Conceptual Framework to Estimate Economic Feasibility of Groundwater Banking on Agricultural Land

By

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To my wife Tara and my family for all their unconditional love and support.

To my committee members for mentoring and guiding me.

To friends and colleagues how helped me succeed with my goals.

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Abstract

Since 1865 California has practiced underground water storage through artificial recharge; however, in many parts of the state these efforts have been insufficient to meet its growing water demands, particularly for irrigated agriculture. During dry periods, vast agricultural areas depend upon groundwater for irrigation. In these areas, groundwater banking (GB) should be an essential strategy of their water management operations. GB is the practice of using surface water for percolation or injection into aquifers for later recovery. One variation of GB currently being studied in California is the use of agricultural lands for this practice (Ag-GB). Economic implications of Ag-GB need to be analyzed to inform water agencies and farmers interested in implementing this practice. This study proposes a conceptual model for determining the economic feasibility of Ag-GB at the irrigation district level. The Orland-Artois Water District (OAWD) in Glenn County is considered as the case study, and alfalfa as the test crop due to its tolerance to flooding and low use of pesticides and fertilizers which could leach into the aquifer. The proposed model consists of four components. The first component, the *agricultural water demand calculator*, calculates agricultural water demands based on historic land use, monthly reference evapotranspiration (ET_0), monthly average precipitation, and average crop coefficient (Kc) values for the region. The second component, the *aquifer mass balance model*, is a one-bucket mass balance model that quantifies inflows and outflows to the simplified aquifer. The third component, the *agronomic model*, estimates costs and benefits of Ag-GB in terms of energy savings from pumping and crop production. The fourth component, the *economic feasibility output*, evaluates costs and benefits are evaluated to determine economic feasibility. The period of analysis is from 1993 through 2013.

Two policies (A and B) for implementation of Ag-GB are proposed and tested. Policy A proposes that all growers in OAWD pay for the implementation of the Ag-GB program. Policy B proposes that alfalfa growers using their lands for Ag-GB (Ag-GB alfalfa growers) are exempted from paying for Ag-GB implementation and the rest of the growers (non Ag-GB growers) pay for it. The economic analysis suggests that Policy A brings more costs than benefits to the Ag-GB alfalfa growers and hence is rejected as feasible. Policy B seems to bring more benefits than costs to all growers in OAWD and therefore it has potential to be economically feasible under the assumptions and limitations of the model.

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1. Introduction

Since 1865 (DWR 1957), California has practiced underground water storage (referred in this document as groundwater banking, GB) through artificial recharge, but in many parts of the state, these efforts have been insufficient to meet its growing water demands, particularly for irrigated agriculture. During dry periods, vast agricultural areas depend upon groundwater for irrigation. In these regions, groundwater banking through underground storage should be an essential part of water management practice (Sandoval-Solis et al. 2010).

GB is an application of conjunctive use of at least two water sources, typically surface water and groundwater. *Conjunctive use of surface and ground waters* is defined (Sahuillo and Lluria 2002) as the "management of surface and groundwater resources in a coordinated operation to ensure that the total benefits of such a system exceed the sum of the benefits produced by managing of the two water sources separately." Benefits also include the prevention of aquifer overdraft and the improvement of water supply reliability. Conjunctive water management presents advantages and disadvantages that require consideration before implementation (Coe 1990). There are two main objectives for recharging aquifers:

1. Replenishment of groundwater is used to avoid environmental consequences such as saline intrusion in coastal areas, and land subsidence as in some areas in the Central Valley; and
2. Storage of water for future recovery; in wet years, excess surface water is diverted to spreading ponds where it percolates into the underlying aquifer; meanwhile in dry years, that stored water is recovered through wells to be delivered to the end user.

As a type of conjunctive use, groundwater banking implies either *active* or *passive* methods for recharging water into aquifers. The *Active* method diverts water from the alternative water source (e.g., surface water) and spreads it into ponds or injecting wells to recharge the aquifer. The *passive* method also referred to as *in-lieu*, uses surface water when available, during which time users may not extract water from the aquifer. This method considers groundwater replenishment by natural recharge and excess water from irrigation.

These approaches to aquifer recharge require purchasing of land and reengineering of said lands to accommodate the site for active aquifer recharge. An alternative to this is the use of agricultural lands with good infiltration rates and crops tolerant to prolonged flooding. Identifiable risks involved in this practice are potential negative economic impacts on farm production and groundwater quality issues.

This work presents a conceptual framework to analyze the potential economic effects of groundwater banking on agricultural land (Ag-GB). The proposed framework looks at the tradeoffs between the potential benefits and costs derived from this practice at the irrigation district level.

A general background of groundwater banking in California is presented in Chapter 2. Some of the most remarkable examples of this practice are presented in this chapter. Chapter 3 gives a brief introduction to the case study: The Orland Artois Water District in Glenn County, California. Chapter 4 provides a detailed explanation of the methods employed in this study. Chapter 5 presents results from all components of the model. Chapter 6 offers a discussion about the interpretation of results. In Chapter 7 conclusions are given from the results incorporating the ideas discussed in Chapter 6. Finally, Chapter 8 summarizes the assumptions and limitations of the model. All supportive data not shown in Chapter 4 is presented in the Appendices section at the end of the document.

Research Objectives

The main goal of this study is the development of a conceptual framework for the quantification of the economic feasibility of Ag-GB.

Specific research objectives are:

1. Development of an agricultural water demand calculator based on land use, crop, precipitation, and water supply data. Knowing water demands and how much water was supplied allows for estimation of how much water was extracted from the aquifer for irrigation.
2. Development of a one-bucket aquifer conceptual model to aid the economic analysis.
3. Estimation of how much water can be used for Ag-GB during the period of analysis.
4. Development of an agronomic model to estimate the impacts of Ag-GB on alfalfa production costs.
5. Calculation of net benefits derived from Ag-GB to determine overall economic feasibility.

2. Background

2.1. Types of Groundwater Banking (GB) in California

GB programs in California are operationally diverse ranging from importing surface water to utilization of recycled or reclaimed water for aquifer recharge. Not only have the sources of water varied among GB projects in the state, the recovery and use of such waters varies as well. Sources and uses of banked water considered in this review are presented in Figure 1. The rest of this chapter looks at existing and proposed GB programs in California, their limitations, and their level of success.

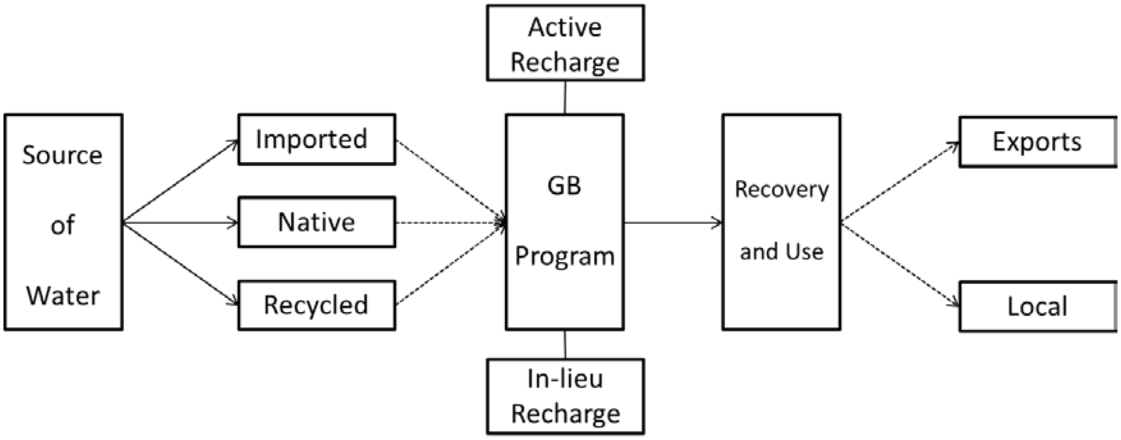


Figure 1: General distribution of water sources and its uses after recovery in Groundwater Banking projects. Dashed lines indicate that sources and uses can be unique or a combination for different GB programs.

2.1.1. Site-Specific and Infrastructure-Dedicated Projects

While various methods exist for aquifer recharge and recovery (Dillon 2005; Tuinhof and Heederick 2003), the system of integrating an infiltration pond (also commonly referred as *infiltration basin*) with an extraction well is one widely practiced method of GB in California

(Figure 2). This approach to GB requires the operator of the system (irrigation or water district) to pay for the initial implementation, and subsequent operation and maintenance. Usually, this is accomplished by creating partnerships with other agencies to qualify for financing programs or grants to facilitate implementation. The following subsections review the institutional, social and legal aspects of GB projects for each specific program categorized on Figure 1.

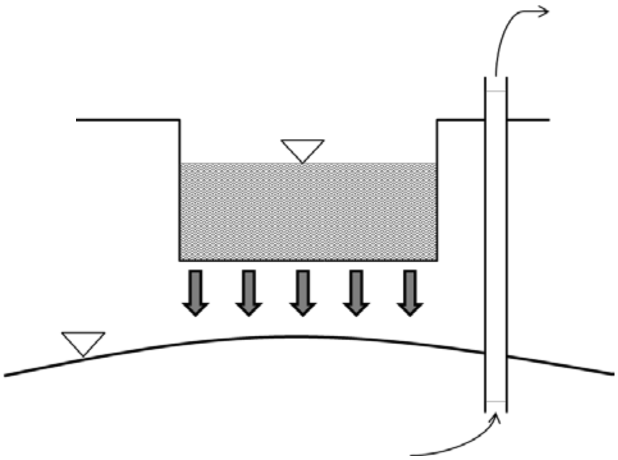


Figure 2: Conceptual configuration of an infiltration pond with a recovery well.

2.1.1.1. *Recharge of Imported or Native Water and Recovery for Local Use and Exports*

Many Central Valley banking projects use *imported* and/or *native* water for their operation. *Native* water refers to naturally occurring streams within a watershed. *Imported* water is water transferred or purchased from another watershed. Imported, rather than native water is usually preferable for banking due to conflicts with existing water right holders who may have a higher priority to the use of native surface water (e.g., riparian rights). Programs, such as the Bakersfield emergency banking program and the Merced Irrigation District program are examples of water banking operations using native water sources. Native, source-driven programs have been successful at the local scale but do not offer insight about transferable institutional features (Thomas 2001), which are essential for water operations in California. The following three projects are used for both local benefits and water exports; however, local use has priority over water exports. For this kind of projects, the definition of *local* is somewhat flexible and extends to all parties participating in these programs.

Kern Water Bank (KWB)

The Kern Water Bank (KWB) began construction in 1988 after water shortages from the State Water Project (SWP) took place in Kern County in the early 1980's. The KWB stores water in the Kern River basin from imported and local sources. The main source of water for the KWB is the California Aqueduct and some flood releases from the Kern River and the Friant-Kern Canal. (Kern Water Bank, "*Recharge and Recovery*" n.d.). The water bank is at the junction of the California Aqueduct and the Kern River, which converges upstream with the Friant-Kern Canal. The strategic location benefits from close proximity to water sources. In addition, the geology and subsurface hydrology underlying the bank allow for high percolation rates (up to 6 in/day), and more than sufficient aquifer storage capacity (about 1,000,000 AF) with an estimated annual recharge capacity of 450,000 AF (Thomas 2001).

The operational configuration of the water bank is simple in concept: participants pay the KWB to store water in the aquifer which then serves as water supply source when surface supplies fall short. In this way the cost for the recharged water is covered by the participants. Participants are other water or irrigation districts within Kern County, who invest into water reliability by delivering surface water to the KWB for later recovery. Of course the underlying aquifer is not exclusive to the water bank and its participants; non-participant water users in the region have access to the aquifer as well. To address this issue the KWB entered into negotiations with these agencies to prevent significant mutual adverse impacts (Thomas 2001). These agreements were consistent with the basic premise of the project: "*all operations from the KWB will not impair the rights of those who use or could use the native groundwater*" (Kletzing 1987, p. 1227).

To meet operational requirements, KWB facilities include about 7,000 acres of recharge ponds, 85 recovery wells, 36 miles of pipelines, and a 6-mile long canal (Kern Water Bank, "*Infrastructure*" n.d.): its construction costs were covered through state and private loans. KWB also has the capacity to sell water to outside agencies through its participants. A participant can choose to sell (or transfer) its water to a third party but only after notifying the other participants who might be interested in purchasing such water. The program is flexible as it allows for water exports while giving priority to project participants.

KWB has been operating successfully since its creation, supplying water for agricultural and municipal uses. Despite all the challenges and initial opposition from local groundwater users, the project moved forward by means of stakeholder and public participation, alignment with the applicable law, compliance with environmental requirements, and an appropriate financial model. The project also created intermittent wetlands and enhancement of the upland habitat to provide critical nesting and foraging habitat for more than 40 species of water fowl and other species (Kern Water Bank, "*A Wildlife Habitat*" n.d.). KWB serves as the link between the project participants and SWP contracts; it represents the local interests of project participants at the state level, and assures operations continuity by encouraging as many agencies as possible to participate in the program as it has the storage and conveyance capacities to deliver recovered water to vast areas.

Semitropic Groundwater Banking Program (Semitropic)

Semitropic Water Storage District (Semitropic) is primarily an agricultural district in Kern County. It operates in a very similar fashion to the KWB. It uses excess water during wet years delivered by banking partners to recharge the underlying aquifer for later recovery. In contrast to the KWB, Semitropic recharges the aquifer mostly through *in-lieu* operation, meaning that during wet years the surplus surface water is delivered to users instead of supplying water from the aquifer. *In-lieu* recharge is also referred to as passive or indirect recharge due to the instead-of element. Because surface water is used instead of groundwater, water in the aquifer is saved for dry years when surface water sources could be reduced. This implies that actual recharge of the aquifer depends on natural processes and excess irrigation from agriculture; the former varies significantly with climate and land use patterns (Healy 2010) while the latter is affected by the efficiency of irrigation systems. An important challenge faced by in-lieu operations is public acceptance; whereas *active* or *direct* recharge allows for groundwater pumping (limits and regulations vary regionally), *passive* recharge programs often require a collective understanding of why stopping pumpage is important in wet years for banking purposes. To a lesser extent Semitropic also stores water through infiltration ponds (Figure 2). These facilities might expand in the future as part of the district's future plans (Semitropic, "*Future Plans*" n.d.).

Semitropic is a landowner-voting district serving primarily agriculture. Because of this, district members share common interests, which facilitated approval of banking operations (97% favorable in 1991 election) (Thomas 2001). In addition to the convenient institutional configuration, the financial model used by Semitropic has been important in making the district as one of the largest groundwater banking programs in the world (Semitropic, "*Groundwater Banking*" n.d.). The program is fully compensated for capital and operational costs by its banking partners and revenues from banking operations have allowed for cost reductions in water charges and pumping due to higher groundwater levels. Until 2010 most water recovery operations in Semitropic were for the California Department of Water Resources (DWR) (Semitropic, "*Monitoring Committee*" 2010). Full recovery and delivery capabilities are still to be tested in the event of many banking partners claiming banked water simultaneously (Thomas 2001).

Arvin-Edison Water Storage District (AEWSD)

Historically, farmers in Kern County use groundwater to irrigate their crops since no substantial streams or rivers are locally available. This dependence on groundwater led to an unsustainable practice and overdraft of the aquifer which triggered the creation of conjunctive use programs in the district.

Operationally, AEWSD works in the same way as the two previous examples and most water banks in the Central Valley. One feature that has helped banking programs in the region is the district's active participation in water exchanges with other agencies such as the Westside Mutual Water Company and Rosedale-Rio Bravo Water Storage District (USBR 2011). Subject to similar challenges, AEWSD has managed to keep their operations running with seeming success. Thomas (2001) lists the following reasons for this:

a) The geology of the region is excellent for percolation and the basin is relatively isolated from other basins which minimize interaction and negative impacts from other districts.
b) Almost half of the banked water remains in the aquifer (i.e., is not recovered) to help reduce groundwater overdraft, and even during times of extreme pumping due to droughts, impacts to the aquifer have been sustainable.

c) The program has resulted in a reduction of annual overdraft and a more reliable water supply for users in the district.

2.1.1.2. *Recharge of Recycled/Reclaimed Wastewater and Recovery for Local Use*

Use of recycled/reclaimed water from municipal use for aquifer recharge has clear environmental benefits and increased local water supply reliability. However, there are potential adverse effects on groundwater quality. Reclaimed wastewater may be suitable for aquifer recharge (depending on case specifics) in infiltration ponds but less so for injection wells (Fetter and Holzmacher 1974). Even small amounts of suspended solids in the water could rapidly clog wells. Other technical and health related challenges of this practice with emphasis in California are found in Asano and Cotruvo (2004).

A widely successful banking program using reclaimed wastewater is the Dan Region Project in Israel, which takes water mostly from Tel-Aviv metropolitan area and serves nearly 1.3 million people (Kanarek and Michali 1996, Icekson-Tal et al. 2003). Another successful GB program using reclaimed wastewater is in El Paso, Texas where over 20 years, more than 60 thousand AF of reclaimed wastewater has been recharged into the local aquifer for wastewater reuse to conserve native groundwater and restore groundwater through artificial recharge (Sheng 2005).

Usually groundwater banks using recycled wastewater need some sort of pre- and post-treatment before aquifer recharge and after recovery (Figure 3). Water treatments vary depending on the end use of the recovered water. For instance, if the recovered water is used for drinking purposes pre- and post-treatments would be appropriate. If the end use of that water is crop irrigation then less treatment is required. Los Angeles County and Orange County aquifer recharge projects are reviewed below. Some other important groundwater recharge programs using reclaimed wastewater in the United States can be found online (Big Bear Water Solutions, "*Nationwide Groundwater Recharge Projects*" n.d.).

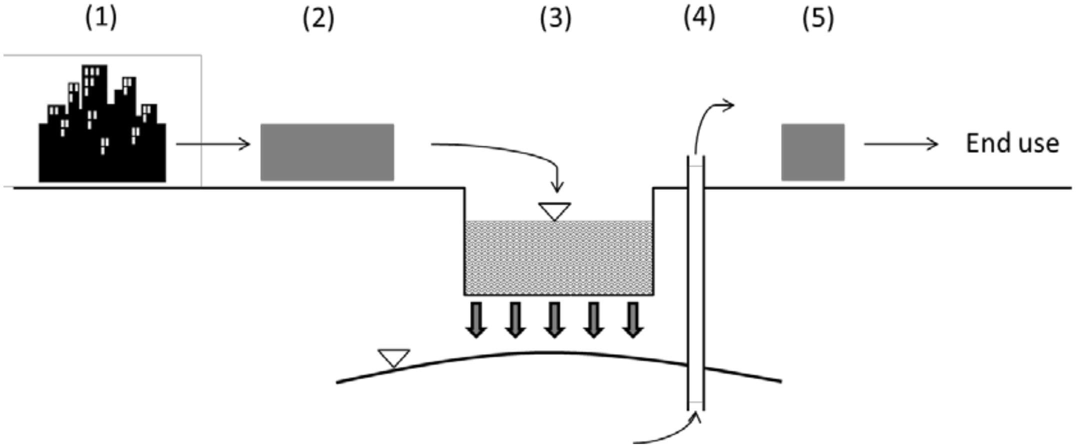


Figure 3: General configuration of a water bank using reclaimed wastewater: (1) wastewater is captured from municipal and/or industrial sources, (2) wastewater is sent to pretreatment plant, (3) pretreated water spread on percolation ponds, (4) water is extracted from aquifer when needed, (5) recovered water goes through post-treatment process; (6) treated water is delivered for end use.

Los Angeles County

Los Angeles County Public Works (LAPW) actively recharges the underlying aquifer with recycled water at 27 spreading facilities. LAPW also imports surface water and uses local runoff for artificial recharge. San Gabriel Canyon (SGC) and the Montebello Forebay (MF) area are the two major spreading facilities in the county. Combined, these projects recharge about 150,000 AF of local, imported, and reclaimed water annually (County of Los Angeles, "*The San Gabriel River and Montebello Forebay*" 1999).

In California, recycled water recharge projects are regulated by the California Department of Public Health (CDPH) and the Regional Water Quality Control Board (RWQCB) (Johnson 2009). These two agencies have determined specific maximum thresholds for the use of recycled water in the MF recharge facilities (CDPH 2008). The amount of recycled water used a) cannot exceed 150,000 AF total over three consecutive years; b) 60,000 AF in any given year; c) 35% of the total water recharged in the MF over three consecutive years; or d) 50% of the total water recharged in the MF in one year. Similar limitations exist for other recharge facilities in Los Angeles County (Johnson 2009). Because of these and other limitations (rainfall runoff and maintenance of percolation ponds); the amount of recycled water used for aquifer recharge varies significantly from year to year. Also, there is an increasing trend of direct use of recycled water (Figure 4) for landscape, agricultural irrigation, environmental projects, and industrial purposes.

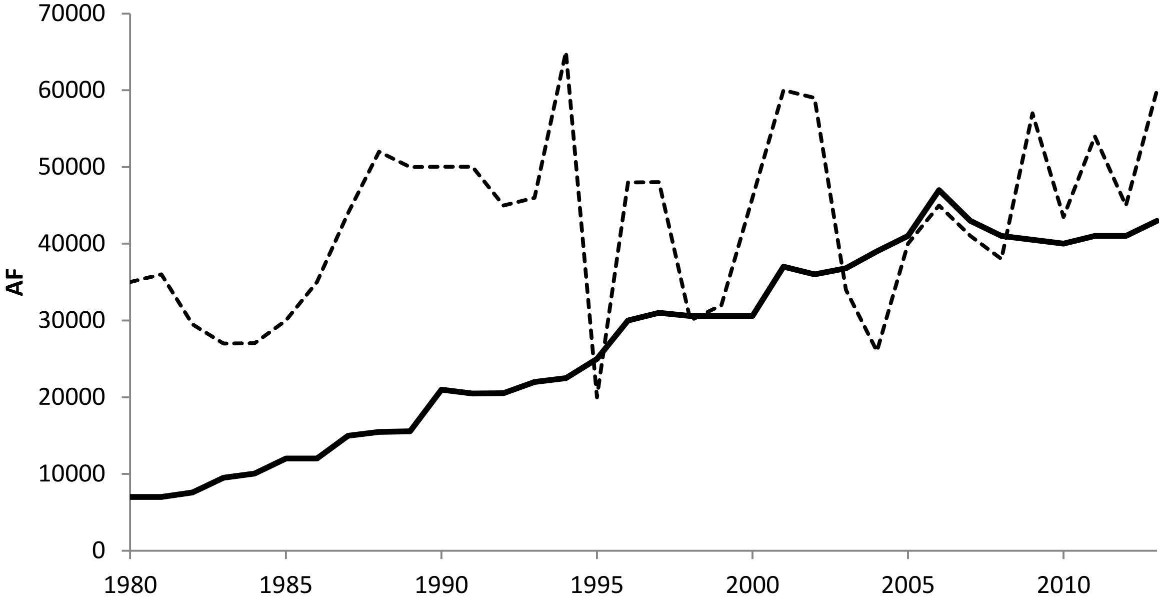


Figure 4: Direct non-potable use vs. recycled groundwater recharge in Los Angeles County. Adapted from Sanitation District of Los Angeles County, Annual Report 2012-2013.

Even with increasing demand for direct use of recycled water, aquifer recharge programs have been successful because they significantly increase local water supply reliability when imported sources are not available. In places like Los Angeles County where rainfall is very limited (~10 in/year), use of recycled water to increase supply reliability and minimize dependency on imported water have been key elements of an almost self-sustained local water supply system.

Orange County Water District (OCWD)

OCWD has been practicing active recharge by injecting recycled wastewater into its heavily used aquifer since 1976. In 2008 the Groundwater Replenishment System (GRS) was created. About 107 AF per day of recycled water are injected into the aquifer to prevent seawater intrusion. Another 107 AF are pumped to OCWD's percolation ponds where GRS water percolates through sand and gravel to the deep aquifer and is eventually pumped from the aquifer for drinking water supply (GRS, "*Where does GRS water go?*" 2014). Recovered groundwater is pumped from over 400 wells operated by local agencies, cities and groundwater users (GRS, "*Groundwater Recharge*" 2014). As a whole, GRS produces 275 AF of treated water per day which is enough to meet water needs of 600,000 people in Orange County. The project is also energy efficient as it uses less than half the energy required to pump imported water to the system (GRS, "*Facts and Figures*" 2014).

The GRS cost $481 million to build, which was paid through grants and bonds from federal, state, and local agencies. Annual operation and maintenance costs are approximately $34 million, of which $7.5 million (for 12 years) are subsidized by the Metropolitan Water District of Southern California. The rest is paid with revenues from water deliveries (GRS, "*Project and Operating Costs*" 2014). A key component of GRS success is close collaboration between

OCWD and the Orange County Sanitation District (OCSD). The project has succeeded in demonstrating effective partnership between the many public agencies in the area.

2.1.2. GB on Agricultural Land

In the Central Valley projects like the KWB, Semitropic and AEWSD have recovered nearly 2,000,000 AF of banked water to their costumers between 2007 and 2009 (Maven's Notebook, "*Water Storage, part 2*" 2013). However, implementation of these types of projects involves great capital and operating costs.

Recently, scientists are exploring capturing flood releases onto agricultural fields for GB purposes. Important costs could be avoided if land does not have to be purchased and engineered for water banking. Of course, limitations and risks come with using agricultural land for water banking. For instance; for GB, the agricultural fields require: a) soils with good infiltration rates, b) existing water conveyance infrastructure (e.g., channels or ditches) in close proximity to the field; and c) crops tolerant to flooding during dormancy (or fallowed). These physical requirements would be just the initial criteria for identifying candidate sites as major regulatory and institutional changes would have to be implemented and also other site-specific adaptations would be needed such as field preparation and placement of new equipment to flood the land (if needed). Furthermore, participation of farmers and landowners would require region-specific studies and creation of incentives to involve them in such programs. Another potential side effect of groundwater banks on agricultural land is its impact on water quality from leaching salts and nitrate.

For example, there is a pilot project conducted at Terranova Ranch in southern Central Valley. Though full implementation of this project is still in progress, it serves as a foundation and template for other agencies interested in implementing similar programs. The highlights of this project are presented here; a complete technical report is found in Bachand et al. (2014).

Terranova Ranch (TR) is located in western Fresno County adjacent to the James Bypass which receives flood releases from Pine Flat Reservoir between December and July. Different types of crops are grown in TR including vineyard, orchard, field (alfalfa) and row crops. The property is located on sandy loams and loamy sands. Experiments on infiltration rates, crop responses to flooding, and water quality were conducted on 1,000 acres. The main objective of the project is to utilize this land for both agriculture and flood control. Key findings from this experiment are:

- Small adaptations were required to receive flows: berms were put to allow fields for shallow inundation and pumps were rented to move the water from the canal onto the fields. Borders or berms are likely to be required on fields using sprinklers or drip irrigation.
- Infiltration rates diminished from above 5 in/day to 2-2.5 in/day over the 20-day flooding period after which infiltration rates remained at 2-2.5 in/day. This gives valuable insights in terms of how much time and acreage is needed to infiltrate water.
- Vineyards yielded the highest performance in terms of flood tolerance. California’s acreage of grapes in 2013 totaled 878,000 acres (USDA 2013).
- Costs of pumping were offset when a portion of the flood flow was used for *in lieu* recharge and groundwater levels were raised by the water directly recharged. At TR it was calculated that using 25% of the flood flow for *in lieu* recharge would generate enough savings in groundwater costs to support an active flood flow capture program.

- Salinity in groundwater increased and is expected to continue increasing in the short term. However, continuous flood flow capture in the future will improve the quality of groundwater over time.
- Results from this pilot experiment open the door for more research and creates a template for implementation of similar programs in California, particularly in areas like the San Joaquin Valley where irrigated agriculture has overdrafted the underlying aquifers.

Results from this pilot experiment open the door for more research and creates a template for implementation of similar programs in California, particularly in areas like the San Joaquin Valley where irrigated agriculture has overdrafted the underlying aquifers.

2.2. Approaches to Modeling Conjunctive-Use Systems

Different research groups have developed computer models for simulation and optimization for proper operation and planning of GB projects. Regardless of the type of conjunctive-use system, there will always be a need for finding ways to adapt the system to changes in climate, water availability, and increasing water demands.

2.2.1. Hydro-Economic Models

Hydro-economic models represent water resources systems while looking at economic values of water demands and costs. These models could be used for simulation or optimization depending on the study objective. Table 1summarizes applications and limitations of these models based on Harou et al. (2009).

Table 1: Applications and limitations of hydro-economic models. Adapted from Harou et al. (2009).

Applications	**Limitations and Challenges**
• Water allocation and markets • Climate change impact analysis • Infrastructure expansion and operations planning • Institutional , social, and economic policies • Basis for regulation and law.	• Need for physical, economic, and regulatory process data simplification, • Linearization of non-linear functions or physical process equations is often employed • Shadow values, range-of-basis, and sensitivity analysis must be evaluated reactively “one-at-a-time” and ignore complex interactions and simultaneous changes among constraint limits, system configuration, and prices • Hydro-economic models can be poor tools to simulate actual water markets since individual agent behavior and transaction costs cannot be represented easily • Mathematical representation of social, political and environmental objectives is often complicated.

2.2.1.1. *Optimization Models*

Determination of the optimal use of water resources and its consequent management is necessary for the stability of social and economic systems. As Buras (1963) noted: “*optimality depends upon the objective: Optimal for whom? For what purpose? Under what conditions?*” These questions not only imply that optimality will differ for different systems under different circumstances, it also implies that what is now considered the optimum way to operate a system will have to change to adapt to changes in social, economic and hydrologic contexts. The approaches to optimization modeling presented here each have limitations to consider and to compare before deciding what approach to apply. Whether to use linear programming, non-linear programming, dynamic programming, genetic algorithms, or even a combination of these, will depend on the particular characteristics of a system.

Economic values are an important part of the optimization process. Some researchers have addressed the optimization process through the application of economy-focused models for simulating groundwater dynamics (Harou and Lund 2008; Pulido-Velazquez et al. 2004). By using an economic–objective-function optimization model, aquifer overdraft can be a variable in the analysis: as part of the objective function (minimization), as a constraint, or as a penalty function. An example of this model is the California Value Integrated Network (Jenkins et al. 2001; Draper et al. 2003). The CALVIN economic-engineering optimization model integrates applicable water-management options to seek economic optimization either in the presence or absence of groundwater overdraft (Harou and Lund 2008) based on historical data. Even though this deterministic approach provides valuable insights about water allocation based on different levels of infrastructure, land use, and population, it is limited in its ability to represent groundwater flow. CALVIN neither simulates groundwater flow nor piezometric head. It only considers fixed groundwater storage volumes in each sub-basin. These limitations may lead to unrealistic representations of the interactions between surface and ground waters in the system, which will introduce inaccuracies in the economic calculations.

To optimize surface/groundwater systems based upon flow dynamics, researchers often turn to integrated hydro-economic models. Pulido-Velazquez et al. (2006) provide a short but concise discussion about advantages and disadvantages of the various groundwater and stream-aquifer interaction simulation models. As in non-integrated hydro-economic models, integrated models can be used to assess groundwater overdraft by: modification of the objective function, modification of the constraints, or by adding penalty functions.

Azaiez and Hariga (2001) approached aquifer overdraft mitigation by assigning high penalties to pumping groundwater while seeking to determine a policy that maximizes benefits. In their study, a hypothetical multi-reservoir system is operated conjunctively with groundwater supplies, and the applied penalty functions force the model to reduce the amount of groundwater used in a given time. This would apply to a location having both surface and groundwater sources, and whose aquifers were suffering from severe overdraft, and where drawing of groundwater would take place only during severe drought.

Another important factor to look at when conducting hydro-economic optimization of a surface/groundwater system is the determination of the shadow values (i.e., monetary value assigned to non-marketed goods or difficult to calculate costs) of banking water in the aquifer for future use. Pulido-Velazquez et al. (2006), Azaiez and Hariga (2001), and Harou and Lund (2008) explore the importance of shadow values in estimating the opportunity cost (i.e., the optimal, net economic impact of a decision) of satisfying reservoir storage, or piezometric head constraints.

2.2.1.2. *Simulation Models*

Optimization algorithms are based on simulation models that represent the process of interest. Nevertheless, simulation models do not represent reality perfectly since many assumptions and simplifications are made before a computer can make the calculations. Simulation and optimization look at two different questions of water resources management: *what if? And what is best?* (Harou et al. 2009). Simulation models allow for analysis of different alternatives.

These alternatives can be related to system operation, hydrologic conditions, and policy of water allocation. George et al. (2011) proposed an integrated modeling framework for the analysis of alternative water allocation scenarios. In this study, surface and groundwater models were coupled with water allocation models to estimate the economic value of the water allocated to different users. Finally a cost-benefit analysis was conducted to determine the economic consequences of the different scenarios over time. Similarly, Booker (1995) developed a hydro-economic model for simulation of potential hydrologic and economic impacts of drought under different policy scenarios in the Colorado River Basin. Different from the previous example, this model focuses on surface water. However, estimation of drought impacts can be applied to conjunctive-use systems in California.

The two examples mentioned above are integrated by three main components: a) a hydrologic model (surface and groundwater) to estimate water availability and demands; b) a water allocation model that represents water distribution to all demands; and c) an economic assessment to calculate costs and benefits of the system. More recently, some have focused their research on economic assessment of conjunctive-use systems. Gao et al. (2014) applied a cost-benefit analysis to a case study in Australia to estimate savings that could be achieved through groundwater banking. Escalante et al. (2014) looked at the economics of managed aquifer recharge (MAR) in Spain using GIS data to identify potential areas for MAR. Arshad et al. (2014) conducted a cost benefit analysis to support decisions about whether to store water in surface reservoirs or in aquifers considering the inherent uncertainty that comes with the latter. Lund et al. (2014) conducted an integrated, multi-benefit analysis comparing surface and underground storage in California. Three general conclusions can be extracted from these studies: 1) conjunctive-use programs offer the potential to efficiently increase water supply reliability; 2) usually aquifers in a region have more storage capacity than surface reservoirs; and 3) depending on the situation, conjunctive-use programs are financially superior to surface storage. In California these findings become more evident as most cost-effective surface reservoir sites have been developed and existing GB programs have proved their capability to aid water reliability during recent droughts.

2.3. Looking Into the Future

A forward-looking perspective of the realistic future of GB projects is discussed next. The potential impact of the new statewide groundwater legislation on existing and future projects is analyzed as well as the opportunity it brings for GB projects on agricultural land (Ag-GB). A brief overview of the interplay between groundwater banking and water markets is also presented.

Potential effects of climate change on aquifer recharge and GB programs are beyond the scope of this work. Nonetheless, climate change is a growing concern among water resources managers and should be considered in GB planning. Effects of climate change on groundwater have been studied globally (Dragoni 2008; Döll 2009; Green et al. 2011), in Europe (Bouraoui et al. 1999; Eckhardt and Ulbrich 2003; Brouyère et al. 2004; van Roosmalen et al. 2007), in Asia (Lee and Chung 2007; Shah 2009), and in North America (Vaccaro 1992; Rosenberg et al. 1999; Karl et al. 1996; Kirshen 2002; Croley and Luukkonen 2003; Loáiciga 2003; Jyrkama and Sykes 2007), among others.

2.3.1. Water Markets

During California's previous and ongoing droughts water transfers have played an important role at keeping the system functioning as it adds flexibility to water supply operations. For example, in southern California conjunctive use operations (e.g., GB) coupled with water markets can (Pulido-Velazquez et al. 2004): 1) reduce scarcity and scarcity costs drastically where most promising transfers come from agricultural regions within the Colorado River basin to supply urban demands; 2) add storage and recharge capacities to take economical advantage or water transfers; and 3) reduce reliance on imported sources.

Hanak (2014) has recently assessed the important role of groundwater banks and water markets in California and stressed the need for several institutional and legal rules necessary to keep GB programs working along with water markets (Maven's Notebook 2014): 1) People should not be able to sell somebody else's water, including water for the environment; 2) special management protocols and rules to carefully monitor who is putting water in and how much and who is extracting water; and 3) transfers that involve large amounts of fallowing should minimize negative economic impacts to people directly affected by the transaction.

Despite the flexibility water markets add to the water supply system, some areas in California have been more active than others (Figure 5) and others have restrictions on water banking and exports (Figure 6).

Most counties in California participate in the water market as shown in Figure 5. Some counties have transferred water within their regions and others even across regions. All these water transfers are possible due to the existing complex conveyance infrastructure provided by the State Water Project (SWP), the Central Valley Project (CVP), and many local conveyance and storage facilities.

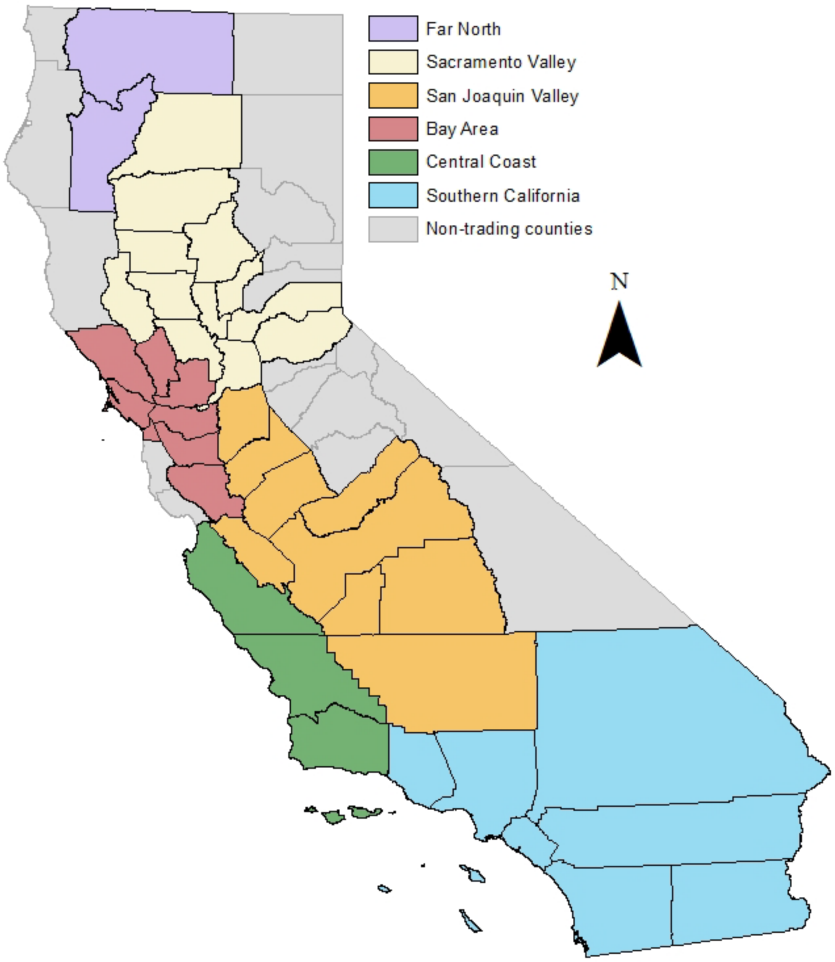


Figure 5: Counties in the water market. Adapted from PPIC as presented online on Maven's Notebook (November, 2014).

In contrast, Figure 6 illustrates which areas are governed by local ordinances restricting water transfers. In this map, all counties in green, blue, and pink are subject to groundwater export restriction. The distinction comes with additional constraints such as groundwater banking with parties outside the county (pink) or applying for permits to export groundwater outside the county (blue). The tight relationship between water markets and GB programs in California seems to provide a promising future for the latter as long as local governments (e.g., counties) keep their regulations aligned with the water markets.

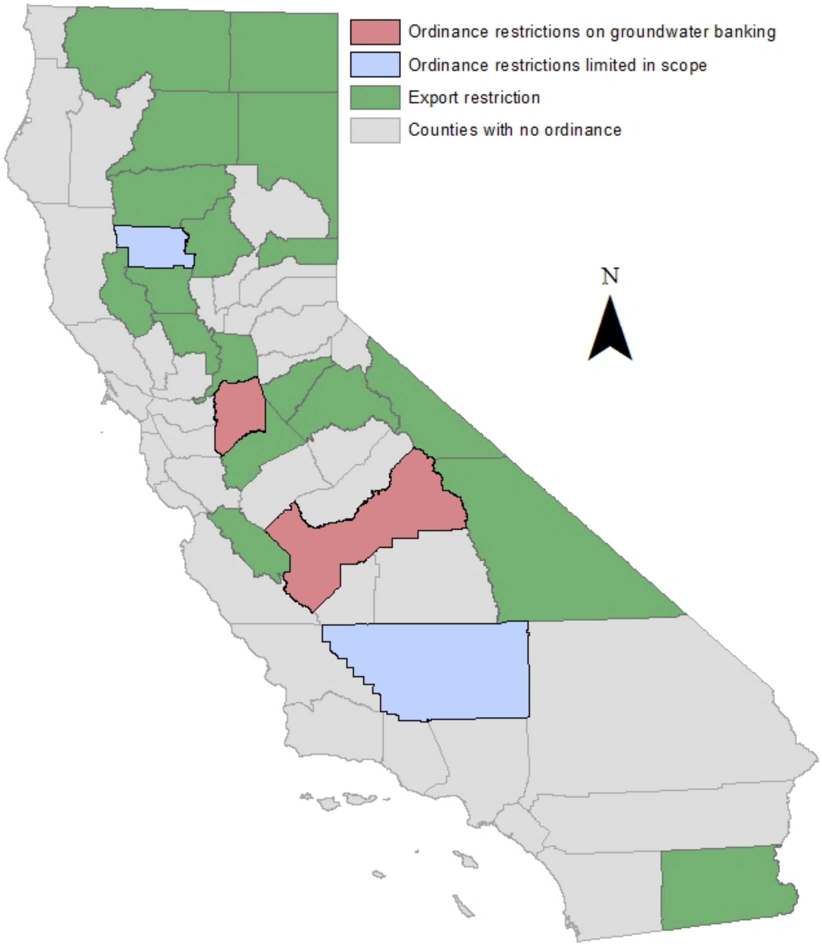


Figure 6: Counties with water exports and banking restrictions. Adapted from PPIC as presented online on Maven's Notebook (November, 2014).

2.3.2. Role of the Statewide Groundwater Regulation

Until recently, California was the only state in the nation without a mandatory statewide groundwater regulation system (Office of Senate Floor Analyses 2014). In 1957, DWR stressed the need to integrate groundwater management into California's water portfolio in Bulletin 3 (DWR 1957). Despite the lack of statewide regulation, some groundwater basins in the state have been sustainably managed by local agencies or through adjudications but many remain unmanaged.

Krieger and Banks (1962) point out four basic principles of successful groundwater regulation: 1) knowledge of the geology and hydrology of the basin, including periodic determination of its safe yield, 2) a legal determination of the quantity of water to which each pumper is entitled (basin adjudication), 3) continuing judicial control over the extractions of water by each person from the basin; and 4) a source of supplemental water. With regard to the first principle, current technology and knowledge of groundwater hydrology have led to more representative computer models integrating geology, and surface and subsurface hydrology. The second principle has been historically controlled by the courts and no permit is required by the State Water Resources Control Board (SWRCB). The third principle is the one that has been lacking in California since the state was formed.

Until 2002, bill AB-3030 (1992) was the only law in the California Water Code related to groundwater management prior to the creation and authorization of bill SB-1938, which required local water agencies that elected to develop a groundwater management plan, to prepare a public written statement describing such plan among other requirements (Water Code §10753.7). AB-3030 encourages and gives authorization to local water agencies to adopt groundwater management plans to control seawater intrusion, mitigation of overdraft, aquifer replenishment, and any other appropriate action to ensure the reliability of groundwater resources. However, agencies are not required to adopt such plans under this statute (Water Code §10750). In 2002, California took another step into better regional groundwater management by passing bill SB-1938 which required local agencies to incorporate groundwater management plans on their own or regionally in coordination with other agencies, in order to obtain certain grants from DWR.

Though this measure is slightly more assertive, agencies not looking for state funding stayed away from this regulation. More recently, in 2009, the state legislature passed Senate (SB) Bill X7-6 providing for monitoring and reporting of groundwater elevations. This was an important step forward to better groundwater management; however, SB X7-6 looked at just part of the information gap confronting California water management (Hanak 2011).

During the 2013-2014 regular session of the California Legislature, two bills -SB-1168, and AB-1739 were passed to create the first statewide groundwater regulation. These bills amend a number of sections to the Water Code as well as the Government Code. Pertaining to groundwater, amended sections include, to mention a few, sections 10927 and 10933 on groundwater level monitoring and reporting; and section 12924 about the role of DWR in conducting, in conjunction with other public agencies, investigations on the state's groundwater basins. This new groundwater regulation brings opportunities for groundwater banking projects as part of a groundwater basin management programs in the state. Both bills are analyzed and summarized in this chapter.

SB-1168

This bill enacts the Sustainable Groundwater Management Act and states that all groundwater basins and subbasins shall be managed sustainably by local entities pursuant to a sustainable groundwater management plan (SGMP).

Earlier legislation in California authorizes local agencies to adopt and implement groundwater management plans, and "encourages" these agencies to adopt such plans by making them a requirement to obtain certain state funding. SB-1168 builds on these previous regulations by allowing the state agency (in this case the State Water Resources Control Board) to take action to create and implement a SGMP when local agencies cannot or will not do so themselves (Office of Senate Floor Analyses 2014). The intent of the legislature (as stated in Part 2.74, Chapter 1, Section 10720.1 (h)) is: "*to manage groundwater basins through local government to the greatest extent possible, while minimizing state intervention to only when necessary to ensure that local agencies manage groundwater in a sustainable manner*." This new power granted to the state will guarantee the eventual inclusion of water agencies financially and/or operationally limited (or other reasons) to implement groundwater management plans.

Particularly beneficial to groundwater banking projects are provisions to increase groundwater storage and removal of impediments to recharge (Water Code §10720.1 (h)), and the appropriation and importation of surface and groundwater by groundwater sustainability agencies (GSAs) to conserve and store this water for the purposes of the new legislation, by means of spreading, storing, retaining, or percolating into the soil of the waters for subsequent use (Water Code §10726.2 (b)). Also, GSAs would be allowed to impose limitations in groundwater extractions (Water Code §10726.4 (a)) which will be important in protecting the banked waters and recovering.

Another promising statute within SB-1168 is section 10727.2 (a) which requires a SGMP to include a map identifying existing and potential recharge areas for the basin. This will allow identification of potential banking sites for those agencies interested in implementing groundwater baking projects as part of their groundwater sustainability plans.

AB-1739

In this bill the Government Code and Water Code are amended to complement statutes provided by SB-1168. Amendments to the Government Code describe the requirements needed for any

GSA to adopt a SGMP as well as general obligations and communication with affected parties (e.g., cities, counties, irrigation districts, etc.). This portion of the bill deals with institutional challenges that may arise upon the development and implementation of SGMP plans.

AB-1739 requires SGMPs in all groundwater basins determined by the DWR to be at medium to high risk of significant economic, social and environmental impacts due to excessive groundwater extractions (CASGEM 2013) (Figure 7). Specifically, this bill requires that by January 1, 2020, in each groundwater basin identified by DWR as high or medium priority, the overlying GSA shall adopt a SGMP with a time span of 50 years and update it every five years.

AB-1739 empowers a GSA among other things to: a) incorporate areas overlying the basin that are not covered by another SMGP; b) raise funds for sustainable groundwater management; c) regulate the pumping of groundwater; and d) establish, assume, or cooperatively manage well permitting programs. These measures were locally implemented by some water agencies and counties prior to the new legislation. However, these mechanisms were subject to a voting process involving all stakeholders.

Figure 7 shows that in the Central Valley about two thirds of all groundwater basins are identified by DWR as high risk and the rest as medium risk. The San Joaquin Valley includes the most high-risk groundwater sub-basins within the Central Valley. The implementation of the new legislation provides the mechanisms needed to further facilitate development of conjunctive use programs in California.

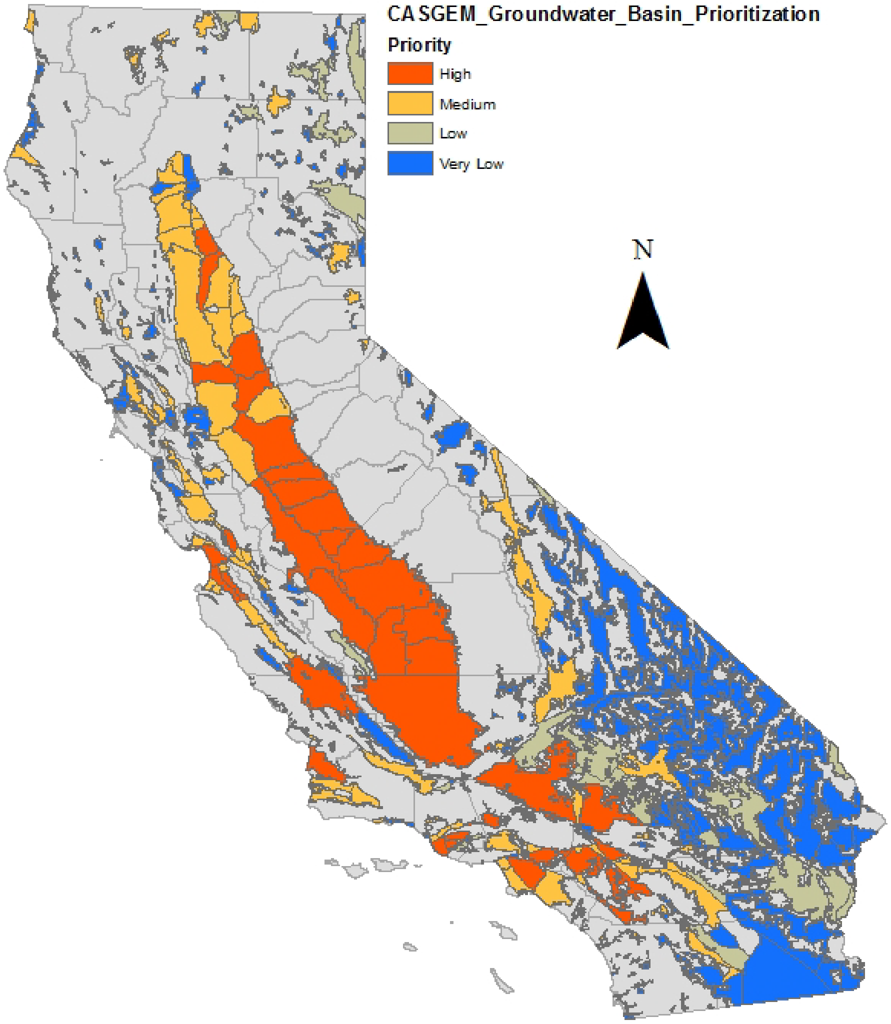


Figure 7: CASGEM Basin Prioritization updated on June, 2014. Source: Groundwater Information Center (gis.water.ca.gov/app/groundwater), Department of Water Resources.

2.3.3. Opportunities for GB on Agricultural Land

As discussed in the previous section, the new statewide groundwater regulation will bring opportunities for new and existing groundwater banking projects. Particularly, section 10720.1 (a) on increasing groundwater storage and removing impediments to recharge; and section 10727.2 (a) requiring the creation of maps identifying existing and potential recharge areas, could become the initial incentive to start studying, developing, and implementing groundwater banking on agricultural land. In this matter, tools developed in recent decades could aid in identifying potential recharge areas such as the Sacramento Soil Moisture Accounting model (SAC-SMA; Burnas 1995), SoilWeb (O'Geen et al. 2008), and more recently the Soil Agricultural Groundwater Banking Index (SAGBI; Saal 2014; O'Geen et al. 2015). SAGBI (Figure 6) provides the first step in identifying potential sites for groundwater banking based on five factors: deep percolation, root zone residence time, topography, soil chemistry, and surface conditions (Saal, 2014).

SAGBI focuses on agricultural land. Figure 8 shows the distribution of the index only in the Central Valley and in portions of the Bay Area where agriculture is practiced. In this index soils are categorized as *Excellent, Good, Moderately Good, Poor,* and *Very Poor* according to performance yield. According to SAGBI, 31% of California's agricultural soils (4.6 million acres) are within the *Excellent, Good,* and *Moderately Good* suitability groups and another 500,000 acres are added if deep tillage in orchards and vineyards are included (Saal, 2014). Information from SAGBI can be used as an initial indicator to further investigate soils at a local scale and to start developing recharge-site maps required by regulation SB-1168.

The distribution of crops in the Central Valley adds another compromise to the potential for groundwater banking projects on agricultural land. As shown in Section 2.2; alfalfa, fallow fields, and vineyards where tested for flood tolerance at Terranova Ranch and vineyards were highly successful at flood tolerance. However, salts and other fertilizers can leach into the groundwater derived from banking. Alfalfa on the other hand, offers a lower tolerance to flooding –about 2 weeks, temperature dependent– (Dahlke 2013) but it requires less fertilizers and pesticides, reducing negative impacts on groundwater quality. Additionally, fallow land could be used for groundwater banking if overlying suitable soils and water infrastructure is available.

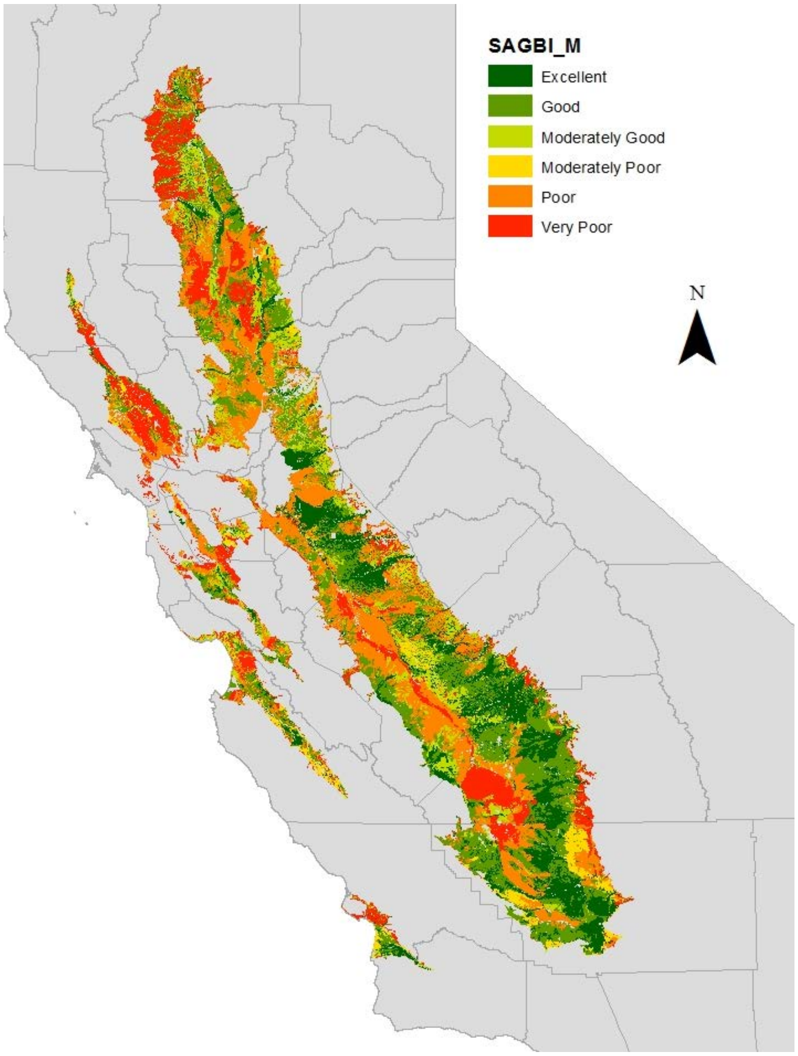


Figure 8: Soil Agricultural Groundwater Banking Index (SAGBI) reflecting deep tillage. Adapted from Saal (2014).

Figure 9 shows the spatial distribution of alfalfa, grapes, and fallow land overlying suitable land for groundwater banking. According to the National Agricultural Statistics Service's (NASS) Cropland Data Layer (nassgeodata.gmu.edu/CropScape/), there are about one million acres of alfalfa in California of which approximately 300,500 acres have soils suitable for groundwater recharge (*Excellent* and *Good*) as defined by SAGBI. Acreage for grapes and fallow land are also presented in Table 2. There are approximately 1,200,000 acres of test crops and fallow land overlying good soils for groundwater banking in California. This rough estimate highlights the important land surface area that could be used for groundwater storage if other factors such as access to water conveyance infrastructure and institutional and legal challenges are resolved.

