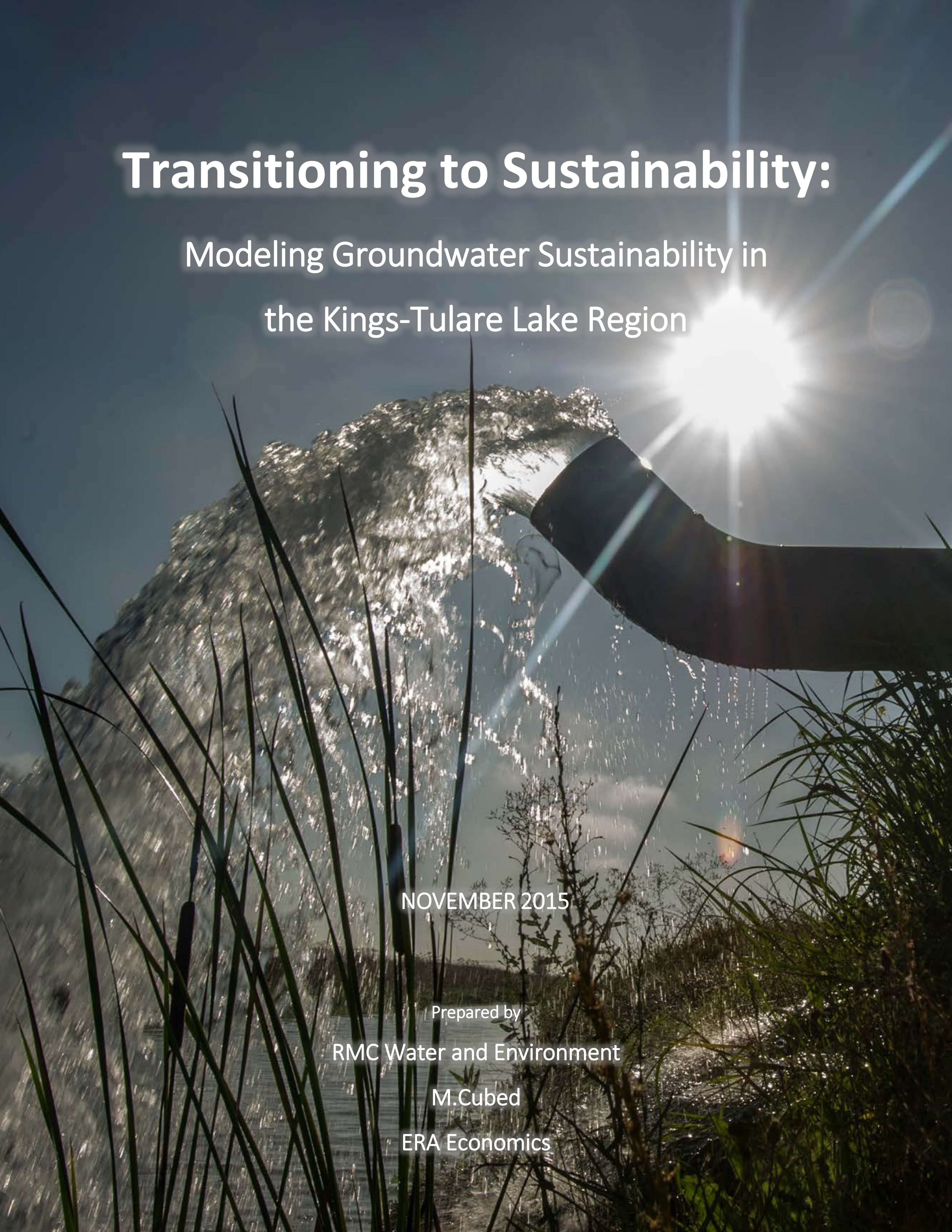

# Transitioning to Sustainability:

## Modeling Groundwater Sustainability in the Kings-Tulare Lake Region

NOVEMBER 2015


Prepared by

RMC Water and Environment

M.Cubed

ERA Economics

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## Project Team

- Ali Taghavi (RMC)
- David Mitchell (M.Cubed)
- Duncan MacEwan (ERA Economics)
- Mesut Cayar (RMC)
- Steve Hatchet, (CH2MHILL)

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CALIFORNIA WATER FOUNDATION

# Abstract

*As California is going through the fourth year of drought, groundwater levels are rapidly declining in many areas, and especially in the basins within California's Central Valley. The Sustainable Groundwater Management Act (SGMA) of 2014 requires local agencies in certain groundwater sub-basins where declines are critical to establish a Groundwater Sustainability Agency (GSA) and work towards development of a Groundwater Sustainability Plan, which would set a course towards sustainable management of groundwater in order to avoid significant and unreasonable adverse effects on the groundwater resources. A major question for much of the agricultural community in the Central Valley is the effects of reduction in groundwater use on the hydrologic, socio-economic, and environmental conditions in the area. This study uses hydrologic and economic models available for the Central Valley to assess these impacts.*

*The study region encompassed the Kings and Tulare Lake groundwater subbasins within Fresno, Kings, and Tulare Counties. Under existing land uses, groundwater extraction averages about 3 MAF per year, comprising 67 percent of total water use in a typical year. In dry years, groundwater may comprise as much as 80 percent of total water use in the region. Groundwater data compiled by regional water agencies and DWR indicate the study region has been in a state of overdraft over the past several decades, with average extraction exceeding average recharge by about 0.3 MAF annually.*

*Achieving sustainable groundwater conditions can be a result of a combination of demand side measures, such as conservation and reduction in groundwater usage, as well as supply side measures, such as increased artificial recharge and conjunctive use opportunities. Indeed, we would expect most regions to implement a combination of supply- and demand-side management strategies. However, for this study, the analytical focus is on the impacts of achieving sustainable groundwater use solely through managing the quantity and timing of groundwater extraction, without the benefit of augmenting the basin's water supply with additional imported water. We do this, not because we believe supply-side strategies are inferior, but rather because we expect the largest negative economic impacts of transitioning to sustainable management will be associated with institutional restrictions on extraction. By focusing on institutional restrictions we are able to place an upper-bound on the potential adverse economic consequences of stabilizing groundwater elevations at their current levels. The goal of the study, therefore, is to assess the hydrologic and economic effects of transitioning to sustainable groundwater management for a high-priority groundwater basin in the San Joaquin Valley by altering the quantity and timing of groundwater extraction.*

*This entailed modeling the complex hydro-economic dynamics of groundwater use in the study region. This modeling was accomplished by integrating DWR's California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) with its Statewide Agricultural Production Model (SWAP). The resulting hydro-economic model was used to simulate changes in agricultural cropping patterns, production costs, farm investment, and farm revenues over an 88-year simulation period with and without institutional restrictions regulating the timing and quantity of groundwater extraction.*

*The hydrologic modeling results show the Kings and Tulare Lake subbasins are not presently on a path of sustainable groundwater management. A reduction in groundwater pumping in the range of 15-20% from current amounts is needed to stabilize average groundwater elevation in the study region. Modeling results also highlight the complex, interdependent nature of groundwater usage, recharge, and flow between subbasins. For example, in order to stabilize groundwater elevations within the study region, it is necessary to assume that neighboring basins are being similarly managed. Otherwise, the gains from sustainable management in the study region would be ceded to the western bordering subbasins due to groundwater migration. This has important implications for the establishment and governance of Groundwater Sustainability Agencies (GSAs). In terms of the economic costs of transitioning to sustainable groundwater management, the modeling indicates that farm-level production losses would be more or less offset by avoided costs of pumping and well investment, and the value of having additional groundwater reserves in dry years.*

## Contents

## Introduction

The purpose of this study is to summarize the methods, data, modeling results, and policy implications of a study funded by the California Water Foundation to simulate transitioning a high-priority groundwater basin in the San Joaquin Valley to sustainability. The study looks at the impacts to the physical groundwater resource and the socio-economic impacts to the agricultural sector and the broader regional economy with and without sustainable groundwater management.

Achieving sustainable groundwater conditions can be a result of a combination of demand side measures, such as conservation and reduction in groundwater usage, as well as supply side measures, such as increased artificial recharge and conjunctive use opportunities. Indeed, we would expect most regions to implement a combination of supply- and demand-side management strategies. However, for this study, the analytical focus is on the impacts of achieving sustainable groundwater use solely through managing the quantity and timing of groundwater extraction, without the benefit of augmenting the basin's groundwater conditions with additional surface supplies. We do this, not because we believe supply-side strategies are inferior, but rather because we expect the largest negative economic impacts of transitioning to sustainable management will be associated with institutional restrictions on extraction.

