Research Report:

Potential Water Savings through Improved Irrigation Efficiency in Pajaro Valley, California

Prepared for:
Pajaro Valley Water Management Agency

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ABSTRACT

Water conservation not only provides short-term benefits for the environment, but more importantly, it constitutes a long-term investment for the future. Pajaro Valley, an agricultural region 90 miles south of San Francisco, is actively pursuing new strategies to improve the sustainability of their water resources. Water use efficiency is included in the valley's Basin Management Plan (BMP) Update (Pajaro Valley Water Management Agency, 2013). This project was developed in partnership with the Pajaro Valley Water Management Agency (PVWMA) to evaluate: (1) how much water could be saved through agricultural conservation, and 2) the economic impact on the PVWMA and growers in Pajaro Valley. This project estimates the potential water savings in Pajaro Valley by applying (a) an interview campaign with growers, (b) an evapotranspiration (ET) consultation with experts, and (c) a statistical analysis of the collected data. Through growers' interviews, data was acquired on quantity of water applied to different crops and the amount of money growers invest in crop production. To answer the water conservation savings question, the applied water and crop ET were compared. By conducting grower interviews, the amount of water different growers applied to their various vegetable and berry crops was determined and the behavior of the study site was applied to the entire valley. In summary, Pajaro Valley has the potential to save **4,600** to **5,100** Acre-Feet per year (AF/year) of water through conservation.

Two sets of data from 2009 and 2011 were analyzed to estimate the average applied water volume per crop. The analysis focused on 2009 because it was a normal year in terms of precipitation and water usage. Land use data provided by PVWMA for this year contained a large acreage (16%) of unknown agriculture. There is an estimated total water savings of 4,600 AF/year if any potential water savings in the "unknown agriculture" area are disregarded. If this area is considered and the unknown agriculture land is assumed to follow the same distribution of crops as the rest of the valley, then the total potential water savings are estimated as 5,100 AF/year.

Water savings will result in a direct decrease in revenue for PVWMA ranging from $862,000 to $951,000. To compensate for this loss in revenue, an increase in extraction fee rates (referred by PVWMA as an augmentation fee) was considered. This action will affect farmers, especially vegetable crop growers in the coastal zone. Coastal zone growers currently estimate $3,910/acre revenue per growing season. If water rates are increased by 50% ($105/AF), the revenue of vegetable coastal growers will be decreased by 6.9% ($271) per growing season. This strategy will affect farmers, lowering their net profit on crops. Growers of strawberries, raspberries, blackberries and nurseries have a larger return per unit water applied; therefore, increased water fees will not significantly impact these growers.

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1. Introduction

1.1. Broad Vision

Of all water on Earth, only 2.5% is freshwater. The remaining 97.5% consists of saltwater which is too saline for human consumption or irrigation without further expensive treatment. Of the freshwater, only 1.3% of this fraction consists of renewable surface water that is readily available for use (U.S. Geological Survey, 2013). This amount of renewable freshwater is a very miniscule amount compared to the total amount of water that exists on Earth. Water is a limited resource and one has to put in the best effort in achieving water sustainability to maintain this vital resource for both current and future generations. Water sustainability is defined as being able to ensure there is enough water to meet the needs of human health and the environment in both present and future time.

In order to achieve water sustainability, efforts can be made to maximize water efficiency and/or water conservation. Water efficiency involves reducing the amount of water required for a particular purpose and focuses on reducing wasted water. Installing low-flow toilets or fixing household leaks are examples of efficiency. The amount of water usage required is lowered, but a person's everyday behavior is not affected by the changes. In contrast, water conservation involves restricting water use and changing water demands, which affects a person's normal behavior. The prohibition of watering lawns or washing cars during a drought is an example of such.

This report focuses on improving water efficiency in the agricultural sector of Pajaro Valley, California. To attain this goal, crop evapotranspiration data was used to attain the volume of applied water needed to irrigate certain crops. These data sets are then compared to actual applied water numbers from farmers to check for accuracy.

1.2. Scope of the Report

This report describes methods to improve irrigation efficiency water management in the Pajaro Valley. The Pajaro Valley Water Management Agency (PVWMA) currently has a Basin Management Plan in place, but struggles to control groundwater overdraft and seawater intrusion to their aquifers. Approximately 90% of water used within Pajaro Valley is groundwater (PVWMA, 2013). Basin modeling indicates that the current basin overdraft is at ~10-12 TAF, 1,500 AF/Y and seawater intrusion is currently at 2,500 AF/Y (PVWMA, 2013). The motivation for this report is to reduce overdraft in the Pajaro Valley aquifers, resulting in less seawater recharge in these basins and diminished overall water extraction. The objective of this report is to explain the methods behind potential water savings in Pajaro Valley, focusing strongly on the water intensive agricultural sector.

2. BACKGROUND

2.1 GEOGRAPHY

The Pajaro Valley Watershed is roughly 1,300 square miles, extending over multiple counties including Santa Cruz, Santa Clara, San Benito, and Monterey Counties (PVWMA, 2013). The PVWMA manages and delivers water to approximately 77,000 acres (120 square miles) of this lower Pajaro River Watershed (Brian Lockwood, personal communication, October 24, 2012).

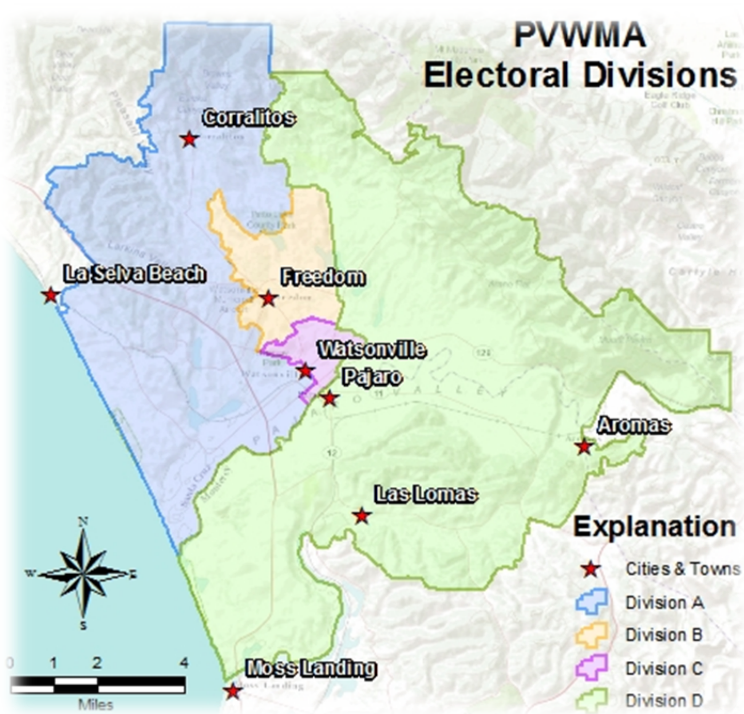

Figure 1. - Areas within PVWMA's Jurisdiction.

(Source: Pajaro Valley Water Management Agency. http://www.pvwma.dst.ca.us/about-pvwma/boundaries.php)

The land is bounded by Monterey County to the north, Santa Cruz County to the south, the San Andreas Fault to the east, and the Pacific Ocean to the west (PVWMA, 2013)

2.2 POPULATION

This report focuses on the people of Watsonville, California. This is due to Watsonville's status as a major producer of fruits and vegetables. Watsonville's population in 2010 consisted of 51,199 people (United States Census Bureau, 2010). Of these citizens, 4,495 people worked in the agriculture, forestry, fishing and hunting, and mining industries. This population represents 20.6% of Watsonville's population and contains a margin of error of plus or minus 3.2% (U.S. Census Bureau, 2010).

Profits earned within the strawberry, raspberry, blackberry, and lettuce market are major regional economic drivers. Many independent farmers in the Pajaro Valley work with corporate agricultural companies such as Driscoll's and Dole Berries.

2.3 ECONOMIC ACTIVITIES

2.3.1 AGRICULTURE

The economy of Pajaro Valley is largely sustained by agriculture. The valley ranks fifth in California in agricultural production and provides 90% of Santa Cruz County's gross agricultural income (Bannister et al., 2012). Many Pajaro Valley farmers grow crops on their own small farms to supply leading agricultural companies. Driscoll's is one of the largest suppliers of berries and can be found year round in over 61 retail locations throughout the United States (Driscoll's, 2013). Watsonville is a major supplier of Driscoll's berries, with annual production starting from the beginning of April to the middle of December (Driscoll's, 2013).

Agriculture uses roughly 80% of the water that is pumped from the basin (PVWMA, 2013). As mentioned earlier, the PVWMA manages 77,000 acres of land in the Pajaro Valley. Table 1-1 shows total agricultural acreage use in 2012 to be 28,367 acres in the Pajaro Valley. Within Pajaro Valley, 41% of total land is used exclusively for agriculture.

Such a high offset of land for agricultural use shows promising results for potential water savings in the agricultural sector.

