AN ANALYSIS OF MEAN GROUNDWATER DEPTH IN VENTURA COUNTY CALIFORNIA BEFORE AND AFTER THE ENACTMENT AND IMPLEMENTATION OF THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT

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AN ANALYSIS OF MEAN GROUNDWATER DEPTH IN VENTURA COUNTY CALIFORNIA BEFORE AND AFTER THE ENACTMENT AND IMPLEMENTATION OF THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT

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Abstract

This thesis explores how the reliance on groundwater has affected the mean level in Ventura California. The efficacy of the Sustainable Groundwater Management Act (SGMA) is examined using an Auto-Regressive Integrated Moving Average (ARIMA) model to better understand the trends of mean groundwater depth. Specifically, mean groundwater depth was analyzed before and after the enactment of the SGMA. The outcomes of this analysis are presented in a bounded fashion where results from the original dataset and a Heckman corrected dataset is used as upper and lower bounds, respectively. In the first observation period, prior to the enactment of the SGMA, the bounded results ranged from a slight deepening to a significant deepening in mean groundwater depth. In the second observation period, after the enactment of the SGMA, the bounded results converged in a significant decrease in the mean groundwater depth in Ventura California. This analysis presents evidence that the SGMA has had a significant effect on reducing the mean groundwater depth and thus mitigating the environmental externalities of chronic groundwater overdraft. Lastly, the metrics and concepts of reporting are explored in terms of how well they report the progress towards sustainable practices.

KEYWORDS: (Groundwater, ARIMA, Ventura County)
JEL CODES: (Q38, Q58, Q25)

ON MY HONOR, I HAVE NEITHER GIVEN NOR RECEIVED
UNAUTHORIZED AID ON THIS THESIS

Samuel C. Kinney

Signature

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I. Introduction

With a changing climate and increasing droughts, the management of water consumption in California is extremely important.[1] While California is large and includes a variety of micro-climates, the overall drying, and reduction of available water is an increasing concern. Historically, California has relied on snowpack in its mountainous regions in order to support municipal and economic development. However, with a predicted 80% reduction in snowpack by the end of the century, sustainable management of California's additional water resources is paramount.[2]

Due to increasing variability in yearly precipitation and snowpack, Californians are becoming increasingly dependent on groundwater.[3] Specifically, it is estimated that groundwater accounts for 40% of the water supply in California.[4] With uncertainty regarding the replenishment rate of underground aquifers, the risk of overdraft threatens the existence of this vital resource. Furthermore, groundwater loss over the last century in an effort to mitigate the effects of drought on water supply has been significant.[5]

In response to the increasing concerns of groundwater management, California passed the Sustainable Groundwater Management Act (SGMA) in 2014.[6] This act created statewide regulations and required the formation of Groundwater Sustainability Agencies

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[1] Harou, J. J., Medellín-Azuara, J., Zhu, T., Tanaka, S. K., Lund, J. R., Stine, S., Olivares, M. A., and Jenkins, M. W. (2010), Economic consequences of optimized water management for a prolonged, severe drought in California, *Water Resour. Res.*, 46, W05522

[2] *Sustainable Groundwater Management in California*. Union of Concerned Scientists. (2015, November 2). Retrieved February 12, 2022.

[3] *Sustainable Groundwater Management in California*. Union of Concerned Scientists.

[4] Person, Hanak, E., Chappelle, C., & Harter, T. (2021, November 7). *Groundwater in California*. Public Policy Institute of California. Retrieved February 24, 2022.

[5] *The future of groundwater in California*. Environmental Defense Fund. (n.d.). Retrieved February 24, 2022.

[6] California, S. of. (n.d.). *Groundwater Sustainability Plans*. Department of Water Resources. Retrieved February 24, 2022.

(GSAs) which are charged with implementing Groundwater Sustainability Plans (GSPs) in order to mitigate undesirable results and overdraft over the next two decades.[7] Additionally, California's Department of Water Resources (DWR) is tasked with oversight and evaluation of GSPs as well as guidance on best practices for local agencies. Overall, the SGMA attempts to address groundwater sustainability through local management by smaller agencies with oversight from state agencies.

While management of groundwater and chronic aquifer overdraft is crucial to sustainability, maintaining and protecting industries that rely on groundwater usage is critical. California's agricultural sector is the largest of any state and produces a third of United States vegetables and two-thirds of the United States fruits and nuts. Thus, in 2020 revenues from the agricultural activity was 49.1 billion dollars.[8] For such a large industry covering a significant geographic area, conclusions regarding groundwater usage for agriculture have the potential to misrepresent the issue or promote inaccurate findings. Therefore, this paper will focus on the Lower Santa Clara River valley located in Ventura County California. Specifically, this paper will examine trends in groundwater levels in the Oxnard, Las Posas, and Pleasant Valley sub-basins before and after the enactment of the SGMA. Specifically, the null hypothesis of this thesis is that there is no significant change in the groundwater level in Ventura County, California after the enactment of the SGMA. The alternate hypothesis is there is a noticeable significant change in groundwater level after the enactment of the SGMA. This is an attempt to understand the effectiveness of the SGMA in a specified geographic area.

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[7] California, S. of. (n.d.). *Groundwater Sustainability Plans*. Department of Water Resources. Retrieved February 24, 2022

[8] California Department of Food and Agriculture. (n.d.). *California Agricultural Production Statistics*. CDFA. Retrieved February 24, 2022.

In 2020, the gross revenue from agriculture in Ventura county was nearly two billion dollars.[9] The area predominantly consists of high-value crops such as strawberries, avocados, and lemons.[10] All three of these crops are perennial which means they require a sizable initial investment and begin producing profits a few years after planting. Additionally, these perennial crops can not be followed without losing the investment and always require a minimum water requirement even when left dormant. This inherently creates larger water requirements for farmers and the potential for demand for water to be greater than supply in years of drought.

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[9] *Ventura County 2020 Crop and Livestock report*. (n.d.). Retrieved February 24, 2022.

[10] *Ventura County 2020 Crop and Livestock report*. (n.d.). Retrieved February 24, 2022.

II. Literature Review

II.1. Groundwater Overview

Using groundwater for agriculture is common practice and has vastly increased the total acreage of irrigated farmland.[11] Furthermore, surface water and groundwater are often used in conjunction in the Central Valley.[12] As discussed in Arellano-Gonzalez and Moore (2020), with access to greater water resources and water banks, farmers have steadily reduced their planting of row crops in favor of perennial crops. The study concludes that the promise of higher returns on perennial crops, such as fruit and nut trees, outweighs the reductions in flexibility regarding water usage. Furthermore, they conclude that areas with immediate access to supplemental water, one of which is groundwater, completed the transition to a larger percentage of perennial crops sooner than other areas. This potentially explains why farmers in Ventura County, with access to large underground aquifers, comprise a large portion of their crop portfolios with high-return perennial crops.[13]

As minimum water requirements increase, the reliance on groundwater becomes even greater as farmers have higher annual requirements with smaller variances due to the planting of high-return perennials. However, this reliance on groundwater may be flawed as underground aquifer replenishment is still an understudied field. In Guilfoos et al (2013) the idea that groundwater flow is instantaneous, that is it is mobile throughout

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[11] Tsur Y (1990) The stabilization role of groundwater when surface-water supplies are uncertain: the implications for groundwater development. Water Resour Res 26:811–818

[12] Faunt, C.C., Sneed, M., Traum, J. *et al.* Water availability and land subsidence in the Central Valley, California, USA. *Hydrogeol J* 24, 675–684 (2016).