*Achieving sustainable groundwater conditions can be a result of a combination of demand side measures, such as conservation and reduction in groundwater usage, as well as supply side measures, such as increased artificial recharge and conjunctive use opportunities. Indeed, we would expect most regions to implement a combination of supply- and demand-side management strategies.*

This study is organized as follows. In the next section we lay out the study goals and objectives. This is followed by a description of the study region, analytical methods and data, and groundwater management scenarios used for the study. We then present the primary findings from the analysis. First we quantitatively and qualitatively describe the physical findings in terms of changes in groundwater elevation, surface water interconnectivity, water quality impacts, and subsidence risk. We then describe the economic findings in terms of long-run impacts to the agricultural sector and changes to the regional economy. Lastly, we consider the policy implications of the study findings as well as important caveats and areas for future inquiry.

## Study Goals and Objectives

Groundwater levels are rapidly declining in many basins within California's Central Valley. These declines, if left unchecked, are unsustainable and could have significant hydrologic, environmental, and economic consequences. State law now requires local agencies in certain groundwater sub-basins where declines are critical to establish a Groundwater Sustainability Agency (GSA) to develop sustainability plans and requirements that will put high- and medium-priority groundwater basins on a path to achieve sustainability by 2040.[1] Within these basins there is a question whether the new law will limit the future

[1] The law was authorized by Assembly Bill 1739, Senate Bill 1168, and Senate Bill 1319. The 2040 deadline applies to high-priority basins. Medium-priority basins have until 2042.

use of groundwater to the possible detriment of the agricultural sector – the primary user of groundwater in the Central Valley – and the regional economy more broadly.

The goal of this study is to model and quantify the hydrologic and economic effects of transitioning to sustainable groundwater management for a high-priority groundwater basin in the San Joaquin Valley. The Kings and Tulare Lake subbasins of the San Joaquin Valley Groundwater Basin, hereafter "study region" were selected for the study. Hydrologic and economic effects are evaluated for two primary future groundwater management scenarios, which we have labeled: (1) Unmanaged Annual Pumping (UNMAP) and (2) Managed Annual Pumping (MAP). The UNMAP scenario is "business as usual" where pumpers extract groundwater to maximize their individual benefits from use with minimal or no regard to how it affects the ability of others to benefit from the resource now or in the future. This is largely how groundwater basins in many areas of the Central Valley are currently operated and therefore the UNMAP scenario provides the baseline condition from which the impacts of transitioning to sustainable management are measured. The MAP scenario represents sustainable management of the groundwater resource. Later in this study, we discuss in more detail how we define groundwater sustainability for the purpose of this study. A third scenario which unrealistically entails perfect foresight on the part of the GSA is also modeled in order to generate information needed to establish pumping management rules for the MAP scenario.

The goal of this study is to model and quantify the hydrologic and economic effects of transitioning to sustainable groundwater management for a high-priority groundwater basin in the San Joaquin Valley.

## Study Region

The study region encompasses the Kings and Tulare Lake groundwater subbasins within Fresno, Kings, and Tulare Counties (see Figure 1). It is bounded by the San Joaquin River to the north, Fresno Slough and James Bypass to the west, Kern County to the south, and the Sierra Nevada foothills to the east. The region encompasses 1.6 million acres (2,450 square miles). The City of Fresno is the largest metropolitan area within the basin. Smaller communities in the basin include Clovis, Hanford, and Selma. Twenty five public and two private water agencies supplying water for urban and agricultural uses operate in the basin.

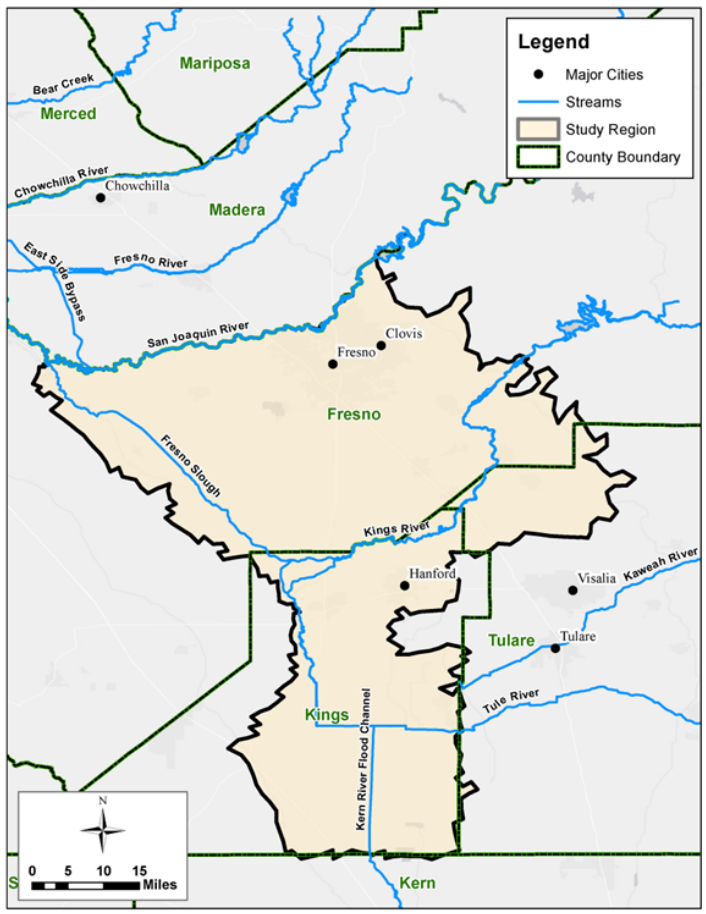



*Figure 1. Study Region*

Groundwater is used conjunctively with surface water for municipal and agricultural purposes in the study region. Groundwater extraction varies annually, depending on hydrologic conditions, availability of surface water supplies, and agricultural and urban demands. Under existing land uses, groundwater extraction averages about 2.95 MAF per year, comprising 67 percent of total water use in a typical year. In dry years, groundwater may comprise as much as 77 percent of total water use.[2]

Groundwater recharge occurs from river and stream seepage, deep percolation of irrigation water, canal seepage, and intentional recharge. Recharge also varies annually. Annual average recharge is estimated to be 2.66 MAF. Groundwater data compiled by regional water agencies and DWR indicate the study region has been in a state of overdraft over the past several decades, with average extraction exceeding average recharge by 0.29 MAF annually. It is important, though, to evaluate the hydrologic conditions of the study region under the future land and water use conditions. Under future land use conditions, hydrologic modeling estimates the annual rate of overdraft would decrease to about 0.23 MAF.[3] This is caused by conversion of agricultural land to urban uses and a shift away from groundwater and towards surface and recycled water by urban water users in the Study Region.

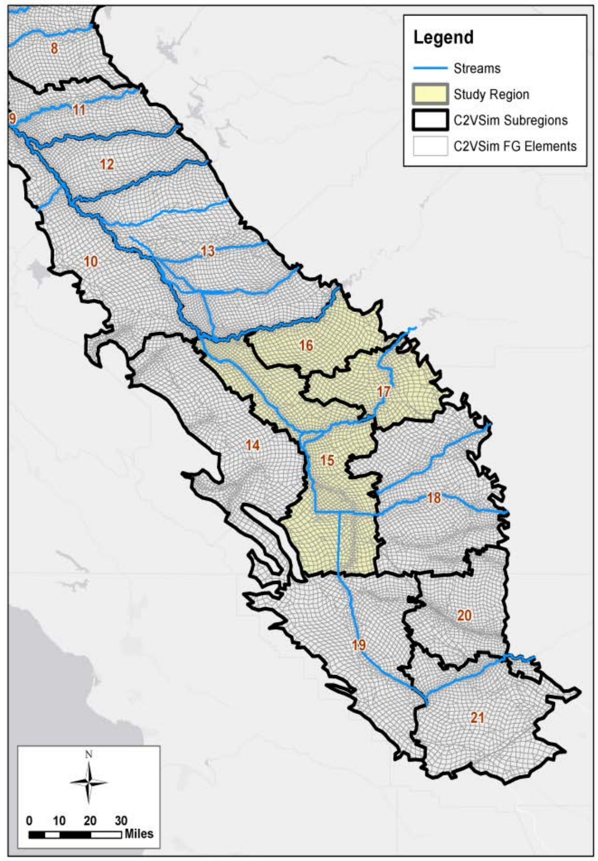



*Figure 2. C2VSim Subregions and Study Region*

Agriculture is the predominant user of groundwater in the study region. Total irrigated crop area is approximately 1 million acres, including close to half a million acres of orchard and vineyard crops. The acreage of orchard and vineyard crops is continuing to expand within the study region due to strong domestic and international demand for nut and grape products. Annual output from the study region's agricultural sector is valued at over two billion dollars.

[2] Urban development within the study region is forecasted to result in a slight shift away from groundwater. Urban development around Fresno and Clovis is projected to convert up to 61,000 acres of agricultural and native land to urban use by buildout. The urban water management plans of both cities call for increased use of surface and recycled water in conjunction with reduction in groundwater use to support much of the new development. Groundwater use by the two cities is projected to decrease from about 147,000 AFY to about 98,000 AFY by 2035 (City of Fresno, 2012 and City of Clovis 2011).