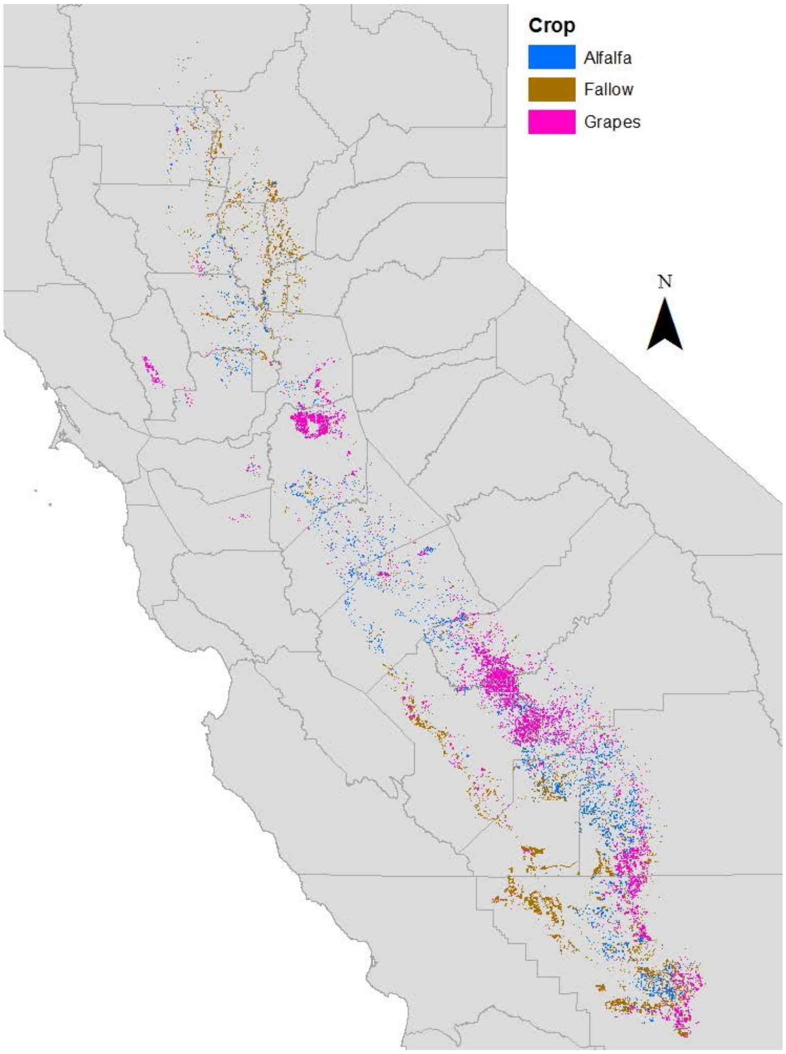


Figure 9: Alfalfa, grapes, and fallow land overlying soils classified by SAGBI as Excellent and Good for groundwater banking. Sources: SAGBI and USDA National Agricultural Statistics Service (NASS) 2013 (nassgeodata.gmu.edu/CropScape/).

Table 2: Distribution of alfalfa, grapes, and fallow land on suitable land.

Crop	**State Total Acreage**[*]	**Acreage on Suitable Land**[**]	**Percentage on Suitable Land**
Alfalfa	1,118,767	300,527	73%
Grapes	910,633	459,820	50%
Fallow land	1,522,528	448,345	70%

*NASS 2013 (nassgeodata.gmu.edu/CropScape/)
**Suitable land refers to the *Excellent* and *Good* soils according to SAGBI

Another incentive to develop GB programs is the limited storage capacity in the existing network of reservoirs and their high costs. Projects presented in section 2.1 have been effective but still required large investments (e.g., land acquisition and conveyance infrastructure). As Banks (1953, p. 221) observed: “In general, costs of underground storage should be far less than for the equivalent amount of salvage obtained by construction and operation of surface reservoirs alone.” In California, this difference in costs is increased as most cost-effective reservoir sites have already been developed (Lund et al. 2014).

Use of agricultural land for GB offers potential to further reduce project and operating costs if land would not have to be purchased by the water agency and existing infrastructure minimizes acquisition of new equipment (e.g., pumps). This assumption would be challenged for specific sites as farming practices and limitations in infrastructure may change among different places, and water must be pumped from the aquifer to be recovered. Nevertheless, pumping costs do not weight significantly when comparing underground storage versus surface storage alone (Banks 1953). At the same time, farming practices would be impacted by GB programs at different levels depending on the type of crop. The tradeoffs between normal and modified farming costs to accommodate GB would have to be analyzed to determine feasibility at the farm level. Additionally, cost-benefit studies at the local level (e.g., irrigation district, county, etc.) would expand the feasibility analysis to all users and non-users overlying the area.

3. Case Study: Orland-Artois Water District

The Orland-Artois Water District (OAWD) is located in the northern Sacramento Valley between the towns of Orland and Willows (Figure 10). OAWD was formed in 1954 to contract with the U.S. Bureau of Reclamation (BOR) for surface water supplies. Water deliveries started in 1976. The original contract expired in 1995 and consisted of a surface water supply of 53,000 AF of water annually. OAWD continues to receive the same amount of water from BOR via the Central Valley Project (CVP) through two-year contracts. OAWD delivers water through 100 miles of buried pipelines. Total delivery capacity from the District's turnouts is 427 cfs (Davids 2002).

Groundwater in the area is used as a supplemental water source for OAWD and as the only water source (besides precipitation) for growers in the GW-Only subunit. The underlying aquifer yields enough water for this purpose; however, groundwater levels have dropped between 1993 and 2013 (Section 4.3.1). The combination of land use, water conveyance infrastructure, types of soils, and groundwater levels make OAWD a candidate to investigate the economic feasibility of Ag-GB on its agricultural lands.

3.1. Subunits and Land Use

The study area extends beyond the limits of OAWD as shown in Figure 10. The area surrounding OAWD is also considered in this analysis because there is groundwater pumping from farmers in the vicinities of OAWD which ultimately impacts GW levels in OAWD.

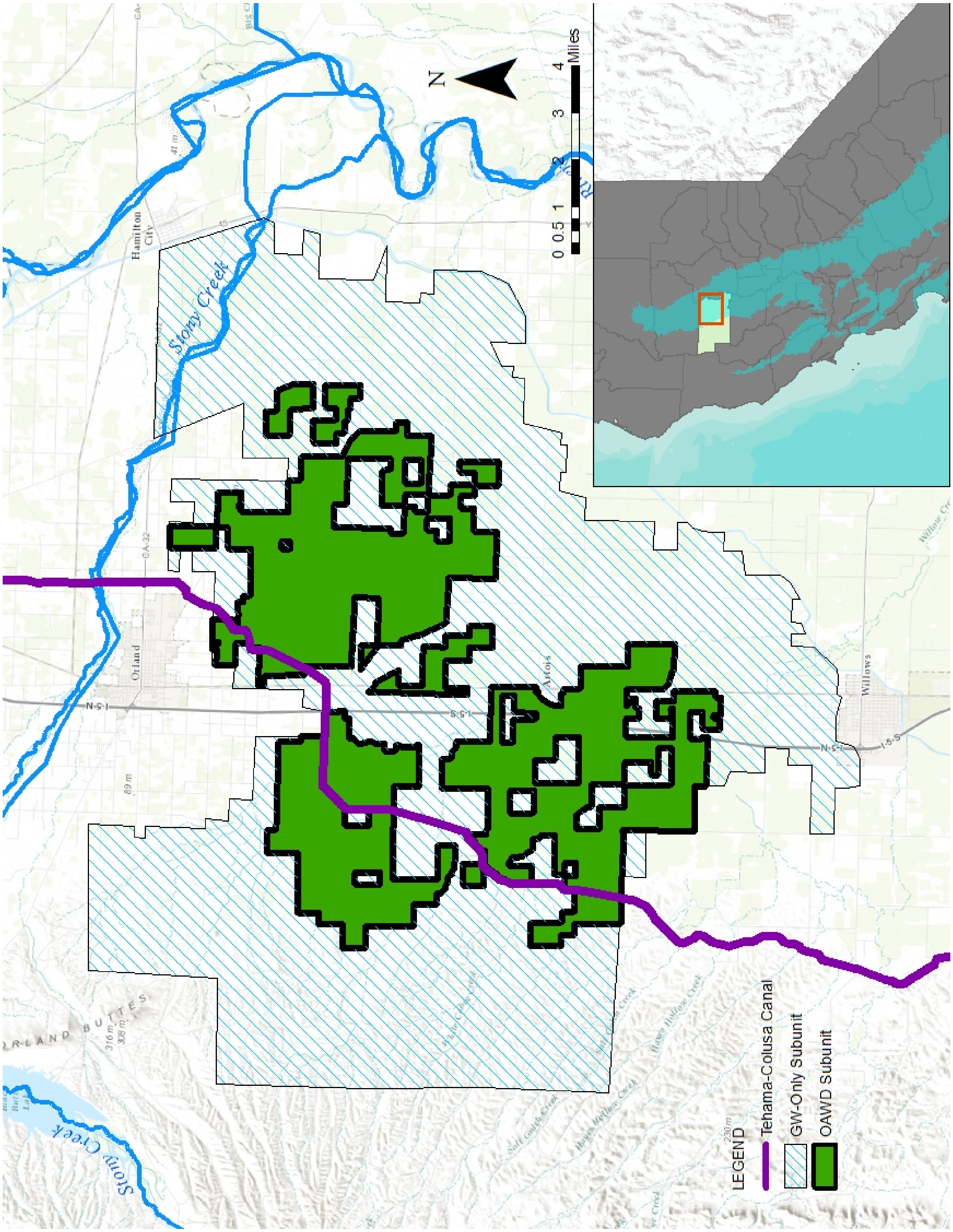


Figure 10: Study area location. The green area is the OAWD subunit and the blue shaded area is the GW-Only subunit.

The study area is divided in two subunits: OAWD and Groundwater-only (GW-Only). The OAWD subunit represents water users with access to two water sources: surface water deliveries through OAWD and groundwater through private wells. The GW-only subunit represents users surrounding the district who only have access to groundwater.

OAWD and GW-Only subunits are comprised of irrigated agriculture and have an area of 31,264 and 78,400 acres respectively for a total of 109,664 acres. In 2013 both subunits had approximately 28,000 and 63,500 acres of irrigated land respectively (See Appendices A and B). Between 1993 and 2013, the general cropping trend in both subunits is an increase of permanent crops (e.g., almonds, pistachios, vineyard, etc.) and a decrease in field crops (e.g., tomato, potato, etc.) and pasture and alfalfa (Section 5.1). This shift in cropping patterns plays an important role in terms of availability of crops suited for Ag-GB such as alfalfa, pasture, and vineyards.

3.2. Water Sources

3.2.1. Precipitation

The study area receives most of its rain between November and April with an annual average of 20 inches (WRCC 2015). Figure 11 shows the average monthly precipitation in the study area as well as average maximum and minimum temperatures. Almost no rain occurs between July and August when temperatures are highest, and 80% of precipitation takes place between November and March. This climate pattern directly affects monthly water requirements.

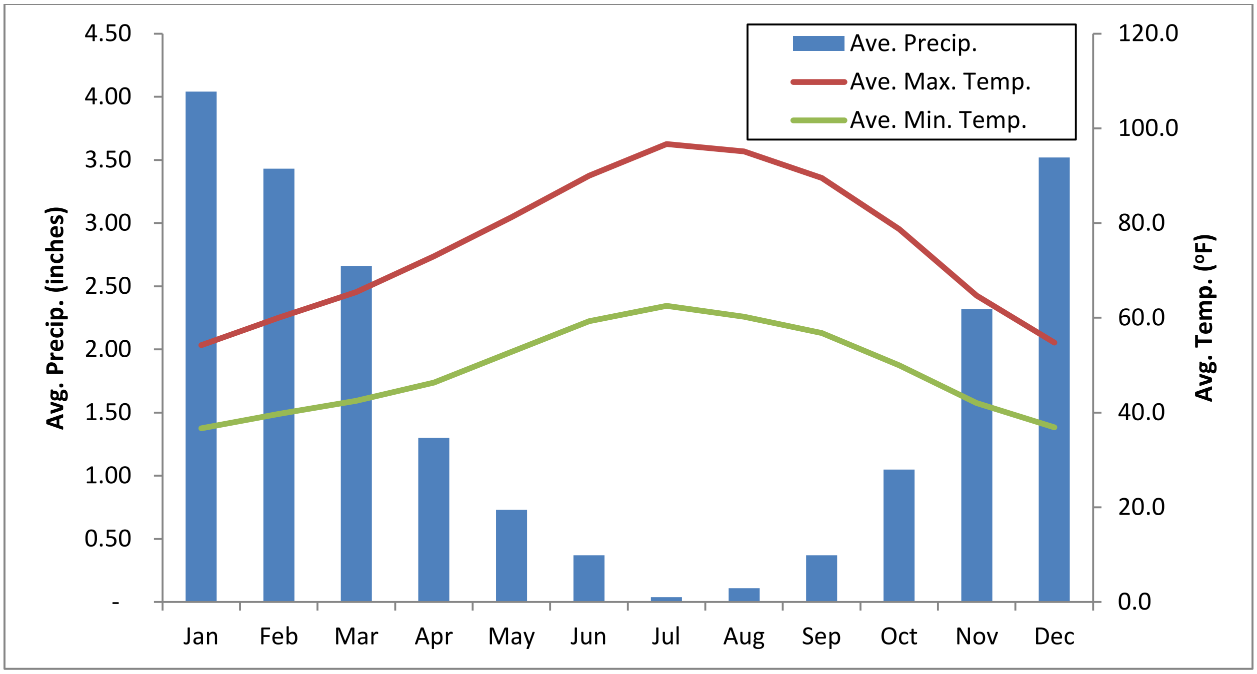


Figure 11: Study area average precipitation and temperature. Adapted from Western Regional Climate Center (WRCC 2015).

3.2.2. Surface Water

The Sacramento River and Stony Creek are the two major sources of surface water in the area. OAWD receives water from the Sacramento River through the Tehama-Colusa canal (TCC) (Figure 10) owned by the BOR. The TCC takes its water from the Sacramento River at the Red Bluff Diversion Dam in Tehama County and flows southward into Colusa County. As previously mentioned, the OAWD annual water right is 53,000 AF diverted from TCC. From 1993 to 2013, results of this study (Section 5.2) estimate an average annual water demand in OAWD of 83,400 AF, with minimum and maximum demands varying between 75,000 and 130,000 AF. The estimated water demand of OAWD is greater than its current water right. To meet the additional demand OAWD utilizes other sources of water such as water imports from other irrigation districts in the region and groundwater.

3.2.3. Groundwater

The OAWD overlies the northern part of the Colusa Groundwater Sub-Basin, which is located on the west side of the Sacramento Valley Groundwater Basin. The Colusa Sub-Basin has a surface area of 1,435 square miles (approximately 918,380 acres) and an estimated storage capacity of 13 million AF at a depth of 200 ft (DWR 2006). Groundwater conditions in OAWD suggest that Stony Creek serves as a water source for aquifer recharge and that groundwater tends to flow from northwest to southeast (Davids 2002). Surface water and groundwater interactions however, vary in time and space in the area and therefore gains and losses to groundwater vary as well (Davids and MWH 2006). Other sources of recharge in the study area are deep percolation from irrigation and precipitation. Figure 12 shows groundwater levels with respect to the mean sea level in the study area in 2013. There is a difference of about 100 ft between the highest level (navy blue) and the lowest one (brown). Higher groundwater levels on the northern part of the study area suggest SW-GW interactions between Stony Creek and the underlying aquifer. Groundwater pumping from farming has led groundwater levels to drop southward, and created a cone of depression, as seen in the western side of the study area.

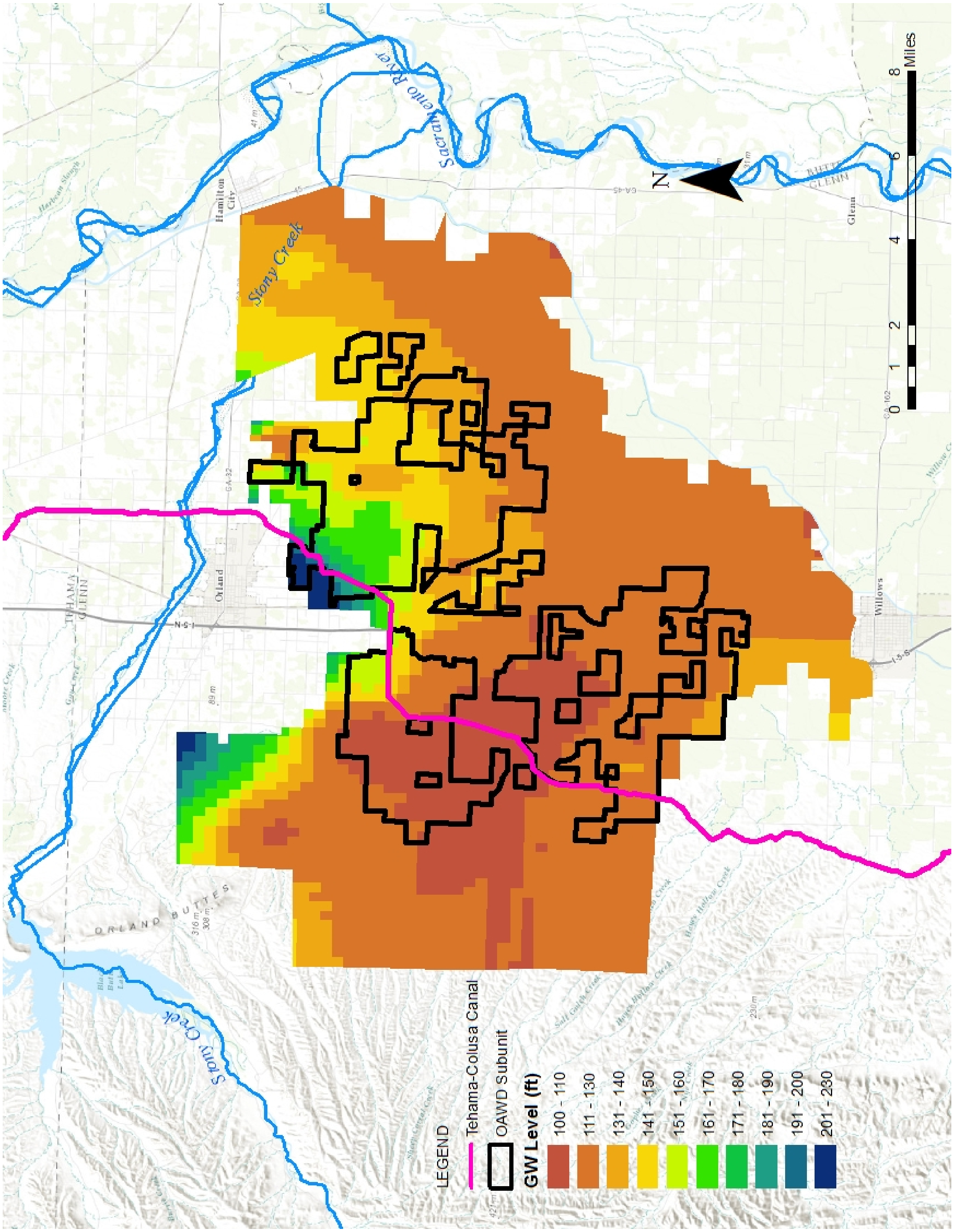


Figure 12: Groundwater levels in 2013.

4. Methodology

A model consisting of 4 components (Figure 13, top four boxes) is proposed to estimate the economic feasibility of Ag-GB in the study area. In Step 1, agricultural water demands are calculated based on land use, crop evapotranspiration (ET), and precipitation (Section 4.2). In Step 2, water demands are fed into the water mass balance model (Section 4.3) to estimate aquifer storage in a given year using the continuity equation under different scenarios.

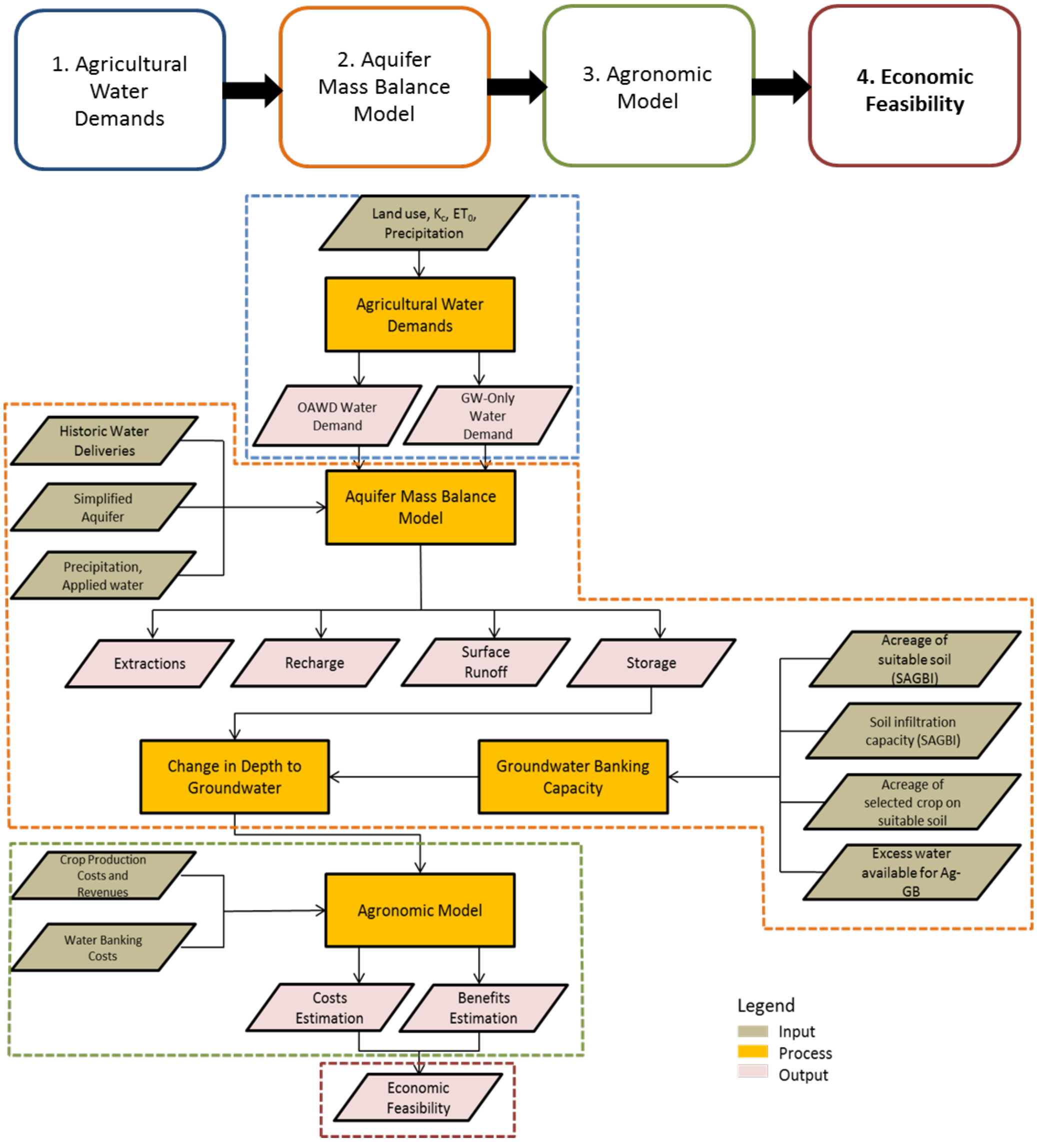


Figure 13: Model Framework.

In Step 3, costs and benefits of Ag-GB are estimated; changes in aquifer storage are used to estimate changes in GW levels to assess economic impacts on pumping and crop production (Section 4.5). Finally in Step 4, costs and benefits derived from Ag-GB are evaluated to determine the economic feasibility.

4.1. Period of Analysis

A hydrologic period of analysis of 21 years (Jan/1993 to Dec/2013) is used in this study. This period contains 3 years of a major drought (2011 – 2015) and a wet period (1995 – 1998), which will provide valuable insight about the effects of climate variability on agronomics and GB in the area. Water deliveries from 1993 to 2013 were provided by OAWD. All major water conveyance infrastructures were introduced in the area prior to the period of analysis. Therefore, land use patterns before and after the introduction of SW in the study area are not presented here. However, the time span considered shows the general cropping trend in the area moving from field crops (e.g., grains, tomatoes) to permanent crops (e.g., almonds, pistachios).

4.2. Agricultural Water Demands

Water demands on irrigated land are calculated at a monthly time step. Inputs to water demands calculations are: land use (Section 4.2.1), evapotranspiration (ET) (Section 4.2.2), precipitation (Section 4.2.3), and application efficiency (Section 4.2.4). Figure 14 shows a flow chart of the water demands, and water sources (precipitation, surface water and groundwater) and their interactions in the study area. Figure 15 expands on Figure 14 showing equations used for steps 1(Agricultural Water Demand) and 2 (Aquifer Mass Balance Model).

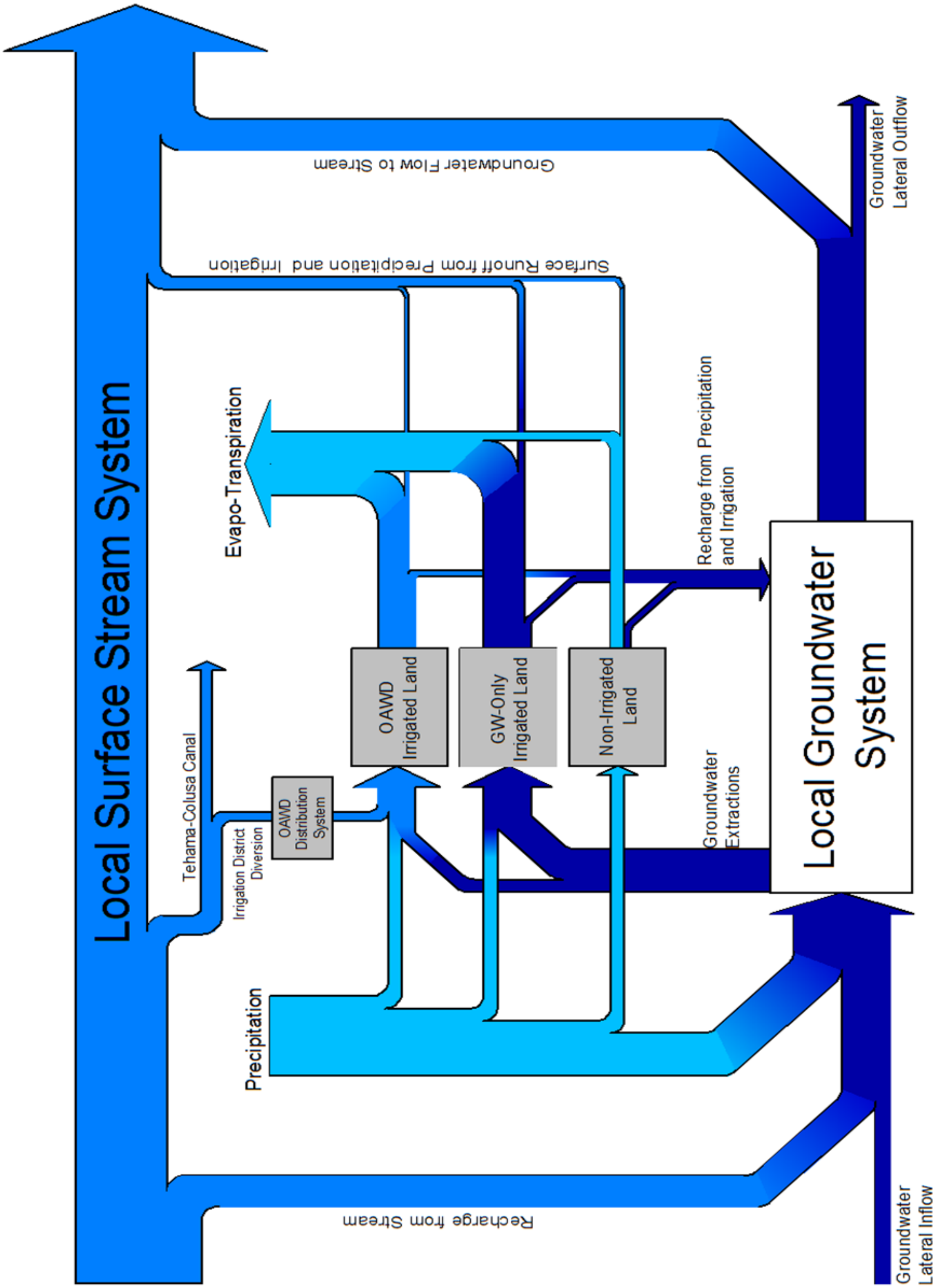


Figure 14: SW-GW Conceptual System.

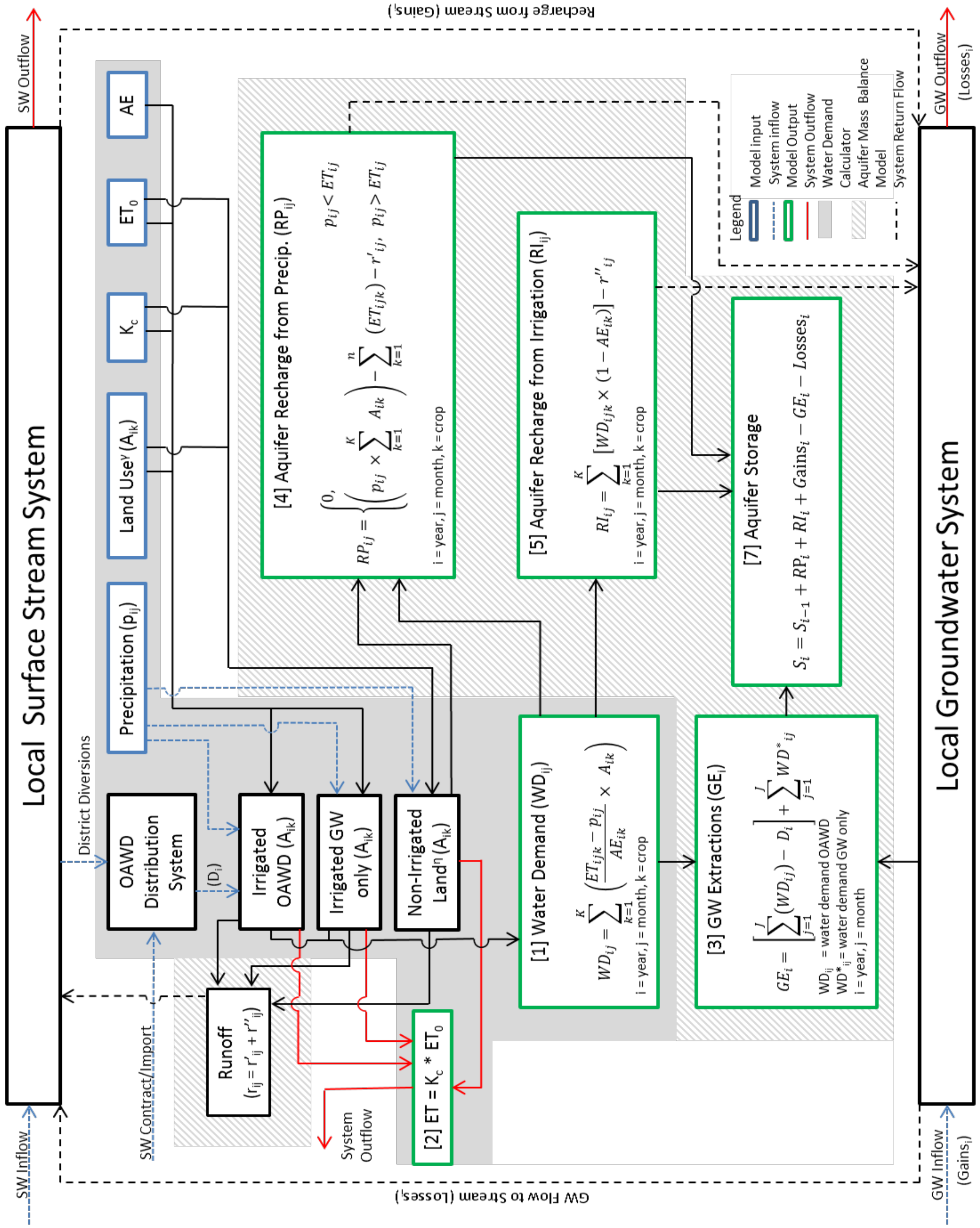


Figure 15: Water demand and aquifer mass balance conceptual models.

Water demands are calculated for the two subunits using the following equations:

$$WD_{ij} = \sum_{k=1}^{K} \left(\frac{ET_{ijk} - p_{ij}}{AE_{ik}} \times \ A_{ik}\right) \qquad [1]$$

$$WD_i = \sum_{j=1}^{J} WD_{ij} \qquad [2]$$

Where WD_{ij} is the water demand (AF) in month j and year i for every crop K; WD_i is the annual water demand (AF) in year i; A_{ik} is the area (acres) of crop k in year i (annual land use data are used and it is assumed there are no land use changes during a given year); ET_{ijk} is the evapotranspiration (ft) for crop k in month j and year i; p_{ij} is the precipitation (ft) in month j and year i; and AE_{ik} is the water application efficiency for crop k in year i.

4.2.1. Land Use

Land use data were obtained from three sources:

1) DWR for 1993, 1998, and 2003 (DWR, *"Land Use Survey"* 2014);
2) Stony Creek Fan Conjunctive Water Management Program Feasibility Investigation (SC) (Davids and MWH 2006) for 1994 through 1997, and 1999 through 2000;
3) USDA through the National Agricultural Statistics Service (NASS) from 2007 through 2013 (USDA, *"CropScape – Cropland Data Layer"* 2013)

Land use data from DWR and NASS are digital Geographic Information System (GIS) files. Data from SC were extracted directly from the report. There is no data available for 2001, 2002, and 2004 through 2006.To fill the missing data it is assumed there is no change in land use. For instance, land use data pertaining to 2003 is assumed to remain the same until 2006 after which there is data for 2007. This assumption is replaced in some cases with a linear interpolation if such trend is defendable with the available information. Appendices A and B show the land use time series data used in this study.

4.2.1.1. *Cross Reference Crops*

Land use data sources listed above group crops differently. In order to estimate evapotranspiration rates and irrigation demands, the different crops are grouped to fit the crop classification provided by DWR through the Detailed Analysis Units (DAUs) (Appendix C). DAU’s are used in this study in addition to being official state estimates, because they provide land use data and crop coefficients (K_c) specific to a region. DWR provides monthly estimates for crop coefficients (K_c) that are specific to the DAU’s land use categories, which are used in this study for water demand calculations. Table 3 shows the grouping of all crops in the area to fit DAU’s crop classification.

Non-irrigated land is also considered to estimate aquifer recharge as explained in Section 4.3.2.1. Non-irrigated land includes urban landscape, residential areas, native vegetation, riparian vegetation, barren land, and water surfaces.

Table 3: Assignment of crops to DAU's crop classification.

Crop Classification	Crops (DWR, NASS)
Grain	Barley, wheat, oats, miscellaneous and mixed grain and hay, vetch,
Rice	Rice
Cotton	Cotton
Sugar Beets	Sugar Beets
Corn	Corn
Dry Beans	Dry Beans
Safflower	Safflower
Other Field Crops	Herbs, sudan, sunflower, misc. vegetables
Alfalfa	Alfalfa
Pasture	Mixed pasture, clover
Tomato	Tomato
Cucurbits	Cucumber, squash, pumpkins, honeydew melon
Onions & Garlic	Onions, garlic
Potatoes	Potatoes
Truck Crops	Carrots, peas, blueberries, strawberries, misc. truck crops
Almond & Pistachios	Almond, pistachios
Other Deciduous	Olives, prunes, walnuts, pears, pecans, plums, peaches, figs, cherries, other tree crops
Citrus & Subtropical	Oranges, eucalyptus, kiwis, citrus
Vineyard	Grapes, table grapes

4.2.1.2. *Land Use from Stony Creek Feasibility Report (SC)*

Land use data from SC (Davids and MWH 2006) were used to determine the proportions at which crop patterns changed over time. These proportions were applied to data from DWR between 1993 and 2000 for both subunits: OAWD and GW-only. SC divides its study area in various subunits and two of them match the ones considered in this study. The crop classification used in SC differs from that of DAUs. Crop groups shown in the left column of Table 3 were reorganized to fit SC's crop classification (Table 4). These proportions were used to compute the change in land use between 1993 and 2000. DAUs' crop classification was used to calculate water demands.

Table 4: DAUs' crop classes redistribution to fit SC's crop classification.

SC's Crop Classification	DAU's crops regrouping
Field Crops	Grain, Cotton, Sugar Beets, Corn, Dry Beans, Safflower, Tomato, Cucurbits, Onions & Garlic, Potatoes, Vineyard, Other Field Crops, Truck Crops
Pasture & Forage	Alfalfa, pasture
Permanent Crops	Almonds & Pistachios, Other Deciduous, Citrus & Subtropical
Rice	Rice

OAWD Subunit

OAWD has a defined area of 31,264 acres. SC provides land use patterns from 1993 to 2000 which were used to estimate the change in acreage for the different crops from 1994 to 1997, 1999, and 2000. Land use field data was collected from DWR for 1993 and 1998 and is publicly available in digital shape files (DWR, *"Land Use Survey"* 2014). The percentage change in acreage between years according to SC was applied to DWR's 1993 crop data. For example, according to SC, field crops had a decrease from 1993 to 1995 as follows: 9% from 1993 to 1994, and 15% between 1994 and 1995. These percentages of change in land use were used to fill DWR's acreage data in years where data was missing (1994-1997, 1999-2000). Figure 16 shows the estimated cropping pattern for the OAWD subunit. Appendix D shows a comparison between the estimated cropping patterns and those from SC.

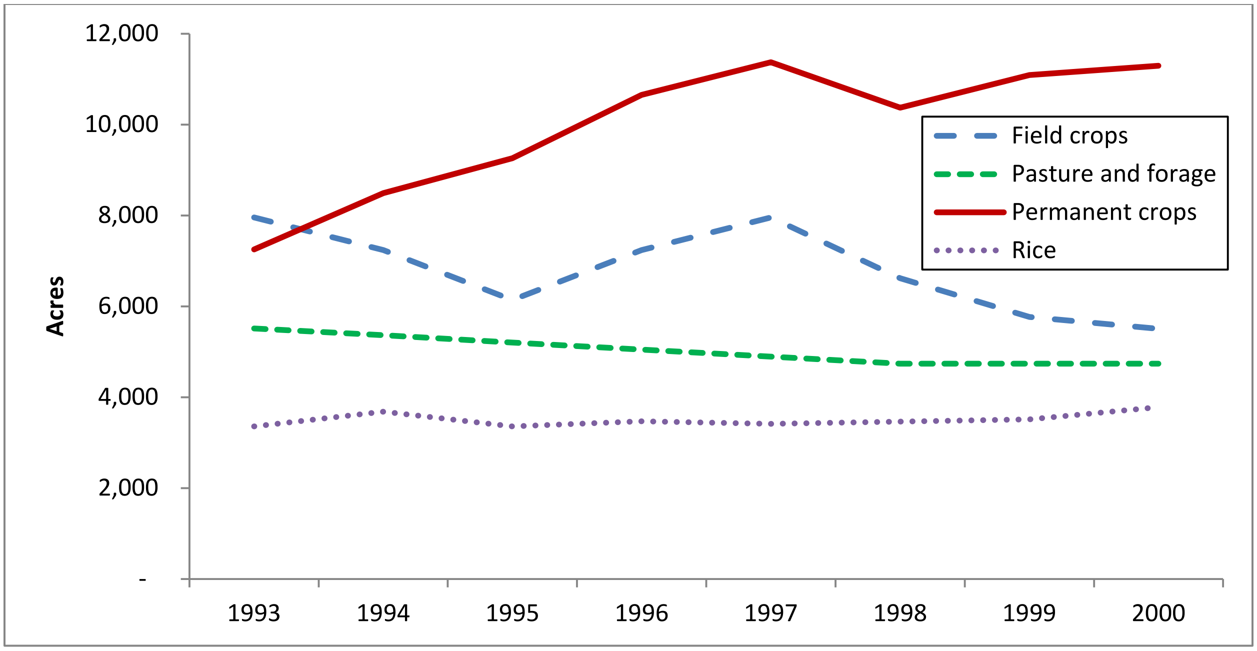


Figure 16: Estimated cropping patterns for the OAWD subunit using SC's crop data from 1993 to 2000.

GW-Only Subunit

The same procedure was used to estimate crop patterns in the GW-only subunit between 1993 and 2000 except that SC considers four areas for growers using only groundwater. Even though the GW-Only subunit in this study is located within the same region as those (i.e., growers using only groundwater) defined in the SC report; none of them match the GW-Only subunit considered in this study. To overcome this discrepancy, cropping patterns in the different SC's subunits were compared to determine if they share a common trend. Appendix E shows that the same pattern is observed among the different subunits included in the SC study (Appendix E). This shared cropping pattern is applied to the GW-Only subunit. A single cropping pattern for each crop group was obtained by taking the average of the four SC subunits. These average patterns were used to compute the missing cropping data in the same way as with OAWD. As shown in Figure 17, the resulting cropping patterns are comparable with those in the OAWD subunit (Figure 16). Permanent crops increase their acreage as pasture and field crops acres are reduced.

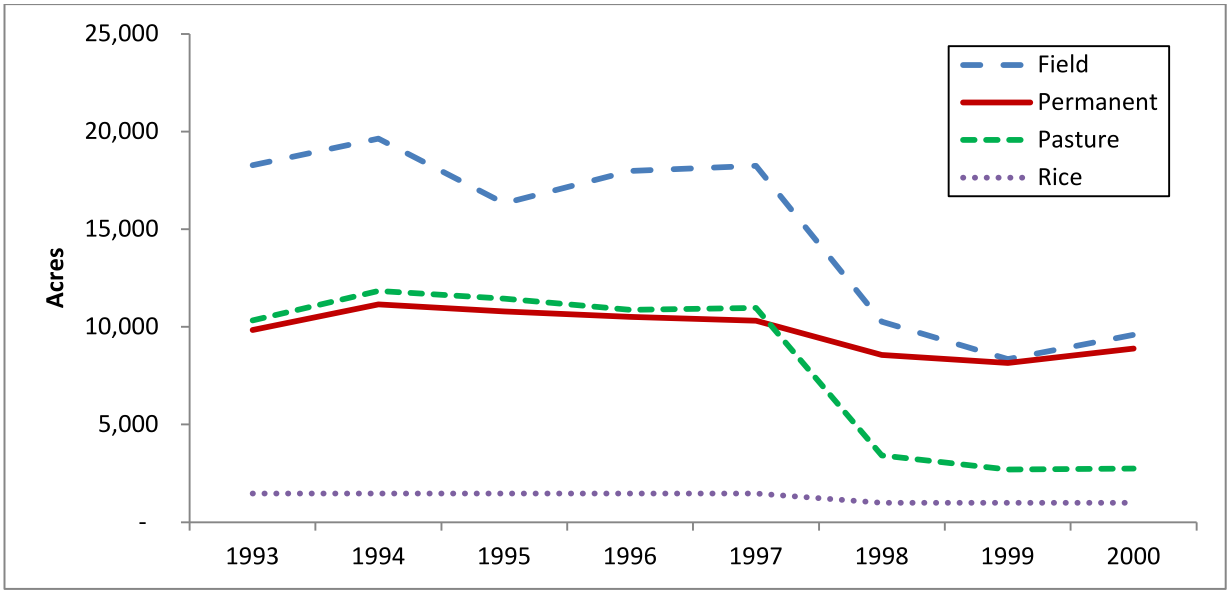


Figure 17: Estimated cropping patterns for the GW-only subunit from 1993 to 2000.

4.2.2. Evapotranspiration (ET)

ET is the combination of evaporation and transpiration processes. During evaporation liquid water at the ground surface becomes water vapor and therefore is considered a water loss to the local system. Similarly, during transpiration liquid water contained in plants is lost to the atmosphere in the form of water vapor. There are models to estimate ET at a daily time step such as the Penman-Monteih equation which requires daily mean temperature, wind speed, solar radiation, and humidity (Allen et al. 1998). For the purposes of this study, ET is estimated at a monthly basis for each crop class using crop coefficients (K_c) and reference evapotranspiration (ET_o) in the study area:

$$ET_{ijk} = Kc_{jk} \times ETo_{ij} \qquad [3]$$

Where ET_{ijk} is the evapotranspiration (ft) for crop k in month j in year i, Kc_{jk} is the crop coefficient (dimensionless) for crop k in month j, and ETo_{ij} is the reference evapotranspiration (ft). ET is computed considering standard conditions. No limitations are placed on crop growth or ET from soil water, salinity stress, crop density, pests and diseases, and low fertility. The effects of various weather conditions are incorporated into ETo_{ij} and crop characteristics and average effects of evaporation from the soil into the Kc_{jk} coefficient (FAO n.d.).

Kc values were obtained from DWR's Detailed Analysis Units (DAUs) for Glenn County (Appendix C). Monthly ET_0 records in the area (CIMIS station 61) from 1993 to 2009 were obtained from DWR's California Irrigation Management Information System (CIMIS). From 2010 to 2013, average monthly ET_0 at CIMIS station 61 were used (Appendix F).

4.2.3. Precipitation

Rainfall is considered a system inflow. Rainfall is partitioned in two components: *net rain fall* and *effective rainfall*. Net rainfall is the total volume of precipitation falling in the area at a given time step. Effective rainfall in this study is the amount of water available for consumptive use (ET) after surface runoff and infiltration beyond the root zone (groundwater recharge) have taken place. In months where effective rainfall is not enough to satisfy ET, additional water is required to sustain crop production.

Data from 1993 to 2013 was obtained from three sources: (1) CIMIS Station 12 at Durham; (2) CIMIS Station 61 at Orland; and (3) National Water Service (NWS) Orland Station. There are missing data for some months in these time series. An average rainfall time series was generated from the three sources (Appendix G). Rainfall is distributed "evenly" over the entire study area; this consideration was assumed given the lack of additional stations to generate a spatial distribution of rain over the area.

4.2.4. Application Efficiency (AE)

AE is a performance criterion for irrigation systems; it is defined as the ratio of the average water depth applied and the target water depth (i.e., crop water requirement) during an irrigation event (Burt et al. 1997). AE is used to determine the additional volume of water needed to meet crop ET requirements (Equation [1], p. 44). Sandoval-Solis et al. (2013) developed estimates of AE for different crops by county using irrigation surveys in California in 2001 (Orang et al. 2008) and 2010 (Tindula et al. 2013) and existing theoretical AE values (Appendix H). Only mean AE values from Appendix H are considered for this study. AE values are used to estimate the depth of applied water (ft) per acre to a given crop. Thus, Equation [1] implies that the depth of applied water is greater than the difference between ET and precipitation. This assumption highlights the fact that, according to the performance of their irrigation systems, growers tend to apply more water to their crops than the amount suggested by ET calculations. From 1993 to 2007, 2001 AE values were considered. Similarly, 2010 AE values were considered from 2008 to 2013.

4.3. Aquifer Mass Balance Model

The proposed model in this section is conceptual and intended to provide a general method of estimating economic impacts of groundwater level changes. A comprehensive economic analysis of this kind must be informed by an actual groundwater model.

The mass balance model estimates GW recharge, extractions, and storage at an annual basis. Aquifer storage is calculated in two ways: 1) using GW levels data (Section 4.3.1), and 2) using Equation [4]. The two results are compared with each other for calibration purposes. The mass balance model considers only the unconfined aquifer underlying the study area.

An annual time step is used for the purposes of the subsequent economic analysis. Inputs to the model consist of delivery records from OAWD from 1993 to 2013, and water demand (WD_i) data (monthly water demands (Section 4.2) are compiled into annual totals to be used in the mass balance model) computed with Equation [2] (p. 44). A mass balance calculation is performed at every time step using the continuity equation:

$$S_i = S_{i-1} + I_i - O_i \qquad [4]$$

Where S_i is the aquifer storage in year i, S_{i-1} is the aquifer storage in the previous year, I_i is the inflows in year i, and O_i is the outflows in year i.

4.3.1. Aquifer Storage from GW Levels Data

GW depth contours were generated in GIS using Inverse Distance Weighted (IDW) interpolation. Interpolation is based on DWR’s annual GW levels data in the area from 1993 through 2013. GW depth contours were created considering 10 ft increments. This analysis is done for years 1993, 1998, 2003, 2008, and 2013. A five-year interval provides enough information regarding change in storage for the subsequent economic analysis. Appendix I summarizes the distribution of areas overlying different GW depths. Figure 18 shows that in the OAWD subunit there has been an increase of areas with deeper groundwater levels between 1993 and 2013. In other words, GW levels during this period have decreased over a larger area. In 1993, 73% of the land had groundwater depths (below soil surface) between 10 and 40 ft, and just 7% of the land had groundwater at depths of or greater than 100 ft. By 2013, 72% of the land had groundwater depths between 20 and 80 ft, and 17% of the area at or greater than 100 ft. This trend is more noticeable between 2008 and 2013 due to the combination of increased acreage of permanent crops and the 2011-2013 drought. Looking at the entire study area (Figure 19), this pattern is more dampened and GW levels are deeper overall because there are no surface water deliveries outside the OAWD subunit. Estimated aquifer storage for these years is used as reference points to adjust aquifer storage calculated with Equation [4].

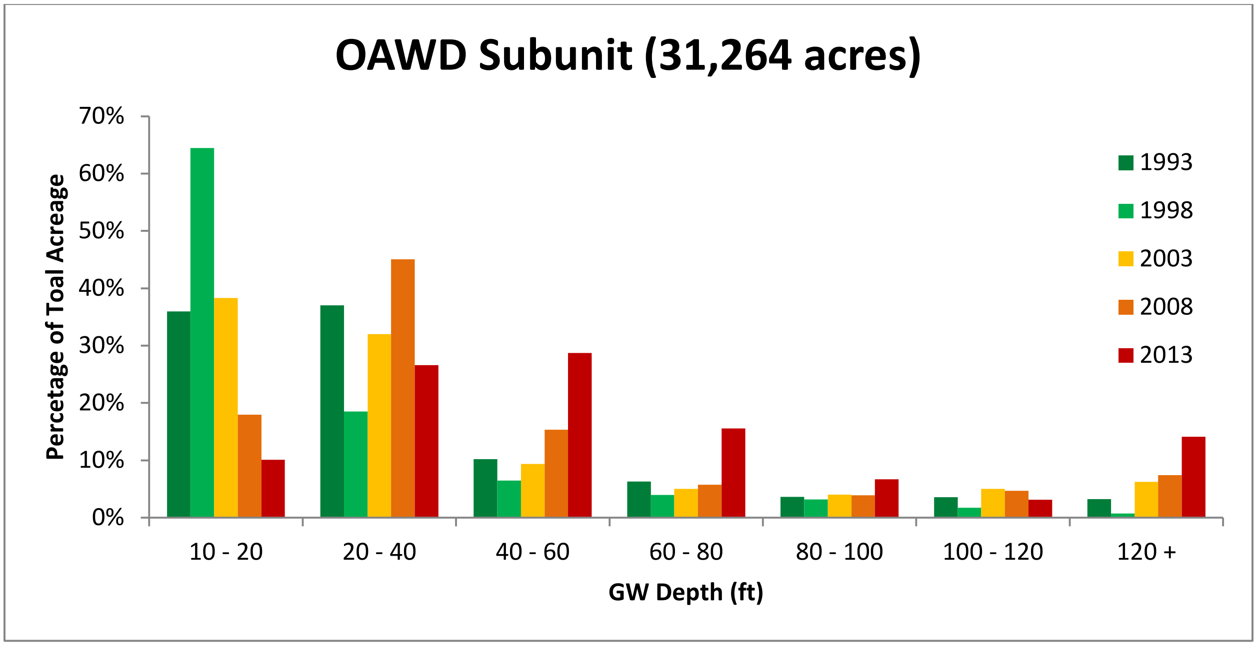


Figure 18: Total acres in OAWD subunit overlying different GW depths.

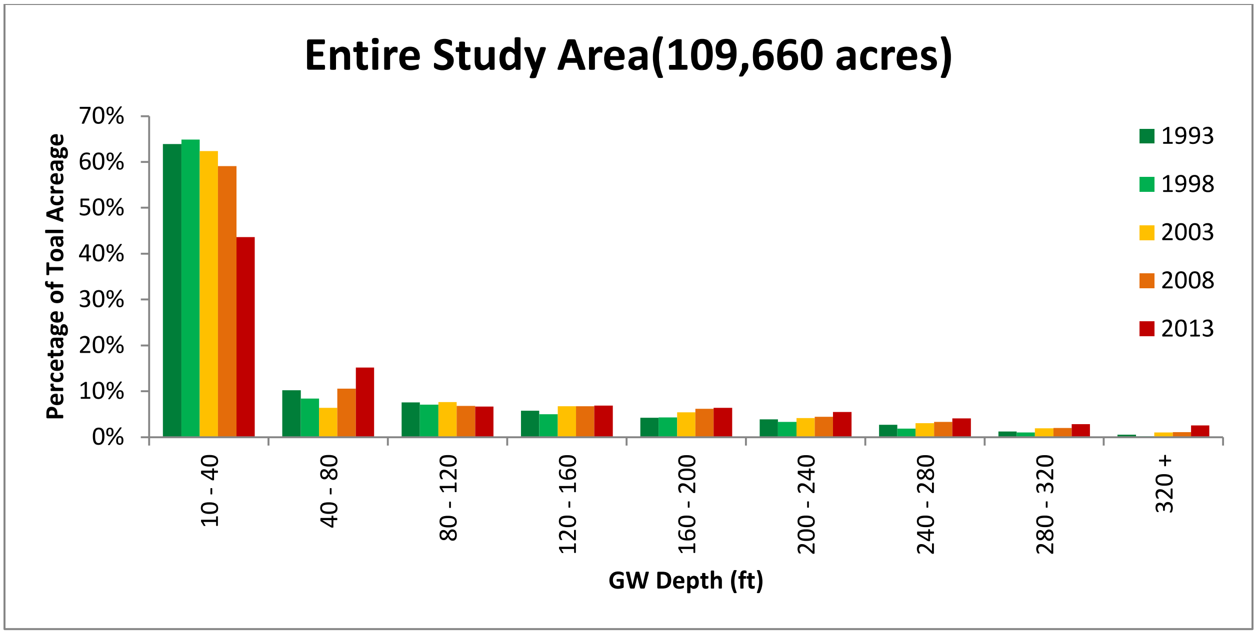


Figure 19: Total acres in the entire study area overlying different GW depths.

Aquifer storage underlying the study area is calculated using Equation [5] and data from Appendix I.

$$S_i = \sum_{m=10}^{M} [A_{im} \times (Z - d_{m-1})] \times n \times \gamma \qquad [5]$$

Where S_i is the aquifer storage (AF) in year i, A_{im} is the area (acres) corresponding to a given GW depth m in year i, Z is a reference datum used to represent aquifer thickness (ft), $d_{m\text{-}1}$ is the previous GW depth (GW depths are sorted from highest to deepest), n is the soil porosity (%), and γ is the specific yield (%). The specific yield represents the amount of water that can be recovered from the aquifer and it is estimated as 7% (DWR 2006). Limitations to this approach are the Z and n parameters. The datum Z represents the bottom of an idealized *one-bucket* aquifer system (Figure 20). The greatest GW depth (430 ft) is used as starting point for Z; thus, Z =

430+x, where *x* is an arbitrary value used for the purposes of this analysis. The soil porosity *n* assumes the soil in the aquifer system is homogeneous in terms of porosity. An average porosity is determined from the types of soils in the area.