Table 1. - Summary of Land Use in Pajaro Valley. (Adopted from PVWMA, 2013).

Land Use Type	Acreage							
	1966	1975	1982	1989	1997	2009	2011	2012
Total Agricultural Acreage	30,448	33,409	31,516	34,463	34,650	28,299	28,264	28,367
Urban Acreage	4,757	6,688	8,018	8,384	12,860	NA	NA	NA
Native Vegetation	61,301	56,409	56,972	53,659	48,996	NA	NA	NA

Values from 1966-1997 are for the model area; acreages from 2009-2012 are for PVWMA service area.
Sources: PVWMA 2002, and PVWMA data, 2012

2.4 PAJARO VALLEY WATER MANAGEMENT AGENCY (PVWMA)

The PVWMA is a state-chartered water committee led by a seven member Board of Directors. The PVWMA Board holds monthly meetings to vote on decisions and oversee project development. The agendas of these meetings includes finalizing contracts with engineering firms, planning projects under CEQA guidelines, and addressing community input. The Board of Directors established Ad Hoc BMP Update Committee and directed agency staff to work with the Committee to develop an Update to its Basin Management Plan that would solve the water resources problems of groundwater overdraft and seawater intrusion. The Committee consisted of twenty one members representing entities consisting of the PVWMA, local county representatives, stakeholders, environmentalists, farmers, and residents (PVWMA, 2013). The main objective for the creation of this committee was to include community input into the BMP Update process.

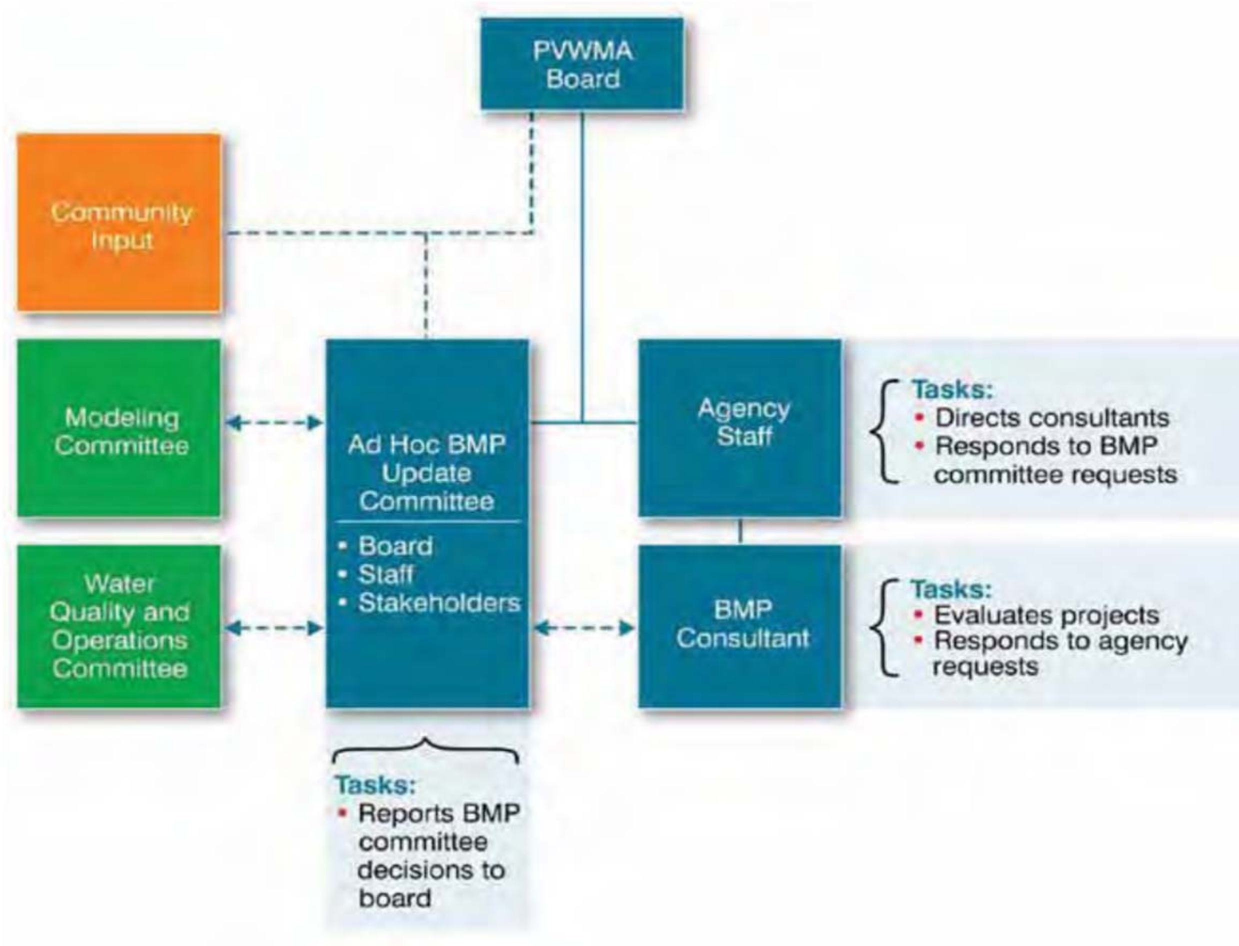

Figure 2. – BMP Committee Resources and Reporting Structure. (Adopted from PVWMA, 2013).

2.4.1 Objective

The PVWMA was chartered to:

1) Sustainably balance water supplies in an efficient and effective manner.

2) Manage water supplies to reduce continuing overdraft of groundwater.

3) Provide and ensure water supply for current and future needs within their boundaries.

2.5 Basin Management Plan (BMP)

The PVWMA's Basin Management Plan (BMP) was first adopted in 1994 and has been updated and redrafted three times ever since (PVWMA, 2013).

The PVWMA recently updated their Basin Management Plan (BMP) in 2012 to address the overdraft and saltwater intrusion problems in the basin. The goals of the BMP stem from the objectives of the PVWMA. They are to:

1. Sustainably balance water demand to match the water supply with current and future water demands.

2. Prevent saltwater intrusion into aquifers—a concurring problem since 1953.

3. Develop a water portfolio and construct strategies to guarantee water quality and supply for future generations.

Proposed solutions for their goals include management strategies that include water conservation, switching to alternative water sources, and developing new water projects (PVWMA, 2013).

All these strategies go through a long review process by the PVWMA including input from water managers, stakeholders, and the community.

2.5.1 Development of the BMP

The Ad Hoc BMP Update Committee was largely responsible for the development of the BMP. The development of the plan was balanced by input from a modeling committee, a water quality and operations committee, and the community. They met for 18 months undergoing the following process to yield their final results:

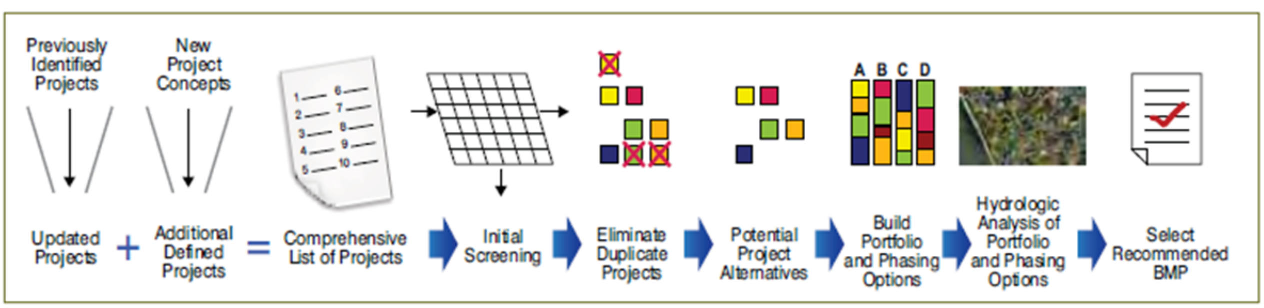

Figure 3.- The 2012 BMP Selection Process. (Adopted from PVWMA, 2013.)

The project screening process began with 44 projects that were analyzed based on the cost, implementation issues, and overlap with different projects regarding water source or location (PVWMA, 2013). All but 14 projects were eliminated and moved into the portfolio development phase. These 14 projects then underwent a hydrologic modeling process to determine the best water portfolio.

2.6 SOLUTIONS

Several strategies were considered by the BMP to reduce overdraft. They are divided into three categories:

1. Develop new supplies
2. Optimize the use of existing supplies
3. Use water more efficiently

The BMP update finalized seven projects and programs that they seek to implement:

1) Conservation
2) Increased nighttime recycled water demand
3) Increased recycled water storage at treatment plant
4) Harkins Slough recharge facilities upgrades
5) Watsonville Slough and North Dunes Recharge Basin
6) College Lake with inland pipeline to Coastal Distribution system (CDS)
7) Murphy Crossing with recharge basins

These strategies are classified according to their different types: groundwater, surface water, recycled water, demand management, sea water, and infrastructure. Projects (1-2) are demand management programs that maximize the use of existing facilities. Project (3) is a recycled water alternative which focuses on maximizing the use of recycled water by increasing the size of the recycled water storage facility. Projects (4-7) are surface water alternatives that involve constructing new infrastructure to divert water from the Pajaro River, the Watsonville Slough, Harkins Slough, and College Lake into recharge basins or the Coastal Distribution System during certain months (PVWMA, 2013). These projects all have an implementation time between 0 to 20 years if approved after CEQA hearings.