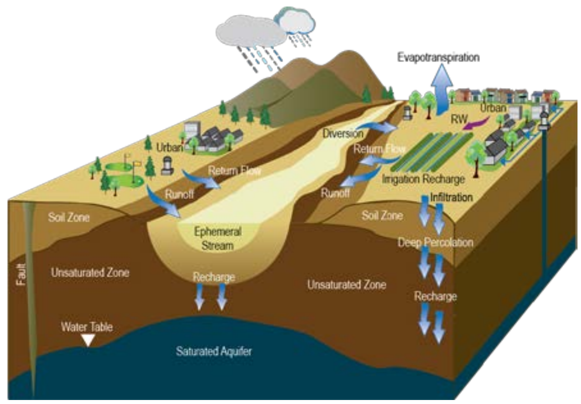
[3] As we discuss later in the report, a reduction in pumping of more than 0.23 MAF is required to stabilize groundwater elevation in the study region because changing the rate of extraction alters the rate of percolation from irrigation and stream seepage and affects the cross-basin flows of groundwater. Given existing levels of artificial recharge, we estimate a 15-20% reduction in groundwater pumping – around 300 to 450 TAF – would be required to stabilize groundwater elevation at the present level. Increases in artificial recharge, for example through increased floodwater capture or recharge of recycled water, could reduce the amount of reduction required.

## Study Methodology and Data

This study involved modeling complex hydro-economic dynamics. This modeling was accomplished by integrating DWR's California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) with its Statewide Agricultural Production Model (SWAP). Following is a brief description of each model and how we integrated them for this study.

### The C2VSim Model

Central Valley groundwater aquifers are part of a highly complex dynamic flow system. Changes in groundwater levels over time are driven by a variety of factors, including hydrology within individual basins, extraction and recharge, and flows across adjacent basins. This study uses DWR's C2VSim model (Brush et al., 2013a & Brush et al.2013b) to analyze the complex relationships that govern groundwater flows, water quality, and elevations within the study region and the basins adjacent to it.[4] The C2VSim model contains monthly historical stream inflows, surface water diversions, precipitation, land use, and crop acreages for a hydrologic period of record starting October 1921 and ending September 2009. Over the hydrologic period of record, C2VSim dynamically calculates crop water demands, allocates contributions from precipitation, soil moisture and surface water diversions, and calculates the groundwater extraction required to meet the remaining demand. The model simulates the historical response of the Central Valley's groundwater and surface water flow system to historical stresses, and can also be used to simulate the response to projected future stresses, as we do in this study.




The C2VSim model divides the Central Valley into 21 subregions. The study region is comprised of model subregions 15, 16, and 17 (see Fig 2).

### The SWAP Model

Like the groundwater system on which it depends, the agricultural sector within the study region is also a complex dynamic system. In response to market conditions, evolving knowledge, variable hydrology, and governing institutions, thousands of individual decision-makers are constantly adjusting their use of land, labor, technology, and other inputs used in the production of agricultural commodities in an effort to yield the greatest possible return to their investment and effort. This study uses the SWAP model to simulate this dynamic system. The SWAP model is the evolution of a series of production models of California agriculture developed by researchers at the University of California at Davis and the California

> The modeling approach for this study was accomplished by integrating DWR's California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) with its Statewide Agricultural Production Model (SWAP).

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[4] DWR maintains course and fine grid versions of the model. We use the fine grid version for this study. The fine grid version contains more than 30,000 nodes and 32,000 elements with the smallest element area of approximately 0.06 square miles (RMC, 2011 & RMC, 2012).

Department of Water Resources, with additional funding and support provided by the United States Bureau of Reclamation. The SWAP model is a regional agricultural production and economic optimization model that simulates the decisions of farmers across 93 percent of agricultural land in California. Model documentation and discussion of sequential calibration checks can be found in the publication by Howitt et al. (2012).

As with C2VSim, the SWAP model of the Central Valley is divided into subregions. These subregions have the same geographic boundaries as the subregions in C2VSim.[5] The overlap of regional definitions in the two models means they can more easily be used in conjunction with one another, which was a key consideration in the design of this study.

## Data Benchmarking and Future Land Use Update

While the C2VSim and SWAP models share the same regional definitions, they rely on slightly different land and water use data. Inconsistencies in the calibration data used in the C2VSim and SWAP models can be explained by differences in data sources, spatial and temporal scales, and aggregation choices. For example, C2VSim uses 13 crop types while SWAP uses 20. Agricultural water use and applied water rates are also slightly different between the two models. In order to align the SWAP and C2VSim models the following steps were taken:

1) Calculate the groundwater applied to crops in the C2VSim model, averaged over 1922-2009 hydrology.
2) Proportionally adjust SWAP surface water supplies such that the baseline level of groundwater pumping in the SWAP model approximates the C2VSim average calculated in step 1.
3) Recalibrate the SWAP model to the surface water and groundwater quantities calculated in step 2 and verify that the models now report the same average baseline groundwater use.

Using this approach, the SWAP model generates the same average surface and groundwater use as C2VSim under the baseline condition.

Data in both models were updated to reflect future land use conditions for the study region. Urban land uses and water demands were changed to be consistent with a 2060 level of development. Total agricultural area was then adjusted to be consistent with the expanded urban land uses. Crop mix is matched to the latest DWR agricultural land use estimates (2005). Surface water supplies are based on recent historic operations of Pine Flat reservoir and surface water delivery patterns.

## SWAP-C2VSim Integration

Neither C2VSim nor SWAP by itself is capable of addressing the central question of this study. C2VSim can simulate the hydrologic dynamics, but lacks the economic dynamics. SWAP can simulate the economic dynamics, but lacks the groundwater dynamics. In order to simulate the economic impacts of transitioning the study region to sustainable groundwater management, we needed a way to combine the hydro-dynamics of C2VSim with the economic dynamics of SWAP. In short, we needed an integrated hydro-economic dynamic model.

[5]Some subregions in the SWAP model are further subdivided to better represent economic conditions, such as irrigation water cost and availability. For example, subregion 15, which is part of the Kings Subbasin, is divided into two parts in the SWAP model, 15A and 15B.

Our approach to integrating the two models entailed three steps (see Figure 3). In the first step we ran C2VSim over a range of groundwater pumping volumes to generate information on the relationship between groundwater elevation and pumping intensity.

In order to simulate the economic impacts of transitioning the study region to sustainable groundwater management, we needed a way to combine the hydro-dynamics of C2VSim with the economic dynamics of SWAP. In short, we needed an integrated hydro-economic dynamic model.

In the second step we used the data generated by C2VSim in the first step to develop groundwater response functions that could be incorporated into the SWAP model. Multivariate regression techniques were used to estimate the response functions. The response functions describe the change in groundwater elevation for each subregion between any two years as a function of agricultural groundwater extraction, water year type (precipitation and surface water availability), interactions between water year type and amount of groundwater extraction, and other trends over time.

In the third step we incorporated the groundwater response functions into the SWAP model. We then modified the SWAP model to operate dynamically on an annual time-step. At the end of each time-step, the model passes to the next time-step the groundwater elevation values and other parameters needed by the model to continue the simulation. This incorporated into SWAP the dynamic groundwater response that would be simulated by C2VSim under similar agricultural production and hydrologic conditions.