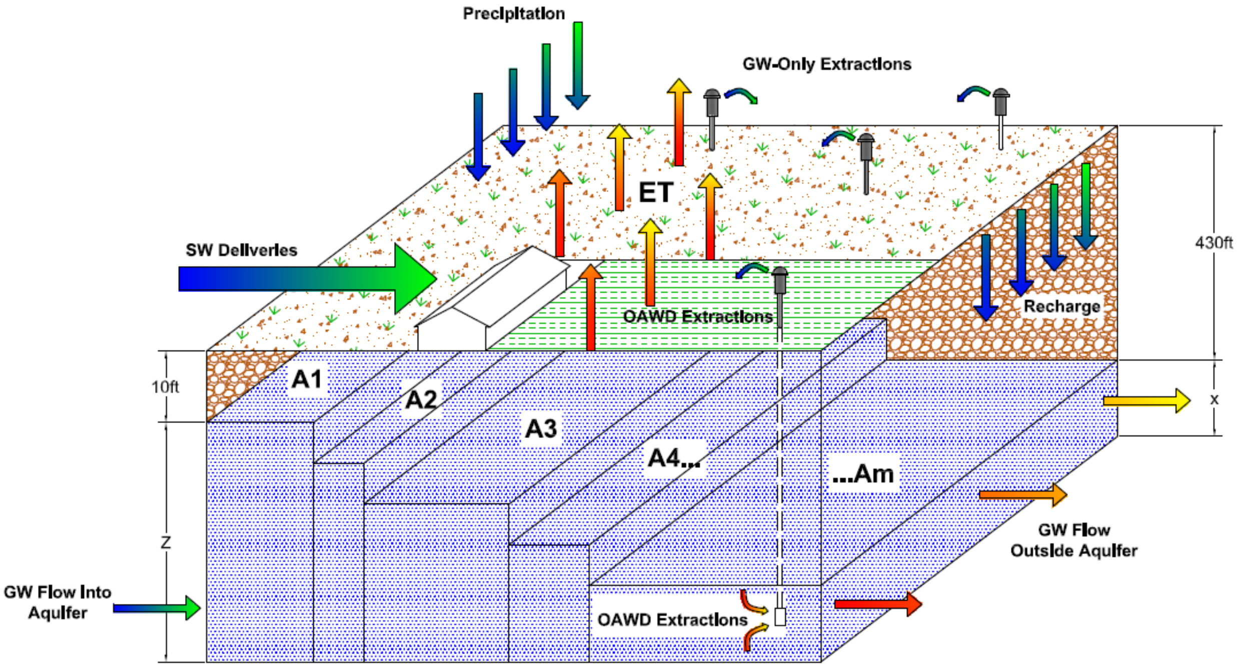


Figure 20: Representation of idealized aquifer system for storage calculations.

In Figure 20, A_1, $A_{2,}\ldots$, A_m represent the acres of land overlying different GW depths. The datum *Z* is measured from the highest GW depth (10 ft) down. In reality, the thickness of the unconfined aquifer varies but for the purposes of this study the one-bucket model is an appropriate approach for the groundwater system.

4.3.2. Aquifer Storage from Water Mass Balance

The inflow and outflow terms of the continuity equation (Equation 4) include all elements shown in Figure 20. Inflows to the aquifer system are recharge from precipitation, recharge from irrigation, and gains (e.g., lateral GW inflow). Outflows are GW extractions, and losses (e.g., GW flow leaving aquifer). Precipitation, SW deliveries, and ET are integrated in the water demand calculator (Section 4.2). With these considerations Equation [4] becomes:

$$S_i = S_{i-1} + RP_i + RI_i + Gains_i - GE_i - Losses_i \quad [6]$$

Where S_i and S_{i-1} remain defined as in Equation [4], RP_i and RI_i are aquifer recharge (AF) from precipitation and irrigation respectively in year i (Section 4.3.2.1), GE_i represents GW extractions (AF) in year i (Section 4.3.2.2), and $Gains_i$ and $Losses_i$ (AF) are calibration parameters representing horizontal inflows and outflows to the aquifer from GW fluxes.

Gains are herein considered as a percentage of the initial storage in a given year. Losses are defined as a percentage of the aquifer recharge. These parameters are adjusted to fit the storage calculated with Equation [6] to that calculated with Equation [5]. GW fluxes into and out of the aquifer system are likely to occur in a given year due to the general groundwater flow direction, geology and topography of the study area. GW fluxes into the aquifer could come from the foothills on the western side and from the Sacramento River east of the study area. Similarly, losses are likely to occur due to SW-GW interactions with the Sacramento River.

4.3.2.1. *Recharge*

Aquifer recharge takes place in the study area from rainfall and irrigation. Total recharge is calculated using Equations [7] and [8]:

$$R_{ij} = RP_{ij} + RI_{ij} \quad [7]$$

$$R_i = \sum_{j=1}^{J} R_{ij} \quad [8]$$

Where R_{ij} is the aquifer recharge (AF) in month *j* and year *i*, R_i is the total recharge (AF) in year *i*, RP_{ij} and RI_{ij} are aquifer recharge (AF) from precipitation and irrigation respectively in month *j* and year *i*.

Equation [9] describes how recharge from precipitation is computed. The model does not calculate soil moisture content. Thus, after ET has been satisfied, and runoff has taken place, excess precipitation percolates into the aquifer.

$$RP_{ij} = \begin{cases} 0, & p_{ij} < ET_{ij} \\ \left(p_{ij} \times \sum_{k=1}^{K} A_{ik}\right) - \sum_{k=1}^{K} \left(ET_{ijk}\right) - r'_{ij}, & p_{ij} > ET_{ij} \end{cases} \qquad [9]$$

Where RP_{ij} is the recharge from precipitation (AF) in month *j* and year *i*, p_{ij} is the amount of precipitation (ft) in month *j* and year *i*, A_{ik} is the area (acres) of crop *k* in year *i*, ET_{ijk} is the evapotranspiration (AF) from crop *k* in month *j* and year *i*, and r'_{ij} is the surface runoff from rainfall in month *j* and year *i*. The assumption in Equation [9] is that there is no recharge when precipitation in a given month is not enough to satisfy ET. In such case all rainfall will be used by the crops.

Similarly, Equation [10] is used to compute recharge from irrigation in a given month.

$$RI_{ij} = \sum_{k=1}^{K} \left[WD_{ijk} \times (1 - AE_{ik})\right] - r''_{ij} \qquad [10]$$

Where WD_{ijk} is the water demand (AF) of crop *k* in month *j* and year *i*, AE_{ik} is the application efficiency for crop *k* in year *i*, and r''_{ij} is the surface runoff from irrigation in month *j* and year *i*.

Surface Runoff

Because the proposed model does not use a soil moisture content approach, surface runoff is used herein as a percentage of rainfall and applied water in the area. Runoff from precipitation (r'_{ij}) is computed using Equation [11]:

$$r'_{ij} = \left(p_{ij} - ET_{ijk}\right) \times \alpha_{ij} \qquad [11]$$

Where α_{ij} is a runoff factor in month j and year i. Using a similar logic, runoff from irrigation (r''_{ij}) is computed using the expression:

$$r''_{ij} = \left[WD_{ijk} \times (1 - AE_{ik})\right] \times \alpha \qquad [12]$$

In this case, α is time invariant and assumed to be 0.03 (Davids and MWH 2006). α takes values between 0 and 1.

Runoff records from 1993 to 2013 where obtained from USGS's Hydrologic Units (HU) Data Base to estimate values for α_{ij}. Data are available for HU levels 2, 4, 6, and 8 (the smaller the number the greater the area). The study area lies within HU8-18020104 (Figure 21) Runoff records from this HU (Appendix J) are used as reference to estimate α_{ij}. Because the HU has a greater area than the study area, only months with low to zero ET and high precipitation (January, February, November, and December) were used for the estimation of α_{ij}. For the rest of the year runoff data is not comparable with the rainfall data used in the model (i.e., in some months there would be negative recharge). In these months α_{ij} does not change and is equal to that of February.

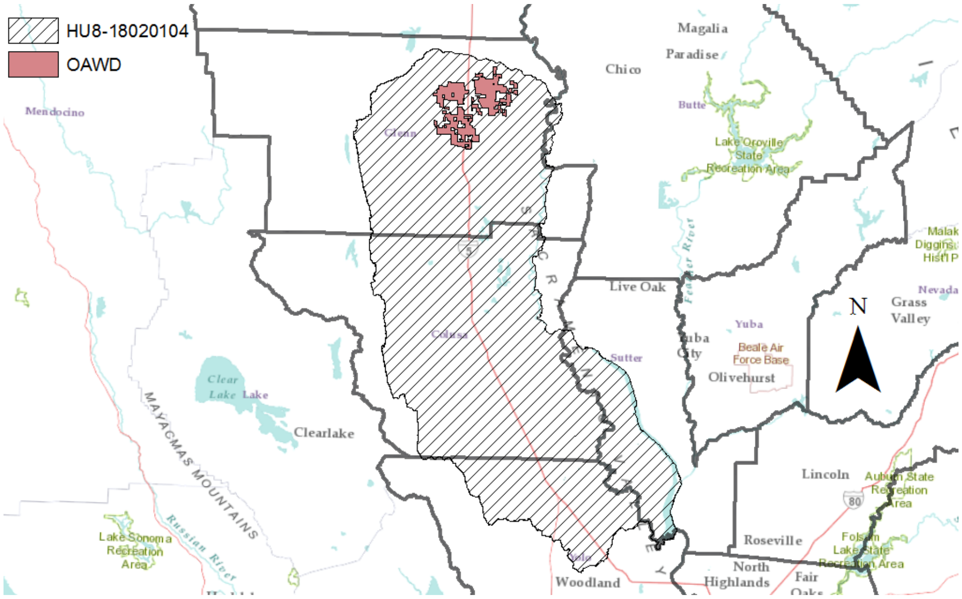


Figure 21: OAWD location relative to Hydrologic Unit HU8-18020104.

In a similar way as outlined in Section 4.2.1.2, the SC report is used to adjust assigned values to α_{ij} and α from 1993 to 2000. α_{ij} was adjusted (ranging from 0.11 to 0.42 with a mean of 0.27) to fit SC's recharge from precipitation in OAWD (Figure 22). Because α is assumed to be 0.03 and time invariant, there is no adjustment to fit SC's recharge from irrigation from 1993 to 2000 (Figure 23).

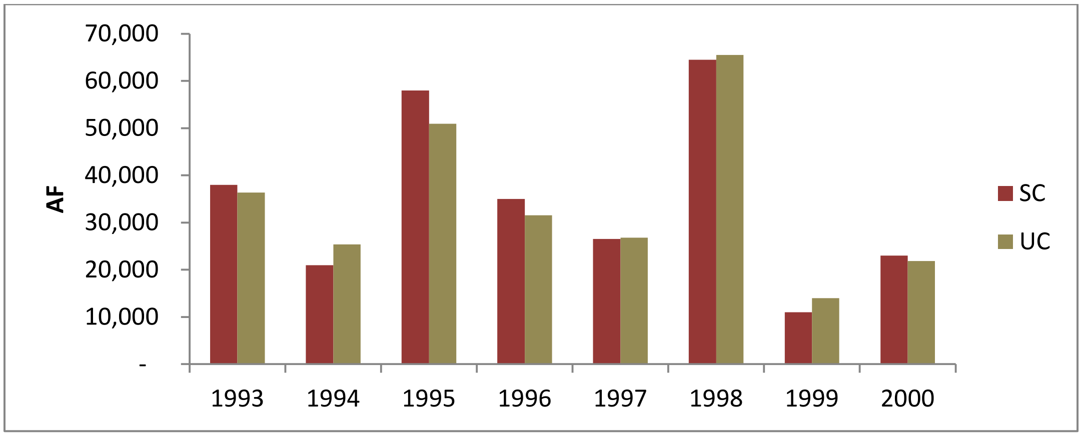


Figure 22: Recharge from precipitation in OAWD adjusted to SC's from 1993 to 2000. SC= Stony Creek report, UC=Estimated values.

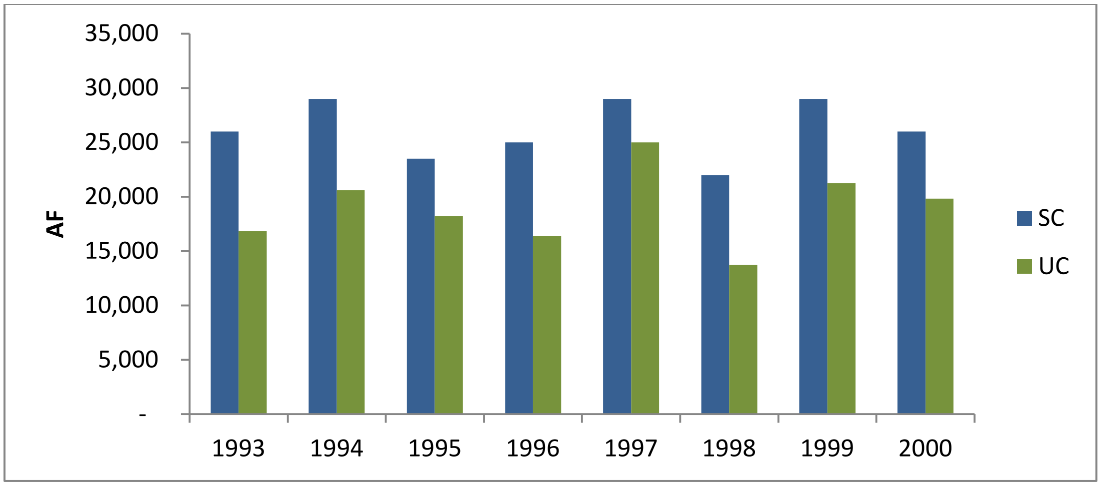


Figure 23: Recharge from Irrigation in OAWD compared to SC's from 1993 to 2000. SC= Stony Creek report, UC=Estimated values.

All considerations mentioned above were used for both subunits OAWD and GW-Only.

4.3.2.2. *GW Extractions*

Extractions from the aquifer are governed by the following equation:

$$GE_i = \left[\sum_{j=1}^{J}\left(WD_{ij}\right) - SW_i\right] + \sum_{j=1}^{J} WD^*{}_{ij} \qquad [13]$$

Where GE_i is the total volume of water (AF) pumped from the aquifer in year *i*, WD_{ij} is the water demand (AF) in the OAWD subunit in month *j* and year *i*, SW_i is the water delivered (AF) by the irrigation district in year *i* (Appendix K), and WD^*_{ij} (calculated with Equation 1, p. 44) is the water demand (AF) in the GW-Only subunit in month *j* and year *i*.

4.4. Groundwater Banking

The general steps to determine if Ag-GB is viable in a given area are shown in Figure 24. The top portion (beige) of the flow chart deals with the land selection criteria, and the bottom portion (green) addresses availability of surface water for Ag-GB.

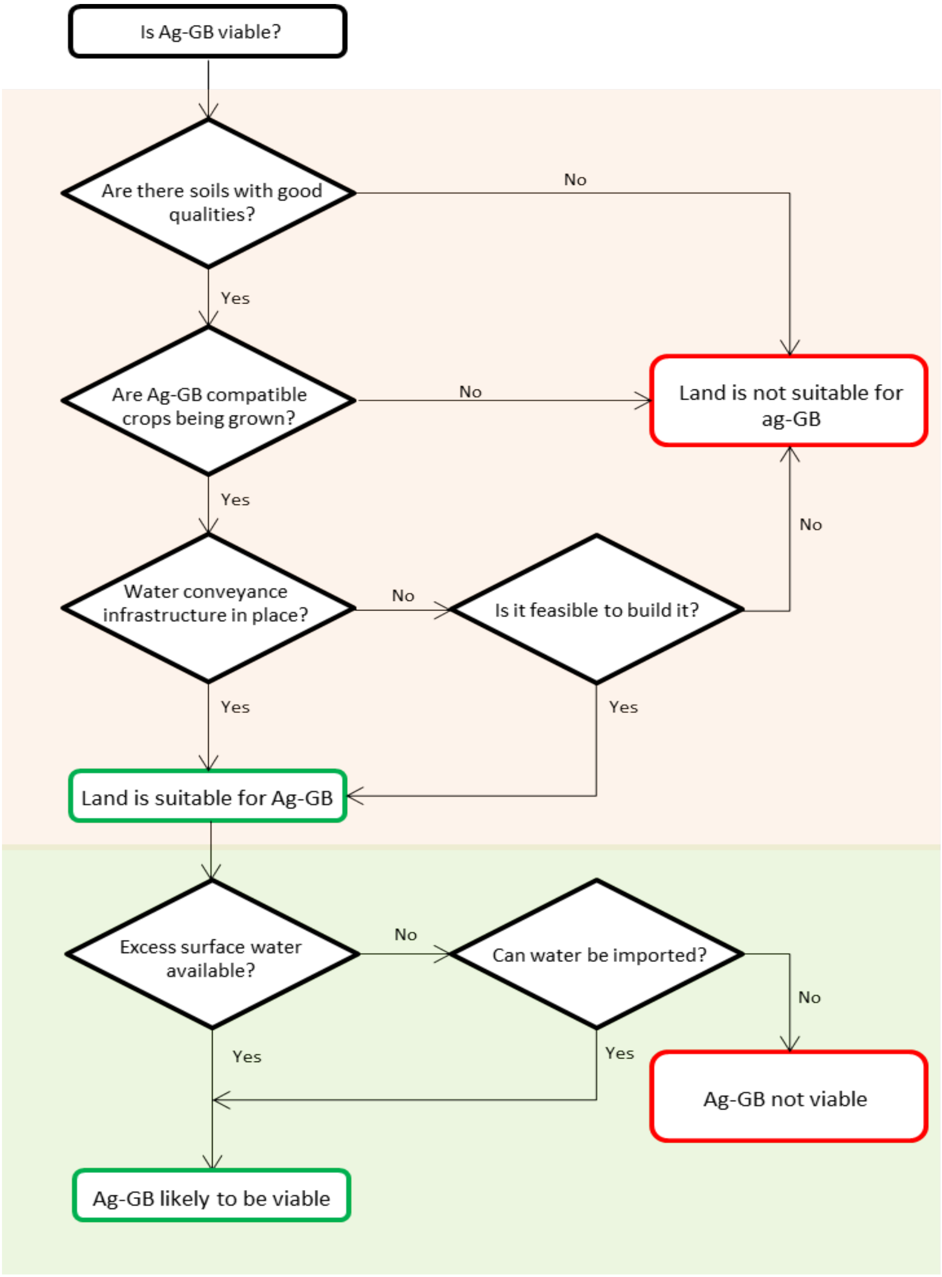


Figure 24: Ag-GB viability flow chart.

Only the OAWD subunit is considered in this study for Ag-GB because the water conveyance infrastructure is in place. Criteria mentioned in Figure 24 are explained in the remainder of this section.

4.4.1. Land Selection Criteria

Three basic criteria for land selection are used:

1) Existing water infrastructure,
2) Type of crop, and
3) Type of soil.

Criterion (1) refers to the availability of water conveyance infrastructure. It is assumed that all growers in the OAWD subunit are connected to the District's water supply system. This minimizes the likelihood of needing additional infrastructure to convey water for Ag-GB. Criterion (2) involves the type of crops being grown on different farms. Some crops have little to no tolerance to flooding and also require significant amounts of fertilizers and/or pesticides that could leach into the aquifer. Criterion (3) deals with the critical factors affecting soil suitability for Ag-GB: root zone drainage, deep percolation, topography, chemical limitations, and surface conditions (Saal 2014).

Criterion (1) is fulfilled as mentioned above by assuming all growers in the OAWD receive surface water from the district which takes water from the Tehama-Colusa Canal. This is an appropriate assumption given the fact that growers join an irrigation district to receive complementary or supplementary surface water.

To address Criterion (2), alfalfa, and vineyards are considered in this study (land use data mentioned in Section 4.2.1 is used for the analysis). Vineyards can withstand prolonged periods of flooding (~ 2 weeks) up to 12 inches deep (Bachand et al. 2012). There is however, a potential negative impact on groundwater quality derived from leaching salts and nitrates (Bachand et al. 2012). Alfalfa on the other hand, require relatively low amounts of fertilizers and pesticides and offer a similar resistance to flooding (~ 2 weeks, temperature dependent) (Dahlke 2013). For the reasons mentioned above, alfalfa is used for the economic analysis and vineyards are used to show the potential areas for Ag-GB using this crop. Finally, the Soil Agricultural Groundwater Banking Index (SAGBI) (Saal 2014) is used to aid with criterion (3). The SAGBI considers different soil qualities relevant to Ag-GB, which are explained below.

4.4.1.1. *Soil Selection*

The SAGBI categorizes soils in California based on deep percolation, root zone residence time (i.e., root zone drainage), topography, chemical limitations, and surface conditions. Five soil suitability categories are derived from SAGBI: *Excellent, Good, Moderately Good, Poor,* and *Very Poor*. Only the *Excellent, Good,* and *Moderately Good* categories are considered in this study due to their high ratings on the five driving factors mentioned above (Figure 25).

The *Excellent* and *Good* soils (E&G) are grouped together in this study to represent suitable land for Ag-GB. *Moderately Good* (ModG) soils are considered to highlight potential sites for Ag-GB. Saal 2014 also developed a modified version of SAGBI to reflect the effects of deep tillage (i.e., destroying of restrictive layers to allow for root penetration).

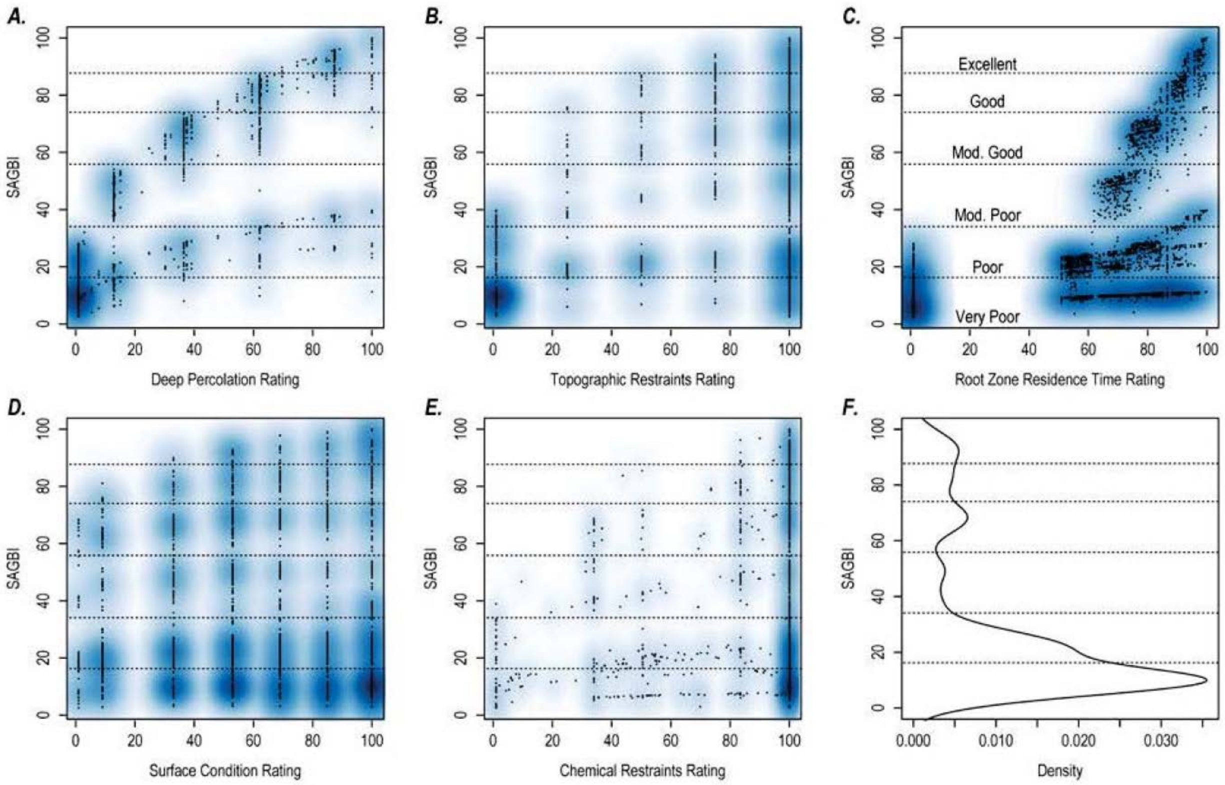


Figure 25: SAGBI's suitability factors ratings (After Saal 2014). A – E: Smoothed colors density representation of individual factor ratings in comparison with final SAGBI score. Darkness of color is correlated with data density, which enables the visual interpretation of repeated data points. F: Probability density function displaying the distribution of SAGBI scores. Natural breaks in the data were used to create suitability groups, represented by the horizontal lines in all plots.

Figure 26 illustrates the coverage of E&G and ModG soils in the OAWD subunit. E&G soils cover approximately 15,400 acres or about 50% of the subunit total area. Soils in this group have a high hydraulic conductivity (between 3 and 49 μm/s), small to flat slopes (< 5%), low salinity (< 0.9 dS/m), and no concerning limitations such as restrictive layers, high water tables, and poor drainage (Saal 2014).

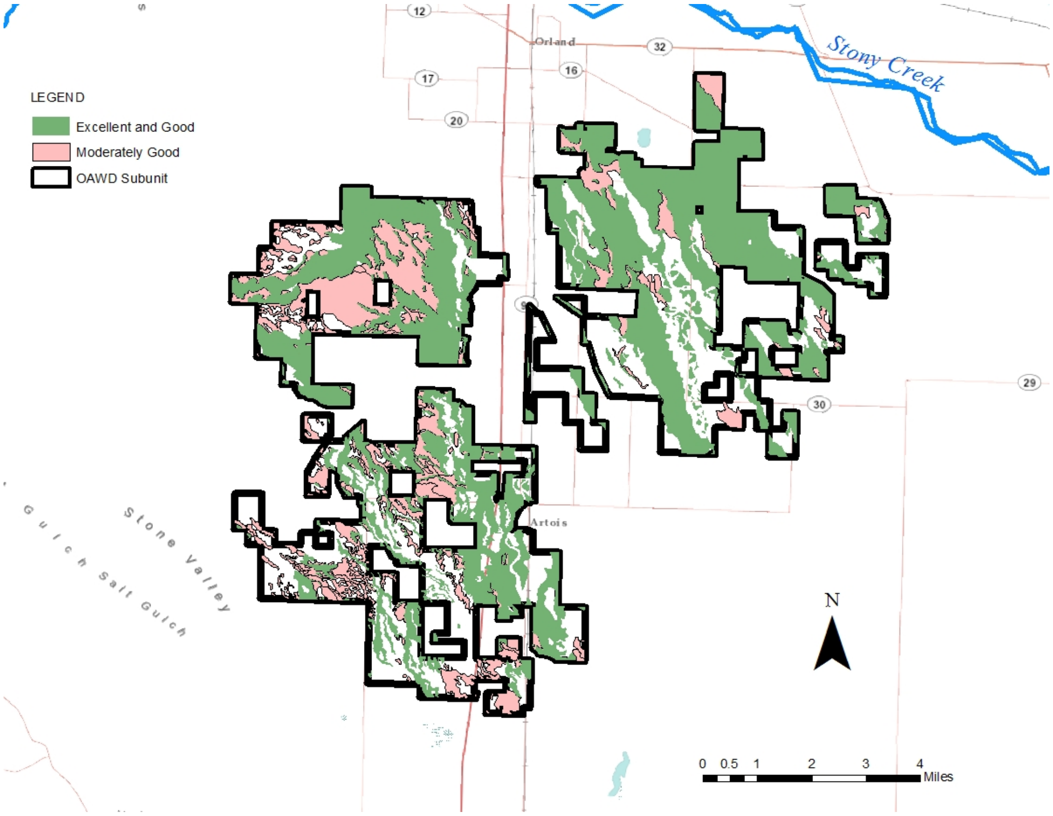


Figure 26: Distribution of suitable and potentially suitable soils according to Modified SAGBI.

ModG soils on the other hand, cover only about 2,600 acres or 8% or the subunit total area. Soils in this group have also high hydraulic conductivity but may be of concern due to salinity (~ 12dS/m), and challenging topography (slopes > 5%) in some areas. Because of these considerations, *potentially suitable* soils are included in this study only to quantify the potential these lands have for Ag-GB.

When deep tillage is not taken into account (Figure 27), E&G soils cover only 1,800 acres and ModG soils 4,500 acres; or 6% and 14% of the total area respectively. Both versions of SAGBI are considered as scenarios in this study.

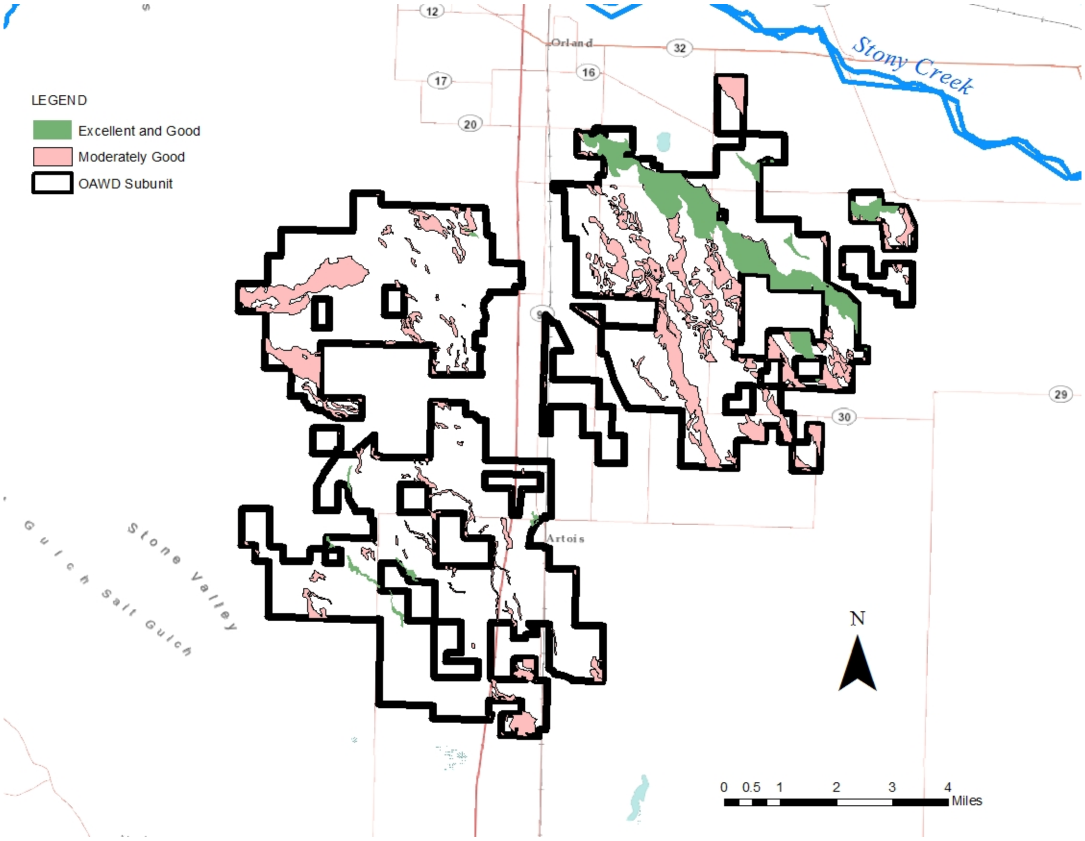


Figure 27: Distribution of suitable soils according to Unmodified SAGBI.

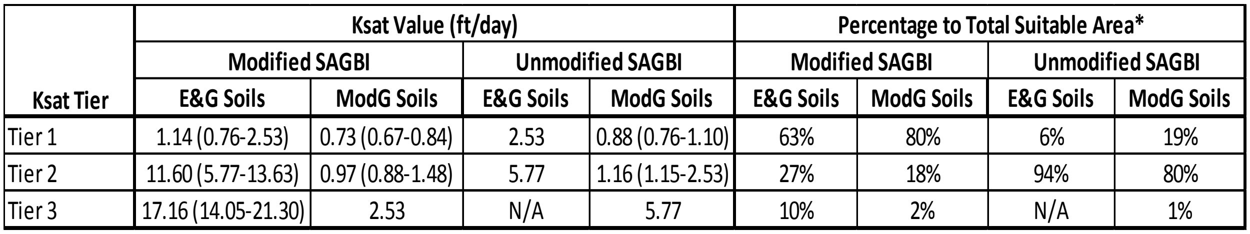
Out of the five critical factors affecting suitability of soils for Ag-GB, the *root zone residence time* or *root zone drainage* is the one of more concern regarding risks to agricultural production. Poorly drained soils can significantly damage some crops, depending on the duration and timing of saturation (Saal 2014).

<u>*Root Zone Drainage*</u>

Saal (2014) proposed using the saturated hydraulic conductivities (K_{sat}) as a predictor for the initial drainage of a saturated soil. This criterion was incorporated into SAGBI and used in this study to aid with estimation of Ag-GB capacity as explained in Section 4.4.2.

The distribution and wide range of Ks_{at} values in both soil groups (Appendix L) considered in this study (E&G and ModG) are not appropriate for use of a single average value. Instead, all K_{sat} distributions were divided into three bins (Appendix L) to better approximate the spatial distribution of K_{sat} in the two soil groups. This level or resolution offers a good description of the distribution of Ksat values without adding too much computational burden to the analysis. Table 5 shows average K_{sat} values for the two soil groups and both versions of the SAGBI.

Table 5: Soils K_{sat} (ft/day) grouping and averaging. Values in parenthesis are the ranges per bin. Some bins have a single value, therefore no range is shown. See Appendix L for graphical distributions of K_{sat}.



	Ksat Value (ft/day)				Percentage to Total Suitable Area*			
	Modified SAGBI		Unmodified SAGBI		Modified SAGBI		Unmodified SAGBI	
Ksat Tier	E&G Soils	ModG Soils	E&G Soils	ModG Soils	E&G Soils	ModG Soils	E&G Soils	ModG Soils
Tier 1	1.14 (0.76-2.53)	0.73 (0.67-0.84)	2.53	0.88 (0.76-1.10)	63%	80%	6%	19%
Tier 2	11.60 (5.77-13.63)	0.97 (0.88-1.48)	5.77	1.16 (1.15-2.53)	27%	18%	94%	80%
Tier 3	17.16 (14.05-21.30)	2.53	N/A	5.77	10%	2%	N/A	1%

*These percentages are with respect to the total area comprised by the respective soil group.

Based on the values in the table above, it can be said that these soils have good drainage. However, it is important to point out that these values are the result of an average and may not represent the actual drainage capacity of such soils. K_{sat} values shown in Appendix L are intended as an initial reference to identify soils with good drainage. Field tests would be required to assess to actual drainage of these soils.

4.4.2. Groundwater Banking Capacity

Though not explicitly stated in Figure 24, it is necessary to estimate the maximum amount of water that can infiltrate into the soil within a time window that minimizes crop damage. This amount of water is estimated as a function of the soil drainage, land surface, water conveyance capacity, and time. To minimize the probability of crop damage the model estimates the maximum amount of water that can be infiltrated in one day. These considerations are evaluated using a simple linear optimization model:

$$Max\ K_i = [\alpha(A_{1in} \times d_{1n}) + \beta(A_{2in} \times d_{2n}) + \theta(A_{3in} \times d_{3n})] \times 0.504 \qquad [14]$$

Subject to:

$(T = d_{mn}/Ksat_{mn}) \leq 24\ hours$

$(A_{imn} \times d_{mn}) \leq Q$

Where K_i is the volume of water (AF) that can be infiltrated into the fields in one day in year *i*, A_{in} is the area (acres) of alfalfa on soil *n* and in year *i*, d_n is the depth of water (ft) per acre on soil *n*, and 0.504 is a conversion factor. Suffixes *1*, *2*, and *3* are the different K_{sat} bins represented with the letter *m* in the constraints equations. *α*, *β*, and *θ* are weighting factors ranging from 0 to 1. These weights allow for analysis of banking capacity using all, just one, or different combinations of K_{sat} bins. *T* is the time (hours) it takes the volume of water to infiltrate into the soil, d_{mn} is the depth of water (ft) diverted onto the field, $Ksat_{mn}$ is the average saturated hydraulic conductivity (ft/day per acre) of soil *n* and bin *m*, *Q* is the maximum water conveyance capacity (cfs), and A_{imn} is the area (acres) of alfalfa on soil *n*, bin *m*, and year *i*. *Q* is governed by the water diversion with the smallest capacity. In this case the turnouts to the individual farms are the ultimate conveyance system the water travels through before being discharged onto the fields. However, for the purpose of aiding the economic analysis at the district scale, the limiting *K* considered herein is that of the district's turnouts from the Tehama-Colusa Canal.

OAWD derives water from the Tehama-Colusa Canal through five turnouts with a collective capacity of 847 AF/day (427 cfs). However, a range of values of Q rather than a single one is considered in this study. This takes into account the fact that OAWD may not be able to distribute 427 cfs onto Ag-GB fields. Therefore, Q takes values of 5, 25, 50, 100, 150…, 400, and 427 cfs. The selection of Q values is arbitrary and intended to cover the range of possible conveyance capacities onto Ag-GB fields.

It is important to highlight that this approach does not take into account the decrease over time of the initial infiltration capacity these soils have due to saturation. Use of K_{sat} implies a constant infiltration rate once the soil is saturated.

4.4.3. Surface Water Availability

Once the land has been selected using the criteria described on Section 4.4.1, the next step is to identify *excess water* flows (e.g., flood control releases) in the stream feeding the study area. The OAWD subunit diverts water from the Tehama-Colusa Canal which takes water from the Sacramento River through the Red Bluff Diversion Dam. Daily flow records are used to identify peak flows that could be diverted into the OAWD subunit for Ag-GB. The closest station to this location measuring the flow of the river is the USGS 11377100 station at Bend Bridge near Red Bluff. Furthermore, the Bend Bridge station is the primary control point downstream of Shasta Dam that determines reservoir releases under real-time operation (USBR 2006). Daily flow data from 1993 to 2013 (USGS, "*National Water Information System*" 2015) were recovered from this station.

The criteria herein used to identify *excess water* flows are based on the USGS's daily flow classification (USGS, "*WaterWatch*" 2015). USGS uses percentiles to classify an average daily flow with respect to all other daily flows in record. Table 6 summarizes the percentile classes used by USGS to classify daily flows.

Table 6: USGS Daily Flow Classification.

USGS Percentile Classes	USGS Daily Flow Classification
>90	Much Above Normal
76-90	Above Normal
25-75	Normal
10-24	Below Normal
<10	Much Below Normal

Only daily flows above the 90th percentile are considered in this study. It is assumed that these flows are *excess water* and can be appropriated by the irrigation district for Ag-GB. This assumption is appropriate for the purposes of the subsequent economic analysis. The author wants to point out that flood control releases and/or spills from the reservoir(s) upstream are necessary to more accurately assess the existence of excess water. Additionally, an accounting of all water flow requirements (i.e., environmental flows, temperature control, water rights, etc.) in the corresponding reach of the stream would be appropriate in conducting such assessment.

Only the season with the lowest ET for alfalfa is considered (November through March) for Ag-GB in this study. It is implied that a small fraction of the water used for Ag-GB will be consumed by the crop ET and the rest infiltrates into the soil. This fraction of water used by the crop ET is referred herein as *in-lieu recharge*, given that this amount of water would have been extracted from the aquifer if Ag-GB had been not implemented.

Same months from different years are grouped to determine which flows are above the 90th for those months only. For instance, the 90th percentile for November between 1993 and

2013 is different to that of December in that same period. Table 7 shows the 90th percentile daily flows for considered months as explained above.

Table 7: 90th percentile flows (AF)

Scenario	Month					
	November	December	January	February	March	Rest of the Year
Direct recharge	16,800	45,400	84,900	107,035	96,200	N/A

Finally, the volume of water available for Ag-GB is determined using the following equation:

$$WGB_i = \sum_{h=1}^{H} \tau_{hi}, \qquad \tau_{hi} = \begin{cases} 0, & \delta_{hi} = 0 \\ \delta_{hi}, & \delta_{hi} < K_{hi} \\ K_{hi}, & \delta_{hi} \geq K_{hi} \end{cases} \tag{15}$$

Where, WGB_i is the water available for Ag-GB (AF) in year i, τ_{hi} is the water available (AF) on day h and in year i, δ_{hi} is the amount of water (AF) above the 90th percentile on day h and in year i, and K_{hi} is the banking capacity (AF) (See Section 4.4.2) on day h and in year i.

4.4.4. Impact of Ag-GB on Water Mass Balance

Inclusion of Ag-GB operations in the district modifies the aquifer mass balance model proposed in Section 4.3.2. Additional water entering the system via Ag-GB must be included in Equation [6] (p. 56):

$$S_i = S_{i-1} + RP_i + RI_i + RB_i + Gains_i - GE_i - Losses_i \tag{16}$$

Where RB_i is the volume of water (AF) recharging the aquifer via Ag-GB in year *i*. All other terms remain as defined in Equation [6] (p. 56).

Also GW extractions (Equation 13, p. 60) need a slight modification to account for *in-lieu* recharge:

$$GE_i = \left[\sum_{j=1}^{J}\left(WD_{ij}\right) - D_i - IR_i\right] + \sum_{j=1}^{J} WD^{*}{}_{ij} \qquad [17]$$

Where IR_i is the portion of the water diverted for Ag-GB (AF) in year *i* that was consumed by the crop and hence used *in-lieu* of groundwater. All other terms remain as defined in Equation [13]. Implementation of Ag-GB as described in this section impacts the aquifer mass balance (Section 4.3.2). This information is used to feed the economic analysis.

4.5. Agronomic Model

Outputs from the Aquifer Mass Balance Model (Section 4.3) are used for the economic calculations. The economic implications of Ag-GB are estimated considering changes in:

- *Pumping costs* derived from Ag-GB implementation.
- *Farming costs*, which include changes in cost of water (surface and ground waters), farming costs (i.e., establishment and production) and additional costs likely to take place upon Ag-GB implementation (e.g., additional labor, berms, pesticides).

These changes in farming costs represent a change in revenues which are also analyzed. All calculations are performed for the OAWD Subunit and alfalfa is used for the agronomic analysis.

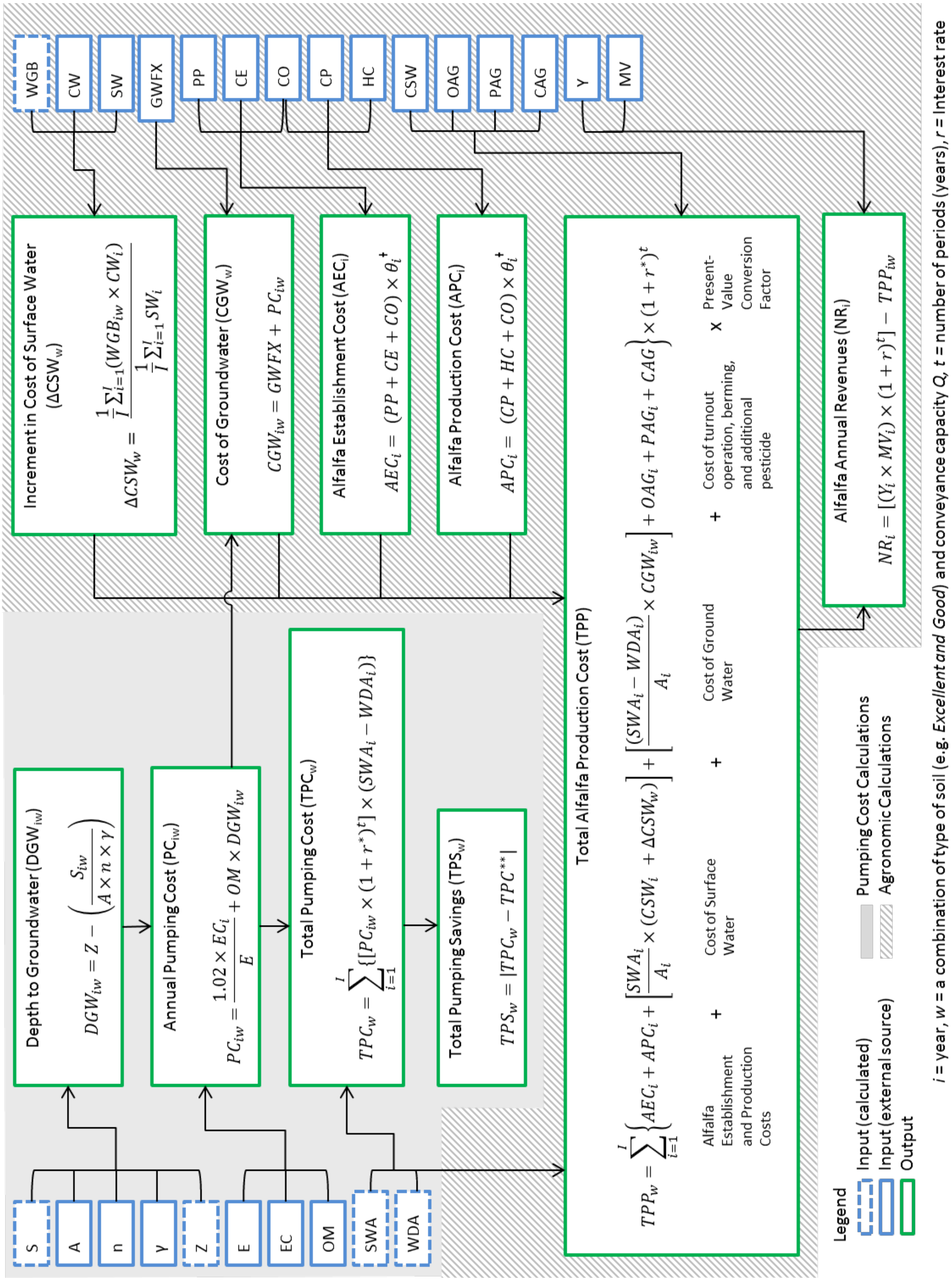


Figure 28: Agronomic model framework.

4.5.1. Pumping Costs

Costs associated with GW pumping increase with lower GW levels. The effect of banking water on GW levels is used in this section to estimate the potential economic consequences of Ag-GB in terms of pumping costs. Pumping costs are not to be confused with the cost of groundwater. Cost of groundwater is equal to pumping costs plus fixed costs as explained in Section 4.5.2.1.

Impact of Ag-GB on GW Levels

Following the concepts described in Section 4.3.1, the one-bucket aquifer is used to quantify the impact of Ag-GB on GW levels. For this study it is assumed that there is a single GW level that raises and drops evenly across the whole domain. This is a simplified approach intended to represent the general concept of banking a volume of water into the underlying aquifer. Further groundwater modeling will be needed for implementation and operation of Ag-GB. Nevertheless, this approach should provide insight for general economic analysis and planning purposes.

Equation [5] (p. 54) is rearranged to determine how GW levels change given the abovementioned considerations:

$$DGW_{iw} = Z - \left(\frac{S_{iw}}{A \times n \times \gamma}\right) \qquad [18]$$

Where, DWG_{iw} is the depth to GW (ft) in year i, and A_i is the total study area (acres). The rest of the terms remain as defined in Equation [5]. Suffix w refers to different combinations of conveyance capacity Q and type of soils.

Pumping Costs Calculations

Annual pumping costs are calculated per AF of water extracted from the aquifer:

$$PC_{iw} = \frac{1.02 \times EC_i}{E} + OM \times DGW_{iw} \qquad [19]$$

Where, PC_{iw} is the total pumping cost ($/AF) in year i, 1.02 is a conversion factor, EC_i is the energy cost ($/Kw-hr) in year i, E is the average pump efficiency (%), OM is the cost of operation and maintenance per foot of lift ($/ft), and DGW_{iw} is the GW depth (ft) in year i calculated with Equation [18]. Suffix w refers to different combinations of conveyance capacity Q and type of soils. EC_i depends on the price of electricity which varies as a function of the region and the season. In this study, EC_i is based on data provided by the *U.S. Energy Information Administration* and is the average of commercial and industrial energy costs in California (Appendix M). OM and E are assumed to be 0.025 $/ft (Howitt et al. 2010) and 70% respectively.

Results from these calculations are shown in Section 5.5.1 as the total cost of pumping (present value) from 1993 to 2013, and are calculated using the following equation:

$$TPC_w = \sum_{i=1}^{I} \{[PC_{iw} \times (1+r)^t] \times (SWA_i - WDA_i)\} \qquad [20]$$

Where, TPC_w is the total present value of pumping cost ($) in the period of analysis, PC_i is the pumping cost ($/AF) in year i calculated with Equation [19], r is the interest rate (6%), t is the number of years in the analysis, SWA_i is the surface water supplied (AF) to the Ag-GB alfalfa fields in year i, and WDA_i is the Ag-GB alfalfa water demand (AF) in year i. SWA_i is estimated as the Ag-GB alfalfa share of water as a function of acreage of the total water supplied in the district. Suffix w refers to different combinations of conveyance capacity Q and type of soils.

Finally, all *TPC's* values are compared to that of the base line scenario to estimate total savings. This calculation is performed using the following equation:

$$TPS_w = TPC - TPC_w \qquad [21]$$

Where, TPS_w is the total present-value pumping savings (\$) given a combination of conveyance capacity Q and type of soil w, TPC_w is the total present value of pumping (\$) as defined in Equation [20], and TPC is the total cost of pumping (\$) in the base line scenario (no Ag-GB).

4.5.2. Farming Costs and Revenues

The impacts of Ag-GB on alfalfa production costs and revenues are analyzed in this section. Cost of water (surface and ground waters) is treated separately and then added to the total costs of crop production (Section 4.5.2.2).

4.5.2.1. *Cost of Water*

<u>*Surface Water*</u>

OAWD charges its users per AF of water delivered. Water charges are divided in three types: base price, municipal and industrial (M&I), and full price. Appendix N shows water charges from 1993 to 2013. Data provided by OAWD (Appendix N) covers the 1996-2013 period; a linear regression is used to estimate charges from 1993 to 1995. It is assumed that all growers pay the base price for water and these water charges do not reflect tiered pricing.

When Ag-GB is implemented, the cost of surface water will change according to the following expression:

$$\Delta CSW_w = \frac{\frac{1}{I}\sum_{i=1}^{I}(WGB_{iw} \times CW_i)}{\frac{1}{I}\sum_{i=1}^{I} SW_i} \qquad [22]$$

Where, ΔCSW_w is the increment in surface water rates ($/AF), WGB_{iw} is the volume of water (AF) to be banked in year i as defined in Equation [15] (p. 71), CW_i is the fare OAWD pays the Bureau of Reclamation for additional water ($/AF) (Appendix O), and SW_i is the volume of surface water delivered by OAWD (Appendix K). Suffix w refers to different combinations of conveyance capacity Q and type of soils. ΔCSW represents the average increment to water rates ($/AF) OAWD would charge its users to pay for the Ag-GB water. The main assumption in this approach is that all users (whether their land is used for Ag-GB or not) share the cost of implementation; this is based on the idea that rather than OAWD extracting and delivering banked water to sell it to its clients; the banked water would be available for users to use when surface water supplies fall short. Therefore, all growers in the OAWD Subunit are assumed to participate in the Ag-GB program and the cost of implementation is split among all of them.

Ground Water

Cost of groundwater is defined by the following equation:

$$CGW_{iw} = GWFX + PC_{iw} \tag{23}$$

Where, CGW_i is the cost of groundwater ($/AF) in year i, $GWFX$ is the fixed cost ($/AF) based on typical well designs and costs within the region (Howitt et al. 2010), and PC_{iw} is the cost of pumping in year i as defined in Equation [19]. Howitt et al. (2010) estimates $GWFX$ in the study area as $27/AF. Suffix w refers to different combinations of conveyance capacity Q and type of soils.

The effects of Ag-GB on the cost of groundwater are implicit in the second term (PC_i) in Equation [22]. PC_i calculates the cost of pumping as a function of lift (i.e., vertical distance to GW).

4.5.2.2. *Crop Production Costs*

Sample costs to produce alfalfa in the Sacramento Valley are taken from Long et al. (2008) and are comprised of establishment costs and production costs. These prices are regional averages and vary according to farm-specific practices. Labor, equipment, materials, and operation and maintenance are included in these costs. Calculations in this section are performed only for alfalfa growers participating in the Ag-GB program. The probability of crop damage from flooding is not included in this analysis. Quantification of the risks imposed to alfalfa by implementation of Ag-GB would be necessary to assess more accurately the economic implications of Ag-GB in terms of crop production.

Establishment Costs

Establishment costs (Appendix P) include land preparation, planting, fertilization, pest management, and overhead costs. These costs are defined by the following equation:

$$AEC_i = (PP + CE + CO) \times \theta_i \qquad [24]$$

Where, AEC_i is the establishment cost ($/acre) in year i, PP is the annual pre-planting cost ($/acre), CE is the annual cultural cost ($/acre), CO is the annual overhead cost ($/acre), θ_i is the deflation/inflation factor in year i to adjust the sample prices from 2008 and it is defined as follows:

$$\theta_i = \begin{cases} (1 + r_i), & i > 2008 \\ \frac{1}{(1+r_i)}, & i < 2008 \end{cases} \qquad [25]$$

Where r_i is the inflation (%) in year i (Appendix R). Equation [24] assumes that prices prior to 2008 were lower according to inflation rates in California. The opposite is assumed for prices after 2008.

Production Costs

Production costs (Appendix Q) include cultural (weed control, fertilization, etc.), harvest costs, and overhead costs. These costs are defined by the following equation:

$$APC_i = (CP + HC + CO) \times \theta_i \qquad [26]$$

Where, APC_i is the production cost of alfalfa in year i (\$/acre), CP is the annual production cultural cost (\$/acre), HC is the annual harvest cost (\$/acre), and CO is the annual production overhead (\$/acre).

The model assumes there is production in an establishment year and the stand life is four years (i.e., establishment costs occur every four years). Calculations are performed assuming the first year of analysis is an establishment year.

Implementation of Ag-GB affect establishment and production costs through increments in SW rates and the cost of GW. When Ag-GB is implemented, by definition, GW levels would be higher and hence costs of pumping would drop. On the other hand the cost of SW would increase due to additional charges to convey the additional water for Ag-GB. These tradeoffs are shown and discussed in Section 5.5.2.

Total Crop Production Cost

Annual costs of surface water and groundwater are added to establishment and production costs to estimate total crop production cost in the entire period of analysis:

$$TPP_w = \sum_{i=1}^{I} \left\{ AEC_i + APC_i + \left[\frac{SWA_i}{A_i} \times (CSW_i \ + \Delta CSW_w) \right] + \left[\frac{(SWA_i - WDA_i)}{A_i} \times CGW_{iw} \right] + OAG_i + PAG_i + CAG \right\} \times (1+r)^t \qquad [27]$$

Where TPP_w is the total present value of crop production costs (\$/acre) for a given combination of type of soil and conveyance capacity Q, AEC_i is the establishment cost (\$/acre) in year i, APC_i is the production cost (\$/acre) in year i, r is the interest rate (6%), t is the count of year i, SWA_i is the surface water supplied to Ag-GB alfalfa fields in year *i* (AF), A_i is the acres of Ag-GB alfalfa in year *i*, CSW_i is the cost of surface water ($/AF), ΔCSW_w is the increment in surface water rates ($/AF) for a given combination of type of soil and conveyance capacity *Q*, WDA_i is the Ag-GB alfalfa water demand in year *i* (AF), CGW_{iw} is the cost of groundwater in year *i* ($/AF) for a given combination of type of soil and conveyance capacity *Q*, OAG_i is the additional cost ($/acre) of operating turnouts for Ag-GB in year *i*, PAG_i is the cost ($/acre) of one additional application of pesticide and herbicide to control worms and weeds that could appear due to flooding, and *CAG* is the capital cost of creating a berm ($/acre) to contain Ag-GB water. *CAG* is assumed to be $12/acre based on similar earthwork costs in the region. OAG_i is averaged at $12/acre in 2008 (Long et al. 2008) for flood irrigation in the Sacramento Valley during normal irrigation season. Because Ag-GB is implemented in the winter, it may be challenging and/or more expensive to find labor for turnout operation. To account for this, different values of OAG_i ($12/acre to $50/acre) are used in the analysis. PAG_i is assumed to be $85/acre based on sample costs from Long et al. (2008). ΔCSW, *OAGi*, PAG_i, and *CAG* are applicable only when Ag-GB is implemented. For the base line scenario these terms are zero.

Two scenarios are considered for implementation of the program: (A) all growers (including alfalfa growers banking water) pay for the increment in cost of SW (ΔCSW), and alfalfa growers banking (Ag-GB growers) water pay for additional operational Ag-GB costs (i.e., labor, berms, and pesticides). (B) Ag-GB growers are waived all Ag-GB implementation costs which in turn are paid by the rest of the OAWD growers. The motivation behind these two policies is to compare the potential economic impacts on all growers in the irrigation district under the two scenarios, and study the effects of incentivizing Ag-GB alfalfa growers to participate in the program by waiving all Ag-GB related costs. These policies are summarized in Table 8.

Table 8. Summary of policy scenarios.