[13] *Ventura County 2020 Crop and Livestock report*. (n.d.). Retrieved February 24, 2022.

the aquifer instantaneously, was challenged. Additionally, the management of groundwater resources provided substantial welfare gains in their field of study. They concluded that management of well spacing and other policies which promote water-saving, increase welfare gains when farmers act myopically.

Groundwater overdraft is a serious problem in California's central valley and lack of management has led to critical overdraft. In the lower Santa Clara River Valley, two of the three sub-basins are listed as critically overdrafted.[14] Specifically, in the 2019 DWR report, both Oxnard and Pleasant Valley sub-basins were listed as critically overdrafted despite adjustments to the boundaries of the sub-basins. The DWR defines critical overdraft as "when [the] continuation of present water management practices would probably result in significant adverse overdraft related environmental, social, or economic impacts".[15] Despite increased reporting and management of groundwater overdraft, the above criteria provided by the DWR is vague without specifications.

II.2. Policy Instruments for Groundwater Management

In Bruno(2018), encompassing analysis of policy instruments related to groundwater management is conducted and presented. The study analyzes cap and trade, excise taxes, and command and control as three possible policy approaches to sustainable groundwater management. Due to the multitude of metrics to measure the effectiveness of a policy, this study focused on which of the three policy methods produced the most economically efficient outcome.

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[14] California, S. of. (n.d.). *Critically overdrafted basins*. Department of Water Resources. Retrieved February 24, 2022.

[15] California, S. of. (n.d.). *Critically overdrafted basins*. Department of Water Resources. Retrieved February 24, 2022.

Cap and trade is a system of groundwater management where the total allocation is capped at a certain level and subsequent transferable usage permits are issued by local agencies. Given high transportation costs, these markets would be relatively local with a few basin coalitions where multiple adjacent basins expand the market to include more than one basin.[16] In light of this, markets would generally be isolated and thus concerns of market power concentration are a potential drawback of this policy instrument. Specifically, the welfare gains from this policy implementation would be largest for the individuals that have market power. Lastly, a key component of an operational cap and trade market is the clear definition of property rights via permit allocation. This study concludes that in order to maximize welfare gains, the process of permit allocation would prevent the concentration of permits for both limited buyers or sellers.[17]

Excise tax policy refers to a method of management where a tax is levied, in this instance on groundwater, in an attempt to internalize the externalities of overdraft on groundwater users. In Bruno (2018) the example of a pump tax is examined. The paper estimates an inelastic demand for groundwater when the tax is levied. Specifically, when controlling for seasonal variation and well-depth, the paper concluded that the demand elasticity was approximately -0.17 which suggests that increased pumping costs minimally reduce extraction.[18] Given this result, higher taxes are required to curtail groundwater extraction to a sustainable level. Imposing this high tax creates a large pool of tax revenue for the agency and without proper redistribution of this revenue, this could

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[16] Bruno, E. M. (2018). *An Evaluation of Policy Instruments for Sustainable Groundwater Management* (dissertation). ProQuest, Ann Arbor, MI.
[17] Bruno, E. M. (2018).
[18] Bruno, E. M. (2018).

have significant consequences on the condensation of the farming market due to increased costs.

Command and control refer to a policy instrument where the authoritative agency sets limits in regards to the resource of interest and requires reductions to meet these limits over time.[19] Bruno (2018) discusses how this policy when applied to groundwater is much less effective at reducing usage and welfare loss when compared with both cap and trade and excise taxes. Specifically, with a 20% reduction in groundwater pumping and permits being issued based on landholdings, the welfare gains from a cap and trade system are 47% greater than the welfare gains from command and control under the same reductions.[20]

Ultimately, Bruno(2018) concludes that market-based policy instruments, with careful observation of market power and condensation, are potentially more effective as adaptive climate change mitigation tools as compared to command and control.

Regardless of which policy instrument is chosen to mitigate groundwater overdraft, each has inherent limitations, however, the framework from which they are viewed plays a critical role in sustainably managing the vital resource. As discussed in Conrad et. al (2019) the need for adaptive GSPs is extremely important as they allow for flexibility in order to achieve the stated goals of a given GSA. The paper specifically discusses key ideas in order to achieve the goals of SGMA. The two most relevant

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[19] Encyclopædia Britannica, inc. (n.d.). *Command and Control Legislation*. Encyclopædia Britannica. Retrieved February 24, 2022.

[20] Bruno, E. M. (2018).

conclusions are first, agreeing on how metrics are linked with action. As previously discussed, SGA's are required to set minimum thresholds and interim milestones in order to achieve the objectives of the SGA. However, Conrad et. al (2019) discussed how it is critically important to have an action plan set in advance in the case that the objectives are not met.[21] Secondly, the paper argues for an adaptive approach to the metrics themselves. This addresses the lack of homogeneity among groundwater basins and the inherent uncertainty that arises from this. Specifically, it suggests that the DWR upon review of the annual reports, done every five years, should include an assessment of whether the chosen metrics are providing an adequate information base for SGA's to make proper management decisions.[22]

II.3. Groundwater Overdraft

Here it is important to note that groundwater overdraft is a vicious downward spiraling issue. Specifically, groundwater is brought to the surface for use via an electric pump. A groundwater pumps efficiency can be thought of as how much water is drawn up relative to the electric power input.[23] Efficiency is thus affected by the depth of the groundwater and is negatively affected by critical overdraft due to the increasing depth of groundwater. Additionally, excessive groundwater drawdown below critical levels increases the rate of contamination and further reduces pumping efficiency.[24] [25]

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[21] Conrad, E., Moran, T., Crankshaw, I., Blomquist, W., Martinez, J., and Szeptycki, L. (2019). Putting Adaptive Management into Practice: Incorporating Quantitative Metrics into Sustainable Groundwater Management. Stanford Digital Repository.

[22] Conrad, E., Moran, T., Crankshaw, I., Blomquist, W., Martinez, J., and Szeptycki, L. (2019).

[23] *Apep Pump Advisory - PG&E, Pacific Gas and Electric*. (n.d.). Retrieved February 24, 2022.

[24] Burlig, Fiona, et al. "Energy, Groundwater, and Crop Choice." *NATIONAL BUREAU OF ECONOMIC RESEARCH*, Apr. 2021.

[25] Levy, Z. F., Jurgens, B. C., Burow, K. R., Voss, S. A., Faulkner, K. E., Arroyo-Lopez, J. A., & Fram, M. S. (2021). Critical aquifer overdraft accelerates degradation of groundwater quality in California's Central Valley during drought. *Geophysical Research Letters*, 48, e2021GL094398.

A 2021 study conducted by Burlig et. al. regarding energy, groundwater, and crop choice discussed these impacts of overdraft. The study astutely observed that measuring groundwater is quite difficult and thus used electricity prices and demand in order to estimate the effects of a groundwater tax consistent with California's sustainability targets.[26] The researchers concluded that the demand elasticity for groundwater was approximately -1.12, which is not only much greater than previously estimated but correlated to a decrease in the quantity demanded equal to the increase in price.[27] This result led to the conclusion that a tax on groundwater usage was much more effective than previously thought.