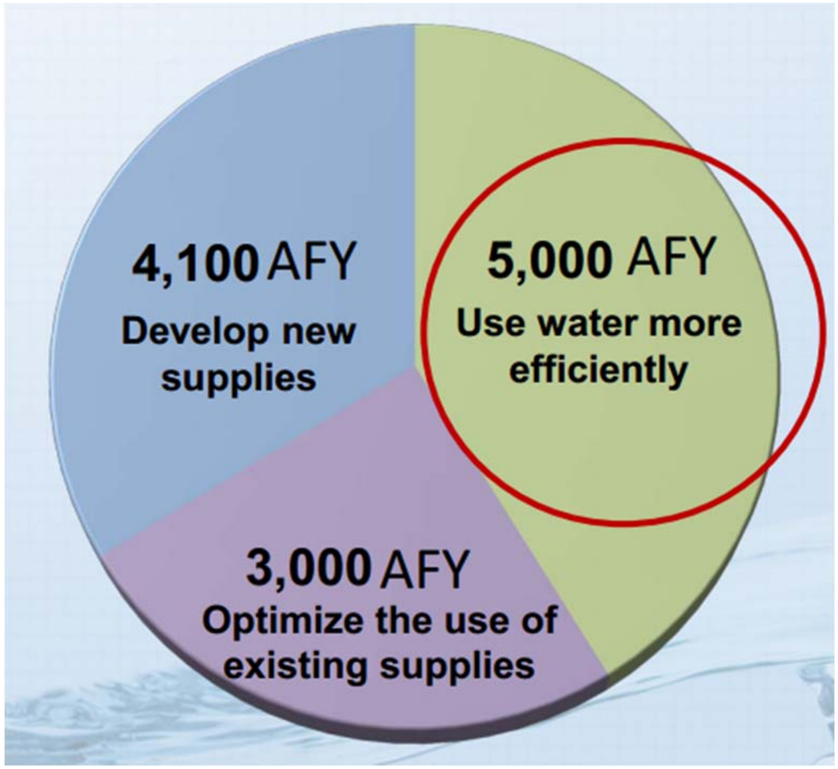

Figure 4.- Distribution of Water Savings in Pajaro Valley. (Adopted from PVWMA, 2013).

3. Methods

3.1. Framework

Two data sets were used to estimate potential agricultural water savings in this study: applied water and evapotranspiration (ET) data. These numbers were then compared against the empirical data provided by growers to further evaluate the relationship between applied water and evapotranspiration.

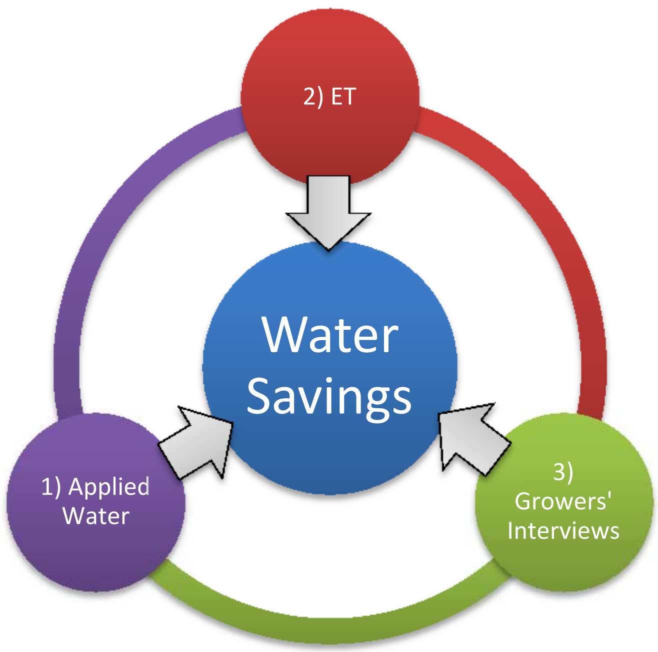

Figure 5.- Framework Behind Potential Water Savings.

3.2. Applied Water

Applied water (AW) was calculated by dividing the volume of water in acre-feet (AF) wells produced by wells by the amount of land use (acres) this water was applied over. Applied water is thus the volume of water applied per crop area.

$$AW = \frac{Well\ Production\ (AF)}{Land\ Use\ (acres)} \qquad \text{... Eq. [1]}$$

Data was analyzed for 54 different farm properties in two different years—a normal year (2009) and a wet year (2011). The calculated AW numbers were later combined with the land use data to calculate water use for different crops through a weighted average.

3.3. Evapotranspiration

Evapotranspiration (ET) is a physical process whereby the transfer of water from land to the atmosphere is facilitated simultaneously by evaporation and transpiration. Water is transferred from soil to the atmosphere through evaporation and from a plant's stomata to the atmosphere by transpiration.

Crop evapotranspiration (ETc) is the ET values of crops under standard conditions. Standard conditions include healthy, well-fertilized, and well-watered crops grown in large fields that allow them to reach their maximum crop production (Allen et al., 1998).

Evapotranspiration values were provided for multiple crops for both wet and dry years by irrigation and water resources expert and farm advisor, Michael Cahn. Crops had lower ET values during the wet year and higher ET value during the dry year.

3.4. Field Campaign

A field campaign was conducted to compare calculated AW numbers and ET values. Farmers were asked to share their AW values and the amount of money they had invested in production. AW was greater during the normal year than the wet year.

4. DATA SOURCES

Two different data sets provided by the PVWMA were compared in this study: well production (AF) and land use (acres). These data were used to calculate the volume of water applied during 2009 (a normal groundwater extraction year) and 2011 (a below average groundwater extraction year). This project focused on 2009 because its data is close to the five year groundwater extraction average in Pajaro Valley.

4.1. APPLIED WATER

Metered well data was provided by the PVWMA for 888 production wells and 46 delivered water turn out connections for the years 2009 and 2011.

4.2. FIELD CAMPAIGN

4.2.1. INTERVIEWS WITH GROWERS

Interviews were conducted with twenty different farmers in the Pajaro Valley. Farmers were asked to share their AW values and the amount of money they had invested in crop production. A wide data sample of crops including nurseries (5), strawberries (4), raspberries and blackberries (3), blueberries, vines and grapes, artichokes, apples, and vegetable row crops (6) was collected.

4.3. EVAPOTRANSPIRATION

Evapotranspiration (ET) values were provided by irrigation and water resources expert and farm advisor, Michael Cahn for vegetable row crops, strawberries, raspberries, and blackberries. Values were given for both wet and dry years. Dr. Jean Caron of Laval University, confirmed these values conducting his own independent research. This project focuses on the aforementioned crops because they represent 75% of the total acreage of plants grown in the valley.

Table 2. – Evapotranspiration Values for Multiple Crops

Crops	ET (AFY/acre) Lower	Upper
Vegetables Row Crops (lettuce, Celery, Zucchini, etc.)	2.20	2.60
Strawberries	1.90	2.20
Raspberries	1.80	2.10
Blackberries	1.90	2.20

AFY – Acre-feet per year

4.4. LAND USE DATA

The land use data was collected through field campaigns of PVWMA. Figure 6 and 7 displays the distribution of crops for 2009 and 2011.

