FOOD GROWS WHERE WATER FLOWS:

SECURING WATER FOR AGRICULTURAL PRODUCTION IN A DROUGHT-STRICKEN CALIFORNIA

by Pamela Bellavita Carvajal
Lic. Arquitectura, Universidad Véritas, 2013

Submitted to the Department of Urban Studies in Partial
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ABSTRACT

The state of California carries a large percentage of the national food security as it is responsible for a considerable amount of the agricultural production consumed in the United States. As climate change causes further challenges for agriculture, it seems wise to work on developing resilience strategies for this industry. Most research on these topics has been focused on generating high-tech systems that require considerable amounts of energy and financial resources. However, the reality is that countries facing the biggest hurdles when it comes to these matters, do not have the necessary means to create sophisticated projects at large scales. The best option right now is to learn how to use drought management strategies and spatial patterns to allow for a better usage of water resources.

This thesis explores how the spatial distribution and interaction of hydrological resources, geological features, climate patterns, topography and water infrastructure impact agricultural production in the Central Valley in California. Rather than developing one final solution, this thesis presents options, for further exploration, based on the specific conditions of California. This will allow readers to better understand how to improve water use and access for agriculture in a scenario of drought. The intention is for this approach to be replicable and adaptable so it can improve agricultural production and food security in other regions or countries facing similar conditions due to climate change.

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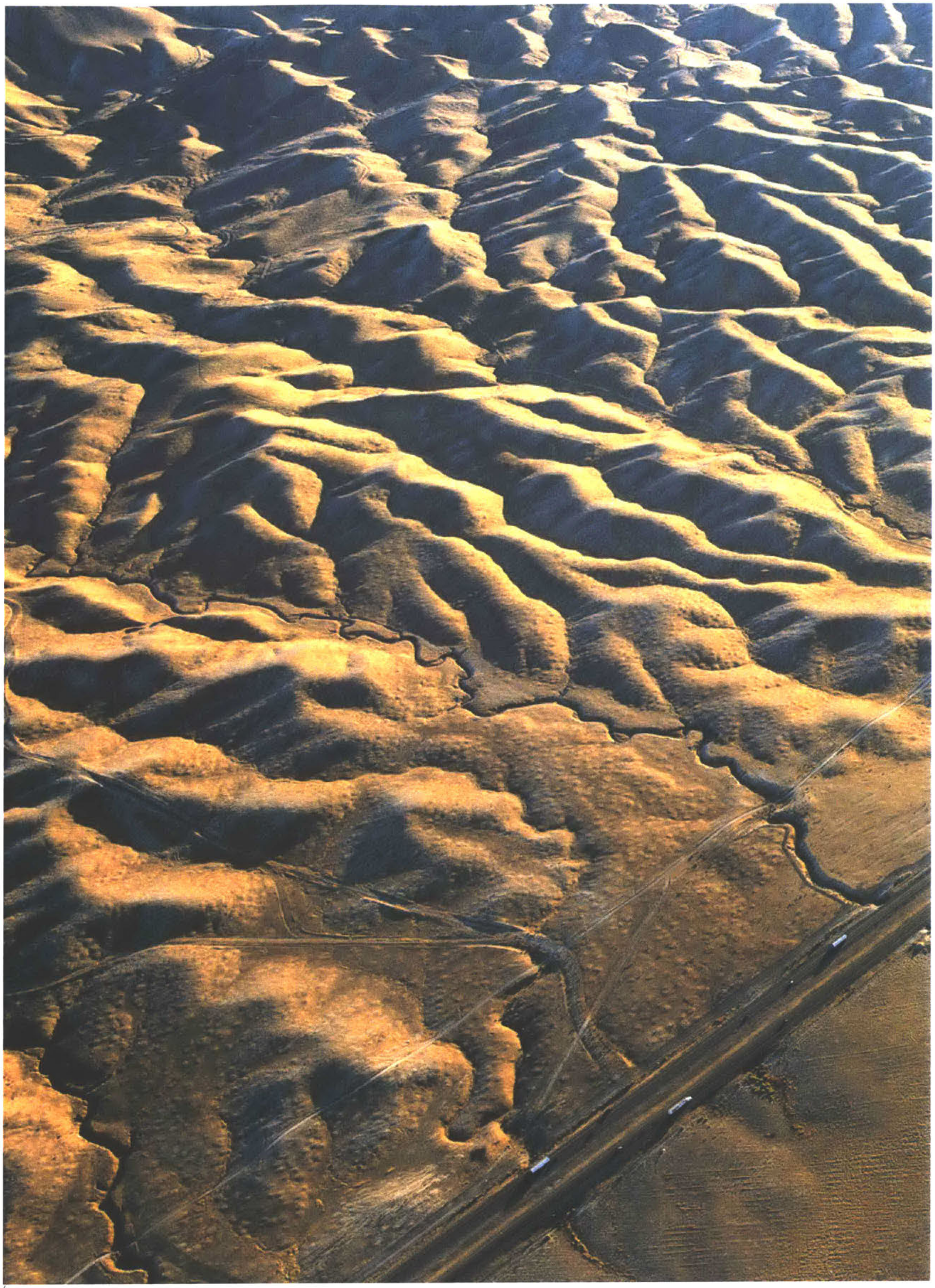

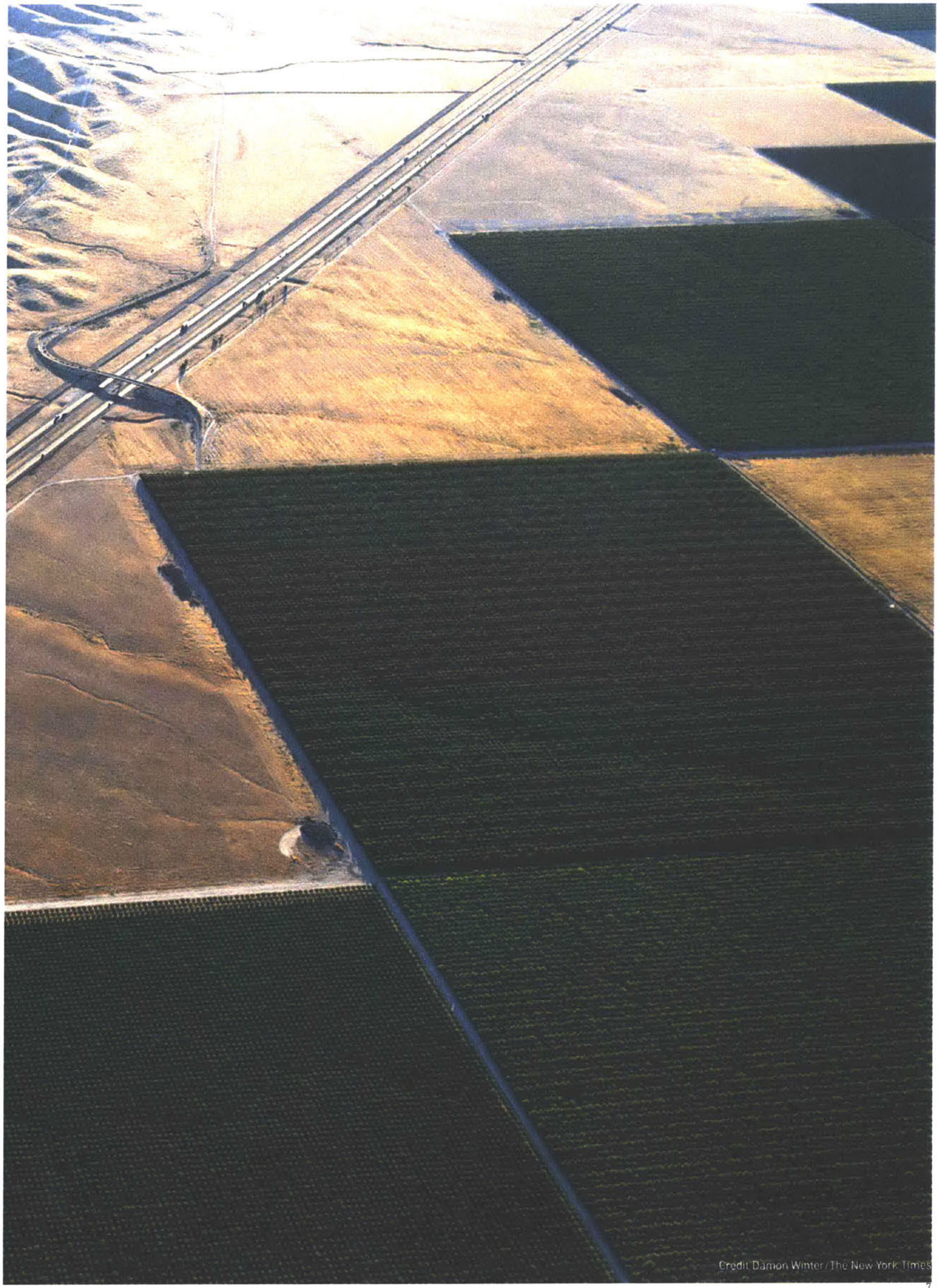
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INTRODUCTION

1.1 PROBLEM STATEMENT

The central valley in California is the world's largest patch of Class 1 soil with a 25-degree temperature swing from day to night and sunshine for nearly 300 days a year; it sounds like the ideal place for growing a wide range of plants. Water, however, has not always been readily available. It took twenty dams and canals 500 miles long, to offer farmers a consistent supply of Northern California water for decades. [Bittman (2012)]

California, the country's largest agricultural producer and exporter, produces over a third of the country's vegetables and two-thirds of the country's fruits and nuts. [Monning (2017)] Its agricultural output was $46.7 billion in 2013, with total U.S. output valued at $269.1 billion. Agriculture makes up just 2.1% of California's economy, but it is still the nation's green grocer, and farming is still the main economic activity of the state's arid center. [Norris (2014)]

However, agriculture requires a considerable amount of water specially when it comes to large-scale agriculture. "California is running through its water supply because, for complicated historical and climatological reasons, it has taken on the burden of feeding the rest of the country," (Johnson as cited in Geiling, 2015).

The recent 5-year drought in California has been the most intense ever recorded, with drier than normal conditions for 10 of the past 14 years; and the last three have been the hottest and driest in about 120 years. According to UCLA Professor Glen MacDonald, the combination of drier weather and increased greenhouse gases could extend the drought until it becomes the new normal in California. [KTLA (2016)]

Farmers in California are currently using 80% of the water managed by the systems in place, while urban agencies were asked to reduce water use by 25%. A study from the University of California, Davis (2015) revealed that the drought is not only affecting the population, but the agricultural sector as well, resulting in a net water shortage of 1.6 million acre-feet which is estimated to cause losses of $810 million in crop revenue and $203 million in dairy and other livestock value, with additional groundwater pumping costing up to $454 million. [Food Business News (2014)]
California as a whole diverts or pumps 43 million acre-feet of water each year to supplement its meager rainfall. Agriculture consumes 34 million acre-feet of that. In an average year, underground aquifers supply the state with 30 to 40% of its water supply. In drought years, however, that number jumps to 60% or 75%. [Geiling (2015)]

California is the second state with the largest amount of irrigated land (behind Nebraska). It has approximately 9 million acres of irrigated farmland which represents approximately 15% of all the irrigated land in the US. Irrigation leads to higher yields but less than half the farmers use low-flow irrigation methods; meaning that there is a considerable amount of water loss in the process. [Geiling (2015)] Excessive irrigation can also lead to salinization, which is already the case in several areas in the valley, where hundreds of thousands of acres cannot be farmed because of salt buildups (the land is naturally salty) and the presence of selenium from irrigation drain water. [Water Education Foundation] As the drought got worse, farmers turned to aquifers, pumping so much ground water that in some places, desiccated fields have collapsed (sunk). [USGS]

Nowadays most research on food security and agriculture has been focused on developing high-tech systems that require considerable amounts of energy and financial resources. However, the reality is that the countries facing the biggest challenges, when it comes to food security and climate change, do not have the necessary means to develop high-tech projects at large scales. The best option right now is to figure out more efficient patterns for agricultural production and irrigation that can be replicated and/or adapted in different scenarios.

1.2 RESEARCH QUESTION

This thesis explores how the spatial distribution and interaction of hydrological resources, geological features, climate patterns, topography and water infrastructure impact agricultural production in the Central Valley in California.