Using a discrete choice model, the study concluded that fallowing and crop switching were the primary responses to the increased groundwater cost. Specifically, the farmers did not respond with changing daily water use on existing crops but rather made this switch between growing seasons. Lastly, this led farmers to reallocate 3.9% of their farmable land to high-value fruit and nut trees, shifting away from lower-value annual crops.[28]

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[26] Burlig, Fiona, et al.

[27] Burlig, Fiona, et al.

[28] Burlig, Fiona, et al.

III. Deeper Analysis of SGMA
III.1. Why SGMA?

As mentioned, the Sustainable Groundwater Management Act was enacted in 2014 and mandated that GSAs implement a sustainable yield concept as their primary objective. While the act was passed in 2014, it allowed flexibility in the implementation of these GSPs until 2020.[29] Additionally, the policy set 2040 as the year when the resource would be sustainable.[30] This policy was quite pertinent as underground aquifer depletion in dry years was much greater than the recharge in wet years. Specifically, since 1960, the Central Valley has lost approximately 123,348.9 million cubic centimeters of groundwater from storage.[31] [32] Additionally, as this groundwater has been removed, it has affected the geography and soil quality of the Central Valley in a catastrophic way. Subsidence is the response from surface topography when groundwater aquifers are continually overdrafted. It refers to the sinking of the earth's surface and in the time period since 1960 has depreciated at a rate of approximately 0.5 meters a year.[33] [34] This has seriously threatened agricultural sustainability in the region and is another externality from critical groundwater overdraft. Lastly, this overdraft has severely increased the salinization of the soil as reductions of groundwater below a certain threshold create a higher rate of saline intrusion into the underground aquifer.[35] While this is a tertiary effect, it is still important to consider when examining why there was and is a need for

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[29] Guardian News and Media. (2020, February 27). *Everything you need to know about California's Historic Water Law*. The Guardian. Retrieved March 6, 2022.

[30] Guardian News and Media. (2020, February 27). *Everything you need to know about California's Historic Water Law*.

[31] Faunt CC (2009) Groundwater availability of the central valley aquifer: U.S. Geological Survey Professional Paper 1766.

[32] Faunt, C.C., Sneed, M., Traum, J. *et al.* Water availability and land subsidence in the Central Valley, California, USA. *Hydrogeol J* 24, 675–684 (2016).

[33] Farr TG, Jones C, Liu Z (2017) Progress Report: Subsidence in California, March 2015–September 2016, Submitted to California Department of Water Resources.

[34] Faunt, C.C., Sneed, M., Traum, J. *et al.* Water availability and land subsidence in the Central Valley, California, USA. *Hydrogeol J* 24, 675–684 (2016)

[35] Schoups G, Hopmans J, Young C, Vrugt J, Wallender W, Tanji K, Panday S (2005) Sustainability of irrigated agriculture in the San Joaquin Valley, California. Proc Natl Acad Sci.

the management of groundwater in California. These stated effects as well as previously mentioned concerns regarding the long-term sustainability of groundwater use for farming operations are the central issues driving this analysis.

III.2. Sustainable Yield

Sustainable yield is quite an evasive metric for groundwater measurement and the intricacies of this concept will be discussed in this section. The SGMA defines sustainable yield as the following, “the maximum quantity of water [...] that can be withdrawn annually from a groundwater supply without causing an undesirable result”.[36] Undesirable results include but are not limited to: depletion of supply from chronic lowering of groundwater level, reduction of groundwater storage, seawater intrusion, water quality degradation, and land subsidence.[37] [38] These concepts for sustainable yield are not only ambiguous but Rudestam and Langridge (2014) concluded that water agency representatives not only lacked a clear understanding of sustainable yield but also lacked confidence in sustainable yield as a viable concept for the reduction in groundwater use.[39]

Miro and Famiglietti (2018) concur on the SGMA's lack of clarity in regards to the sustainable yield concept and propose a new framework from which to view the concept. This framework is based on three core procedures. The first procedure is the quantification of a baseline sustainable yield value. While the process of quantification is

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[36] Sustainable Groundwater Management Act (2014) Sustainable Groundwater Management Act (And Related Statutory Provisions from SB1168 (Pavley), AB1739 (Dickinson), and SB1319 (Pavley) as Chaptered).

[37] State of California (2017) Legislation—more about SGMA, State of California. California Groundwater.

[38] State Water Resources Control Board (2016b) Triggering state intervention—Sustainable Groundwater Management Act (SGMA). California Environmental Protection Agency

[39] Rudestam K, Langridge R (2014) Sustainable yield in theory and practice: bridging scientific and mainstream vernacular. Groundwater 52:90–99.

debated the researchers state that, ‘the baseline sustainable yield corresponds to the average level of extraction that causes zero average groundwater level change.[40] This is to say that the amount of groundwater extracted is equal to the natural recharge rate of the aquifer and thus usage does not affect the average groundwater level. Second, the paper states that constraints from the aforementioned undesirable results be integrated into the quantification of the sustainable yield. This would result in a constraint-adjusted sustainable yield. Finally, “the projection of basin response to the use of sustainable yield-based strategies over the management horizon”.[41] This portion of the framework is promoting a thoughtful approach to management by considering how the implemented policies will affect the users of the groundwater within the basin. This is quite transcendent as it considers all parties connected to the resource and incorporates them into the sustainable use of groundwater for economic activity.

Overall, the framework provided by Miro and Famiglietti provides a more dynamic approach to the concept of sustainable yield. Additionally, the conclusion that sustainable yields should be calculated on a yearly basis as compared to the current five-year reporting period is significant. The most important takeaway from this paper is that with current monitoring and reporting systems, the sustainability of groundwater resources could ultimately mean complete depletion. Therefore, it is of extreme importance to balance usage with recharge rates in order to sustainably use this vital resource.

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[40] Miro, M.E., Famiglietti, J.S. A framework for quantifying sustainable yield under California’s Sustainable Groundwater Management Act (SGMA). *Sustain. Water Resour. Manag.* 5, 1165–1177 (2019).

[41] Miro, M.E., Famiglietti, J.S

IV. Theory and Model

For this analysis, an ARIMA model was used to analyze well depth measurements in order to understand trends before and after the enactment of the SGMA in 2014. An ARIMA model is a compound model made up of three components. The first portion is the autoregressive portion (AR). This portion of the model regresses previous lagged observations against themselves and ultimately creates a linear regression for a single variable of interest. The second portion of this compound model is the differencing portion (I). This portion of the model is when observed values are differenced from previous values in order to stabilize seasonal variability within the data.[42] This reduction in seasonal variability helps stabilize the mean, variance, and auto-correlation of the data which ultimately helps mitigate temporal dependence.[43] The last portion of the model is the Moving Average (MA). This portion of the model has a window whose length is defined to be the number of values incorporated into the moving average. This is to say that the moving average is calculated from a specified number of previously recorded, potentially differenced, values.[44]

There are three parameters in the ARIMA model and each one corresponds to the previously mentioned components. The parameter for the auto-regressive portion is denoted as p. The parameter p refers to the lag order of the specific ARIMA model. Lag order can be defined as the number of lagged observations that are included in the auto-regressive portion of the model. For example, $p = 16$ signals for 16 lagged

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[42] Autoregressive Integrated Moving Average. *Autoregressive Integrated Moving Average - an Overview | ScienceDirect Topics*.