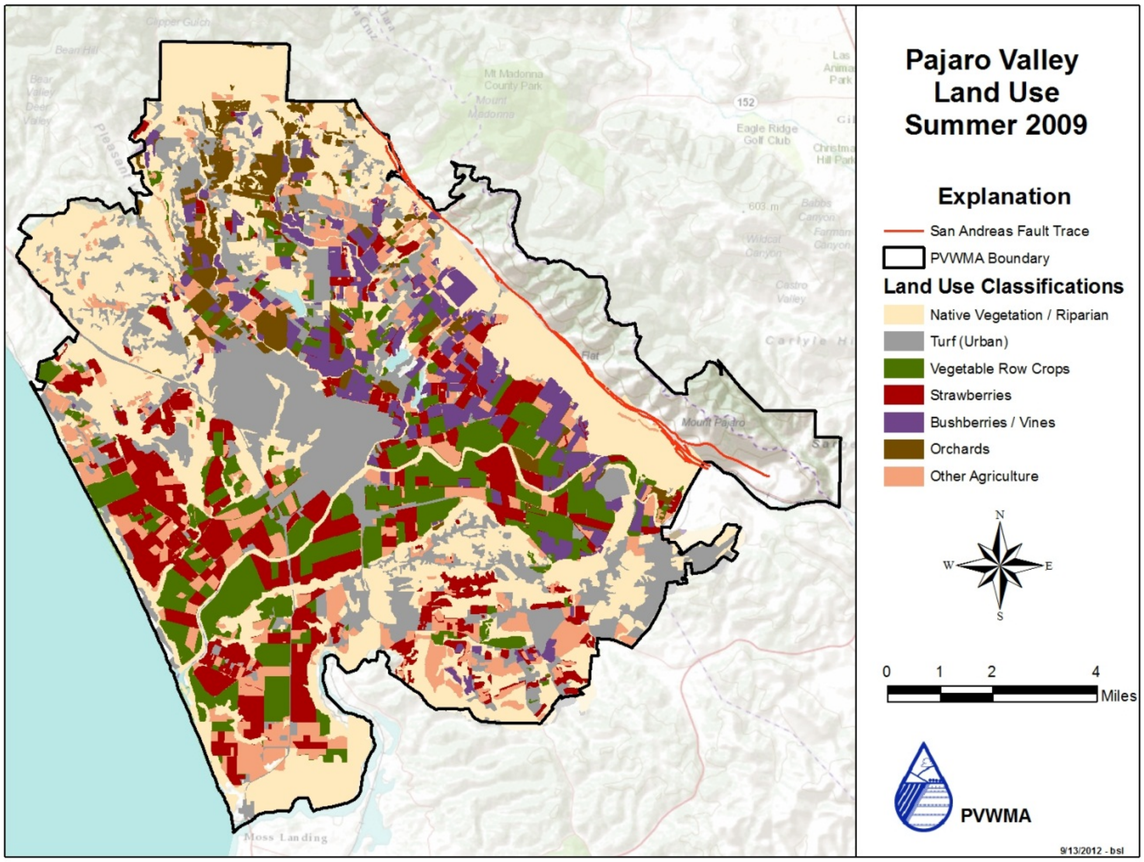

Figure 6.- 2009 Pajaro Valley Land Use Data. (Adopted from PVWMA, 2013).

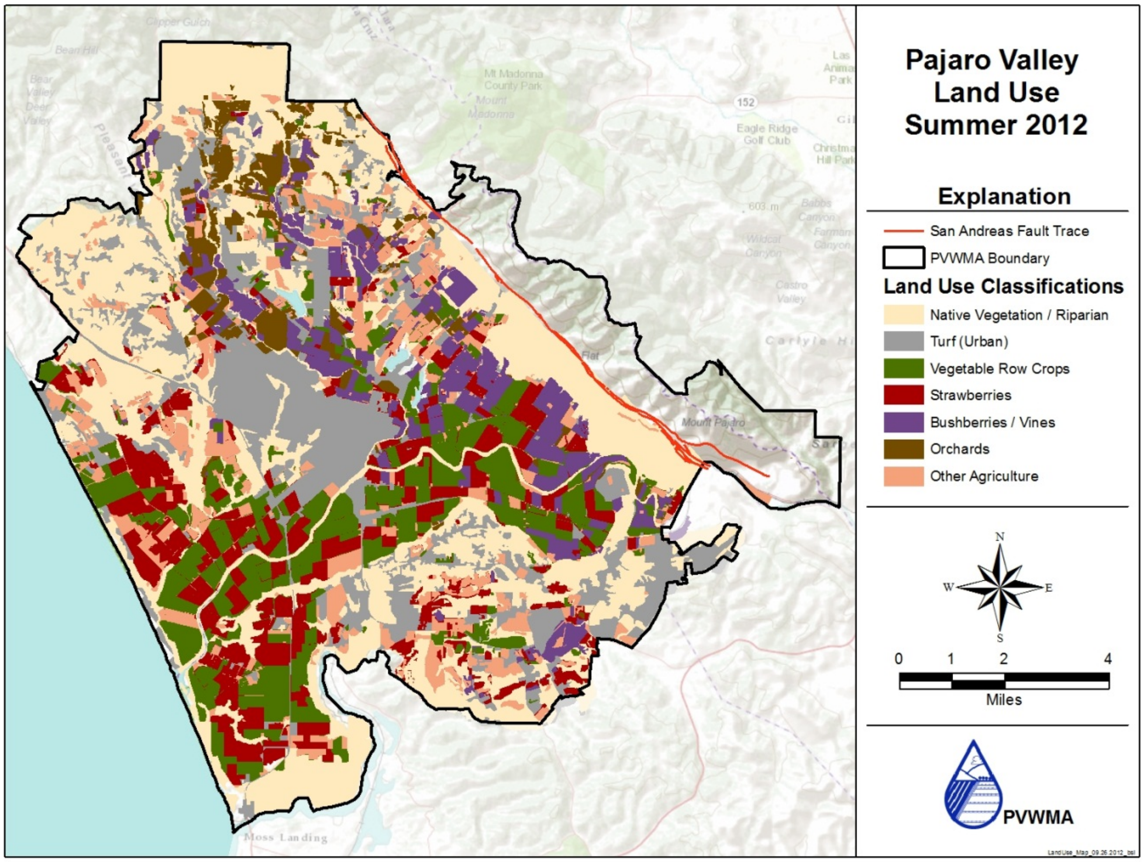

Figure 7.- 2011 Pajaro Valley Land Use Data. (Adopted from PVWMA, 2013).

4.5. GROUNDWATER DATA

Groundwater data was collected using flow meters installed and maintained by PVWMA. This data is referred to by PVWMA as "production well" data meaning these wells are used to extract water from the ground. Metered production data is kept in a database by PVWMA. This information also includes Coastal Distribution System called "turn outs data," which refers to pipe connections to the Coastal Distribution System (CDS) installed by PVWMA. The CDS is the infrastructure through which water deliveries for irrigation purposes are made to growers in the impacted coastal area. Sources of delivered water include recycled water, groundwater and water recovered from the PVWMA's Managed Aquifer Recharge and

Recovery Facility. Figure 8 shows the distribution of production wells and turn outs in Pajaro Valley.

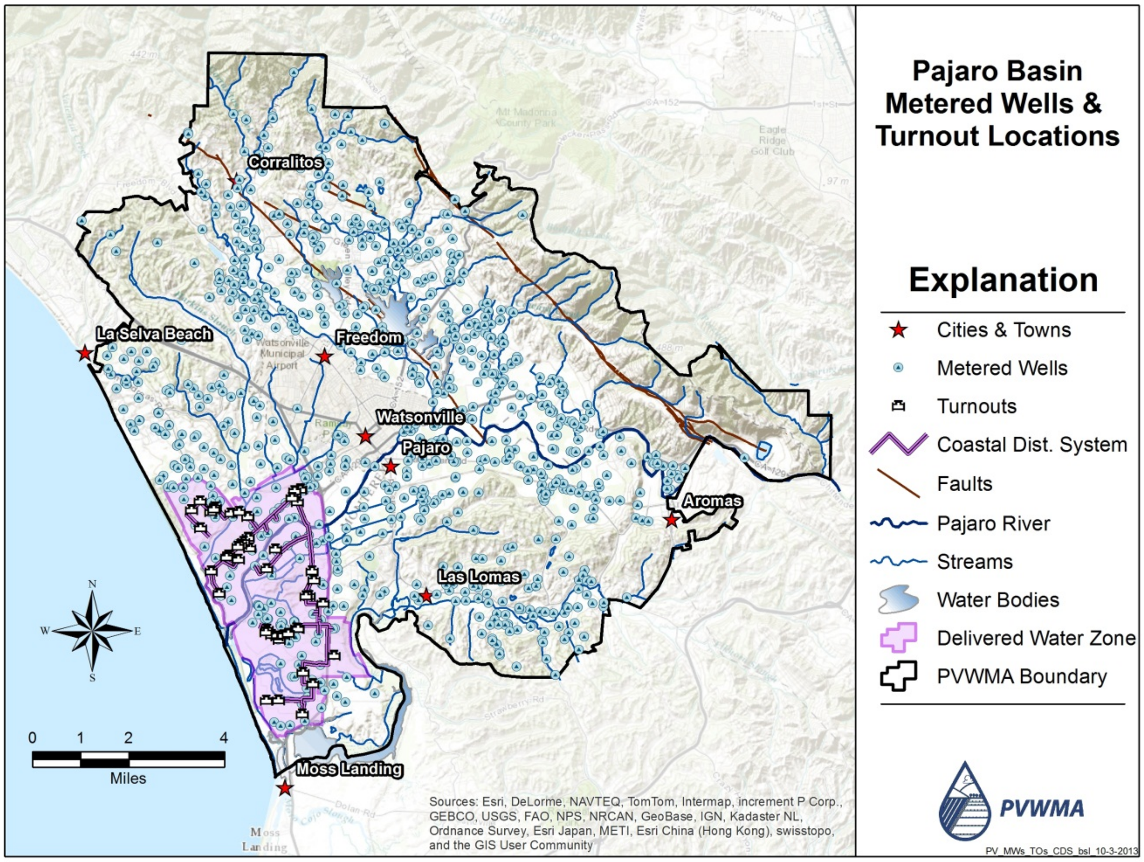

Figure 8.- Pajaro Valley metered well and turn out locations. (Adopted from PVWMA, 2013.)