Type of Grower	Definition	Policy Scenario	Implication
Ag-GB Alfalfa Grower	Alfalfa grower using their land for Ag-GB	A	Grower required to pay ΔCSW and Ag-GB on-farm costs.
		B	Grower exempted from any Ag-GB related costs.
Non Ag-GB Grower	the rest of growers in OAWD	A	Grower required to pay ΔCSW only.
		B	Grower required to pay ΔCSW and Ag-GB on-farm costs.

4.5.2.3. *Crop Revenues*

Average annual production yields and market values of alfalfa were obtained from the Glenn County Crop Reports (Appendix S). These data are used to observe the impact of Ag-GB on the Ag-GB alfalfa farmers. Net annual revenues are calculated with the following equation.

$$NR_i = [(Y_i \times MV_i) \times (1 + r)^t] - TPP_i \qquad [28]$$

Where, NR_i is the present-value net revenue (\$/acre) in year i, Y_i is the production yield (ton/acre) in year i, MV_i is the market value of alfalfa (\$/ton) in year i, r is the interest rate (6%), t is the count of year i, and TTP_i is the present-value total production cost (\$/acre) in year i. Equation [28] is used for both the base line and Ag-GB scenarios.

Outputs from Equation [28] are not shown in Section 5 due to lack of reasonable results. This is due to use of average regional data for both costs and revenues. Sample production costs were obtained for 2008 for the entire Sacramento Valley (Long et al. 2008) and then deflated/inflate accordingly. Similarly, annual production yields and market values of alfalfa were obtained from the Glenn County Crop Reports (Appendix S). These average costs and revenues lead to mostly negative revenues when Equation [28] is applied; and when revenues are positive these are too small to be rentable. The method shown below is included in this document to illustrate the original intent of the author. Equation [28] however, is valid if populated with representative values specific to the study area.

4.6. Feasibility Analysis

The analysis to determine economic feasibility has three steps: (1) Pumping savings are compared to increments in cost of surface water (ΔCSW), (2) Policies A and B are analyzed for Ag-GB alfalfa growers, and (3) the policy that performs better for Ag-GB alfalfa growers is tested for the rest of the growers in OAWD (non Ag-GB growers). Ag-GB options that offer positive benefits for both Ag-GB and Non Ag-GB growers are considered economically feasible.

4.6.1. Pumping Savings v. Increment in cost of surface water (ΔCSW)

This portion of the analysis is performed to show the potential benefits of Ag-GB for the OAWD subunit in terms of pumping costs. The averages of pumping savings and ΔCSW are used for the calculations. Net benefits in terms of pumping costs are calculated using the following equation:

$$APB_{iw} = \left[\frac{1}{I}\sum_{i=1}^{I}(PC_{iw} - PC_i)\right] - \Delta CSW_w \qquad [29]$$

Where, APB_{iw} is the average annual net benefit (\$/AF) in year i, PC_{iw} is the pumping cost (\$/AF) in year i, PC_i is the pumping cost (\$/AF) in year i in the base line scenario (no Ag-GB), and ΔCSW_w is the increment in cost (\$/AF) of surface water. Suffix *w* refers to different combinations of conveyance capacity Q and type of soils.

A two-sample, two-tail t-test is performed between the pumping savings and the two sets of SW cost increments to determine if the differences are statistically significant. The Data Analysis Tool Kit within *Excel* is used to perform this test. A significance level of $\alpha = 0.05$ and a t threshold of 1.98 are used to determine the reliability of the test results.

Finally, only Ag-GB options that offer positive net benefits to Ag-GB alfalfa growers and non Ag-GB growers are considered for the feasibility analysis. As a results, an assortment of Ag-GB options are presented that show the potential to yield benefits to all growers in OAWD.

4.6.2. Impact of Banking on Ag-GB Alfalfa Growers

As explained in Section 4.5.2, implementation of Ag-GB on alfalfa fields has an economic impact on production costs. Total present-value production costs from all combinations of conveyance capacity Q and types of soils are compared between the two proposed policies. A net benefit approach (NB) is used to determine which policy is economically feasible. To do this, present-value total costs are converted to annual costs. Options with a NB greater than zero are considered economically feasible. The following equation is used:

$$NBAG_{wz} = (TPP \times \varphi) - (TPP_{wz} \times \varphi) \quad , \quad \varphi = \frac{r \times (1+r)^t}{(1+r)^t - 1} \qquad [30]$$

Where $NBAG_{wz}$ is the net benefit (\$/acre) for a given combination of Q and soil type w under a policy z, TPP in the present-value total production cost (\$/acre) in the base line scenario (no Ag-GB), TPP_{wz} is the present-value total production cost (\$/acre) for a given combination of Q and type of soil w under a policy z, and φ is the conversion factor from present value to annual value.

4.6.3. Impact of Banking on Non Ag-GB Growers

This study assumes that growers in OAWD not using their land for Ag-GB would have to pay for implementation of the program under both policies. The net benefits for these farmers are estimated as a function of the total pumping savings and Ag-GB related costs (ΔCSW, and on-farm operational costs for Ag-GB growers in the case of policy B). Similar to Equation [28] (p. 82), all costs are annualized. The following equation is used:

$$NBN_{wz} = \frac{(TPS_w \times \varphi) - \sum_{i=1}^{I}(SW_i \times \Delta CSW) - \sum_{i=1}^{I}[(OAG_i + PAG_i + CAG) \times A_i]}{\bar{A}} \qquad [31]$$

Where, NBN_{wz} is the net benefit (\$/acre) for all non Ag-GB growers for a given combination of Q and type of soil w, TPS_w is the total present-value pumping savings (\$) (Equation 21, p. 76) for a given combination of Q and type of soil w, SW_i is the amount of water (AF) delivered to non Ag-GB growers in year i, ΔCSW is the corresponding increment in cost of surface water (\$/AF) (Equation 22, p. 77), $\bar{A}$ is the average acreage of non Ag-GB growers in the period of analysis, and φ is the conversion factor from present value to annual value (Equation 29, p. 84). All other terms remain as defined in Equation [27] (p. 81).

5. Results

Model results pertaining to land use distribution, agricultural water demands, aquifer mass balance, and economic analysis are presented and discussed in this section. Aquifer mass balance and economic results are presented considering the scenarios described in the methodology (Section 3).

5.1. Land Use

Figures 29 and 30 show the land use patterns between 1993 and 2013 in the OAWD and GW-Only subunits respectively. Permanent crops (orchards and vineyards) had a dramatic increase over the years in both subunits: ~140% in OAWD and ~200% in GW-Only. On the other hand, field crops (tomatoes, corn, cotton, berries, etc.) had a decline: ~40% in OAWD and ~50% in GW-Only. Pasture (alfalfa and pasture) however, showed a slight decline overall despite experiencing significant ups and downs over the years: ~40% in OAWD and ~20% in GW-Only. The flat sections in the graphs correspond to those years with no available land use data as mentioned in Section 4.2.1. A year-by-year breakdown of the changes in land use for these crops is shown in Table 9. The shift from field crops to permanent crops reflect the tendency of growers to move to high value crops as the cost of water (mostly from pumping and/or deepening wells) increases. This tendency translates to higher water demands and greater economic impacts if water sources were to be significantly reduced.

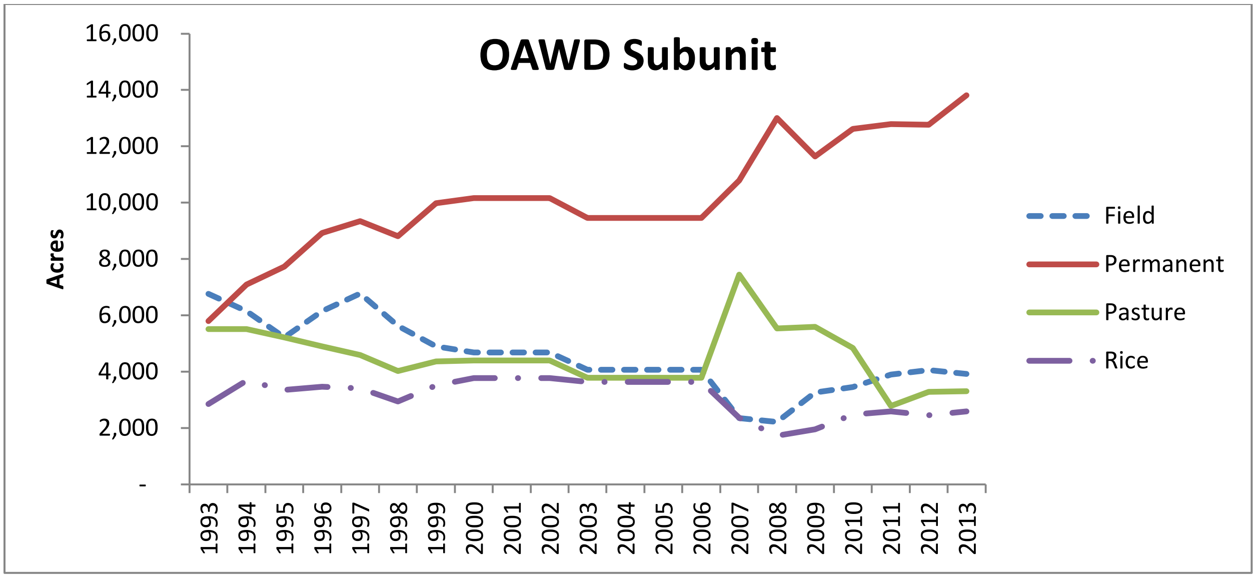


Figure 29: Land use patterns in the OAWD Subunit.

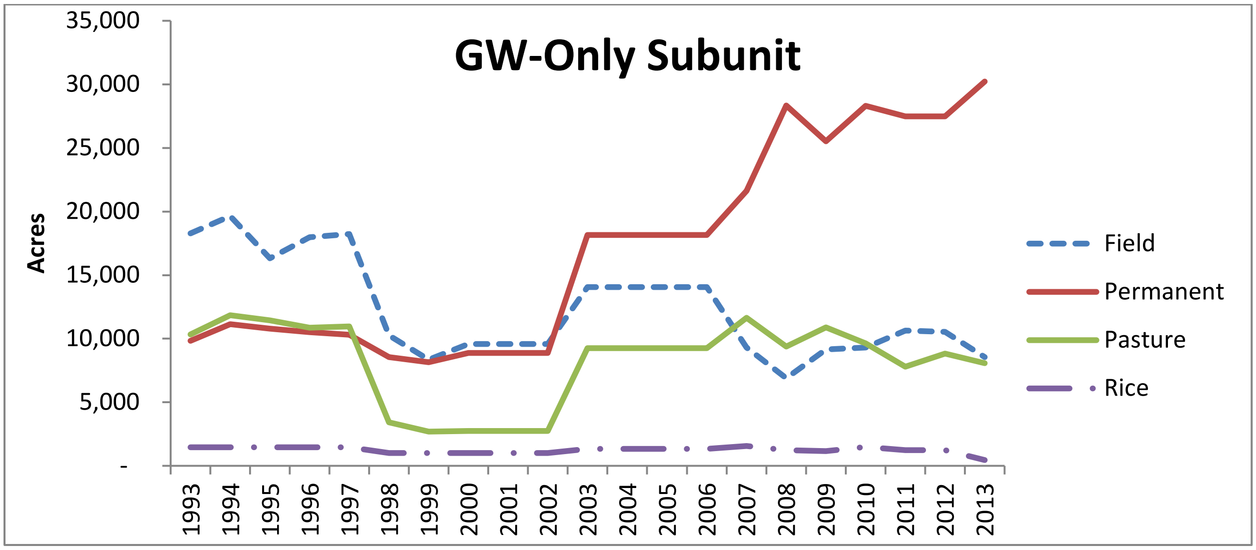


Figure 30: Land use patterns in the GW-Only Subunit.

Table 9: Annual percentage change in land use by crop group.

Year	OAWD Subunit				GW-Only Subunit			
	Field	ermanen	Pasture	Rice	Field	Permanent	Pasture	Rice
1993	-	-	-	-	-	-	-	-
1994	-9%	22%	0%	29%	7%	13%	15%	0%
1995	-15%	9%	-5%	-9%	-17%	-3%	-3%	0%
1996	18%	15%	-6%	3%	10%	-3%	-5%	0%
1997	10%	5%	-6%	-2%	1%	-2%	1%	0%
1998	-17%	-6%	-12%	-14%	-44%	-17%	-69%	-32%
1999	-13%	13%	8%	19%	-19%	-5%	-21%	0%
2000	-4%	2%	1%	8%	15%	9%	2%	0%
2001	0%	0%	0%	0%	0%	0%	0%	0%
2002	0%	0%	0%	0%	0%	0%	0%	0%
2003	-13%	-7%	-14%	-4%	47%	104%	237%	34%
2004	0%	0%	0%	0%	0%	0%	0%	0%
2005	0%	0%	0%	0%	0%	0%	0%	0%
2006	0%	0%	0%	0%	0%	0%	0%	0%
2007	-42%	14%	97%	-35%	-34%	19%	26%	16%
2008	-5%	21%	-26%	-27%	-26%	31%	-19%	-20%
2009	47%	-11%	1%	13%	33%	-10%	16%	-7%
2010	6%	8%	-13%	27%	2%	11%	-11%	28%
2011	13%	1%	-43%	5%	14%	-3%	-19%	-17%
2012	4%	0%	18%	-5%	-1%	0%	13%	1%
2013	-3%	8%	1%	6%	-19%	10%	-8%	-63%

5.2. Agricultural Water Demands

As mentioned in the previous section, the increase in permanent crops represents a proportional increase in water demand. As shown in Figure 31, water demands in the OAWD Subunit went from 72,300 AF in 1993 to 101,100 AF in 2013, with a maximum of 111,300 AF in 2008 when permanent crops and pasture and alfalfa acres peaked combined. The lowest water demand was 53,500 AF in 1998. Similarly, water demands in the GW-Only Subunit varied from 133,100 AF in 1993 to 204,000 AF in 2013, with the highest demand at 225,300 AF in 2008 and the lowest demand at 47,200 AF in 1998. As mentioned in Section 3, the OAWD subunit contracts every two years with the USBR to receive 53,000 AF annually. It becomes evident that growers in the OAWD Subunit depend on groundwater to satisfy their water demand as shown in Section 5.3.2.

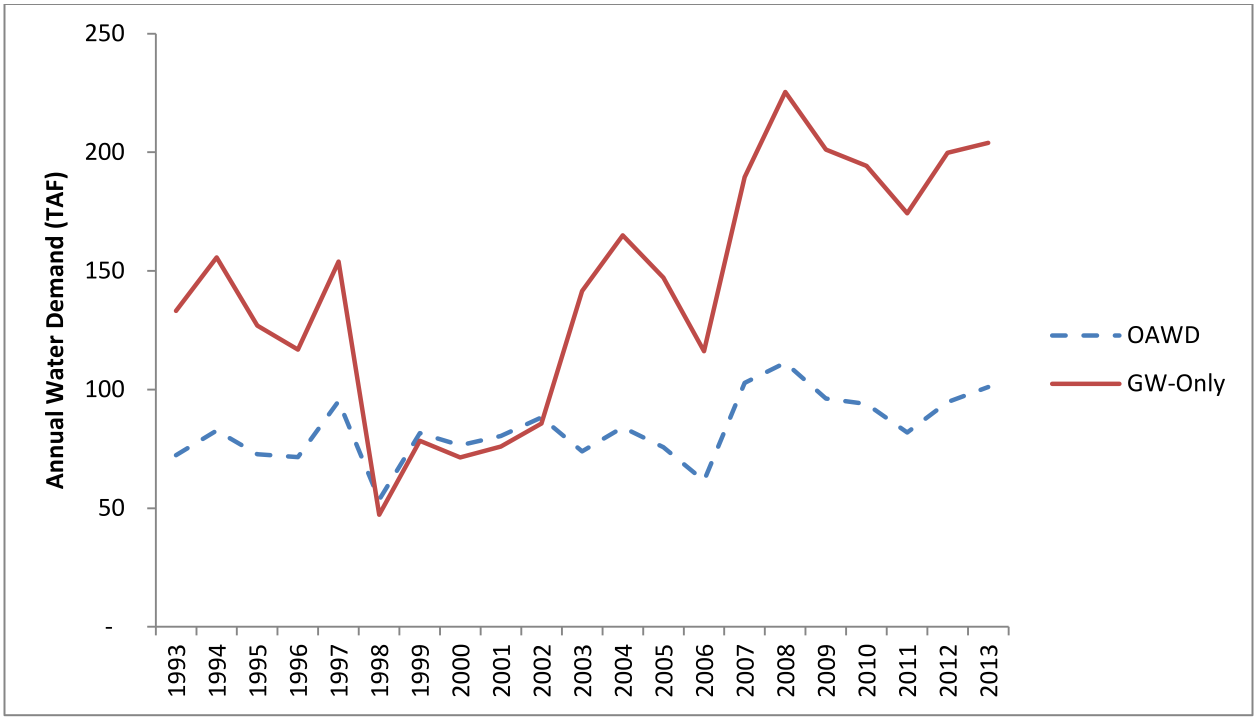


Figure 31: Annual agricultural water demand

5.3. Aquifer Mass Balance

5.3.1. Aquifer Storage from GW Levels Data

The aquifer storage in the entire study area was estimated for the different years. Porosity *n* is given a value of 0.20 and the safe yield γ is 7% as mentioned in Section 4.3.1. The datum *Z* is set as 600 ft. With these considerations and applying Equation [5] (p. 54), the resulting aquifer storage for the corresponding years is shown in Figure 32. The vertical axis in this figure starts at 700 TAF rather than zero to offer a better visualization of changes in storage overtime.

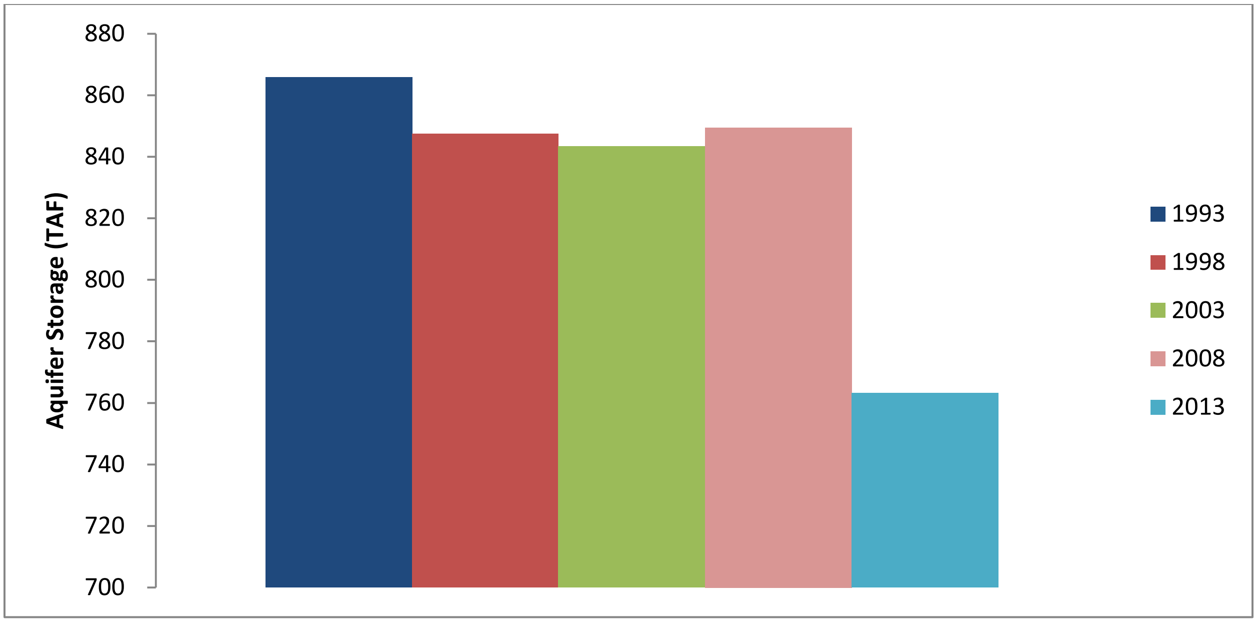


Figure 32: Aquifer storage from GW levels data.

Even though changes in storage shown in the figure above appear to be significant (notice the vertical axis starts at 700 TAF), particularly the one between 2008 and 2013; they represent a decline in total storage of -2.6% on average. Table 10 shows these changes in storage as volume and percentage. Even between 2008 and 2013, where the current drought takes place (starting in 2011), the change in storage is 10.2%. The fact that the aquifer tends to recover from annual extractions suggests that annual recharge in the area tends to be greater than annual extractions; or, groundwater lateral inflows are greater than outflows. It could be also a combination of the two. These assumptions are tested in Section 5.3.2. Results in this section are used to calibrate the aquifer storage time series calculated as explained in Section 4.3.2.

Table 10: Changes in storage in the entire study area.

Year	ΔS	
	AF	%
1993-1998	-18362.7	-0.5%
1998-2003	-4157.2	-0.5%
2003-2008	6195.1	0.7%
2008-2013	-86289.5	-10.2%

5.3.2. Aquifer Storage from Water Mass Balance

Following the methods described in Section 4.3.2, aquifer recharge, extractions from the aquifer, and the aquifer storage time series are presented in this section.

Recharge

Aquifer recharge is divided in recharge from precipitation and recharge from irrigation. Figure 33 shows total annual recharge in AF and its contributions from precipitation and irrigation. There are three features worth observing in the figure above. Firstly, there is a clear decline in total annual recharge. This trend is reflected in the change in storage estimated in Section 5.3.1. Whether total annual recharge tends to be greater than total annual extractions is discussed later in this section. Secondly, precipitation plays a major role in recharging the aquifer every year as it represents ~70% of the annual total on average; the rest coming from excess irrigation. Thirdly, despite representing roughly 30% of the total annual recharge, recharge from irrigation shows a slight increase over time. This increase allows recharge from irrigation to surpass recharge from precipitation in 2007 and 2013. These findings highlight the role irrigated agriculture can play in recharging the aquifers during a drought. This role however, is reduced as more efficient irrigation systems are implemented.

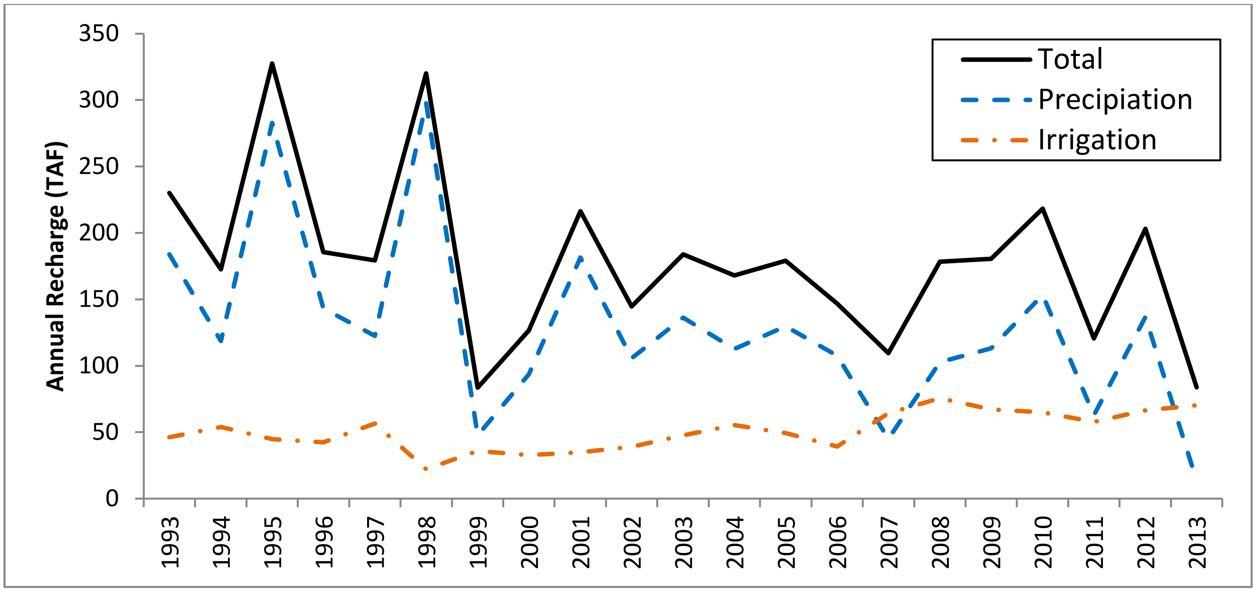


Figure 33: Annual aquifer recharge.

<u>GW Extractions</u>

Groundwater extractions were calculated using Equation [13] (p. 60) for both subunits. Figure 34 shows results from these calculations. Extractions in the GW-Only Subunit are equal to its water demands (Section 5.2) because growers in this subunit do not receive supplemental surface water for irrigation. Because of this, GW-Only growers pump as much as 80% of the total annual extractions in the study area on average. OAWD growers on the other hand, extract only the 20% of the annual total on average. Despite these numbers, the OAWD Subunit had a sustained increase in GW extractions between 2006 and 2013, reaching its highest point in 2008 with 82,000 AF. These results are coherent with land use trends shown in Section 5.1.

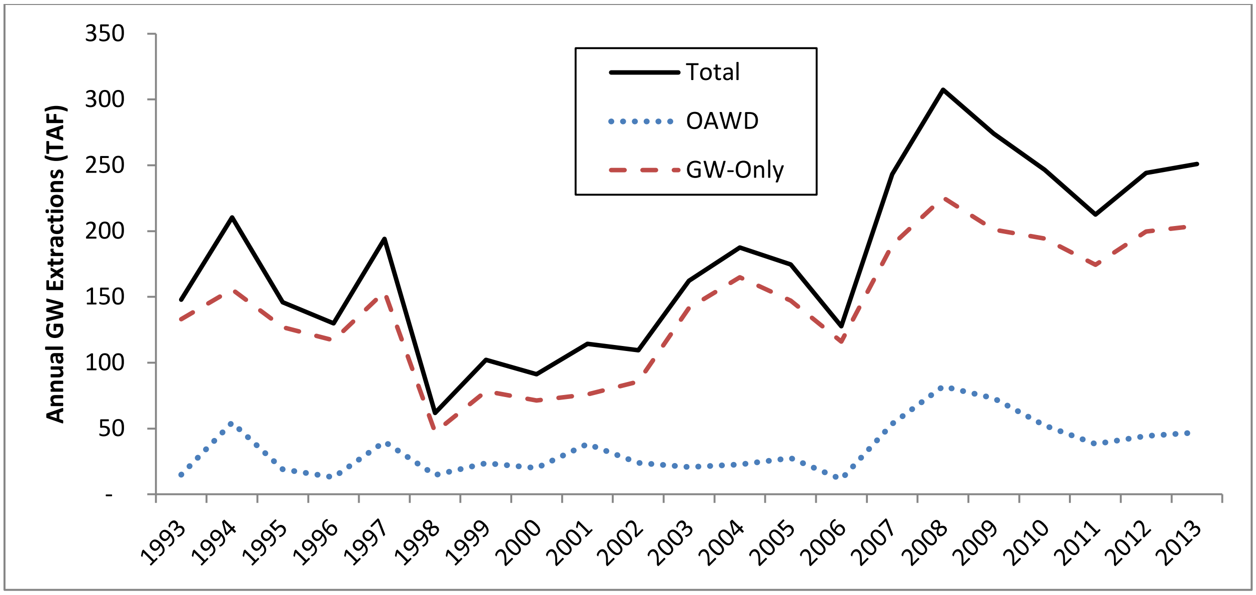


Figure 34: Total annual GW extractions.

Aquifer Mass Balance

The aquifer mass balance is calculated with Equation [6] (p. 56). Aquifer recharge, GW extractions, and water deliveries to the district (Appendix M) are used as inputs. Results of these calculations are shown in Figure 35.

The red squares in Figure 35 represent the aquifer storage estimated using Equation [5] (p. 54) and are used as reference points to adjust aquifer storage calculated with Equation [6] (blue line). As mentioned in Section 4.3.2, the aquifer mass balance was fitted to the reference points by adjusting the gains and losses to the aquifer.

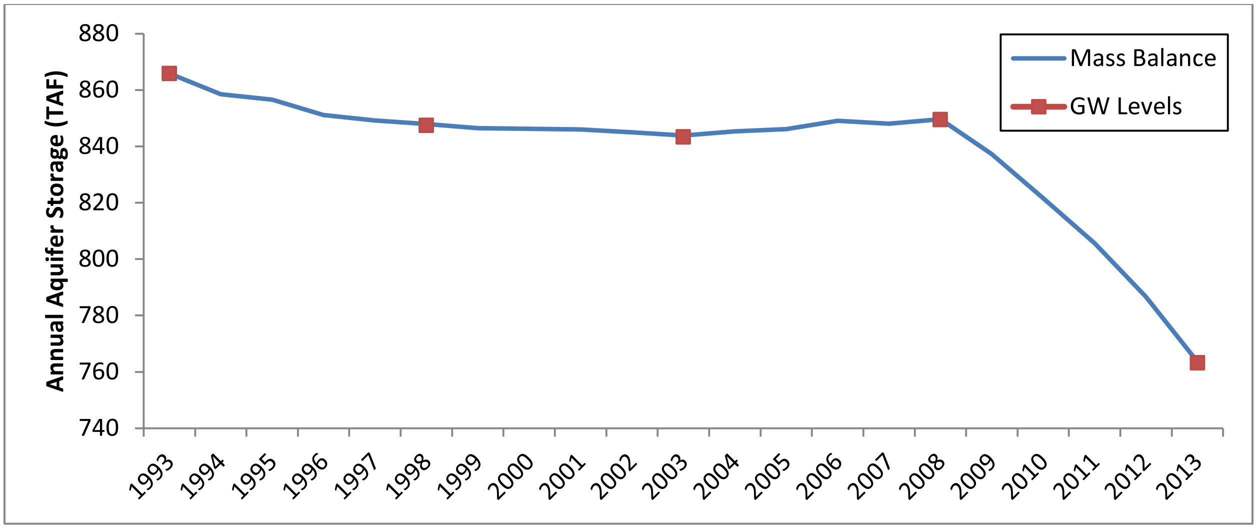


Figure 35: Aquifer storage from water mass balance.

Table 11 summarizes results from Equation [6] and shows that between 1993 and 2013, annual recharge is greater than total GW extractions during the period of analysis. Also, aquifer gains and losses are in close proximity (losses are ~6% greater). These findings support assumptions made in Section 5.3.1 regarding the general behavior of the aquifer. Under these considerations, it appears that fluxes in the aquifer are large and the amount of water entering the aquifer is approximately equal to that leaving the aquifer. However, between 2004 and 2013, aquifer outflows are greater than inflows. This behavior corresponds to the recent water table drawdown in this region. These results show that there is a high potential for Ag-GB; however, given the considerable amount of horizontal movement of water in the aquifer (lateral inflows and outflows), the banked water may not remain in the aquifer for a long enough period of time. This factor is currently being investigated in a high-resolution IWFM model of the area. However, this possibility is largely ignored in the economic analysis presented in this study.

Table 11: Summary of aquifer mass balance (AF) from 1993 to 2013.

Mass Balance Component	Subunit		Total
	OAWD	GW-Only	
Surface Water Delivered	178,964	0	178,964
Water Demand	1,752,341	3,003,092	4,755,432
GW Extractions	735,091	3,003,092	3,738,182
Aquifer Recharge	-	-	3,758,246
Aquifer Gains	-	-	701,301
Aquifer Losses	-	-	741,522

5.4. Groundwater Banking

5.4.1. Groundwater Banking Capacity

As explained in Section 4.4.2, the amount of water that can be diverted into the OAWD for Ag-GB is limited by four factors: (1) total acres of suitable land with appropriate crops, (2) infiltration rates of such lands, (3) surplus water availability, and (4) water conveyance capacity. Results for these factors are presented in this section.

Total Suitable Land Available

Figures 36 to 39 show the acres of alfalfa on soils considered in this study. These soils are divided into K_{sat} tiers (Table 5) as explained in Section 4.4.1.1. From these images it can be seen the significant gap between acres of alfalfa overlying different K_{sat} tiers. Also, when deep tillage is considered (Figures 36 and 37), soils with the smallest K_{sat} dominate (i.e., have more acres). When deep tillage is not considered (Figures 38 and 39), soils with greater Ksat dominate. Table 12summarizes these results.

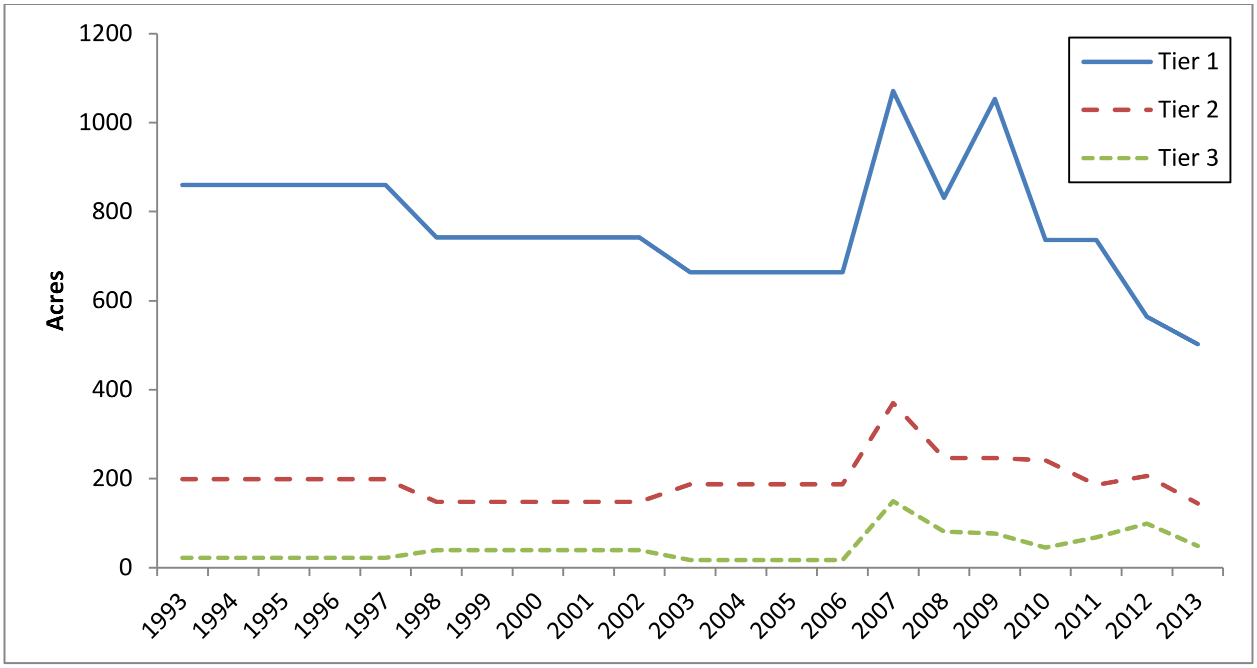


Figure 36: Acres of alfalfa on *Excellent* and *Good* soils (modified SAGBI). Tier 1 = 1.14 ft/day, tier 2 = 11.60 ft/day, tier 3 = 17.16 ft/day.

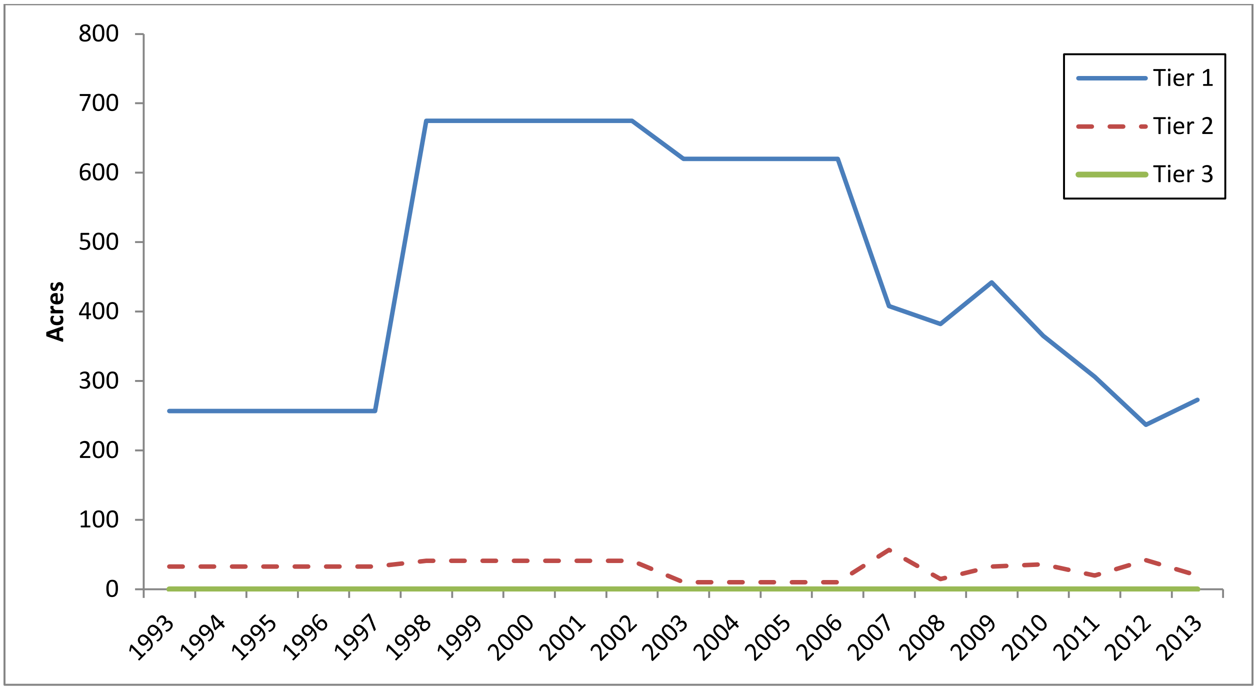


Figure 37: Acres of alfalfa on *Moderately Good* soils (modified SAGBI). Tier 1 = 0.73 ft/day, tier 2 = 0.98 ft/day, tier 3 = 2.53 ft/day.

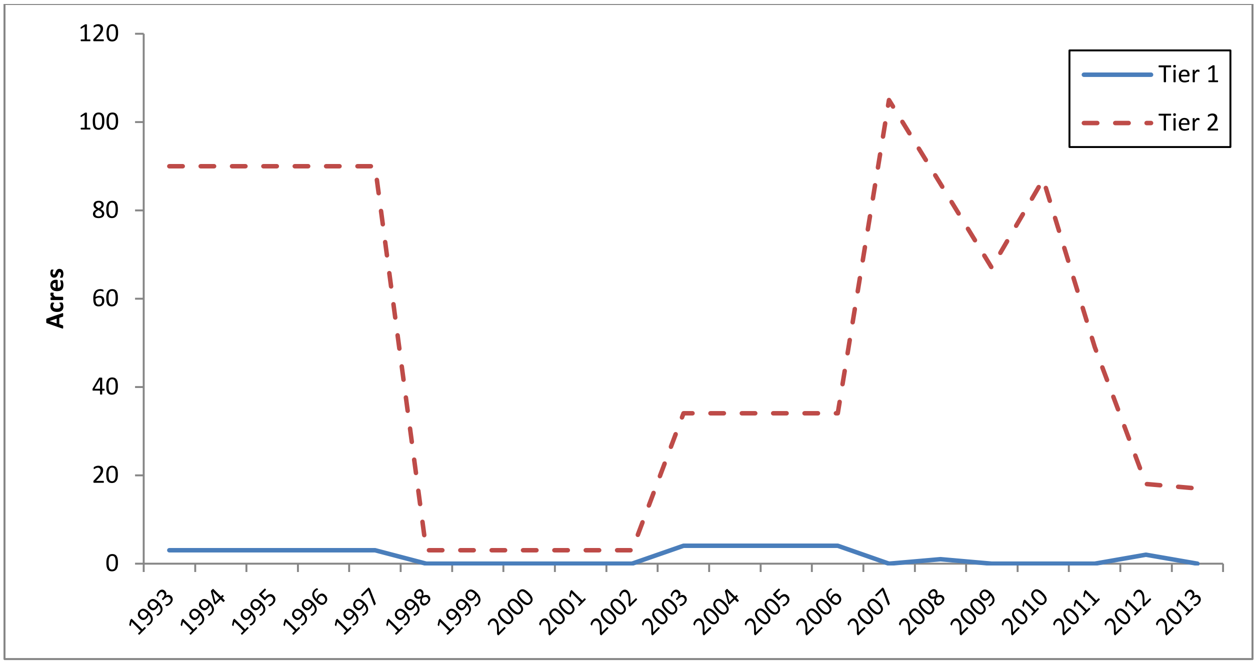


Figure 38: Acres of alfalfa on *Excellent* and *Good* soils (unmodified SAGBI). Tier 1 = 1.48 ft/day, tier 2= 5.78 ft/day.

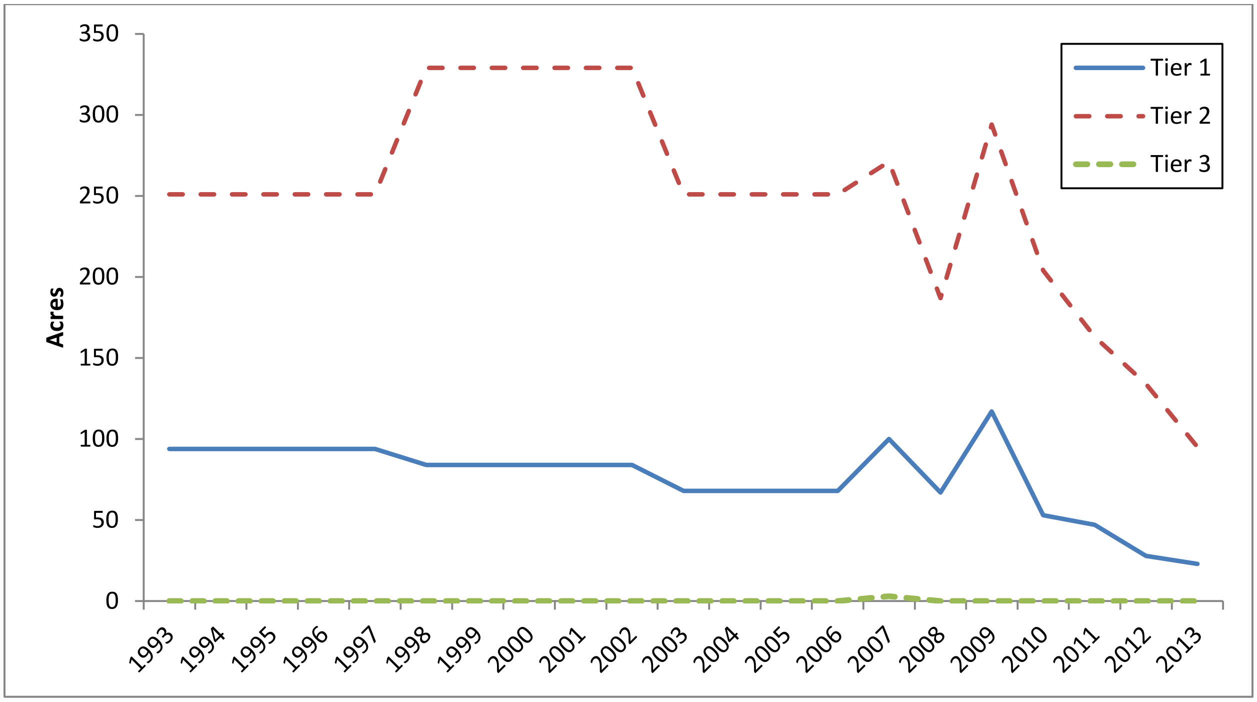


Figure 39: Acres of alfalfa on *Moderately Good* soils (unmodified SAGBI). Tier 1 = 0.90 ft/day, tier 2 = 1.16 ft/day, tier 3 = 5.78 ft/day.

Table 12: Summary of acres of alfalfa on different soils.

Type of soil	Unmodified SAGBI (acres)									Modified SAGBI (acres)								
	Tier 1			Tier 2			Tier 3			Tier 1			Tier 2			Tier 3		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Excellent and Good	0	4	2	3	105	49	-	-	-	502	1071	769	144	370	196	17	149	45
Mod. Good	23	117	76	95	329	250	0	3	0	237	675	455	10	57	30	0	0	0

Surplus Water Availability for Ag-GB

Results from methods explained in Section 4.4.3 are presented here. Table 13 shows the total volume of water above the 90th percentile in each year as well as the number of days the flow in the river exceeded said threshold. These volumes of water are not the total water that can be diverted into OAWD for Ag-GB; they only provide an estimate of water that occurs during large flow events.

Table 13: Total annual excess water (above the 90th percentile).

Year	# of Days w/ Excess Water	Excess Water (AF)	Year	# of Days w/ Excess Water	Excess Water (AF)
1993	12	476,587	2004	20	971,076
1994	0	0	2005	10	696,561
1995	32	1,786,832	2006	17	735,081
1996	24	1,294,354	2007	0	0
1997	29	1,128,442	2008	0	0
1998	81	2,887,323	2009	0	0
1999	3	7,895	2010	6	228,273
2000	18	774,180	2011	28	528,362
2001	6	74,841	2012	10	299,722
2002	11	535,942	2013	0	0
2003	8	296,305	-	**Total**	**12,721,776**

Water Available for Ag-GB

Results from Equation [15] (p. 71) are shown in this section. Table 14 and Figure 40 show the total volume of banked water in the study area (both subunits) during the period of analysis. Figure 40 shows the linear relationship between *Q* (Section 4.4.2) and the cumulative volume of banked water during the period of analysis (*WGB*). This linear relationship exists due to the combination of large areas with high infiltration rates. When either infiltration rates or acreage – or both– are not sufficient to capture the diversion capacity (i.e., turnouts) the aforementioned relationship is no longer linear.

Table 14: Total (1993-2013) water banked (AF) using different proposed conveyance capacities *Q*.

Q (cfs)	Modified SAGBI		Unmodified SAGBI	
	E&G	ModG	E&G	ModG
427	253,768	118,575	63,855	116,176
400	239,856	118,575	63,855	116,176
350	210,156	118,575	63,855	116,176
300	180,456	118,575	63,855	116,176
250	150,756	114,515	62,195	116,176
200	121,000	99,372	53,195	109,755
150	90,972	82,121	44,195	88,138
100	60,617	61,245	33,708	60,068
50	30,159	30,788	18,767	29,810
25	14,991	15,620	10,799	14,643
5	2,425	3,020	3,344	2,182
0	-	-	-	-

Figure 40 also highlights the potential the considered soils have in terms of infiltration capacity. For instance, the *Excellent* and *Good* soils (Modified SAGBI, labeled as E&G M) show potential to accommodate the maximum diversion capacity of OAWD (427 cfs). On the other hand, the *Excellent* and *Good* soils (Unmodified SAGBI, labeled as E&G U) could take up to about 300 cfs. Similarly, the *Moderately Good* soils (both versions of SAGBI) could infiltrate water up to a rate of about 300 cfs.

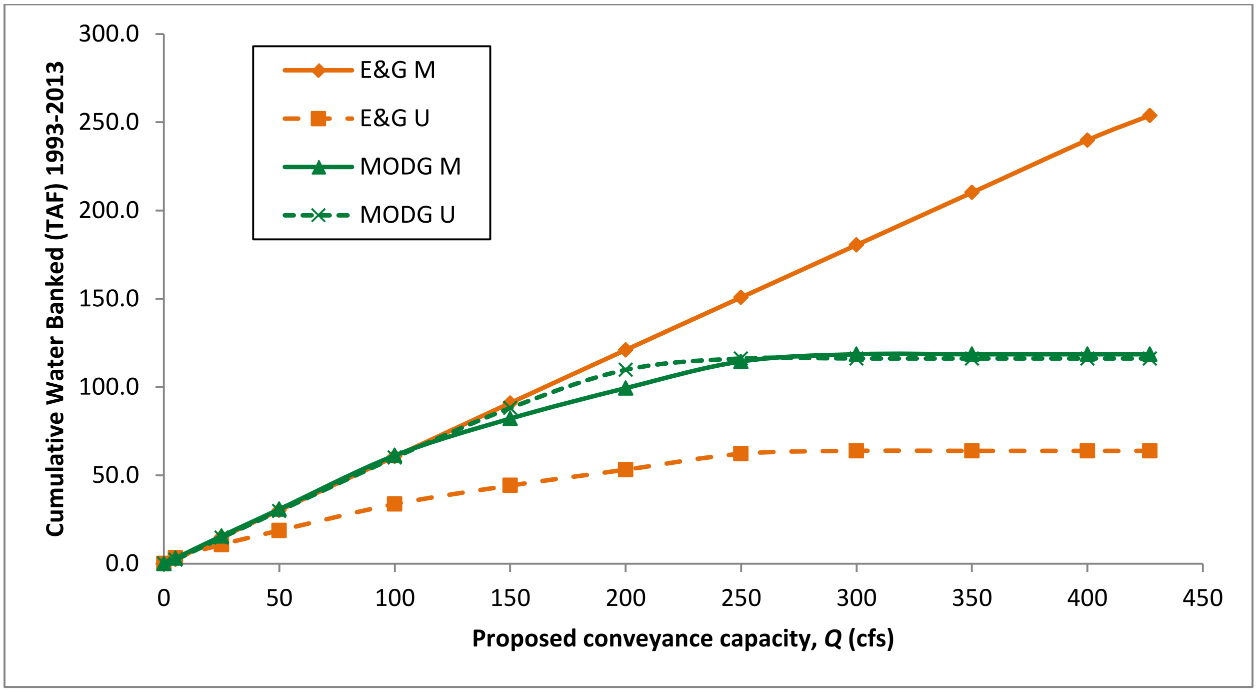


Figure 40: Total (1993-2013) water banked (AF) using different proposed conveyance capacities *Q*.

The plateaus in Figure 40 mean that either or both infiltration capacities and acreage of these soils are not sufficient to infiltrate water within 24 hours at rates greater than 300 cfs. In these cases, the maximum volume of water to be banked *K* (Section 4.4.2) is limited by the conveyance capacity *Q* of 300 cfs. After these maximum *K* values are reached no more water can be diverted onto the fields on the same day (24-hour period). These results are presented as depth of water per acre (ft/acre or AF/acre) in Appendix T.

5.5. Agronomic Model

Results in this section are presented for all combinations of conveyance capacity *Q*, soil types, and costs of turnout operation under policies A and B. Refer to Appendix AA for a graphical distribution of these variables.

5.5.1. Pumping Costs

GW Levels

Model runs using Equation [18] (p. 75) and different combinations of *Q* (5 cfs < *Q* <427 cfs) and soils (Modified and Unmodified SAGBI, Excellent and Good and Moderately Good) are shown in Figure 41. This figure shows the envelope of potential groundwater levels considering all the different permutations of the aforementioned parameters. In this plot the maximum and minimum (dashed lines) GW depth changes are highlighted along with those from the base line scenario (no Ag-GB).

The best performance is yielded by the *Excellent and Good* soils when deep tillage is considered (Modified SAGBI) and assuming the maximum *Q* (427 cfs) can be diverted for Ag-GB. On the other hand, the *Excellent and Good* soils when deep tillage is considered yielded the smallest improvement to GW levels assuming a *Q* of 5 cfs. An adjustment was necessary for some model runs due to generation of negative GW depths (i.e., GW depths above ground level). This is due to the inherent limitations of the conceptual one-bucket model. In these cases, a maximum GW depth of 10 ft was defined in the model.

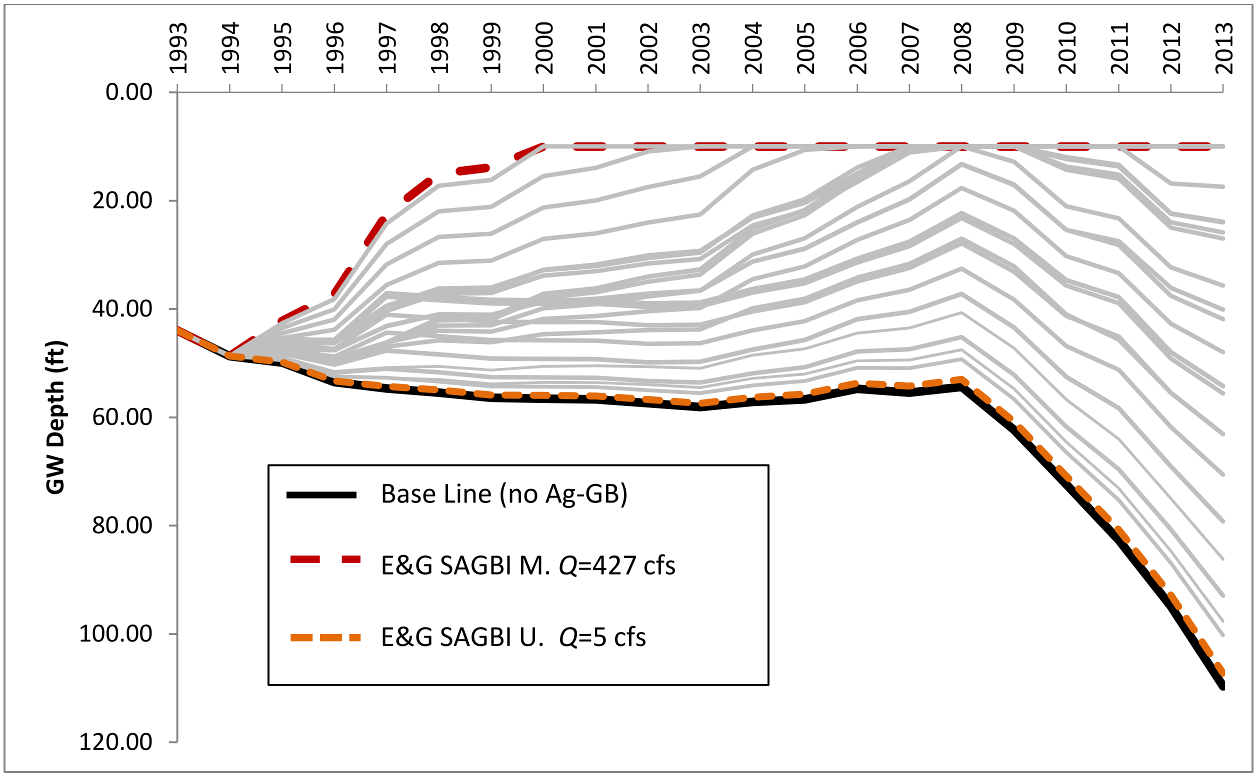


Figure 41: GW depths (ft) model runs.

Pumping Costs

Results from Equation [19] (p. 75) and Equation [20] (p. 76) are shown in the figures below. Figure 42 shows the annual variation in pumping costs per AF. For the base line scenario (no Ag-GB) the average annual pumping cost is $11/AF with a maximum of $23.30/AF in 2013 and a minimum of $6.80/AF. This means a ~240% increase in pumping costs between 1993 and 2013. The best performance (*Excellent and Good* soils, Modified SAGBI; *Q* =427 cfs) yields savings of $21.17/AF (~90%) compared to the pumping cost in 2013 in the base line scenario. The poorest performance (*Excellent and Good* soils, Unmodified SAGBI; *Q* =5 cfs) yields $0.6/AF (~2%) in savings in the same year.