[43] Business, F. S. of. (n.d.). *ARIMA models for time series forecasting*. Introduction to arima models. Retrieved March 3, 2022.

[44] Hayes, Adam. Autoregressive Integrated Moving Average (ARIMA). *Investopedia*, Investopedia, 8 Feb. 2022.

observations to be included in the regression, meaning that 16 prior observations are being used to forecast future observations.

The second parameter is denoted by *d.* This parameter is associated with the differencing portion of the model and is referred to as the degree of differencing. As mentioned, differencing is done in order to make the dataset stationary. The degree of differencing is how many times the raw observations are differenced. If consecutive observations exhibit a high degree of collinearity then this often requires a higher degree of differencing. Lastly, time-series data with a high degree of seasonal variability generally requires a higher degree of differencing in order to make the data stationary. Stationary data is more optimal for the ARIMA model as it allows for trends and observations to be non-seasonal and therefore more general. This is especially valuable when analyzing economic or market trends, as seasonal structures are removed so as to not manipulate the trends in data.

The last parameter is denoted by *q.* The *q* parameter refers to the size of the window for the moving average portion of the model. That is, the window size is the length or number of observations included when calculating the moving average. For example, $q = 16$ signals for the 16 previous residuals to be included when calculating the moving average for this specific case. Larger *q* values generally correlate to more precise estimated values as including more residuals into the prediction of the next observation smooths the data, and makes trend more observable.

In conclusion, to specify the parameters of the ARIMA model, we use the notation ARIMA(*p,d,q)* where the value of *p* is the lag order, *d* is the degree of differencing, and *q* is the window length for the moving average. Here it is important to note that *p,d,* and *q* are optimized to reproduce the observed data with the goal of predicting future trends and are not chosen at random. Lastly, if any of the parameter values is equal to zero then that portion of the model is unused as the best fit ARIMA does not make use of that portion of the model in order to reproduce the data.

V. Data

The dataset used was downloaded from the California Natural Resource Agencies open data sets.[45] The dataset contains a combination of numeric and categorical variables regarding measurements of groundwater depths at various well sites. The data set was sorted and cleaned. First, all observations outside of Ventura County were removed. Next, the data was sorted by the site code in order to classify the observations according to which well it was collected from. All duplicate observations with equal dates and site codes were removed. Due to the variability of the observation periods among the sorted wells, observations were only included if they occurred between 01–01–2011 and 10–28–2021. This was in an attempt to create a complete data set. This sorted data set contained four hundred unique wells. Next, because the wells had an inconsistent number of observations in the specified time period, time groups were created. Time groups were defined as 61-day intervals with the first day of the first group beginning on 01–01–2011, and the first day of the second group beginning on the 62nd day, etc. There were a total of 65 time groups. This dataset was chosen because Ventura County California has a large agricultural sector with a high percentage of perennial crops. Furthermore, the minimum water requirements were large thus making it a good point of observation regarding the implementation of the SGMA and whether there was a change in the trend of mean groundwater depth. The time group length of 61 days was chosen because it allowed for approximately 6 groups per year.

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[45] *Groundwater level data*. California Natural Resources Agency Open Data. (n.d.). Retrieved December 14, 2021.

Each well was not analyzed individually due to the lack of consistency in the reporting interval. As seen in *Table 1* for each unique well, the number of observations varies greatly.

	min	**1st Q**	**median**	**mean**	**3rd Q**	**max**
Number of observations	32	43	82	108	144	535

Table 1: *this table represents the summary statistics for the number of observations for each unique well.*

Therefore for each time period, if a well had more than a single observation, the observations were appropriately averaged. This allowed for the creation of a time series data set of mean groundwater depth and time group. The time series was created by averaging groundwater depths for all wells which had a measurement in the specified time period. Due to the fact that all wells did not have an observation in each period, a Heckman correction was performed in order to correct for potential bias as many of the missing observations occurred in the final twelve time periods. This process is discussed in detail in the Methods section (V.1). This Heckman correction allowed for the data set to be complete in the sense that each well had a minimum of one observation per time period or an average of multiple unique observations. After this correction was inserted the above averaging technique was used to create the time series dataset.

The dataset was then partitioned by time group in order to better observe the trend in groundwater. Specifically, time groups 1 through 27 were partitioned to be the first observation period. The length of this observation period was calculated to be four and half years after the first observation and a year and a half after the passing of the SGMA.

The second observation period began on the first day of the thirty-third time group, July 6th, 2016, and ended on the last day of the sixty-fifth time group, October 28th, 2021. There was a buffer period of six time groups, approximately a year, left in between the two observation periods in order to better observe the trends of mean groundwater depths before and after the enactment of the SGMA. As previously stated, the implementation of GSPs was due to be completed by 2020 but it was in the best interest of all concerned parties to begin implementing sustainability policies before then. This reality has greatly influenced the creation of time groups and the observation periods, including the buffer period, for the data set.

V.1. Methods

As previously stated a Heckman correction was done on the data set to correct for potential bias. The potential bias was due to the fact that wells that had missing observations in the final twelve time periods had significantly deeper groundwater depths in the first 53 time groups. The missing measurements are depicted by the white area in the bottom right corner of *Figure 1*.

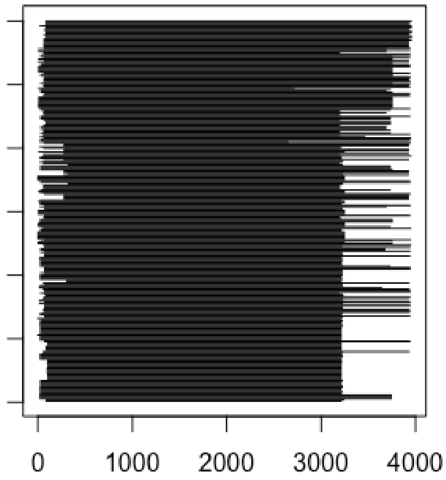

Figure 1: *This figure depicts the length of the observation period for each specific well in the dataset. The y-axis has no value because each unit represents a unique well. The x-axis is the number of days since 01–01–2011, a continuous black line signals a complete observation period.*

As stated, the wells which had the missing observation in the final twelve time groups had significantly deeper mean depth as compared to the mean mean depth of wells that did not have missing observations in the final twelve time groups. This is clearly observable in *Figure 2* as the black line, representing the mean depth of the wells with missing observations, is significantly above the blue line, which represents wells that had no missing observations in the final twelve time periods. This test was the motive for conducting a Heckman correction in order to avoid biased conclusions regarding the trend in mean groundwater depth.

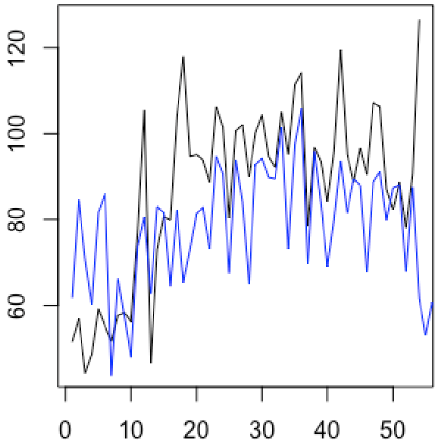

Figure 2: *This figure depicts the mean groundwater depth for wells with missing observations in the final twelve time periods (black line) and the mean groundwater depth for wells with no missing observations in the final twelve time periods (blue line). The y-axis is the mean groundwater depth in feet and the x-axis is time groups 1:53.*

In order to correct this, for each well, a probit was run. This probit, for each individual well, went through each time group and if there was a missing value assigned the well a 1 and if non-missing assigned it a 0. From this generated list of 1s and 0s, it was determined that the probability of observing an observation in each time group for each individual well, was a function of the time group and a well specific constant. This equation is depicted in *EQ1*.