5. WATER BUDGET ANALYSIS

5.1. APPLIED WATER

5.1.1. SUMMARY OF RESULTS

This section explains the water budget created to estimate the amount of water used for each crop category and the distribution of applied water within each crop. Table 3 shows the summary of results for 2009. In summary, total applied water is the product of the acreage (Column 1, Table 9) of each crop times the average AW (AF/acre) (Column 3, Table 9) used on each particular crop. These values were multiplied by an *Acreage Factor* (Column 4, Table 9), considering only a fraction of the surface area on a property is used for crop production.

Table 3. - Summary of applied water (*AW*) results for 2009.

Calendar Year: 2009 Land Use Type	Acres	(%)	Wat. Use (AF/acre)	Acreage Factor	Applied Water (acre-feet)
Fallow	2,767	10%			
Vegetables Row Crops[1]	6,318	22%	2.67	0.80	13,513
Strawberries[1]	7,068	25%	2.36	0.80	13,338
Raspberries, Blackberries[1]	3,655	13%	2.34	0.80	6,832
Blueberries[3]	0	0%			
Vines / Grapes[3]	27	0%	2.68	0.80	58
Artichokes[2]	180	1%	1.50	0.80	215
Deciduous (Apple Orchards) [1]	1,530	5%	0.52	0.80	639
Nurseries / Flower / Subtropical Plants[2]	1,397	5%	4.21	0.13	765
Other[1]	788	3%	1.93	0.80	1,215
Unknown Ag. Use[3]	4,569	16%	2.68	0.80	9,794
Total	28,299	100%	2.05	0.80	**46,370**

Notes:
1 – Average applied water per acre calculated from the production well and land use data provided by PVWMA.
2.- Applied water provided by experts and Pajaro Valley growers.
3.- Applied water derived once the rest of the crops were calculated.

5.1.2. ACREAGE FACTOR

The acreage factor (AF) is estimated as a ratio of the acreage of crop production to the total acreage of land on the property, and as thus, is critical in quantifying applied water to the surveyed area. The total acreage of multiple properties was provided by the PVWMA through their land use survey. However, assuming growers grew crops on every acre of their property, the amount of applied water used would be underestimated and the potential water savings would be less realistic and more difficult to attain. In order to determine the productive areas on a property, polygons were drawn from aerial footage of the surveyed area using ArcGIS. By using aerial footage, the production area of certain properties was outlined. ArcGIS was used to estimate the acreage of land that was used for production.

Type of Crop: Strawberries
Area
Polygon = 14.6 acres
Production = 11.2 acres
Acreage Factor
Acreage Factor = Production/Polygon
Acreage Factor = 11.2/14.6 = 0.77

What does 0.77 mean?

It means the production area is ≈ 80% of the polygon area provided in the Land Use (LU) survey.

Figure 10.- Acreage Factor Sample Calculation.

In Figure 10, the acreage factor (AF) of strawberries was estimated as a ratio of acres of strawberry production over the total acres of land on the property. Strawberry production area was already provided by growers. The total land area was determined by drawing a polygon from aerial footage in the area provided in the Land Use survey. After acreage calculations, the total area of the property in the Land Use survey was determined to be 14.6 acres. An AF of 0.77 was calculated after dividing the acres of strawberry production over the total acres of property. This number means roughly 80% of the property is used for strawberry production.

Table 4. - Sample Sizes of Well Production Data.

Crop	Sample Size
Vegetables Row Crops (lettuce, Celery, Zucchini, etc.)	12
Strawberries	13
Raspberries, Blackberries	14
Blueberries*	1
Vines / Grapes*	1
Artichokes*	2
Deciduous (Apple Orchards)	15
Nurseries / Flower / Subtropical Plants*	5
Other	---

* These values were provided by the empirical knowledge of Pajaro Valley growers

Fifty-four different properties were assessed in this project. Based on field crop data in the land use survey, the average AF of these 54 properties was calculated to be about 0.80. Therefore, it is assumed that farmers allocate 80% of their total property acreage to crops. Nurseries are a special case, carrying an AF of 0.13 due to requirements for only a very small, concentrated area of production. There were not enough interviews conducted for blueberries, vines and grapes, artichokes, and nurseries so we used values based on the expertise of growers.

5.1.3. Water Use

As stated in Equation [1], Well production data is critical in calculating AW. This data was provided by the PVWMA. The agency shared data regarding 888 production wells including the properties that withdrew water from these wells and the volume of well water used. The productive acreage on each of the 54 sampled properties were calculated using the aerial methods described in the previous section. All farmers in the surveyed area were assumed to exhibit the same behavior as the 54 farmers selected for analysis. The *Water Use* (Table 5) was estimated as an average of different water use samples that were calculated using the procedure explained in section 5.1.

Table 5. – 2009 Applied Water Data.

Calendar Year: 2009 Land Use Type	Wat. Use (AF/acre)
Fallow	
Vegetables Row Crops (lettuce, Celery, Zucchini, etc.)	2.67
Strawberries	2.36
Raspberries, Blackberries	2.34
Blueberries	
Vines / Grapes	2.68
Artichokes	1.50
Deciduous (Apple Orchards)	0.52
Nurseries / Flower / Subtropical Plants	4.21
Other	1.93
Unknown Ag. Use	2.68
Total	2.05

5.1.4. Applied Water: 2009 and 2011

Table 6. – Applied Water and Evapotranspiration Data for Normal (2009) and Low (2011) Groundwater Extraction Years.

	Normal (2009)		Low (2011)	
Crop	*ET*	*AW*	*ET*	*AW*
Fallow				
Vegetable Row Crops	**2.58**	**2.67**	**2.17**	**2.24**
Strawberries	**2.23**	**2.36**	**1.89**	**2.24**
Raspberries/Blackberries	**2.25**	**2.34**	**1.88**	**2.03**
Blueberries*		1.75		1.75
Artichokes*		1.50		1.50
Deciduous (Apple Orchards)*	0.50*	0.52	0.35*	0.34
Nurseries/Flowers/Subtropical Plants*	4.00*	4.21	3.85*	3.85

Units - Acre-Feet per Year (AFY)
*Grower

AW value was ground greater than the ET value except for deciduous crops during the wet year. The goal is to reduce the amount of AW to the recommended ET value for all crops in order to improve water efficiency.

6. Data Analysis to Estimate Potential Water Savings

6.1. Summary of Results for Potential Water Savings

The goal of this project was to determine the amount of water that can potentially be saved per acre foot of production land. This required calculating a target value of applied water based on a crop's ET value. The ET value indicates optimum water amounts that should be applied in order for the water to be completely beneficial. Applying any more water than the ET value is considered wasteful because the excess water is not taken up by the crops. After considering ET values in our calculations, there was a total water savings of 4,600 to 5,100 acre feet per year for the land surveyed area. This is a big improvement, with an average water use efficiency of 91% in the production area. The previous results were obtained by conducting a distribution analysis for each crop. This process essentially involved estimating how many farmers used more water than required by a crop's ET.

Table 7. – Potential Water Savings: Lower End.

Calendar Year: 2009		Wat. Use	Applied Water	Water Savings (AFY)		
Land Use Type	Acres	(AF/acre)	(acre-feet)	Coastal	Inland	Total
Fallow	2,767					
Vegetable Row Crops[1]	7,219	2.67	15,441	636	1,089	1,725
Strawberries[1]	8,076	2.36	15,242	948	1,114	2,063
Raspberries, Blackberries[1]	4,171	2.34	7,796	---	596	596
Blueberries	0					
Vines / Grapes[3]	27	3.96	86			
Artichokes[2]	180	1.50	215			
Deciduous (Apple Orchards)[1]	2,129	0.52	889	---	189	189
Nurseries / Flowers / Subtropical Plants[2]	1,463	4.21	801	13	42	54
Other[1]	788	1.93	1,215			
Unknown Ag. Use[3]	1,480	3.96	4,684	0	0	0
Total	28,300	2.05	**46,370**	1,597	3,030	4,627

Notes:
1.- Average applied water per acre calculated from well production and land use data provided by PVWMA.
2.- Applied water provided by experts and Pajaro Valley growers.

3.- Applied water derived once the AW values of (1) and (2) were calculated.

Table 8. – Potential Water Savings: Upper End.