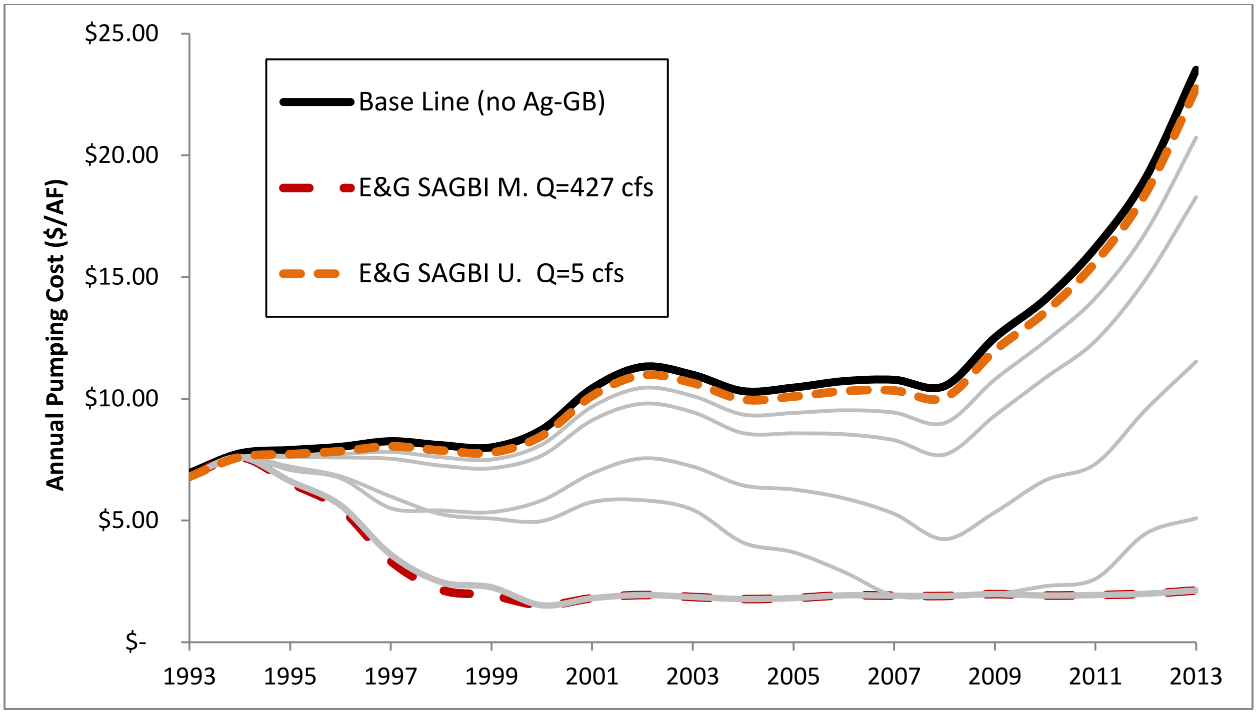


Figure 42: OAWD Annual pumping costs ($/AF).

Figure 43 and Figure 44 show the total present value of pumping cost (Equation 20), and the present-value pumping savings (Equation 21) respectively. In this plot, pumping costs are the sum of annual total costs ($/AF times total pumping volume in AF) in the OAWD Subunit between 1993 and 2013. These total costs are subtracted from those of the base line scenario to estimate total savings (present value) during the period of analysis. From Figure 44 it can be seen the variation in total pumping savings with different combinations of *Q* and types of soil. For instance, using the *Excellent and Good* soils (Unmodified SAGBI) and assuming that 300 cfs of water can be banked every time there is excess water available; total costs amount to about $8M compared to $12.5M in the base line scenario, meaning roughly $4.5M in savings between 1993 and 2013.

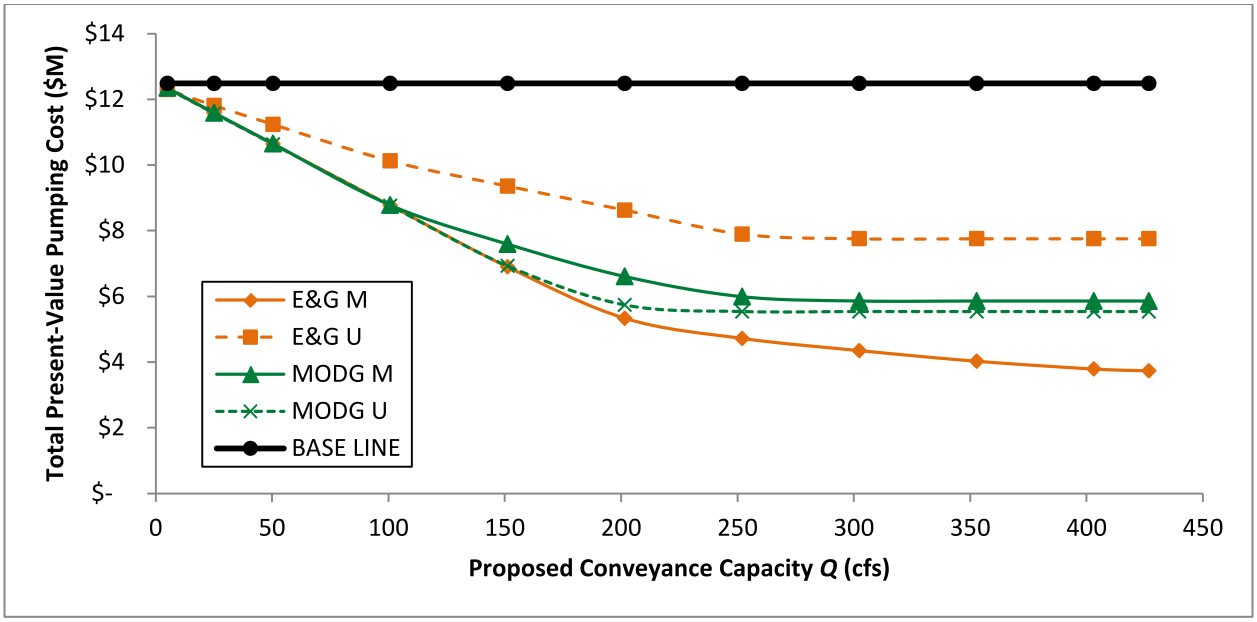


Figure 43: Total pumping costs (present value) from 1993 to 2013.

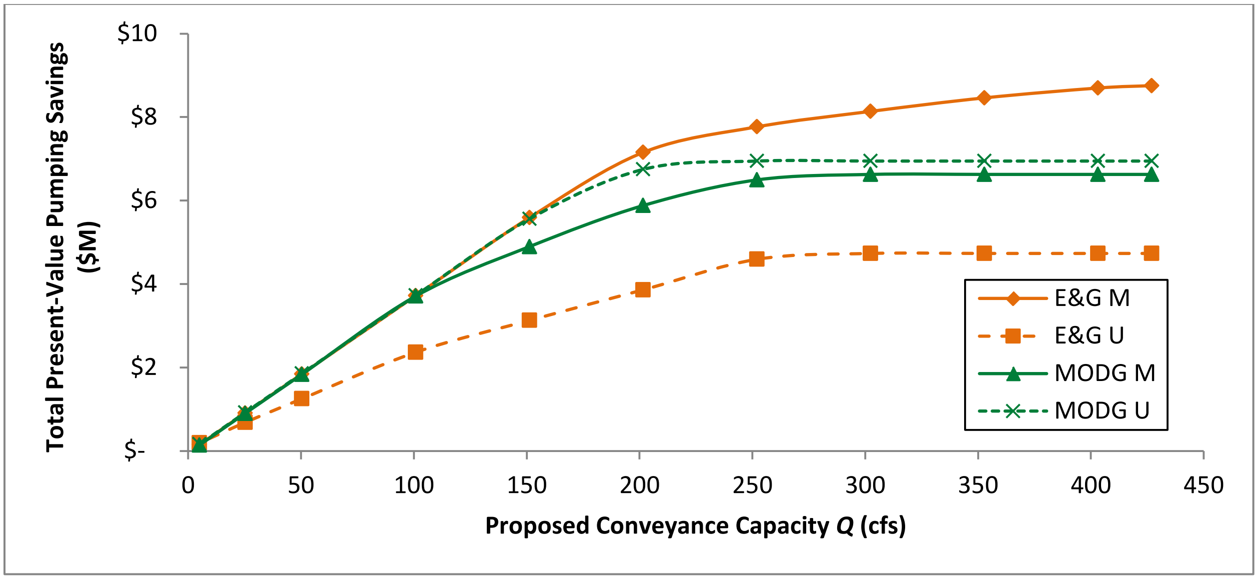


Figure 44: OAWD total pumping savings (present value) from 1993 to 2013.

Except for the *Excellent and Good* soils (Modified SAGBI), the curves in Figure 44 have a plateau around 250 cfs. This is due to the limiting banking capacities shown in Figure 40. In these cases the banking capacity is dictated by the soils properties and available acreage rather than the assumed water diversion capacity.

Results shown above were calculated assuming an average pump efficiency of 70%. It is likely that many pumps in the irrigation district have efficiencies lower than 70% and because this information is not available, a range of efficiencies is presented in Figure 45. In this graph the average total savings for each *Q* (i.e., average of all four types of soils) is plotted with different pump efficiencies. It can be seen that with smaller efficiencies (55%) the effect over time is greater savings in pumping costs. The opposite happens with higher efficiencies. This of course is true for the conceptual one-bucket model used in this study and its GW levels rising and dropping evenly in time and space. Use of a GW model may lead to different results.

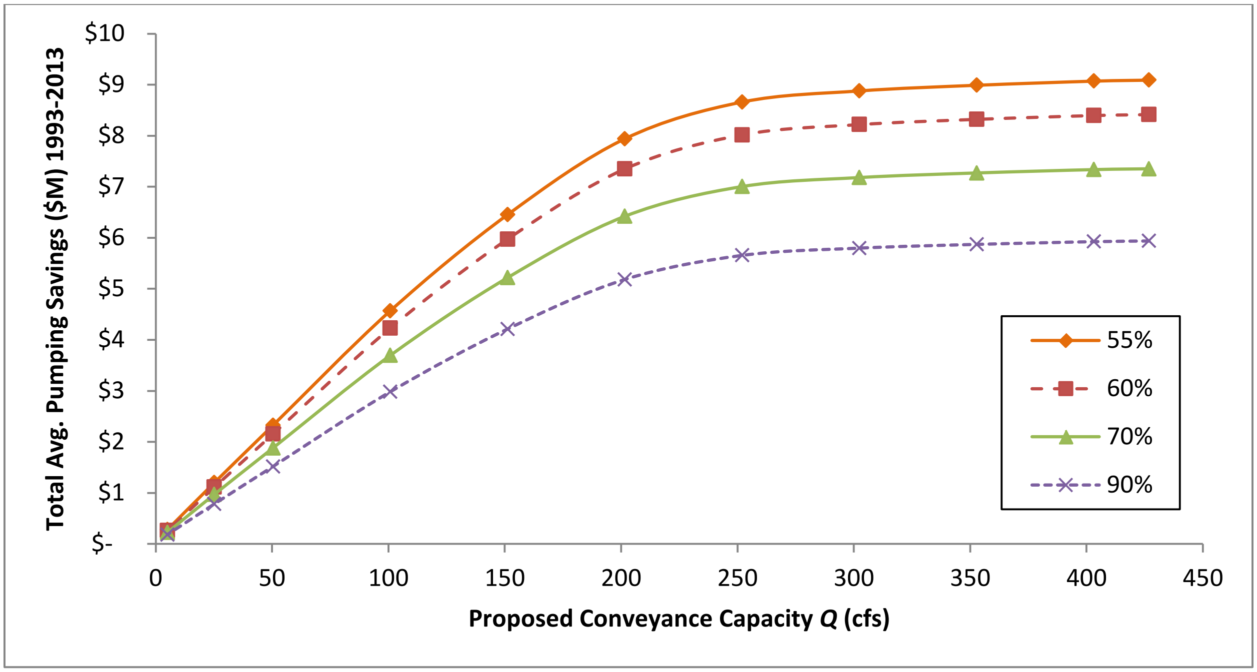


Figure 45: Total average pumping cost savings with different pump efficiencies.

5.5.2. Production Costs

Results of increment in surface water rates (*ΔCSW*) (Eq. 22, p. 77) and Total Crop production (Eq. 27, p. 81) are presented here for the two policy scenarios mentioned in Section 4.5.2.2.

5.5.2.1. *Cost of Surface Water*

Table 15 shows the average annual water banked and the cost to bank this water in OAWD under different scenarios of conveyance capacity used for Ag-GB (*Q)* and soil type (*Excellent and Good* and *Moderately Good*, Modified and Unmodified SAGBI). These values are required to calculate the increment in cost of surface water (*ΔCSW*). OAWD has historically paid the *contract rate* ($/AF) to the USBR for additional water, which is lower than the *cost of service* (Appendix O). Results using the *contract rate* are shown in this and the next sections. Results considering the *cost of service* are included in the appendices. In the table below the cost of purchasing excess water under *contract rate* is shown (See Appendix U for results under *cost of service*). The same results are shown graphically in Figure 46.

Table 15: Average annual water banked and its cost (contract rate).

	Modified SAGBI				Unmodified SAGBI			
	E&G		Mod G		E&G		Mod G	
Q (cfs)	Avg. Annual Water Banked (TAF)	Avg. Annual Cost ($K)	Avg. Annual Water Banked (TAF)	Avg. Annual Cost ($K)	Avg. Annual Water Banked (TAF)	Avg. Annual Cost ($K)	Avg. Annual Water Banked (TAF)	Avg. Annual Cost ($K)
427	12.08	$ 160.88	5.65	$ 71.40	3.04	$ 42.38	5.53	$ 70.21
400	11.42	$ 152.09	5.65	$ 71.40	3.04	$ 42.38	5.53	$ 70.21
350	10.01	$ 133.30	5.65	$ 69.42	3.04	$ 41.35	5.53	$ 70.21
300	8.59	$ 114.52	5.65	$ 71.40	3.04	$ 42.38	5.53	$ 70.21
250	7.18	$ 95.74	5.45	$ 69.42	2.96	$ 41.35	5.53	$ 70.21
200	5.76	$ 76.87	4.73	$ 61.12	2.53	$ 35.73	5.23	$ 67.09
150	4.33	$ 57.79	3.91	$ 51.28	2.10	$ 30.11	4.20	$ 54.78
100	2.89	$ 38.52	2.92	$ 38.93	1.61	$ 23.39	2.86	$ 38.03
50	1.44	$ 19.19	1.47	$ 19.60	0.89	$ 13.33	1.42	$ 19.00
25	0.71	$ 9.56	0.74	$ 9.98	0.51	$ 7.53	0.70	$ 9.38
5	0.12	$ 1.54	0.14	$ 1.93	0.16	$ 2.25	0.10	$ 1.41

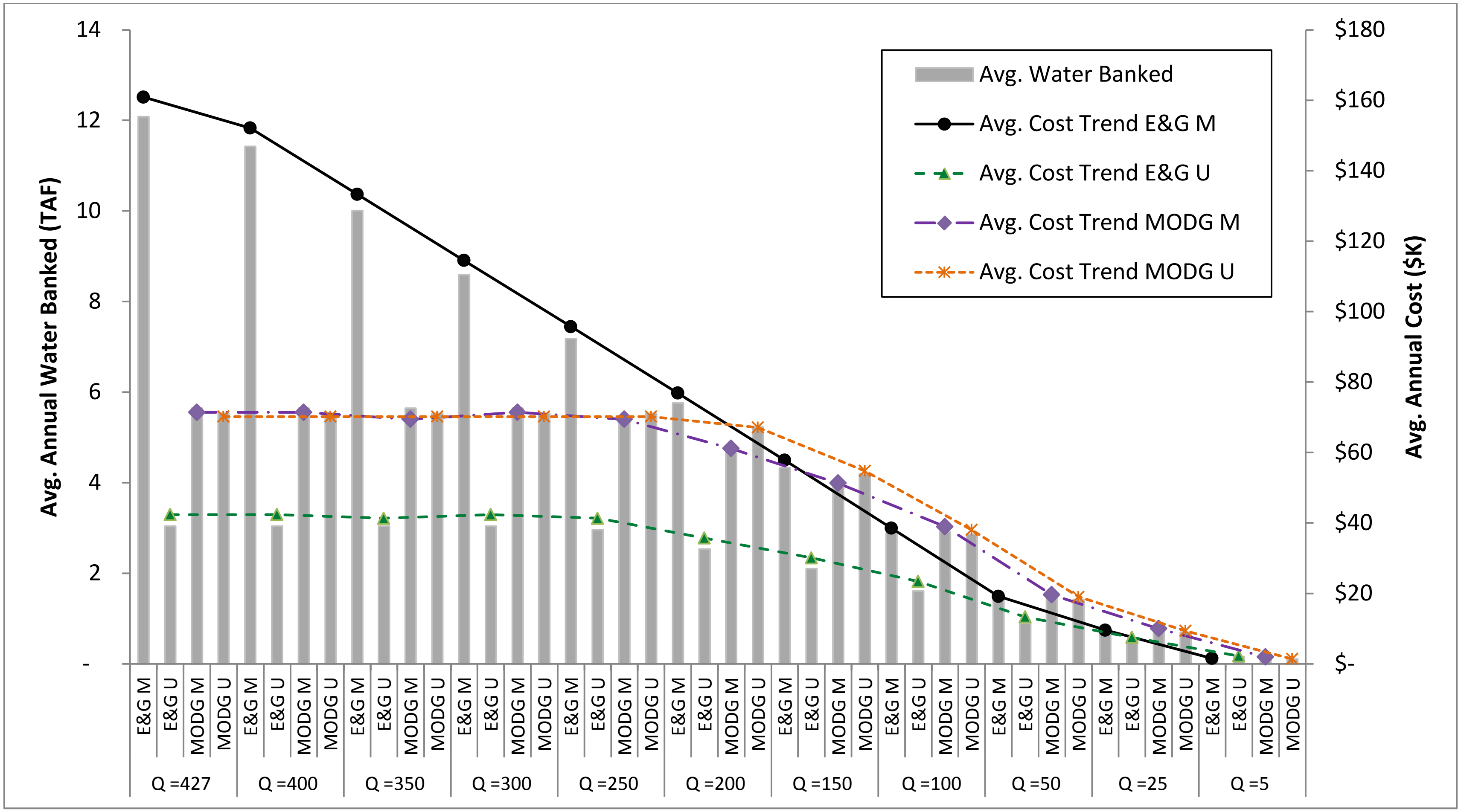


Figure 46: Average annual water banked and its cost.

Policy A: All Growers Pay

Table 16 shows the increment in cost of surface water (*ΔCSW*) for different conveyance capacities *Q* and types of soils. In this policy scenario all growers pay the water charge increase to OAWD during the period of analysis. Ag-GB alfalfa growers still have to pay for additional operational costs (e.g., labor, berms, etc.) (See Appendix V for results under *cost of service*).

Table 16: Surface water cost increments (*ΔCSW*) ($/AF) for different combinations of conveyance capacity *Q* and types of soils under Policy A.

	Contract Rate			
	Modified SAGBI		Unmodified SAGBI	
Q (cfs)	E&G	Mod G	E&G	ModG
427	$ 3.32	$ 1.47	$ 0.87	$ 1.45
400	$ 3.14	$ 1.47	$ 0.87	$ 1.45
350	$ 2.75	$ 1.47	$ 0.87	$ 1.45
300	$ 2.36	$ 1.47	$ 0.87	$ 1.45
250	$ 1.98	$ 1.43	$ 0.85	$ 1.45
200	$ 1.59	$ 1.26	$ 0.74	$ 1.38
150	$ 1.19	$ 1.06	$ 0.62	$ 1.13
100	$ 0.80	$ 0.80	$ 0.48	$ 0.79
50	$ 0.40	$ 0.40	$ 0.28	$ 0.39
25	$ 0.20	$ 0.21	$ 0.16	$ 0.19
5	$ 0.03	$ 0.04	$ 0.05	$ 0.03

Policy B: Ag-GB alfalfa growers do not pay

In this policy scenario alfalfa growers using their lands for banking (Ag-GB growers) are waived all Ag-GB related costs (*ΔCSW*, additional labor, berms, etc.). All other farmers in OAWD would pay for these costs. Table 17 shows the increment in cost of surface water (*ΔCSW*) under policy B. Results shown in Tables 15 and 16 are presented graphically in Figure 47.

Table 17: SW cost increments ($/AF) for different combinations of conveyance capacity *Q* and types of soils under Policy B.

	Contract Rate			
	Modified SAGBI		Unmodified SAGBI	
Q (cfs)	E&G	Mod G	E&G	ModG
427	$ 3.65	$ 1.62	$ 0.96	$ 1.59
400	$ 3.45	$ 1.62	$ 0.96	$ 1.59
350	$ 3.02	$ 1.62	$ 0.96	$ 1.59
300	$ 2.60	$ 1.62	$ 0.96	$ 1.59
250	$ 2.17	$ 1.58	$ 0.94	$ 1.59
200	$ 1.74	$ 1.39	$ 0.81	$ 1.52
150	$ 1.31	$ 1.16	$ 0.68	$ 1.24
100	$ 0.87	$ 0.88	$ 0.53	$ 0.86
50	$ 0.44	$ 0.44	$ 0.30	$ 0.43
25	$ 0.22	$ 0.23	$ 0.17	$ 0.21
5	$ 0.03	$ 0.04	$ 0.05	$ 0.03

Differences between the increment in cost of surface water (ΔCSW) from policies A and B are not significant. There is an increase of 10% in cost across all combinations of *Q* and types of soils between the two policy scenarios. In terms of cost of surface water, both policies seem not to pose a significant burden on growers in the OAWD subunit. Policy B represents increases of 10% in ΔCSW. These observations can be easily seen in Figure 47. To illustrate these results, growers in the OAWD subunits had to pay $14.10/AF in 1993 and $45.49/AF in 2012 (highest between 1993 and 2013) in the base line scenario. After implementation of Ag-GB and considering the E&G M soils and a *Q* of 427 cfs; growers would have payed $17.42/AF and $48.41/AF for those same years under Policy A. Under Policy B these cost would have amount to $17.75/AF and $49.10/AF respectively.

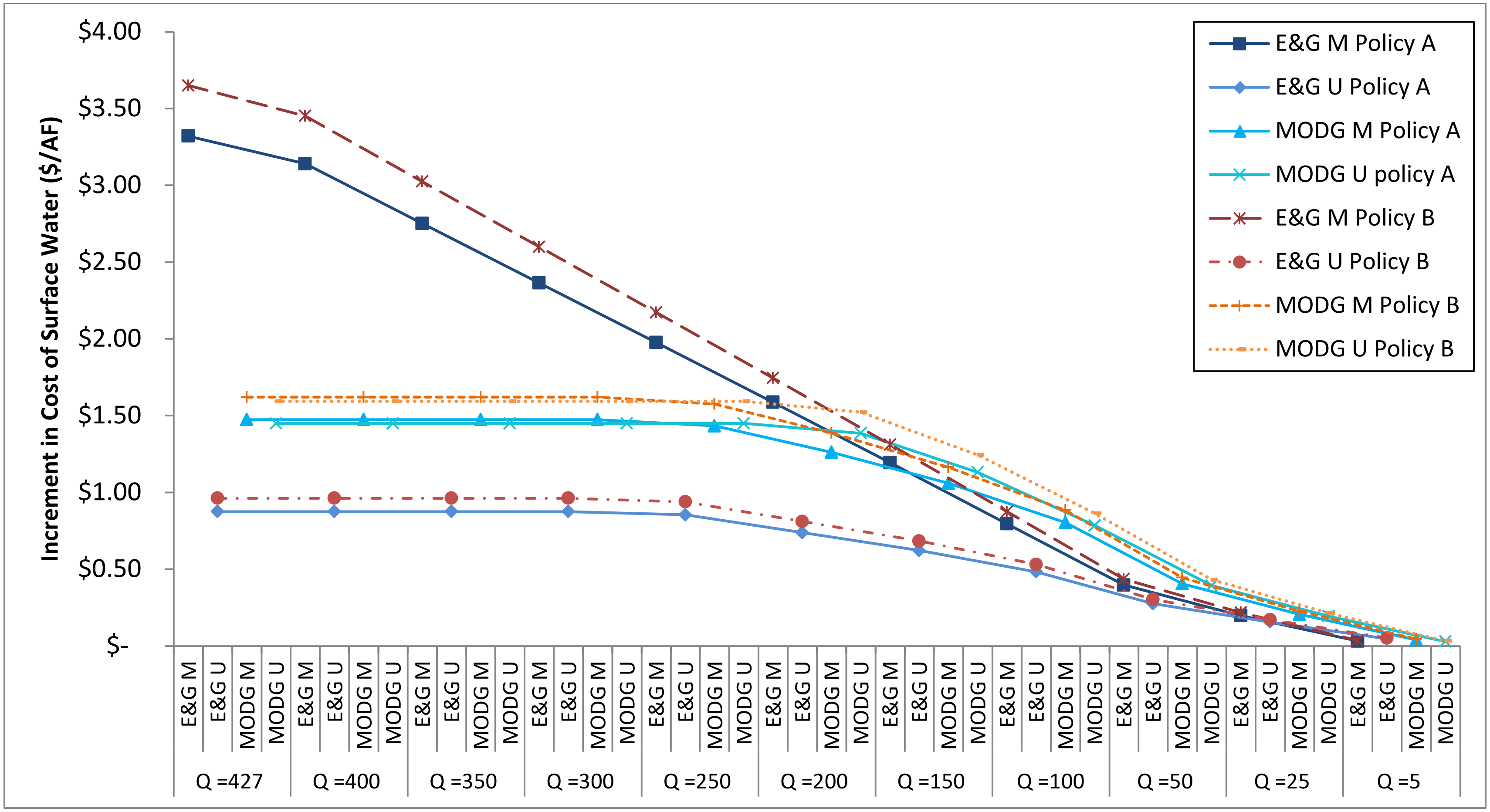


Figure 47: Increment in cost of surface water (*ΔCSW*) for different combinations of conveyance capacity *Q* and types of soils under policies A and B.

5.5.2.2. *Production Costs*

Results from total production cost (Equation 27, p. 80) are presented from two perspectives: (1) Ag-GB alfalfa growers, and (2) the rest of growers in OAWD (Non Ag-GB growers).

Ag-GB Alfalfa Growers

The impacts of *contract rate* versus *cost of service* become negligible when all production costs are considered; hence these are not shown in the tables and chart below. However, different costs per acre to operate turnouts have a significant impact on total production costs. Table 18 shows the total (accumulated) present-value production costs after Ag-GB implementation. These costs include default establishment and production cost along with Ag-GB implementation costs. These costs were calculated assuming a turnout operation cost of $30/acre. The change in total production costs with different turnout operation costs is shown in Figure 48. The total present-value production cost in the base line scenario (no Ag-GB) is $32,260/acre (black line in Figure 48).

Table 18: Total present-value production costs ($/acre) for Ag-GB alfalfa growers. Turnout operation set as $30/acre.

	Policy A				Policy B			
	Modified SAGBI		Unmodified SAGBI		Modified SAGBI		Unmodified SAGBI	
Q (cfs)	E&G	Mod G	E&G	ModG	E&G	Mod G	E&G	ModG
427	$ 35,866	$ 35,812	$ 35,837	$ 35,792	$ 31,860	$ 31,969	$ 32,047	$ 31,952
400	$ 35,853	$ 35,812	$ 35,837	$ 35,792	$ 31,863	$ 31,969	$ 32,047	$ 31,952
350	$ 35,831	$ 35,812	$ 35,837	$ 35,792	$ 31,876	$ 31,969	$ 32,047	$ 31,952
300	$ 35,815	$ 35,812	$ 35,837	$ 35,792	$ 31,893	$ 31,969	$ 32,047	$ 31,952
250	$ 35,800	$ 35,814	$ 35,841	$ 35,792	$ 31,913	$ 31,975	$ 32,053	$ 31,952
200	$ 35,796	$ 35,826	$ 35,864	$ 35,795	$ 31,943	$ 32,002	$ 32,086	$ 31,960
150	$ 35,830	$ 35,850	$ 35,887	$ 35,826	$ 32,012	$ 32,044	$ 32,120	$ 32,014
100	$ 35,878	$ 35,879	$ 35,910	$ 35,876	$ 32,095	$ 32,095	$ 32,154	$ 32,095
50	$ 35,925	$ 35,926	$ 35,940	$ 35,924	$ 32,177	$ 32,178	$ 32,204	$ 32,177
25	$ 35,949	$ 35,950	$ 35,955	$ 35,948	$ 32,219	$ 32,219	$ 32,229	$ 32,218
5	$ 35,967	$ 35,968	$ 35,967	$ 35,967	$ 32,252	$ 32,252	$ 32,250	$ 32,252

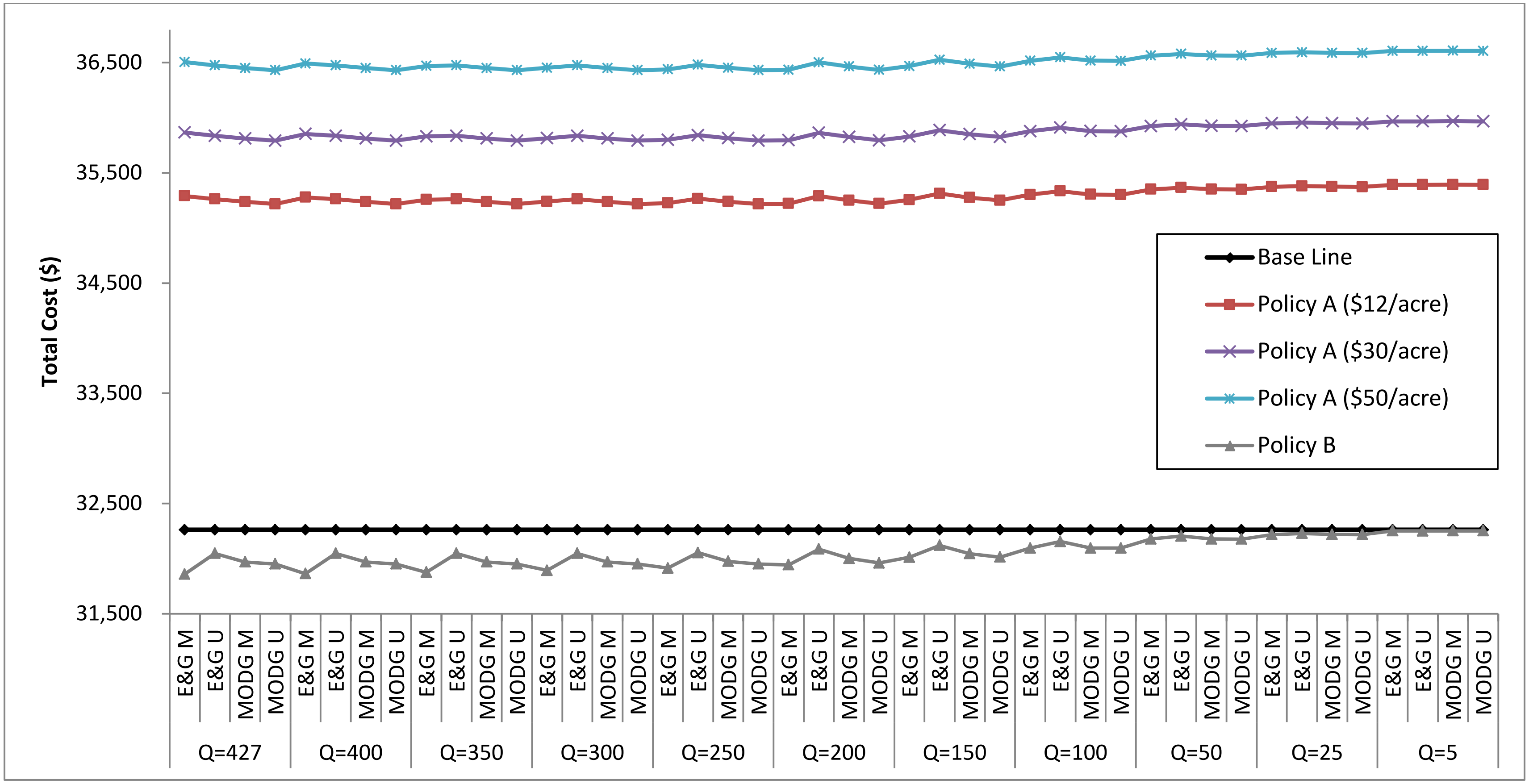


Figure 48: Total present-value production costs ($/acre) for Ag-GB alfalfa growers. Values in parenthesis are costs of turnout operation.

Non Ag-GB Growers

The rest of growers in OAWD not using their land for Ag-GB would have to pay for implementation of the Ag-GB program under policies A and B. Under policy A Non Ag-GB growers would pay only for the increment in surface water charge (*ΔCSW*). Under policy B, Non Ag-GB growers would have to pay *ΔCSW* plus all Ag-GB in-farm operational costs (See Appendix W for results under *cost of service*). Table 19 shows these results in millions of dollars.

Table 19: Total present-value costs ($M) for Non Ag-GB growers under Policies A and B.

	Policy A				Policy B			
	Modified SAGBI		Unmodified SAGBI		Modified SAGBI		Unmodified SAGBI	
Q (cfs)	E&G	Mod G	E&G	ModG	E&G	Mod G	E&G	ModG
427	$ 6.54	$ 2.90	$ 1.72	$ 2.85	$ 7.18	$ 4.76	$ 1.88	$ 4.13
400	$ 6.18	$ 2.90	$ 1.72	$ 2.85	$ 6.82	$ 4.76	$ 1.88	$ 4.13
350	$ 5.42	$ 2.90	$ 1.72	$ 2.85	$ 6.06	$ 4.76	$ 1.88	$ 4.13
300	$ 4.65	$ 2.90	$ 1.72	$ 2.85	$ 5.30	$ 4.76	$ 1.88	$ 4.13
250	$ 3.89	$ 2.82	$ 1.68	$ 2.85	$ 4.54	$ 4.68	$ 1.84	$ 4.13
200	$ 3.12	$ 2.48	$ 1.45	$ 2.73	$ 3.78	$ 4.35	$ 1.62	$ 4.01
150	$ 2.35	$ 2.08	$ 1.22	$ 2.23	$ 3.01	$ 3.95	$ 1.39	$ 3.51
100	$ 1.56	$ 1.58	$ 0.95	$ 1.54	$ 2.23	$ 3.45	$ 1.12	$ 2.83
50	$ 0.78	$ 0.80	$ 0.54	$ 0.77	$ 1.19	$ 1.87	$ 0.64	$ 1.56
25	$ 0.39	$ 0.41	$ 0.31	$ 0.38	$ 0.80	$ 1.48	$ 0.41	$ 0.99
5	$ 0.06	$ 0.08	$ 0.09	$ 0.06	$ 0.47	$ 1.15	$ 0.20	$ 0.67

Total cost differences between policies A and B vary and average at 122% increment under policy B. In this case, *ΔCSW* has a significant weight whereas Ag-GB costs have little impact. This is due to the small acreage of land used for banking compared to the rest of the irrigated land in the district. Figure 49 shows these results graphically. Clearly, Policy A yields the smallest total costs for all combinations of *Q* and types of soils. On the other hand, Policy B has the greatest total costs.

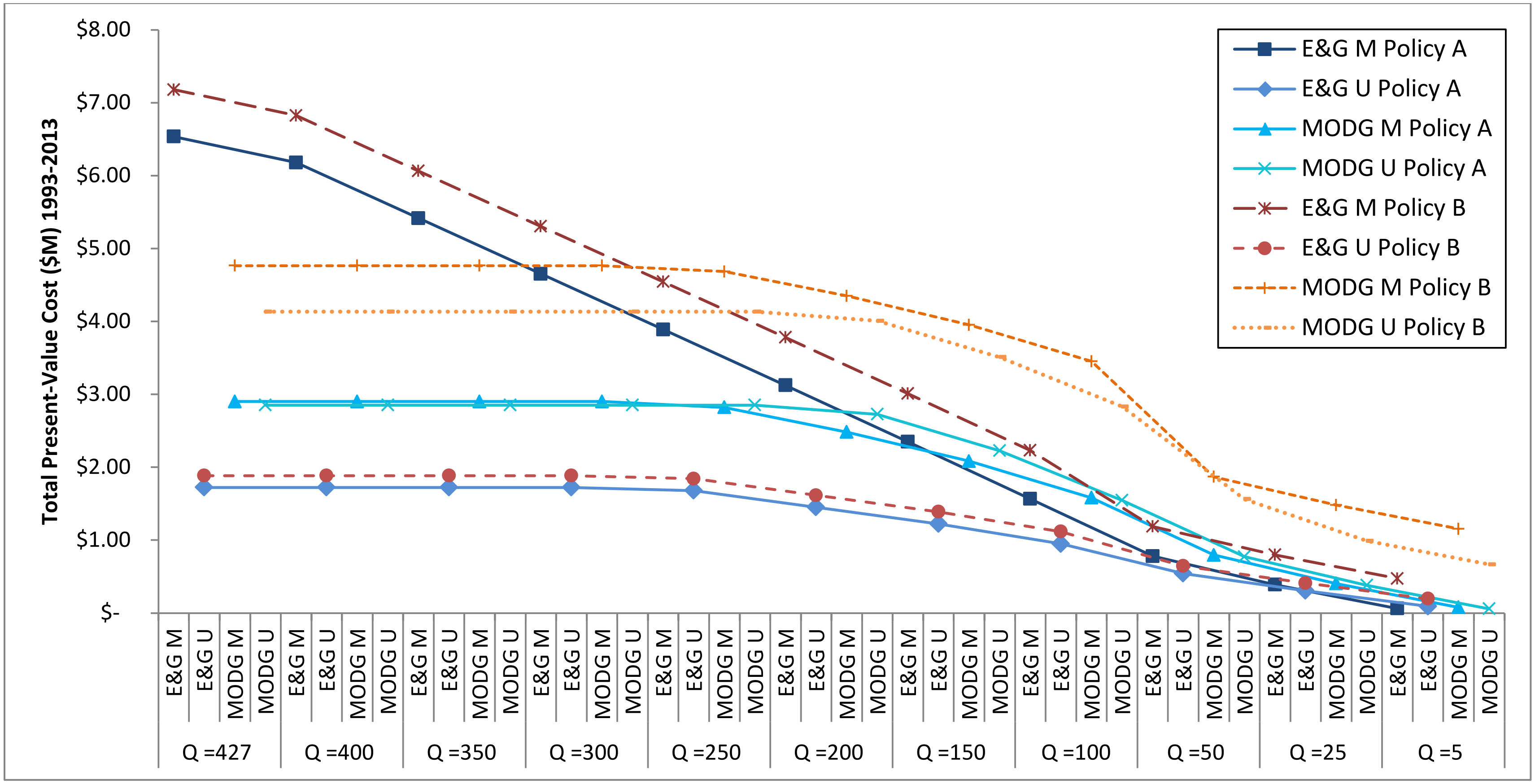


Figure 49: Total present-value costs for Non Ag-GB growers under Policies A and B.

5.6. Feasibility Analysis

5.6.1. Pumping Savings versus Increment in Cost of Surface Water (ΔCSW)

Average annual pumping savings (first term in Equation 29, p. 84) and surface water costs increments (ΔCSW, second term in Equation 29) are plotted in Figure 50. The average ΔCSW between Policies A and B is shown in this chart. **Considering only pumping costs, all Ag-GB options have the potential to offset the increment in cost of surface water (ΔCSW) and to be economically feasible**. It is important to point out that these costs are per AF of water. These considerations are tested and results are shown in Section 5.6.3. An independent two-sample, two-tail t-Test was conducted to compare pumping savings to ΔCSW under policies A and B and for both water service rates (*contract rate* and *cost of service*). There is a significant statistical difference between pumping savings and ΔCSW (see Table 20). All P values are by far below the significance level 0.05 and estimated *t* values are significantly greater than *t critical*.

Table 20: Two-sample, two-tail t-test results.

Variable	Mean	Variance	t Stat	t Critical	P	df
Pumping savings	4.09	5.97	-	-	-	-
ΔCSW Policy A (contract rate)	1.01	0.52	7.95	1.98	8.E-12	84
ΔCSW Policy A (cost of service)	1.84	1.77	5.32	1.98	9.E-07	84
ΔCSW Policy B (contract rate)	1.11	0.63	7.63	1.98	3.E-11	84
ΔCSW Policy B (cost of service)	2.02	2.14	4.77	1.98	8.E-06	84

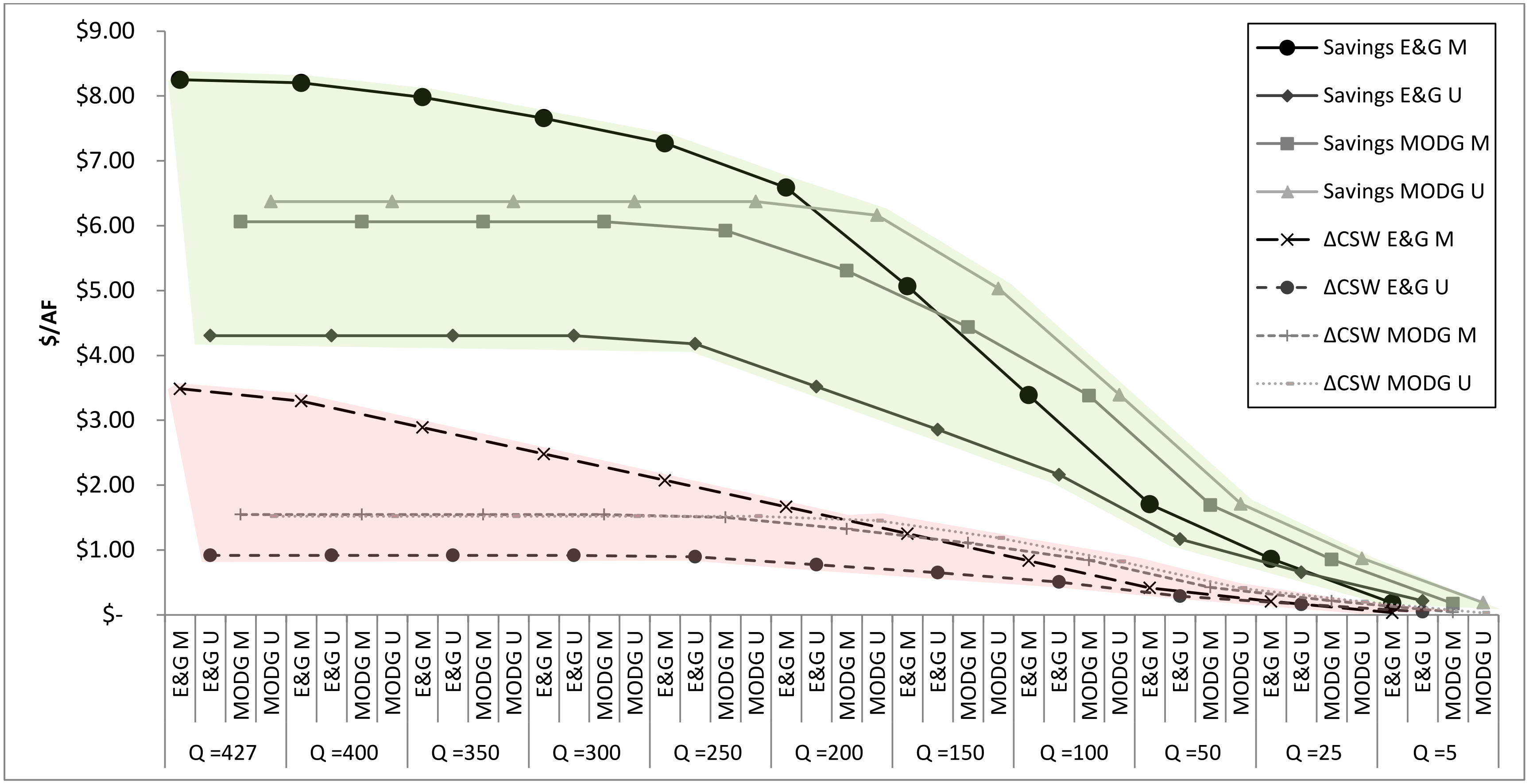


Figure 50: Average annual pumping savings ($/AF) v. increments in cost of surface water (*ΔCSW*) under Policies A and B. Horizontal axis show types of soils (e.g., E&G M) and conveyance capacity *Q* (cfs) (e.g., 250). The green and red shaded areas illustrate the gap between pumping savings and *ΔCSW*. This difference shows statistical significance as mentioned on page 115.

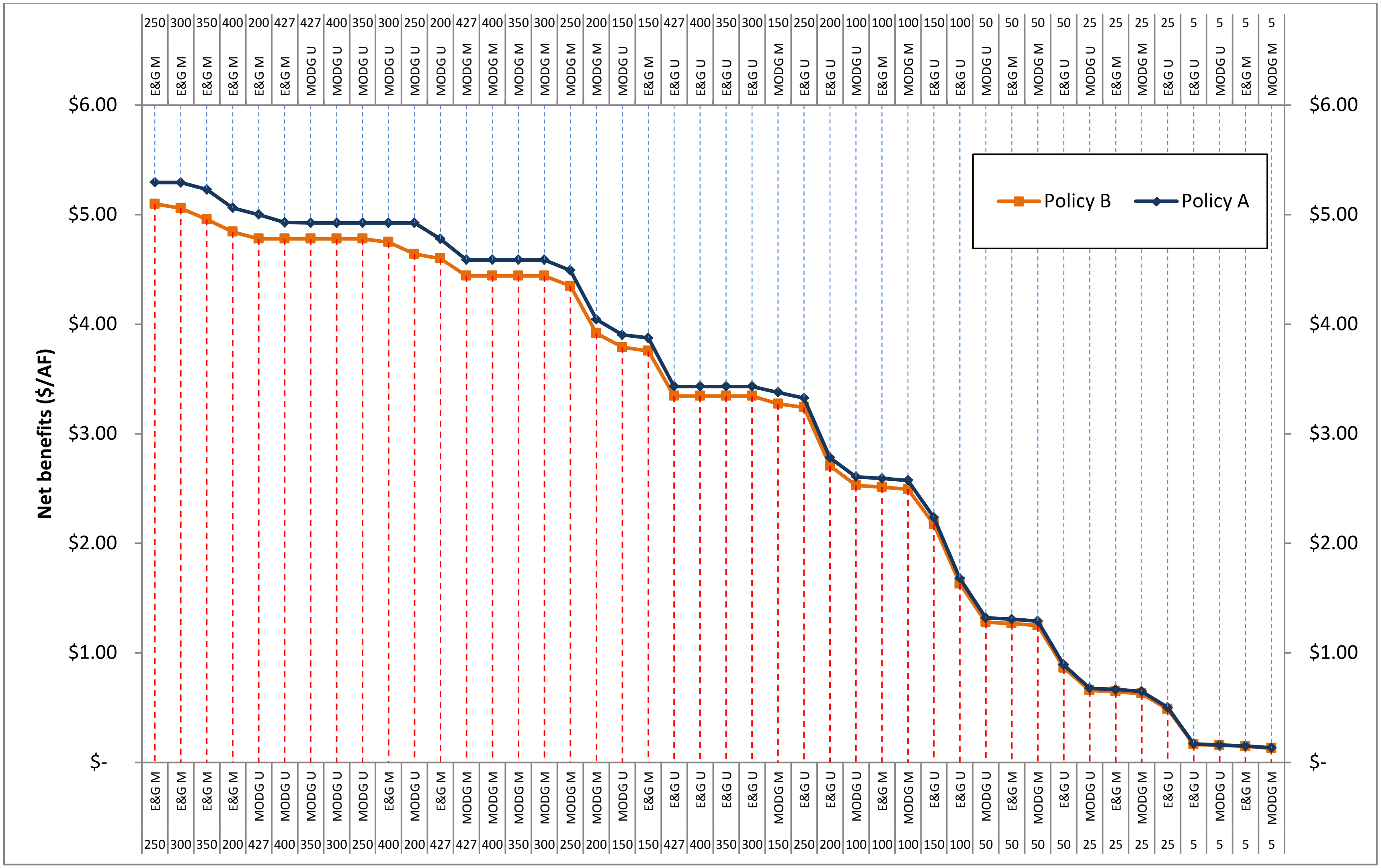


Figure 51: Average annual net benefits ($/AF) from pumping costs savings. Horizontal axis show types of soils (e.g., E&G M) and conveyance capacity *Q* (cfs) (e.g., 250).

Net benefits calculated with Equation [29] (p. 84) are shown in Figure 51. In this plot the data set corresponds to the *contract rate* water service fare. Ag-GB options (type of soil and *Q*) are presented for both policies A and B. Vertical dashed lines in Figure 51 indicate to which horizontal axis the data sets correspond. Blue lines are for Policy A (upper horizontal axis) and red lines are for Policy B (lower horizontal axis). These results are also shown in tabular format in Appendix X along with those calculated using the *cost of service* water fare. **The Ag-GB option that yields the greatest benefits under both policies is E&G M 250 (*Excellent and Good* soils from Modified SAGBI, *Q*= 250)** with $5.20/AF on average. The smallest benefit for both policies is $0.13/AF and comes from MODG M 5 (*Moderately Good* soils from Modified SAGBI, *Q*= 5 cfs). Similarly, if OAWD pays the *cost of service* for additional water (Appendix X) the greatest benefit is $3.71/AF (E&G M 200) and the smallest is $0.09/AF (MODG M 5). There is a decrease of ~30% between the two top Ag-GB options.

5.6.2. Ag-GB Alfalfa Growers

A simple inspection of results shown in Section 5.5.2.2, Figure 48 allows for judgment of Policy A as not economically feasible for Ag-GB alfalfa growers. All combinations of *Q* and types of soils under this policy yield production costs greater to those of the base line scenario (no Ag-GB). These conclusions are corroborated with Equation [30] (p. 85) since none of the tested options yield a net benefit greater than zero. On the other hand, **Policy B presents positive benefits with all combination of *Q* and types of soils**. These results are shown in Table 21 and Figure 52. These results are not affected by water service rates (*contract rate* or *cost of service*) and therefore not mentioned below. **A *Q* of 427 cfs and the *Excellent and Good* soils from the Modified SAGBI (E&G M 427) yields the greatest net benefit with ~$35/acre.** The smallest net benefit is ~$0.74/acre with a *Q* of 5 cfs and the *Moderately Good* soils from the Modified SAGBI.

Considering results from Section 5.6.1, the Ag-GB option that yields the greatest benefit to Ag-GB alfalfa growers in terms of farming costs ($/acre), is not the option that gives the greatest net benefits in terms of pumping costs to all growers in OAWD. E&GM 427 ranks at number 24 from the top with an average annual net benefit of $4.60/AF if OAWD pays the *contract rate* for additional water. If the *cost of service* is to be paid, then E&GM 427 is number 62 from the top with an average annual net benefit of $1.64/acre.

These results are reevaluated in the next section to determine what Ag-GB options are beneficial to all growers in OAWD.

Table 21: Annualized net benefits ($/acre) for Ag-GB alfalfa growers under Policy B.

	Modified SAGBI		Unmodified SAGBI	
Q (cfs)	E&G	Mod G	E&G	Mod G
427	$ 34.99	$ 25.44	$ 18.67	$ 26.96
400	$ 34.71	$ 25.44	$ 18.67	$ 26.96
350	$ 33.59	$ 25.44	$ 18.67	$ 26.96
300	$ 32.07	$ 25.44	$ 18.67	$ 26.96
250	$ 30.33	$ 24.93	$ 18.11	$ 26.96
200	$ 27.69	$ 22.60	$ 15.21	$ 26.19
150	$ 21.66	$ 18.92	$ 12.30	$ 21.56
100	$ 14.48	$ 14.44	$ 9.28	$ 14.50
50	$ 7.28	$ 7.24	$ 4.99	$ 7.31
25	$ 3.68	$ 3.64	$ 2.81	$ 3.71
5	$ 0.78	$ 0.74	$ 0.93	$ 0.80

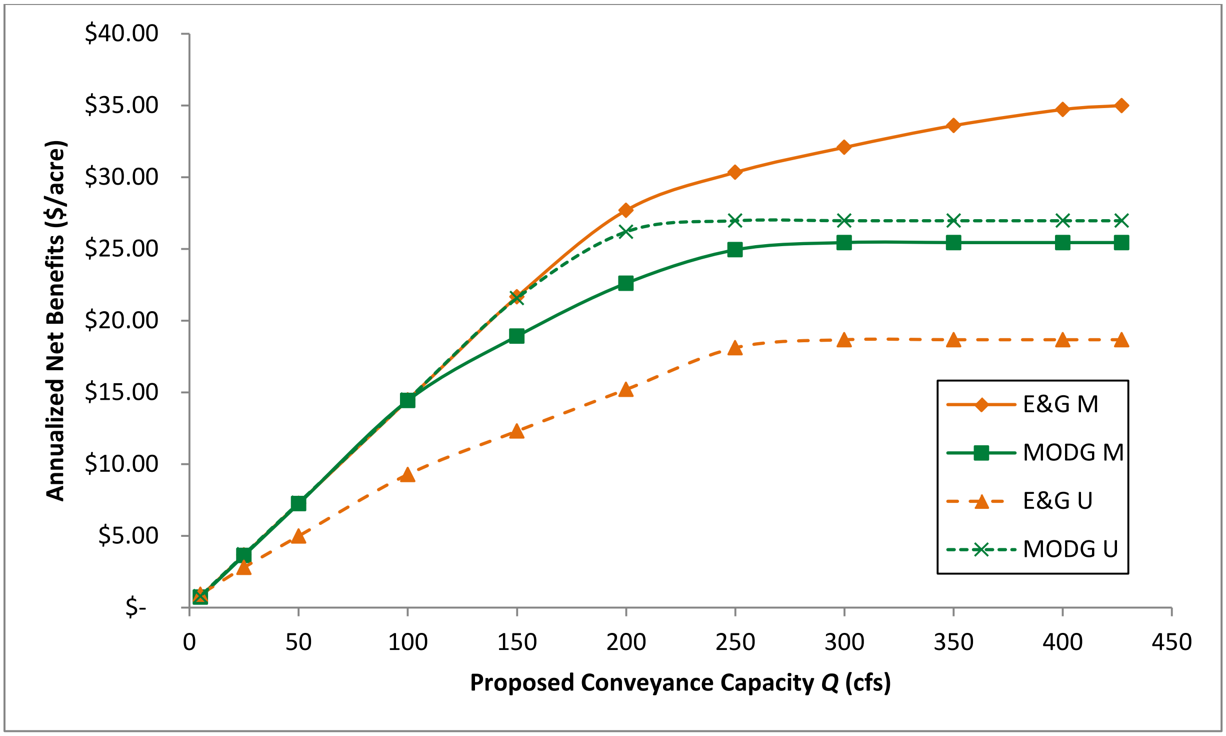


Figure 52: Annualized net benefits ($/acre) for Ag-GB alfalfa growers under Policy B.

5.6.3. Non Ag-GB Growers

Policy A has been shown to not be feasible for Ag-GB alfalfa growers. Policy B is further analyzed to see if it brings benefits to non Ag-GB growers as well. Total pumping savings are compared to total Ag-GB costs (Equation 31, p. 85). The impacts of different costs to operate turnouts are considered in the analysis. Results shown in this section correspond to those calculated using the *contract rate* water fare. Results in tabular format are shown in Appendix Y for both *contract rate* and *cost of service*. Figure 53 shows how savings from pumping compare to costs of Ag-GB implementation under Policy B. Most Ag-GB options show savings greater than costs when OAWD pays contract rate prices to the USBR for additional water. The gap between savings and costs narrows dramatically with conveyance capacities below 100 cfs. Furthermore, costs start to surpass savings when *Q* drops to 25 cfs or lower.

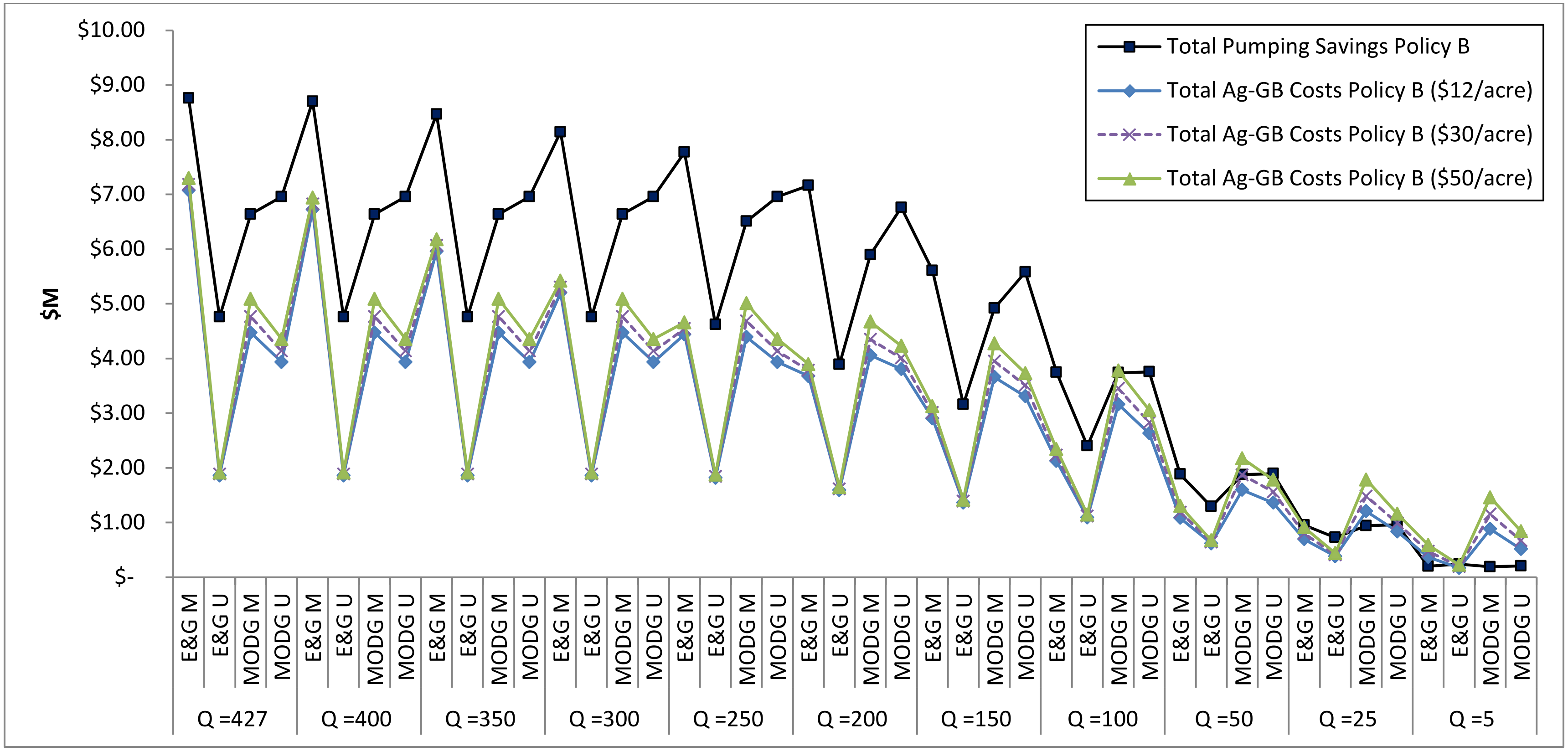


Figure 53: Total pumping savings ($M) compared to total Ag-GB costs ($M) under Policy B. Values in parenthesis are the different costs ($/acre) of turnout operation considered.