EQ1: prob(observed values)= *f* (time group, well specific constant)

EQ1 was used to generate an inverse mills ratio for each well. Next, for each well, if a 1 was assigned to a specific time group an observation was created based on the frequency of previous observations. From here for each well, well depth was regressed against its own lagged values, the inverse mills ratio, and a well-specific constant. This equation can be seen in *EQ2* where the well-specific constant is represented by the term X_0.

EQ2: Well Depth = $X_0 + X_1$(lagged values) + X_2(inverse mills ratio) + e

X_1 and X_2 represent the coefficients of the lagged values of the groundwater depth and the inverse mills ratio, respectively. Next, the values from the coefficients in *EQ2* were used to predict the values of the previously mentioned created observations. The final step of this correction was to fill in the missing values with the predicted ones. This correction made the data set complete and thus filled in the white area in the bottom right of *Figure 1* with well-specific values.

VII. Results

An ARIMA model was fitted to the partitioned time series data. Specifically, the data set was organized into four subsets. For the first and second observation periods, an ARIMA model was fitted to both the original and Heckman corrected data sets. This led to the creation of four ARIMA models fitted to each subset. The creation of the aforementioned subsets was in an attempt to avoid overcorrection bias.

All of the specified ARIMA models were generated in Rstudio using the auto-Arima function. When fitting models to the data the function used minimizes Akaike Information Criterion (AIC) to generate the model with the best fit. AIC is calculated based on how well the predicted model reproduces the observed data. Thus minimizing AIC in this scenario is selecting the best model that reproduces the data.

In the first observation period using the original dataset, Rstudio fitted an ARIMA(2,1,0) to the observed data. For this specific model, p being equal to two indicates there are two autoregressive terms. The order of differencing in this model is one, as $d=1$. This indicates that the predicted ARIMA model for this subset has a differencing order of one which stipulates that the mean groundwater level in the $t-2$ time group is subtracted from the mean groundwater level in time group $t-1$. The moving average parameter for this predicted ARIMA is equal to zero which means there is no moving average component. As depicted in *Figure 3*, the ARIMA(2,1,0) prediction fits the uncorrected data fairly well.

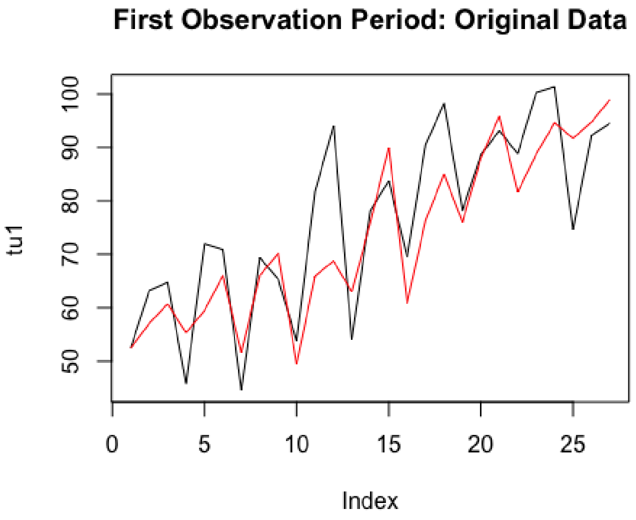

Figure 3: *This graph is a depiction of the mean groundwater depth in the first observation period(1:27) for the uncorrected data (black) and the predicted ARIMA(2,1,0) values for the same data set over the same time period (red). The x-axis is the time group (from 1:27) and the y-axis is the mean groundwater depth in feet.*

For the first observation period using the Heckman corrected dataset, Rstudio was again used to predict the best ARIMA model. The result was an ARIMA(2,1,0) with a drift. Similar to the predicted ARIMA from the original data, p=2, and d=1. This indicates that there are again two autoregressive terms and the degree of differencing is 1. This predicted model differs from the predicted model of the original dataset as the ARIMA contains a drift. A drift term in an ARIMA model is a constant non-zero term that is inserted into the calculation of the next term in order to account for a time trend. Essentially, if the constant term, let us call it C, is non-zero then the data exhibits a time trend. As shown in *Figure 4*, the ARIMA predicted values fit the data well.

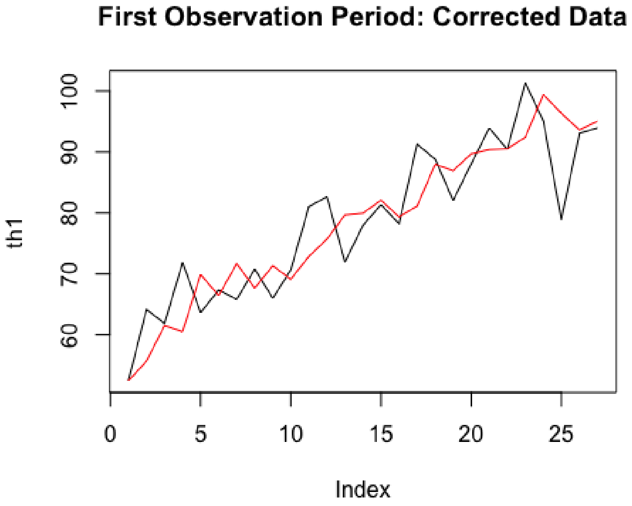

Figure 4: *This graph is a depiction of the mean groundwater depth in time period one for the Heckman corrected data depicted as the black line, and the ARIMA(2,1,0), with a drift, predicted values for the same data set in the same time period in red. The x-axis is the time group (going from 1:27) and the y-axis is the mean groundwater depth in feet.*

In the second observation period using the original dataset, an ARIMA(2,1,0) with a drift was predicted. This again translates to *p=2* and *d=1*. However, it is important to note that this ARIMA differs from the previous two in that its trend is in the other direction. Furthermore, with the presence of non-zero C term, the data exhibits a time trend where the mean of the dependent variable, groundwater level, is exhibiting a clear path in a specific direction. This is observable in *Figure 5* where the predicted values of our ARIMA(2,1,0), with a drift, are plotted alongside the original data from the second observation period.