The objective is to learn how to use drought management strategies and spatial patterns to allow for a better usage of water resources.
This will allow readers to better understand how to improve water use and access for agriculture in a scenario of drought. Hopefully the proposed system will be replicable and adaptable so it can improve agricultural production and food security in other regions or countries facing similar conditions due to climate change.

CALIFORNIA
Area: 163,696 sq mi (423,970 km2)
Population 39,250,017

GSP: $2.514 trillion on 2016, the largest in the United States

Agriculture accounts for 2.2 percent of the state's GSP and employs around three percent of its total workforce. Farming-related sales more than quadrupled over the past three decades, from $7.3 billion in 1974 to nearly $31 billion in 2004.

1.3 HYPOTHESIS

Restructuring agricultural production based on the natural and artificial physical features seems like a promising solution.

The restructuring would most likely include one main strategy and 4 specific plans that would tackle the problem at different scales and from different angles.

- Changing the existing spatial patterns of agriculture and irrigation systems for a new system that is based on the specific conditions of the site.

- Changing or relocating crops according to water usage and availability.

- Implementing drought management strategies such as Keyline design to maximize the use of water resources.

- Reusing water from other uses for agricultural productions which would help reduce the water footprint of highly consumptive crops.

- Using water salvage as a way to fund the development of new water infrastructure.

1.4 DISCIPLINARY POSITIONING

Agricultural production is inherently dependent on natural resources, climatologic and ecologic conditions. Weather, soil quality and water availability are key determinants of which crops can be produced in a specific location, their quality and the yield that can be obtained from them. Geologic conditions and watersheds are independent from artificial political divisions or the Jefferson grid. As this is a spatial and systemic problem in nature, it cannot be approached solely from a policy standpoint. Design should play a bigger role when it comes to solving such complex territorial problems. Agriculture should be approached from a large-scale design and planning perspective where the entire system is considered before proposing an intervention.

Water conservation planning focuses mostly on creating measures for water utilities to use on conservation programs. These measures can broadly be divided into 3 categories. The first category includes metering, accounting, loss control and its most controversial topic: costing and pricing. Planners tend to use pricing as a way to convey value to water customers and to nudge them into reducing their consumption. [US EPA, (1998)] This practice can be especially problematic in cases where you are dealing with low income communities or agricultural production. Higher costs in water will translate into elevated costs for food.

Reduction of outdoor water usage or landscape efficiency proposes the use of lower water demand plants and efficient irrigation. This measure, however, does not apply to agricultural production. There is no clear strategy on how to regu late the use of water, implemented irrigation systems or the types of crops that should be produced according to water availability.

Reuse and recycling are perhaps the most promising out of all the water conservation measures when it comes to reducing the water footprint of the agricultural industry. According to the United States Environmental Protection Agency, recycled wastewater can be used for some industrial, and agricultural purposes, groundwater recharge, and direct reuse.

Integrated planning for water, land and watershed has a more comprehensive approach, "adopting a wide range of strategies to manage a multitude of current and future challenges, pressures and changes in watersheds." It recognizes the interconnections between surface water and groundwater, water quantity and quality, land and water. Integrated watershed planning also proposes managing land development in patterns that stabilize the hydrologic cycle, reduce vulnerability to water-related hazards, and increase resiliency by implementing climate change adaptation strategies. It proposes controlling land use and land cover as a strategy to reduce imperviousness and avoid a negative impact on hydrology, erosion and sedimentation, aquatic habitats, and overall watershed health. Integrated planning is getting on step closer to solving the problem by proposing some sort of physical intervention that takes into consideration all the systems involved. [Fraser Basin Council]

On Landscape as Urbanism, Waldheim (2006) quotes Allen (2001) explaining that in order to activate spaces, landscape draws from surface conditions for configuration, materiality and most importantly, performance. According to Waldheim,

Corner argues that "only through a synthetic and imaginative reordering of categories in the built environment might we escape our present predicament in the cul-de-sac of post-industrial modernity, and the "bureaucratic and uninspired failings" of the planning profession." (2006, p.38)
Landscape architecture comes in proposing to use infrastructural systems and public landscapes as the ordering elements of urban settlements having a fluid exchange between natural and engineered infrastructural systems; it rejects the idea of camouflaging ecological systems and proposes that large scale landscape be regarded as infrastructure and a primary element of urban order.
"In common landscape practice, work is more often than not conducted in the shadow of the infrastructural object, which is given priority over the field into which it is to be inserted. However, as any landscape architect knows, the landscape itself is a medium through which all ecological transactions must pass: it is the infrastructure of the future" (Weller (2001) as quoted by Waldheim(2006). p. 44)
Bélanger (2016), proposes to question the complex and inflexible patterns of urbanization and re-conceptualize infrastructure ecologically as "open systems of live media operating across different geographical, politic, and temporal scales." (p.191)
The author proposes that if landscape is seen as infrastructure (and vice versa), new strategies of design can be proposed where both the landscape and infrastructure fields collaborate to address the flows of capital, population and dynamic ecologies to re-scale urban economies and create flexible and alternative models of organization away from

disciplinary dominance.

This new perspective on urbanism sees the environment as a "megastructure". The environment is no longer considered a constraint, but an open system that crosses different scales. The idea is to use these open-ended systems to integrate infrastructure and ecological processes to recover abandoned spaces and intensify others. These "systems within systems" cross all kinds of scales with constant flows of materials and wastes developing re-circulating patterns that impact the re-programming of the urban surfaces.

Along this same line, but with a more applicable approach, Berger (2009) with his Systemic Design proposal draws from the theory and work of several planning, architecture and landscape architecture professionals such as Ian McHarg, Buckminster Fuller, and Field Operations. Berger explains how Systems Theory has been adopted by design schools and practitioners in order to consider the economic, environmental and programmatic needs and their demands on regional areas. Berger (2009) also suggests, that spatial research needs to broaden its toolkit and take advantage of more innovative visualization and mapping techniques. Using software and physical field observations and applying all this "large scale logic in smaller scale proposals".

As stated in the book, Systemic Design begins with a broad and tangential information gathering to understand the issues surrounding a specific site. Through the research process, information begins to cluster into what Berger calls "Systemic Bundles" that connect regional systems that are unrelated to an area, with the local site driven framework. Systemic Bundles, according to Berger are exactly the places that need to be examined.

The planning and design professions need to strive for a more systemic and scientific approach to regional planning, urban design and landscape architecture. One that is based on the natural systems and achieving efficiency and sustainability in resource management rather than the current market driven approach which is entirely focused on profit. Nature based systems will have a greater resilience and therefore have better chances at bouncing back from disaster and overcoming the challenges posed by Climate Change.

1.5 IMPLICATIONS/IMPACT

As aforementioned, the state of California carries the burden of providing a considerable amount of the agricultural production consumed in the rest of the country. As climate change causes further challenges for agriculture, it seems wise to work on developing resilience strategies for this industry. Most research on these topics has been focused on generating high-tech systems that require considerable amounts of energy and financial resources. However, the reality is that countries facing the biggest hurdles when it comes to these matters, do not have the necessary means to create sophisticated projects at large scales. The best option right now is to figure out more efficient distribution for agricultural production and irrigation that can be replicated and/or adapted in different scenarios. This thesis proposes 3 different strategies that can be implemented from both a bottom-up and top-down approach providing alternatives for both individual farmers and planners.

1.6 METHODS

- Case studies

Drought management strategies implemented in India and Keyline design cases in Australia

- Modeling of secondary data

Using visualization and mapping techniques to understand all the systems that are interacting and influencing in one way or another the agricultural production.

The process starts by collecting GIS shapefiles and raster data from different sources (mainly Cropscape, USGS and USDA), overlaying and clipping them to generate tables to quantify areas and identify specific crops or cities.

- Interpretative research

After mapping, identifying conflicts and systemic bundles to know how and where to intervene in order to have the biggest possible impact.

From the spatial analysis several areas were identified for the implementation of 3 different strategies. The numeric data generated through the mapping exercise was combined with additional data scrapped from several sources (mostly USDA) to estimate agricultural water footprint and revenue, residential water consumption and wastewater generation in order to determine the reuse potential.

- Generating Strategies

3 different strategies were created to cover most of the different scenarios and problems found on the research phase.

THEORETICAL CONTEXT

2.1 AGRICULTURE

Agriculture, according to the Merriam Webster dictionary, is the science, art, or practice of cultivating the soil, producing crops, and raising livestock and in varying degrees the preparation and marketing of the resulting products.

According to the Genographic Project (2017), agriculture began around 12,000 years ago, causing major changes in society. Switching from hunting and gathering to a reliable food supply allowed the creation of permanent settlements, and the growth of civilization from approximately five million people 10,000 years ago, to more than seven billion today.

The "Neolithic Revolution" and subsequent agricultural revolutions "have had a greater per cápita impact on the earth's landscape than the average modern day person." (Brand, Year, p.2010). According to Ruddiman (2005), quoted by Brand (2010, on Whole Earth Discipline, "farming is not nature, but rather the largest alteration of Earth's surface from its natural state that humans have yet achieved."

For a long time now, many researches have been looking into how to control the supply of food in order to meet the demand, what are the main factors that contribute to obtaining a good yield and how can they be improved.
The main three variables that determine agricultural output are: land, nutrients and water.

LAND

Increasing cultivated areas has long been the main strategy implemented to augment yields. The more cultivated land, the more yield. This may seem really obvious but it is still worth mentioning given the environmental impact of this practice. According to the FAO (2011), out of the 13.2 billion ha of global land area, 12% are agricultural crops (1.6 billion ha), 28% are forests (3.7 billion ha), and 35% are grasslands and woodland ecosystems (4.6 billion ha). The percentage dedicated to agricultural crops keeps rising every year. The world's net cultivated area has grown by 12% over the last 50 years, mostly at the expense of forest, wetlands and grassland habitats.

NUTRIENTS

Provided that there is water accessibility, the next most important factor is nutrient availability and the nutrient retention capacity of the soil. Its depth and drainage can also affect plant rooting. The structure, which is linked to its chemistry is also important and can determine cultivation practices. Slopes are another relevant factor to consider as soil quality can be affected by erosion from runoff. [FAO (2011)]

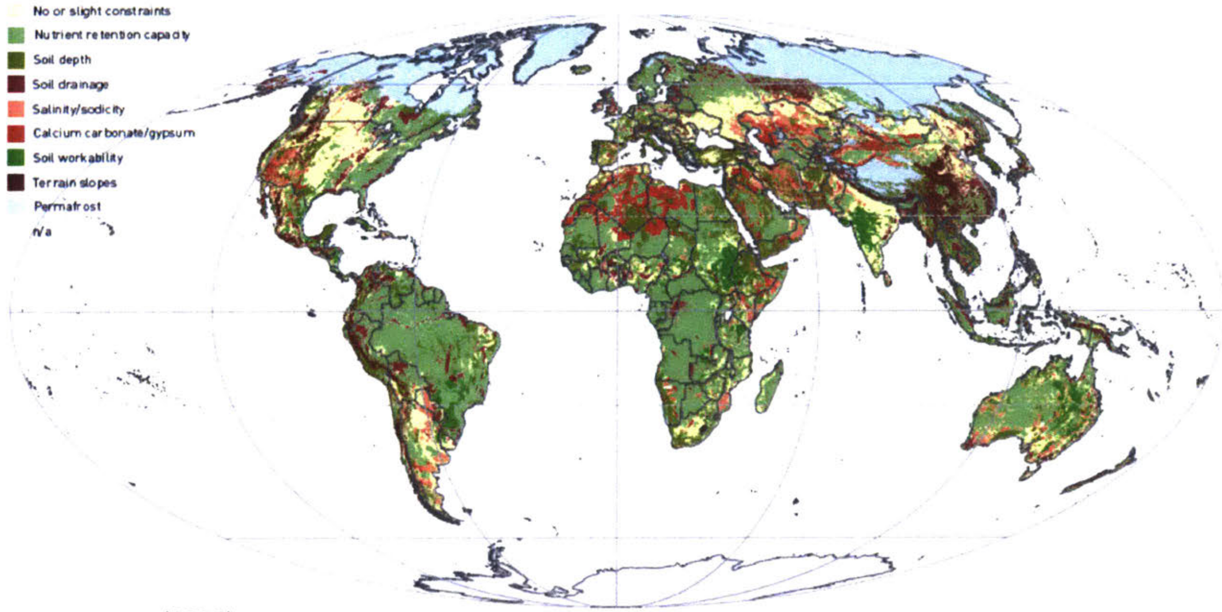
The main limitation in current cultivated land in most regions is nutrient availability. High-income countries account for the highest share with no or minor nutrient availability constraints (76%) compared to 68% in low-income countries.
Soil quality can be improved with good management. High-input farming conditions, can alleviate a natural low nutrient availability by applying fertilizer as long as the soil has good

retention capacity. [FAO (2011)]

The use of fertilizers however, is considered controversial in certain circles for both its environmental and economic impact. In 2008, an increase in costs raised the suspicion that the world's nutrient reserves were at a critically low level. However, according to Fixen (2009) the reserves for nitrogen (N), phosphorous (P), potassium (K), and sulfur (S) will hold for the foreseeable future. Nutrient costs are still expected to rise over time as materials are consumed and of course, this will increase food prices.