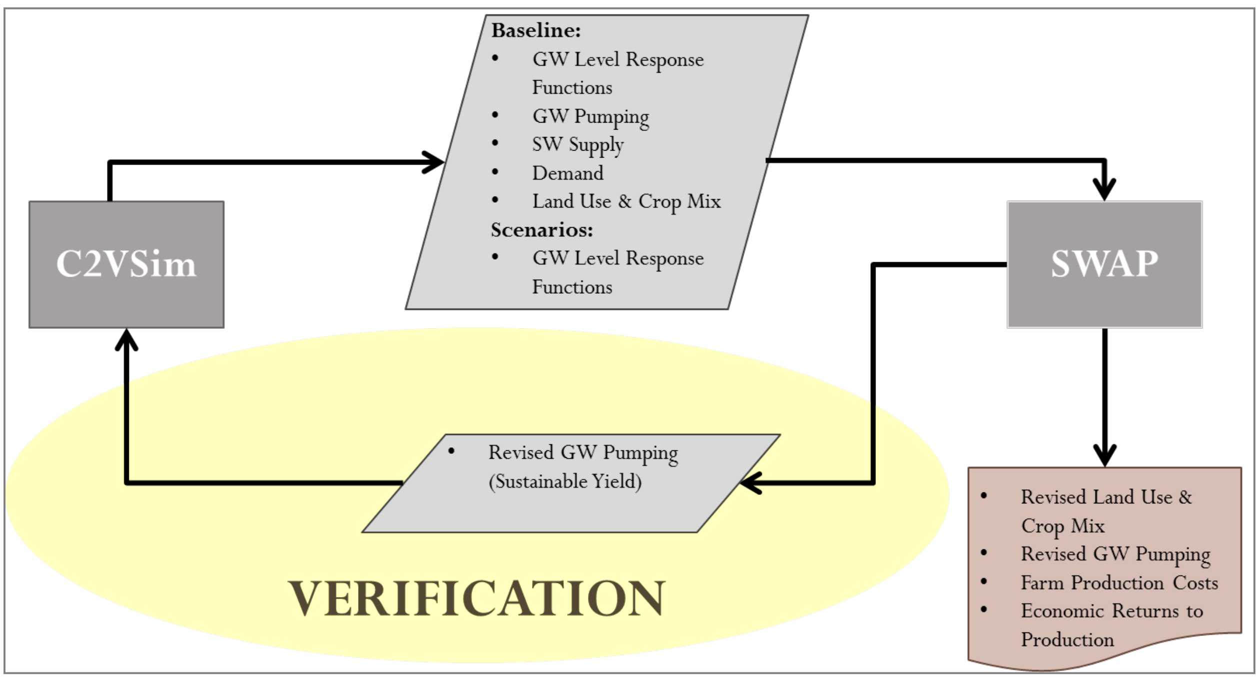


*Figure 3. SWAP-C2VSim Integrated Model Development*

To test the groundwater response functions, we ran validity checks by simulating the SWAP model over the 1922-2009 hydrology, recording the estimated groundwater level, and comparing those results to the C2VSim model. These checks were able to confirm that the groundwater elevation changes generated by the response functions in the SWAP-C2VSim integrated model closely approximated those produced by C2VSim.

## Study Definition of Sustainable Groundwater Management

The Sustainable Groundwater Management Act (SGMA) of 2014 defines guidelines for what constitutes the sustainable groundwater management. In particular, SGMA requires management of groundwater in a sustainable manner so that the following significant and unreasonable undesirable results are prevented:

- Chronic lowering of groundwater levels
- Reduction of groundwater storage
- Seawater intrusion
- Degraded water quality / contaminant plume migration
- Land subsidence
- Depletions of interconnected surface water

For modeling purposes, we focus on minimizing chronic groundwater level declines. In this study, sustainable groundwater management means a set of institutional practices and rules such that groundwater elevation in each subregion in the model is reasonably stabilized over the planning horizon[6] at its current level. Given this definition, groundwater extraction for a subregion in the model is considered sustainable if the long-term trend in the change in groundwater elevation is roughly zero over the planning horizon. Note that this definition accommodates the use of groundwater as a buffer stock in dry years when surface water supply may be diminished, provided these dry-year withdrawals are replaced in normal or wet years, so that on balance withdrawal matches recharge over the long-run. In this study, the long-run is defined over the entire 87-year hydrologic sequence used in the hydrologic and agricultural economic model simulations.

Most groundwater basins, including the study region, have a portfolio of water supply and demand management options. Within the study region, for example, artificial recharge through floodwater capture is likely to be a primary component of the region's groundwater management strategy. Our study does not directly consider artificial recharge management strategies, instead it focuses on institutional restrictions on groundwater extraction to achieve sustainable groundwater management. We do this, not because we think artificial recharge strategies are inferior, but rather because we expect the largest negative economic impacts of transitioning to sustainable management will be associated with institutional restrictions on extraction. By focusing on institutional restrictions we are able to place an upper-bound on the potential adverse economic consequences of stabilizing groundwater elevations at their current levels. Management scenarios that incorporate artificial recharge instead of or in addition

[6] The planning horizon in our analysis is 87 years (2015 – 2102), based on the 87 year hydrologic time series (1922 – 2009) in the C2VSim model. The analysis implicitly assumes that future hydrologic patterns will be similar to those observed over the last century. Potential impacts of climate change on basin demands, surface water availability, and basin recharge are not addressed in this study, though the modeling framework could incorporate climate change impacts given suitable hydrology data sets.

to institutional restrictions on pumping may limit adverse economic effects and thereby increase the overall net benefits of sustainable groundwater management.[7]

## Groundwater Management Scenarios

As previously mentioned we model two primary management scenarios: (1) Unmanaged Annual Pumping (UNMAP) and (2) Managed Annual Pumping (MAP). The UNMAP scenario serves as a baseline and is used as the reference condition from which impacts of transitioning to managed groundwater extraction are measured. In the UNMAP scenario decisions about groundwater extraction are made without regard to impacts to others or the natural environment now or in the future.[8] This is the classic tragedy of the commons, where the lack of well-defined property rights over a collective resource creates a use it or lose it imperative that favors extraction today over conserving the resource for use in the future. Under the UNMAP scenario, the groundwater resource is mined and groundwater elevations steadily decline over the planning horizon. As we show below, at current levels of artificial recharge, UNMAP extraction rates are not consistent with the study definition of sustainable groundwater management.

From economic perspective, optimal extraction of groundwater would consider not only the value from using the resource today, but also the value from conserving the resource for future use. Optimal extraction would consider these intertemporal tradeoffs and choose an extraction path that maximized the present value of the resource subject to the sustainability condition. When this is done using the SWAP-C2VSim integrated model a pattern of economically optimal extraction emerges that shows constrained use of groundwater in normal and wet years and more liberal use of groundwater in dry years. By pumping less groundwater and irrigating fewer low-value crops in normal and wet years, the study region is able to bank groundwater for use on higher-value crops in dry years, thereby minimizing the economic cost of sustainable groundwater management.

The optimal pattern of extraction is predicated on perfect foresight of future hydrologic conditions, which clearly is not realistic. But the outputs from the perfect foresight simulation can be used to craft simple decision-rules for how much groundwater extraction could be allowed in wet, normal, and dry years, such that on average groundwater extraction would be sustainable. We craft such rules and use them in the MAP scenario. Under the MAP scenario, the groundwater sustainability agency makes a forecast of hydrologic conditions prior to the start of the irrigation season. It then sets regional extraction limits based on the average amount of pumping for that year-type in the perfect foresight model run. The SWAP-C2VSim integrated model is then run with these year-type extraction limits.

[7] Whether this would turn out to be the case would depend largely on the cost of artificial recharge options.

[8] Note that it is not necessary in this scenario to assume that groundwater users are uncaring of other users or have no regard for the future. Rather, it is only necessary to acknowledge that the economic incentives within the system induce individual decision makers to act as though this were the case.

# Hydrologic Modeling Results

As noted before, the C2VSim model was used to evaluate the hydrologic conditions under the future baseline conditions (UNMAP scenario) and under the sustainable groundwater condition (MAP scenario).

## Depth to Groundwater and Rate of Overdraft

Under the future land and water use conditions, the simulated annual average depth to groundwater in the study region under the UNMAP and the MAP conditions are shown in Figure 4.[9] It is important to note that there is considerable variation in starting and ending depths at the sub-regional level. For some parts of the study region, the groundwater level recovery under the MAP conditions is significantly greater than what is reflected in the regional average. Looking at the study region as a whole, long-term groundwater level recovery under the MAP conditions is expected to be around 90 feet. As shown in Figures 5 and 6, which provides the long-term average annual as well as the annual groundwater budget for the study region under the UNMAP scenario, the average annual rate of overdraft in the region, under the future land and water use conditions, is estimated to be 0.23 MAF, with a cumulative groundwater overdraft estimated at about 21 MAF. This is in addition to the overdraft that has already occurred in the study region[10].

Under the MAP scenario, the average groundwater depth is stabilized just below the groundwater elevation at the start of the simulation. It takes several years for the management actions under the MAP scenario to significantly impact groundwater elevations, but after the initial adjustment period the average groundwater depth stabilizes between 240 and 260 feet. Figures 7 and 8 show the long-term average annual as well as the annual groundwater budget for the MAP scenario. With managed pumping, overdraft in the study region is eliminated. The initial short-term decline in groundwater elevations under the MAP scenario is a result of the time required for management actions to achieve a stable condition in average groundwater levels.

It is important to recognize that reducing groundwater pumping in a basin results in a number of responses which affect groundwater elevations. These responses include a reduction in the amount of deep percolation of applied water, less seepage into the basin from streams, and less subsurface flow into the basin from adjacent groundwater basins. For example, any reduction in groundwater pumping directly reduces applied water volumes during the irrigation season, which in turn reduces the deep percolation of that applied water back into the basin. In addition, a reduction in groundwater pumping raises groundwater elevations, which in turn reduces seepage into the basin from streams. Lastly, changes in groundwater levels as a result of reduced groundwater pumping result in less subsurface flows across the study region boundary from adjacent basins.

The integrated hydrologic and economic modeling results show that in order to achieve sustainable groundwater conditions in the study region, a reduction of approximately 15-20 percent in groundwater pumping needs to be implemented. This range is reflective of both variations in hydrologic, and land and water use conditions in the study region over time, as well as economic assessment of changes in crop

[9] As discussed above, the analysis is based on future urban land use conditions, as reflected in the City of Fresno MetroPlan and City of Clovis General Plan, and associated increases in urban surface and groundwater use.