Calendar Year: 2009		Wat. Use	Applied Water	Wat. Savings (AFY)		
Land Use Type	Acres	(AF/acre)	(acre-feet)	Coastal	Inland	Total
Fallow	2,767					
Vegetable Row Crops[1]	7,219	2.67	15,441	636	1,089	1,725
Strawberries[1]	8,076	2.36	15,242	948	1,114	2,063
Raspberries, Blackberries[1]	4,171	2.34	7,796	---	596	596
Blueberries	0					
Vines / Grapes[3]	27	3.96	86			
Artichokes[2]	180	1.50	215			
Deciduous (Apple Orchards)[1]	2,129	0.52	889	---	189	189
Nurseries / Flowers / Subtropical Plants[2]	1,463	4.21	801	13	42	54
Other[1]	788	1.93	1,215			
Unknown Ag. Use[3]	1,480	3.96	4,684	196	272	468
Total	28,300	2.47	46,370	1,793	3,302	5,095

Notes:
1.- Average applied water per acre calculated from well production and land use data provided by PVWMA.
2.- Applied water provided by experts and Pajaro Valley growers.
3.- Applied water derived once the AW values of (1) and (2) were calculated.

6.2. WATER USE DISTRIBUTION ANALYSIS AND WATER SAVINGS

In order to estimate water use distribution throughout the valley, the water use data of the twelve sampled properties was applied to the entire surveyed area. For vegetable row crops, farmers applied water ranging from 2.00 to 3.83 AF or 24 to 45 inches per acre. Intervals of two inches/acre were used to bin farmers into separate water use groups.

Table 9. – Vegetable Row Crop Data.

The red line indicates the target volume of water for vegetable growers.

	(1)		(2)	(3)	(4)	(5)
Inches	Feet	Frequency	Frequency(%)	Acreage	Applied Water	Wat. Savings
24	2.00	3	25%	1805	2993	
26	2.17	1	8%	602	1048	
28	2.33	2	17%	1203	2256	
30	2.50	1	8%	602	1208	
32	2.67	0	0%	0	0	0
34	2.83	0	0%	0	0	0
36	3.00	1	8%	602	1449	201
38	3.17	2	17%	1203	3058	561
40	3.33	1	8%	602	1609	361
42	3.50	0	0%	0	0	0
44	3.67	0	0%	0	0	0
45	3.83	1	8%	602	1850	602
		12	100%	7219	15471	1725

A sample calculation for the total acreage of vegetable row crops show in Table 9. Three farmers applied 24 inches of water per acre of land. Since these three farmers were out of a sample of twelve, 25% of all farmers in the surveyed area were assumed to have applied 24 inches of water per acre of land. The frequency of water use was multiplied by the total land area (7219 acres) to calculate how much acreage received a specific range of water per acre feet.

Column 7 from Table 9 provides an estimation of total potential water savings. In order to do this, the exact amount of water required for crops to be put to beneficial use was calculated and subtracted from the previously calculated AW value in column 6 of Table 9. The water usage (Column 5) most significantly influences the outcomes of the calculations. For vegetable crops, farmers used 2.08 to 3.83 feet of water per acre foot. ET values from Cahn (personal communication) indicate that applying 2.58 AF of water during a normal year is sufficient for the crop to thrive. As seen in Table 9, there are no water savings for farmers above the red line because they are already applying water below the ET value.

6.2.1. Coastal and Inland Regions

The crop acreage for inland and coastal zones was provided by the land use data. All farmers in these regions were assumed to display the same water use distribution as the farmers sampled, as explained in the previous section. We estimated how many acres of land were using more water than the suggested ET value for both coastal and inland regions. Potential water savings were estimated based on the difference between the pre-adjusted water use values and the adjusted ET values across the acreages of crops not meeting the ET value.

Table 10. – Lower Bound Vegetable Row Crop Water Savings.

		Coastal (acre) 2146	**Inland (acre) 5073**	**Water Savings**	
				Coastal	**Inland**
Inches	*Frequency(%)*	*Acreage*	*Acreage*	*Wat. Savings*	*Wat. Savings*
24	25%	537	1043		
26	8%	179	348		
28	17%	358	695		
30	8%	179	348		
32	0%	0	0	0	0
34	0%	0	0	0	0
36	8%	179	348	60	116
38	17%	358	695	167	324
40	8%	179	348	107	209
42	0%	0	0	0	0
44	0%	0	0	0	0
45	8%	179	348	179	348
	100%	2146	4171	**513**	**996**

Table 11. – Upper Bound Vegetable Row Crop Water Savings.

		Coastal (acre)	**Inland (acre)**	**Coastal**	**Inland**	**Unknown Ag. Coastal**	**Unknown Ag. Inland**
Inches	*Frequency(%)*	*Acreage*	*Acreage*	*Wat. Savings*	*Wat. Savings*	*Wat. Savings*	*Wat. Savings*
25	25%	537	1043				
27	8%	179	348				
29	17%	358	695				
31	8%	179	348				
33	0%	0	0	0	0	0	0
35	0%	0	0	0	0	0	0
37	8%	179	348	60	116	40	11
39	17%	358	695	167	324	40	30
41	8%	179	348	107	209	26	19
43	0%	0	0	0	0	0	0
45	0%	0	0	0	0	0	0
47	8%	179	348	179	348	43	32
	100%	2146	4171	**513**	**996**	**123**	**92**

From our vegetable crop sample, it can be seen that there is a higher potential for water savings in inland regions versus the coastal regions. This pattern is consistent with the rest of the crops sampled. Two data sets were used to address the land use uncertainties regarding unspecified crops grown in some areas of the land use survey.

6.3. UNCERTAINTIES: UNKNOWN AG. USE

In the 2009 land use data, there is a crop category labeled as "Unknown Ag Use" which accounts for **16%** of the total crop acreage in the surveyed area. The PVWMA did not determine some specific crop varieties while obtaining the data for this land survey. Discounting the acreages of unknown agriculture use, the water savings in Pajaro Valley are estimated to be 4,600 AF. However, if this 16% of land was accounted for and, crops in the unknown agriculture category were assumed to be distributed in the same percentage as the rest of the land in the valley, there is an estimated water savings of 5,100 AF.

7. Economic Analysis

7.1. Introduction

The objective of this section is to present the economic impacts of:

1) Saving water in Pajaro Valley and the expected reduction in revenue for PVWMA as a result of water conservation
2) Raising water extraction fees in Pajaro Valley

7.2. Expected Economic Impact of Water Conservation

According to this report, the PVWMA has the potential to save between 4,600 and 5,100 AF of water per year by practicing water conservation. This has a direct impact on the agency as they will lose the annual revenue that would otherwise be collected if conservation measures were not put into place. This loss of revenue will be a major issue as the agency is already in debt.

PVWMA charges an augmentation fee to those who pumped water within the agency's boundaries. For Fiscal Year 2013/2014, the augmentation fee is $174 AF for inland areas and $210 AF for coastal zones. (PVWMA, 2013). The farmers interviewed also presented average electricity bills of $110 per AF of water paid to Pacific Gas & Electric Company (PG&E). Therefore, pumping water from any well costs $284/AF in inland areas and $320/AF in coastal zones.

Assuming the PVWMA maintains its augmentation fee of $174 and $210 per AF, the PVWMA would lose between $862,000 and $951,000 in revenue per year. These values are based on our lower and upper bound water savings estimates. The BMP estimates the loss in revenue to be a maximum of $1,000,000 per year, a value similar to our estimation (PVWMA, 2013). This document also predicts an annual operation and maintenance cost of $250,000 to $300,000 for the first three to five years of the conservation program. These water costs and revenue loses are not adjusted for inflation, but it is assumed they will increase as the PVWMA increases its rates every July based on the Consumer Price Index (PVWMA, 2013).

7.3. INCREASE IN WATER FEES TO COMPENSATE WATER CONSERVATION

To compensate for the $862,000 to $951,000 yearly loss in revenue from water conservation, one strategy is to raise extraction fees. This strategy will affect farmers by lowering the net profit on crops.

Table 12. – Revenue per Crop Prior to Rate Increases

	Profit	**Inland**		**Coast**	
	Inland & Coastal* ($)	Investment** ($) per AF	Net Profit ($) per AF	Investment** ($) per AF	Net Profit ($) per AF
Vegetables	$10,000	$6,000	$4,000	$6,090	$3,910
Strawberries	$68,000	$27,500	$40,500	$27,583	$40,417
Raspberries	$59,000	$23,110	$35,890	$23,182	$35,818
Blackberries	$59,000	$25,000	$34,000	$25,082	$33,918
Nurseries	$205,000	$75,500	$129,500	$75,647	$129,353

* Profit. Average profit of both coastal and inland regions. The profit of crops per acre were obtained through the 2012 Ag. Commissioner report (Monterey County Agricultural Commissioner, 2012).
** Investment. This data was collected through interviews with growers in Pajaro Valley.

Table 12 shows the average amount of money farmers invest in their crops, their profits, and their net profit. The investment data was gathered through grower interviews and the profits were calculated using data from Monterey County's 2012 Crop Report (Monterey County Agricultural Commissioner, 2012). Subtracting investments from profits provided the net profit obtained from different crops per AF of water.