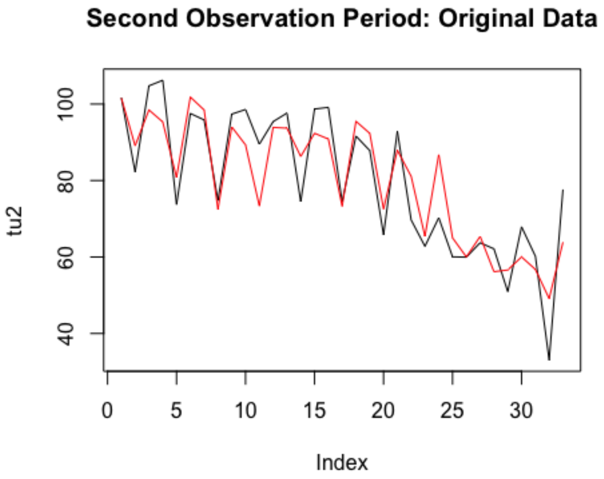

Figure 5: *This graph is a depiction of the mean groundwater depth in time period one for the Heckman corrected data depicted as the black line, and the ARIMA(2,1,0), with a drift, predicted values for the same data set in the same time period in red. The x-axis is the time group (going from 1:27) and the y-axis is the mean groundwater depth in feet.*

Regarding the second observation period for the Heckman corrected dataset, an ARIMA(2,1,2) with a drift was fitted to the data. Again, in this predicted model *p=2* and *d=1*. Additionally, *q*=2. This indicates the presence of a moving average window. This corresponds to the moving average term being calculated by multiplying the error terms from the *t-1* time group and the *t-2* time group by some unique coefficient. The drift again signals the presence of an observable trend over time. This can be observed in *Figure 6* as well as the fact that the specified ARIMA fits the data.

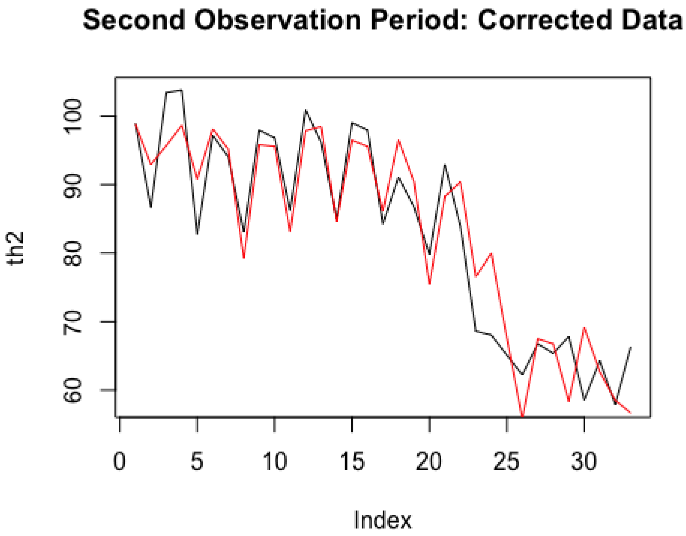

Figure 6: *This graph is a depiction of the mean groundwater depth in time period one for the Heckman corrected data depicted as the black line, and the ARIMA(2,1,0), with a drift, predicted values for the same data set in the same time period in red. The x-axis is the time group (going from 1:27) and the y-axis is the mean groundwater depth in feet*

Before discussing the results of this analysis a few things must be addressed. First, each groundwater level measurement is independent as there is no dependence between measurements. This allows us to assume there is non-significant auto-correlation between observations and more importantly between any observation in our averaged time-series dataset. Furthermore, since our model has only one independent variable, time, we assume there is no multicollinearity present. Second, to avoid overcorrection bias, the results will be discussed in unison based on the observation period using the results from the original data set as one bound and the results from the Heckman corrected as the other.

For the first observation period, as stated, using the original uncorrected data set the best fit ARIMA model was an ARIMA(2,1,0). When using the Heckman corrected data set the best fit ARIMA was an ARIMA(2,1,0) with a drift. The general equations are listed below as *EQ3* and *EQ4* respectively.

$$\textbf{\textit{EQ3}}\textbf{:}\ Y_t = \boldsymbol{\beta}_1\Delta Y_{t-1} + \boldsymbol{\beta}_2\Delta Y_{t-2} + e_t$$

$$\textbf{\textit{EQ4}}\textbf{:}\ Y_t = C + \boldsymbol{\beta}_1\Delta Y_{t-1} + \boldsymbol{\beta}_2\Delta Y_{t-2} + e_t$$

Notice the only difference between the two equations is the presence of C. These general equations are stating that the observation in the current time period t is a function of the previous two values each multiplied by some coefficient $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$ respectively. However, in *EQ4* the predicted observation in time group t is also a function of a constant term C, where the value of $C = drift*(1- ar1 -ar2)$.

Coefficients:	**ar1**	**ar2**
Value:	-0.7832	-0.7678
S.E:	0.1188	0.1101

σ^2 = 101.8

Table 2: *R generated coefficients and standard errors for the ARIMA model fit to the original data in the first observation period.*

Coefficients:	**ar1**	**ar2**	**drift**
Value:	-0.5681	-0.4554	1.3205
S.E:	0.1801	0.1833	0.6339

σ^2 = 45.36

Table 3: *R generated coefficients and standard errors for the ARIMA model fit to the Heckman corrected data in the first observation period.*

$$\textbf{\textit{EQ5}}\textbf{:}\ Y_t = (-0.7832)\Delta Y_{t-1} + (-0.7678)\Delta Y_{t-2} + e_t$$

$$\textbf{\textit{EQ6}}\textbf{:}\ Y_t = (2.671) + (-0.5681)\Delta Y_{t-1} + (-0.4554)\Delta Y_{t-2} + e_t$$

EQ5 is *EQ3* and with filled-in coefficient values from *Table 2*. *EQ6* is *EQ4* with the coefficient values from *Table 3* where the constant term was calculated using the stated equation for *C*. In *EQ5* due to the fact that both beta coefficients are negative, our data is mean reverting with alternating signs.[46] This is to say that in sequential time periods the value of Y_t alternates above and below the mean of the data set. This result can be seen in *Figure 3* as the groundwater level exhibits a somewhat sinusoidal pattern.

Here it is important to note that an increase in mean groundwater depth is harmful and an undesirable result. While the ARIMA model from *EQ5* insinuates an alternating pattern, this result can be clearly seen in *Figure 3* as the alternating pattern coincides with a deepening of mean groundwater level. Despite the detectable trend in *Figure 3*, it would be an overextended conjecture to state there is conclusive evidence for a deepening trend in mean groundwater level.

The statements made regarding *EQ5* are also true for *EQ6*, however, there are some intricacies that make it different; namely, the presence of a positive non-zero *C* term. The presence of this term demonstrates that there is a clear time trend in the dataset. C=2.671 indicates the constant will always pull the alternating value of Y_t in a positive direction. This result is clearly observable in *Figure 4* despite the large dip around the twenty-fifth time group. Another interesting point to note is that due to the magnitude of the coefficients being smaller in *EQ6* relative to *EQ5*, *Figure 4* exhibits a smaller range between time periods as compared to *Figure 3*.

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[46] Business, F. S. of. (n.d.). *ARIMA models for time series forecasting*. Introduction to arima models. Retrieved March 3, 2022.