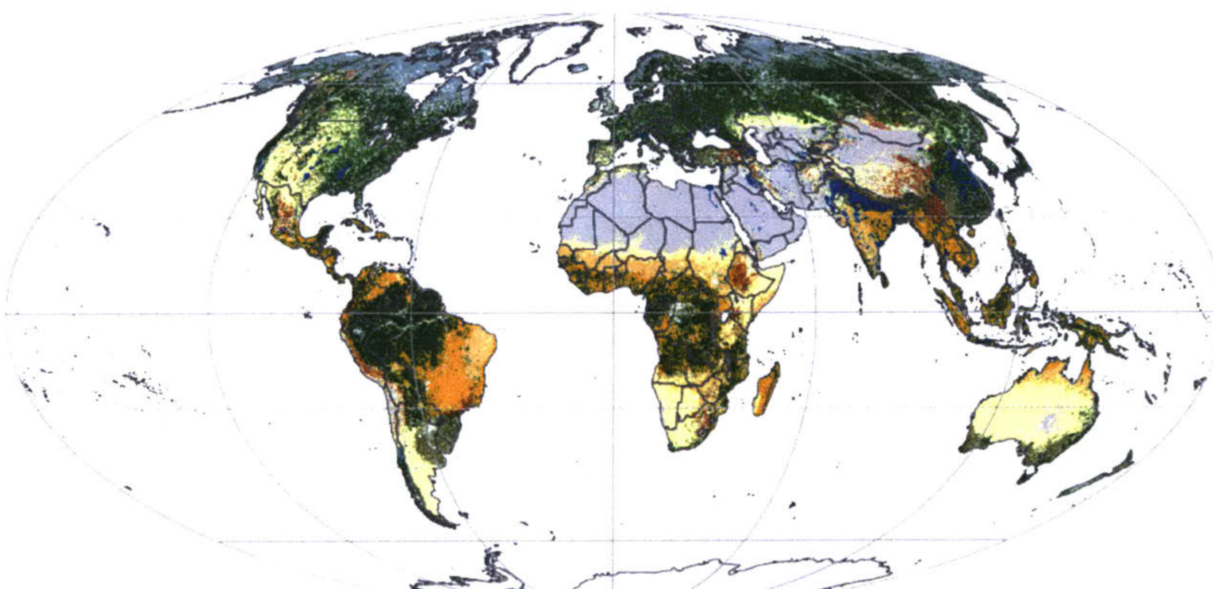
Another common problem caused by the use of fertilizers is eutrophication. According to NOAA "Eutrophication stimulates an explosive growth of algae that depletes the water of oxygen when the algae die and are eaten by bacteria." Eutrophication is deadly to animals and plants in estuaries. Also known as "nutrient pollution", it is considered the largest contamination problem for U.S. coastal waters with "Over 60 percent of the coastal rivers and bays in the United States are moderately to severely affected by nutrient pollution".

SOIL AND TERRAIN CONSTRAINTS



Credit IIASA / FAO (2010)

MAJOR AGRICULTURAL SYSTEMS



Credit FAO

WATER

According to the FAO (2011), rainfed agriculture is still the predominant agricultural production system worldwide.
It is estimated that 80% of world cultivated area is rainfed agriculture, which contributes about 60% of the global crop output. It is projected that by 2030, an increment of 43% of the production will come from rainfed agriculture. This is extremely important considering that due to climate change, precipitation patterns will vary.

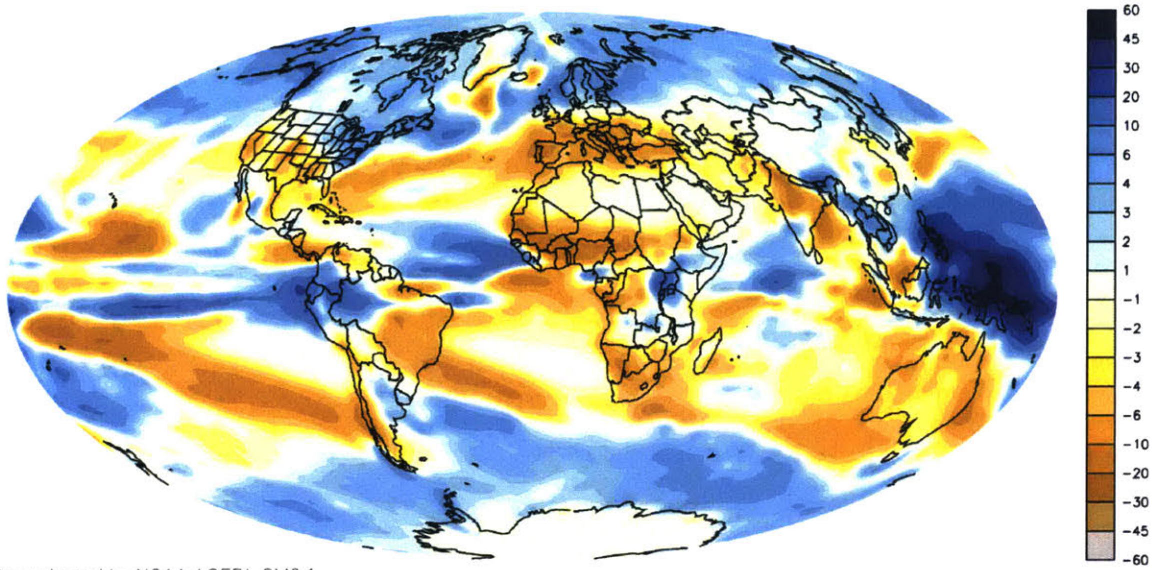
Irrigation systems typically have at least twice as much yield as nearby rainfed crops, which explains why in the last 50 years the global irrigated area has doubled, and water withdrawals for agriculture have consistently intensified. Approximately 70% of the extraction of freshwater goes towards irrigating 20% of the world's cultivated area, which produces about 40% of the global crop output. [FAO (2011)]

These systems draw water from rivers, lakes and aquifers. Of the irrigated area, 62% is supplied from surface water, and 38% is procured from groundwater.

The use of irrigation systems can also lead to the silting of canals, overexploitation of resources (groundwater depletion), institutional failure, soil salinity (about 10 Mha of global agricultural land is lost annually due to salinization, of which 1.5 Mha approximately is in irrigated areas.), and general deteriorating quality of surface and groundwater sources. [Noble (2012)]

CHANGE IN PRECIPITATION BY THE END OF 21ST CENTURY

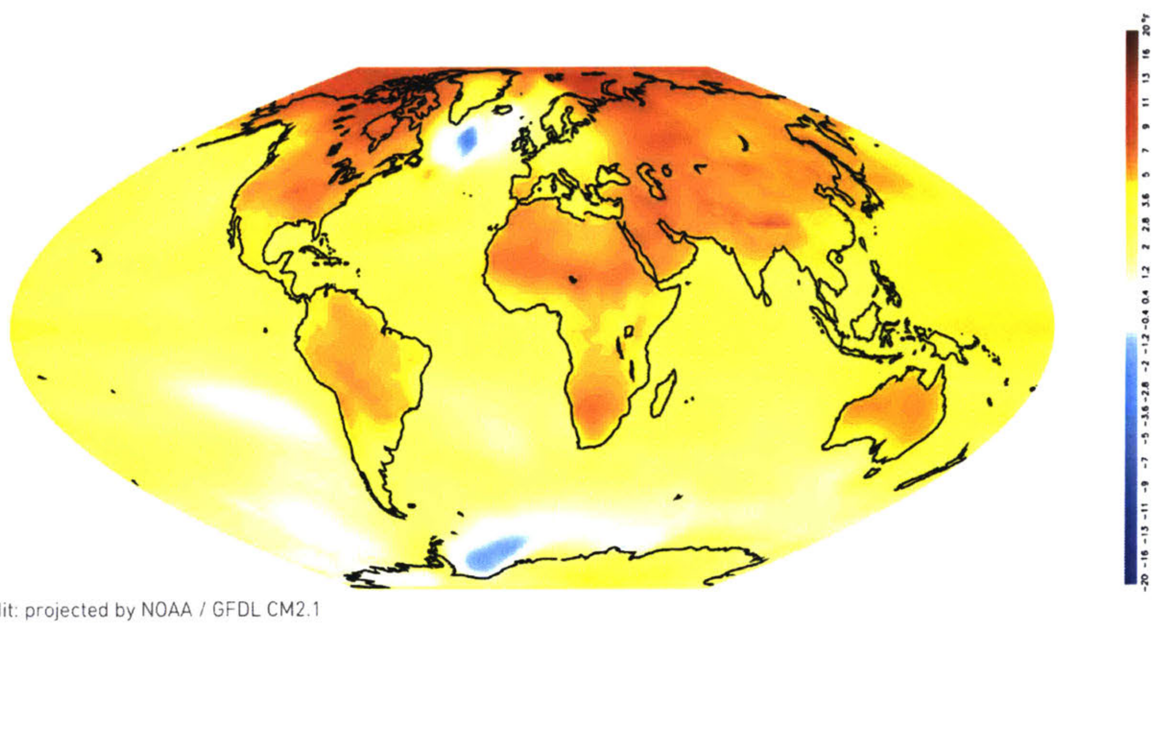
INCHES OF LIQUID WATER PER YEAR



Credit: projected by NOAA / GFDL CM2.1

SURFACE AIR TEMPERATURE CHANGE (^{0}F)

2050s AVERAGE MINUS 1971-2000 AVERAGE



Credit: projected by NOAA / GFDL CM2.1

2.2 CLIMATE CHANGE AND ITS IMPACT ON AGRICULTURE

According to several studies and papers, including the IPCC (2013) report, climate change is having and will continue to have negative impacts over food production. The specific effects vary but can be summarized in decreased yield and lower quality. Smaller yields mean that many people will have difficulties accessing food and that price stability will be greatly affected as well. Global food prices are expected to increase between 3% and 84% as a result of fluctuations in temperature and precipitation.

The main three challenges for agricultural production resulting from climate change are: increases in temperature, pests, higher CO_2 levels and variation in rainfall.

TEMPERATURE

Between 1901 and 2012 annual average temperatures all over the world increased between 0.2 and 2.5 degrees Celsius (IPCC, 2013). Global temperatures are expected to increase up to 4 degrees Celsius by the end of the century. This poses a threat to food security because, according to many sources including the IPCC, there is a large negative sensitivity of crop yields to temperatures around 30°C. One of the most commonly cited examples are maize and wheat, where in the tropics, yields begin to decline with 1°C to 2°C of local warming and that temperate maize and tropical rice yields are significantly affected with warming of 3°C to 5°C.

PESTS

Pre-harvest losses are also expected to increase as a result of climate change (Yudelman et al, 1998). As Ewel (1986) explains, fungi, bacteria and epiphylls thrive in warm weather, which means that, as the Earth grows warmer, pest populations will augment. Pests are currently responsible for the loss of 30% to 60% of agricultural yield. Some are also expected to increase as the result of higher levels of CO2.

Losses to pests are particularly important because they happen at a point where most of the land and water required to grow a crop have already been invested. Reducing destruction by pests and pathogens would be the equivalent to creating more land and water.

Another problem with pests is the subsequent use of pesticides in order to control them. Many of the herbicides used over the past 50 years have been classified as toxic or slightly toxic to both animals and humans. Although newer herbicides, such as glyphosate, are considered non- toxic, they are essentially a modified amino acid that blocks a chloroplast enzyme affecting crops as well. (Yudelman et al, 1998).

The use of insecticides (even the organic ones) leads to insects developing resistance to them, the injury of non target species, contamination of surface and groundwater, and health problems to both consumers and agricultural workers.