Figure 53 also shows how total Ag-GB costs change with different turnout operation labor costs. A simple visual inspection reveals that the smaller *Qs* (50 cfs and smaller) yield pumping savings smaller than the costs they produce. By definition, these Ag-GB options are considered not feasible (i.e., they yield negative net benefits) and are not shown in the summary results from Equation [30] (p. 85).

Annual net benefits calculated with Equation [30] and using *contract rate* are shown in Figure 54. These results are shown in tabular format along with those calculated using *cost of service* in Appendix Z. The three data sets in Figure 54 represent annual net benefits assuming different labor costs of turnout operation. These annual benefits decrease as the labor cost to operate turnouts increase (other costs could also increase, but are assumed to be fixed in this study). From Figures 51 and 52 can be also observed that the number of Ag-GB options that yield positive net benefits would be dramatically reduced if OAWD had to pay *cost of service* for additional water.

From Figure 54, **<u>the greatest net benefit assuming a turnout operation cost of $30/acre is $13.40/acre and its given by soils E&G Modified SAGBI *Q*=200 cfs (*Excellent and Good* soils from Modified SAGBI, *Q*= 200 cfs). This means a net annual benefit of $27.69/acre for Ag-GB alfalfa growers (Table 21, p. 119), and $4.84/AF average annual net benefit in terms of pumping savings v. *ΔCSW* for the entire district (Figure 54, p. 117).</u>** Similarly, if the *cost of service* were to be paid for additional water, the greatest annual net benefit is estimated as $6.60/acre yielded by E&GU 427 (*Excellent and Good* soils from Unmodified SAGBI, *Q*=427 cfs) which means a net benefit of $18.67/acre for Ag-GB alfalfa growers, and $2.27/AF net benefits in terms of pumping savings for the entire district.

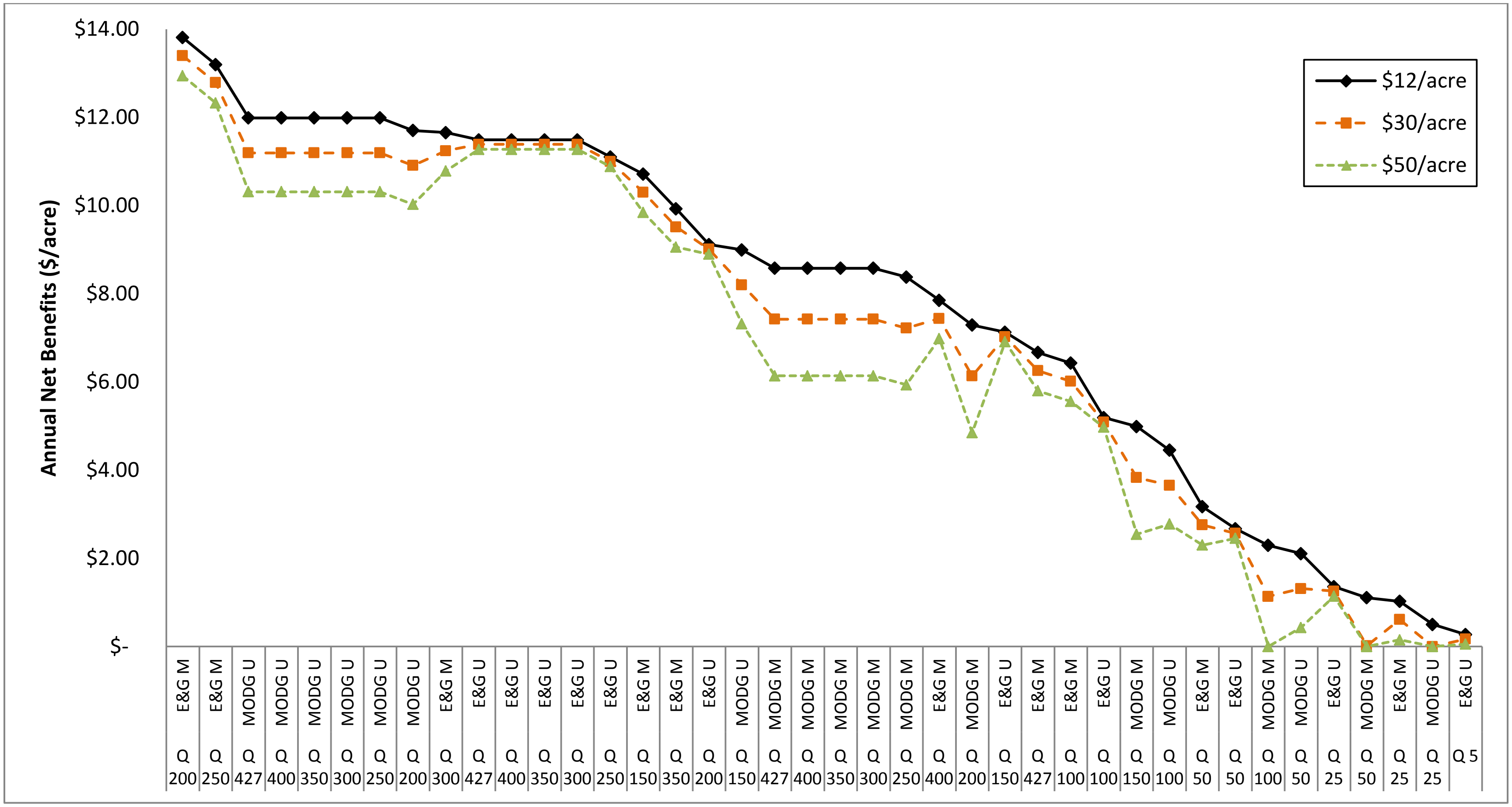


Figure 54: Annualized net benefits ($K) for Non Ag-GB growers under Policy B and assuming *contract rate.* Each data set represent benefits calculated with different costs of turnout operation.

6. Discussion

The methodology presented in this study stablishes a general framework to estimate economic feasibility of groundwater banking on agricultural land (Ag-GB). A discussion of the most important aspects of each of the four modules proposed in the methodology is presented in this section.

6.1. Agricultural Water Demands

The proposed agricultural water demand calculator is intended for planning purposes at the irrigation district level. To calculate water demands at the farm level a soil-moisture approach would be more appropriate.

A practical mass-balance approach has been applied to the water demand calculator. Results shown in Section 5.2 reflect the gradual shift from field crops (tomatoes, berries, potatoes, etc.) to permanent crops (orchards and vineyards) in the study area between 1993 and 2013 (Section 5.1). Orchards particularly require a larger amount of water per year to be productive (~4.30 AF/acre) than field crops (~2.2 AF/acre). As a result, there has been a trend of increasing water demand during the period of analysis. Data used in this portion of the model were taken from several sources as specified in Section 4.2 and for the most part are average values for the region in which the study area is located. The most detailed input data used are the historic monthly ET_0 values from CIMIS. Other data such as precipitation, application efficiencies, and Kc values correspond to regional (Glenn County) average values. With this in mind, water demands in the OAWD Subunit were estimated as 83,400 AF/year on average, and as 143,000 AF/year on average in the GW-Only Subunit. Because OAWD has a contract with the USBR for 53,000 AF/year, farmers in the district supply themselves with groundwater to meet their water demands.

6.2. Aquifer Mass Balance Model

Results from methods explained in Section 4.3 and shown in Section 5.3 show that during the period of analysis the unconfined aquifer did not experienced dramatic changes in storage. There are areas with GW levels as low as 400 ft (from ground level). These areas however, represent about 0.1% of the study area. Furthermore, roughly 50% of the land in the study area has GW at depths between 10 and 40 ft during the period of analysis. This speaks of the important role of natural recharge in the area: GW extractions average at 178 TAF/year in the study area, aquifer recharge (from precipitation and irrigation) at 178.9 TAF/year. These average values however, are likely to have a greater gap between them during prolong droughts (GW extractions are likely to increase as the aquifer recharge decreases) such as the current one. Furthermore, increasing water demands coupled with declining aquifer recharge can set the aquifer into overdraft in the near future, should these trends continue their current course. This can be observed in the study area between 2008 and 2013 (Figure 55).

Groundwater lateral inflows and outflows (gains and losses) were estimated as roughly the same: 33 and 35 TAF respectively. These values may depart at some degree from those estimated using a GW model. However, the behavior of the unconfined aquifer as suggested in this study (magnitude and proportion of lateral inflows and outflows) are expected to be similar to those found using a comprehensive groundwater model.

Model limitations are related how fast (or slow) water moves underground. The model works with total volumes of water entering and leaving the idealized aquifer but no with the time-steps involved in the process. As a result, the model assumes the majority of the volume of water banked in a given year (a fraction of the banked water is assumed to leave the aquifer as part of the GW lateral outflows) is available for recovery in the same year. This may not apply in the field.

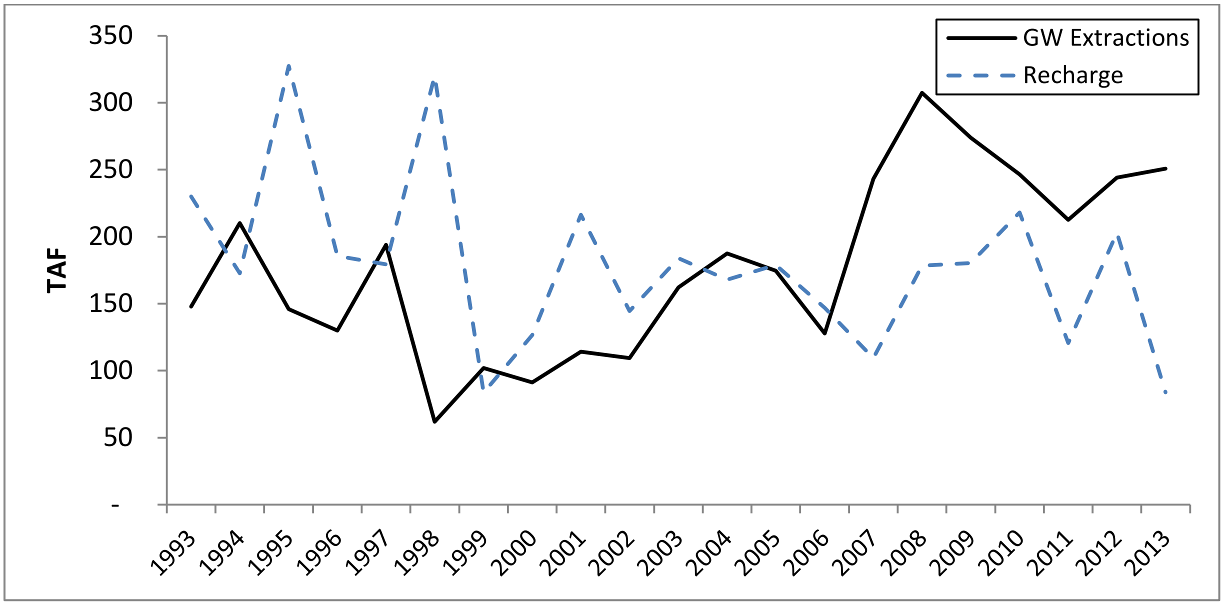


Figure 55: GW extractions v. aquifer recharge.

6.3. Groundwater Banking

The proposed methodology for estimating how much water can be banked in OAWD in a given year is a function of a number of variables: (1) existence of excess water for banking, (2) infiltration capacity of the soils, (3) acres of those soils with appropriate crops, and (4) water conveyance capacity.

Excess water from the Sacramento River was estimated by taking all daily flows above the 90th percentile. In reality, these amounts of water in excess (i.e., with no use for temperature control, environmental flows, or water rights) may be different to the ones estimated in this analysis. Excess water released from reservoirs depends on the hydrology and operational objectives of Shasta and Whiskeytown dams. Coordination with the USBR in this case will be require to divert excess flows into OAWD, or any other irrigation district for that matter, for Ag-GB.

Infiltration capacities of the soils are based on the saturated hydraulic conductivities (Ksat) of the most restrictive layers according to SAGBI. This approach does not take into account the decrease in infiltration capacity over time, or how Ksat changes as the water moves further underground. Also, the soils ranked by SAGBI as *Excellent* and *Moderately Good* were assumed to be time invariant whereas the land use did change over time. The main objective however, is to present the areas that seem suitable for further investigation of the soil properties. Infiltration tests are required for an appropriate determination of infiltration profiles for specific sites.

Alfalfa was used in this study as suitable crop for Ag-GB and its acres on suitable land varied over time (Appendix T). The model looks at the total acres of alfalfa suitable for Ag-GB and does not deal with the number of farms owning said acres of alfalfa. It is also assumed that all of these acres of alfalfa have access to surface water irrigation. It is important to highlight that other crops could be used for Ag-GB such as pasture and vineyards (special attention to water quality must be paid if vineyards are considered due to heavy use of fertilizers and pesticides). Another alternative worth exploring is the use of fallowed land.

The individual conveyance capacity of each farm to flood their alfalfa fields in unknown. However, the collective conveyance capacity of the 5 turnouts owned by OAWD is 427 cfs. The model splits water at different flow rates (from 427 to 5 cfs) over the acres of alfalfa on suitable land. In this way, the model shows the banking capacity potential in OAWD under different combinations of conveyance capacity and types of soils, assuming infiltration capacities of the soils and acreage of alfalfa are true.

Finally, the water depths per acre shown in Appendix T serve as a guide to evaluate what would be physically doable in terms of flow rates.

6.4. Agronomic Model

The first assumption in the agronomic model is that GW levels are the same across the entire study area and so they drop and rise evenly. Even though this assumption departs from what happens in reality, it offers a practical way to aid the economic analysis in the absence of a comprehensive groundwater model. Furthermore, the proposed approach offers an insight applicable for planning purposes. In other words, results shown in this study are rough estimates. Greater attention should be paid to the differences among them, their proportions, and general trends. For instance, results shown in Section 5.6.3 must be looked at as the options that show promising results rather than looking at the numbers attached to said results.

Because the model estimates the amount of water that can be infiltrated per day, damages to alfalfa are not considered in costs derived from Ag-GB. In reality, time involved in draining a shallow-flooded field may take longer than a day. To account for this, it is necessary to estimate the probability and magnitude of crop damage in monetary terms. These costs from crop damage could be included in the analysis as a reduction in crop yield or costs related to loss of the alfalfa stand. It could also be handled separately as a risk management assessment.

The proposed agronomic model is intended to look at the potential benefits Ag-GB could bring to all farmers in the irrigation district in terms of pumping costs and compare those to the costs derived from Ag-GB implementation. To do this the model assumes that all growers participate in the program (i.e., to pay for the program whether or not they lend their lands for Ag-GB). Two variations of this main assumption are proposed: (1) all growers pay equally for the cost of Ag-GB implementation (Policy A), and (2) alfalfa growers using their fields for Ag-GB (Ag-GB alfalfa growers) are waived from paying these costs which in return are paid for by the rest of the growers in OAWD (Policy B). Results shown in Section 5.5 suggest that Policy B yields positive annual net benefits to all growers in OAWD. This finding however must be taken with caution. As mentioned before, the GW levels do not move up and down evenly as assumed in the aquifer mass balance model, therefore benefits in terms of pumping costs from a higher water table are likely to be different for different farmers. Other policies that could be applied are giving incentives to farmers to bank water using their fields, monetary compensation in case of crop damage/loss, or subsidies to waive the irrigation districts from paying for excess water for Ag-GB.

6.5. Feasibility Analysis

The proposed model looks at the net benefits (gross benefits minus costs) that could potentially be achieved upon Ag-GB implementation. These benefits are associated to the irrigation district as a whole.

Taking into account all the assumptions discussed previously, the model calculated what the annual net benefits would be under different combinations of conveyance capacity and types of soils. Policy A was labeled as unfeasible since all Ag-GB options under this policy yielded negative net benefits (i.e., costs were greater than benefits) for Ag-GB alfalfa growers. On the other hand, under Policy B, all Ag-GB options yielded positive net benefits to Ag-GB alfalfa growers (Table 21, Figure 52), and most Ag-GB options yielded positive net benefits to Non Ag-GB growers which are presented from greatest to smallest (Figure 54). It is important to point out that even when these results highlight the Ag-GB options that are economically feasible, they do not speak of operational feasibility. In other words, flooding 200 acres of alfalfa at a rate of 427 cfs (4.3ft/acre in one day) yields great annual net benefits to all growers in OAWD. However, such an operation may not be physically possible in reality. This is why the model offers and array of different options from which some could be physically possible.

It is also important to point out that all of these calculations were based on the amount of water that could be infiltrated into the aquifer within 24 hours. For instance, there were 12 days in 1993 above the 90th percentile totaling about 476,500 AF of excess water (Table 13) in the Sacramento River. The total amount of banked water in 1993 would decrease as the flooding-draining process takes longer than 24 hours. These times depend on actual infiltration rates of the soils and acres available of land in a given year.

7. Conclusions

The proposed model establishes a conceptual framework to determine economic feasibility of groundwater banking on agricultural land (Ag-GB). Based on the research objectives, it is concluded:

1. An agricultural water demand calculator was developed using land use, crop, precipitation, and water supply data (Section 4.2). Results from this portion of the conceptual model allowed for the subsequent estimation of groundwater extractions during the period of analysis.

2. A one-bucket conceptual model of the unconfined aquifer was developed to aid the economic analysis (Section 4.3). The water balance calculated using this model suggests a great influence of horizontal water movement (i.e., lateral inflows and outflows) in the unconfined portion of the aquifer and that natural recharge in the study area played a vital role in replenishing the aquifer during the period of analysis. Also, groundwater extractions and total recharge calculated with the proposed methods are similar to those calculated using a soil-moisture demand calculator (Section 4.3). These findings need to be corroborated using a comprehensive groundwater model of the area.
3. The volume of water available for Ag-GB during the period of analysis was estimated considering daily flows above the 90th percentile between November and March (Section 4.4.3). Use of the 90th percentile allows for a more conservative approach than using the 76-90 percentile range referred by the USGS as “above normal” (USGS, “*Water Watch*” 2015). Results show an average of 600,000 AF of water per year that could be available for Ag-GB. This average value needs to be compared to water flow requirements in the river including water right obligations.
4. An agronomic model to study the impacts of Ag-GB on alfalfa production costs and to estimate economic feasibility was also developed (Section 4.5). Two policies were evaluated and compared to the baseline scenario (no Ag-GB). *Policy A* considers that the cost of implementing Ag-GB is distributed evenly among all growers in OAWD except for incidental on-farm costs (e.g., berms, turnout operation, additional pesticides, and crop damage) which are attached to Ag-GB alfalfa growers only. *Policy B* considers that costs of implementation, including incidental on-farm costs, are to be paid by Non Ag-GB growers only. With the assumptions stated in Section 4.5 the model suggests that

Policy A would be economically infeasible because costs of implementation for Ag-GB alfalfa growers would increase compared to the base line scenario (No Ag-GB). On the other hand, the model suggests that Policy B is likely to be economically feasible for bringing positive net benefits to OAWD as a whole. **Under Policy B and paying the *contract* rate for Ag-GB water, the greatest average annual net benefit for non Ag-GB growers is $13.40/acre (assuming $30/acre to operate turnouts) and is achieved with a conveyance capacity *Q* of 200 cfs** (i.e., capacity to collectively deliver 200 cfs onto the alfalfa fields) **and using all alfalfa fields on *Excellent and Good* soils** (Modified SAGBI). In other words, **it would take 2ft/acre of water per day** (i.e., every time there is excess water) **on 200 acres of alfalfa with an infiltration capacity of 11.60 ft/day**. **This means an average annual net benefit for Ag-GB alfalfa growers of $27.70/acre** (Table 21) and an average annual net benefit in terms of pumping costs for all growers in OAWD of $4.90/AF (Figure 51). The smallest average annual net benefit for non Ag-GB growers is estimated at $0.17/acre (assuming $30/acre to operate turnouts) with a *Q* of 5 cfs and using all alfalfa fields on *Excellent and Good* soils (Unmodified SAGBI) or; 0.5 ft/acre of water on 20 acres of alfalfa with an infiltration capacity of 5.8 ft/day. This means an annual net benefit of $0.93/acre for Ag-GB alfalfa growers and $0.16/AF in terms of pumping costs for all growers in OAWD. If OAWD had to pay the *cost of service* for additional water, the greatest average annual net benefit for non Ag-GB growers would be $6.60/acre with a *Q* of 427 cfs and using alfalfa fields on *Excellent and Good* soils (Unmodified SAGBI) or; 2.3ft/acre of water on 370 acres of alfalfa with an infiltration rate of 11.60 ft/day. This translates to $18.70/acre in annual net benefits for Ag-GB alfalfa growers and $2.82/AF for all growers in OAWD in terms of pumping costs. The smallest average annual net benefit for non Ag-GB growers is estimated as \$0.25/acre with a *Q* of 50 cfs and using alfalfa fields on *Excellent and Good* soils (Modified SAGBI) or, 0.5 ft/acre of water on 200 acres of alfalfa with an infiltration rate of 11.60ft/day. This means \$7.30/acre in annual net benefits for Ag-GB alfalfa growers and \$0.90/AF for all growers in OAWD in terms of pumping costs. Net benefits calculated using a *Q* of 25 cfs or smaller have a greater probability to become unfeasible than those estimated using *Q* values of 50 cfs or greater upon implementation of a comprehensive groundwater model. Similarly, existing water conveyance infrastructure in OAWD may not be capable of diverting 427 cfs onto Ag-GB fields. Taking this into account and results shown in Section 5.6.3, a safer range of *Q* to consider would be between 50 and 300 cfs with their respective type of soil and its acreage (Appendix T).

These results represent a rough approximation of the overall hydrologic behavior in the study area and the potential economic impacts of implementing Ag-GB. **Close attention must be given to: (1) limitations to how much water can be diverted onto Ag-GB fields regardless of how much water is available in streams as excess water; these limits are a function of the type of soil and acreage. (2) Diverting small amounts of water (50 cfs or less) for Ag-GB is likely to raise more costs than benefits. (3) Participation of all growers in the irrigation district is an important component to keeping repayment of Ag-GB implementation costs low.** In this case, it was shown that even when all of these costs are paid for by Non Ag-GB growers only, there is potential for benefits for everyone in the district.

It is also concluded that OAWD has the elements necessary for implementation of Ag-GB: access to excess water, water conveyance infrastructure, and suitable soils and

crops. Results from this study recommend further investigation in the area to quantify these qualities. **Implementation of Ag-GB shows potential to be economically feasible under Policy B.** However, other financial mechanism could work as well.

The application of a comprehensive groundwater model will determine more accurately if the behavior of the underlying aquifer allows for similar economic benefits to those estimated in this study to take place.

Even though not quantified in this study, domestic wells are likely to be benefitted too as these wells usually pump water from shallow aquifers. The cost of domestic wells running dry could be avoided in some cases. There are also qualitative benefits that could be present with implementation of Ag-GB, namely environmental benefits and increased water resource reliability.

8. Limitations

Applicability of models is always subject to limitations. Even though the limitations of the proposed model have been mentioned throughout this document, they are summarized in this section.

- Land use data had to be estimated in some instances due to lack of data for some years. In other cases data had to be adjusted because the GIS files had a significant amount of noise.
- The Aquifer Mass Balance Model conceptualizes the underlying aquifer as a *one-bucket* model in which what matters is the total volumes of water entering and exiting the bucket. This approach deals only with the unconfined aquifer. This portion of the model assumes that GW levels change evenly across the study area. Substitution of the Aquifer

Mass Balance Model by a comprehensive GW model would be required for more accurate results.

- Because of the way the mass balance model works, the agronomic model assumes that all growers in OAWD pump water at the same depth. Feasibility results were computed under this assumption.
- Farming costs used in the agronomic model are sample costs from 2008 for growing Alfalfa in the Sacramento Valley (Long et al. 2008). These costs where deflated and inflated accordingly to populate the time series from 1993 to 2013.
- Crop yield and market value data used to estimate revenues are historic average values for Glenn County. Historic yield and market value may have been different in OAWD.
- The Agronomic Model does not consider costs derived from yield reduction or loss due to prolonged flooding and/or excess moisture in the soil. Loss of crop production because of Ag-GB could render the practice unfeasible depending on the circumstances.
- The proposed conceptual framework is a deterministic approach and does not look into future scenarios.
- The proposed conceptual framework does not consider water quality concerns derived from legacy salts and other chemicals leaching into the aquifers from the agricultural fields. Depending on the magnitude, impacts on water quality could also render Ag-GB economically unfeasible.

9. Notation

The following symbols are used in this thesis:

A = total area of study area (acre);
AE = water application efficiency (%);
AEC_i = alfalfa establishment cost in year *i* ($/acre);
AF = acre-feet;
Ag-GB = agricultural groundwater banking;
A_{ik} = area of crop/land use *k* in year *i* (acre);
APB_{iw} = annual average net benefit from pumping savings ($/AF);
APC_i = alfalfa production cost in year *i* ($/acre);
BOR = United States Bureau of Reclamation;
CAG = capital cost of berming the field for shallow flooding ($/acre);
CE = alfalfa establishment cultural cost ($/acre);
CO = annual overhead cost ($/acre);
CP = alfalfa production cultural cost ($/acre);
CSW_i = cost of surface water paid by users to *OAWD* in year *i* ($/AF);
CWG_{iw} = cost of groundwater for a given *Ag-GB* option in year *i* ($/AF);
CW_i = fare paid by *OAWD* to *BOR* for additional surface water ($/AF);
cfs = Cubic feet per second;
DGW_{iw} = depth to groundwater for a given *Ag-GB* option *w* in year *i* (ft);
D_i = surface water delivered in year *i* (AF);
d_{mn} = depth of water diverted onto the field with soil *n* and K_{sat} *m*;
E = average pumping efficiency (%);
EC_i = average energy cost ($/Kw-hr);
ET = crop/land use evapotranspiration (ft);
ET_o = reference evapotranspiration (in);
E&G M = excellent and good soils in the modified version of SAGBI;
E&G U = excellent and good soils in the unmodified version of SAGBI;
ft = feet;
GB = groundwater banking;
GE_i = groundwater extractions in year *i* (AF);
GW = groundwater;
GWFX = groundwater fixed cost ($/AF);
HC = alfalfa harvesting cost ($/acre);
IWFM = integrated water flow model;
K_c = crop coefficient;
K_i = water banking capacity of the fields in year *i* (AF);
MODG M = moderately good soils in the modified version of SAGBI;
MODG U = moderately good soils in the unmodified version of SAGBI;
MV = crop market value in year *i* ($/ton)
$NBAG_{wz}$ = annual average net benefits for *Ag-GB alfalfa growers* given an *Ag-GB* option and policy *z* ($/acre);

NBN_{wz} = annual average net benefits for *non Ag-GB growers* given an *Ag-GB* option and policy z (\$/acre);
n = soil porosity (%);
OAG_i = cost of turnout operation in year i (\$/acre);
$OAWD$ = Orland-Artois water district;
OM = cost of operation and maintenance per meter of lift (\$/ft)
PAG_i = cost of additional pesticide application (\$/acre);
PC_i = pumping cost in the base line scenario (no *Ag-GB*) in year i (\$/AF);
PC_{iw} = pumping cost for a given Ag-GB option w in year i (\$/AF)
p_{ij} = average precipitation in month j and year i (in);
PP = alfalfa pre-planting cost (\$/acre);
Q = conveyance capacity (cfs);
RI_{ij} = aquifer recharge from irrigation in month j and year i (AF);
RP_{ij} = aquifer recharge from precipitation in month j and year i (AF);
r = interest rate (%);
r_{ij} = total surface runoff in month j and year i (AF)
r'_{ij} = surface runoff from precipitation in month j and year i (AF)
r''_{ij} = surface runoff from irrigation in month j and year i (AF)
S_i = aquifer storage in year i (AF)
$SAGBI$ = soil agricultural groundwater banking index;
SWA_i = surface water supplied to *Ag-GB* alfalfa fields in year i (AF)
SW = surface water;
SW_i = volume of surface water delivered by *OAWD* in year i (AF)
T = time required for diverted water to infiltrate into the soil (hr);
TAF = Thousand acre-feet;
TPC = total pumping costs (1993-2013) in the base line scenario (no *Ag-GB*) (\$)
TPC_w = total pumping costs (1993-2013) for a given *Ag-GB* option w (\$)
TPP = total (1993-2013) alfalfa production cost in the base line scenario (no *Ag-GB*) (\$/acre);
TPP_w = total (1993-2013) alfalfa production cost (\$/acre);
TPS_w = total pumping cost savings (1993-2013) for a given *Ag-GB* option w (\$);
WDA_i = *Ag-GB* alfalfa water demand in year i (AF);
WD_{ij} = water demand in year i (AF);
WGB_{iw} = volume of water banked in year i given an *Ag-GB* option w (AF);
Y = crop yield in year i (ton/acre);
Z = reference datum (ft);
γ = aquifer specific yield (%);
ΔCSW_w = increment in cost of surface water for a given *Ag-GB* option (\$/AF);
θ_i = deflation/inflation factor in year i; and
φ = present-to-annual-value conversion factor.

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Appendices

Appendix A: Land use time series used for OAWD subunit

Year	Crop																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1993	4,076	2,855	-	469	1,359	4	128	706	2,503	3,012	-	-	23	-	-	4	2,873	1,513	357	1,056
1994	3,706	3,682	-	426	1,235	3	116	642	2,503	3,012	-	-	25	-	-	4	3,512	1,850	437	1,291
1995	3,142	3,359	-	361	1,047	3	99	544	2,369	2,851	-	-	21	-	-	3	3,831	2,018	476	1,408
1996	3,706	3,467	-	426	1,235	3	116	642	2,225	2,677	-	-	25	-	-	4	4,419	2,327	549	1,624
1997	4,076	3,413	-	469	1,359	4	128	706	2,085	2,510	-	-	27	-	-	4	4,630	2,439	576	1,702
1998	2,690	2,942	-	45	2,428	336	1	89	1,896	2,132	-	-	34	-	-	-	4,980	2,139	370	1,323
1999	2,344	3,515	-	39	2,115	293	1	78	2,054	2,309	-	-	34	-	-	-	5,641	2,423	419	1,499
2000	2,238	3,781	-	37	2,020	279	1	74	2,075	2,332	-	-	33	-	-	-	5,744	2,467	427	1,526
2001	2,238	3,781	-	37	2,020	279	1	74	2,075	2,332	-	-	33	-	-	-	5,744	2,467	427	1,526
2002	2,238	3,781	-	37	2,020	279	1	74	2,075	2,332	-	-	33	-	-	-	5,744	2,467	427	1,526
2003	1,999	3,643	-	-	1,620	265	58	47	1,997	1,785	-	-	37	-	37	5	6,303	1,686	261	1,204
2004	1,999	3,643	-	-	1,620	265	58	47	1,997	1,785	-	-	37	-	37	5	6,303	1,686	261	1,204
2005	1,999	3,643	-	-	1,620	265	58	47	1,997	1,785	-	-	37	-	37	5	6,303	1,686	261	1,204
2006	1,999	3,643	-	-	1,620	265	58	47	1,997	1,785	-	-	37	-	37	5	6,303	1,686	261	1,204
2007	1,402	2,365	28	-	860	3	14	40	2,712	4,730	-	3	-	-	-	-	7,593	3,158	-	38
2008	937	1,729	154	-	1,076	-	3	26	1,852	3,680	-	3	-	-	-	22	10,245	2,759	3	2
2009	2,075	1,953	32	-	731	351	4	74	2,252	3,340	-	1	-	-	-	-	6,731	4,370	78	461
2010	1,560	2,479	159	-	1,633	1	59	14	1,656	3,187	-	9	-	-	-	18	8,597	3,522	60	441
2011	1,942	2,597	37	-	1,518	111	19	252	1,334	1,450	-	8	2	-	-	12	8,526	3,789	30	439
2012	1,487	2,455	7	-	2,117	18	52	355	1,374	1,916	-	3	-	-	-	19	8,156	4,135	84	388
2013	1,567	2,593	150	-	1,698	21	1	362	1,189	2,125	-	5	5	-	-	119	9,095	4,085	53	578

*1= grains, 2= rice, 3= cotton, 4= sugar beets, 5= corn, 6= dry beans, 7= safflower, 8= other field crops, 9= alfalfa, 10= pasture, 12= tomato, 13= cucurbits, 14= onion & garlic, 15= potatoes, 16=truck crops, 17= almond & pistachios, 18= other deciduous, 19= citrus & subtropical, 20= vineyard

Appendix B: Land use time series used for GW-Only subunit

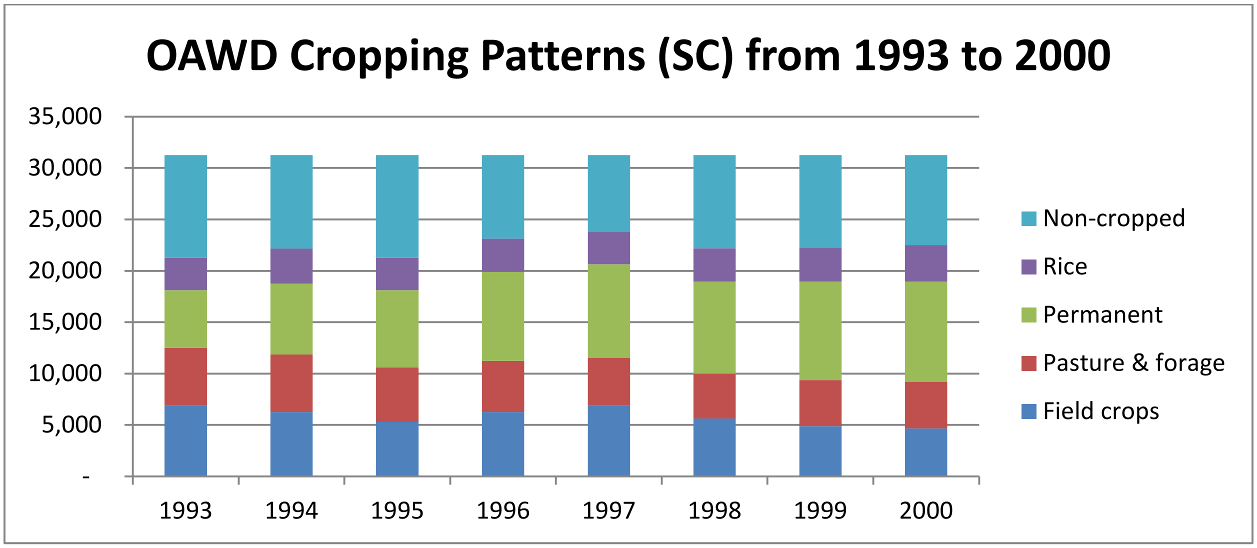
Year	Crop																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1993	9,111	1,473	41	2,420	4,034	691	871	1,027	5,805	4,522	-	-	4	-	-	75	6,435	2,856	317	236
1994	9,659	1,473	47	2,670	4,353	784	969	1,047	6,655	5,184	-	-	26	-	-	85	7,544	3,282	312	15
1995	8,031	1,473	39	2,220	3,619	652	805	871	6,435	5,013	-	-	22	-	-	71	7,302	3,177	302	15
1996	8,844	1,473	43	2,445	3,986	718	887	959	6,112	4,761	-	-	24	-	-	78	7,105	3,091	294	15
1997	8,971	1,473	43	2,480	4,043	728	900	973	6,170	4,807	-	-	24	-	-	79	6,980	3,037	289	14
1998	7,881	1,000	-	89	1,612	336	3	102	2,587	839	-	-	201	-	-	45	7,071	1,268	216	-
1999	6,670	1,000	-	73	1,066	249	2	78	2,239	460	-	-	176	-	-	41	6,973	1,002	170	-
2000	7,658	1,000	-	83	1,224	286	3	90	2,277	468	-	-	202	-	-	47	7,605	1,093	186	-
2001	7,658	1,000	-	83	1,224	286	3	90	2,277	468	-	-	202	-	-	47	7,605	1,093	186	-
2002	7,658	1,000	-	83	1,224	286	3	90	2,277	468	-	-	202	-	-	47	7,605	1,093	186	-
2003	7,602	1,338	-	-	3,917	813	608	264	5,807	3,439	-	11	676	-	7	170	13,902	3,879	189	188
2004	7,602	1,338	-	-	3,917	813	608	264	5,807	3,439	-	11	676	-	7	170	13,902	3,879	189	188
2005	7,602	1,338	-	-	3,917	813	608	264	5,807	3,439	-	11	676	-	7	170	13,902	3,879	189	188
2006	7,602	1,338	-	-	3,917	813	608	264	5,807	3,439	-	11	676	-	7	170	13,902	3,879	189	188
2007	4,146	1,557	87	-	4,247	58	116	568	6,250	5,397	-	87	-	-	-	-	15,617	5,936	2	73
2008	2,442	1,246	344	-	3,733	2	98	256	5,430	3,963	-	3	1	2	-	12	23,493	4,845	0	2
2009	4,932	1,165	443	-	2,538	736	15	477	6,528	4,353	-	8	-	-	-	-	18,463	6,886	16	161
2010	5,058	1,492	327	-	3,623	2	146	85	5,663	3,975	-	19	-	0	-	37	21,695	6,444	12	154
2011	5,123	1,237	77	-	3,758	260	115	1,053	4,406	3,389	-	34	15	0	-	193	18,969	8,322	5	178
2012	4,722	1,249	5	-	4,194	339	17	1,208	5,482	3,351	-	23	0	-	-	21	19,915	7,418	59	101
2013	4,708	467	127	-	2,392	22	1	943	4,367	3,718	-	16	18	0	-	317	21,668	8,416	11	129

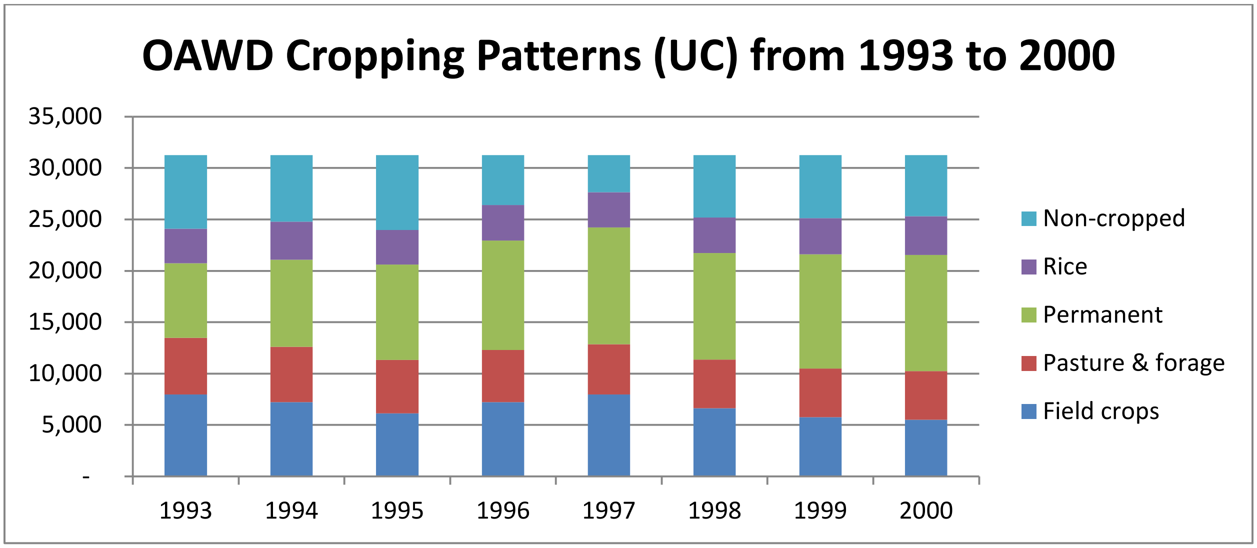
*1= grains, 2= rice, 3= cotton, 4= sugar beets, 5= corn, 6= dry beans, 7= safflower, 8= other field crops, 9= alfalfa, 10= pasture, 12= tomato, 13= cucurbits, 14= onion & garlic, 15= potatoes, 16=truck crops, 17= almond & pistachios, 18= other deciduous, 19= citrus & subtropical, 20= vineyard

Appendix C: Crop coefficients (Kc)

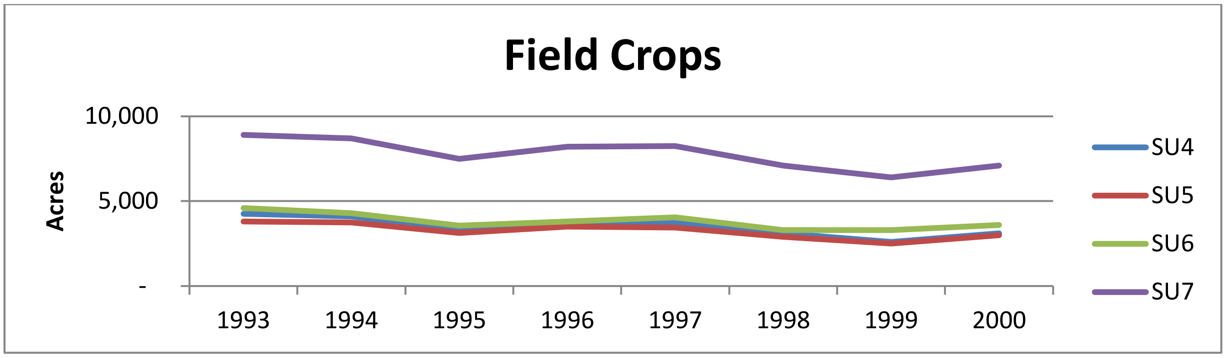
Crop Information		Crop		Growing Season				Irrig. Freq.	Crop Coefficients				Percent Season		
Crp Cat. #	Crop #	Crop	Type	Begin Mon	Begin Day	End Mon	End Day	F	KcB	KcC	KcD	KcE	A-B	A-C	A-D
1	1	Grain	1	10	15	5	31	30	0.3	1.13	1.13	0.35	19	43	76
2	2	Rice	1	5	1	9	22	30	1.1	1	1	0.6	18	24	78
3	3	Cotton	1	5	1	10	15	30	0.3	1.1	1.1	0.9	15	41	72
4	4	Sugar Beets	1	3	1	9	15	30	0.3	1.15	1.15	1.05	17	42	75
5	5	Corn	1	5	1	9	30	30	0.2	1.1	1.1	0.67	17	45	81
6	6	Dry Beans	1	6	1	9	30	30	0.2	1.1	1.1	0.1	16	43	79
7	7	Safflower	1	5	1	8	31	30	0.3	1.1	1.1	0.3	16	44	80
8	8	Other Field Crops	1	5	15	9	30	30	0.35	1.1	1.1	0.6	16	44	79
9	9	Alfalfa	2	10	1	9	30	30	1	1	1	1	25	50	75
10	10	Pasture	2	10	1	9	30	30	0.95	0.95	0.95	0.95	0	33	67
11	11	Tomato Processing	1	3	9	8	31	30	0.2	1.2	1.2	0.6	25	50	80
12	12	Tomato Fresh	1	2	9	8	31	30	0.2	1.2	1.2	1	25	50	80
13	13	Cucurbits	1	6	15	9	30	30	0.49	1.04	1.04	0.75	21	50	83
14	14	Onions & Garlic	1	9	15	7	31	30	0.55	1.2	1.2	0.55	10	27	73
15	15	Potatoes	1	5	1	9	30	30	0.4	1.15	1.15	0.75	21	45	79
16	16	Truck Crops	1	5	15	9	30	30	0.7	1	1	0.95	27	67	87
17	17	Almond & Pistacios	3	2	1	10	30	30	0.7	1.2	1.2	0.5	0	33	78
18	18	Other Deciduous	3	3	1	10	31	30	0.5	1.2	1.2	1	0	37	77
19	19	Citrus & Subtropical	4	10	1	9	30	30	1	1	1	1	0	41	89
20	20	Vineyard	3	4	1	11	15	30	0.4	0.8	0.8	0.4	0	25	75
21	21	Urban Landscape	2	1	1	12	31	30	0.8	0.8	0.8	0.8	25	50	75
22	22	Riparian	3	1	1	12	31	30	0.8	1.1	1.1	0.8	25	50	75
23	23	Native Vegetation	3	1	1	12	31	30	1	0.4	0.3	1	25	50	75
24	24	Water Surface	4	1	1	12	31	30	1.2	1.2	1.2	1.2	25	50	75

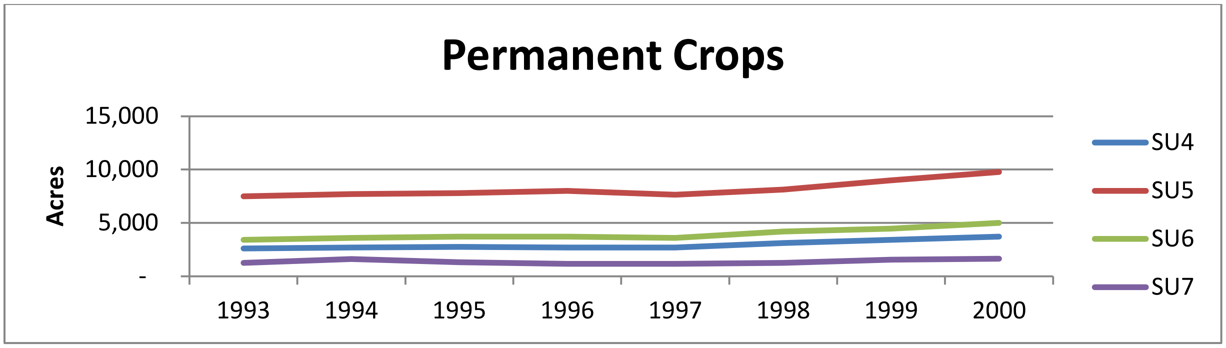
Appendix D: Top plot: cropping patterns as presented in SC report. Bottom plot: estimated cropping patterns using SC's cropping proportions.

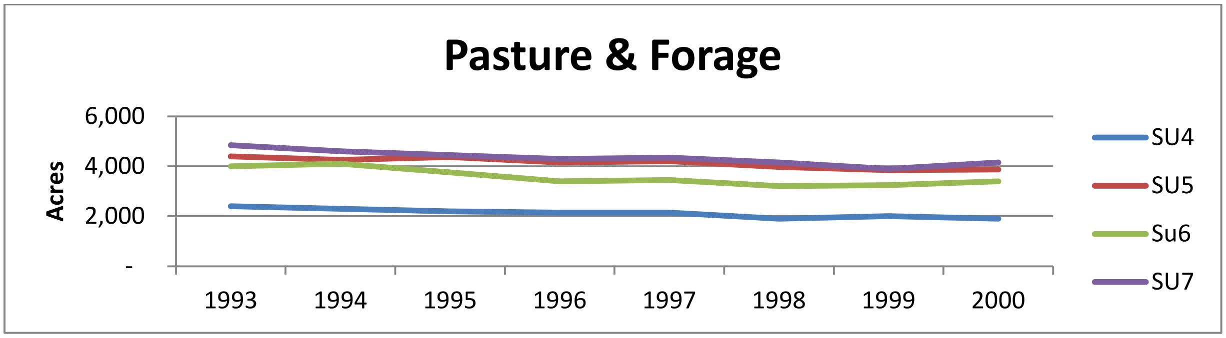


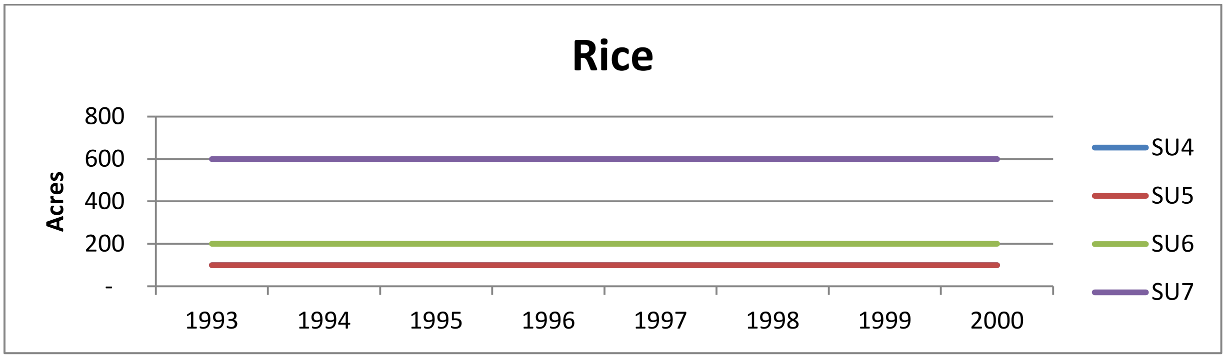


Appendix E: SC's cropping patterns for its different GW-Only subunits









Appendix F: Historic ET_0 (ft) in Orland, CA. (CIMIS Station 61)*

		Year																				
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Month	Jan	0.09	0.14	0.04	0.09	0.10	0.04	0.11	0.09	0.12	0.12	0.07	0.08	0.08	0.10	0.20	0.10	0.18	0.10	0.10	0.10	0.10
	Feb	0.11	0.14	0.13	0.14	0.23	0.08	0.12	0.10	0.16	0.19	0.19	0.14	0.14	0.21	0.15	0.18	0.14	0.16	0.16	0.16	0.16
	Mar	0.22	0.33	0.24	0.33	0.36	0.26	0.25	0.34	0.32	0.30	0.30	0.36	0.30	0.20	0.34	0.34	0.34	0.29	0.29	0.29	0.29
	Apr	0.36	0.42	0.36	0.33	0.47	0.36	0.50	0.41	0.39	0.39	0.31	0.47	0.40	0.32	0.43	0.46	0.45	0.41	0.41	0.41	0.41
	May	0.52	0.52	0.50	0.57	0.60	0.32	0.62	0.51	0.71	0.60	0.52	0.54	0.46	0.57	0.65	0.62	0.60	0.56	0.56	0.56	0.56
	Jun	0.68	0.67	0.63	0.10	0.64	0.50	0.60	0.72	0.64	0.71	0.65	0.64	0.62	0.60	0.69	0.68	0.61	0.64	0.64	0.64	0.64
	Jul	0.74	0.68	0.70	0.68	0.65	0.60	0.65	0.65	0.62	0.64	0.65	0.64	0.68	0.65	0.64	0.58	0.70	0.65	0.65	0.65	0.65
	Aug	0.59	0.58	0.62	0.60	0.56	0.57	0.53	0.58	0.58	0.58	0.53	0.58	0.61	0.11	0.59	0.62	0.60	0.57	0.57	0.57	0.57
	Sep	0.44	0.43	0.45	0.42	0.47	0.40	0.46	0.46	0.43	0.46	0.47	0.49	0.44	0.48	0.41	0.47	0.47	0.44	0.44	0.44	0.44
	Oct	0.29	0.33	0.40	0.27	0.32	0.34	0.32	0.29	0.34	0.33	0.36	0.30	0.30	0.34	0.28	0.34	0.15	0.32	0.32	0.32	0.32
	Nov	0.23	0.14	0.17	0.14	0.10	0.10	0.11	0.19	0.12	0.17	0.12	0.16	0.16	0.11	0.21	0.16	0.15	0.15	0.15	0.15	0.15
	Dec	0.10	0.04	0.07	0.09	0.14	0.13	0.15	0.14	0.08	0.07	0.06	0.11	0.08	0.12	0.14	0.09	0.12	0.12	0.12	0.12	0.12

*2010 through 2013 are monthly average values from CIMIS Station 61.

Appendix G: Average Historic Precipitation (ft) in Orland, CA from 1993 to 2013.