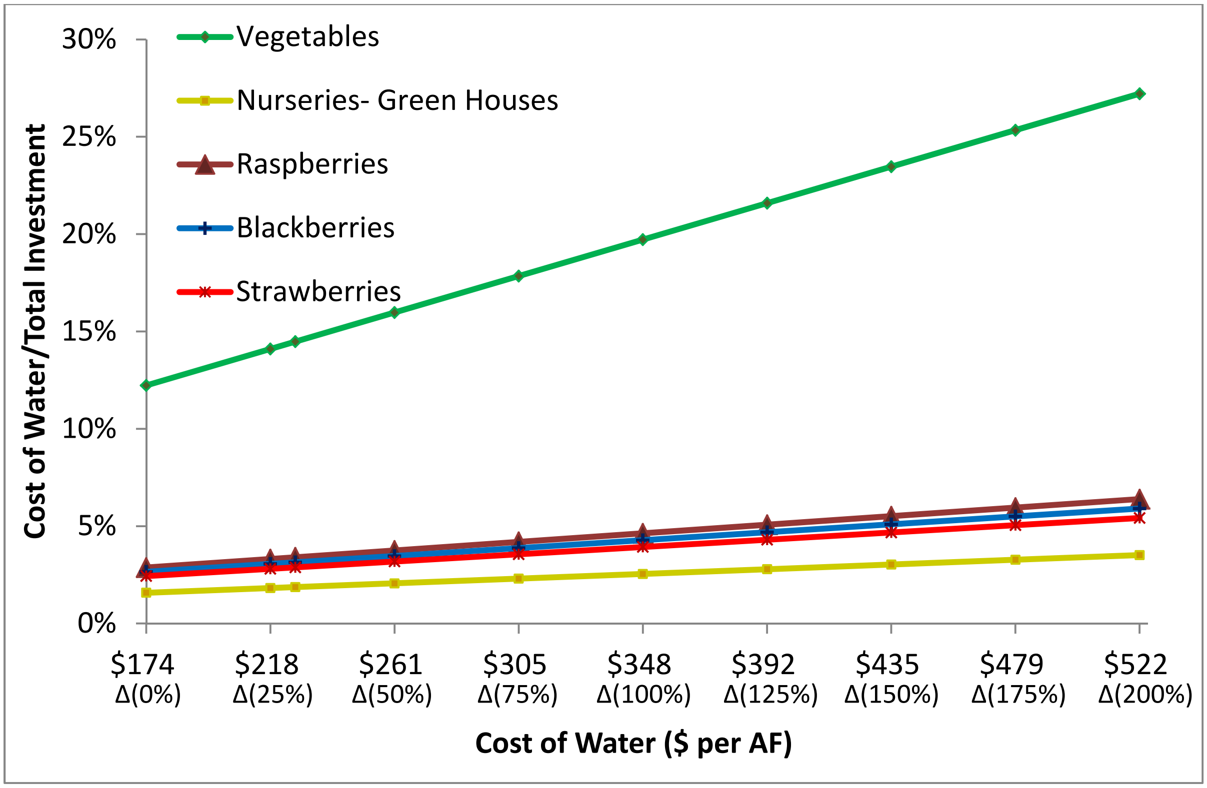

Figure 11.- (Inland zone) relationship between the cost of water and the proportion of total crop investment spent on water for key crop types.

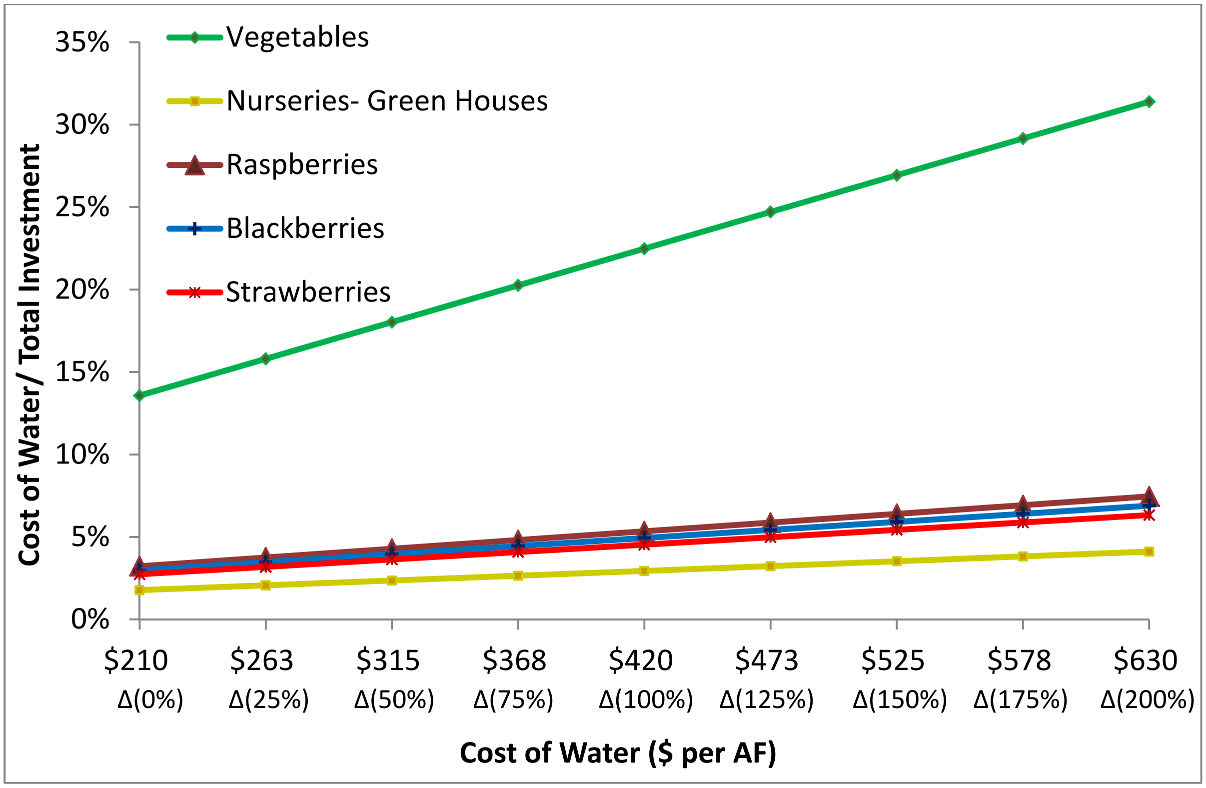

Figure 12.- (Coastal zone) relationship between the cost of water and the proportion of total crop investment spent on water for key crop types.

Figures 11 and 12 show the relationship between the cost of water and the proportion of total crop investment spent on water for key crop types. Results suggest that the net profit per AF depends heavily on the type of crop being produced. Vegetables have a return of $4,000 per AF of water as opposed to nurseries with a return of $129,000 per AF. Vegetable growers will be the most significantly impacted by the increase of water rates because their investment per AF of water will increase, substantially lowering their total net profits. For instance, for a coastal farmer, if the water extraction fee is increased by 50% (from $210 to $315), the cost of water relative to the total investment cost will increase from 13.6% to 18.0%. In other words, the water cost will increase from $827 to $1,098 per acre for the crop season. Strawberries, raspberries, blackberries will be moderately affected by the rate increase, and nurseries will only see a minor decrease in their net profits.

Table 13. – Increase in Investment Costs with Rate Increases (Inland).

	Investment ($)	Applied Water (AF/acre)		**$/AF** **$174**	Δ(50%) $261	Δ(75%) $305	Δ(100%) $348	Δ(150%) $435	Δ(200%) $522
Vegetables	$6,000	2.6	IIC	12.2%	16.0%	17.8%	19.7%	23.3%	27.2%
			DV	$0	$958	$1071	$1183	$1408	$1633
Strawberries	$27,500	2.4	IIC	2.4%	3.2%	3.6%	3.9%	4.7%	5.4%
			DV	$0	$875	$978	$1080	$1286	$1491
Raspberries	$23,100	2.3	IIC	2.9%	3.8%	4.2%	4.6%	5.5%	6.4%
			DV	$0	$867	$968	$1070	$1273	$1477
Blackberries	$25,000	2.3	IIC	2.7%	3.5%	3.9%	4.3%	5.1%	5.9%
			DV	$0	$867	$968	$1070	$1273	$1477
Nurseries	$75,500	4.2	IIC	1.6%	2.1%	2.3%	2.5%	3.0%	3.5%
			DV	$0	$1558	$1741	$1924	$2289	$2654

* IIC – Increase in cost as a percentage of the total crop investment
**DV – Dollar value of the increase in investment costs

Table 14. – Increase in Investment Costs with Rate Increases (Coastal).