CO2

Some studies have suggested that higher levels of CO2. could lead to higher yields because this would be enhancing photosynthesis. However, the IPCC (2013) report states that the effects vary between crops. Yield enhancement due to CO2 concentration tends to be higher in C3 plants (wheat, rice, cotton, soybean, sugar beets, and potatoes) than in C4 plants (corn, sorghum, sugarcane) because photosynthesis rates are not the same. Furthermore, this effect depends on temperature, water availability and nutrients. Both low and high temperatures will reduce the effects of elevated CO2. Nutritional value will also decrease.

O3

Not all greenhouse gases have positive impacts on yield. Ozone (O3) according to the IPCC (2013) is a powerful oxidant, that reduces photosynthesis which translates to inferior crop quality, and decreased yields. On the year 2000, losses due to O3 were estimated to be between 8.5% and 14% in soybean, 3.9% and 15% in wheat, and 2.2% and 5.5% in maize.

PRECIPITATION

Fluctuations in precipitation could potentially affect food security as well. As aforementioned, rainfed agriculture is expected to take the lead in production increase by 2030, yet this is very uncertain given the changes in rain patterns. Most studies using precipitation as a variable for agricultural yield have found a correlation between the two. The relationship is best described as a downward concave curve. Initially, yields are higher when precipitation is more abundant, but when there is excess rain (flooding), yields decrease dramatically. [FAO (2011)]

2.3 AGRICULTURE AND ITS IMPACT ON CLIMATE CHANGE

Agriculture also participates in climate change with greenhouse emissions, which in 2005 accounted for 13.8% of total emissions. The greenhouse gases emanated from agriculture are mostly Methane and Nitrous Oxide. Another way in which agriculture affects is by land use change and deforestation. [Herzog (2009)]

Lastly, agricultural trade also plays an important role in the world food system; however, it has become a controversial topic in recent years for two main reasons. The first being the excessively large carbon footprint of food. According to the NRDC (2007) in 2005 alone, the import of fruits, nuts, and vegetables to California by airplane released more than 70,000 tons of CO2. Secondly, agricultural trade leads to land grabbing and the trade of virtual or embedded water. Approximately a fifth of the global cropland area and water utilization in the world is destined to the production of agricultural products consumed abroad. This topic is particularly difficult for countries facing water insecurity. [Graham et al. (2015)]
The impacts of climate change over agriculture will vary greatly from one country to another; nevertheless, it is safe to say that food security will become even more dependent on technological advances and trade. Climate change might lead to economic paradigm shifts as many countries that are currently subject to cash crops will face great challenges to maintain their average levels of production and some other industrialized countries might be having better climatic conditions for agriculture.

2.4 AGRICULTURE TECHNOLOGIES AND TRENDS

The need for food security has led to the development of multiple strategies ranging from extremely high-tech systems and bioengineering, to organic agriculture and permaculture. Recent technological developments such as drones and sensors have made their way into agriculture in order to increase efficiency and accuracy in the production process whether it is out on the field, or inside a lab. One of such initiatives is the Open Agriculture (Open Ag) at MIT. The "Food Computer" they created is "a controlled-environment agriculture technology platform that uses robotic systems to control and monitor climate, energy, and plant growth inside a specialized growing chamber." [Kocsis (2017)] The objective is to control the set of conditions "as a climate recipe, and each recipe produces unique results in the phenotypes of the plants. Plants grown under different conditions may vary in colour, size, texture growth rate, yield, flavour, and nutrient density." [Magee(2017)]

The Open Ag is basically automating a hydroponic farm with open source hardware and software platforms for sensor-controlled systems.

HYDROPONICS

Hydroponic farms grow vegetables in nutrient solutions instead of soil. The production happens within a controlled environment, which means there is better protection against severe weather conditions, plagues and pests. Among other benefits, water and nutrients are conserved reducing the resources necessary to grow food and no nutrition pollution is released into the environment because of the controlled system. As for disadvantages, hydroponics requires a considerable upfront investment and continue to have a high energy consumption, which makes the produce more expensive.

This thesis stems from the conviction that it is highly unlikely for even first world countries to switch all their agricultural production to such high-tech systems regardless of how efficient they are, the necessary investment would be too big. Most of the food will continue to be produced out on the field for a long time. Making "outdoor" agriculture more effective and resilient is the best bet for the foreseeable future.

GENETICALLY MODIFIED ORGANISMS (GMOs)

All in all, agricultural output has continued to increase over the years as a result of intensification and expansion, still, another plausible explanation for its growth is the use of genetically engineered crops, which are more resilient to rising temperatures, decreased water availability, flooding, incrementing salinity, and changing pathogen and insect threats. In 2008, 30 genetically engineered crops were grown on almost 300 million acres in 25 countries, 15 of which were developing countries. [Ronald (2011)]

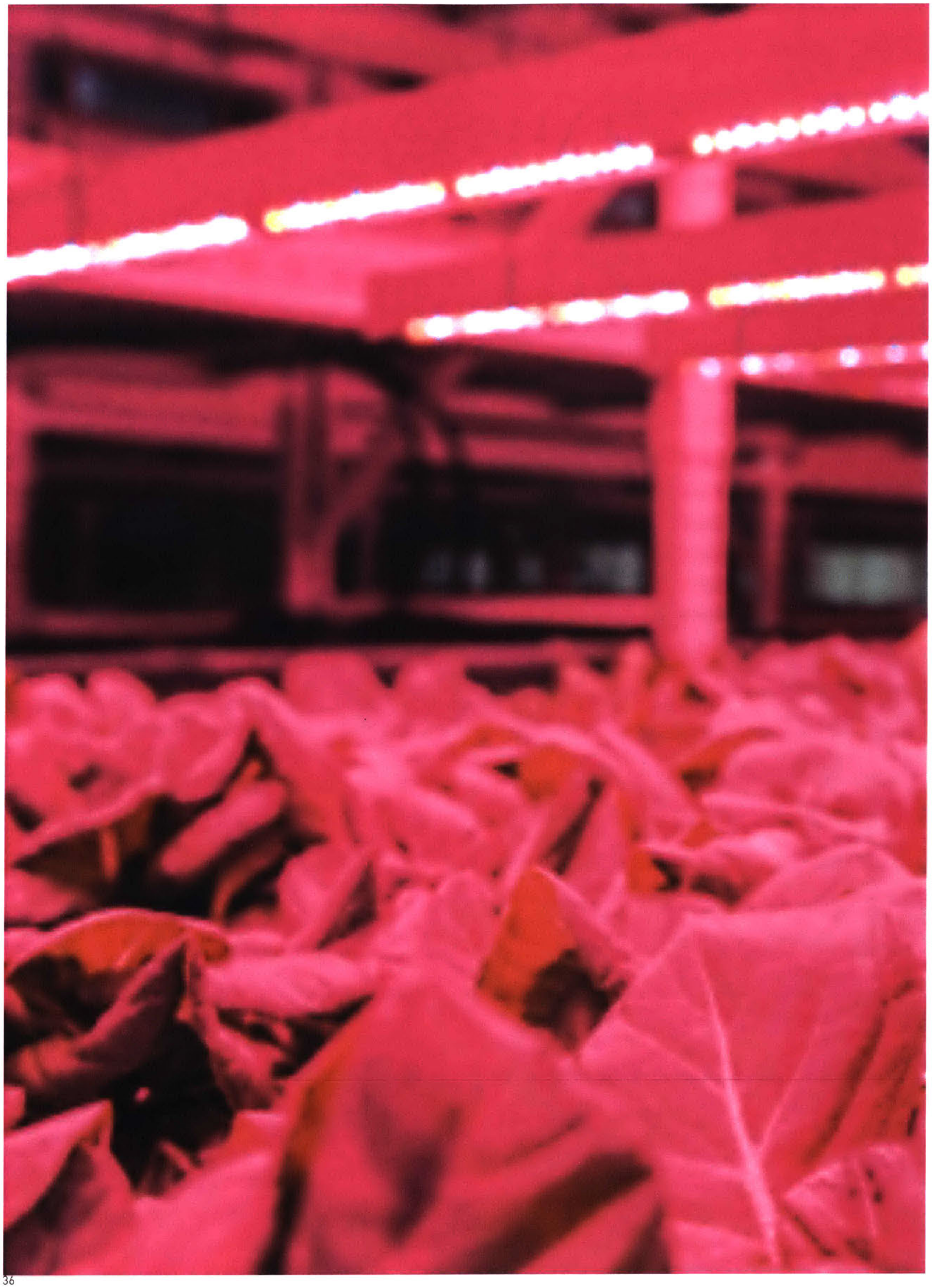
Among other benefits reported, there is an increased profit for farmers, a boost in crop yields, reduction of water eutrophication caused by fertilizers and diminution of greenhouse gas emissions resulting from the energy required to chemically synthesize fertilizers.

After 14 years of cultivation and a total of 2 billion acres planted, no adverse health has resulted from genetically engineered crops, they are safe to eat. As for disadvantages, biotech giants are "for profit" companies and the existence of intellectual copyrights for GMOs has made them expensive for farmers who have to continuously buy seeds as they are not allowed to collects seeds and use them. It only makes sense for a farmer to make the investment if the potential benefits (increased yield) outweighs the losses (due to pests, high temperatures, drought, floods, lack of nutrients etc.)

This thesis assumes that GMOs will continue to be used by farmers who find it financially feasible, especially in the face of climate change.

ORGANIC FOOD

Organic food has become a major trend in recent years. There is a widespread belief that organic agricultural systems are more sustainable. However, this system tends to obtain considerably lower yields and make an inefficient use of land. Conventional farming systems can match organic yields using only 50-70% of the farmland. Organic systems also tend to be very labor intensive which leads to higher prices. [Foley et al (2012)]



AGRICULTURE IN A DROUGHT SCENARIO

case studies

3.1 REUSING WATER FOR AGRICULTURE

The World Water Day 2017 will have a focus on water reuse. The Food and Agriculture Organization of the United Nations (FAO) is incentivizing the reuse of wastewater for agricultural use given that "if properly managed, wastewater can be used safely to support crop production directly through irrigation or indirectly by recharging aquifers." (2017)

Agriculture represents one of the most water intensive uses, consuming up to 70% of the global freshwater; therefore, it is reasonable to make use of this new resource that is reclaimed water. However, reusing water for agricultural purposes does come with a series of challenges, including estimating demand, given the seasonality and quality.

There are many water reclamation projects worldwide, yet there is one that particularly stands out. The Shafdan treatment plant in Israel was selected by the UN along with other thirty projects as a global role model for how to deal with environmental problems. [Cuen (2012)]

The plant uses "the natural filtration qualities of sand in order to improve the quality of sewage. After wastewater is purified in an ordinary facility, it is recharged into the ground, where it undergoes an additional, natural filtration in the sands of Rishon Letzion and Yavne. This improves the quality of the water such that it can ultimately be used safely for all forms of irrigation." [Duke (2013)] This last purification process is carried out by Mekorot, the national water company.

The Dan Region Wastewater Treatment Plant (Shafdan) is an inter-regional system that "collects, treats and reclaims municipal wastewater in high density urban areas and industrial zones". [IGUDAN] Shafdan serves a population of approximately 2.5 million and it has become one of the largest producers of water from a single source in Israel, next to the National Water Carrier.

The treated wastewater is sent to the Negev Desert where the problem of the water shortage has existed for many years. With rainfall irregularity and shortage of potable water, reusing treated wastewater for agricultural irrigation was necessary.

Nowadays, Mekorot injects 130 million cubic meters of purified sewage water into an aquifer for final filtration and pumps it back out after six months. This water accounts for about a 70% of the water used for agriculture in the Negev.

The system is called Soil Aquifer Treatment (SAT), it has been practiced since 1977 and it uses "the unsaturated zone above the aquifer and the aquifer itself for advanced effluent treatment, which removes a wide range of contaminants from the recharged effluent." [Avraham et al. (2003, p.239)]
The effluent is recharged to the aquifer via four basins recharge zones built in areas of predominantly sandy soils.