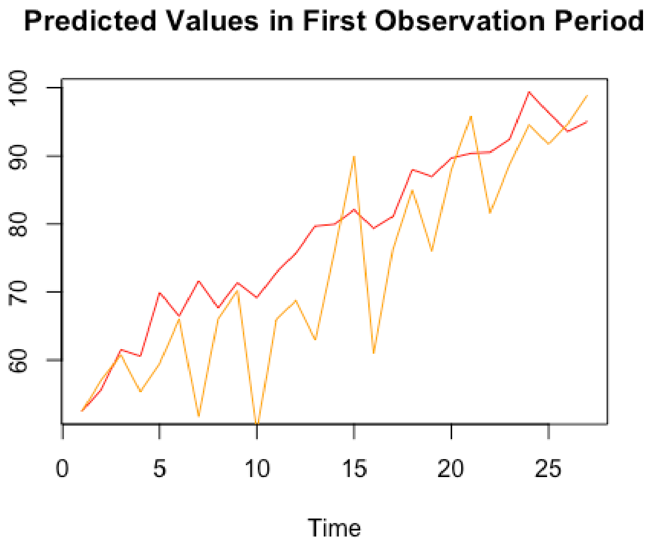

Figure 7: *This graph is a depiction of the fitted ARIMA values for the first observation period. The x-axis represents the time group(1:27) and the y-axis is the mean depth of groundwater in feet. The orange line is the predicted values from the ARIMA(2,1,0) for the original data. The red line is the predicted values from the ARIMA(2,1,0) with drift for the Heckman corrected data.*

Using the stated results from *EQ5*, *EQ6*, and *Figure 7* stronger conclusions can be made regarding the mean groundwater level in Ventura County prior to the passing and enactment of the SGMA. If the predictions from *EQ5* and *Figure 3* are thought of as the lower bound of the trend then it can be said that the mean groundwater level in Ventura California is slightly deepening via an alternating pattern with no observable trend. Additionally, if the results from *EQ6* and *Figure 4* are thought of as the upper bound of the trend, then the mean groundwater level in Ventura California is deepening significantly with an observable trend over time. In *Figure 7,* it is clearly observable that the variance of the red line, the fitted values for the corrected data, is smaller than that of the orange line, the fitted values of the original data. However, they generally move in the same direction despite a few idiosyncrasies from time groups 5 through 10. Despite this, it can still be said that the true trend in mean groundwater depth is contained somewhere between these two lines and is moving in a generally positive direction over time.

For the second observation period, as previously mentioned, using the original uncorrected data set the best fit ARIMA model was an ARIMA(2,1,0) with a drift. When using the Heckman corrected data set the best fit ARIMA was an ARIMA(2,1,2) with a drift. The general equations are listed below as *EQ5* and *EQ6* respectively.

$$\textbf{\textit{EQ7}}\textbf{:}\ Y_t = C + \boldsymbol{\beta}_1 \Delta Y_{t-1} + \boldsymbol{\beta}_2 \Delta Y_{t-2} + e_t$$

$$\textbf{\textit{EQ8}}\textbf{:}\ Y_t = C + \boldsymbol{\beta}_1 \Delta Y_{t-1} + \boldsymbol{\beta}_2 \Delta Y_{t-2} + \phi_1 e_{t-1} + \phi_2 e_{t-2} + e_t$$

A key difference between *EQ7* and *EQ8* is that *EQ8* contains two moving average components represented by ϕ. Another interesting result from the best fit ARIMA is that both *EQ7* and *EQ8* have non-zero C terms which indicate a time trend. Again, $C = drift*(1 - ar1 - ar2)$. In *EQ7* the mean groundwater level is a function of the two previous observations each multiplied by the coefficients $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$ respectively and a constant term *C.* In *EQ8*, the mean groundwater level in time period *t* is a function of the two previous values each multiplied by the coefficients $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$. Additionally, the residuals, equal to the difference between the ARIMA predicted value and the observed value for each time group, are multiplied by the coefficients ϕ_1 and ϕ_2 respectively.

Coefficients:	**ar1**	**ar2**	**drift**
Value:	-1.0220	-0.8937	-1.3012
S.E:	0.0936	0.0767	0.4998

$\sigma^2 = 70.4$

Table 4: *R generated coefficients and standard errors for the ARIMA model fit to the original data in the second observation period.*

Coefficients:	**ar1**	**ar2**	**ma1**	**ma2**	**drift**
Value:	-0.9704	-0.9723	0.6287	0.7172	-0.8791
S.E:	0.0609	0.0328	0.1359	0.3060	0.7710

σ^2 = 34.75

Table 5: *R generated coefficients and standard errors for the ARIMA model fit to the Heckman corrected data in the second observation period.*

EQ9 is *EQ7* with the R generated coefficients from *Table 4*. *EQ10* is *EQ8* with the R generated coefficients from *Table 5*.

$$\textbf{\textit{EQ9}}\textbf{:}\ Y_t = (-3.794) + (-1.0220)\Delta Y_{t-1} + (-0.8937)\Delta Y_{t-2} + e_t$$

$$\textbf{\textit{EQ10}}\textbf{:}\ Y_t = (-2.587) + (-0.9704)\Delta Y_{t-1} + (-0.9723)\Delta Y_{t-2} + (0.6287)e_{t-1} + (0.7172)e_{t-2} + e_t$$

For *EQ9* the autoregressive coefficients are both negative which again signals that our data is exhibiting mean reversion with an alternating pattern where consecutive values alternate above and below the mean. However, the presence of a negative non-zero C term indicates that our alternating pattern exhibits a trend in the negative direction. This is observable in *Figure 5* where the mean groundwater level for the second observation period again exhibits a somewhat sinusoidal pattern with a time trend in the negative direction.

The results from *EQ10* are similar to those of *EQ9*, however, due to the presence of two moving average components, the analysis is a bit more nuanced. The presence of two negative autoregressive terms and a negative non-zero *C* term indicates an alternating mean-reverting pattern with a negative time trend. Yet, the presence of the two moving average components indicates a more complex interpretation. Moving average components incorporate the residuals, in this case of the two previous values, into the model in order to smooth the trend of the time series and reduce the effect of outliers. Because the magnitude of both of our moving average coefficients are closer to one than they are zero, our predicted ARIMA model is indicating to incorporate the errors of the previous two predictions into our prediction in time period *t*.[47] This result can be viewed when comparing the mean groundwater level for the last seven time groups in *Figure 5* and *Figure 6.* Specifically, in *Figure 6*, the time trend is more easily observable due to the presence of the moving average components present in *EQ10* from the Heckman corrected dataset in the second observation period.

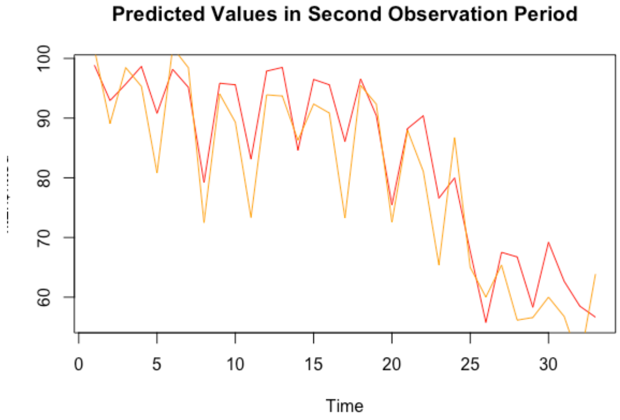

Figure 8: *This graph is a depiction of the fitted ARIMA values for the second observation period. The x-axis represents the time group(33:65) and the y-axis is the mean depth of groundwater in feet. The orange line is the predicted values from the ARIMA(2,1,0) with drift for the original data. The red line is the predicted values from the ARIMA(2,1,2) with drift for the Heckman corrected data.*

Using the results from *EQ9, EQ10,* and *figure 8* in the second observation period allows for more accurate conjectures. Specifically, if the lower bound of the true trend in the second observation period is an alternating mean-reverting trend in the negative direction, as described by *EQ9* and *figure 5.* It can be concluded that at the very least the SGMA has caused a significant reduction in the mean groundwater depth. Additionally, considering the upper bound of the true trend to be the results from *EQ10* and *Figure 8.*

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[47] Business, F. S. of. (n.d.). *ARIMA models for time series forecasting*. Introduction to arima models. Retrieved March 3, 2022.