[10] The groundwater budget information are developed based on the DWR's calibrated C2VSim-FG model. The latest version of the model has incorporated the information from local and regional plans and models in the Kings and Tulare area.

mix and irrigation practices. Our hydrologic modeling analysis quantified all of the hydrological responses that resulted from reduced agricultural pumping. A comparison of Figures 5 and 7 indicates that the reduction in groundwater pumping has the domino effect of reduced applied water and therefore reduced deep percolation of applied water. In addition, the sustainable conditions results in higher groundwater levels in the long-term, compared to the baseline conditions. This, in turn, results in a reduced seepage from the river and unlined canal systems to the groundwater system, as well as reduced subsurface flows to the study region from the adjacent regions. It is also important to note that the indicator for sustainability in this study is long-term regional average stable groundwater levels in the study region as well as the neighboring regions in Tulare Basin. Figure 7 shows the long-term change in groundwater storage (based on the 1922-09 hydrology and future land and water use conditions) is negative, indicating continued overdraft. However, Figure 8 shows this overdraft stops after about 25-30 years of operating the basin in a managed condition under the MAP scenario.

In summary, the annual average overdraft in the study region by urban and agricultural users is about 0.23 MAF, representing about 8 percent of the 3 MAF in average annual groundwater pumping. When we account for changes in deep percolation, seepage, and subsurface flow, the reduction in pumping required to stabilize groundwater levels is approximately 0.44 MAF, or 15 percent of the 3 MAF in total groundwater pumping.

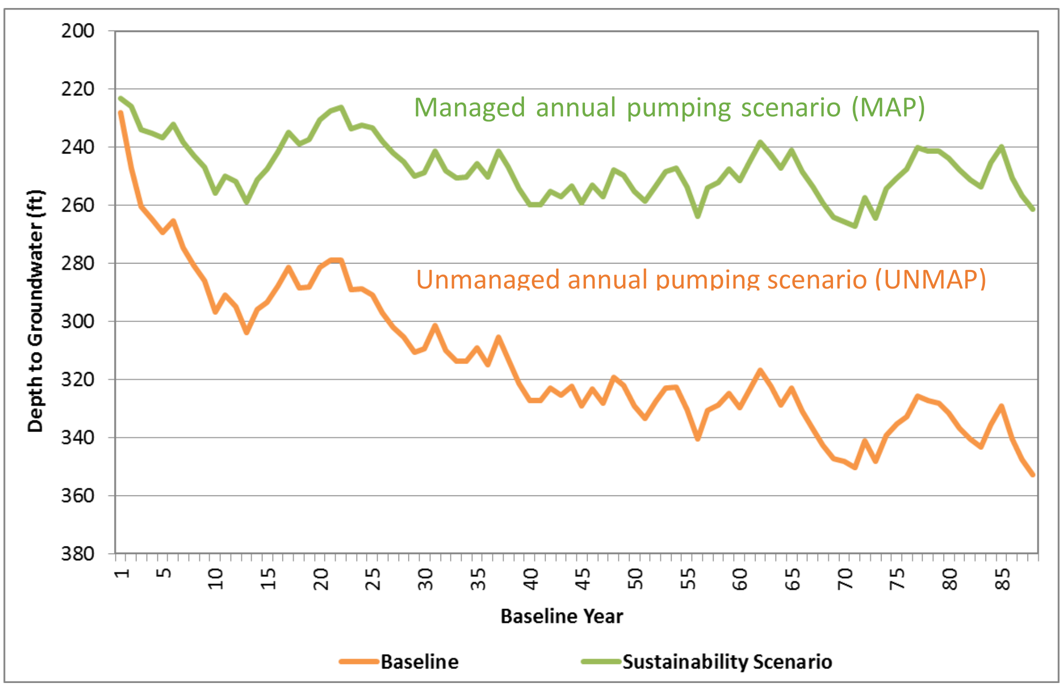


*Figure 4. Average Depth to Groundwater in Study Region under UNMAP and MAP Scenarios*

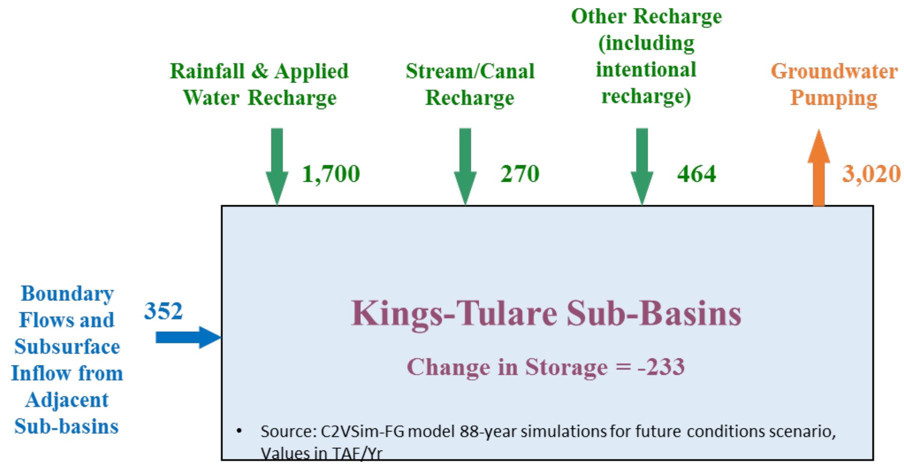


*Figure 5. Long-Term Average Annual Groundwater Budget in Study Region for Future Baseline Conditions (in thousand acre-feet per year)*

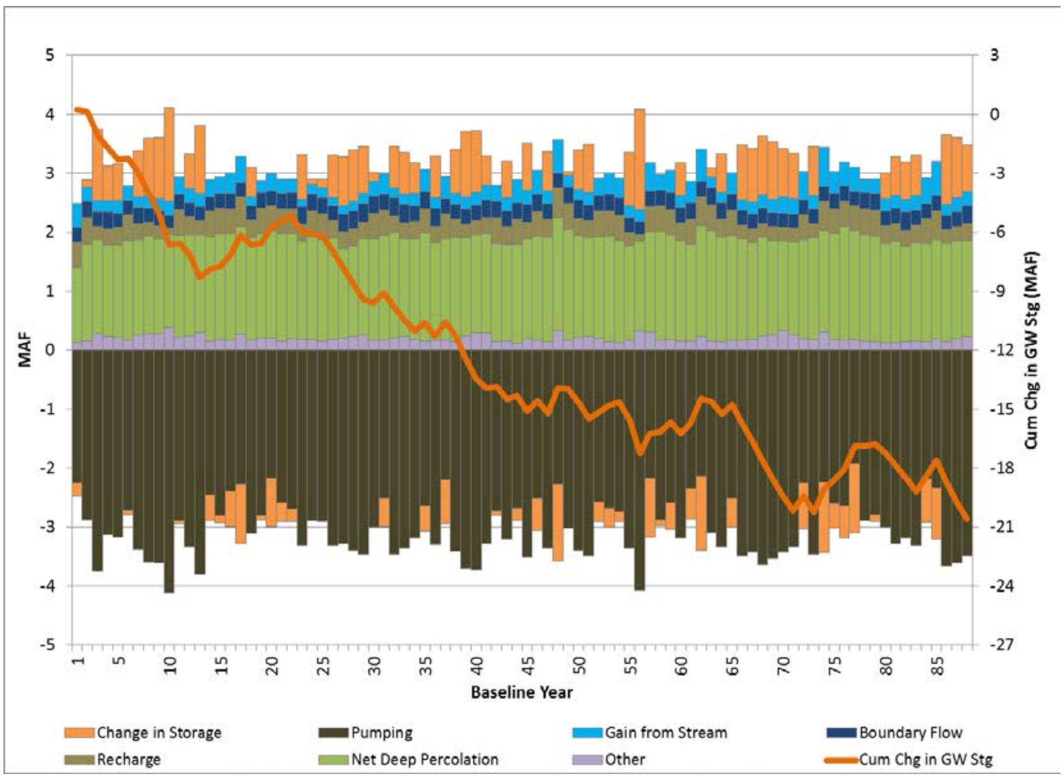


*Figure 6. Simulated Annual Groundwater Budget under the UNMAP Scenario*

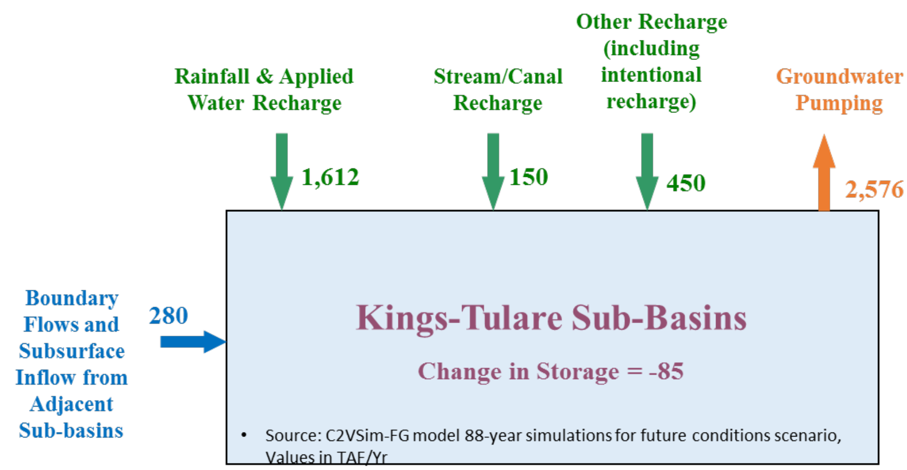


*Figure 7. Long-Term Average Annual Groundwater Budget under the MAP Scenario (in thousand acre-feet per year)*