"The following is a brief description of the Dan Region's SAT system. Each recharge zone consists of several recharge basins which are divided into sub-basins. The operation of the recharge basins is intermittent, i.e., flooding periods alternate with drying periods to maintain high infiltration rates through the upper soil layer and to allow oxygen to penetrate into the soil, thus enhancing and diversifying the soil purification capacity. The recharged effluent gradually displaces the native groundwater and moves towards a ring of recovery wells surrounding the recharge basins. The recovery wells pump the high-quality reclaimed water obtained after SAT to a separate, non-potable conveyance system, which is used only for unrestricted irrigation of agricultural crops. The zone of the aquifer enclosed within the ring of recovery wells is hydrologically separated from the rest of the aquifer, which is not affected by the effluent recharge operation and continues to supply potable water." [Avraham et al. (2003, p.240)]

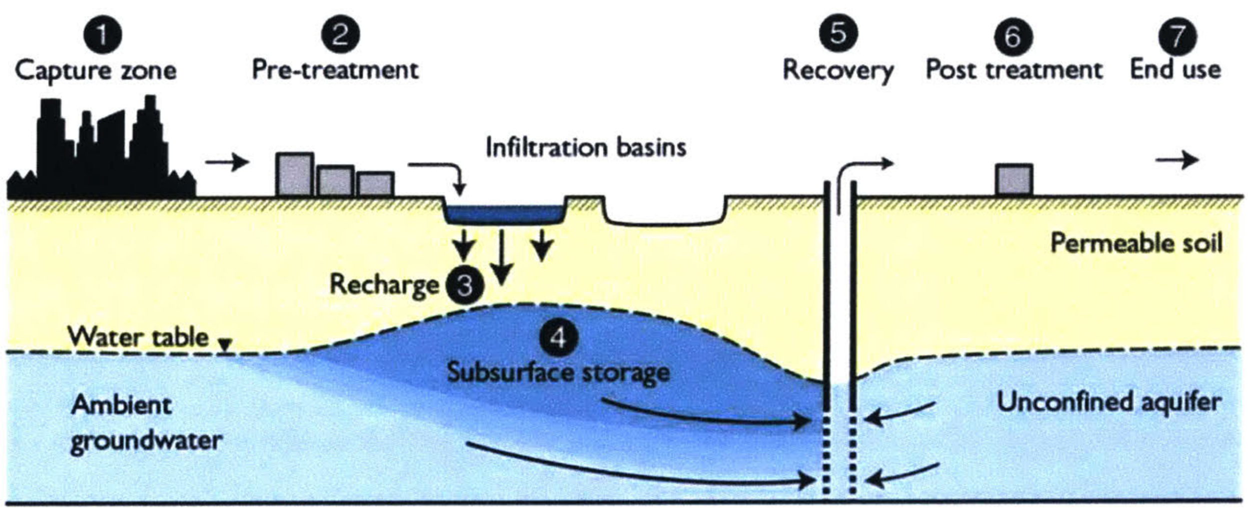


Image source: Miotlinski et al. (2010) SAT System

3.2 KEYLINE DESIGN

Keyline design was created by P.A. Yeomans in the 1950's as a practical response to the unpredictable rain patterns in Sydney, Australia. Yeomans was initially using soil conservation strategies created by the US Army Corp of Engineers but quickly realized that there were deficiencies with water flow. He, then, proposed landscape patterning to capture and store rainwater in large ponds to keep farms "so lush and green all year round, they would be virtually fireproof and drought-proof." According to Yeomans flood rains should be banked as "money" in the richer soils and behind the walls of farm dams. [Collins and Doherty (2009)]

Keyline as described by Collins and Doherty (2009) is "A comprehensive design strategy for agricultural and urban development based on fundamental, repeating land shapes that have been created by water".

Yeomans combined the ever-repeating patterns of ridges and valleys, with contour cultivation. He realized, that "off contour cultivation", could reverse the natural flow and concentration of water into valleys, and drift it to adjacent ridges. The contour line, that runs through that point of a valley, where the steepness of the valley floor increases is called "The Keyline". Cultivating parallel to the Keyline, both above the line and below it, produced off contour furrows, drifting water out of the valley.

Yeomans created the Keyline Scale of Permanence based on what he called the 'inseparable trinity of landscape design':

climate, topography and water supply. He considered roads, trees, buildings, fencing and soils to be more negotiable. The system is based "firstly, on these generally constant features of land shape, and, secondly, on the general subdivision of land that can be made according to these natural shapes and as disclosed by the various patterns of water flow." (1958)

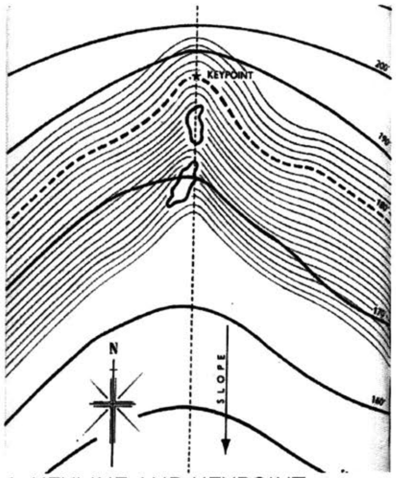
The purpose of the plan is to maintain "as much water in the soil from each rainfall as the soil can use for its own improvement according to its particular state of development. If all the rain that falls is needed, then all is conserved, and techniques are provided to this end for the economical storage and profitable use of this water. All surplus run-off is conserved in farm dams of various kinds and for particular usages." [Yeomans (1958)]

According to Yeomans (1958) the key components are:
-Fast development of fertile soil in a systematically designed landscape. Over a period of three-years, four to six inches of new topsoil are formed each year. This new topsoil stores large quantities of water in the landscape.

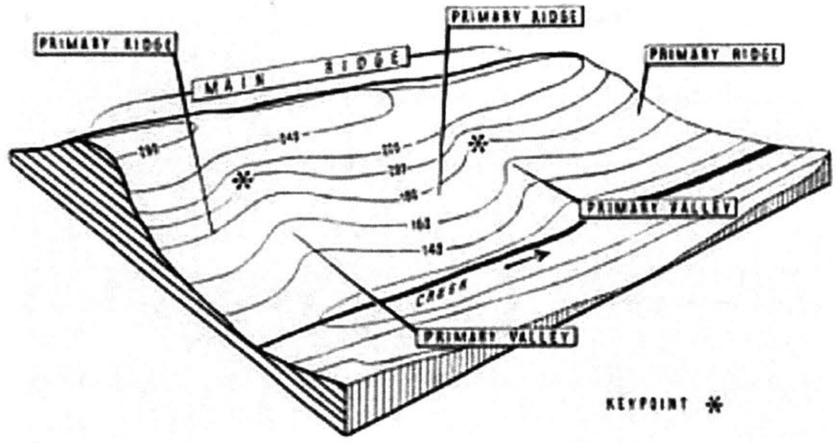
- Design for the harvest, storage and distribution of water on the landscape forms the foundation of the Keyline Plan.

- Run-off water is stored in Keyline dams. This water is later released for rapid, gravity-powered flood-irrigation.

- Location of roads, forests and buildings is based on primary water layout and topography.



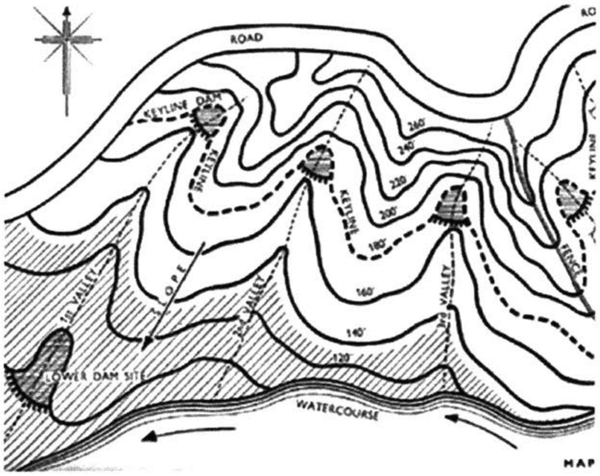
1. KEYLINE AND KEYPOINT



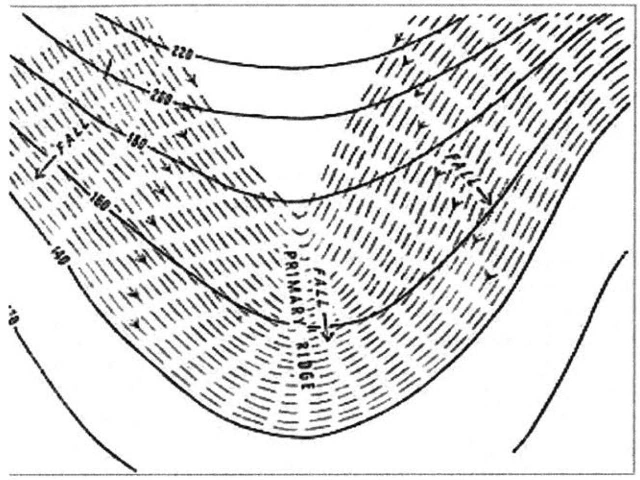
2. THREE PRIMARY LANDSCAPE COMPONENTS

In Keyline design, every infrastructure component helps ensure the maintenance and renewal of the topsoil. Another one of the ideals behind the Keyline plan is the importance of sharing knowledge. Given that the system is based on the study of climate and land shape, it is practically adaptable to any type of agricultural land. [Yeomans (1958)]

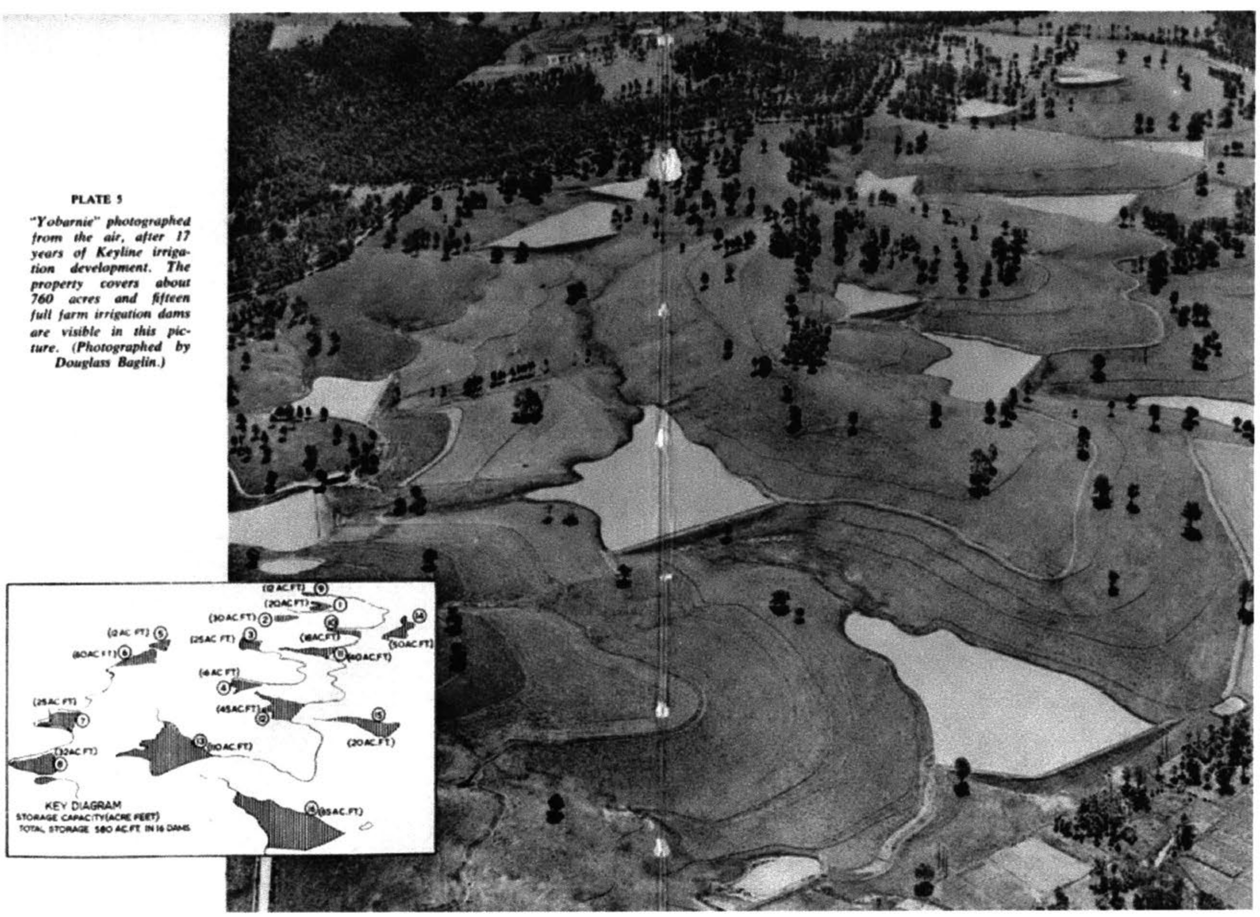
The Keyline plan relates greatly to what Waldheim, Allen and Corner propose. It draws from surface conditions and performance to reimagine landscape. It proposes the use of landscape as an ordering element, incorporating ecological systems and keeping a fluid exchange between natural and engineered systems. It basically, recommends that topography, which is both a large and small scale system, be used as infrastructure and the primary element or order.



