to the same outlet) and precipitation as explanatory variables. She finds that contributing drainage area and mean annual or mean seasonal precipitation are the most significant basin characteristics in each region. The elasticity of precipitation on stream flow is relatively close across regions. However, temperature is not included as an explanatory variable, thus the effect of the evaporation/evapotranspiration on stream flow is ignored.

Chen, Gillig, and McCarl (2001) employ a regression analysis to estimate the effects of temperature and precipitation on historically observed recharge in the Edwards Aquifer.

They find out that the temperature coefficients are negative and the precipitation coefficients have positive signs, indicating that higher temperature would increase evaporation and plant water use, thus reducing the amount of recharge to the aquifer. On the other hand, a positive precipitation coefficient indicates that the recharge to the aquifer increases as rainfall increases. However, their estimation is by county and by month and is based on recharge data from 1950 to 1996, leading to very small sample size (47). Thus, the results may not be reliable.

Considering the distinct characteristics in Texas water supply and previous research work, we hypothesis that rainfall, intensity of rainfall, drainage area and temperature are some variables influencing monthly runoffs. Rainfall is a primary source of surface water supply. Intensity of rainfall will influence the intensity of runoffs. Temperature may be related to evaporation/evapotranspiration on stream flow, especially reservoirs. Drainage area will capture the physical difference between gauge stations, defined in U.S. Geological Survey (USGS). Thus, a panel model with random effects with the following specification is proposed:

(1)

$$\begin{aligned}\log(Inflow_{i,t}) = {} & \alpha_0 + \alpha_1 * \log(Temp_{i,t}) + \alpha_2 * \log(\mathrm{Drainage}_{i}) + \alpha_3 * \log(\Pr ep_{i,t}) \\ & + \alpha_4 * M_t + \alpha_5 * M_t * \log(\Pr ep_{i,t}) + \alpha_5 * Intense100_{i,t} + \alpha_6 * Intense50_{i,t} + \alpha_7 * Intense25_{i,t} \\ & + v_i + \varepsilon_{it}\end{aligned}$$

where, i=river place (or USGS gauge station), t =Jan. 196 to Dec. 1989

Where *Inflow* is the net water flow at a river place *i*. Variables *temp and prep* stand for monthly temperature and precipitation, respectively. *Drainage* is the drainage area for river place *i*. *M* would be the monthly dummy variable. *Intense100, Intense50* and *Intense25* are three variables representing rainfall intensity. *Intense100* stands for the percentage of precipitation where daily rainfall is greater than 1.0 inch. In other words, it is the percentage of rainfall from moderate or heavy rain. *Intense50* denotes the percentage of precipitation where daily rainfall is between 1.0 and 0.50 inches (slight rain). *Intense25* denotes the percentage of precipitation where daily rainfall is between 0.50 and 0.25 inches (little rain). v_i is the unobserved individual effect, which is a source of time invariant heterogeneity. ε_{it} is an independent and identically distributed random error (i.i.d) with mean zero and finite variance. In this model, strong exogeneity is assumed where the error term ε_{it} is uncorrelated with the past, present, or future values of repressors. Finally, the vector of repressors is uncorrelated with unobserved effects v_i such that the random effects model is valid (Greene 2005). Several hypotheses are put forth in terms of the relevant effects on stream flows. First, the effects of rainfall in different months may be different. Second, the rainfall intensity effect may be different across the three intensity variables.

Inflow in Equation (1) is derived from the naturalized stream flow. Naturalized stream flow is defined as flow that would have occurred in the absence of today's water uses, water management facilities, etc. Naturalized stream flow for the USGS gauge stations in Texas from the year 1950 to 1989 is simulated using the Water Right Analysis Package (Wurbs 2003). Downstream naturalized flow is subtracted from naturalized upstream flows to get the net inflow. Monthly temperature and daily precipitation for individual weather stations for the period 1950-1989 are collected from the National Climatic Data Center (NCDC). These weather stations are then mapped to where river places locate. Monthly precipitation and rainfall intensity are thus calculated from daily precipitation. Contributing drainage areas are extracted from the USGS.

Table 1 presents the results obtained from the panel model with random effects estimation. Two model specifications are included here, where intensity variables are included in model 1b but not in model 1a. Temperature, precipitation, contribution drainage areas, and rainfall intensity (*Intense100* and *Intense50*) are statistically significant. The sign for temperature is negative, indicating a negative relationship between inflow and temperature. This does make sense since higher temperature will cause higher evaporation/evapotranspiration, thus reducing water availability. Positive signs of precipitation suggest that the more precipitation, the more water inflow. However, a Wald test for equality of the interaction term Log(Prep)*M_t is rejected, suggesting that the effects of precipitation across months are different. More specifically, more rainfall is converted to stream flows in April, May, and June than the rest of the months. Rainfall intensity is positively correlated to water inflow. The coefficient for *Intense100* is greater than the coefficient for *Intense50,* which is then greater than the coefficient for *Intense25.* As we know, precipitation is locally intense but short-lived. When rainfall is more intense, more rainwater flows into stream and river channels with less infiltrating into soil.

Climate projections from the year 1950 to 2100 are from a web-based information service, hosted at LLNL Green Data Oasis at Santa Clara University. The data contains fine resolution (12km x 12 km) translations of climate projections, allowing a more detailed regional analysis. However, Global Circulation Models generally yield somewhat different projections, where CCCma (the Canadian model developed by the Canadian Center for

Climate Modeling and Analysis), Hadley (developed by the United Kingdom Meteorological Office) are most widely used. To compare the differences of climate projections from other models, we also select BCM2.0, developed by Bjerknes Centre for Climate Research in Norway (named as *BCCR* in this article), and PCM by the U.S. National Centre for Atmospheric Research for scenario analysis (named as *NCAR*). These GCMs are run under different SRES scenarios. The SRES, labeled as A1B, A2, and B1, describes major alternative futures in terms of climate change driving forces—specifically, population growth, economic well being, energy use, greenhouse gas, and aerosol emissions and their evolution during the 21st century (IPCC, 2007) —along with other different demographic, social, economic, technological, and environmental developments.

This downscaled climate change data allows us to map climate data to its closest county location according to its latitude and longitude. The average monthly temperature and precipitation from 1960 to 1989 serve as a baseline. Future temperature and precipitation projections are 10-year average centered on each decade from 2010 to 2090. Thus, climate change for future periods is the difference between the climate projection and the baseline climate projection.

Incorporating these climate change results into the regression model, we can quantify climate change impact on surface water supply. Figure 1 displays the percentage change of water supply in 2060. The change of temperature and precipitation has significant effects on water inflow. These effects are different across models, scenarios, and counties. In 2060, water supply for the majority of counties in Texas is projected to decline significantly in the BCCR model under the A1B and A2 scenarios and in the Hadley model under the A1B scenario, and to increase in the CCCma model under the A2 and B1 scenarios, in the Hadley model under the A2 scenario, and in the NCAR model under the B1 scenario. However, in the other models, water supply may increase in some counties and decrease in other counties. There is no clear pattern showing that West Texas will have less water than East Texas.

Climate change impact on municipal water demand

Municipal water demand is sensitive to climate with more water used during summer. Griffin and Chang (1991) present estimates on how municipal water demand varies with temperature and precipitation. They find that monthly price elasticity is around -0.3 and summer price elasticity is 30 percent greater than winter price elasticity. However, the generalized Cobb-Douglas and translog form in their estimation make it extremely difficult to calculate the net effect of precipitation and climate index.

Using a new survey from 385 Texas communities for water supply and price from January 1999 to December 2003, Bell and Griffin (2008) and Bell and Griffin (2005) construct new indices of marginal and average price. An annual quasi-difference approach is used to estimate the relationship between residential water consumption and average water price, marginal water price, average sewer price, marginal sewer price, monthly income, mean minimum daily temperature, mean maximum daily temperature, and climate index. The results from the log-linear functional form suggest that the signs for mean maximum temperature and dry days are positive and negative for the mean minimum temperature and precipitation. Bell and Griffin (2005) also perform monthly regression where monthly price elasticity is comparable with the monthly price elasticity from the pooled data.

The monthly price elasticity of water demand and climate elasticity from Bell and Griffin (2005) is used to obtain the municipal water demand shifts during 2010 and 2060. The results (table 2) are the percentage change of municipal water demand under different climate change scenarios. Municipal water demand will increase slightly at a range of 0.4 percent to 6.12 percent.

Climate change impact on crop yield and irrigation water requirement

The influence of climate change on the agricultural sector has been widely studied and is reviewed by the Intergovernmental Panel on Climate Change Assessments (2007) and the U.S. National Assessment (Reilly et al 2002). Many studies indicate that climate change alters crop mean yields (Adams et al 1990; Reilly et al 2003) and land value (Deschenes and Greenstone 2007), and yields variability (McCarl, Villavicencio, and Wu 2008; Chen, McCarl, and Schimmelpfenning 2004). Chen, McCarl, and Schimmelpfennig (2004) investigate the mean and variance of crop yield for corn, cotton, sorghum, soybeans, and wheat by modeling them as functions of climate conditions, agricultural land usage and other inputs, time trend, and regional dummies using spatial analogue techniques. McCarl, Villavicencio, and Wu (2008) develop a richer specification than Chen, McCarl, and Schimmelpfennig (2004) by using both mean temperature and variance of temperature during the growing season as exogenous variables in the model. They also include a precipitation intensity index and the Palmer Drought Severity Index (PDSI) to capture the variability. Schlenker and Roberts (2008) examine the links between U.S. corn, soybeans, and cotton yields to daily temperature within each county. They find a robust and significant nonlinear relationship between temperature and yield, showing yield increases with temperature up to a critical threshold of 29°C for corn, 30°C for soybeans, and 32°C for cotton, above which higher temperature significantly harms yield. One drawback for this study is that the effect of precipitation is ignored.

Previous studies have several flaws. First, the effects of climate change on crop yields from previous studies are quite different. The results from McCarl, Villavicencio, and Wu (2008) indicate that yields for corn, cotton, soybeans, and winter wheat will increase, while yield for sorghum may decline under the Hadley model. However, Schlenker and Roberts (2008) report that yields for corn, cotton, and soybeans for the years 2070-2099 are predicted to decline by 43 percent, 36 percent, and 31 percent, respectively, under the Hadley model with the B1 scenario. Second, these studies only focus on major crops in the United States, such as corn, cotton, soybeans, winter wheat, and sorghum, due to limited data, leaving other crops untouched. Third, these studies do not differentiate crop yields under irrigation or non-irrigation. As we know, rainfall is the sole source of water for dryland crops. As climate change will lead to changing precipitation and increasing temperature, crop dryland yields may be affected greater than yields for irrigated crop.