	Data Source						Data Source				
Month /Year	**Duhram (CIMIS)**	**Orland (CIMIS)**	**Orland (NWS COOP)**	**Average (in)**	**Average (ft)**	**Month/ Year**	**Duhram (CIMIS)**	**Orland (CIMIS)**	**Orland (NWS COOP)**	**Average (in)**	**Average (ft)**
Jan-93	8.62	7.17	9.15	8.31	**0.693**	Jul-96	0.00	0.00	0.01	0.00	**0.000**
Feb-93	7.68		7.10	7.39	**0.616**	Aug-96	0.00	0.00	0.00	0.00	**0.000**
Mar-93	2.01		1.35	1.68	**0.140**	Sep-96	0.16	0.31	0.36	0.28	**0.023**
Apr-93	1.85		0.87	1.36	**0.113**	Oct-96	1.77	2.09	1.78	1.88	**0.157**
May-93	2.40		2.65	2.53	**0.210**	Nov-96	1.42	2.32	2.71	2.15	**0.179**
Jun-93	0.00			0.00	**0.000**	Dec-96	7.28	6.10	5.09	6.16	**0.513**
Jul-93	0.00		0.00	0.00	**0.000**	Jan-97	7.95	6.26	6.80	7.00	**0.584**
Aug-93	0.20	0.00	0.00	0.07	**0.006**	Feb-97	0.31	0.20	0.33	0.28	**0.023**
Sep-93	1.61	0.00	0.00	0.54	**0.045**	Mar-97	1.81	1.73	1.79	1.78	**0.148**
Oct-93	0.39	0.63	1.38	0.80	**0.067**	Apr-97	0.08	0.31	0.49	0.29	**0.024**
Nov-93	1.42	1.57	1.53	1.51	**0.126**	May-97	0.00	0.43	0.46	0.30	**0.025**
Dec-93	2.44	1.85	1.99	2.09	**0.174**	Jun-97	0.00	0.00	0.52	0.17	**0.014**
Jan-94	2.52	2.76	2.92	2.73	**0.228**	Jul-97	0.00	0.00		0.00	**0.000**
Feb-94	5.00	5.08	5.12	5.07	**0.422**	Aug-97	0.47	0.63	0.64	0.58	**0.048**
Mar-94	0.31	0.00		0.16	**0.013**	Sep-97	0.16	0.00	0.16	0.11	**0.009**
Apr-94	0.98	0.83	0.68	0.83	**0.069**	Oct-97	2.01	0.12	0.69	0.94	**0.078**
May-94	1.14	1.54	1.63	1.44	**0.120**	Nov-97	5.87	6.73	6.57	6.39	**0.532**
Jun-94	0.00	0.08	0.00	0.03	**0.002**	Dec-97	2.36	2.48	2.38	2.41	**0.201**
Jul-94	0.00	0.00	0.00	0.00	**0.000**	Jan-98	8.43	7.80	7.56	7.93	**0.661**
Aug-94	0.00	0.00	0.00	0.00	**0.000**	Feb-98	12.87	15.91	18.04	15.61	**1.301**
Sep-94	0.00	0.00	0.12	0.04	**0.003**	Mar-98	4.37	3.78	3.39	3.85	**0.321**
Oct-94	1.06	0.39	0.35	0.60	**0.050**	Apr-98	2.91	1.54	2.80	2.42	**0.201**
Nov-94	4.29	3.39	3.20	3.63	**0.302**	May-98	3.82	3.98	4.65	4.15	**0.346**
Dec-94	4.92	3.66	3.27	3.95	**0.329**	Jun-98	0.12	0.12	1.19	0.48	**0.040**
Jan-95	13.70	17.99	17.37	16.35	**1.363**	Jul-98	0.00	0.00	0.00	0.00	**0.000**
Feb-95	0.35	0.67	0.89	0.64	**0.053**	Aug-98	0.00	0.00	0.00	0.00	**0.000**
Mar-95	1.85	8.98	8.84	6.56	**0.546**	Sep-98	0.51	0.08	0.04	0.21	**0.017**
Apr-95	3.27	1.85	1.28	2.13	**0.178**	Oct-98	1.46	1.81	1.92	1.73	**0.144**
May-95	1.06	1.81	2.51	1.79	**0.149**	Nov-98	5.24	4.25	3.83	4.44	**0.370**
Jun-95	1.65	0.63		1.14	**0.095**	Dec-98	1.18	1.61	1.40	1.40	**0.116**
Jul-95	0.00	0.00	0.00	0.00	**0.000**	Jan-99	1.46	0.94	1.06	1.15	**0.096**
Aug-95	0.00	0.00	0.00	0.00	**0.000**	Feb-99	5.59	3.74	3.81	4.38	**0.365**
Sep-95	1.73	0.00	0.00	0.58	**0.048**	Mar-99	1.61	2.32	2.59	2.17	**0.181**
Oct-95	0.04	0.00	0.00	0.01	**0.001**	Apr-99	1.22	0.79	0.96	0.99	**0.082**
Nov-95	0.00	0.00	0.00	0.00	**0.000**	May-99	0.00	0.00	0.06	0.02	**0.002**
Dec-95	7.48	6.81	6.09	6.79	**0.566**	Jun-99	0.08	0.79	0.68	0.52	**0.043**
Jan-96	5.12	5.63	5.44	5.40	**0.450**	Jul-99	0.00	0.00	0.00	0.00	**0.000**
Feb-96	5.59	7.05	6.54	6.39	**0.533**	Aug-99	0.00	0.00	0.19	0.06	**0.005**
Mar-96	1.97	1.73	2.13	1.94	**0.162**	Sep-99	0.91	0.00	0.00	0.30	**0.025**
Apr-96	0.87	1.77	1.25	1.30	**0.108**	Oct-99	0.00	0.22	0.00	0.07	**0.006**
May-96	2.91	2.40		2.66	**0.221**	Nov-99	2.61	2.19	2.71	2.50	**0.209**
Jun-96	0.00	0.00	0.04	0.01	**0.001**	Dec-99	0.33	0.23	0.28	0.28	**0.023**

	Data Source						Data Source				
Month/ Year	**Duhram (CIMIS)**	**Orland (CIMIS)**	**Orland (NWS COOP)**	**Average (in)**	**Average (ft)**	**Month/ Year**	**Duhram (CIMIS)**	**Orland (CIMIS)**	**Orland (NWS COOP)**	**Average (in)**	**Average (ft)**
Jan-00	5.32	4.53	4.79	4.88	**0.407**	Jul-03	0.00	0.00	0.02	0.01	**0.001**
Feb-00	7.64	6.22	5.95	6.60	**0.550**	Aug-03	0.00	0.98	1.03	0.67	**0.056**
Mar-00	2.52	2.40	2.52	2.48	**0.207**	Sep-03	0.00	0.00	0.04	0.01	**0.001**
Apr-00	1.75	1.87	2.11	1.91	**0.159**	Oct-03	0.00	0.31	0.19	0.17	**0.014**
May-00	0.92	1.04	1.21	1.06	**0.088**	Nov-03	2.14	2.06	3.61	2.60	**0.217**
Jun-00	0.00	0.23	0.45	0.23	**0.019**	Dec-03	7.16	7.08	8.12	7.45	**0.621**
Jul-00	0.00	0.00	0.00	0.00	**0.000**	Jan-04	2.59	1.49	2.76	2.28	**0.190**
Aug-00	0.19	0.00	0.00	0.06	**0.005**	Feb-04	5.87	2.62	6.74	5.08	**0.423**
Sep-00	0.19	0.06	0.17	0.14	**0.012**	Mar-04	1.25	1.06	1.40	1.24	**0.103**
Oct-00	2.49	1.55	1.98	2.01	**0.167**	Apr-04	0.69	0.35	0.21	0.42	**0.035**
Nov-00	0.64	0.62	0.67	0.64	**0.054**	May-04	0.57	0.26	0.05	0.29	**0.024**
Dec-00	0.47	0.26	0.31	0.35	**0.029**	Jun-04	0.00	0.00	0.00	0.00	**0.000**
Jan-01	4.95	5.21	5.84	5.33	**0.444**	Jul-04	0.00	0.00	0.00	0.00	**0.000**
Feb-01	4.53	4.13	4.51	4.39	**0.366**	Aug-04	0.00	0.00	0.00	0.00	**0.000**
Mar-01	2.44	2.32	2.45	2.40	**0.200**	Sep-04	0.00	0.00	0.00	0.00	**0.000**
Apr-01	1.44	1.17	1.31	1.31	**0.109**	Oct-04	3.51	2.66	3.62	3.26	**0.272**
May-01	0.00	0.00	0.00	0.00	**0.000**	Nov-04	1.56	1.57	1.81	1.65	**0.137**
Jun-01	0.00	0.50	0.68	0.39	**0.033**	Dec-04	4.76	5.44	6.34	5.51	**0.459**
Jul-01	0.00	0.00	0.00	0.00	**0.000**	Jan-05	4.41	3.58	6.29	4.76	**0.397**
Aug-01	0.00	0.00	0.00	0.00	**0.000**	Feb-05	2.27	0.80	3.32	2.13	**0.177**
Sep-01	0.31	0.41	0.43	0.38	**0.032**	Mar-05	2.14	0.04	2.72	1.63	**0.136**
Oct-01	1.21	0.92	0.91	1.01	**0.084**	Apr-05	1.47	0.02	1.80	1.10	**0.091**
Nov-01	6.35	4.98	5.24	5.52	**0.460**	May-05	2.59	0.04	3.21	1.95	**0.162**
Dec-01	6.59	5.71	6.29	6.20	**0.516**	Jun-05	1.24	0.52	0.71	0.82	**0.069**
Jan-02	3.36	2.12	2.60	2.69	**0.224**	Jul-05	0.00	0.00	0.00	0.00	**0.000**
Feb-02	0.76	0.45	0.45	0.55	**0.046**	Aug-05	0.00	0.00	0.00	0.00	**0.000**
Mar-02	2.27	0.85	0.97	1.36	**0.114**	Sep-05	0.00	0.00	0.00	0.00	**0.000**
Apr-02	0.06	0.06	0.03	0.05	**0.004**	Oct-05	0.94	0.45	0.40	0.60	**0.050**
May-02	0.00	0.91	1.03	0.65	**0.054**	Nov-05	2.53	2.37	2.21	2.37	**0.197**
Jun-02	0.00	0.00	0.00	0.00	**0.000**	Dec-05	7.83	6.91	8.59	7.78	**0.648**
Jul-02	0.00	0.00	0.02	0.01	**0.001**	Jan-06	3.02	2.61	3.22	2.95	**0.246**
Aug-02	0.00	0.00	0.00	0.00	**0.000**	Feb-06	3.05	2.39	2.87	2.77	**0.231**
Sep-02	0.00	0.00	0.00	0.00	**0.000**	Mar-06	6.77	5.15	5.69	5.87	**0.489**
Oct-02	0.00	0.02	0.00	0.01	**0.001**	Apr-06	3.68	3.95	5.40	4.34	**0.362**
Nov-02	0.43	1.89	2.00	1.44	**0.120**	May-06	0.64	0.66	0.63	0.64	**0.054**
Dec-02	9.18	8.31	10.18	9.22	**0.769**	Jun-06	0.00	0.10	0.27	0.12	**0.010**
Jan-03	3.79	3.21	3.66	3.55	**0.296**	Jul-06	0.00	0.00	0.00	0.00	**0.000**
Feb-03	2.42	1.93	2.07	2.14	**0.178**	Aug-06	0.00	0.00	0.00	0.00	**0.000**
Mar-03	1.96	2.36	2.88	2.40	**0.200**	Sep-06	0.00	0.00	0.00	0.00	**0.000**
Apr-03	3.89	2.57	2.97	3.14	**0.262**	Oct-06	0.48	0.04	0.09	0.20	**0.017**
May-03	0.81	0.71	1.30	0.94	**0.078**	Nov-06	2.09	1.48	1.64	1.74	**0.145**
Jun-03	0.00	0.00	0.00	0.00	**0.000**	Dec-06	3.27	2.58	3.10	2.98	**0.249**

	Data Source						Data Source				
Month/ Year	Duhram (CIMIS)	Orland (CIMIS)	Orland (NWS COOP)	Average (in)	Average (ft)	Month/ Year	Duhram (CIMIS)	Orland (CIMIS)	Orland (NWS COOP)	Average (in)	Average (ft)
Jan-07	0.00	0.07	0.04	0.04	**0.003**	Jul-10	0.00		0.00	0.00	**0.000**
Feb-07	4.10	3.09	3.31	3.50	**0.292**	Aug-10	0.00		0.00	0.00	**0.000**
Mar-07	0.29	0.07	0.12	0.16	**0.013**	Sep-10	0.00		0.62	0.31	**0.026**
Apr-07	1.73	0.95	1.59	1.42	**0.119**	Oct-10	1.92		2.38	2.15	**0.179**
May-07	2.01	0.29	0.33	0.88	**0.073**	Nov-10	2.47		1.33	1.90	**0.158**
Jun-07	1.53	0.35	0.15	0.68	**0.056**	Dec-10	6.02		4.93	5.48	**0.456**
Jul-07	0.95	0.45	0.47	0.62	**0.052**	Jan-11	1.52		1.31	1.42	**0.118**
Aug-07	0.00	0.00	0.00	0.00	**0.000**	Feb-11	2.99		2.50	2.75	**0.229**
Sep-07	0.00	0.93	0.93	0.62	**0.052**	Mar-11	4.90		5.79	5.35	**0.445**
Oct-07	1.10	0.75	0.77	0.87	**0.073**	Apr-11	0.13			0.13	**0.011**
Nov-07	0.44	0.40	0.43	0.42	**0.035**	May-11	3.21		2.02	2.62	**0.218**
Dec-07	3.80	2.41	3.13	3.11	**0.259**	Jun-11	2.04		1.23	1.64	**0.136**
Jan-08	6.18	7.72	8.90	7.60	**0.633**	Jul-11	0.02		0.00	0.01	**0.001**
Feb-08	2.98	2.24	2.71	2.64	**0.220**	Aug-11	0.00		0.00	0.00	**0.000**
Mar-08	0.29	0.00	0.00	0.10	**0.008**	Sep-11	0.00			0.00	**0.000**
Apr-08	0.44	0.07	0.07	0.19	**0.016**	Oct-11	1.83			1.83	**0.152**
May-08	0.00	0.17	0.21	0.13	**0.011**	Nov-11	1.67		2.68	2.18	**0.181**
Jun-08	0.00	0.00	0.00	0.00	**0.000**	Dec-11	0.23			0.23	**0.019**
Jul-08	0.00	0.00	0.00	0.00	**0.000**	Jan-12	3.87		3.62	3.75	**0.312**
Aug-08	0.00	0.01	0.00	0.00	**0.000**	Feb-12	0.75		0.86	0.81	**0.067**
Sep-08	0.00	0.00	0.00	0.00	**0.000**	Mar-12	3.78		3.38	3.58	**0.298**
Oct-08	1.94	0.85	0.80	1.20	**0.100**	Apr-12	1.68		1.67	1.68	**0.140**
Nov-08	1.88	1.93	2.18	2.00	**0.166**	May-12	0.04		0.00	0.02	**0.002**
Dec-08	2.12	1.21	1.38	1.57	**0.131**	Jun-12	0.17			0.17	**0.014**
Jan-09	2.56	0.89	0.80	1.42	**0.118**	Jul-12	0.00		0.00	0.00	**0.000**
Feb-09	5.81	7.70	9.13	7.55	**0.629**	Aug-12	0.00		0.00	0.00	**0.000**
Mar-09	1.51	1.44	1.59	1.51	**0.126**	Sep-12	0.00		0.00	0.00	**0.000**
Apr-09	0.28	0.35	0.47	0.37	**0.031**	Oct-12	0.23		0.37	0.30	**0.025**
May-09	1.04	0.52	0.55	0.70	**0.059**	Nov-12	3.92		4.11	4.02	**0.335**
Jun-09	0.00	0.46	0.75	0.40	**0.034**	Dec-12	7.20		6.90	7.05	**0.587**
Jul-09	0.00	0.00	0.00	0.00	**0.000**	Jan-13	0.87		1.27	1.07	**0.089**
Aug-09	0.00	0.01	0.00	0.00	**0.000**	Feb-13	0.22		0.31	0.27	**0.022**
Sep-09	0.00	0.07	0.05	0.04	**0.003**	Mar-13	3.46		1.06	2.26	**0.188**
Oct-09	1.38	1.81	2.30	1.83	**0.152**	Apr-13	0.58		0.70	0.64	**0.053**
Nov-09	1.94	0.53	0.63	1.03	**0.086**	May-13	0.28		0.13	0.21	**0.017**
Dec-09	3.91	2.56	3.07	3.18	**0.265**	Jun-13	0.61		0.13	0.37	**0.031**
Jan-10	7.06		9.36	8.21	**0.684**	Jul-13	0.00		0.00	0.00	**0.000**
Feb-10	3.29		3.92	3.61	**0.300**	Aug-13	0.00		0.00	0.00	**0.000**
Mar-10	0.74		0.90	0.82	**0.068**	Sep-13	0.98		1.60	1.29	**0.107**
Apr-10	1.46		3.32	2.39	**0.199**	Oct-13	0.54		0.04	0.29	**0.024**
May-10	1.05		1.17	1.11	**0.092**	Nov-13	1.47		0.67	1.07	**0.089**
Jun-10	0.01		0.00	0.01	**0.000**	Dec-13	1.07		0.11	0.59	**0.049**

Appendix H: Application Efficiency by Crop in Glenn County in 2001 and 2010**

Glenn		2001			2010		
Crop No.	**Crop Name**	**Low AE (%)**	**High AE (%)**	**Mean AE (%)**	**Low AE (%)**	**High AE (%)**	**Mean AE (%)**
1	Corn	75.6	94.1	84.5	68.0	89.5	78.6
2	Cotton	62.3	81.5	72.2	64.0	83.2	73.9
3	Dry beans	--	--	--	--	--	--
4	Grains	60.2	84.7	72.4	59.8	84.5	72.5
5	Safflower	--	--	--	60.0	85.0	72.5
6	Sugar Beets	60.0	85.0	72.5	--	--	--
7	Other Field crops	58.9	83.8	72.4	59.6	85.7	73.8
8	Alfalfa	--	--	--	--	--	--
9	Pasture	--	--	--	--	--	--
10	Cucurbits	60.0	84.8	72.5	60.2	85.2	73.4
11	Onion &Garlic	60.6	82.6	71.9	60.4	84.1	73.0
12	Potato	60.3	81.9	71.6	59.2	82.8	72.1
13	Tomato (fresh)	58.2	85.2	72.6	64.4	85.4	74.9
14	Tomato (process)	--	--	--	--	--	--
15	Other Truck Crops	--	--	--	--	--	--
16	Almond & Pistachios	--	--	--	--	--	--
17	Other Deciduous	--	--	--	--	--	--
18	Subtropical Trees	--	--	--	62.3	85.6	74.0
19	Turfgrass & landscape	67.6	80.8	74.1	68.0	80.8	74.3
20	Vineyard	60.5	74.3	67.6	62.8	74.7	68.8
	Average	**68.7**	**86.4**	**77.5**	**67.0**	**86.1**	**77.2**

**Missing values are assigned the average AE of all crops

Appendix I: Distribution of land as a function of GW depth ~.

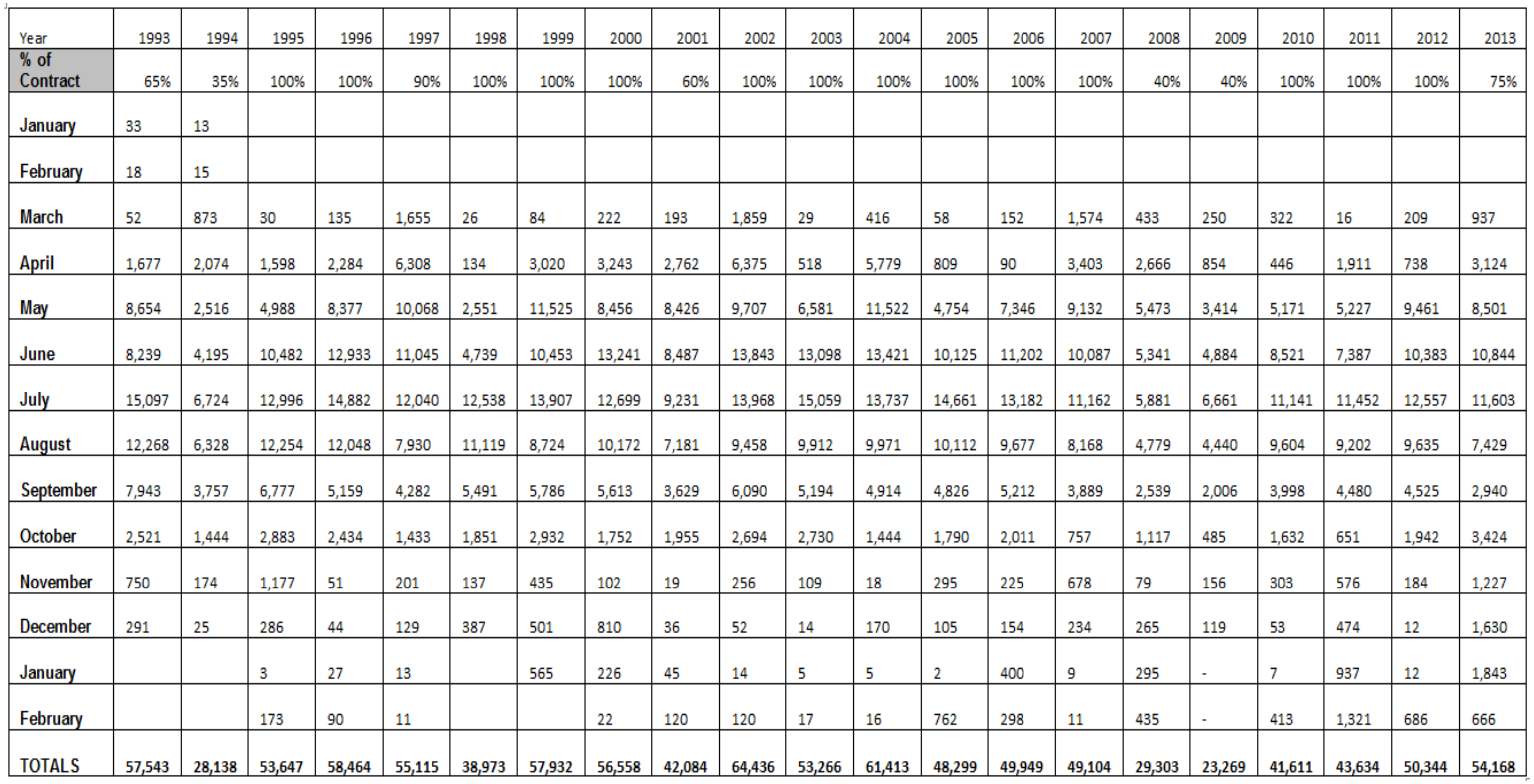
GW depth (ft)	Total Acres									
	OAWD					GW-Only				
	1993	1998	2003	2008	2013	1993	1998	2003	2008	2013
20	8,009	7,375	8,554	3,297	1,543	26,765	17,604	29,675	18,136	7,642
30	7,930	3,832	6,339	6,480	2,673	19,513	6,916	18,042	21,530	20,946
40	3,646	1,956	3,664	7,610	5,645	8,426	3,606	7,214	14,122	15,388
50	1,850	1,306	1,275	2,859	5,547	3,485	2,695	1,275	4,956	2,159
60	1,344	719	1,664	1,935	3,443	2,840	2,364	2,324	3,435	6,361
70	1,172	538	861	1,248	2,863	2,557	1,865	1,789	2,026	4,989
80	808	711	714	556	2,007	2,550	2,534	1,751	1,436	3,499
90	727	580	545	592	1,306	2,356	2,059	2,177	1,949	2,134
100	412	421	719	631	782	1,968	2,294	1,997	1,768	1,744
110	580	384	931	736	738	2,033	1,926	2,433	1,888	2,325
120	540	161	648	738	245	2,120	1,693	2,006	1,992	1,252
130	500	136	681	940	526	2,171	1,754	2,233	2,369	1,754
140	271	87	344	463	617	1,142	1,347	1,472	2,022	1,753
150	133	-	469	492	705	1,180	1,244	2,089	1,482	2,159
160	114	-	215	187	941	1,950	1,245	1,736	1,720	2,079
170	-	-	173	205	683	1,181	972	1,814	2,121	2,134
180	-	-	79	43	475	1,243	1,708	1,487	1,565	1,740
190	-	-	-	-	202	1,042	1,086	1,509	1,590	1,933
200	-	-	-	-	131	1,290	1,055	1,251	1,692	1,346
210	-	-	-	-	122	1,065	1,083	1,381	1,298	1,785
220	-	-	-	-	19	991	942	923	1,237	1,239
230	-	-	-	-	-	1,147	606	1,080	1,182	1,739
240	-	-	-	-	-	1,177	1,072	1,316	1,254	1,394
250	-	-	-	-	-	609	569	1,277	1,243	1,456
260	-	-	-	-	-	737	623	667	979	932
270	-	-	-	-	-	1,030	499	655	646	1,159
280	-	-	-	-	-	655	380	778	827	1,036
290	-	-	-	-	-	413	394	689	490	1,041
300	-	-	-	-	-	365	322	578	889	607
310	-	-	-	-	-	228	222	492	404	890
320	-	-	-	-	-	391	194	398	469	618
330	-	-	-	-	-	194	78	270	239	563
340	-	-	-	-	-	64	11	242	247	664
350	-	-	-	-	-	211	49	299	252	383
360	-	-	-	-	-	70	66	137	222	350
370	-	-	-	-	-	-	-	124	104	327
380	-	-	-	-	-	68	-	37	37	228
390	-	-	-	-	-	19	36	56	51	69
400	-	-	-	-	-	-	-	-	28	140
410	-	-	-	-	-	-	-	-	-	92
420	-	-	-	-	-	-	-	-	-	49
430	-	-	-	-	-	-	-	-	-	12

~Total acres include irrigated (cropped) and non-irrigated land (urban, riparian, etc).

Appendix J: Monthly runoff records for hydrologic region HU8-18020104.

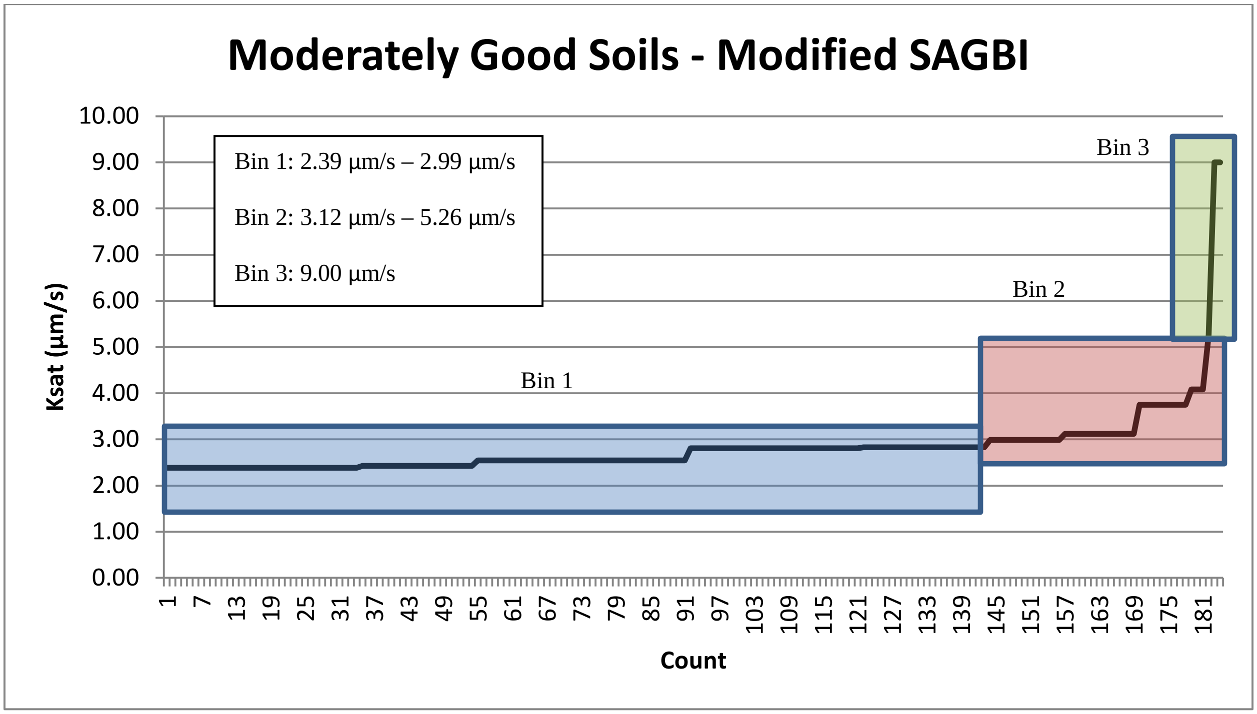
Date	mm	Date	mm	Date	mm	Date	mm	Date	mm	Date	mm
Jan-93	48.80	Jul-96	20.10	Jan-00	23.50	Jul-03	22.70	Jan-07	15.20	Jul-10	17.10
Feb-93	43.10	Aug-96	21.00	Feb-00	56.20	Aug-03	19.90	Feb-07	22.50	Aug-10	17.90
Mar-93	48.50	Sep-96	17.00	Mar-00	58.80	Sep-03	15.70	Mar-07	19.20	Sep-10	18.10
Apr-93	41.30	Oct-96	11.30	Apr-00	25.60	Oct-03	11.30	Apr-07	14.00	Oct-10	13.50
May-93	21.00	Nov-96	13.00	May-00	19.90	Nov-03	12.20	May-07	10.60	Nov-10	13.00
Jun-93	27.50	Dec-96	52.20	Jun-00	16.20	Dec-03	30.10	Jun-07	12.60	Dec-10	42.30
Jul-93	17.20	Jan-97	84.10	Jul-00	21.80	Jan-04	38.40	Jul-07	19.60	Jan-11	35.00
Aug-93	20.50	Feb-97	50.50	Aug-00	19.40	Feb-04	44.50	Aug-07	18.10	Feb-11	22.80
Sep-93	15.60	Mar-97	22.20	Sep-00	15.80	Mar-04	49.00	Sep-07	16.60	Mar-11	53.40
Oct-93	13.30	Apr-97	12.50	Oct-00	11.70	Apr-04	21.50	Oct-07	12.00	Apr-11	50.60
Nov-93	11.50	May-97	11.10	Nov-00	11.80	May-04	13.00	Nov-07	11.60	May-11	33.50
Dec-93	19.80	Jun-97	15.00	Dec-00	13.60	Jun-04	15.60	Dec-07	14.30	Jun-11	36.50
Jan-94	13.90	Jul-97	21.80	Jan-01	18.10	Jul-04	21.00	Jan-08	25.90	Jul-11	20.10
Feb-94	18.80	Aug-97	19.00	Feb-01	20.20	Aug-04	19.20	Feb-08	28.20	Aug-11	17.20
Mar-94	13.70	Sep-97	13.80	Mar-01	26.20	Sep-04	15.40	Mar-08	15.30	Sep-11	20.70
Apr-94	8.30	Oct-97	11.30	Apr-01	12.20	Oct-04	12.90	Apr-08	11.60	Oct-11	17.20
May-94	9.70	Nov-97	13.80	May-01	9.30	Nov-04	11.60	May-08	10.60	Nov-11	12.90
Jun-94	7.70	Dec-97	21.70	Jun-01	12.20	Dec-04	18.40	Jun-08	11.10	Dec-11	15.40
Jul-94	12.20	Jan-98	53.20	Jul-01	16.00	Jan-05	35.30	Jul-08	13.80	Jan-12	16.70
Aug-94	12.70	Feb-98	74.70	Aug-01	14.40	Feb-05	21.30	Aug-08	12.90	Feb-12	14.40
Sep-94	15.00	Mar-98	63.50	Sep-01	12.90	Mar-05	27.80	Sep-08	12.20	Mar-12	22.50
Oct-94	8.50	Apr-98	52.50	Oct-01	8.70	Apr-05	18.70	Oct-08	9.30	Apr-12	25.50
Nov-94	8.70	May-98	43.10	Nov-01	12.80	May-05	38.50	Nov-08	10.70	May-12	12.60
Dec-94	17.00	Jun-98	51.30	Dec-01	29.40	Jun-05	23.30	Dec-08	10.30	Jun-12	13.30
Jan-95	63.40	Jul-98	25.80	Jan-02	40.10	Jul-05	18.30	Jan-09	10.50	Jul-12	20.40
Feb-95	55.10	Aug-98	24.80	Feb-02	17.20	Aug-05	16.00	Feb-09	21.50	Aug-12	18.90
Mar-95	71.60	Sep-98	23.80	Mar-02	21.00	Sep-05	16.60	Mar-09	24.90	Sep-12	16.60
Apr-95	59.30	Oct-98	15.40	Apr-02	12.50	Oct-05	13.90	Apr-09	13.10	Oct-12	12.70
May-95	58.30	Nov-98	20.40	May-02	12.80	Nov-05	12.80	May-09	16.10	Nov-12	12.50
Jun-95	35.60	Dec-98	46.30	Jun-02	13.80	Dec-05	33.70	Jun-09	12.10	Dec-12	48.40
Jul-95	22.10	Jan-99	32.10	Jul-02	19.30	Jan-06	66.30	Jul-09	18.20	Jan-13	22.70
Aug-95	19.50	Feb-99	56.30	Aug-02	18.30	Feb-06	42.00	Aug-09	15.70	Feb-13	14.40
Sep-95	22.20	Mar-99	56.70	Sep-02	14.10	Mar-06	70.90	Sep-09	12.60	Mar-13	14.20
Oct-95	13.10	Apr-99	28.60	Oct-02	10.30	Apr-06	74.70	Oct-09	10.50	Apr-13	13.10
Nov-95	11.50	May-99	17.80	Nov-02	11.90	May-06	48.70	Nov-09	9.50	May-13	13.20
Dec-95	25.00	Jun-99	15.40	Dec-02	31.20	Jun-06	24.30	Dec-09	11.80	Jun-13	13.80
Jan-96	35.40	Jul-99	21.10	Jan-03	55.90	Jul-06	18.30	Jan-10	31.50	Jul-13	17.90
Feb-96	67.10	Aug-99	17.80	Feb-03	32.30	Aug-06	19.20	Feb-10	28.70	Aug-13	18.40
Mar-96	56.80	Sep-99	15.30	Mar-03	23.50	Sep-06	18.40	Mar-10	21.40	Sep-13	14.20
Apr-96	33.20	Oct-99	11.30	Apr-03	22.20	Oct-06	12.40	Apr-10	20.30	Oct-13	0.00
May-96	36.20	Nov-99	12.60	May-03	40.70	Nov-06	12.10	May-10	16.10	Nov-13	0.00
Jun-96	20.50	Dec-99	16.20	Jun-03	20.70	Dec-06	18.30	Jun-10	18.70	Dec-13	0.00

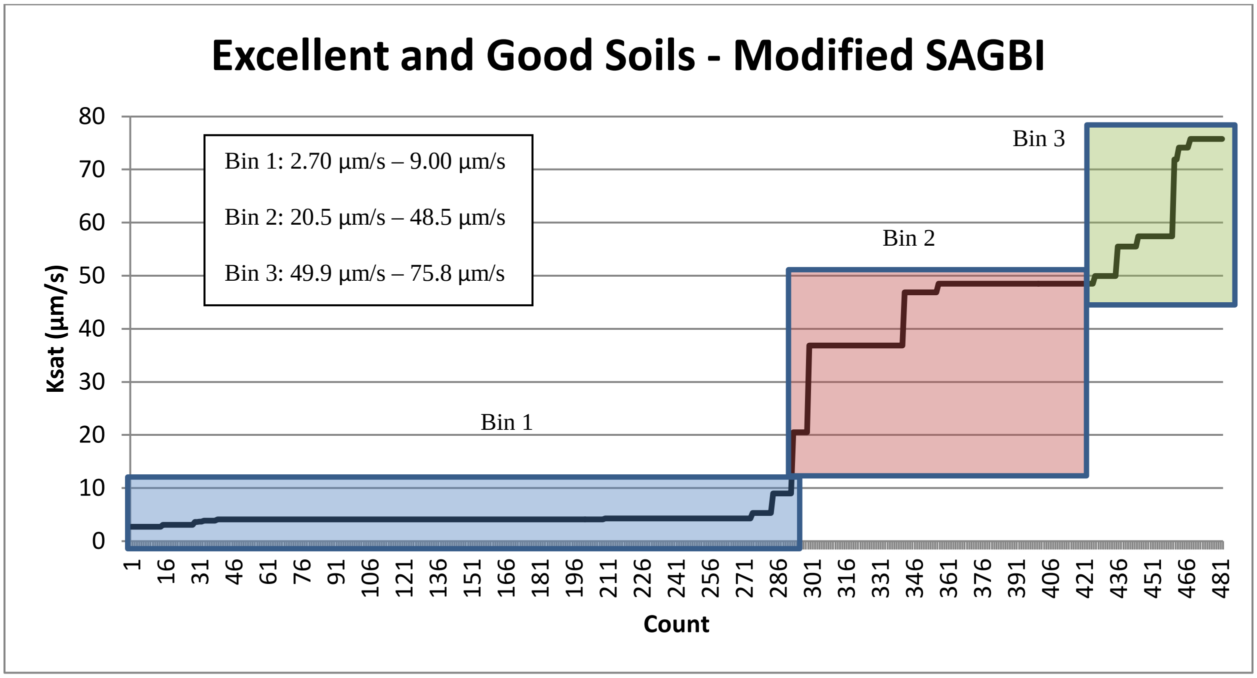
Appendix K: SW delivered in OAWD between 1993 and 2013. Source: Orland-Artois Water District Management.

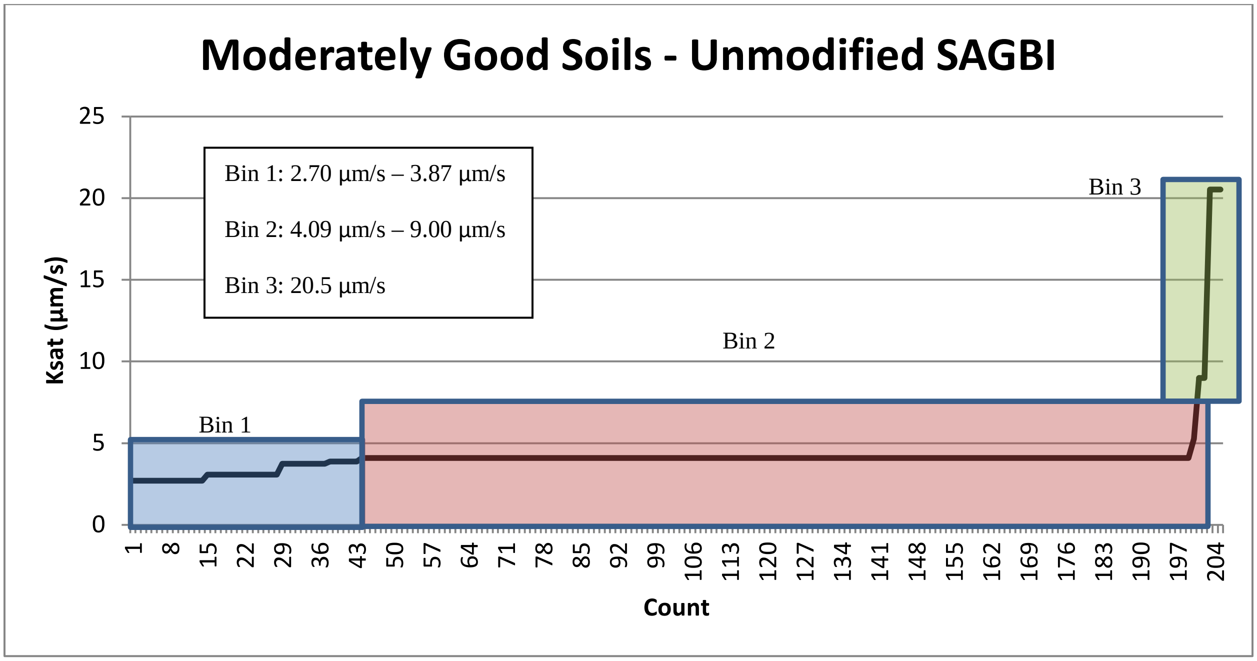


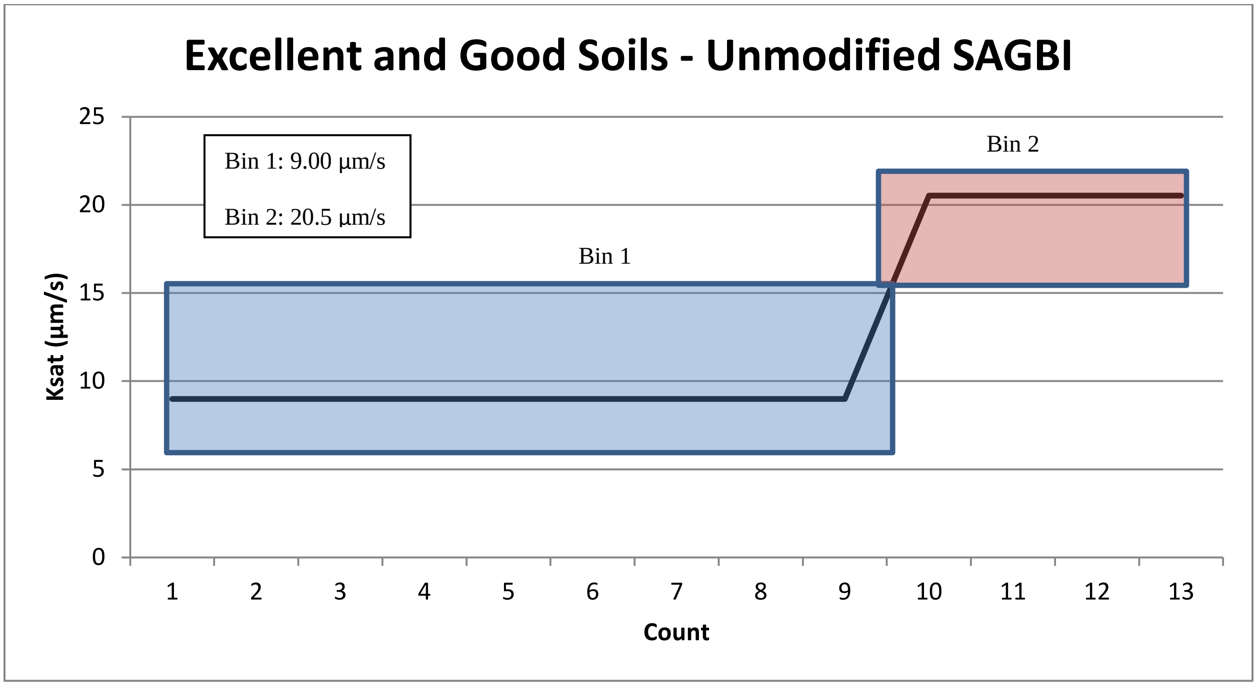
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
% of Contract	65%	35%	100%	100%	90%	100%	100%	100%	60%	100%	100%	100%	100%	100%	100%	40%	40%	100%	100%	100%	75%
January	33	13																			
February	18	15																			
March	52	873	30	135	1,655	26	84	222	193	1,859	29	416	58	152	1,574	433	250	322	16	209	937
April	1,677	2,074	1,598	2,284	6,308	134	3,020	3,243	2,762	6,375	518	5,779	809	90	3,403	2,666	854	446	1,911	738	3,124
May	8,654	2,516	4,988	8,377	10,068	2,551	11,525	8,456	8,426	9,707	6,581	11,522	4,754	7,346	9,132	5,473	3,414	5,171	5,227	9,461	8,501
June	8,239	4,195	10,482	12,933	11,045	4,739	10,453	13,241	8,487	13,843	13,098	13,421	10,125	11,202	10,087	5,341	4,884	8,521	7,387	10,383	10,844
July	15,097	6,724	12,996	14,882	12,040	12,538	13,907	12,699	9,231	13,968	15,059	13,737	14,661	13,182	11,162	5,881	6,661	11,141	11,452	12,557	11,603
August	12,268	6,328	12,254	12,048	7,930	11,119	8,724	10,172	7,181	9,458	9,912	9,971	10,112	9,677	8,168	4,779	4,440	9,604	9,202	9,635	7,429
September	7,943	3,757	6,777	5,159	4,282	5,491	5,786	5,613	3,629	6,090	5,194	4,914	4,826	5,212	3,889	2,539	2,006	3,998	4,480	4,525	2,940
October	2,521	1,444	2,883	2,434	1,433	1,851	2,932	1,752	1,955	2,694	2,730	1,444	1,790	2,011	757	1,117	485	1,632	651	1,942	3,424
November	750	174	1,177	51	201	137	435	102	19	256	109	18	295	225	678	79	156	303	576	184	1,227
December	291	25	286	44	129	387	501	810	36	52	14	170	105	154	234	265	119	53	474	12	1,630
January			3	27	13		565	226	45	14	5	5	2	400	9	295	-	7	937	12	1,843
February			173	90	11			22	120	120	17	16	762	298	11	435	-	413	1,321	686	666
TOTALS	**57,543**	**28,138**	**53,647**	**58,464**	**55,115**	**38,973**	**57,932**	**56,558**	**42,084**	**64,436**	**53,266**	**61,413**	**48,299**	**49,949**	**49,104**	**29,303**	**23,269**	**41,611**	**43,634**	**50,344**	**54,168**

Appendix L: Grouping of K_{sat} values (from SAGBI) into bins.






Moderately Good Soils - Unmodified SAGBI
Bin 1: 2.70 µm/s – 3.87 µm/s
Bin 2: 4.09 µm/s – 9.00 µm/s
Bin 3: 20.5 µm/s
Bin 1
Bin 2
Bin 3
Ksat (µm/s)
0
5
10
15
20
25
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
120
127
134
141
148
155
162
169
176
183
190
197
204
Count


Excellent and Good Soils - Unmodified SAGBI
Bin 1: 9.00 µm/s
Bin 2: 20.5 µm/s
Bin 1
Bin 2
Ksat (µm/s)
0
5
10
15
20
25
1
2
3
4
5
6
7
8
9
10
11
12
13
Count

Appendix M: Estimated energy costs for irrigation. Costs estimated as the average of commercial and industrial energy rates in California. Source: U.S. Energy Information Administration (www.eia.gov).

Year	$/Kw-hr
1993	$ 0.089
1994	$ 0.090
1995	$ 0.089
1996	$ 0.084
1997	$ 0.085
1998	$ 0.081
1999	$ 0.079
2000	$ 0.087
2001	$ 0.107
2002	$ 0.116
2003	$ 0.110
2004	$ 0.105
2005	$ 0.107
2006	$ 0.115
2007	$ 0.114
2008	$ 0.113
2009	$ 0.118
2010	$ 0.114
2011	$ 0.116
2012	$ 0.120
2013	$ 0.129

Appendix N: Surface water charges in OAWD from 1993 to 2013[*]. B/P= base price, F/C= full price. It is assumed that all growers pay B/P for their surface water. Source: Orland-Artois Water District Management.

Year	B/P	F/C
1993	**$ 14.10**	-
1994	**$ 15.19**	-
1995	**$ 16.29**	-
1996	$ 16.50	$ 110.50
1997	$ 20.56	$ 107.66
1998	$ 21.97	$ 107.66
1999	$ 21.06	$ 119.79
2000	$ 22.35	$ 121.54
2001	$ 24.64	$ 123.62
2002	$ 21.68	$ 123.08
2003	$ 24.79	$ 123.76
2004	$ 25.88	$ 124.07
2005	$ 27.00	$ 124.02
2006	$ 27.91	$ 123.16
2007	$ 30.30	$ 129.08
2008	$ 33.50	$ 132.05
2009	$ 45.00	$ 143.76
2010	$ 38.00	$ 138.50
2011	$ 34.44	$ 126.99
2012	$ 45.49	$ 141.17
2013	$ 25.00	$ 139.13

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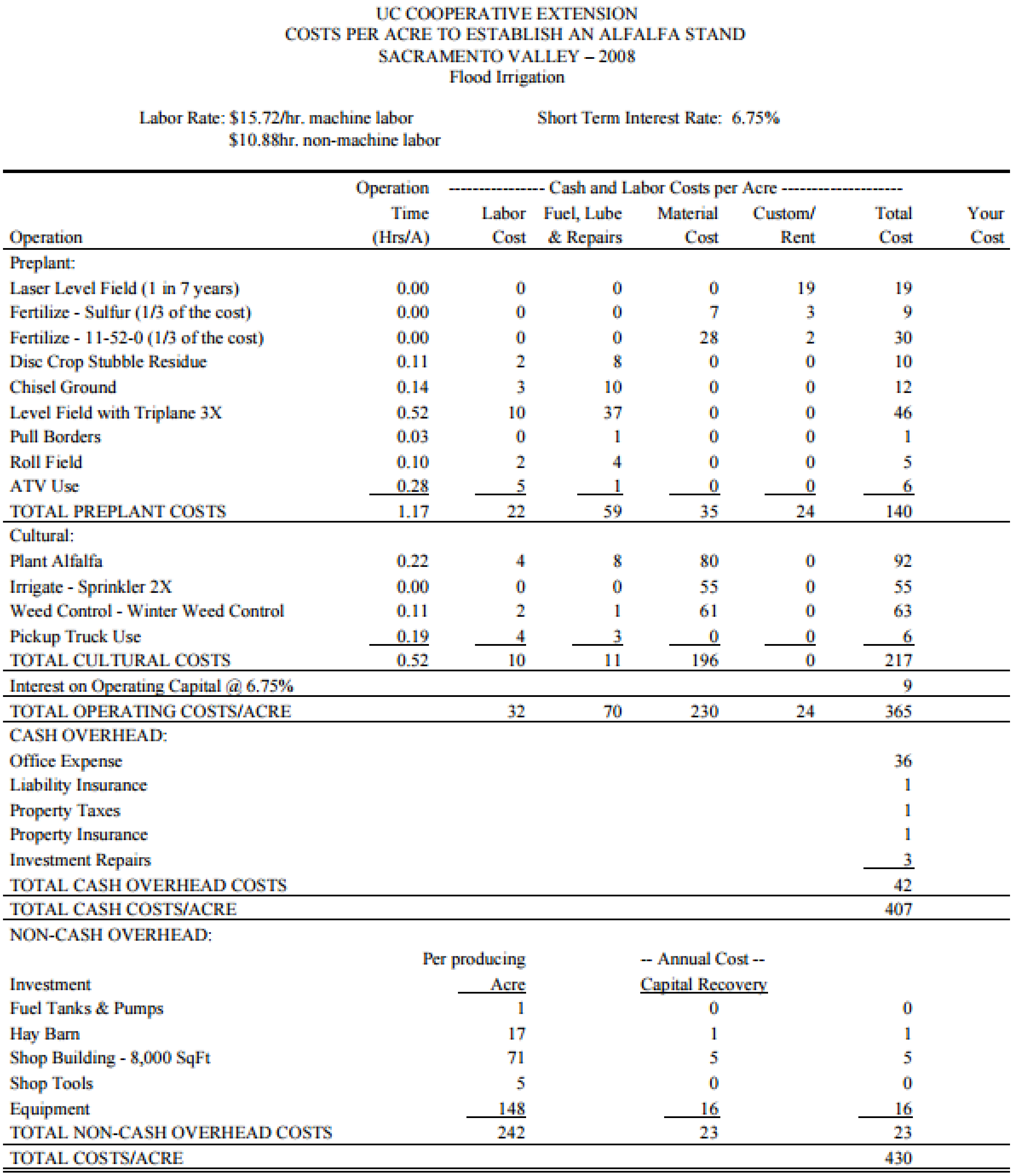
[*] Bold values were estimated using a linear regression.

Appendix O: Water service rates charged by the USBR. Historically, OAWD has paid the *contract rate* for its water. Source: http://www.usbr.gov/mp/cvpwaterrates/ratebooks/index.html.

YEAR	WATER SERVICE RATE ($/AF)	
	Cost of service	Contract Rate
1993	$ 22.26	$ 3.50
1994	$ 23.36	$ 3.50
1995	$ 21.24	$ 21.24
1996	$ 24.70	$ 13.22
1997	$ 20.46	$ 8.79
1998	$ 21.85	$ 9.64
1999	$ 22.97	$ 10.36
2000	$ 24.51	$ 11.37
2001	$ 23.77	$ 12.06
2002	$ 23.53	$ 11.53
2003	$ 26.54	$ 14.48
2004	$ 27.96	$ 16.11
2005	$ 27.36	$ 15.53
2006	$ 26.68	$ 15.94
2007	$ 31.06	$ 18.20
2008	$ 28.08	$ 14.99
2009	$ 27.90	$ 14.69
2010	$ 28.06	$ 13.74
2011	$ 31.08	$ 15.66
2012	$ 32.90	$ 32.90
2013	$ 35.11	$ 19.21

Appendix P: Sample costs to establish alfalfa using flood irrigation in the Sacramento Valley (2008). The cost of water was calculated separately in the analysis. Complete document: http://coststudyfiles.ucdavis.edu/uploads/cs_public/f2/0e/f20ea94b-1cf4-4364-bf51-79dc5ad44790/alfalfasv08.pdf.



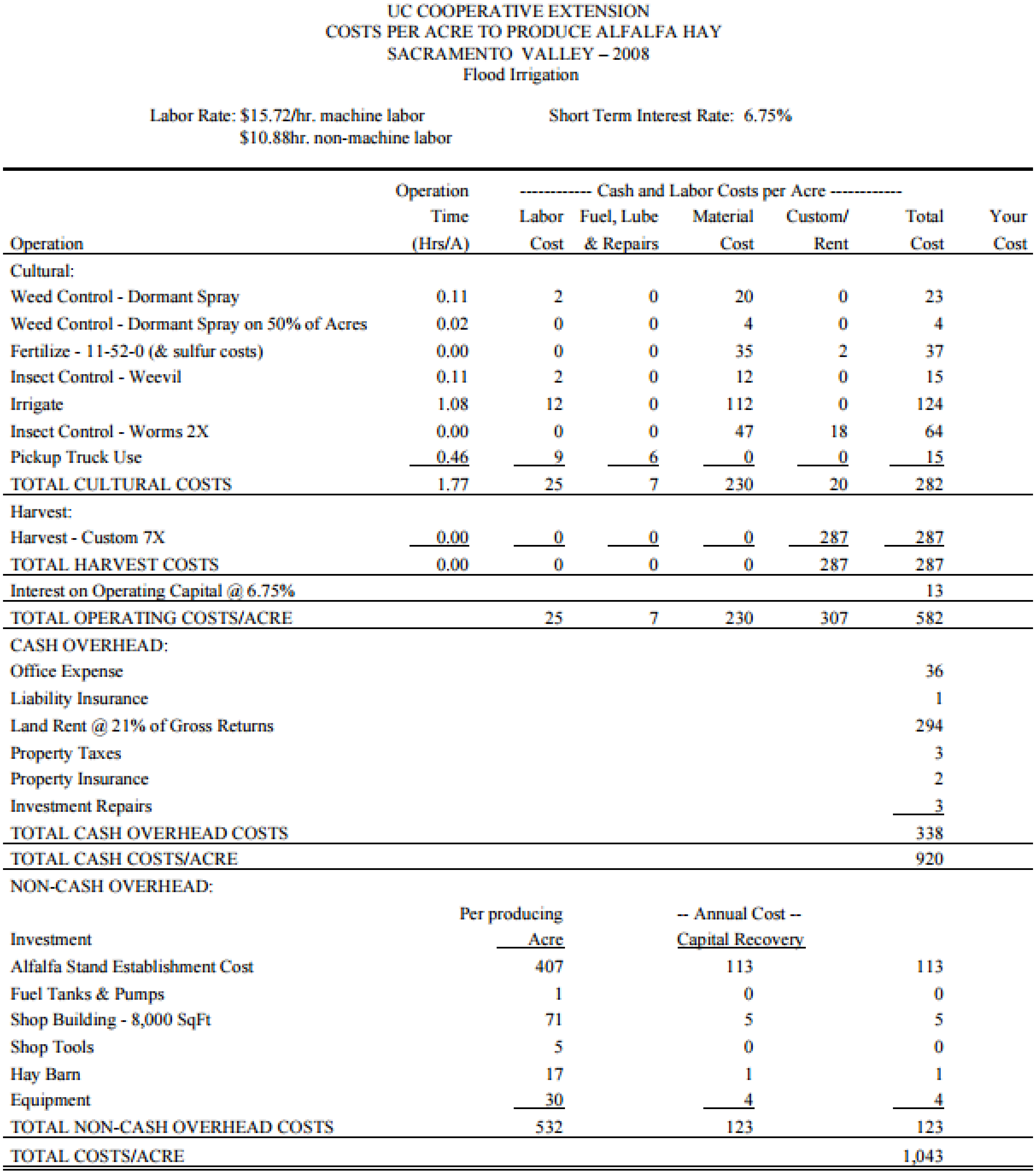
UC COOPERATIVE EXTENSION
COSTS PER ACRE TO ESTABLISH AN ALFALFA STAND
SACRAMENTO VALLEY – 2008
Flood Irrigation

Labor Rate: $15.72/hr. machine labor
$10.88hr. non-machine labor

Short Term Interest Rate: 6.75%

Operation	Operation Time (Hrs/A)	Labor Cost	Fuel, Lube & Repairs	Material Cost	Custom/ Rent	Total Cost	Your Cost
Preplant:							
Laser Level Field (1 in 7 years)	0.00	0	0	0	19	19	
Fertilize - Sulfur (1/3 of the cost)	0.00	0	0	7	3	9	
Fertilize - 11-52-0 (1/3 of the cost)	0.00	0	0	28	2	30	
Disc Crop Stubble Residue	0.11	2	8	0	0	10	
Chisel Ground	0.14	3	10	0	0	12	
Level Field with Triplane 3X	0.52	10	37	0	0	46	
Pull Borders	0.03	0	1	0	0	1	
Roll Field	0.10	2	4	0	0	5	
ATV Use	0.28	5	1	0	0	6	
TOTAL PREPLANT COSTS	1.17	22	59	35	24	140	
Cultural:							
Plant Alfalfa	0.22	4	8	80	0	92	
Irrigate - Sprinkler 2X	0.00	0	0	55	0	55	
Weed Control - Winter Weed Control	0.11	2	1	61	0	63	
Pickup Truck Use	0.19	4	3	0	0	6	
TOTAL CULTURAL COSTS	0.52	10	11	196	0	217	
Interest on Operating Capital @ 6.75%						9	
TOTAL OPERATING COSTS/ACRE		32	70	230	24	365	
CASH OVERHEAD:							
Office Expense						36	
Liability Insurance						1	
Property Taxes						1	
Property Insurance						1	
Investment Repairs						3	
TOTAL CASH OVERHEAD COSTS						42	
TOTAL CASH COSTS/ACRE						407	
NON-CASH OVERHEAD:							
		Per producing		-- Annual Cost --			
Investment		Acre		Capital Recovery			
Fuel Tanks & Pumps		1		0		0	
Hay Barn		17		1		1	
Shop Building - 8,000 SqFt		71		5		5	
Shop Tools		5		0		0	
Equipment		148		16		16	
TOTAL NON-CASH OVERHEAD COSTS		242		23		23	
TOTAL COSTS/ACRE						430	

Appendix Q: Sample costs to produce alfalfa using flood irrigation in the Sacramento Valley (2008). The cost of water was calculated separately in the analysis. Complete document: http://coststudyfiles.ucdavis.edu/uploads/cs_public/f2/0e/f20ea94b-1cf4-4364-bf51-79dc5ad44790/alfalfasv08.pdf.