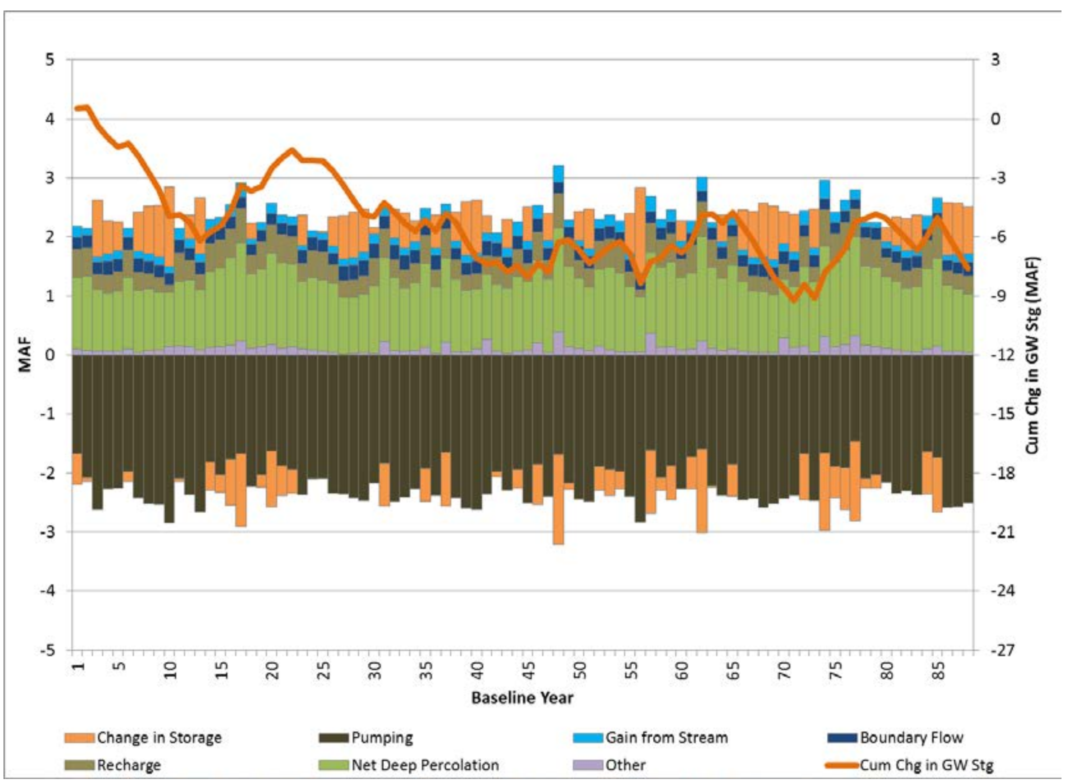


*Figure 8. Simulated Annual Groundwater Budget under the MAP Scenario*

## Surface Water Interconnectivity

The study region is under the influence of the operations of the Pine Flat reservoir and Kings River flows. Historically, the Kings River seepage has contributed significant recharge to the groundwater system. The UNMAP and MAP scenarios assume no changes to Pine Flat reservoir operations. Under a more comprehensive evaluation of groundwater management options, reservoir reoperation might be included as part of the management strategy. However, re-operation of Pine Flat reservoir was outside the scope of this study. Therefore, the upstream Kings River flows and releases from Pine Flat remain the same under the UNMAP and MAP scenarios. However, since the model simulates the seepage losses from Kings River as a function of differential hydraulic gradient between the river stage and groundwater levels on a fairly detailed basis, changes in depth to groundwater levels would result in changes to the Kings River seepage losses. Figure 9 shows changes in seepage losses between the MAP and UNMAP scenarios. Note that overall, there is an average annual of 120 TAF less seepage losses under the MAP conditions, which would result in higher stream flows, especially during dry years. The decrease in seepage loss amounts to approximately 9 percent of the average annual Kings River flow below Pine Flat reservoir, a non-trivial potential increase in flow. Both Figures 7 and 8 also show the changes in long-term and annual changes in seepage loss from the river to the groundwater system as a result of managing the basin under the MAP scenario. Although not directly analyzed and quantified by this study, the higher stream flows would potentially benefit water quality conditions and the dependent ecosystems.

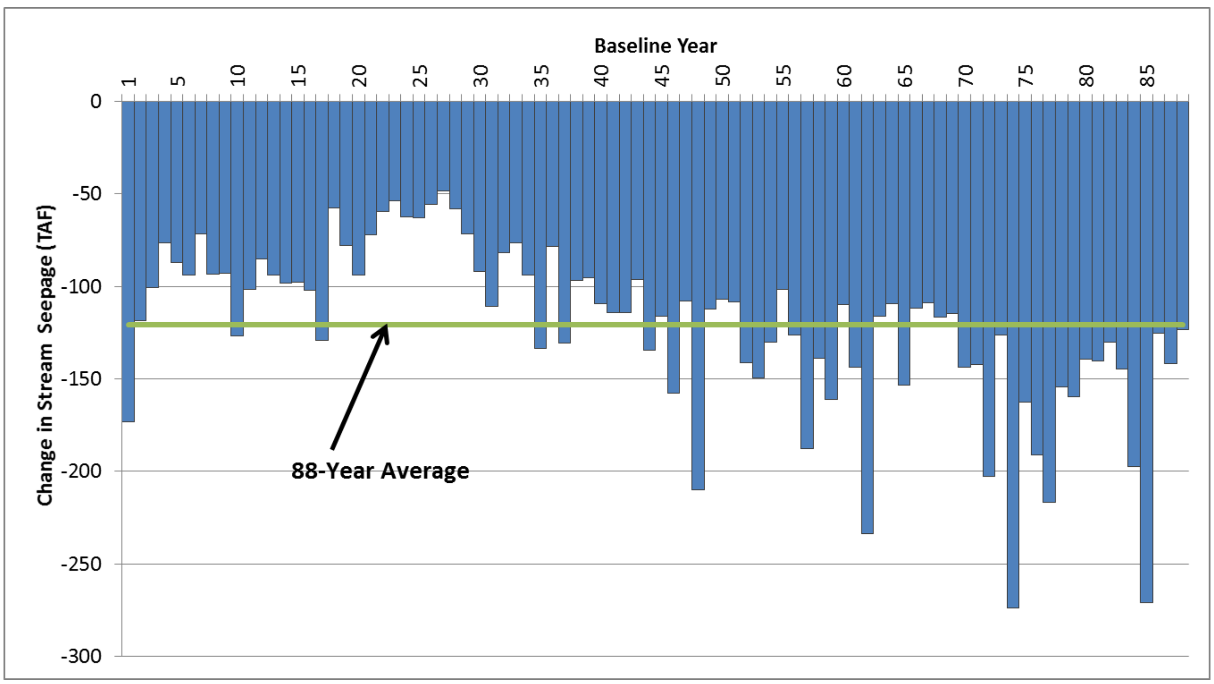


*Figure 9. Change in Regional Stream Seepage Losses for MAP Scenario Relative to UNMAP Scenario*

## Subsidence Risk

Land subsidence has not been a major issue in the study region the way it has in other parts of the San Joaquin Valley. Land subsidence can occur when extraction of groundwater causes increased pressure on fine grained deposits below the confining layer, resulting in soil compaction and deformation of the ground surface. Data on land subsidence in the San Joaquin Valley compiled for the California Water Foundation for the period January 2007 through March 2011 indicates no significant subsidence on the east side of the study region, a small degree of subsidence (0-0.5 feet) on the west side near Fresno Slough, and up to two and a half feet of subsidence in the southern portion of the study region (CWF 2014). Earlier studies (Ireland, et al. 1984, Faunt 2009) have reported evidence of two to five feet of subsidence since the 1920s.