This article is trying to address these problems. First, for major crops where data is available, a statistical approach is used for both irrigated and dryland crops. Second, for those minor crops and vegetables, the Blaney-Criddle procedure is used. The empirical model is specified as:

(2)
$$\log Y_{it} = \beta_0 + \beta_1 Temp_{it} + \beta_2 Tempstd_{it} + \beta_3 \Pr ep_{it} + \beta_4 T_t + v_i + \varepsilon_{it}$$

where i =county, t =1960 to 1989

where Y stands for crop yield. *Temp* and *Tempstd* are annual mean temperature (F) and standard deviation of temperature during the growing season. *Prep* is annual precipitation (inch), and T is the trend variable capturing technical advancement on increasing crop yields. v_i is the time invariant unobserved individual effect. ε_{it} is an i.i.d random error with mean zero and finite variance. The error term ε_{it} is assumed uncorrelated with the past, present, or future values of regressors. The vector of repressors is assumed uncorrelated with unobserved effects v_i.

Irrigated and dryland crop yields by county from 1960 to 1989 are from the National Agricultural Statistics Service (NASS). However, not all crops grow in each county, and not all crops are planted in every year during 1960 to 1989 in some counties. Only seven crops—corn for grain (*Corng*), cotton upland (*CottonU*), pima cotton (*CottonP*), spanish peanuts (*Peanuts*), grain sorghum (*Sorghum*), soybeans (*Soybeans)* and winter wheat (*Winwht*)—have enough observations for estimation. The remaining 24 crops (or vegetables) covered in the TEXRIVERSIM model are not available. All available data are used for regressions, resulting in unbalanced panels in most cases.

Monthly temperature and precipitation data for individual weather stations from 1960 to 1989 are obtained from NCDC. The weather stations are then mapped to their county location. Annual mean temperature is the average monthly temperature in a year. Standard deviation of temperature for each crop is calculated corresponding to its growing season. For example, November to March is for winter wheat and April to November is for all other crops. Yearly precipitation is obtained by summing the monthly rainfall in a year.

A generalized least squares approach is used to estimate this panel model. To determine if the model has a random effect, fixed effect, or between effects, Breusch and Pagan’s Lagrangian multiplier test for random effects is performed. Except for pima cotton, the regression models for the other crops have random effects.

Climate effects on irrigated and dryland crop yields are different (the detailed results is not reported here due to its size, but it is available upon request). Temperature and variance of temperature have significant and negative effects on irrigated corn for grain, but insignificant effects on dryland corn for grain. However, precipitation has positive and significant influences on both dryland and irrigated corn for grain. For pima cotton, higher temperature will increase irrigated cotton yield while higher variation of temperature will decrease dryland cotton yield. Rainfall has opposite effects on cotton yields, that is, the effects are negative on irrigated cotton and positive on dryland cotton. Higher temperature reduces yields for both dryland and irrigated peanuts, while variation of temperature has no significant influence on yields. More rainfall will increase dryland peanut yield and have no effect on irrigated yield. Temperature has negative effects on irrigated sorghum and positive effects on dryland sorghum. Climate effects for soybeans are the same no matter if they are irrigated or dryland.

Changes in climatic conditions influencing crop irrigation requirements are estimated using the Blaney-Criddle procedure and the EPIC Model. Both procedures take daylight, rainfall, and temperature into consideration while simultaneously incorporating crop yield factor, yield response factor, and irrigation efficiency (Doorenbos and Pruitt, 1979). A summary of the resultant effects are presented in table 3.

Climate change impact on water dependent economy

In this section, we first brief review TEXRIVERSIM model (see Cai and McCarl (2007) for more detail), then we discuss the model results.

Model specification

TEXRIVERSIM model is an economic, hydrological, and environmental model implicitly incorporating: (a) uncertainty about future climate which may influence water use, and water supply thereafter; (b) price and climate elastic water demand curve from municipality and price elastic demand for industrial use; (c) recreational and environment demands; (d) activity analysis of farm irrigation models permitting reversion to dryland; (e) spatial river flow relationships including in-stream flow, diversion, reservoir storage and evaporation, and return flows; (f) surface, ground water and its interaction through discharge and recharge; (g) institutional constraints specifying how much water can be distributed under institutional regulations and (h) the investment choice and operation of 51 inter-basin water transfer possibilities.

TEXRIVERSIM maximizes expected net statewide welfare from municipal, industrial, agricultural, recreational, and other types of water use, as well as water flow out to bay less the cost of IBTs. In doing this, it chooses optimal IBTs and water allocation, in-stream flows, return flows, reservoir storage, ground water recharge, spring discharge, and bays and estuary freshwater outflows. The model includes 21 Texas river basins explicitly covering 70 major municipal cities, 50 major industrial counties, all agricultural counties and 36 crops, and 51 IBTs.

Benefit from municipal and industrial water use are consumer and producer surplus, where water demand for major cities is price and climate elastic, while water demand for major industrial counties are price elastic but climate inelastic. On the other side, water demand for small cities and small industrial counties has constant marginal benefit. Benefits from agricultural water use are net farm income from irrigated and dryland crop productions, where crop yields along with irrigation water requirements differ by state of nature. Recreational water use, in-stream flow and water flow out to bay have constant marginal benefits that vary by region (see figure 2 in appendixes for detailed explanation on sectors). Cost for IBT-related facility construction is amortized over the project time span.

Agriculture has several constraints. Crop mix will follow a historical observed mix pattern reflecting rotation considerations. Cropland use across crop mix patterns is constrained by land endowment. Land conversion is allowed to reflect the trends of agriculture and the value of irrigation water. Previous irrigated, furrow or sprinkler land can be converted to dryland. Previous furrow land can even be converted to sprinkler land as long as the gain exceeds the conversion-related cost. However, no dryland is allowed to convert to irrigate land. The hydrological constraints involve water supply-demand balance in a specific control point. Naturalized flow, return flow, in-stream flow, reservoir storage/evaporation, water diversion, water transferring into/out, fresh water running to the bay, interaction between ground and surface water through discharge and recharge, are factors affecting the stream flow balance. Institutional constraints set up the maximum amount of water can be diverted at a control point by a particular water right. Financial constraints say that an IBT is optimal only if the benefit from the IBT is greater than the cost. If an IBT is built, the cost will be incurred and maximum yield constraints will go in effect.

Uncertainty is modeled as a multiple stage stochastic process with decision of crop choice made in the first stage without knowledge of exact climate and water availability, and what irrigation strategies to use and how much water is applied in the second stage depending on water availability. TEXRIVERSIM model is a two-stage stochastic programming model with recourse implemented using the General Algebraic Modeling System (GAMS). Nine states of nature ranging from very dry to very wet are defined in the model to reflect climate variability with probabilities reflecting historical frequency in a 50-year period. These probabilities serve as weights in the objective function. Therefore, the model is stochastic, reflecting nine states of nature for water flows following the historical climate patterns.

Water scarcity in the baseline

Climate change impacts on the water demand and water supply, crop yields, and water requirements are incorporated into TEXRIVERSIM through the objective function and constraints. We hope to examine water scarcity problems under climate change scenarios and the climate change impact on environmental water flow and a water dependent economy. In this subsection, a baseline model is run where no IBTs are allowed to be built (*Base*). In the next subsection, an optimal model where all IBTs are candidates (*Opt*) is run to investigate the impacts of IBTs under climate change scenarios. In each subsection, we will discuss the water scarcity with/without climate change. Then climate change impact in the environmental in-stream flow is discussed. Third, we will lay out the results of warfare impact.

Water scarcity for major cities, major industrial counties, and agricultural counties in the baseline scenario are displayed in table 4, 5 and 6 respectively. "*Without climate change*" stands for the results where climate change is not taken into consideration. Without climate change, 40 major cities, out of 70 major cities, in Texas face different degrees of water shortage. Water demand for Houston is largely met by the year 2030, while Dallas and Austin begin to face small shortages in 2010. Water shortages rise dramatically in Fort Worth, Austin, and Dallas and remain stable in Arlington from the year 2010 to 2060. Under climate change, 21~26 more cities join in this group and water scarcity in the existing water hungry cities becomes even more severe.

On the other side, without climate change, 28 cities, concentrated in the Edwards Aquifer region, have sufficient water. Both ground and surface water supplies play an important role in meeting increasing water demand. Under climate change, this number declines to seven, at most, in 2060, in the NCAR under the B1 scenario, or to as low as two in the Hadley model under the A1B scenario. More importantly, these water-sufficient cities have very limited water surplus that is less than 4 thousand ac-ft. Previous big water surplus cities begin to have water deficits, such as San Antonio in 2010, Guadalupe in 2020, and Bexar in 2040.

All of the four models under A1B, A2, and B1 scenarios consistently predict that there is a rising water shortage for the industrial sector, with a relatively smaller magnitude than the municipal sector (table 5). Because of uneven distribution of water use, we should check the results with more detail. Without climate change, 19 counties do not have enough water, where water shortage is a consistent problem in Harris, Brazoria, Harrison, Dallas, Victoria, Tarrant, Comal, and Hutchinson counties from the year 2010 to 2060. This shortage is mainly because of increasing water demand versus stable water supply from both surface and ground water over the time.

Under climate change, this number varies from 13 in the B1 scenario to 22 in the A1B scenario. Counties with sufficient water have fewer surpluses under climate change than without climate change. Water scarcity in the other counties becomes slightly severe. The result that climate change has a slight impact on industrial water shortage is mainly attributed to the assumption that industrial water demand is insensitive to climate.

In terms of agricultural land use, without climate change, majority of irrigated land is converted to dryland, 30 percent of furrow land is converted to dryland, and around 80 percent of sprinkler land is retained. Land conversion between irrigated and dryland mainly take place in Brazos, Canadian, and Red, while sprinkle land is profitable to sustain in the Guadalupe-San Antonio River Basin and the Nueces River Basin, where land conversion happens mainly between furrow and dryland. Under climate change, around 80 more thousand acres of sprinkler land from Guadalupe-San Antonio River Basin and the Nueces River Basin are lost. This land use pattern is stable from the year 2010 to the year 2060.

Water use in the baseline

This section discusses how water use changes under climate change (table 7). Without climate change, total water use (excluding water flow out to bay and in-stream flow) increases slightly from 5.9 million ac-ft in 2010 to 6.1 million ac-ft in 2060, where the increase is from municipal water use for major cities and industrial water use for major counties. Agricultural water use is decreasing slightly, while water use from the rest sectors remains unchanged during the period from 2010 to 2060.