UC COOPERATIVE EXTENSION
COSTS PER ACRE TO PRODUCE ALFALFA HAY
SACRAMENTO VALLEY – 2008
Flood Irrigation

Labor Rate: $15.72/hr. machine labor
$10.88hr. non-machine labor

Short Term Interest Rate: 6.75%

Operation	Operation Time (Hrs/A)	Labor Cost	Fuel, Lube & Repairs	Material Cost	Custom/ Rent	Total Cost	Your Cost
		------------ Cash and Labor Costs per Acre ------------					
Cultural:							
Weed Control - Dormant Spray	0.11	2	0	20	0	23	
Weed Control - Dormant Spray on 50% of Acres	0.02	0	0	4	0	4	
Fertilize - 11-52-0 (& sulfur costs)	0.00	0	0	35	2	37	
Insect Control - Weevil	0.11	2	0	12	0	15	
Irrigate	1.08	12	0	112	0	124	
Insect Control - Worms 2X	0.00	0	0	47	18	64	
Pickup Truck Use	0.46	9	6	0	0	15	
TOTAL CULTURAL COSTS	1.77	25	7	230	20	282	
Harvest:							
Harvest - Custom 7X	0.00	0	0	0	287	287	
TOTAL HARVEST COSTS	0.00	0	0	0	287	287	
Interest on Operating Capital @ 6.75%						13	
TOTAL OPERATING COSTS/ACRE		25	7	230	307	582	
CASH OVERHEAD:							
Office Expense						36	
Liability Insurance						1	
Land Rent @ 21% of Gross Returns						294	
Property Taxes						3	
Property Insurance						2	
Investment Repairs						3	
TOTAL CASH OVERHEAD COSTS						338	
TOTAL CASH COSTS/ACRE						920	
NON-CASH OVERHEAD:							
Investment		Per producing Acre		-- Annual Cost -- Capital Recovery			
Alfalfa Stand Establishment Cost		407		113		113	
Fuel Tanks & Pumps		1		0		0	
Shop Building - 8,000 SqFt		71		5		5	
Shop Tools		5		0		0	
Hay Barn		17		1		1	
Equipment		30		4		4	
TOTAL NON-CASH OVERHEAD COSTS		532		123		123	
TOTAL COSTS/ACRE						1,043	

Appendix R: Average inflation rates in California between 1993 and 2013. Source: http://sacramentoforecastproject.org/ca/CALIF.htm.

YEAR	%
1993	0.026
1994	0.015
1995	0.017
1996	0.021
1997	0.025
1998	0.023
1999	0.032
2000	0.039
2001	0.045
2002	0.022
2003	0.022
2004	0.022
2005	0.032
2006	0.037
2007	0.032
2008	0.034
2009	0
2010	0.013
2011	0.026
2012	0.023
2013	0.020

Appendix S: Historic average yield and value of alfalfa in Glenn County between 1993 and 2013. Source: http://www.countyofglenn.net/govt/departments/ag/crop_reports.aspx.

Year	Yield (ton/acre)	Value ($/ton)
1993	7.00	$ 100.00
1994	7.93	$ 81.57
1995	6.50	$ 100.00
1996	6.61	$ 97.00
1997	7.10	$ 125.00
1998	4.20	$ 90.00
1999	7.00	$ 80.00
2000	6.50	$ 85.00
2001	7.63	$ 105.00
2002	7.50	$ 95.50
2003	7.30	$ 83.00
2004	7.60	$ 98.00
2005	6.60	$ 115.00
2006	5.98	$ 123.00
2007	7.29	$ 135.00
2008	6.75	$ 186.00
2009	7.18	$ 103.00
2010	6.41	$ 100.00
2011	6.27	$ 202.00
2012	6.12	$ 197.00
2013	6.71	$ 215.00

Appendix T: Summary of water banking capacities per day. Infiltration capacities (Ksat) are shown below each type of soil.

Year	Q=427 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	4.3	5.8	0.7	1.0	0.9	1.2	847	520	188	32	83	291
1994	199	90	257	33	94	251	4.3	5.8	0.7	1.0	0.9	1.2	847	520	188	32	83	291
1995	199	90	257	33	94	251	4.3	5.8	0.7	1.0	0.9	1.2	847	520	188	32	83	291
1996	199	90	257	33	94	251	4.3	5.8	0.7	1.0	0.9	1.2	847	520	188	32	83	291
1997	199	90	257	33	94	251	4.3	5.8	0.7	1.0	0.9	1.2	847	520	188	32	83	291
1998	148	3	675	41	84	329	5.7	5.8	0.7	1.0	0.9	1.2	847	17	495	40	74	381
1999	148	3	675	41	84	329	5.7	5.8	0.7	1.0	0.9	1.2	847	17	495	40	74	381
2000	148	3	675	41	84	329	5.7	5.8	0.7	1.0	0.9	1.2	847	17	495	40	74	381
2001	148	3	675	41	84	329	5.7	5.8	0.7	1.0	0.9	1.2	847	17	495	40	74	381
2002	148	3	675	41	84	329	5.7	5.8	0.7	1.0	0.9	1.2	847	17	495	40	74	381
2003	187	34	620	10	68	251	4.5	5.8	0.7	1.0	0.9	1.2	847	196	455	10	60	291
2004	187	34	620	10	68	251	4.5	5.8	0.7	1.0	0.9	1.2	847	196	455	10	60	291
2005	187	34	620	10	68	251	4.5	5.8	0.7	1.0	0.9	1.2	847	196	455	10	60	291
2006	187	34	620	10	68	251	4.5	5.8	0.7	1.0	0.9	1.2	847	196	455	10	60	291
2007	370	105	408	57	100	271	2.3	5.8	0.7	1.0	0.9	1.2	847	606	299	56	88	314
2008	246	86	382	15	67	187	3.4	5.8	0.7	1.0	0.9	1.2	847	497	280	15	59	217
2009	246	67	442	33	117	294	3.4	5.8	0.7	1.0	0.9	1.2	847	387	324	32	103	341
2010	241	87	365	36	53	204	3.5	5.8	0.7	1.0	0.9	1.2	847	502	268	35	47	236
2011	186	49	306	20	47	163	4.6	5.8	0.7	1.0	0.9	1.2	847	283	224	20	42	189
2012	206	18	237	42	28	134	4.1	5.8	0.7	1.0	0.9	1.2	847	104	174	41	25	155
2013	144	17	273	20	23	95	5.9	5.8	0.7	1.0	0.9	1.2	847	98	200	20	20	110

Year	Q =400 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	4.0	5.8	0.7	1.0	0.9	1.2	800	520	188	32	83	291
1994	199	90	257	33	94	251	4.0	5.8	0.7	1.0	0.9	1.2	800	520	188	32	83	291
1995	199	90	257	33	94	251	4.0	5.8	0.7	1.0	0.9	1.2	800	520	188	32	83	291
1996	199	90	257	33	94	251	4.0	5.8	0.7	1.0	0.9	1.2	800	520	188	32	83	291
1997	199	90	257	33	94	251	4.0	5.8	0.7	1.0	0.9	1.2	800	520	188	32	83	291
1998	148	3	675	41	84	329	5.4	5.8	0.7	1.0	0.9	1.2	800	17	495	40	74	381
1999	148	3	675	41	84	329	5.4	5.8	0.7	1.0	0.9	1.2	800	17	495	40	74	381
2000	148	3	675	41	84	329	5.4	5.8	0.7	1.0	0.9	1.2	800	17	495	40	74	381
2001	148	3	675	41	84	329	5.4	5.8	0.7	1.0	0.9	1.2	800	17	495	40	74	381
2002	148	3	675	41	84	329	5.4	5.8	0.7	1.0	0.9	1.2	800	17	495	40	74	381
2003	187	34	620	10	68	251	4.3	5.8	0.7	1.0	0.9	1.2	800	196	455	10	60	291
2004	187	34	620	10	68	251	4.3	5.8	0.7	1.0	0.9	1.2	800	196	455	10	60	291
2005	187	34	620	10	68	251	4.3	5.8	0.7	1.0	0.9	1.2	800	196	455	10	60	291
2006	187	34	620	10	68	251	4.3	5.8	0.7	1.0	0.9	1.2	800	196	455	10	60	291
2007	370	105	408	57	100	271	2.2	5.8	0.7	1.0	0.9	1.2	800	606	299	56	88	314
2008	246	86	382	15	67	187	3.3	5.8	0.7	1.0	0.9	1.2	800	497	280	15	59	217
2009	246	67	442	33	117	294	3.3	5.8	0.7	1.0	0.9	1.2	800	387	324	32	103	341
2010	241	87	365	36	53	204	3.3	5.8	0.7	1.0	0.9	1.2	800	502	268	35	47	236
2011	186	49	306	20	47	163	4.3	5.8	0.7	1.0	0.9	1.2	800	283	224	20	42	189
2012	206	18	237	42	28	134	3.9	5.8	0.7	1.0	0.9	1.2	800	104	174	41	25	155
2013	144	17	273	20	23	95	5.6	5.8	0.7	1.0	0.9	1.2	800	98	200	20	20	110

Year	Q=350 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	3.5	5.8	0.7	1.0	0.9	1.2	700	520	188	32	83	291
1994	199	90	257	33	94	251	3.5	5.8	0.7	1.0	0.9	1.2	700	520	188	32	83	291
1995	199	90	257	33	94	251	3.5	5.8	0.7	1.0	0.9	1.2	700	520	188	32	83	291
1996	199	90	257	33	94	251	3.5	5.8	0.7	1.0	0.9	1.2	700	520	188	32	83	291
1997	199	90	257	33	94	251	3.5	5.8	0.7	1.0	0.9	1.2	700	520	188	32	83	291
1998	148	3	675	41	84	329	4.7	5.8	0.7	1.0	0.9	1.2	700	17	495	40	74	381
1999	148	3	675	41	84	329	4.7	5.8	0.7	1.0	0.9	1.2	700	17	495	40	74	381
2000	148	3	675	41	84	329	4.7	5.8	0.7	1.0	0.9	1.2	700	17	495	40	74	381
2001	148	3	675	41	84	329	4.7	5.8	0.7	1.0	0.9	1.2	700	17	495	40	74	381
2002	148	3	675	41	84	329	4.7	5.8	0.7	1.0	0.9	1.2	700	17	495	40	74	381
2003	187	34	620	10	68	251	3.7	5.8	0.7	1.0	0.9	1.2	700	196	455	10	60	291
2004	187	34	620	10	68	251	3.7	5.8	0.7	1.0	0.9	1.2	700	196	455	10	60	291
2005	187	34	620	10	68	251	3.7	5.8	0.7	1.0	0.9	1.2	700	196	455	10	60	291
2006	187	34	620	10	68	251	3.7	5.8	0.7	1.0	0.9	1.2	700	196	455	10	60	291
2007	370	105	408	57	100	271	1.9	5.8	0.7	1.0	0.9	1.2	700	606	299	56	88	314
2008	246	86	382	15	67	187	2.8	5.8	0.7	1.0	0.9	1.2	700	497	280	15	59	217
2009	246	67	442	33	117	294	2.8	5.8	0.7	1.0	0.9	1.2	700	387	324	32	103	341
2010	241	87	365	36	53	204	2.9	5.8	0.7	1.0	0.9	1.2	700	502	268	35	47	236
2011	186	49	306	20	47	163	3.8	5.8	0.7	1.0	0.9	1.2	700	283	224	20	42	189
2012	206	18	237	42	28	134	3.4	5.8	0.7	1.0	0.9	1.2	700	104	174	41	25	155
2013	144	17	273	20	23	95	4.9	5.8	0.7	1.0	0.9	1.2	700	98	200	20	20	110

Year	Q=300 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	3.0	5.8	0.7	1.0	0.9	1.2	600	520	188	32	83	291
1994	199	90	257	33	94	251	3.0	5.8	0.7	1.0	0.9	1.2	600	520	188	32	83	291
1995	199	90	257	33	94	251	3.0	5.8	0.7	1.0	0.9	1.2	600	520	188	32	83	291
1996	199	90	257	33	94	251	3.0	5.8	0.7	1.0	0.9	1.2	600	520	188	32	83	291
1997	199	90	257	33	94	251	3.0	5.8	0.7	1.0	0.9	1.2	600	520	188	32	83	291
1998	148	3	675	41	84	329	4.1	5.8	0.7	1.0	0.9	1.2	600	17	495	40	74	381
1999	148	3	675	41	84	329	4.1	5.8	0.7	1.0	0.9	1.2	600	17	495	40	74	381
2000	148	3	675	41	84	329	4.1	5.8	0.7	1.0	0.9	1.2	600	17	495	40	74	381
2001	148	3	675	41	84	329	4.1	5.8	0.7	1.0	0.9	1.2	600	17	495	40	74	381
2002	148	3	675	41	84	329	4.1	5.8	0.7	1.0	0.9	1.2	600	17	495	40	74	381
2003	187	34	620	10	68	251	3.2	5.8	0.7	1.0	0.9	1.2	600	196	455	10	60	291
2004	187	34	620	10	68	251	3.2	5.8	0.7	1.0	0.9	1.2	600	196	455	10	60	291
2005	187	34	620	10	68	251	3.2	5.8	0.7	1.0	0.9	1.2	600	196	455	10	60	291
2006	187	34	620	10	68	251	3.2	5.8	0.7	1.0	0.9	1.2	600	196	455	10	60	291
2007	370	105	408	57	100	271	1.6	5.7	0.7	1.0	0.9	1.2	600	600	299	56	88	314
2008	246	86	382	15	67	187	2.4	5.8	0.7	1.0	0.9	1.2	600	497	280	15	59	217
2009	246	67	442	33	117	294	2.4	5.8	0.7	1.0	0.9	1.2	600	387	324	32	103	341
2010	241	87	365	36	53	204	2.5	5.8	0.7	1.0	0.9	1.2	600	502	268	35	47	236
2011	186	49	306	20	47	163	3.2	5.8	0.7	1.0	0.9	1.2	600	283	224	20	42	189
2012	206	18	237	42	28	134	2.9	5.8	0.7	1.0	0.9	1.2	600	104	174	41	25	155
2013	144	17	273	20	23	95	4.2	5.8	0.7	1.0	0.9	1.2	600	98	200	20	20	110

Year	Q=250 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	2.5	5.6	0.7	1.0	0.9	1.2	500	500	188	32	83	291
1994	199	90	257	33	94	251	2.5	5.6	0.7	1.0	0.9	1.2	500	500	188	32	83	291
1995	199	90	257	33	94	251	2.5	5.6	0.7	1.0	0.9	1.2	500	500	188	32	83	291
1996	199	90	257	33	94	251	2.5	5.6	0.7	1.0	0.9	1.2	500	500	188	32	83	291
1997	199	90	257	33	94	251	2.5	5.6	0.7	1.0	0.9	1.2	500	500	188	32	83	291
1998	148	3	675	41	84	329	3.4	5.8	0.7	0.1	0.9	1.2	500	17	495	5	74	381
1999	148	3	675	41	84	329	3.4	5.8	0.7	0.1	0.9	1.2	500	17	495	5	74	381
2000	148	3	675	41	84	329	3.4	5.8	0.7	0.1	0.9	1.2	500	17	495	5	74	381
2001	148	3	675	41	84	329	3.4	5.8	0.7	0.1	0.9	1.2	500	17	495	5	74	381
2002	148	3	675	41	84	329	3.4	5.8	0.7	0.1	0.9	1.2	500	17	495	5	74	381
2003	187	34	620	10	68	251	2.7	5.8	0.7	1.0	0.9	1.2	500	196	455	10	60	291
2004	187	34	620	10	68	251	2.7	5.8	0.7	1.0	0.9	1.2	500	196	455	10	60	291
2005	187	34	620	10	68	251	2.7	5.8	0.7	1.0	0.9	1.2	500	196	455	10	60	291
2006	187	34	620	10	68	251	2.7	5.8	0.7	1.0	0.9	1.2	500	196	455	10	60	291
2007	370	105	408	57	100	271	1.4	4.8	0.7	1.0	0.9	1.2	500	500	299	56	88	314
2008	246	86	382	15	67	187	2.0	5.8	0.7	1.0	0.9	1.2	500	497	280	15	59	217
2009	246	67	442	33	117	294	2.0	5.8	0.7	1.0	0.9	1.2	500	387	324	32	103	341
2010	241	87	365	36	53	204	2.1	5.7	0.7	1.0	0.9	1.2	500	500	268	35	47	236
2011	186	49	306	20	47	163	2.7	5.8	0.7	1.0	0.9	1.2	500	283	224	20	42	189
2012	206	18	237	42	28	134	2.4	5.8	0.7	1.0	0.9	1.2	500	104	174	41	25	155
2013	144	17	273	20	23	95	3.5	5.8	0.7	1.0	0.9	1.2	500	98	200	20	20	110

Year	Q=200 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	2.0	4.4	0.7	1.0	0.9	1.2	400	400	188	32	83	291
1994	199	90	257	33	94	251	2.0	4.4	0.7	1.0	0.9	1.2	400	400	188	32	83	291
1995	199	90	257	33	94	251	2.0	4.4	0.7	1.0	0.9	1.2	400	400	188	32	83	291
1996	199	90	257	33	94	251	2.0	4.4	0.7	1.0	0.9	1.2	400	400	188	32	83	291
1997	199	90	257	33	94	251	2.0	4.4	0.7	1.0	0.9	1.2	400	400	188	32	83	291
1998	148	3	675	41	84	329	2.7	5.8	0.6	0.0	0.3	1.1	400	17	399	1	24	376
1999	148	3	675	41	84	329	2.7	5.8	0.6	0.0	0.3	1.1	400	17	399	1	24	376
2000	148	3	675	41	84	329	2.7	5.8	0.6	0.0	0.3	1.1	400	17	399	1	24	376
2001	148	3	675	41	84	329	2.7	5.8	0.6	0.0	0.3	1.1	400	17	399	1	24	376
2002	148	3	675	41	84	329	2.7	5.8	0.6	0.0	0.3	1.1	400	17	399	1	24	376
2003	187	34	620	10	68	251	2.1	5.8	0.6	0.0	0.9	1.2	400	196	400	0	60	291
2004	187	34	620	10	68	251	2.1	5.8	0.6	0.0	0.9	1.2	400	196	400	0	60	291
2005	187	34	620	10	68	251	2.1	5.8	0.6	0.0	0.9	1.2	400	196	400	0	60	291
2006	187	34	620	10	68	251	2.1	5.8	0.6	0.0	0.9	1.2	400	196	400	0	60	291
2007	370	105	408	57	100	271	1.1	3.8	0.7	1.0	0.9	1.2	400	400	299	56	86	314
2008	246	86	382	15	67	187	1.6	4.7	0.7	1.0	0.9	1.2	400	400	280	15	59	217
2009	246	67	442	33	117	294	1.6	5.8	0.7	1.0	0.5	1.2	400	387	324	32	59	341
2010	241	87	365	36	53	204	1.7	4.6	0.7	1.0	0.9	1.2	400	400	268	35	47	236
2011	186	49	306	20	47	163	2.2	5.8	0.7	1.0	0.9	1.2	400	283	224	20	42	189
2012	206	18	237	42	28	134	1.9	5.8	0.7	1.0	0.9	1.2	400	104	174	41	25	155
2013	144	17	273	20	23	95	2.8	5.8	0.7	1.0	0.9	1.2	400	98	200	20	20	110

Year	Q=150 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	1.5	3.3	0.7	1.0	0.4	1.0	300	300	188	32	37	263
1994	199	90	257	33	94	251	1.5	3.3	0.7	1.0	0.4	1.0	300	300	188	32	37	263
1995	199	90	257	33	94	251	1.5	3.3	0.7	1.0	0.4	1.0	300	300	188	32	37	263
1996	199	90	257	33	94	251	1.5	3.3	0.7	1.0	0.4	1.0	300	300	188	32	37	263
1997	199	90	257	33	94	251	1.5	3.3	0.7	1.0	0.4	1.0	300	300	188	32	37	263
1998	148	3	675	41	84	329	2.0	5.8	0.4	0.03	0.2	0.9	300	17	299	1.1	18	282
1999	148	3	675	41	84	329	2.0	5.8	0.4	0.03	0.2	0.9	300	17	299	1.1	18	282
2000	148	3	675	41	84	329	2.0	5.8	0.4	0.03	0.2	0.9	300	17	299	1.1	18	282
2001	148	3	675	41	84	329	2.0	5.8	0.4	0.03	0.2	0.9	300	17	299	1.1	18	282
2002	148	3	675	41	84	329	2.0	5.8	0.4	0.03	0.2	0.9	300	17	299	1.1	18	282
2003	187	34	620	10	68	251	1.6	5.8	0.5	0.01	0.3	1.1	300	196	300	0.1	21	279
2004	187	34	620	10	68	251	1.6	5.8	0.5	0.01	0.3	1.1	300	196	300	0.1	21	279
2005	187	34	620	10	68	251	1.6	5.8	0.5	0.01	0.3	1.1	300	196	300	0.1	21	279
2006	187	34	620	10	68	251	1.6	5.8	0.5	0.01	0.3	1.1	300	196	300	0.1	21	279
2007	370	105	408	57	100	271	0.8	2.9	0.7	0.1	0.4	1.0	300	300	294	6	36	264
2008	246	86	382	15	67	187	1.2	3.5	0.7	1.0	0.9	1.2	300	300	280	15	59	217
2009	246	67	442	33	117	294	1.2	4.5	0.7	0.1	0.4	0.9	300	300	298	2	41	259
2010	241	87	365	36	53	204	1.2	3.4	0.7	0.9	0.9	1.2	300	300	268	32	47	236
2011	186	49	306	20	47	163	1.6	5.8	0.7	1.0	0.9	1.2	300	283	224	20	42	189
2012	206	18	237	42	28	134	1.5	5.8	0.7	1.0	0.9	1.2	300	104	174	41	25	155
2013	144	17	273	20	23	95	2.1	5.8	0.7	1.0	0.9	1.2	300	98	200	20	20	110

Year	Q=100 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	1.0	2.2	0.7	1.0	0.3	0.7	200	200	168	32	25	175
1994	199	90	257	33	94	251	1.0	2.2	0.7	1.0	0.3	0.7	200	200	168	32	25	175
1995	199	90	257	33	94	251	1.0	2.2	0.7	1.0	0.3	0.7	200	200	168	32	25	175
1996	199	90	257	33	94	251	1.0	2.2	0.7	1.0	0.3	0.7	200	200	168	32	25	175
1997	199	90	257	33	94	251	1.0	2.2	0.7	1.0	0.3	0.7	200	200	168	32	25	175
1998	148	3	675	41	84	329	1.4	5.8	0.3	0.0	0.1	0.6	200	17	199	1	12	188
1999	148	3	675	41	84	329	1.4	5.8	0.3	0.0	0.1	0.6	200	17	199	1	12	188
2000	148	3	675	41	84	329	1.4	5.8	0.3	0.0	0.1	0.6	200	17	199	1	12	188
2001	148	3	675	41	84	329	1.4	5.8	0.3	0.0	0.1	0.6	200	17	199	1	12	188
2002	148	3	675	41	84	329	1.4	5.8	0.3	0.0	0.1	0.6	200	17	199	1	12	188
2003	187	34	620	10	68	251	1.1	5.8	0.3	0.0	0.2	0.7	200	196	200	0	14	186
2004	187	34	620	10	68	251	1.1	5.8	0.3	0.0	0.2	0.7	200	196	200	0	14	186
2005	187	34	620	10	68	251	1.1	5.8	0.3	0.0	0.2	0.7	200	196	200	0	14	186
2006	187	34	620	10	68	251	1.1	5.8	0.3	0.0	0.2	0.7	200	196	200	0	14	186
2007	370	105	408	57	100	271	0.5	1.9	0.5	0.1	0.2	0.6	200	200	196	4	24	176
2008	246	86	382	15	67	187	0.8	2.3	0.5	0.0	0.9	0.8	200	200	200	0	59	141
2009	246	67	442	33	117	294	0.8	3.0	0.4	0.0	0.2	0.6	200	200	199	1	27	173
2010	241	87	365	36	53	204	0.8	2.3	0.5	0.1	0.2	0.9	200	200	198	2	13	187
2011	186	49	306	20	47	163	1.1	4.1	0.7	0.0	0.3	1.1	200	200	199	1	15	185
2012	206	18	237	42	28	134	1.0	5.8	0.7	0.6	0.9	1.2	200	104	174	26	25	155
2013	144	17	273	20	23	95	1.4	5.8	0.7	0.1	0.9	1.2	200	98	199	1	20	110

Year	Q=50 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	0.5	1.1	0.4	-	0.1	0.3	100	100	100	-	12	88
1994	199	90	257	33	94	251	0.5	1.1	0.4	-	0.1	0.3	100	100	100	-	12	88
1995	199	90	257	33	94	251	0.5	1.1	0.4	-	0.1	0.3	100	100	100	-	12	88
1996	199	90	257	33	94	251	0.5	1.1	0.4	-	0.1	0.3	100	100	100	-	12	88
1997	199	90	257	33	94	251	0.5	1.1	0.4	-	0.1	0.3	100	100	100	-	12	88
1998	148	3	675	41	84	329	0.7	5.8	0.1	-	0.1	0.3	100	17	100	-	6	94
1999	148	3	675	41	84	329	0.7	5.8	0.1	-	0.1	0.3	100	17	100	-	6	94
2000	148	3	675	41	84	329	0.7	5.8	0.1	-	0.1	0.3	100	17	100	-	6	94
2001	148	3	675	41	84	329	0.7	5.8	0.1	-	0.1	0.3	100	17	100	-	6	94
2002	148	3	675	41	84	329	0.7	5.8	0.1	-	0.1	0.3	100	17	100	-	6	94
2003	187	34	620	10	68	251	0.5	2.9	0.2	-	0.1	0.4	100	100	100	-	7	93
2004	187	34	620	10	68	251	0.5	2.9	0.2	-	0.1	0.4	100	100	100	-	7	93
2005	187	34	620	10	68	251	0.5	2.9	0.2	-	0.1	0.4	100	100	100	-	7	93
2006	187	34	620	10	68	251	0.5	2.9	0.2	-	0.1	0.4	100	100	100	-	7	93
2007	370	105	408	57	100	271	0.3	1.0	0.2	-	0.1	0.3	100	100	100	-	12	88
2008	246	86	382	15	67	187	0.4	1.2	0.3	-	0.3	0.4	100	100	100	-	20	80
2009	246	67	442	33	117	294	0.4	1.5	0.2	-	0.1	0.3	100	100	100	-	14	86
2010	241	87	365	36	53	204	0.4	1.1	0.3	-	0.1	0.5	100	100	100	-	6	94
2011	186	49	306	20	47	163	0.5	2.0	0.3	-	0.2	0.6	100	100	100	-	8	92
2012	206	18	237	42	28	134	0.5	5.6	0.4	-	0.1	0.7	100	100	100	-	4	96
2013	144	17	273	20	23	95	0.7	5.8	0.4	-	0.2	1.0	100	98	100	-	6	94

Year	Q=25 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	0.3	0.6	0.2	-	-	0.2	50	50	50	-	-	50
1994	199	90	257	33	94	251	0.3	0.6	0.2	-	-	0.2	50	50	50	-	-	50
1995	199	90	257	33	94	251	0.3	0.6	0.2	-	-	0.2	50	50	50	-	-	50
1996	199	90	257	33	94	251	0.3	0.6	0.2	-	-	0.2	50	50	50	-	-	50
1997	199	90	257	33	94	251	0.3	0.6	0.2	-	-	0.2	50	50	50	-	-	50
1998	148	3	675	41	84	329	0.3	5.8	0.1	-	-	0.2	50	17	50	-	-	50
1999	148	3	675	41	84	329	0.3	5.8	0.1	-	-	0.2	50	17	50	-	-	50
2000	148	3	675	41	84	329	0.3	5.8	0.1	-	-	0.2	50	17	50	-	-	50
2001	148	3	675	41	84	329	0.3	5.8	0.1	-	-	0.2	50	17	50	-	-	50
2002	148	3	675	41	84	329	0.3	5.8	0.1	-	-	0.2	50	17	50	-	-	50
2003	187	34	620	10	68	251	0.3	1.5	0.1	-	-	0.2	50	50	50	-	-	50
2004	187	34	620	10	68	251	0.3	1.5	0.1	-	-	0.2	50	50	50	-	-	50
2005	187	34	620	10	68	251	0.3	1.5	0.1	-	-	0.2	50	50	50	-	-	50
2006	187	34	620	10	68	251	0.3	1.5	0.1	-	-	0.2	50	50	50	-	-	50
2007	370	105	408	57	100	271	0.1	0.5	0.1	-	-	0.2	50	50	50	-	-	50
2008	246	86	382	15	67	187	0.2	0.6	0.1	-	-	0.3	50	50	50	-	-	50
2009	246	67	442	33	117	294	0.2	0.7	0.1	-	-	0.2	50	50	50	-	-	50
2010	241	87	365	36	53	204	0.2	0.6	0.1	-	-	0.2	50	50	50	-	-	50
2011	186	49	306	20	47	163	0.3	1.0	0.2	-	-	0.3	50	50	50	-	-	50
2012	206	18	237	42	28	134	0.2	2.8	0.2	-	-	0.4	50	50	50	-	-	50
2013	144	17	273	20	23	95	0.3	2.9	0.2	-	-	0.5	50	50	50	-	-	50

Year	Q=5 cfs																	
	Alfalfa acres						ft/acre per day						AF per day					
	E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U		E&G M	E&G U	MODG M		MODG U	
	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day	11.60 ft/day	5.8 ft/day	0.73 ft/day	0.98 ft/day	0.9 ft/day	1.16 ft/day
1993	199	90	257	33	94	251	0.05	0.1	0.04	-	-	0.0	10	10	10	-	-	10
1994	199	90	257	33	94	251	0.05	0.1	0.04	-	-	0.0	10	10	10	-	-	10
1995	199	90	257	33	94	251	0.05	0.1	0.04	-	-	0.0	10	10	10	-	-	10
1996	199	90	257	33	94	251	0.05	0.1	0.04	-	-	0.0	10	10	10	-	-	10
1997	199	90	257	33	94	251	0.05	0.1	0.04	-	-	0.0	10	10	10	-	-	10
1998	148	3	675	41	84	329	0.07	3.3	0.01	-	-	0.0	10	10	10	-	-	10
1999	148	3	675	41	84	329	0.07	3.3	0.01	-	-	0.0	10	10	10	-	-	10
2000	148	3	675	41	84	329	0.07	3.3	0.01	-	-	0.0	10	10	10	-	-	10
2001	148	3	675	41	84	329	0.07	3.3	0.01	-	-	0.0	10	10	10	-	-	10
2002	148	3	675	41	84	329	0.07	3.3	0.01	-	-	0.0	10	10	10	-	-	10
2003	187	34	620	10	68	251	0.05	0.3	0.02	-	-	0.0	10	10	10	-	-	10
2004	187	34	620	10	68	251	0.05	0.3	0.02	-	-	0.0	10	10	10	-	-	10
2005	187	34	620	10	68	251	0.05	0.3	0.02	-	-	0.0	10	10	10	-	-	10
2006	187	34	620	10	68	251	0.05	0.3	0.02	-	-	0.0	10	10	10	-	-	10
2007	370	105	408	57	100	271	0.03	0.1	0.02	-	-	0.0	10	10	10	-	-	10
2008	246	86	382	15	67	187	0.04	0.1	0.03	-	-	0.1	10	10	10	-	-	10
2009	246	67	442	33	117	294	0.04	0.1	0.02	-	-	0.0	10	10	10	-	-	10
2010	241	87	365	36	53	204	0.04	0.1	0.03	-	-	0.0	10	10	10	-	-	10
2011	186	49	306	20	47	163	0.05	0.2	0.03	-	-	0.1	10	10	10	-	-	10
2012	206	18	237	42	28	134	0.05	0.6	0.04	-	-	0.1	10	10	10	-	-	10
2013	144	17	273	20	23	95	0.07	0.6	0.04	-	-	0.1	10	10	10	-	-	10

Appendix U: Average annual water banked and its cost using *cost of service* as water price per AF.

Q (cfs)	Modified SAGBI				Unmodified SAGBI			
	E&G		Mod G		E&G		Mod G	
	Avg. Annual Water Banked (TAF)	Avg. Cost. ($K)	Avg. Annual Water Banked (TAF)	Avg. Cost. ($K)	Avg. Annual Water Banked (TAF)	Avg. Cost. ($K)	Avg. Annual Water Banked (TAF)	Avg. Cost. ($K)
427	12.08	$ 291.50	5.65	$ 135.87	3.04	$ 72.16	5.53	$ 131.11
400	11.42	$ 275.56	5.65	$ 135.87	3.04	$ 72.16	5.53	$ 131.11
350	10.01	$ 241.50	5.65	$ 135.87	3.04	$ 72.16	5.53	$ 131.11
300	8.59	$ 207.44	5.65	$ 135.87	3.04	$ 72.16	5.53	$ 131.11
250	7.18	$ 173.38	5.45	$ 131.51	2.96	$ 70.44	5.53	$ 131.11
200	5.76	$ 139.24	4.73	$ 114.46	2.53	$ 60.96	5.23	$ 124.22
150	4.33	$ 104.74	3.91	$ 94.71	2.10	$ 51.48	4.20	$ 100.59
100	2.89	$ 69.84	2.92	$ 70.59	1.61	$ 39.83	2.86	$ 69.14
50	1.44	$ 34.81	1.47	$ 35.56	0.89	$ 22.36	1.42	$ 34.42
25	0.71	$ 17.39	0.74	$ 18.14	0.51	$ 12.87	0.70	$ 17.00
5	0.12	$ 2.80	0.14	$ 3.51	0.16	$ 3.92	0.10	$ 2.52

Appendix V: SW cost increments ($/AF) for different combinations of conveyance capacity Q and types of soils using *cost of* service as water price per AF.

Policy A:

	Cost of Service			
	Modified SAGBI		Unmodified SAGBI	
Q (cfs)	E&G	Mod G	E&G	ModG
427	$ 6.02	$ 2.80	$ 1.49	$ 2.71
400	$ 5.69	$ 2.80	$ 1.49	$ 2.71
350	$ 4.99	$ 2.80	$ 1.49	$ 2.71
300	$ 4.28	$ 2.80	$ 1.49	$ 2.71
250	$ 3.58	$ 2.71	$ 1.45	$ 2.71
200	$ 2.87	$ 2.36	$ 1.26	$ 2.56
150	$ 2.16	$ 1.96	$ 1.06	$ 2.08
100	$ 1.44	$ 1.46	$ 0.82	$ 1.43
50	$ 0.72	$ 0.73	$ 0.46	$ 0.71
25	$ 0.36	$ 0.37	$ 0.27	$ 0.35
5	$ 0.06	$ 0.07	$ 0.08	$ 0.05

Policy B:

	Cost of Service			
	Modified SAGBI		Unmodified SAGBI	
Q (cfs)	E&G	Mod G	E&G	ModG
427	$ 6.61	$ 3.08	$ 1.64	$ 2.98
400	$ 6.25	$ 3.08	$ 1.64	$ 2.98
350	$ 5.48	$ 3.08	$ 1.64	$ 2.98
300	$ 4.71	$ 3.08	$ 1.64	$ 2.98
250	$ 3.93	$ 2.98	$ 1.60	$ 2.98
200	$ 3.16	$ 2.60	$ 1.38	$ 2.82
150	$ 2.38	$ 2.15	$ 1.17	$ 2.28
100	$ 1.58	$ 1.60	$ 0.90	$ 1.57
50	$ 0.79	$ 0.81	$ 0.51	$ 0.78
25	$ 0.39	$ 0.41	$ 0.29	$ 0.39
5	$ 0.06	$ 0.08	$ 0.09	$ 0.06

Appendix W: Total present-value costs ($M) for Non Ag-GB growers using *cost of* service as water price per AF.

Policy A:

Q (cfs)	Cost of Service			
	Modified SAGBI		Unmodified SAGBI	
	E&G	Mod G	E&G	ModG
427	$ 11.84	$ 5.52	$ 2.93	$ 5.33
400	$ 11.19	$ 5.52	$ 2.93	$ 5.33
350	$ 9.81	$ 5.52	$ 2.93	$ 5.33
300	$ 8.43	$ 5.52	$ 2.93	$ 5.33
250	$ 7.04	$ 5.34	$ 2.86	$ 5.33
200	$ 5.66	$ 4.65	$ 2.48	$ 5.05
150	$ 4.26	$ 3.85	$ 2.09	$ 4.09
100	$ 2.84	$ 2.87	$ 1.62	$ 2.81
50	$ 1.41	$ 1.44	$ 0.91	$ 1.40
25	$ 0.71	$ 0.74	$ 0.52	$ 0.69
5	$ 0.11	$ 0.14	$ 0.16	$ 0.10

Policy B:

Q (cfs)	Cost of Service			
	Modified SAGBI		Unmodified SAGBI	
	E&G	Mod G	E&G	ModG
427	$ 12.46	$ 7.37	$ 3.09	$ 6.60
400	$ 11.82	$ 7.37	$ 3.09	$ 6.60
350	$ 10.44	$ 7.37	$ 3.09	$ 6.60
300	$ 9.06	$ 7.37	$ 3.09	$ 6.60
250	$ 7.68	$ 7.20	$ 3.02	$ 6.60
200	$ 6.30	$ 6.51	$ 2.64	$ 6.32
150	$ 4.91	$ 5.71	$ 2.25	$ 5.36
100	$ 3.50	$ 4.73	$ 1.78	$ 4.09
50	$ 1.82	$ 2.51	$ 1.01	$ 2.18
25	$ 1.12	$ 1.81	$ 0.63	$ 1.30
5	$ 0.53	$ 1.22	$ 0.26	$ 0.71

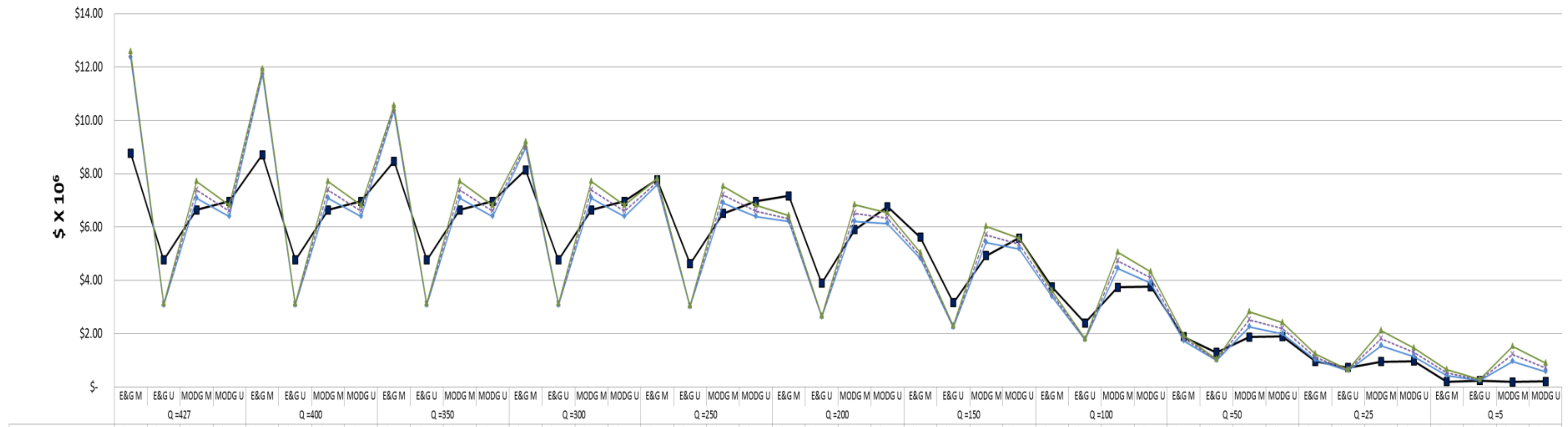
Appendix X: Average annual net benefits ($/AF) from pumping savings compared to ΔCWS. Benefits are sorted from largest to smallest.

Contract Rate						Cost of Service					
Policy A			Policy B			Policy A			Policy B		
Net Benefit ($/AF)	Q (cfs)	Type of Soil	Net Benefit ($/AF)	Q (cfs)	Type of Soil	Net Benefit ($/AF)	Q (cfs)	Type of Soil	Net Benefit ($/AF)	Q (cfs)	Type of Soil
$ 5.29	250	E&G M	$ 5.10	250	E&G M	$ 3.71	200	E&G M	$ 3.43	200	E&G M
$ 5.29	300	E&G M	$ 5.06	300	E&G M	$ 3.69	250	E&G M	$ 3.40	427	MODGG U
$ 5.23	350	E&G M	$ 4.96	350	E&G M	$ 3.67	427	MODGG U	$ 3.40	400	MODGG U
$ 5.06	400	E&G M	$ 4.84	200	E&G M	$ 3.67	400	MODGG U	$ 3.40	350	MODGG U
$ 5.00	200	E&G M	$ 4.78	427	MODG U	$ 3.67	350	MODGG U	$ 3.40	300	MODGG U
$ 4.93	427	E&G M	$ 4.78	400	MODG U	$ 3.67	300	MODGG U	$ 3.40	250	MODGG U
$ 4.92	427	MODG U	$ 4.78	350	MODG U	$ 3.67	250	MODGG U	$ 3.34	200	MODGG U
$ 4.92	400	MODG U	$ 4.78	300	MODG U	$ 3.60	200	MODGG U	$ 3.34	250	E&G M
$ 4.92	350	MODG U	$ 4.78	250	MODG U	$ 3.38	300	E&G M	$ 2.98	427	MODGG M
$ 4.92	300	MODG U	$ 4.75	400	E&G M	$ 3.26	427	MODGG M	$ 2.98	400	MODGG M
$ 4.92	250	MODG U	$ 4.64	200	MODG U	$ 3.26	400	MODGG M	$ 2.98	350	MODGG M
$ 4.78	200	MODG U	$ 4.60	427	E&G M	$ 3.26	350	MODGG M	$ 2.98	300	MODGG M
$ 4.59	427	MODG M	$ 4.44	427	MODG M	$ 3.26	300	MODGG M	$ 2.95	300	E&G M
$ 4.59	400	MODG M	$ 4.44	400	MODG M	$ 3.21	250	MODGG M	$ 2.94	250	MODGG M
$ 4.59	350	MODG M	$ 4.44	350	MODG M	$ 3.00	350	E&G M	$ 2.75	150	MODGG U
$ 4.59	300	MODG M	$ 4.44	300	MODG M	$ 2.96	150	MODGG U	$ 2.71	200	MODGG M
$ 4.49	250	MODG M	$ 4.35	250	MODG M	$ 2.94	200	MODGG M	$ 2.69	150	E&G M
$ 4.04	200	MODG M	$ 3.92	200	MODG M	$ 2.91	150	E&G M	$ 2.67	427	E&G U
$ 3.90	150	MODG U	$ 3.79	150	MODG U	$ 2.82	427	E&G U	$ 2.67	400	E&G U
$ 3.87	150	E&G M	$ 3.76	150	E&G M	$ 2.82	400	E&G U	$ 2.67	350	E&G U
$ 3.43	427	E&G U	$ 3.34	427	E&G U	$ 2.82	350	E&G U	$ 2.67	300	E&G U
$ 3.43	400	E&G U	$ 3.34	400	E&G U	$ 2.82	300	E&G U	$ 2.58	250	E&G U
$ 3.43	350	E&G U	$ 3.34	350	E&G U	$ 2.73	250	E&G U	$ 2.50	350	E&G M
$ 3.43	300	E&G U	$ 3.34	300	E&G U	$ 2.51	400	E&G M	$ 2.29	150	MODGG M
$ 3.38	150	MODG M	$ 3.27	150	MODG M	$ 2.48	150	MODGG M	$ 2.13	200	E&G U
$ 3.33	250	E&G U	$ 3.24	250	E&G U	$ 2.26	200	E&G U	$ 1.95	400	E&G M
$ 2.78	200	E&G U	$ 2.71	200	E&G U	$ 2.23	427	E&G M	$ 1.82	100	MODGG U
$ 2.61	100	MODG U	$ 2.53	100	MODG U	$ 1.97	100	MODGG U	$ 1.80	100	E&G M
$ 2.59	100	E&G M	$ 2.51	100	E&G M	$ 1.95	100	E&G M	$ 1.78	100	MODGG M
$ 2.57	100	MODG M	$ 2.49	100	MODG M	$ 1.92	100	MODGG M	$ 1.69	150	E&G U
$ 2.24	150	E&G U	$ 2.17	150	E&G U	$ 1.79	150	E&G U	$ 1.64	427	E&G M
$ 1.68	100	E&G U	$ 1.63	100	E&G U	$ 1.34	100	E&G U	$ 1.26	100	E&G U
$ 1.32	50	MODG U	$ 1.28	50	MODG U	$ 1.00	50	MODGG U	$ 0.93	50	MODGG U
$ 1.31	50	E&G M	$ 1.27	50	E&G M	$ 0.99	50	E&G M	$ 0.91	50	E&G M
$ 1.29	50	MODG M	$ 1.25	50	MODG M	$ 0.96	50	MODGG M	$ 0.89	50	MODGG M
$ 0.89	50	E&G U	$ 0.86	50	E&G U	$ 0.70	50	E&G U	$ 0.66	50	E&G U
$ 0.68	25	MODG U	$ 0.66	25	MODG U	$ 0.52	25	MODGG U	$ 0.49	25	MODGG U
$ 0.67	25	E&G M	$ 0.65	25	E&G M	$ 0.50	25	E&G M	$ 0.47	25	E&G M
$ 0.65	25	MODG M	$ 0.63	25	MODG M	$ 0.48	25	MODGG M	$ 0.44	25	MODGG M
$ 0.50	25	E&G U	$ 0.49	25	E&G U	$ 0.39	25	E&G U	$ 0.37	25	E&G U
$ 0.17	5	E&G U	$ 0.17	5	E&G U	$ 0.14	5	MODGG U	$ 0.13	5	MODGG U
$ 0.16	5	MODG U	$ 0.16	5	MODG U	$ 0.14	5	E&G U	$ 0.13	5	E&G U
$ 0.15	5	E&G M	$ 0.15	5	E&G M	$ 0.12	5	E&G M	$ 0.12	5	E&G M
$ 0.13	5	MODG M	$ 0.13	5	MODG M	$ 0.10	5	MODGG M	$ 0.09	5	MODGG M

Appendix Y: Total pumping savings ($M) compared to total Ag-GB costs using *cost of service**.

	Q =427				Q =400				Q =350				Q =300				Q =250			
	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U
Pumping Savings Policy B	$8.76	$4.76	$6.64	$6.96	$8.70	$4.76	$6.64	$6.96	$8.46	$4.76	$6.64	$6.96	$8.14	$4.76	$6.64	$6.96	$7.77	$4.62	$6.51	$6.96
Costs Policy B ($12/acre)	$7.08	$1.86	$4.47	$3.93	$6.72	$1.86	$4.47	$3.93	$5.96	$1.86	$4.47	$3.93	$5.20	$1.86	$4.47	$3.93	$4.44	$1.82	$4.39	$3.93
Costs Policy B ($30/acre)	$7.18	$1.88	$4.76	$4.13	$6.82	$1.88	$4.76	$4.13	$6.06	$1.88	$4.76	$4.13	$5.30	$1.88	$4.76	$4.13	$4.54	$1.84	$4.68	$4.13
Costs Policy B ($50/acre)	$7.29	$1.91	$5.09	$4.36	$6.94	$1.91	$5.09	$4.36	$6.18	$1.91	$5.09	$4.36	$5.42	$1.91	$5.09	$4.36	$4.66	$1.87	$5.01	$4.36

	Q =200				Q =150				Q =100				Q =50				Q =25				Q =5			
	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U
Pumping Savings Policy B	$7.16	$3.89	$5.90	$6.76	$5.61	$3.16	$4.92	$5.58	$3.75	$2.40	$3.74	$3.75	$1.88	$1.29	$1.87	$1.89	$0.95	$0.73	$0.94	$0.96	$0.20	$0.24	$0.19	$0.21
Costs Policy B ($12/acre)	$3.68	$1.59	$4.06	$3.81	$2.91	$1.36	$3.66	$3.31	$2.13	$1.09	$3.16	$2.63	$1.08	$0.62	$1.59	$1.36	$0.69	$0.38	$1.21	$0.83	$0.37	$0.17	$0.88	$0.51
Costs Policy B ($30/acre)	$3.78	$1.62	$4.35	$4.01	$3.01	$1.39	$3.95	$3.51	$2.23	$1.12	$3.45	$2.83	$1.19	$0.64	$1.87	$1.56	$0.80	$0.41	$1.48	$0.99	$0.47	$0.20	$1.15	$0.67
Costs Policy B ($50/acre)	$3.90	$1.64	$4.67	$4.23	$3.12	$1.42	$4.28	$3.73	$2.35	$1.15	$3.78	$3.05	$1.30	$0.67	$2.17	$1.78	$0.91	$0.44	$1.78	$1.16	$0.59	$0.22	$1.46	$0.84



	Q =427				Q =400				Q =350				Q =300				Q =250			
	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U
Pumping Savings Policy B	$8.76	$4.76	$6.64	$6.96	$8.70	$4.76	$6.64	$6.96	$8.46	$4.76	$6.64	$6.96	$8.14	$4.76	$6.64	$6.96	$7.77	$4.62	$6.51	$6.96
Costs Policy B ($12/acre)	$12.36	$3.06	$7.08	$6.40	$11.71	$3.06	$7.08	$6.40	$10.34	$3.06	$7.08	$6.40	$8.96	$3.06	$7.08	$6.40	$7.58	$2.99	$6.90	$6.40
Costs Policy B ($30/acre)	$12.46	$3.09	$7.37	$6.60	$11.82	$3.09	$7.37	$6.60	$10.44	$3.09	$7.37	$6.60	$9.06	$3.09	$7.37	$6.60	$7.68	$3.02	$7.20	$6.60
Costs Policy B ($50/acre)	$12.58	$3.12	$7.70	$6.82	$11.93	$3.12	$7.70	$6.82	$10.56	$3.12	$7.70	$6.82	$9.18	$3.12	$7.70	$6.82	$7.80	$3.05	$7.52	$6.82

	Q =200				Q =150				Q =100				Q =50				Q =25				Q =5			
	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U	E&G M	E&G U	MODG M	MODG U
Pumping Savings Policy B	$7.16	$3.89	$5.90	$6.76	$5.61	$3.16	$4.92	$5.58	$3.75	$2.40	$3.74	$3.75	$1.88	$1.29	$1.87	$1.89	$0.95	$0.73	$0.94	$0.96	$0.20	$0.24	$0.19	$0.21
Costs Policy B ($12/acre)	$6.20	$2.61	$6.21	$6.12	$4.80	$2.23	$5.42	$5.16	$3.39	$1.76	$4.44	$3.89	$1.72	$0.98	$2.24	$1.98	$1.01	$0.60	$1.54	$1.14	$0.42	$0.24	$0.94	$0.56
Costs Policy B ($30/acre)	$6.30	$2.64	$6.51	$6.32	$4.91	$2.25	$5.71	$5.36	$3.50	$1.78	$4.73	$4.09	$1.82	$1.01	$2.51	$2.18	$1.12	$0.63	$1.81	$1.30	$0.53	$0.26	$1.22	$0.71
Costs Policy B ($50/acre)	$6.42	$2.67	$6.83	$6.54	$5.02	$2.28	$6.03	$5.58	$3.61	$1.81	$5.06	$4.31	$1.94	$1.04	$2.82	$2.41	$1.23	$0.65	$2.11	$1.47	$0.64	$0.29	$1.52	$0.88

*Left chart: contract rate. Right chart: cost of service.

Appendix Z: Annual net benefits ($/acre) for Non Ag-GB growers considering different costs of turnout operation ($/acre).

Cost of Service					Contract Rate									
Q (cfs)	Type of Soil	$12/acre	$30/acre	$50/acre	Q (cfs)	Type of Soil	$12/acre	$30/acre	$50/acre	Q (cfs)	Type of Soil	$12/acre	$30/acre	$50/acre
427	E&G U	$ 6.72	$ 6.61	$ 6.50	200	E&G M	$ 13.81	$ 13.40	$ 12.94	250	MODG M	$ 8.38	$ 7.22	$ 5.94
400	E&G U	$ 6.72	$ 6.61	$ 6.50	250	E&G M	$ 13.20	$ 12.79	$ 12.33	400	E&G M	$ 7.85	$ 7.44	$ 6.98
350	E&G U	$ 6.72	$ 6.61	$ 6.50	427	MODG U	$ 11.99	$ 11.19	$ 10.31	200	MODG M	$ 7.29	$ 6.13	$ 4.85
300	E&G U	$ 6.72	$ 6.61	$ 6.50	400	MODG U	$ 11.99	$ 11.19	$ 10.31	150	E&G U	$ 7.13	$ 7.03	$ 6.91
250	E&G U	$ 6.44	$ 6.33	$ 6.22	350	MODG U	$ 11.99	$ 11.19	$ 10.31	427	E&G M	$ 6.67	$ 6.26	$ 5.80
200	E&G U	$ 5.07	$ 4.97	$ 4.85	300	MODG U	$ 11.99	$ 11.19	$ 10.31	100	E&G M	$ 6.43	$ 6.02	$ 5.56
200	E&G M	$ 3.81	$ 3.40	$ 2.94	250	MODG U	$ 11.99	$ 11.19	$ 10.31	100	E&G U	$ 5.19	$ 5.09	$ 4.97
150	E&G U	$ 3.70	$ 3.60	$ 3.48	200	MODG U	$ 11.70	$ 10.91	$ 10.03	150	MODG M	$ 4.99	$ 3.83	$ 2.55
150	E&G M	$ 3.19	$ 2.77	$ 2.32	300	E&G M	$ 11.65	$ 11.24	$ 10.78	100	MODG U	$ 4.45	$ 3.66	$ 2.78
100	E&G U	$ 2.56	$ 2.45	$ 2.34	427	E&G U	$ 11.49	$ 11.39	$ 11.27	50	E&G M	$ 3.17	$ 2.76	$ 2.30
200	MODG U	$ 2.54	$ 1.75	$ 0.87	400	E&G U	$ 11.49	$ 11.39	$ 11.27	50	E&G U	$ 2.67	$ 2.57	$ 2.45
427	MODG U	$ 2.23	$ 1.43	$ 0.55	350	E&G U	$ 11.49	$ 11.39	$ 11.27	100	MODG M	$ 2.29	$ 1.14	$ -
400	MODG U	$ 2.23	$ 1.43	$ 0.55	300	E&G U	$ 11.49	$ 11.39	$ 11.27	50	MODG U	$ 2.11	$ 1.32	$ 0.43
350	MODG U	$ 2.23	$ 1.43	$ 0.55	250	E&G U	$ 11.10	$ 11.00	$ 10.88	25	E&G U	$ 1.36	$ 1.26	$ 1.14
300	MODG U	$ 2.23	$ 1.43	$ 0.55	150	E&G M	$ 10.71	$ 10.30	$ 9.84	50	MODG M	$ 1.11	$ 0.02	$ -
250	MODG U	$ 2.23	$ 1.43	$ 0.55	350	E&G M	$ 9.93	$ 9.51	$ 9.06	25	E&G M	$ 1.03	$ 0.61	$ 0.16
150	MODG U	$ 1.65	$ 0.86	$ -	200	E&G U	$ 9.12	$ 9.01	$ 8.90	25	MODG U	$ 0.50	$ -	$ -
100	E&G M	$ 1.41	$ 1.00	$ 0.54	150	MODG U	$ 8.99	$ 8.20	$ 7.32	5	E&G U	$ 0.27	$ 0.17	$ 0.06
50	E&G U	$ 1.22	$ 1.12	$ 1.01	427	MODG M	$ 8.58	$ 7.42	$ 6.14	-	-	-	-	-
250	E&G M	$ 0.75	$ 0.34	$ -	400	MODG M	$ 8.58	$ 7.42	$ 6.14	-	-	-	-	-
50	E&G M	$ 0.67	$ 0.25	$ -	350	MODG M	$ 8.58	$ 7.42	$ 6.14	-	-	-	-	-
25	E&G U	$ 0.50	$ 0.40	$ 0.29	300	MODG M	$ 8.58	$ 7.42	$ 6.14	-	-	-	-	-

Appendix AA: combination of variables used for different scenarios.