3.KEYLINE DAMS



4. CULTIVATION PATTERNS

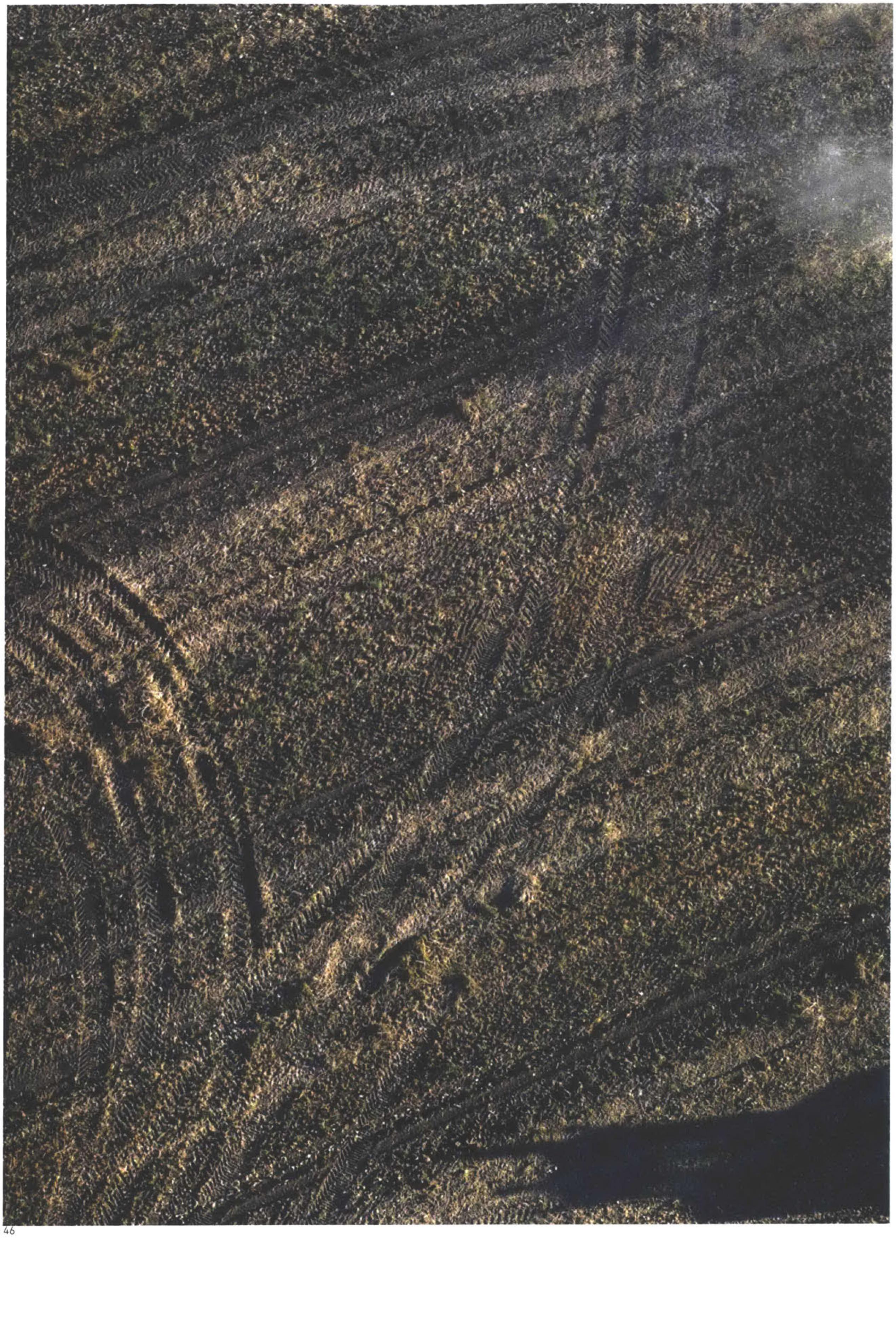


5. YOBARNIE

Images 1.2.3 source: http://permaculturenews.org/2013/12/09/keyline-design-organizing-pattern-permaculture-design-part-1-sweden/

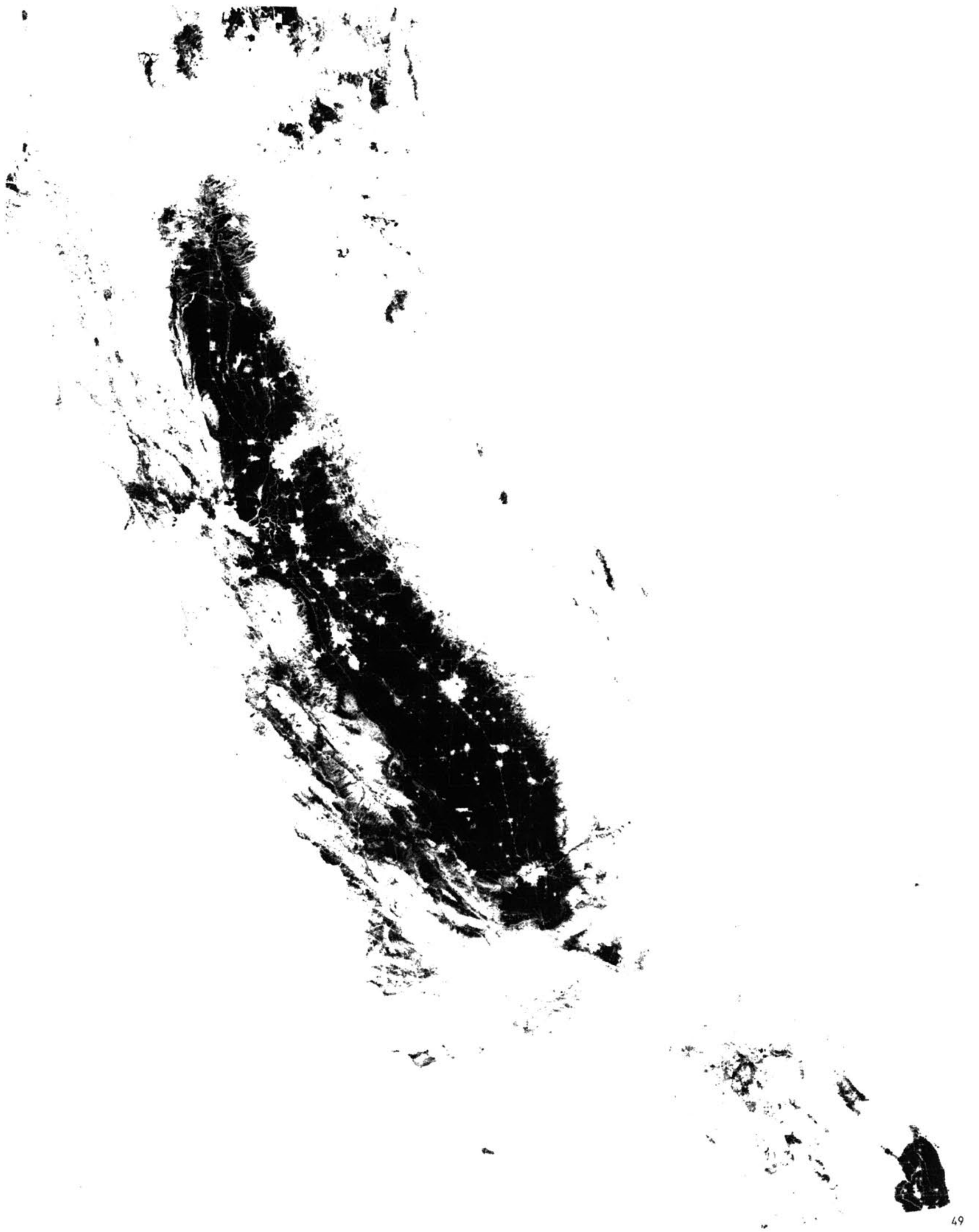
Image 4 source: http://yeomansplow.com.au/4-professor-holmes-on-keyline/