Under climate change, total water use across all of the GCM models and three SRES scenarios is consistently more than the total water use without climate change. However, the magnitude gradually declines over time. At the same period, more surface water is used for major cities under climate change than without climate change. Surface water used for major industrial counties increases, accompanied by bigger declines in ground water use. Surprisingly, both ground and surface water use for agricultural purposes increases significantly in all four models. There is a slight change for the recreational and the other type of water use.

Environmental in-stream flow in the baseline

Table 8 and table 9 display the climate change impact on the in-stream and water flow out to bay. Average in-stream flow may increase or decrease depending on the GCM models. Water flow out to bay generally decreases in most of the models and SRES.

Welfare in the baseline

In this subsection, welfare impact from climate change is displayed in table 10. Without climate change, total welfare reaches $98.8 billion in 2010 and increase to $165 billion in 2060. Municipal water benefit (*Mun*) is the largest component, accounting for at least 93 percent of the total benefits, of which the benefit from major cities plays a dominant role. The second largest benefit is from industrial water use, of which the benefit from the major counties is dominant over the benefit from the small counties. Agricultural water benefit

(*Ag*) is the third largest component, and it slightly declines from 2010 to 2060. Water benefits from recreation (*Rec*) and other (*Other*), and the value of freshwater flow to a bay (*Outtobay*), are playing trivial roles in the total benefits. The net benefit from the major municipal cities (*Mun-city*) and the major industrial counties (*Ind-main*) must be carefully interpreted since their benefits are measured as consumer and producer surplus, the area below a constant elastic demand curve and above a marginal cost curve. That measure is large as the quantity of water approaches zero, so the price approaches infinity, yielding very large areas. Although the marginal benefit is flattened where water use is less than 25 percent of the projected demand, it still generates large welfare, giving the inelastic water demand. However, the net benefits from agriculture, recreation, and other, as well as the value of freshwater inflow to bays and estuaries, have real meaning. They are the real net income, either from agriculture production or from other activities. Value from freshwater flows to bays and estuaries is very small due to the assumption that its marginal net value is $0.01/ac-ft.

Under climate change, the overall welfare increases slightly at earlier decades (less than 2 percent), which may decline slightly in 2060 depending on the GCM model (see table 10). The welfare from municipal suffers slightly, while climate change has a mixed effect on industrial benefit. Climate change has a significant impact on agricultural water benefit. One major reason is that crop yields increase under climate change. Climate change does not have an impact on recreational water benefit or and benefit from water flow out to bay. Nueces and Guadalupe-San Antonio are two basins realizing significant gains, as they are major agricultural basins, while the other basins have slight welfare loss.

Evaluation of inter-basin water transfer

Now we turn to the IBT appraisal examining the impact of IBTs and implications for the source basins, destination basins, as well as third basins with/without climate change. Under this scenario, all of the 51 IBT projects are candidates, so the socially optimal choice for IBTs will be obtained. We first discuss the economically feasible IBTs, then their impact on water scarcity, water allocation, in-stream flow/water flow out to bay and water benefit.

Optimal IBTs

An IBT is justified if the benefit it brings is greater than its cost. Table 11 displays the optimal IBTs, where *A* and *X* denote an IBT is optimal without/with climate change respectively. Water transferred by IBTs is displayed in table 12. Without climate change, 5 IBTs in 2010 and 12 from 2040 to 2060 are optimal. Water transferred is mainly used for municipal and industrial purpose, where municipality and industry use 133 thousand ac-ft and 546 thousand ac-ft respectively in 2010, increase to 577 thousand ac-ft and 584 thousand ac-ft in 2060. These economically feasible IBTs are listed as follows:

- The Luce Bayou Channel Project (Bayou_TriToSan): Water originates at Lake Livingston in the Trinity River Basin and goes to Lake Houston in the San Jacinto River Basin to supply water to north and northwest areas of Houston in Harris County. This IBT has a firm yield of water (maximum 540 thousand ac-ft) and the lowest cost of water ($30/ac-ft fixed cost and $9.27/ac-ft variable cost) among the 51 IBTs. Although Harris County has a water surplus every year, it is economically efficient for this IBT given the very low cost of water.

- The LCRA/BRA Alliance (LCRABRA_ColToBrz) with option 1, option 2 and option 3: Water is transferred from Lake Travis in the Colorado Basin to Williamson County in the Brazos Basin to supply cities such as Round Rock, Georgetown, Cedar Park, and Liberty Hill. These supply options are sized to meet 54 percent of the water shortage in Williamson County by 2060. Option 2 transfers 15.9 thousand ac-ft in 2010 and 20.9 thousand ac-ft by 2020 municipally, regardless of the state of nature, while option 1 begins to serve 3.5 thousand ac-ft in 2020 for municipal use. Option 3 starts to act in 2030, bringing 1.8 ac-ft water to Liberty Hill. The construction of these three options would entail low to moderate environmental effects in Williamson County and a low impact below Lake Travis on environmental water needs, in-stream flow, and Matagorda Bay. However, the pipeline construction could have moderate to high impacts on karst invertebrates and other wildlife in Travis and Williamson Counties.
- The LCRA-SAWS Water Project (LCRASAWS_ColToGdsn) with option 2: Under this IBT, 12.3 thousand ac-ft in 2010 and 18.0 thousand ac-ft since 2020 are shipped from Bastrop on the Lower Colorado River Basin to Hays County in the Guadalupe River Basin for municipal use in Austin. This IBT project is expensive (fixed cost of $533/ac-ft and variable cost of $611/ac-ft).
- GBRA/Hays County (Marcoshays_GdsnToCol) with option 1 and option 2: Water is transferred from the city of Buda through the Guadalupe-Blanco River to eastern Hays County to provide water for the nearby Austin metropolitan area. The implementation of this project would have a positive benefit by reducing the demand on Barton Springs, which is a portion of the Edwards Aquifer.

- George Parkhouse Lake N (Parkhouse_SulToTrin) with option 1: Water originates from George Parkhouse Lake in the Sulfur Basin and goes to the Dallas region in the Trinity Basin. This IBT is relatively cheap with a fixed cost of $248/ac-ft, a variable cost of $77.8/ac-ft, and a yielding maximum of 112 thousand ac-ft annually. It may have a medium to high impact on the environment, where a range between 25.3 and 32.7 thousand ac-ft of water will be used industrially regardless of states of nature while a range of 6.6 to 75.8 thousand ac-ft is transferred municipally to solve the water shortage problem faced by the Dallas region.
- The Patman System (Patman_SulToTrin) with option 3 and option 7: Under this IBT, water is purchased from Texarkana in the Sulfur Basin and is then shipped to Forth Worth in the Trinity Basin. Option 3 involves building a pipeline from Lake Patman to a water treatment plant in Forth Worth, while option 7 ships water from Lake Patman to Eagle Mountain Lake. The capacities for these two options (100 thousand ac-ft for option 3 and 180 thousand ac-ft for option 7) are fully operated once they are built.
- The Cypress Basin Supplies Project (Pines_CypToTrin) with option 2 and 3: In option 2, water is transferred from Lake O' Pine in the Cypress Basin to Lake Lavon where water is pumped by the new water treatment plant at Farmersville in the Trinity Basin. Lake Lavon is operated by the North Texas Municipal Water District (NTMWD) and supplies water to cities such as Plano, Farmersville, Forney, Garland, McKinney, Mesquite, Princeton, Rockwall, Royse City, Wylie, and Richardson. Although it is expensive, it has very low environmental impact. It is economically optimal in 2060, bringing 86.7 thousand ac-ft of water for municipal use. In option 3, water flows from

Lake O' Pines to the Trinity River Basin where the possible owner would be Tarrant Regional Water District with supplies dedicated to Fort Worth municipality and industry.

- The Lake Texoma with Desalination Project (Texoma_RedToTrin) with option 1 and option 3: Water is transferred from Lake Texoma in the Red River Basin and supplies to multiple users, such as Allen, Frisco, and Richardson in the Trinity River Basin. These two options are relatively cheap with variable costs of $56/ac-ft and $76/ac-ft, respectively.

When climate change is taken into consideration, optimal IBTs remain at 5 in 2010, and the number increases to 13 in 2050 and 14 in 2060. A new IBT is proved economically feasible in 2060. It is:

- Fork_SabToTri1 with option 1: Water is delivered from Lake Fork in the Sabine Basin to Dallas Water Utility to satisfy increasing municipal water demand in Dallas in the Trinity Basin. It can yield 119.9 thousand ac-ft with a fixed cost of $225.7/ac-ft and variable cost of $48.9/ac-ft.

In addition, LCRABRA_ColToBrz with option 3, Patman_SulToTrin with option 7, and Pines_CypToTrin with option 2 become optimal at earlier decades. Climate change has a slightly positive impact on water transferred at an earlier period and a much greater impact in 2060 in most models excluding the NCAR model under the B1 scenario. The increased amount of water transferred is mainly used for major cities.

Impacts of IBTs on water scarcity

As seen in the previous subsection, water transferred is mainly used for municipal and industrial purposes. In this subsection, we will discuss the IBTs' impact on water scarcity for major cities, major industrial counties, and agricultural land use with/without climate change.

Table 13 displays IBT impact on municipal water scarcity for major cities. Without climate change, optimal IBTs bring an additional 133 thousand ac-ft in 2010 and 577 thousand ac-ft in 2060 of surface water for 18 major cities. Fort Worth, Dallas, Frisco, Plano, McKinney, and Mansfield are a few major cities that benefit from these IBTs. Water shortages in these cities are somewhat reduced but not completely solved. Under climate change, ground water use for major cities slightly decreases, while additional IBTs bring a few more thousand ac-ft of surface water for major cities such as Dallas, Fort Worth, Austin, Denton, Frisco, and McKinney. We can see that under climate change, more optimal IBTs play an important role in reducing water scarcity for major cities.

Table 14 displays the IBTs' impact on water use for major industrial counties. Without climate change, optimal IBTs can bring an additional 546 thousand ac-ft in 2010 and 584 thousand ac-ft in 2060 for major industrial counties, which almost entirely comes from surface water. Harris, Dallas, and Tarrant are the three largest counties receiving the majority of the transferred water. 540 thousand ac-ft of water transferred through Bayou_TriToSan is exclusively used by Harris County, making water use in Harris County greater than its projected demand. Pines_CypToTrin under option 3 brings 5.6 thousand ac-ft in 2010 and 13.8 thousand ac-ft in 2060 to Tarrant County. Parkhouse_SulToTrin with option 1 brings 25.3 thousand ac-ft in 2020 and 29.9 thousand ac-ft in 2060 to Dallas County. The water scarcity in these two counties is greatly reduced. The results from the four GCMs and three SRES indicated that climate change has very trivial effect on industrial water scarcity.