Current groundwater extraction rates in the study region exceed recharge and have put the basin into an overdraft condition. Under the UNMAP groundwater management scenario overdraft is projected to continue, with cumulative additional net withdrawal of 21 MAF from the study region by the end of the simulation period. This is expected to lower the groundwater levels by 90 to 100 feet, on average, and can significantly increase the risk of future land subsidence. The MAP groundwater management scenario, which stabilizes groundwater elevation at approximately its current levels, would greatly reduce the risk of further land subsidence in the study region.

### Groundwater Quality Impacts

Groundwater in the study region is generally of good quality, meeting secondary standards for drinking water in much of the area, though there have been some problems in meeting requirements at a number of drinking water wells. This includes incidences of contamination from both point sources such as leaking underground storage tanks, and nonpoint sources associated with agricultural and municipal land uses (e.g. from application of fertilizers). The salinity and TDS of the groundwater typically increases from foothills to the east, into the western part of the study region, and range from an average of 550 mg/L to 1000 mg/L (CV-SALTS, 2013). In addition, due to agricultural activities and application of fertilizers, elevated levels of nitrate have been observed in the study region. The elevated nitrate levels are particularly apparent in urbanized areas due to urban loading. The typical range of nitrates (as N) reported for the study region is from 3.0 mg/L to 11.6 mg/L (CV-SALTS, 2013). The groundwater gradient is from east to west and groundwater generally picks up more dissolved solids as it moves westward (WRIME, 2007). It is expected that reductions in groundwater pumping would increase the ratio of usage of high quality Kings River surface water for agricultural demand and provide a net benefit to groundwater quality.

## Economic Modeling Results

The key economic question examined by this study is whether the gains from sustainable groundwater management in terms of improved surface water interconnectivity (and related ecosystem function), improved groundwater quality, and reduced subsidence risk would come at the expense of the agricultural sector. In this section we summarize the results from the SWAP-C2VSim integrated model which was used to examine this question.

### Economic Impacts in the Agricultural Sector

Transitioning the study region to sustainable groundwater management is expected to impact the agricultural sector in three key ways. First, institutional restrictions on groundwater extraction are likely to alter the mix of crops grown in the region and the amount produced. Second, stabilized groundwater elevations are predicted to reduce groundwater pumping costs over time, thereby lowering costs of production. Third, stabilized groundwater elevations are expected to reduce the need for capital investment to refurbish existing wells and develop new ones.

To evaluate the impact of these adjustments on farm profitability, we used the SWAP-C2VSim integrated model to simulate net returns to land and management under the UNMAP and MAP groundwater management scenarios. The results of these simulations are summarized in Table 1. The simulated transition of the study region to sustainable groundwater management results in essentially no difference in long-run returns to agricultural land and management.

This is an important finding because it suggests that, at least for the part of the San Joaquin Valley we studied, reduced groundwater pumping cost and avoided well investment cost can be of sufficient magnitude to offset the reduction in agricultural output brought about by the institutional restrictions on groundwater extraction. This is illustrated in Table 2, which breaks down the change in net return to land and management by avoided pumping cost, well investment cost, and farm gate net revenue from crop production under the MAP groundwater management scenario.

*Table 1. Simulated Net Returns to Agricultural Land and Management under Alternative Groundwater Management Scenarios*

| **Scenario** | **Present Value of Net Returns to Land and Management over 87 Year Simulation Period (millions of 2014 dollars)** |
|---|---|
| **UNMAP** | $43,868 |
| **MAP** | $43,842 |
| **Difference** | ($26) |
| **% Difference** | -0.06% |

*Table 2. Component Changes in Net Returns to Agricultural Land and Management under MAP Groundwater Management Scenario*

| **Net Return Component** | **Present Value over 88 Year Simulation Period (millions of 2014 dollars)** |
|---|---|
| **Avoided Pumping Cost** | $2,016 |
| **Avoided Well Cost** | $981 |
| **Foregone Farm Gate Net Revenue** | ($3,023) |
| **Total** | ($26) |

Acreage under production, crop mix, and output value are somewhat different between the two scenarios, with acreage under production and output values generally being lower under the MAP scenario. Table 3 summarizes the crop mix under the UNMAP and MAP scenarios. In response to the pumping restrictions under the MAP scenario, the total irrigated area declines by 90,000 acres or approximately 8.5 percent. However, as shown in Table 1 above, the corresponding change in net farm income (returns to land and management) is less than 1 percent. Under the MAP scenario the value of water for irrigation increases and water is directed toward generally higher value and less water-intensive crops. There is a region-wide shift towards a more flexible cropping system which preserves the high-value perennial and vegetable crops. The average acreage planted to forage, grain, and other field crops decreases by 16 percent whereas vegetable, orchard, and vineyard acreage decreases by less than 1 percent. The result is a decrease in the total irrigated footprint and a smaller decrease in net farm income. We address the potential implications for regional economic activity within the study region in the next section.

The economic analysis of this study suggests that, at least for the part of the San Joaquin Valley we studied, reduced groundwater pumping cost and avoided well investment cost can be of sufficient magnitude to offset the reduction in agricultural output brought about by the institutional restrictions on groundwater extraction.

*Table 3. Simulated Irrigated Crop Area and Management under Alternative Groundwater Management Scenarios*

| | Average Crop Mix over 87 Year Simulation Period (acres) | | | | | |
|---|---|---|---|---|---|---|
| **Scenario** | **Forage** | **Orchard and Vineyards** | **Other Field and Cotton** | **Grain** | **Vegetables** | **Total** |
| **UNMAP** | 102,460 | 452,820 | 309,680 | 135,390 | 63,530 | 1,063,880 |
| **MAP** | 63,440 | 449,890 | 294,730 | 100,260 | 62,780 | 971,100 |
| **Difference** | -39,020 | -2,930 | -14,950 | -35,130 | -750 | -92,780 |
| **% Difference** | -38.1% | -0.6% | -4.9% | -25.9% | -1.2% | -8.7% |

## Regional Economic Impacts

To evaluate the regional economic impacts of transitioning the study region to sustainable groundwater management, we developed a regional input-output model encompassing Fresno, Kings, and Tulare counties. The input-output model was developed with IMPLAN software and uses IMPLAN's 2011 county-level datasets. The model was used to evaluate differences in regional employment and value added between the UNMAP and MAP groundwater management scenarios.[11]

Transitioning the study region to sustainable groundwater management is expected to have mixed effects on the regional economy. As we showed in the previous section, on balance net returns to agricultural production are essentially the same. However, the pattern of regional expenditure changes when the region moves from the UNMAP to the MAP scenario and these changes affect the overall economy. In particular, the change in agricultural output under the MAP scenario results in reduced expenditures for

[11] Value added is the residual of output value after deducting the cost of intermediate inputs. It is akin to gross domestic product used in state and national income accounting.

farm labor and other farm inputs. Similarly, the reduction in well investment reduces regional demand for well drilling services. These categories of regional output are therefore negatively impacted. On the other hand, the reduction in groundwater pumping cost and avoided well investment boosts the incomes of farm owner/operators, which positively impacts the regional economy.

On balance, the simulated net impact to regional economic activity is negative but small. Regional employment under the MAP scenario averages 0.4% lower than under the UNMAP scenario. IMPLAN measures employment impacts as the sum of part-time, seasonal, and full-time jobs. Much of the employment loss is in the agricultural sector, which has a higher proportion of seasonal and part-time employment than the rest of the economy. The employment impacts, if expressed in full-time equivalent jobs, would therefore be lower. This is reflected in the change in regional value added, which shows an average annual reduction of only 0.15% relative to the UNMAP scenario.

Regional economic impacts vary from year-to-year depending on water year type and institutional limits on groundwater extraction. In the worst case year, employment and value added are 0.6% and 0.5% lower, respectively. In the best case year, employment is 0.2% lower but value added is 0.3% higher.

Relative to the size of the three-county economy that was modeled, the changes in employment and value added resulting from transitioning to sustainable groundwater management are negligible. Certainly they fall well within the margin of error of the regional input-output model. This suggests that regional impacts resulting from transitioning to sustainable groundwater management may prove to be statistically undetectable from macro-economic indicators like regional employment or household income.

As with most changes to the status quo, benefits and costs of transitioning to sustainable groundwater management would not be distributed uniformly throughout the region. Though the modeling shows the net impact would be negligible at an aggregate regional level, at a more disaggregated level there would be winners and losers. For example, agricultural production in some subregions would be more adversely impacted than in other subregions. Similarly, some industries, such as well drilling, may experience decreased demand for their services, while other industries, such as suppliers of irrigation equipment and technology, may experience increased demand.[12]

## Other Unquantified Regional Economic Benefits of Sustainable Groundwater Management

There are other regional economic benefits of transitioning to sustainable groundwater management that were outside the scope of this study. We describe them briefly in this section. A potentially important economic benefit that was not directly quantified by this study is the economic value of the increase in stored groundwater at the end of the simulation period under the MAP scenario. The amount of additional storage is approximately 14 MAF (compare Figures 6 and 8). This is groundwater that would otherwise not be available for use by future generations in the region. Stabilizing groundwater elevations would also benefit municipal and domestic wells in the region by lowering future pumping costs and reducing the number of domestic wells going dry, particularly in drought years.[13]

[12] Increasing investment in irrigation efficiency is a likely outcome of regional groundwater management if it increases the marginal cost of water.