Image 5 source: https://www.milkwood.net/2011/08/01/yeomans-and-the-art-affair/




Credit Damon Winter/The New York Times

CALIFORNIA, CENTRAL VALLEY



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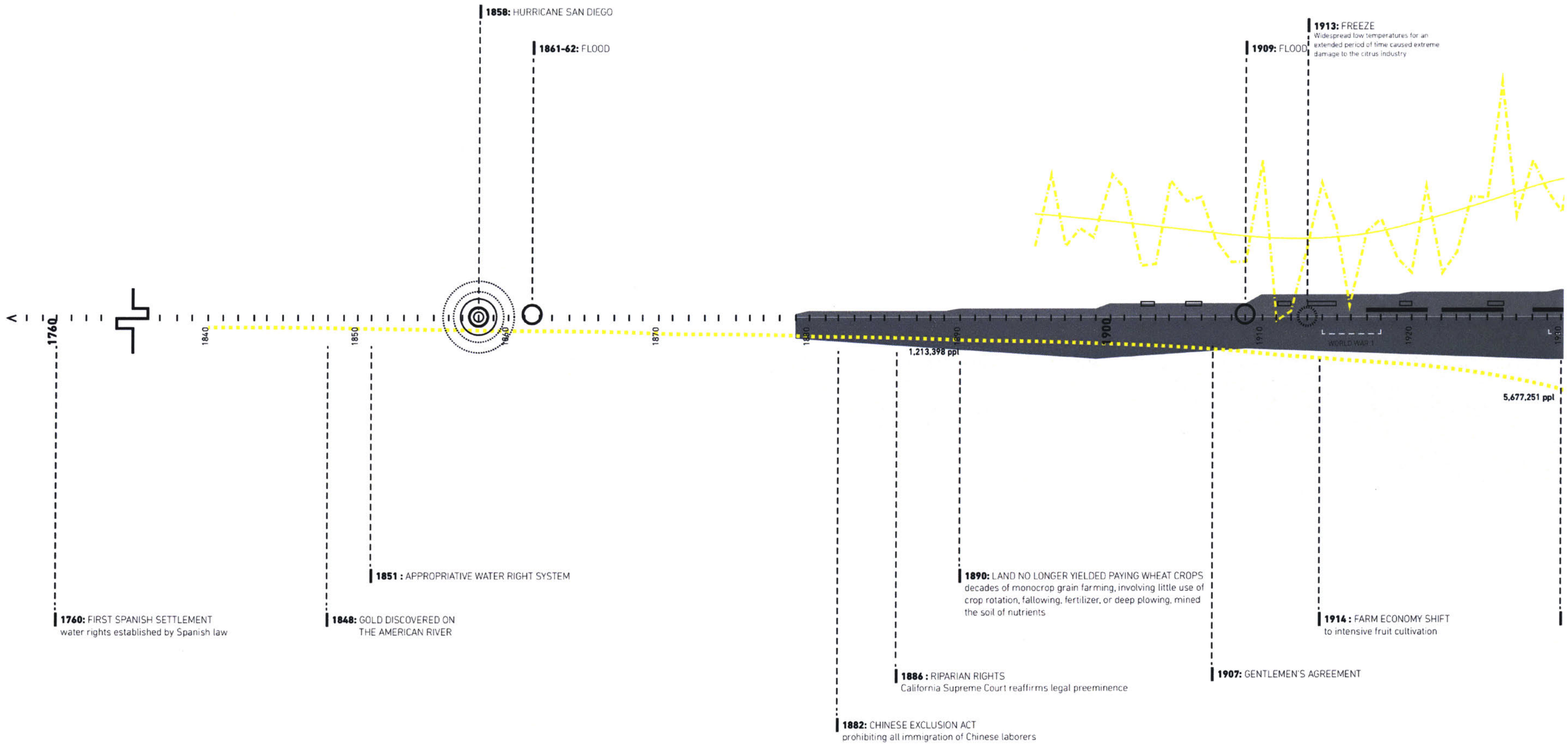
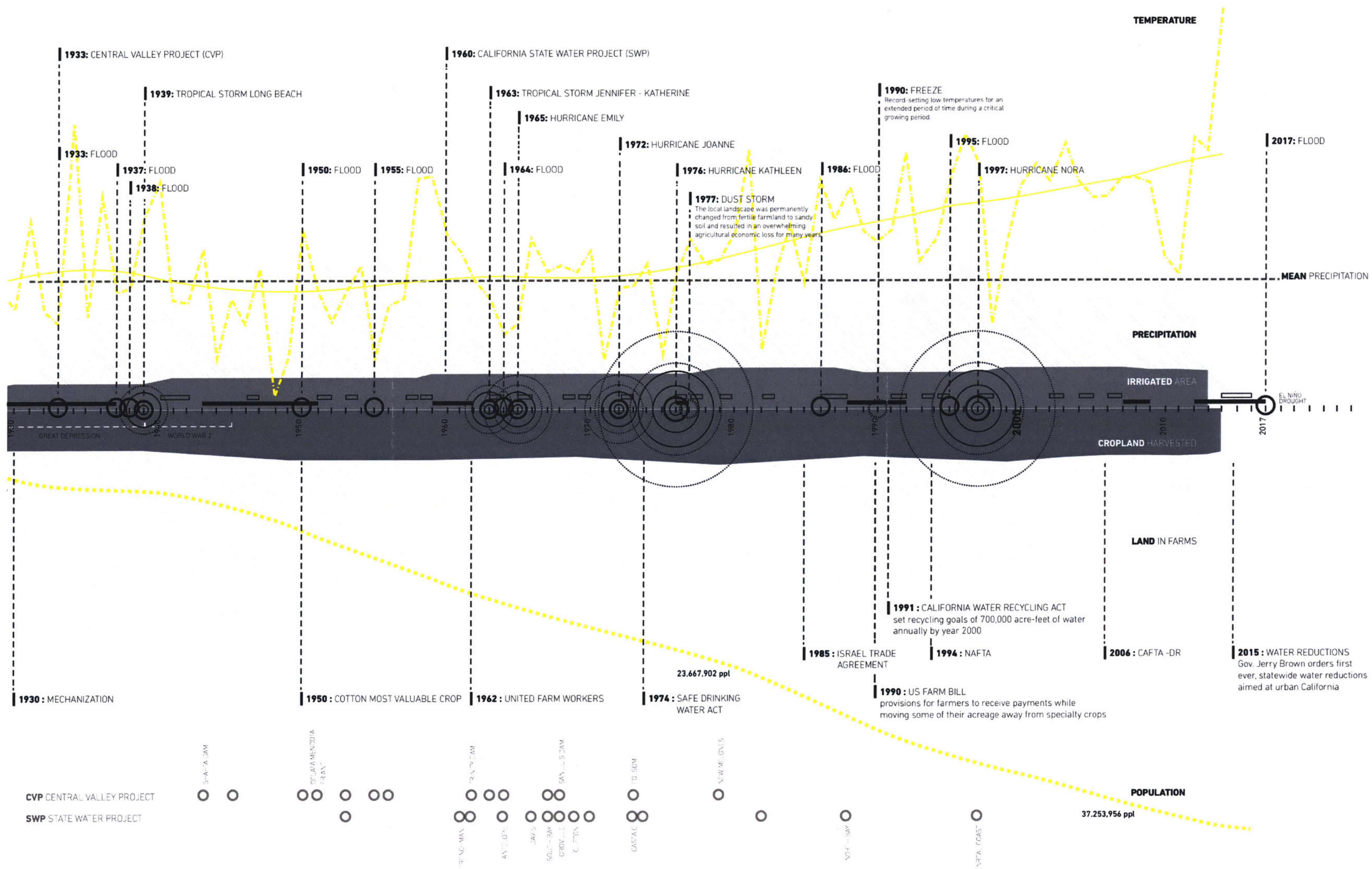


1858: HURRICANE SAN DIEGO
1861-62: FLOOD
1909: FLOOD
1913: FREEZE
Widespread low temperatures for an extended period of time caused extreme damage to the citrus industry
1760
1840
1850
1870
1900
1910
1920
1930
WORLD WAR 1
1,213,398 ppl
5,677,251 ppl
1760: FIRST SPANISH SETTLEMENT
water rights established by Spanish law
1848: GOLD DISCOVERED ON THE AMERICAN RIVER
1851 : APPROPRIATIVE WATER RIGHT SYSTEM
1882: CHINESE EXCLUSION ACT
prohibiting all immigration of Chinese laborers
1886 : RIPARIAN RIGHTS
California Supreme Court reaffirms legal preeminence
1890: LAND NO LONGER YIELDED PAYING WHEAT CROPS
decades of monocrop grain farming, involving little use of crop rotation, fallowing, fertilizer, or deep plowing, mined the soil of nutrients
1907: GENTLEMEN'S AGREEMENT
1914 : FARM ECONOMY SHIFT
to intensive fruit cultivation


TEMPERATURE
1933: CENTRAL VALLEY PROJECT (CVP)
1960: CALIFORNIA STATE WATER PROJECT (SWP)
1939: TROPICAL STORM LONG BEACH
1963: TROPICAL STORM JENNIFER - KATHERINE
1965: HURRICANE EMILY
1990: FREEZE
Record-setting low temperatures for an extended period of time during a critical growing period.
1972: HURRICANE JOANNE
1995: FLOOD
2017: FLOOD
1933: FLOOD
1937: FLOOD
1938: FLOOD
1950: FLOOD
1955: FLOOD
1964: FLOOD
1976: HURRICANE KATHLEEN
1986: FLOOD
1997: HURRICANE NORA
1977: DUST STORM
The local landscape was permanently changed from fertile farmland to sandy soil and resulted in an overwhelming agricultural economic loss for many years
MEAN PRECIPITATION
PRECIPITATION
IRRIGATED AREA
CROPLAND HARVESTED
EL NINO DROUGHT
GREAT DEPRESSION
WORLD WAR 2
1930
1940
1950
1960
1970
1980
1990
2000
2010
2017
LAND IN FARMS
1991 : CALIFORNIA WATER RECYCLING ACT
set recycling goals of 700,000 acre-feet of water annually by year 2000
1985 : ISRAEL TRADE AGREEMENT
1994 : NAFTA
2006 : CAFTA -DR
2015 : WATER REDUCTIONS
Gov. Jerry Brown orders first ever, statewide water reductions aimed at urban California
23,667,902 ppl
1930 : MECHANIZATION
1950 : COTTON MOST VALUABLE CROP
1962 : UNITED FARM WORKERS
1974 : SAFE DRINKING WATER ACT
1990 : US FARM BILL
provisions for farmers to receive payments while moving some of their acreage away from specialty crops
POPULATION
37,253,956 ppl
CVP CENTRAL VALLEY PROJECT
SWP STATE WATER PROJECT

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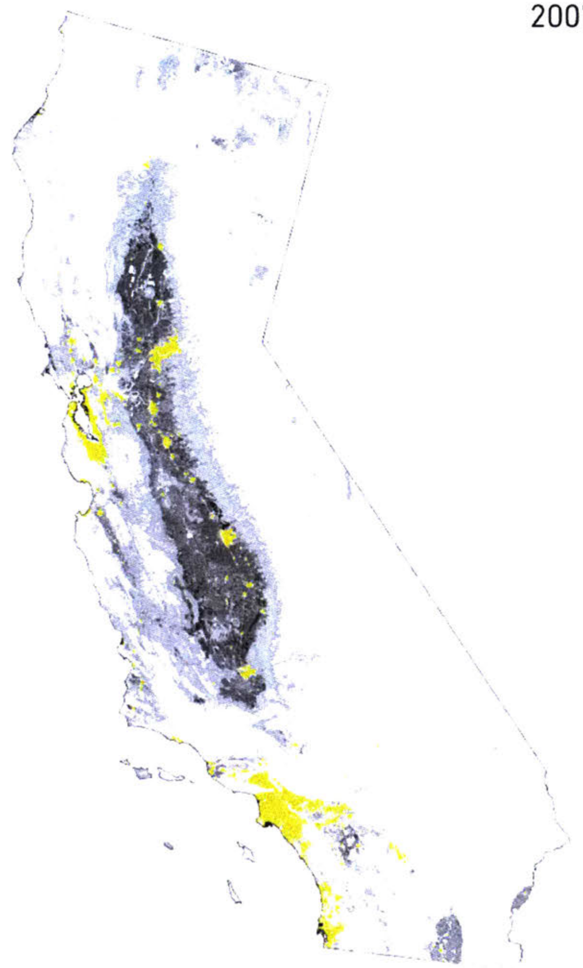
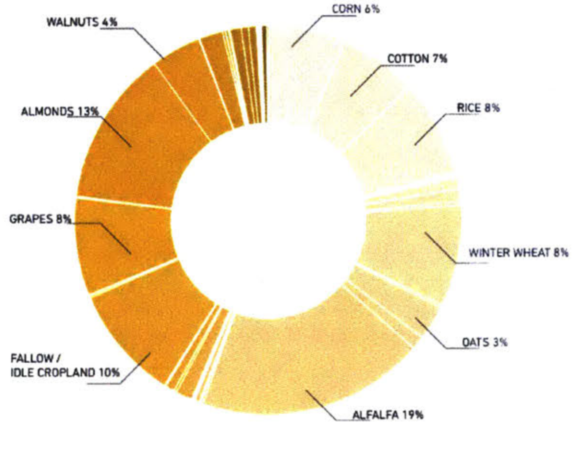
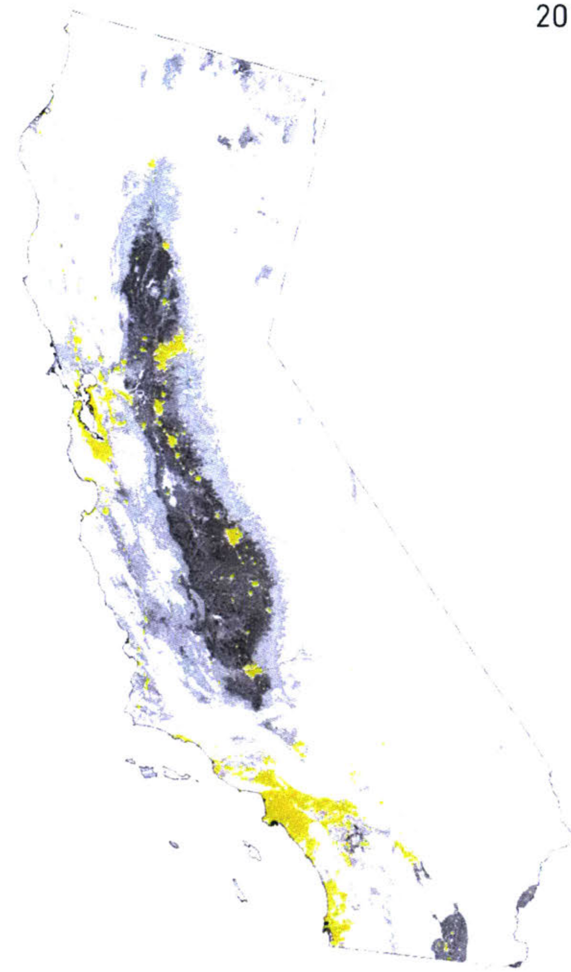
2007