Without climate change, IBTs have no impact on agricultural land use (see table 15). However, this becomes not true under climate change conditions. Both furrow and sprinkler land slightly increase, while dryland slightly decreases, irrigated land is essentially unaffected. These land changes mainly occur in the Guadalupe-San Antonio Basin and Nueces Basin.

IBT impact on water use and environmental stream flow

Table 16 displays IBT impact on total water use excluding water flow out to bay and in-stream flow with/without climate change. Without climate change, economically feasible IBTs yield 713 thousand ac-ft in 2010 and 1.25 million ac-ft in 2060 water, where majority goes to major cities and major counties. Water use for small cities and small industrial counties is slightly affected, while some impact happens in the agricultural sector, where IBTs increase ground water used for irrigation. Recreational water use and other types of water use are almost unaffected by IBTs. Under climate change, total water use increases slightly from 2050, as a result of additional IBTs brings more water for major cities. This result is consistent for all of the GCM models.

Table 17 and 18 show the impact of IBTs on average in-stream flow and water flow out to bay. There is dramatic reduction in the in-stream water flow and water flow out to bay, where climate change makes the situation worse off especially in the later periods.

When checking with more detail, we find out that water is transferred from in-stream flow in the source basins to supply municipal or industrial purposes in the destination basins, while the reduction of in-stream flow leads to the reduction of freshwater inflows to bays and estuaries. More specifically, as sole source basins of the optimal IBTs, Cypress, Red, and Sulphur experience a net loss in both in-stream flow and water flow out to bay. On the other side, the destination basins San Jacinto and Brazos incur a significant increase in either municipal or industrial use as well as water flow out to bay. Trinity, Colorado, and Guadalupe-San Antonio are three basins that serve as both source basins for some IBTs and destination basins for other IBTs, but they behave differently. Trinity serves as both a source basin for Bayou_TriToSan and destination basin for Parkhouse_SulToTrin, Pines_CypToTrin, and Texoma_RedToTrin; therefore, the impact on water allocation is mixed. On one side, water used for municipal and industrial purposes increases by 111 thousand ac-ft in 2010 and 574 thousand ac-ft in 2060, while Trinity also incurs a dramatic loss in freshwater flow to bay as the Bayou_TriToSan project transfers water 540 thousand ac-ft to San Jacinto. Colorado gains in water used for major cities accompanied by reduction in in-stream flow to bay. Guadalupe-San Antonio is a sole winner in both the municipal water use as well as in-stream water flow, though serving as the source basin for Marcoshays_GdsnToCol with option 1 and 2, and the destination basin for LCRASAWS_ColToGdsn with option 2. There is a slight impact on agricultural water use with both ground and surface water. However, the impact is offset among Lavaca, Red, Nueces, Brazos, Colorado, Guadalupe-San Antonio, and Red.

Overall, the source of water transferred is a surplus of in-stream flows in the source basins while the beneficiary is municipal and industrial sectors. The impact of IBTs on other sectors, for example the agricultural sector, for source basins, destination basins, and third basins is trivial.

IBT impact on welfare

In this subsection, we discuss the impact of IBTs on total welfare in Texas with/without climate change (see table 19). The costs of constructing IBTs are assumed to be incurred by the destination basin. Without climate change, IBTs bring expected net benefits of $679 million in 2010 and $3,979 million in 2060 statewide, with the majority arising in industrial and municipal water use. The impact on small industrial counties and value from *outtobay* is minimal given the small amount of impact on small counties or very low value of water flow out to bay. The agriculture sector gains around $10 million in early 2010, but the gain gradually disappears over the years. As destination basins, Trinity, Colorado, San Jacinto, Trinity-San Jacinto, Guadalupe-San Antonio, Red, and Brazos receive the majority of gains from IBTs. As third basins, Colorado-Lavaca, Sabine, and Lavaca-Guadalupe experience trivial mixed effects over time.

Climate change has mixed effect on welfare in the earlier periods and slightly larger positive effects since 2050, with the majority arising from water use in major cities.

Conclusions

Climate change is likely to have an impact on every aspect of human life involving water, and this has been largely overlooked by the Texas Water Development Board in the 2007 State Plan. This article is motivated to fill this gap by addressing climate change impact on water demand, water supply, and water dependent economy in Texas and inter-basin water transfers.

In the statistical analysis, a panel model with random effects is used for the water inflows to river locations. The estimation indicates precipitation and rainfall intensity have positive and significant effects on in-stream flow, while temperature negatively affects in-stream flow. Given the climate change projections from the GCMs and SRES, in-stream water supply in Texas may fluctuate at a range of -50% to +60% in 2060. Municipal water demand is projected to increase by 0.4% to 6.12%. A second panel model over crop yields suggests that temperature, variability of temperature, and precipitation have different positive or negative effects on crop yields depending on the type of crop, location and irrigation status. Crop yields increase or decrease under climate change.

These statistical results are then added into TEXRIVERSIM through the objective function and hydrological constraints. When IBTs are not an option, the without climate change results from TEXRIVERSIM suggest that by 2060 there are 40 major cities (out of 70 major cities) and 19 major industrial counties (out of 50 major industrial counties) that face water shortages, with it rising dramatically in Fort Worth, Austin and Dallas. Majority of irrigated and furrow land is converted to dryland, while 80% of sprinkler land is remained. Under climate change scenario, 61~66 cities and 13~22 industrial counties experience more severe water shortages. Around 80 more thousand acres of sprinkler land is lost. Average in-stream flow may increase or decrease depending on the scenarios and water flow out to bay generally decreases in most GCMs and SRES. The overall welfare increases slightly at earlier decades (less than 2 percent), and declines slightly in 2060 depending on the GCM model.

When IBTs are taken into consideration, 5 IBTs in 2010 and 12 in 2060 are economically feasible without climate change. Water is transferred from in-stream flows in the source basins and used for major cities and major industrial counties in the destination basins, which greatly relaxes water scarcity problems in these cities and counties, but also creates growth opportunity Harris County. However, while destination basins receive the benefits from inter-basin water transfers, source basins will experience dramatic reduction in in-stream flow and water flows to bays and estuaries. Climate change requires accelerated water development with more IBTs proving economically feasible depending on the GCMs and SRES scenarios.

Thus, this article yields a comprehensive evaluation of water scarcity problems faced in Texas due to increasing population growth, economic growth, and climate change conditions. It generates information about the feasibility of water management strategies and their impact on regional economy and environmental in-stream flow. Such information can help state agencies to manage water resources more effectively and more efficiently.

There are some tasks for future research. First, according to the Senate Bill 1, a permit amendment for an inter-basin transfer would result in the assignment of a junior priority date to the water rights transferred from the basin of origin. Thus, the junior water right status of water transfers needs to be incorporated in the future model for a more concise understanding of water use and flows in these basins. Second, climate change is likely to affect ground water supply, which is not dealt with in TEXRIVERSIM. Future work should extend the ground water component statewide. Third, although not reported here, TEXRIVERSIM has the capability to examine water scarcity under extreme dry conditions and possible flood control under extreme wet conditions, which may have significant policy implications.

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Table 1. A Panel Model with Random Effects for Water Inflow

	Model 1a			*Model 1b*		
	Coef.	Robust. Std	P>|z|	Coef.	Robust. Std	P>|z|
Intercept	11.926	0.574	0	11.187	0.556	0
Log(Temp)	-1.355	0.108	0	-1.324	0.107	0
Log(Prep)	0.511	0.022	0	0.464	0.022	0
Log(Drainage)	0.249	0.065	0	0.312	0.061	0
M1	-0.040	0.079	0.614	0.004	0.077	0.954
M2	0.604	0.080	0	0.587	0.078	0
M3	0.623	0.078	0	0.611	0.076	0
M4	1.066	0.078	0	0.986	0.076	0
M5	1.726	0.080	0	1.626	0.078	0
M6	1.419	0.084	0	1.336	0.083	0
M7	0.346	0.089	0	0.312	0.087	0
M8	-0.101	0.094	0.28	-0.132	0.092	0.152
M9	0.464	0.085	0	0.381	0.084	0
M10	0.468	0.082	0	0.372	0.080	0
M11	-0.243	0.077	0.002	-0.270	0.076	0
Log(Prep)*M1	-0.071	0.030	0.017	-0.064	0.029	0.027
Log(Prep)*M2	0.152	0.034	0	0.142	0.033	0
Log(Prep)*M3	0.026	0.031	0.403	0.017	0.030	0.565
Log(Prep)*M4	0.163	0.033	0	0.137	0.032	0
Log(Prep)*M5	0.399	0.039	0	0.367	0.037	0
Log(Prep)*M6	0.204	0.034	0	0.180	0.033	0
Log(Prep)*M7	-0.107	0.031	0.001	-0.112	0.030	0
Log(Prep)*M8	-0.102	0.035	0.004	-0.108	0.035	0.002
Log(Prep)*M9	0.174	0.038	0	0.153	0.037	0
Log(Prep)*M10	0.116	0.035	0.001	0.092	0.034	0.007
Log(Prep)*M11	-0.126	0.033	0	-0.134	0.032	0
Intense100				1.031	0.051	0
Intense50				0.264	0.056	0
Intense25				0.096	0.064	0.135
Sigma_U	0.928			0.852		
Sigma_E	1.444			1.431		
Rho	0.292			0.261		

Table 2. Average Percentage Change of Municipal Water Demand in Texas under Climate Change Scenarios

GCM	SRES	2010	2020	2030	2040	2050	2060
CCCma	A1B	2.96	2.95	2.89	3.17	4.50	4.55
	A2	1.64	3.03	2.69	3.51	4.18	5.64
	B1	2.14	2.32	2.09	3.29	3.29	3.81
Hadley	A1B	3.25	2.23	4.2	4.55	4.95	6.12
	A2	0.89	1.68	3.12	4.00	4.07	5.15
	B1	1.54	2.24	2.73	3.22	3.91	4.57
BCCR	A1B	1.32	2.19	1.77	2.00	2.67	3.81
	A2	1.73	1.92	2.03	2.24	3.30	4.02
	B1	1.84	2.33	2.73	1.71	3.30	2.64
NCAR	A1B	0.46	1.45	1.07	1.69	2.15	2.68
	A2	0.41	1.71	1.04	2.05	2.36	2.75
	B1	1.53	1.61	1.61	1.23	1.99	1.48

Table 3. Changing Crop Water Requirement under Climate Change Scenario (inch)