[13] Failure of domestic and municipal wells due to falling groundwater tables was a significant problem in some parts of the San Joaquin Valley and elsewhere in California this summer. Well problems disproportionately affect poor and disadvantaged communities. See, for example, "California's Dogged Drought Cutting Off Water Supplies to State's Poor," Brett Walton, Circle of Blue Publications, August 26, 2014

## Summary of Economic Impacts

Table 4 summarizes the positive and negative economic impacts of transitioning the study region to sustainable groundwater management. Quantified impacts are shown in the second column in the table. Qualitative impacts are shown in the last column. We use a +/- sign to indicate the direction of impact. While this study was not able to quantify the full range of physical and economic impacts from sustainable groundwater management, those that were not quantified are expected to be positive, while those that were quantified net to approximately zero. This suggests that on balance transitioning to sustainable groundwater management would result in net regional benefits.

*Table 4. Quantified and Qualitative Impacts of MAP Groundwater Management Scenario*

| Change from UNMAP Scenario | Quantified Impact | Qualitative Impact |
|---|---|---|
| **Physical/Environmental** | | |
| Increased Stream Flow | +10% increase in average annual flow | (+) expected improvement in water quality and function of dependent ecosystems |
| Groundwater Quality | Not quantified | (+) expected improvement in groundwater quality over time |
| Land Subsidence | Not quantified | (+) expected reduction in future subsidence risk |
| GW Depth/Storage | +90 ft gain in elevation by end of simulation period<br>+14 MAF by end of simulation period | (+) increased GW availability and reduced pumping depth/cost for future generations of GW users |
| **Agricultural Sector** | | |
| Avoided GW Pumping | +$2,016 million in present value | |
| Avoided GW Well Investment | +$981 million in present value | |
| Foregone Farm Gate Net Revenue | -$3,023 million in present value | |
| **Urban Sector** | | |
| Avoided GW Pumping | Not quantified | (+) lower pumping costs incurred for municipal and domestic wells |
| Avoided GW Well Investment | Not quantified | (+) lower replacement costs incurred for municipal and domestic wells. Fewer domestic wells running dry during drought periods. |

(http://www.circleofblue.org/waternews/2014/world/californias-dogged-drought-cutting-water-supplies-states-poor/).

# Policy Implications of Study Findings

The results of this study are relevant to on-going groundwater management policy discussions in California. In this section we summarize key implications for groundwater policy as it relates to the study region specifically and California more generally:

- The hydrologic modeling results clearly show the Kings and Tulare Lake subbasins are not presently on a path of sustainable groundwater management. Without either a reduction in the average rate of groundwater extraction, a significant increase in managed recharge, or some combination of the two, groundwater overdraft is projected to continue under the current and future expected land uses. Relative to the current groundwater storage in the study region, cumulative overdraft is projected to increase an additional nearly 21 MAF within this century given current extraction rates.

- The C2VSim simulation results show that continued groundwater overdraft would adversely impact surface stream flow in the study region. Under the managed pumping scenario, annual stream flow seepage is reduced by an average of 120 TAF. This is equivalent to 9 percent of the average annual flow in the Kings River below Pine Flat reservoir. Managed pumping is also expected to benefit groundwater quality and to significantly mitigate the risk of future land subsidence.

- The hydrologic modeling results suggest that reduction in groundwater pumping has a rippling effect of reduction in deep percolation of applied water, stream seepage to groundwater, and subsurface inflow into the study region.

- The hydrologic modeling results also highlight the complex, interdependent nature of groundwater usage, recharge, and flow between subbasins. For example, in order to stabilize groundwater elevations within the study region, it was necessary to assume that neighboring basins were also being similarly managed. Otherwise, the gains from sustainable management in the study region would be ceded to the western bordering subbasins due to groundwater migration. As we discuss more below, this has important implications for the establishment and governance of GSAs.

- The hydrologic and economic simulations done for this study indicate that a reduction in groundwater pumping in the range of 15-20% from current amounts would stabilize average groundwater elevation in the study region.

- The economic modeling results suggest sustainable groundwater management in the study region would not be a zero-sum game for the region. The benefits associated with protection of water quality, improved surface flows, and reduced risks of subsidence would not come at a large cost to the agricultural sector. If groundwater is managed differently from the current status quo, our study findings strongly suggest that the changes within the agricultural sector would be relatively minor. The modeling shows that on a region-wide basis the net return to agricultural production over the planning horizon would be essentially the same under sustainable groundwater management as it is assuming groundwater extraction continues on its current path. The same holds true for the broader regional economy. This result obtains because reductions in groundwater pumping and well investment costs offset foregone crop production and because losses to high-value orchard and vineyard crops during dry years are, on average, lower under sustainable groundwater management. The balanced gains and losses in the agricultural sector suggest that the other, unquantified benefits from sustainable groundwater management would produce a long-run net gain to the regional economy.

- Much of our hydrologic and economic modeling effort was spent during this study addressing subbasin interdependencies. It quickly became clear that it was not possible to assess the effects of management actions in one basin without also considering what was happening in adjacent basins. These interdependencies mean that groundwater management is unlikely to be successful when done in isolation or on too small a scale. Management externalities would simply be too great. This has important implications for the formation of GSAs and the regulations, best management practices, and dispute resolution processes the state is charged with developing to guide GSAs going forward. For example:
  - While local agencies are provided considerable latitude to tailor sustainable groundwater plans to their regional economic and environmental needs under the new law, this study indicates there will also be a need for criteria to determine appropriate regional scale and consideration of subbasin interdependencies when forming GSAs. If GSAs are too atomized, the law is less likely to achieve its purposes.
  - In this regard, state regulations could encourage regions to undertake investigations to determine minimum effective management units within medium- and high-priority basins so that jurisdictional boundaries of proposed GSAs are reasonably aligned with hydrologic boundaries.
  - Hydrologic interdependencies between subbasins also mean that once GSAs are formed, they will need to coordinate and harmonize their actions in order to be successful. Given the complex nature of groundwater use, recharge, and flow, disputes between GSAs will inevitably occur from time to time. In anticipation of this inevitability, the state will need to develop procedures and administrative capacity for hearing and resolving such disputes.

## Further Considerations and Areas for Future Inquiry

- Assuming appropriate management scale and coordination is arrived at, this study shows that it is fairly simple to derive annual caps on pumping tied to water-year-type which could be an effective way to transition basins to sustainable groundwater management. Nevertheless, allocating basin-wide caps to individual wells would likely produce winners and losers even though the basin would gain overall.

- Regarding the previous point, this study does not delve into the much thornier issue of how to efficiently and fairly allocate an aggregate cap on pumping across individual groundwater users. Developing politically feasible strategies to do this is an important area of future inquiry. For example, approaches such as tradable permits could avoid a strict cap per well and provide greater flexibility for each well owner.[14]

- There is also an important distinction to be made between physically sustainable and economically sustainable groundwater management that this study does not directly address. This study looked at the physical and economic implications of stabilizing groundwater depth at its present elevation. From an economic standpoint, this is not necessarily optimal. An economic criterion for optimal groundwater management requires that the pumping depth corresponding to the sustainable yield is that which balances the capitalized value of future pumping costs incurred by an incremental increase in pumping depth against the current value of that acre-foot of water used in its least profitable use. We note this because our findings are expressed without regard to this criterion. Impacts of transitioning to sustainable groundwater management may be further mitigated by allowing additional drawdown in basins with high water tables before imposing steady state pumping constraints.[15]

- A more complete accounting of regional benefits and costs would include monetary estimates of benefits left unquantified in this report. These benefits include: avoided subsidence costs, avoided environmental and water quality impacts, the value of pumping benefits to non-agricultural groundwater users, and the long-term value of groundwater storage beyond the limited time horizon considered here. This study identified the expected direction of these economic changes, but not their magnitudes.

- Lastly, it is important to say that the usual “mileage may vary” caveats apply to this study’s findings. Our modeling results pertain to the Kings and Tulare Lake subbasins and cannot be directly applied to other parts of the Central Valley. That said, given the geographic coverage of the C2VSIM and SWAP models, we believe the study provides a potentially useful and expedient modeling framework for examining the effects of sustainable groundwater management in many other parts of the Central Valley.

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[14]For example, within the Mojave Basin, where groundwater rights have been adjudicated, Hanak (2002) reports there is an active annual market among rights-holders that enables buyers to use more than their allotment.

[15] This would necessarily entail numerous considerations, including groundwater-surface water interactions and potential adverse ecosystem impacts of additional drawdown.

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