	Investment ($)	Applied Water (AF/acre)		**$/AF** **$210**	Δ(50%) $315	Δ(75%) $368	Δ(100%) $420	Δ(150%) $525	Δ(200%) $630
Vegetables	$6,090	2.6	IIC	13.6%	18.0%	20.3%	22.5%	26.9%	31.4%
			DV	$0	$1098	$1234	$1369	$1640	$1912
Strawberries	$27,583	2.4	IIC	2.7%	3.6%	4.1%	4.5%	5.4%	6.3%
			DV	$0	$1003	$1126	$1250	$1498	$1746
Raspberries	$23,182	2.3	IIC	3.2%	4.3%	4.8%	5.3%	6.4%	7.5%
			DV	$0	$993	$1116	$1238	$1484	$1729
Blackberries	$25,082	2.3	IIC	3.0%	4.0%	4.4%	4.9%	5.9%	6.9%
			DV	$0	$993	$1116	$1238	$1484	$1729
Nurseries	$75,647	4.2	IIC	1.8%	2.4%	2.7%	2.9%	3.5%	4.1%
			DV	$0	$1785	$2006	$2226	$2667	$3108

* IIC – Increase in cost as a percentage of the total crop investment
**DV – Dollar value of the increase in investment costs

8. Conclusion

For this report, a comprehensive project was launched that successfully estimated the potential water savings in Pajaro Valley. This project consisted of (1) an interview campaign with growers, (2) an ET value consultation with experts, and (3) a statistical analysis of data collected. Through growers' interviews, data was acquired regarding the amount of money growers invest in crop production and their applied water data. ET data was provided by Michael Cahn of UC Davis and confirmed with similar data from Jean Caron of Laval University. This was a successful project, as it allowed us to calibrate our data with growers' information and compare it with expert knowledge.

The potential water savings in Pajaro Valley were estimated based on a combination of results acquired from the field campaign, expert-based criteria, remote sensing, and water metered data analysis. These results suggest that Pajaro Valley can save 4,600 to 5,100 AF of water per year through conservation measures. These numbers were attained by analyzing data for the 2009 water year, which was a normal year considering precipitation and climate conditions. A range of savings is proposed because there are some uncertainties with the "Unknown Agriculture" category of crops. Most of the land use data was very specific, but PVWMA was unsure of 16% of the crops grown in the valley. If we do not include the land with unknown agriculture as an area with potential water savings, the total water savings of the valley is estimated to be **4,600 AF/year**. If we consider the unknown agriculture and assume the land follows the same distribution of crops as the rest of the valley, then the total potential water savings are estimated as **5,100 AF/year**.

This increase in water savings was shown to influence a direct decrease in revenue for PVWMA ranging from $862,000 to $951,000 per year. To compensate for this loss in revenue, an increase in extraction fee rates was considered. This increase would affect farmers, especially vegetable crop growers in the coastal zone. These growers currently receive an estimated revenue of $3,910 per growing season (Monterey County Agricultural Commissioner, 2012). If water rates are increased by 50% ($105/AF), their revenue will be decreased 6.9% ($271) per growing season. This strategy will dramatically affect farmers, lowering their net profit on crops. Strawberry, raspberry, blackberry and nursery growers have a larger return, so increased water fees will affect them less severely.

It may be logical to suggest that all vegetable growers in Pajaro Valley should simply switch to growing other crops to avoid high losses. However, this is not as simple as it sounds. There is a rotation of crops between strawberries and vegetables. In essence, fields that are grown with strawberries for a given growing season will be grown with vegetables crops the following season. This rotation is practiced in order to keep the soil productive to maintain high strawberry crop yields. The other alternative is to fallow the land after the growing season, but that is not economically feasible for many growers.

From the data collected in this report, it is clear that there is room for water conservation in the Pajaro Valley. The PVWMA plans to complete seven projects, including a rigorous conservation program. The beauty of the program is that it will contribute to over one third of the estimated water savings potential in the valley without the construction of additional infrastructure. Instead, it seeks to improve water savings through the infrastructure growers already have. The main obstacle is closing the gap between our current knowledge and the traditional beliefs of growers. With the data collected from this project, growers can be better informed about applying water based on ET data. If all growers in the Pajaro Valley were briefed with this information, the Pajaro Valley could very easily see yearly water savings between 4,600 and 5,100 AF.

8.1. LIMITATIONS

In order to estimate the potential water savings in Pajaro Valley, we had to make some subjective assumptions. These assumptions include (1) the crops grown under the "Unknown Agriculture" category carry the same distribution as the rest of the crops in the valley, (2) the average ET value is reflective of the entire valley, and (3) all growers display the same behavior as those interviewed in our sample area. For the first assumption, we cannot accurately predict what is unknown. Secondly, ET changes with different microclimates so it is unlikely that one ET value is reflective of the entire valley. The coastal regions of Pajaro Valley are frequented by fog during the night and morning hours, and it is extremely difficult to get an accurate ET value for areas subjected to foggy weather. Geographically specific ET values could improve the water savings estimations. The third assumption is uncertain because we did not choose to include organic growers who use more water than conventional growers. This suggests that not all growers used the same amount of water as those in our sample. The potential water savings may have been overestimated by not accounting for organic crops.

Although there were some uncertainties that we tried to account for, this was a very comprehensive project that yielded numbers in which we are very confident. Many different data sources were compared in order to accurately estimate the potential water savings in Pajaro Valley.

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APPENDIX

This section explains in detail the procedure to calculate the water savings shown in Figure A1-1 and A1-2 as follows:

Column 1 (acres) was provided by the PVWMA.

Column 2 represents the percentage of certain crops that are grown in the production zones of the total surveyed area.

Column 3 describes the irrigation methods growers used.

Column 4 is the Acreage Factor explained in section *5.1.2*.

Column 5 (water use) is the average Applied water estimated in Section *5.1.3*.

Column 6 is the estimated applied water per crop and column 7 represents the estimated water savings. Calculations for these columns are explained in the following section 6.2.

Column 8 is the water use efficiency (WUE), basically comparing the amount of water that can be saved and the amount of water that is been used. This was estimated as WUE = 1 – Wat. Savings (Column 7) / Applied Water (Column 6).

Column 9 and 10 simply breaks down the potential water savings into the different coastal and inland areas. There is almost double the amount of potential water savings in inland areas versus the coastal areas.

Table A1-1. – Potential Water Savings: Lower End.

	1 (Prov.)	2	3	4 (Est.)	5 (Calc.)	6 (6=1x4x5)	7	8 (8=1-7/6)	9	10
Calendar Year: 2009			Irrigation	Acreage	Wat. Use	Applied Water	Wat. Savings	Wat. Use Effic.	Wat. Savings	Wat. Savings
Land Use Type	Acres	(%)	Method	Factor	(AF/acre)	(acre-feet)	(acre-feet)	(%)	Coastal (acre-feet)	Inland (acre-feet)
Fallow	2,767	10%								
Vegetables Row Crops	7,219	26%	Sprinkler/Drip	0.80	2.67	15,441	1,725	89%	636	1,089
Strawberries	8,076	29%	Drip	0.80	2.36	15,242	2,063	86%	948	1,114
Raspberries, Blackberries	4,171	15%	Drip	0.80	2.34	7,796	596	92%	---	596
Blueberries	0	0%	---							
Vines / Grapes	27	0%	Drip	0.80	3.96	86				
Artichokes	180	1%	---	0.80	1.50	215				
Deciduous (Apple Orchards)	2,129	8%	Sprinklers	0.80	0.52	889	189	79%	---	189
Nurseries / Flower / Subtropical Plants	1,463	5%	---	0.13	4.21	801	54	93%	13	42
Other	788	3%	---	0.80	1.93	1,215				
Unknown Ag. Use	1,480	5%	---	0.80	3.96	4,684	0		0	0
Total	28,300	100%	91%		2.47	46,370	4,627	90%	1,597	3,030

Table A1-2. – Potential Water Savings: Upper End.

	1	2	3	4	5	6	7	8	9	10
	(Prov.)			(Est.)	(Calc.)	(6=1x4x5)		(8=1-7/6)		
Calendar Year: 2009			Irrigation	Acreage	Wat. Use	Applied Water	Wat. Savings	Wat. Use Effic.	Wat. Savings	Wat. Savings
Land Use Type	Acres	(%)	Method	Factor	(AF/acre)	(acre-feet)	(acre-feet)	(%)	Coastal (acre-feet)	Inland (acre-feet)
Fallow	2,767	10%								
Vegetables Row Crops	7,219	26%	Sprinkler/Drip	0.80	2.67	15,441	1,725	89%	636	1,089
Strawberries	8,076	29%	Drip	0.80	2.36	15,242	2,063	86%	948	1,114
Raspberries, Blackberries	4,171	15%	Drip	0.80	2.34	7,796	596	92%	---	596
Blueberries	0	0%	---							
Vines / Grapes	27	0%	Drip	0.80	3.96	86				
Artichokes	180	1%	---	0.80	1.50	215				
Deciduous (Apple Orchards)	2,129	8%	Sprinklers	0.80	0.52	889	189	79%	---	189
Nurseries / Flower / Subtropical Plants	1,463	5%	---	0.13	4.21	801	54	93%	13	42
Other	788	3%	---	0.80	1.93	1,215				
Unknown Ag. Use	1,480	5%	---	0.80	3.96	4,684	468		196	272
Total	28,300	100%	91%		2.47	46,370	5,095	89%	1,793	3,302

There can be a potential total water savings from 4,600 AF per year up to 5,100 AF per year.