Irrstatus	*Range*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Irrigated	min	-0.135	-0.138	-0.030	-0.023	-0.064	-0.027
	max	0.118	0.245	0.245	0.203	0.307	0.273
Furrow	min	-0.228	-0.188	-0.050	-0.042	-0.121	-0.036
	max	0.170	0.315	0.332	0.330	0.438	0.501
Sprinkler	min	-0.118	-0.097	-0.026	-0.022	-0.063	-0.019
	max	0.088	0.163	0.172	0.171	0.227	0.259

Table 4. Water Shortage for Major Cities in the Baseline (thousand ac-ft)

GCM	*SRES*	*City*	*Scenario*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Total	Base	-129	-302	-484	-672	-930	-1,270
CCCma	A2	Total	Base	-227	-429	-625	-857	-1,167	-1,555
	A1B	Total	Base	-239	-445	-615	-839	-1,128	-1,540
	B1	Total	Base	-239	-395	-594	-827	-1,089	-1,475
Hadley	A2	Total	Base	-220	-420	-632	-888	-1,165	-1,531
	A1B	Total	Base	-260	-447	-696	-897	-1,193	-1,603
	B1	Total	Base	-252	-466	-658	-878	-1,144	-1,533
BCCR	A2	Total	Base	-246	-455	-614	-836	-1,127	-1,526
	A1B	Total	Base	-234	-440	-638	-825	-1,124	-1,529
	B1	Total	Base	-255	-434	-649	-821	-1,134	-1,452
NCAR	A2	Total	Base	-217	-438	-611	-811	-1,088	-1,448
	A1B	Total	Base	-247	-428	-620	-817	-1,140	-1,462
	B1	Total	Base	-234	-451	-634	-801	-1,060	-1,403

Note: The value is the difference between optimal water use and projected water demand for major cities, indicating water surplus (positive) or shortage (negative).

Table 5. Water Scarcity for Major Industrial Counties in the Baseline (thousand ac-ft)

GCM	*SRES*	*County*	*Scenario*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Total	Base	-193	-279	-358	-447	-520	-568
CCCma	A2	Total	Base	-229	-323	-416	-498	-573	-613
	A1B	Total	Base	-234	-333	-405	-496	-556	-620
	B1	Total	Base	-233	-285	-402	-486	-552	-608
Hadley	A2	Total	Base	-228	-322	-402	-513	-571	-616
	A1B	Total	Base	-254	-346	-434	-508	-567	-626
	B1	Total	Base	-264	-355	-429	-513	-565	-618
BCCR	A2	Total	Base	-259	-354	-415	-505	-569	-619
	A1B	Total	Base	-247	-352	-432	-504	-575	-627
	B1	Total	Base	-257	-343	-427	-506	-572	-616
NCAR	A2	Total	Base	-234	-346	-426	-499	-567	-615
	A1B	Total	Base	-265	-346	-426	-503	-579	-619
	B1	Total	Base	-234	-353	-431	-497	-554	-610

Table 6. Change of Agricultural Land Use in the Baseline (thousand acres)

GCM	*SRES*	*County*	*Type*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Total	Irrigated	31	31	31	31	31	31
		Total	Dryland	2,061	2,061	2,062	2,062	2,063	2,063
		Total	Furrow	34	34	34	34	34	34
		Total	Sprinkler	133	133	133	132	132	131
CCCma	A2	Total	Irrigated	13	1	-1	-4	-1	-3
		Total	Dryland	41	61	57	78	74	65
		Total	Furrow	29	20	27	9	11	20
		Total	Sprinkler	-83	-83	-83	-84	-83	-81
CCCma	A1B	Total	Irrigated	-3	-5	-7	-6	-7	-9
		Total	Dryland	43	62	61	73	77	88
		Total	Furrow	36	26	26	15	10	4
		Total	Sprinkler	-77	-82	-81	-82	-81	-83
CCCma	B1	Total	Irrigated	-6	-5	-4	-7	-6	-7
		Total	Dryland	72	54	62	64	56	72
		Total	Furrow	18	29	24	24	27	16
		Total	Sprinkler	-84	-78	-82	-81	-78	-81
Hadley	A2	Total	Irrigated	0	-2	-3	-7	-8	-7
		Total	Dryland	54	74	77	95	103	93
		Total	Furrow	26	11	8	-5	-12	-6
		Total	Sprinkler	-80	-83	-82	-83	-82	-80
Hadley	A1B	Total	Irrigated	-3	-11	-6	-6	-16	-14
		Total	Dryland	70	86	89	80	99	109
		Total	Furrow	20	9	0	9	0	-13
		Total	Sprinkler	-87	-84	-84	-83	-84	-81
Hadley	B1	Total	Irrigated	-2	-7	-9	-6	-11	-13
		Total	Dryland	73	85	90	92	91	103
		Total	Furrow	16	4	0	-4	2	-13
		Total	Sprinkler	-86	-82	-81	-82	-82	-78
BCCR	A2	Total	Irrigated	-2	-3	-6	-5	-8	-8
		Total	Dryland	72	77	80	84	87	92
		Total	Furrow	17	9	8	5	4	1
		Total	Sprinkler	-86	-83	-82	-84	-84	-85

Table 6. Continued

GCM	*SRES*	*County*	*Type*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
BCCR	A1B	Total	Irrigated	-2	-2	-2	-6	-8	-7
		Total	Dryland	59	71	82	87	99	93
		Total	Furrow	27	17	2	2	-7	-1
		Total	Sprinkler	-84	-86	-81	-83	-83	-85
BCCR	B1	Total	Irrigated	-2	-8	-5	-7	-4	-6
		Total	Dryland	77	80	85	84	84	88
		Total	Furrow	7	12	5	7	4	0
		Total	Sprinkler	-82	-84	-86	-84	-84	-82
NCAR	A2	Total	Irrigated	-5	0	-5	-3	-5	-7
		Total	Dryland	71	68	76	65	86	83
		Total	Furrow	18	16	15	21	-2	7
		Total	Sprinkler	-85	-84	-85	-83	-79	-82
NCAR	A1B	Total	Irrigated	0	-8	-3	-3	-4	-5
		Total	Dryland	69	63	80	72	87	90
		Total	Furrow	15	29	7	15	-1	-7
		Total	Sprinkler	-84	-84	-83	-84	-83	-77
NCAR	B1	Total	Irrigated	-3	2	-5	-3	-6	-7
		Total	Dryland	63	64	77	74	70	81
		Total	Furrow	22	17	10	9	16	3
		Total	Sprinkler	-81	-83	-82	-80	-81	-76

Table 7. Total Water Use Change in the Baseline (thousand ac-ft)

GCM	***SRES***	***River Basin***	***Sector***	***2010***	***2020***	***2030***	***2040***	***2050***	***2060***
Without climate change		Total	Sum	5,917	6,068	6,165	6,221	6,283	6,314
CCCma	A2	Total	Sum	160	160	73	141	90	86
	A1B	Total	Sum	121	132	102	144	143	55
	B1	Total	Sum	170	156	125	126	77	95
Hadley	A2	Total	Sum	172	181	212	102	96	151
	A1B	Total	Sum	103	57	61	55	83	13
	B1	Total	Sum	111	50	129	72	125	110
BCCR	A2	Total	Sum	89	106	162	111	105	47
	A1B	Total	Sum	106	52	126	134	77	22
	B1	Total	Sum	163	120	72	91	64	129
NCAR	A2	Total	Sum	153	108	94	91	160	113
	A1B	Total	Sum	121	34	129	90	39	123
	B1	Total	Sum	152	93	98	155	119	149

Note: *Sum* means total water use excluding water flow out to bay and in-stream flow. The value without climate change is the optimal total water use, while the value under each GCM model is the change of total water use with respect to the total water use without climate change.

Table 8. Average In-stream Flow Change in the Baseline (thousand ac-ft)

GCM	***SRES***	***River Basin***	***2010***	***2020***	***2030***	***2040***	***2050***	***2060***
Without climate change		Total	291	291	291	291	290	290
CCCma	A2	Total	-9	63	-49	-28	-58	-54
	A1B	Total	28	20	-4	27	32	-80
	B1	Total	41	51	30	-7	-20	-3
Hadley	A2	Total	39	3	18	-51	-74	-23
	A1B	Total	-67	-85	-99	-69	-81	-100
	B1	Total	-60	-84	-39	-90	-38	-64
BCCR	A2	Total	-47	-54	35	-61	-55	-91
	A1B	Total	-44	-38	0	-31	-79	-97
	B1	Total	7	-19	-76	-55	-61	-47
NCAR	A2	Total	23	-16	-24	-6	46	-16
	A1B	Total	-29	-70	-28	-53	-87	-46
	B1	Total	43	6	24	57	30	39

Note: The value without climate change is the average in-stream flow, while the value under each GCM model is the change of water use with respect to the average in-stream flow without climate change.

Table 9. Total Change for Water Flow out to Bay in the Baseline (thousand ac-ft)

GCM	*SRES*	*River Basin*	*Sector*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Total	Outtobay	102,028	101,969	101,912	101,870	101,837	101,819
CCCma	A2	Total	Outtobay	-2,607	20,821	-17,866	-6,421	-17,365	-13,161
	A1B	Total	Outtobay	8,353	2,462	-406	5,007	6,761	-19,470
	B1	Total	Outtobay	6,382	14,200	11,269	-6,208	-10,195	-5,892
Hadley	A2	Total	Outtobay	11,290	1,044	3,449	-22,795	-24,703	-6,701
	A1B	Total	Outtobay	-19,680	-25,067	-34,306	-19,863	-20,791	-31,570
	B1	Total	Outtobay	-18,478	-20,771	-11,946	-29,100	-11,373	-20,572
BCCR	A2	Total	Outtobay	-19,117	-21,577	1,439	-20,117	-22,659	-29,310
	A1B	Total	Outtobay	-17,760	-21,031	-1,479	-10,290	-30,618	-29,556
	B1	Total	Outtobay	-6,634	-10,340	-28,205	-18,554	-21,333	-19,223
NCAR	A2	Total	Outtobay	-744	-14,106	-11,785	-8,546	4,592	-10,908
	A1B	Total	Outtobay	-4,343	-19,953	-10,779	-18,678	-23,282	-16,337
	B1	Total	Outtobay	46	-4,738	-630	12,555	2,899	5,974

Note: The value without climate change is the average water flow out to bay, while the value under each GCM model is the change of water use with respect to the average water flow out to bay without climate change.