Then the SGMA is clearly exhibiting a positive outcome as the trend in mean groundwater level is clearly negative which correlates to a reduction in the mean groundwater depth in Ventura California. In F*igure 8*, both the original and Heckman corrected fitted values move in the same direction with slight variation in level. Regardless of this slight difference in magnitude, the true trend in mean groundwater depth is contained between the red and orange lines in *Figure 8*. Therefore, when considering these results in unison, the second observation period clearly exhibits a reduction in the mean groundwater depth in Ventura California.

For all four specified ARIMA models, Engle's ARCH test was conducted to examine if heteroskedasticity was present in the variance of the specified estimators. An Engle's ARCH test assumes homoscedasticity and returns a p-value based on how likely the variance of the estimators would be observed at random. For all four predicted models, the p-values were non-significant. This indicates that while the variance of the estimators may experience some variability, this variability is random and does not follow a predictable pattern.

One limitation of this analysis is the potential omitted variable bias. When constructing the time series for the Heckman corrected and original datasets, time and mean groundwater depth were the only variables entered into the process. While this was done to best observe potential trends, it does not account for the yearly variance in rainfall and extenuating circumstances from the previous year. Specifically, the recorded drought from 2012-2016 is not factored into this analysis.[48] Additionally, this model does not consider the mean groundwater level for drought compared to non-drought years and there is no accounting for if a drought extends multiple years– which would obviously increase the reliance on and use of groundwater. While these are potential limitations, they were omitted as the most basic trend in mean groundwater level was the focus of this analysis.

To test the normality of the residuals for each model a Jarque-Bera test was conducted. The results for each test are listed in *Table 6*.

Model:	ARIMA(2,1,0) first observation period original data	ARIMA(2,1,0) w/ drift for Heckman corrected data in first observation period	ARIMA(2,1,0) w/ drift for original data in second observation period	ARIMA(2,1,2) for Heckman corrected data in second observation period
X-squared value:	0.10036	1.1434	0.349139	0.62945
p-value	0.9511	0.5646	0.8431	0.73

Table 6: *this table depicts the results of the Jarque-Bera test conducted in R. The x-squared value represents the test statistic and the p-value indicates whether to reject the null hypothesis that the data is normally distributed.*

While the values of the test statistic (x-squared) exhibit some variability, the p-values for each statistic are quite high. This signals to fail to reject the null hypothesis of this test, where the null hypothesis is that the errors of our models are normally distributed. Furthermore, this allows for the assumption that our model is robust and its predictions are accurate as the residuals are relatively normally distributed.

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[48] Person, Mount, J., Escriva-Bou, A., & Sencan, G. (2021, October 5). *Droughts in California*. Public Policy Institute of California. Retrieved March 14, 2022.

These tests were conducted in order to better understand the accuracy and robustness of each model. Specifically, these tests were conducted to see if each specified model reproduced the data accurately across the entirety of the time horizon. In passing these tests it can be concluded that each model not only fits the data well but is a robust estimator for the mean groundwater depth in Ventura California.

VIII. Discussion

As discussed in the literature review, chronic groundwater overdraft has serious environmental and economic implications. Furthermore, chronic groundwater overdraft, if unmanaged, leads to irreversible depletion of groundwater in underground aquifers. Considering the results from the first observation period prior to the implementation of the SGMA, it can be said that the mean groundwater level in Ventura California is bound by a slight deepening and a significant deepening, as seen in *Figure 7*. Regardless of magnitude, this result has serious implications for all concerned parties. For farmers, due to the adjusting of crop portfolios to include more perennial crops with higher yearly water requirements, a deepening of mean groundwater level imposes a cost increase on production as more electricity is required to draw groundwater to the surface. These higher production costs are likely to be felt by consumers of the products produced by farmers in Ventura California. Lastly, the environmental effects of land subsidence and aquifer salinization pose serious externalities upon the communities in Ventura California as unregulated use of groundwater would lead to the exhausting of the resource.

In the second observation period, after the SGMA had been passed but not fully enacted, there is clearly a trend in the reduction of the mean groundwater depth. Because both ARIMA models for the second observation period exhibit a clear time trend, it can be concluded that the SGMA's partial implementation has reduced the mean groundwater depth, as seen in *Figure 8*. While this result can be partially attributed to variables not included in the model, specifically a yearly precipitation variable and a yearly aquifer recharge variable, the result is still a positive one. However, in order to better manage the vital resource, policymakers and local politicians should consider how the metrics which are used to determine the efficacy of the SGMA are reported. Specifically, frequency of soundings is a major area of improvement and if they had been implemented there would have been no need to do a Heckman correction to our data set due to missing values. Additionally, this lack of consistency in reporting is perhaps giving all concerned parties the illusion of a longer time horizon for reaching sustainability targets than is actually present. Specifically, while the mean groundwater depth appears to be decreasing in recent years, allowing until 2040 for the sustainability goals to be fully implemented and not increasing the consistency of reporting potentially create short term improvement with long term deterioration of the resource.

Lastly, in regards to the hypothesis of this analysis, the null hypothesis can be rejected. Specifically, it can be rejected because the mean groundwater depth clearly exhibits a change of trend after the enactment of the SGMA. Furthermore, both ARIMA models in the second observation period exhibit time trends in the negative direction– a decrease in mean depth. Therefore, it can be concluded that the SGMA is having a positive effect on the mean groundwater depth in Ventura California.

IX. Conclusion

Climate change poses a serious threat to the human experience as variability in yearly seasonality increases. Management of vital resources is of increasing concern as myopic behavior threatens their exhaustion. The continual drying of California imposes harsh realities regarding the availability of water for both municipal and economic maintenance and development. Ventura County California is a microcosm of the many prosperous regions in California. Specifically, the combination of a highly profitable agricultural business and an increasing human population impose ever greater demands for natural resources– namely water. However, as discussed, when these ever-increasing demands are not curtailed serious externalities arise. In regards to groundwater, land subsidence, aquifer salinization, and chronic overdraft threaten the long-term viability of this resource. Prior to the enactment of the Sustainable Groundwater Management Act, the stated analysis shows a problematic trend in the increasing mean groundwater depth. Furthermore, the null hypothesis assumed there was no significant change of trend after the enactment of the SGMA. However, as stated, there was a significant change in the trend of the mean groundwater depth. While this result is not to be taken as absolute, it at the very least gives hope to the idea that policy is an effective way to combat climate change.

While achieving sustainable use of vital resources is the ultimate goal, examining how we define sustainability is a worthwhile endeavor. In regards to Ventura County California, curtailing the exhaustion of groundwater via SGMA is a significant first step. However, to reach long-term sustainability, careful analysis of the metrics used to assess progress is crucial. Furthermore, implementing concepts like sustainable yield along with water markets could be a creative way to manage vital resources. In conclusion, the SGMA has clearly had a positive effect on the mean groundwater depth in Ventura California yet there is still much to do in order to achieve long-term sustainable practices.

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