Table 10. Change of Total Welfare in the Baseline (million $)

GCM	*SRES*	*River Basin*	*Sector*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Total	Sum	98,671	112,680	125,149	136,964	150,796	165,166
CCCma	A2	Total	Sum	1,408	1,453	870	992	547	349
	A1B	Total	Sum	1,682	1,826	1,155	1,075	914	-34
	B1	Total	Sum	1,361	1,723	890	1,573	995	690
Hadley	A2	Total	Sum	1,312	1,228	840	1,177	-31	-238
	A1B	Total	Sum	1,295	1,229	392	671	150	-729
	B1	Total	Sum	1,177	1,020	502	664	471	-542
BCCR	A2	Total	Sum	1,080	1,123	598	1,002	168	491
	A1B	Total	Sum	1,383	1,656	577	796	1	214
	B1	Total	Sum	972	1,110	634	1,104	351	-47
NCAR	A2	Total	Sum	1,342	1,379	799	1,454	484	345
	A1B	Total	Sum	1,216	1,571	654	1,338	305	328
	B1	Total	Sum	1,317	1,562	771	1,116	986	577

Note: *Sum* means total welfare including water flow out to bay. “without climate change” serves as a baseline scenario, while the value under each GCM model is the change of benefit with respect to the baseline welfare.

Table 11. Optimal IBTs

IBTs	*Option*	*Capacity*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Bayou_TriToSan	Opt1	540	A|X	A|X	A|X	A|X	A|X	A|X
Fork_SabToTri	Opt1	119.9						X
LCRABRA_ColToBrz	Opt1	3.5		A|X	A|X	A|X	A|X	A|X
LCRABRA_ColToBrz	Opt2	20.9	A|X	A|X	A|X	A|X	A|X	A|X
LCRABRA_ColToBrz	Opt3	1.8		X	A|X	A|X	A|X	A|X
LCRASAWS_ColToGdsn	Opt2	18	A|X	A|X	A|X	A|X	A|X	A|X
Marcoshays_GdsnToCol	Opt1	1.7			A|X	A|X	A|X	A|X
Marcoshays_GdsnToCol	Opt2	1.3			A|X	A|X	A|X	A|X
Parkhouse_SulToTrin	Opt1	112		A|X	A|X	A|X	A|X	A|X
Patman_SulToTrin	Opt3	100			A|X	A|X	A	X
Patman_SulToTrin	Opt7	180					X	A|X
Pines_CypToTrin[1]	Opt2	87.9					X	A|X
Pines_CypToTrin	Opt3	87.9	A|X	A|X		A|X	A|X	A|X
Texoma_RedToTrin	Opt1	113	A|X	A|X	A|X	A|X	A|X	A|X
Texoma_RedToTrin[2]	Opt3	50				A|X	A|X	
Total number			5|5	7|8	10|10	12|12	12|13	12|14

Note: 1. It is not optimal in 2050 in the CCCma_B1, BCCR_A1B, BCCR_A2 and NCAR models
2. It is only optimal in 2050 in the CCCma_B1, BCCR_A1B, BCCR_A2 and NCAR models
3. A and X denotes an IBT is optimal without/with climate change respectively.

Table 12. Water Transferred by IBTs (thousand ac-ft)

GCM	*SRES*	*Sector*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Sum	678	805	838	973	998	1,160
CCCma	A2	Sum	7	6	5	13	113	153
	A1B	Sum	10	8	2	5	105	156
	B1	Sum	8	6	0	10	72	80
Hadley	A2	Sum	4	7	1	14	120	150
	A1B	Sum	13	10	53	18	124	173
	B1	Sum	7	10	3	16	111	156
BCCR	A2	Sum	8	8	-2	13	73	159
	A1B	Sum	7	8	0	8	77	157
	B1	Sum	9	8	7	11	110	140
NCAR	A2	Sum	2	6	1	4	61	77
	A1B	Sum	3	8	1	10	79	139
	B1	Sum	6	6	0	0	67	2

Note: "without climate change" serves as a baseline scenario, while the value under each GCM model is the change of water transferred from IBTs with respect to amount of water transferred under the baseline.

Table 13. Water Shortage for Major Cities (thousand ac-ft)

GCM	*SRES*	*Type*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
		Mun-citygw						
		Mun-citysw	133	232	270	388	415	577
Without climate change		Mun-city	133	232	270	388	415	577
		Shortage without IBT	-129	-302	-484	-672	-930	-1,270
		Shortage with IBT	4	-70	-215	-285	-515	-693
		Mun-citygw	-1	-2	-2	-1	-3	-1
		Mun-citysw	139	239	275	401	524	723
CCCma	A2	Mun-city	138	236	273	400	521	722
		Shortage without IBT	-120	-271	-482	-680	-929	-1,242
		Shortage with IBT	18	-35	-210	-280	-409	-520
		Mun-citygw	-1	-2	-3	-2	0	0
		Mun-citysw	143	241	271	394	514	726
CCCma	A1B	Mun-city	142	238	269	392	514	726
		Shortage without IBT	-130	-277	-474	-670	-899	-1,235
		Shortage with IBT	12	-39	-205	-278	-385	-509
		Mun-citygw	-2	0	-3	-2	0	-1
		Mun-citysw	141	238	270	398	480	652
CCCma	B1	Mun-city	139	238	267	396	480	651
		Shortage without IBT	-126	-270	-458	-663	-870	-1,183
		Shortage with IBT	13	-32	-192	-267	-389	-532
		Mun-citygw	-3	-5	-2	-1		
		Mun-citysw	137	239	271	403	531	719
Hadley	A2	Mun-city	134	234	268	402	531	719
		Shortage without IBT	-117	-269	-511	-712	-913	-1,197
		Shortage with IBT	17	-34	-243	-310	-382	-478
		Mun-citygw	-2	-3	0	-3	0	
		Mun-citysw	146	242	323	408	535	743
Hadley	A1B	Mun-city	144	239	323	405	535	743
		Shortage without IBT	-138	-283	-549	-712	-954	-1,254
		Shortage with IBT		-44	-226	-307	-419	-511
		Mun-citygw	-2	-4	-2	0	-1	
		Mun-citysw	140	243	273	405	521	726
Hadley	B1	Mun-city	138	239	271	405	520	726
		Shortage without IBT	-143	-303	-518	-709	-916	-1,204
		Shortage with IBT	-5	-64	-247	-305	-395	-478
		Mun-citygw	-2	-3	-3	0	0	
		Mun-citysw	141	240	268	401	483	729
BCCR	A2	Mun-city	139	237	266	401	482	729
		Shortage without IBT	-161	-293	-481	-676	-900	-1,201
		Shortage with IBT	-22	-56	-215	-275	-418	-472

Table 13. Continued

GCM	***SRES***	***Type***	***2010***	***2020***	***2030***	***2040***	***2050***	***2060***
BCCR	A1B	*Mun-citygw*	-2	-3	-2			
		Mun-citysw	139	240	269	396	487	727
		Mun-city	138	237	268	396	487	727
		Shortage without IBT	-159	-276	-499	-654	-875	-1,196
		Shortage with IBT	-21	-40	-231	-257	-388	-469
BCCR	B1	*Mun-citygw*	-3	-4	-2	0		
		Mun-citysw	141	240	278	399	520	708
		Mun-city	139	236	276	399	520	708
		Shortage without IBT	-150	-271	-513	-665	-903	-1,146
		Shortage with IBT	-11	-35	-237	-266	-384	-438
NCAR	A2	*Mun-citygw*	-3	-4	-2	-1	0	0
		Mun-citysw	135	238	271	392	470	649
		Mun-city	132	234	269	391	469	649
		Shortage without IBT	-114	-277	-476	-647	-864	-1,171
		Shortage with IBT	19	-42	-207	-256	-395	-522
NCAR	A1B	*Mun-citygw*	-4	0	-1	-2	0	
		Mun-citysw	136	240	271	398	490	707
		Mun-city	132	240	270	396	490	707
		Shortage without IBT	-142	-283	-494	-658	-913	-1,146
		Shortage with IBT	-10	-43	-224	-262	-423	-439
NCAR	B1	*Mun-citygw*	-2	-3	-2	-2	-1	
		Mun-citysw	139	238	269	388	476	580
		Mun-city	137	235	267	386	475	580
		Shortage without IBT	-123	-290	-494	-640	-846	-1,108
		Shortage with IBT	14	-55	-227	-253	-371	-529

Note: Mun-city = Mun-citygw + Mun-citysw (see figure 2 in appendix for the definition); Shortage with IBT/ Shortage without IBT: water shortage for major cities whether IBTs are allowed or not

Table 14. Water Scarcity for Industrial Water Use (thousand ac-ft)

GCM	***SRES***	***Type***	***2010***	***2020***	***2030***	***2040***	***2050***	***2060***
Without climate change		*Ind-maingw*						
		Ind-mainsw	546	573	568	585	583	584
		Ind-main	546	573	568	585	583	584
		Shortage without IBT	-143	-201	-219	-272	-299	-294
		Shortage with IBT	411	381	357	321	291	295
CCCma	A2	*Ind-maingw*	0	-1	-1	0	0	0
		Ind-mainsw	546	573	568	585	588	591
		Ind-main	545	572	567	585	588	591
		Shortage without IBT	-144	-227	-265	-302	-330	-314
		Shortage with IBT	409	352	321	289	270	281
CCCma	A1B	*Ind-maingw*	-3	0	-1	0	0	
		Ind-mainsw	546	573	568	585	590	591
		Ind-main	543	573	568	585	590	591
		Shortage without IBT	-170	-215	-252	-296	-318	-331
		Shortage with IBT	389	362	327	292	272	260
CCCma	B1	*Ind-maingw*	-1	0	0	-1	0	0
		Ind-mainsw	546	573	568	585	589	589
		Ind-main	545	573	568	584	589	589
		Shortage without IBT	-167	-199	-248	-296	-319	-319
		Shortage with IBT	397	380	329	297	280	273
Hadley	A2	*Ind-maingw*	0	-1	0	0		
		Ind-mainsw	546	573	568	585	588	592
		Ind-main	545	573	568	585	588	592
		Shortage without IBT	-143	-215	-245	-312	-336	-331
		Shortage with IBT	409	373	335	280	252	261
Hadley	A1B	*Ind-maingw*	0	-1	0	0	0	
		Ind-mainsw	546	574	568	584	588	590
		Ind-main	546	573	568	584	588	590
		Shortage without IBT	-175	-237	-262	-296	-326	-331
		Shortage with IBT	374	344	307	291	265	259
Hadley	B1	*Ind-maingw*	0	-1	0	0	0	
		Ind-mainsw	546	574	568	584	588	591
		Ind-main	545	572	568	584	588	591
		Shortage without IBT	-179	-251	-256	-307	-322	-331
		Shortage with IBT	372	334	321	278	266	260
BCCR	A2	*Ind-maingw*	0	-2	0		0	0
		Ind-mainsw	546	574	568	585	589	591
		Ind-main	545	572	568	585	589	591
		Shortage without IBT	-179	-243	-254	-314	-331	-326
		Shortage with IBT	372	344	316	271	266	270

Table 14. Continued

GCM	*SRES*	*Type*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
BCCR	A1B	*Ind-maingw*	-1	-1	0			0
		Ind-mainsw	546	573	568	585	589	591
		Ind-main	545	572	568	585	589	591
		Shortage without IBT	-172	-242	-274	-305	-339	-328
		Shortage with IBT	379	346	306	285	253	263
BCCR	B1	*Ind-maingw*	-1	0	0	0		
		Ind-mainsw	546	573	568	585	589	592
		Ind-main	545	573	568	585	589	592
		Shortage without IBT	-180	-228	-264	-305	-336	-331
		Shortage with IBT	375	348	313	283	253	261
NCAR	A2	*Ind-maingw*	0	-1	0	0	0	
		Ind-mainsw	546	573	568	585	590	589
		Ind-main	545	573	568	585	590	589
		Shortage without IBT	-198	-230	-267	-306	-326	-331
		Shortage with IBT	352	348	306	281	267	258
NCAR	A1B	*Ind-maingw*	-1	0	0	0	0	
		Ind-mainsw	546	573	568	585	588	592
		Ind-main	545	573	568	585	588	592
		Shortage without IBT	-185	-242	-260	-293	-335	-331
		Shortage with IBT	370	343	311	295	256	261
NCAR	B1	*Ind-maingw*	0	-1	0	-1	0	0
		Ind-mainsw	546	573	568	585	590	583
		Ind-main	546	572	568	585	590	583
		Shortage without IBT	-165	-242	-265	-294	-329	-322
		Shortage with IBT	387	345	308	301	267	265

Note: Ind-main = Ind-maingw + Ind-mainsw (see figure 2 in appendix for the definition); Shortage with IBT/ Shortage without IBT: water shortage for major industrial counties whether IBTs are allowed or not

Table 15. Agricultural Land Change (thousand acres)

GCM	*SRES*	*Type*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Dryland	0	0	0	0	0	0
		Furrow	0	0	0	0	0	0
		Sprinkler	0	0	0	0	0	0
CCCma	A2	Dryland	-0.51	-1.33	-1.07	-0.12	-0.42	-0.37
		Furrow	0.14	1.15	0.46	0.07	0.42	0.32
		Sprinkler	0.37	0.17	0.61	0.05		0.05
CCCma	A1B	Dryland		-0.94	-1.12	-0.61	-0.03	-0.04
		Furrow	0.05	0.18	0.21	0.44	0.02	0.04
		Sprinkler	-0.05	0.76	0.91	0.17	0.01	
CCCma	B1	Dryland	-0.69		-1.3	-1.35		-0.56
		Furrow	0.56		1.13	1.18		0.49
		Sprinkler	0.14		0.17	0.17		0.07
Hadley	A2	Dryland	-1.03	-0.79	-0.55	-0.11		
		Furrow	0.27	0.6	0.45	0.11		
		Sprinkler	0.76	0.19	0.1			
Hadley	A1B	Dryland	-0.63	-0.82	-0.07	-0.58	-0.06	
		Furrow	0.53	0.8	0.07	0.51	0.06	
		Sprinkler	0.1	0.02		0.06		
Hadley	B1	Dryland	-0.58	-0.63	-0.44	-0.08	-0.15	
		Furrow	0.12	0.64	0.08	-0.01	0.05	
		Sprinkler	0.46		0.35	0.09	0.11	
BCCR	A2	Dryland	-0.55	-0.68	-0.37		-0.15	
		Furrow	-0.71	0.69	0.28		0.15	
		Sprinkler	1.26		0.09			
BCCR	A1B	Dryland	-0.83	-1.35	-0.34			
		Furrow	0.21	1.18	0.02			
		Sprinkler	0.62	0.18	0.32			
BCCR	B1	Dryland	-0.62	-1	-0.42	-0.06		
		Furrow	0.04	0.82	0.34	0.06		
		Sprinkler	0.58	0.18	0.08			
NCAR	A2	Dryland	-1.01	-0.78	-0.36	-0.41	-0.14	-0.09
		Furrow	0.87	0.11	0.29	0.35	0.02	0.07
		Sprinkler	0.14	0.67	0.07	0.05	0.12	0.02
NCAR	A1B	Dryland	-0.67		-0.17	-0.6	-0.05	
		Furrow	-0.15		0.14	0.12	0.01	
		Sprinkler	0.82		0.03	0.48	0.04	
NCAR	B1	Dryland	-0.48	-0.89	-0.61	-0.18	-0.45	
		Furrow	0.28	0.72	0.52	-0.82	0.09	
		Sprinkler	0.21	0.17	0.1	1	0.36	

Note: no land use change for irrigated land

Table 16. IBT Impact on Total Water Use (thousand ac-ft)

GCM	*SRES*	*Sector*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Sum	713	865	899	1,053	1,077	1,250
CCCma	A2	Sum	721	871	905	1,065	1,203	1,404
	A1B	Sum	726	873	901	1,059	1,195	1,406
	B1	Sum	723	872	899	1,062	1,148	1,331
Hadley	A2	Sum	717	871	900	1,066	1,209	1,401
	A1B	Sum	729	876	971	1,071	1,213	1,422
	B1	Sum	722	877	902	1,068	1,199	1,406
BCCR	A2	Sum	722	872	897	1,065	1,150	1,409
	A1B	Sum	721	872	899	1,061	1,153	1,408
	B1	Sum	723	872	907	1,063	1,199	1,390
NCAR	A2	Sum	715	870	899	1,056	1,138	1,328
	A1B	Sum	717	873	900	1,062	1,157	1,389
	B1	Sum	720	870	898	1,053	1,144	1,252

Note: *Sum* means total water use excluding water flow out to bay and in-stream flow; the value is the difference of total water use in the opt scenario and the baseline scenario

Table 17. Impact on Average In-stream Flow (thousand ac-ft)

GCM	*SRES*	*Type*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Instream	-3.0	-3.3	-2.5	-2.6	-2.8	-3.1
CCCma	A2	Instream	-3.0	-3.3	-2.6	-2.7	-2.7	-3.7
	A1B	Instream	-3.1	-3.4	-2.5	-2.7	-2.6	-3.7
	B1	Instream	-3.0	-3.3	-2.5	-2.7	-2.2	-2.3
Hadley	A2	Instream	-3.0	-3.4	-2.5	-2.7	-2.7	-3.6
	A1B	Instream	-3.0	-3.4	-2.5	-2.8	-2.8	-3.8
	B1	Instream	-3.0	-3.4	-2.5	-2.7	-2.6	-3.7
BCCR	A2	Instream	-3.0	-3.4	-2.5	-2.7	-2.2	-3.7
	A1B	Instream	-3.0	-3.3	-2.5	-2.7	-2.3	-3.7
	B1	Instream	-3.0	-3.4	-2.6	-2.7	-2.7	-3.6
NCAR	A2	Instream	-3.2	-3.6	-2.6	-2.8	-2.3	-2.5
	A1B	Instream	-3.0	-3.4	-2.5	-2.7	-2.3	-3.6
	B1	Instream	-3.0	-3.3	-2.5	-2.6	-2.2	-3.1

Note: The value is the difference of total water use in the opt scenario and the baseline scenario

Table 18. Impact on Water Flow out to Bay (thousand ac-ft)

GCM	*SRES*	*Sector*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Outtobay	-423	-487	-500	-566	-576	-650
CCCma	A2	Outtobay	-426	-490	-506	-573	-633	-722
	A1B	Outtobay	-430	-491	-503	-569	-626	-724
	B1	Outtobay	-427	-489	-501	-571	-610	-688
Hadley	A2	Outtobay	-426	-492	-502	-573	-633	-720
	A1B	Outtobay	-429	-494	-527	-576	-634	-733
	B1	Outtobay	-427	-496	-503	-574	-628	-723
BCCR	A2	Outtobay	-429	-493	-502	-571	-613	-726
	A1B	Outtobay	-427	-490	-502	-569	-613	-726
	B1	Outtobay	-429	-491	-506	-571	-629	-716
NCAR	A2	Outtobay	-424	-493	-501	-567	-606	-687
	A1B	Outtobay	-429	-490	-501	-571	-616	-715
	B1	Outtobay	-426	-490	-501	-569	-609	-651

Note: The value is the difference of total water use in the opt scenario and the baseline scenario

Table 19. Total Welfare Impact ($ millions)

GCM	*SRES*	*Sector*	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*
Without climate change		Sum	679	1,220	1,740	1,915	2,258	3,979
CCCma	A2	Sum	727	1,068	2,158	1,933	2,565	4,760
	A1B	Sum	760	765	1,863	1,969	2,217	4,756
	B1	Sum	618	922	2,057	1,467	2,853	4,333
Hadley	A2	Sum	899	1,230	1,901	1,612	2,951	5,093
	A1B	Sum	853	1,327	2,195	2,243	2,711	5,196
	B1	Sum	731	1,519	1,872	2,042	2,519	5,126
BCCR	A2	Sum	766	1,400	2,056	1,857	3,035	4,117
	A1B	Sum	840	871	1,939	1,973	2,975	4,419
	B1	Sum	798	1,455	2,103	1,914	2,726	4,699
NCAR	A2	Sum	614	1,279	1,932	1,566	2,473	4,610
	A1B	Sum	626	1,095	2,203	1,792	2,594	4,416
	B1	Sum	890	712	1,913	2,037	2,440	4,367

Note: *Sum* means total welfare including water flow out to bay; the value is the difference of total water use in the opt scenario and the baseline scenario

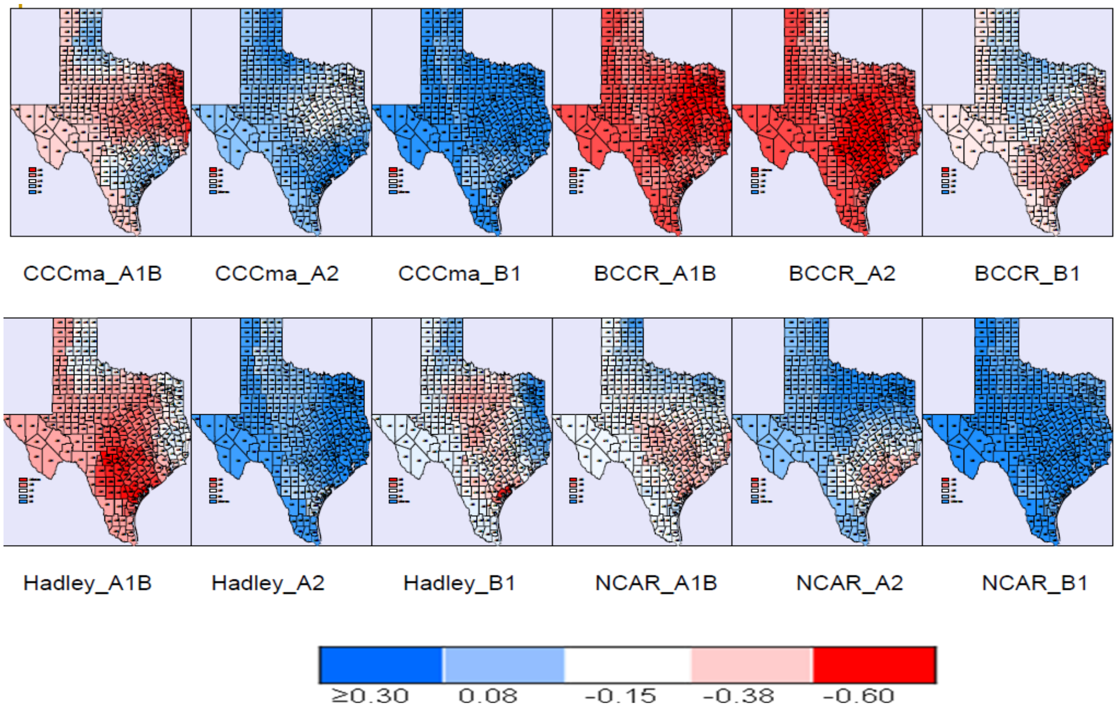


Figure 1. Percentage change of water inflows in Texas, 2060

APPENDIX

Table 20. Inter-basin Water Transfers in the Model

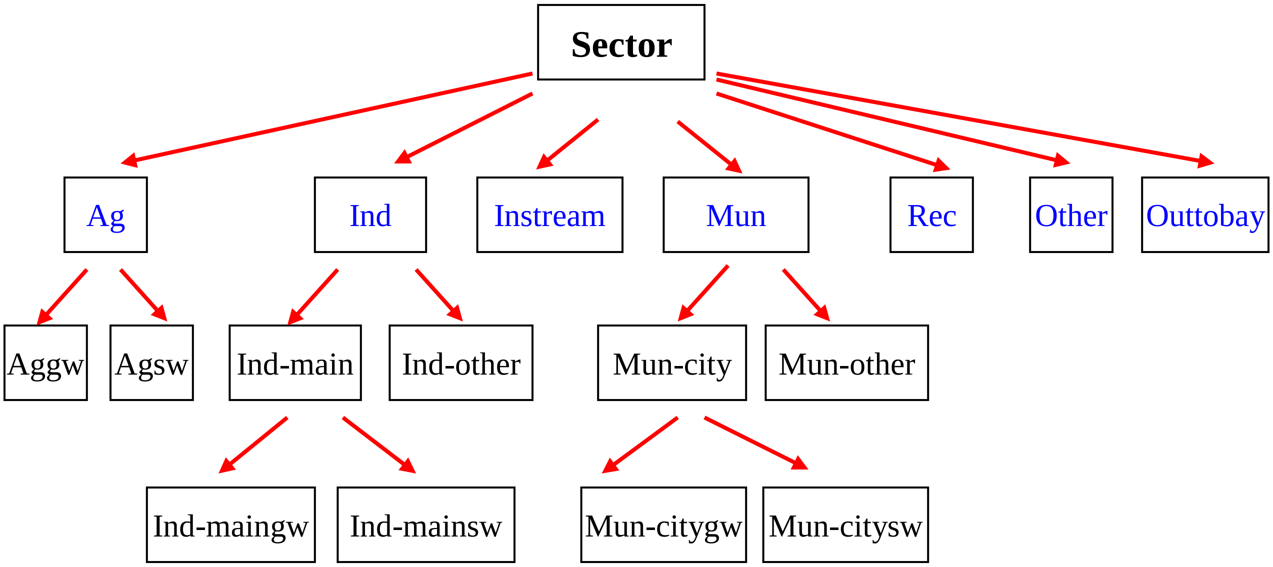
IBT	*Option*	*Origin*	*Destination*	*Capacity*	*FC*	*VC*
Toledo_SabToTrin	Opt1	Sabine	Trinity	50.0	136.00	128.9
Toledo_SabToTrin	Opt2	Sabine	Trinity	50.0	215.00	143.2
Toledo_SabToTrin	Opt3	Sabine	Trinity	50.0	173.00	151.4
Marvin_SulToTrin	Opt1	Sulphur	Trinity	172.8	155.00	115.2
Marvin_SulToTrin	Opt2	Sulphur	Trinity	174.8	160.00	97.5
Patman_SulToTrin	Opt1	Sulphur	Trinity	100.0	35.28	203.3
Patman_SulToTrin	Opt2	Sulphur	Trinity	100.0	32.03	233.4
Patman_SulToTrin	Opt3	Sulphur	Trinity	100.0	32.03	233.4
Patman_SulToTrin	Opt4	Sulphur	Trinity	112.1	42.47	110.0
Patman_SulToTrin	Opt5	Sulphur	Trinity	180.0	68.23	110.5
Patman_SulToTrin	Opt6	Sulphur	Trinity	180.0	61.35	120.5
Patman_SulToTrin	Opt7	Sulphur	Trinity	180.0	77.22	165.8
Patman_SulToTrin	Opt8	Sulphur	Trinity	130.0	141.00	180.2
Texoma_RedToTrin	Opt1	Red	Trinity	113.0	15.02	55.8
Texoma_RedToTrin	Opt2	Red	Trinity	105.0	43.75	222.3
Texoma_RedToTrin	Opt3	Red	Trinity	50.0	13.62	75.8
Texoma_RedToTrin	Opt4	Red	Trinity	105.0	49.94	231.0
Rayburn_NecToTrin	Opt1	Neches	Trinity	200.0	97.28	179.1
Rayburn_NecToTrin	Opt2	Neches	Trinity	200.0	105.00	211.0
Rayburn_NecToTrin	Opt3	Neches	Trinity	200.0	97.28	179.1
BoisdArc_RedToTrin	Opt1	Red	Trinity	123.0	29.61	41.8
Fork_SabToTri	Opt1	Sabine	Trinity	119.9	27.07	48.9
Parkhouse_SulToTrin	Opt1	Sulphur	Trinity	112.0	27.79	77.8
Parkhouse_SulToTrin	Opt2	Sulphur	Trinity	119.0	26.93	69.5
Palestine_NecToTrin	Opt1	Neches	Trinity	111.5	30.99	73.7
Palestine_NecToTrin	Opt2	Neches	Trinity	133.4	37.16	75.9
Fastrill_NecToTrin	Opt1	Neches	Trinity	112.1	42.25	79.2
Parkhouse_SulToTrin	Opt3	Sulphur	Trinity	108.5	35.54	77.1
Pines_CypToTrin	Opt1	Cypress	Trinity	89.6	25.71	201.5
Pines_CypToTrin	Opt2	Cypress	Trinity	87.9	19.23	188.8
Pines_CypToTrin	Opt3	Cypress	Trinity	87.9	35.00	243.0
RalphHall_SulToTrin	Opt1	Sulphur	Trinity	32.9	15.65	75.3
Columbia_NecToTrin	Opt1	Neches	Trinity	35.8	16.54	80.6
Marcoshays_GdsnToCol	Opt1	Guadsan	Colorado	1.7	0.58	354.7

Table 20. Continued

IBT	***Option***	***Origin***	***Destination***	***Capacity***	***FC***	***VC***
Marcoshays_GdsnToCol	Opt2	Guadsan	Colorado	1.3	0.45	354.0
LCRASAWS_ColToGdsn	Opt1	Colorado	Guadsan	75.0	153.00	302.8
LCRASAWS_ColToGdsn	Opt2	Colorado	Guadsan	18.0	9.60	611.1
AlanHenry_BrzToCol	Opt1	Brazos	Colorado	16.8	17.95	130.6
LCRABRA_ColToBrz	Opt1	Colorado	Brazos	3.5	1.48	338.3
LCRABRA_ColToBrz	Opt2	Colorado	Brazos	20.9	8.13	332.1
LCRABRA_ColToBrz	Opt3	Colorado	Brazos	1.8	0.81	338.7
JoePool_TrinToBrz	Opt1	Trinity	Brazos	20.0	6.29	285.9
Bayou_TriToSan	Opt1	Trinity	SanJacinto	540.0	11.17	9.3
Bedias_TriToSan	Opt1	Trinity	SanJacinto	90.7	5.98	135.3
ETWT_SabNecToTri	Opt1	Sabine	Trinity	155.6	23.41	15.6
ETWT_SabNecToTri	Opt1	Neches	Trinity	117.3	--	15.6
Livingston_TriToSan	Opt1	Trinity	SanJacinto	59.0	15.81	226.1
Garwood_ColToNus	Opt1	Colorado	Nueces	35.0	5.61	399.9
Garwood_ColToNus	Opt2	Colorado	Nueces	35.0	0.47	399.9
Garwood_ColToNus	Opt3	Colorado	Nueces	35.0	3.62	399.9

Note: Option: alternative IBTs; Origin/Destination: source/destination river basin; Capacity: maximium amount of water can be transferred annually, thousand ac-ft; FC: fixed cost ($ million); VC: variable unit cost ($/ac-ft)

Source: Texas Water Development Board**, “**2007 State Water Plan**”**



Note: Ag – Agricultural water use
Aggw –Agricultural water use from ground water
Agsw –Agricultural water use from surface water
Ind – Industrial water use
Ind-main – Water use for major industrial counties
Ind-maingw – Water use for major industrial counties supplied by surface water
Ind-maingw – Water use for major industrial counties supplied by ground water
Ind-other – Water use for small industrial counties supplied by surface water
Instream – In-stream water flow
Mun – Municipal water use
Mun-city – Municipal water use for major cities
Mun-citygw – Municipal water use for major cities supplied by ground water
Mun-citysw – Municipal water use for major cities supplied by surface water
Rec – Recreational water use
Other – Other type of water use
Outtobay – Water flow out to bay

Figure 2. Water use sectors in the TEXRIVERSIM model