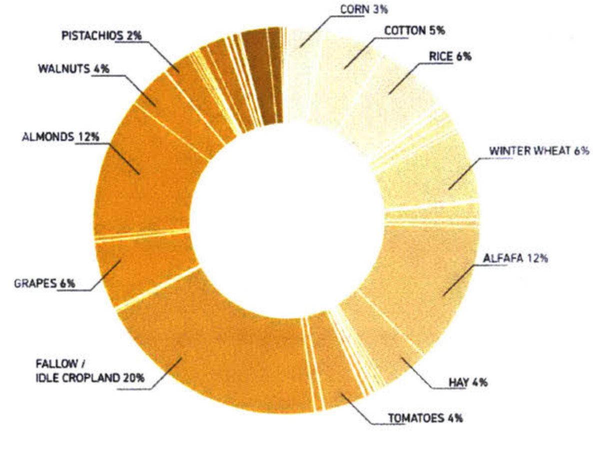
TOTAL AREA: 8,623,750.9 ACRES



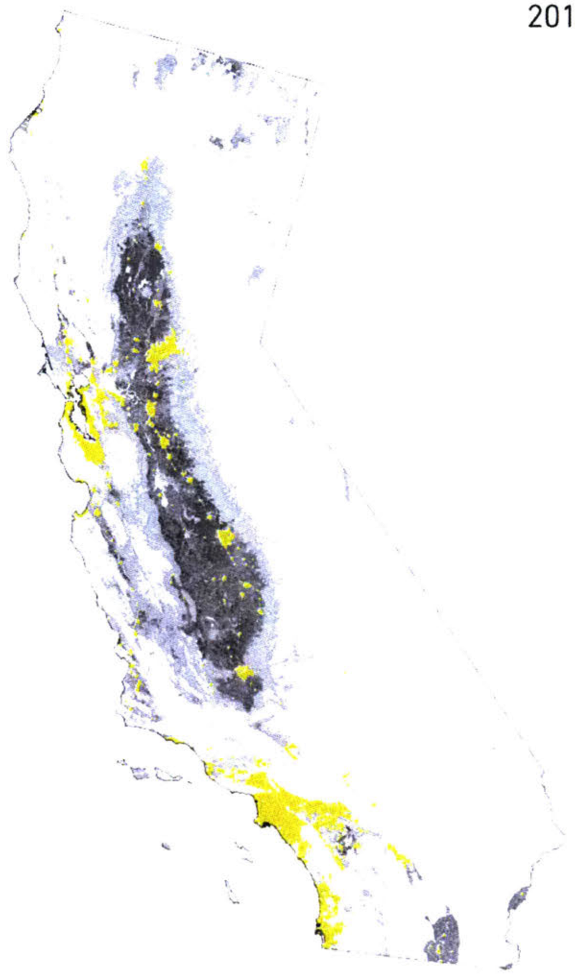
2011



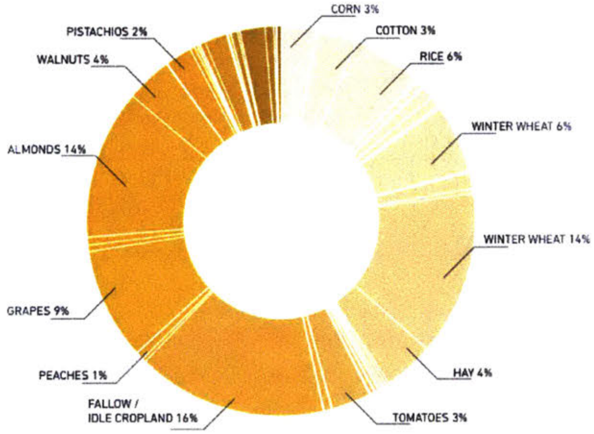
TOTAL AREA: 9,517,311.7 ACRES



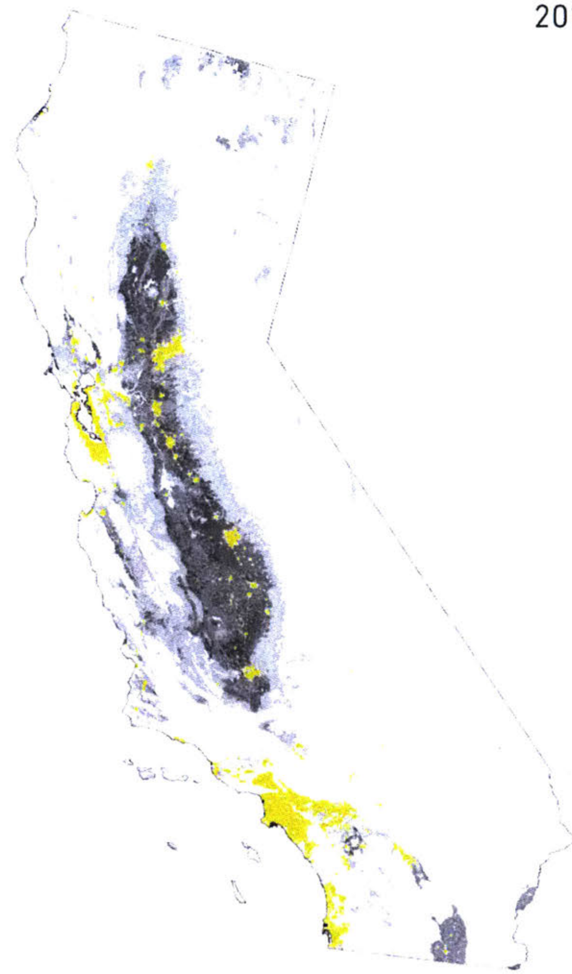
2013



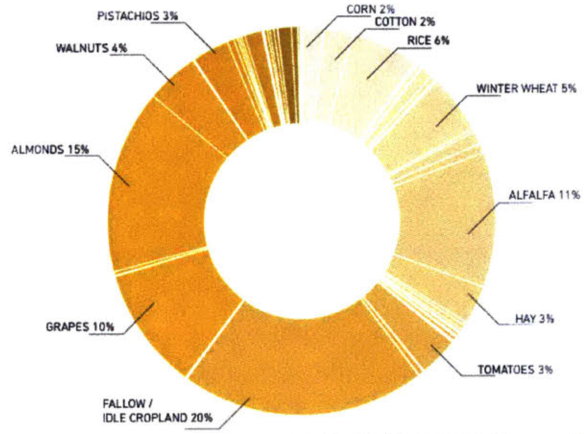
TOTAL AREA: 9,830,383.3 ACRES



2016



TOTAL AREA: 9,683,607 ACRES



DATA SOURCE: USDA NATIONAL AGRICULTURAL STATISTICS SERVICE CROPSCAPE

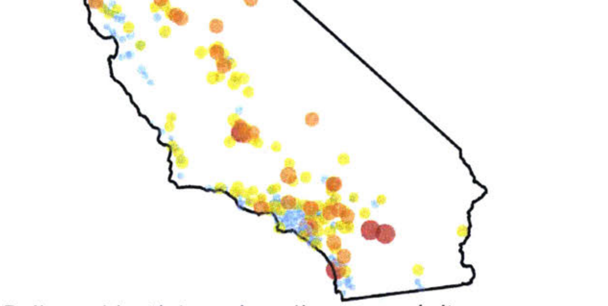
4.2 POPULATION AND WATER USE

According to the United States Census Bureau, California is the most populous state in the country with an approximate population of 39,250,017 by the year 2016. Despite population growth, total urban water use has been falling. Even before the latest drought, per capita water use had declined as a result of pricing incentives and water saving technologies. In 2015, drought conservation requirements managed to reduce per cápita water use to 130 gallons per day according to the Public Policy Institute of California.

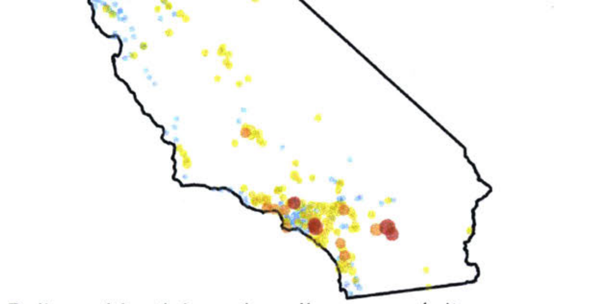
With a limited water supply and unreliable dry season rainfall, water reuse is drawing more attention. According to the Pacific Institute the current recycled water use in California is 670,000 acre-feet per year with a potential for additional water reuse of 1.2 million to 1.8 million acre-feet per year.

Approximately a 64 percent of this potential water reuse is from residences. Commercial businesses and institutions would account for a 21% and industry for a 15%.

Understanding wastewater as a potential source of water for agriculture, the purpose in mapping residential water consumption was to have a better idea of how much wastewater is being generated and where.



Daily residential use in gallons per cápita

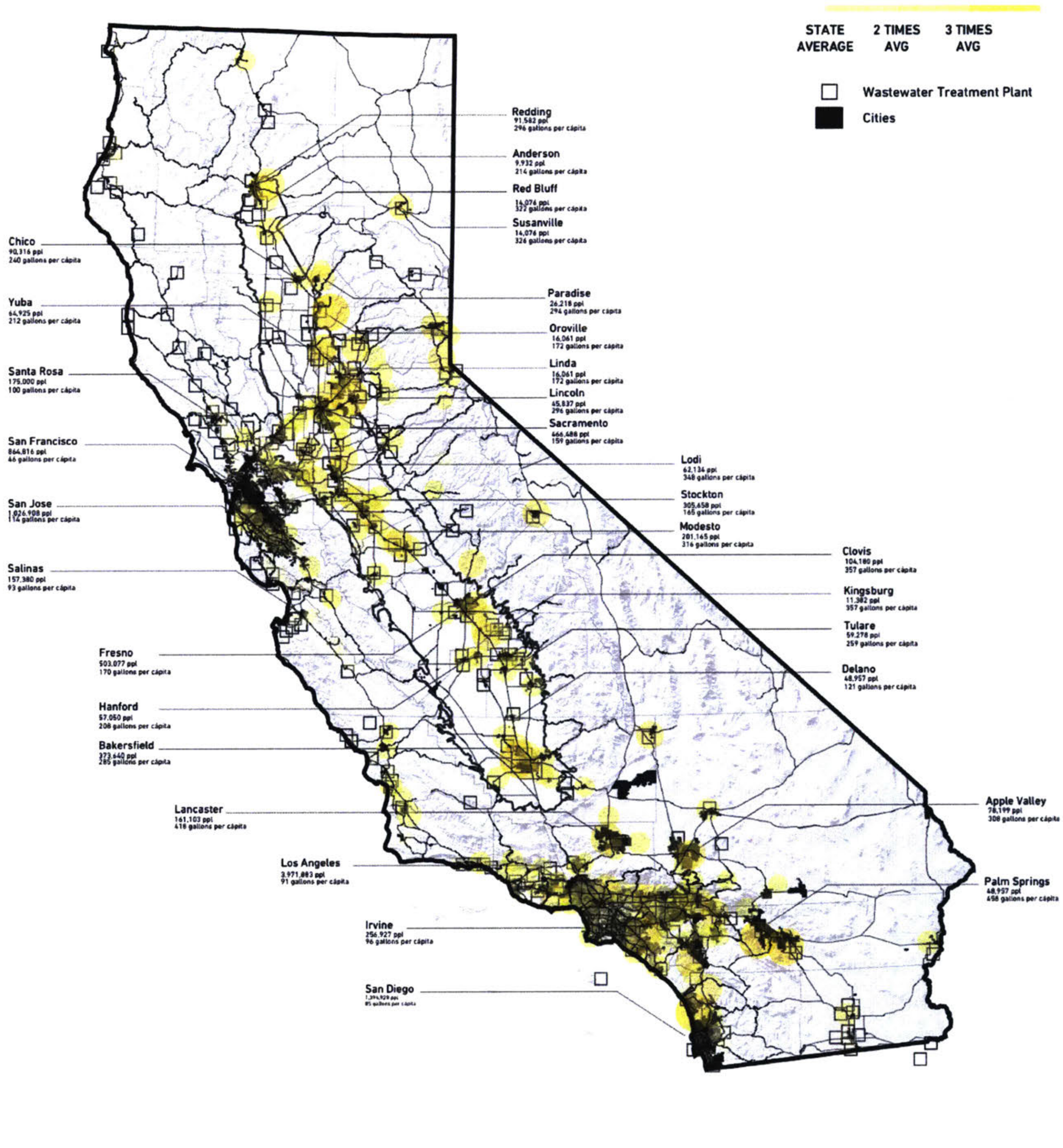


Daily residential use in gallons per cápita

IMAGE SOURCE: Modified from image on the New York Times

5,102,502,210 gallons per day
approximate residential water use in California.

2.5 million acre - feet approx per year potential water reuse. This represents a 7.3% annual agricultural gross water use.



DATA SOURCE: New York Times, United States Census Bureau, ESRI, USGS

4.3 INFRASTRUCTURE

California's water system serves more than 30 million people and provides irrigation to approximately 5,680,000 acres of farmland. It is considered the world's largest, most productive, and most controversial water system according to Hundley (2001). On a yearly basis it manages over 40,000,000 acre feet of water. (Draper et al, 2004)

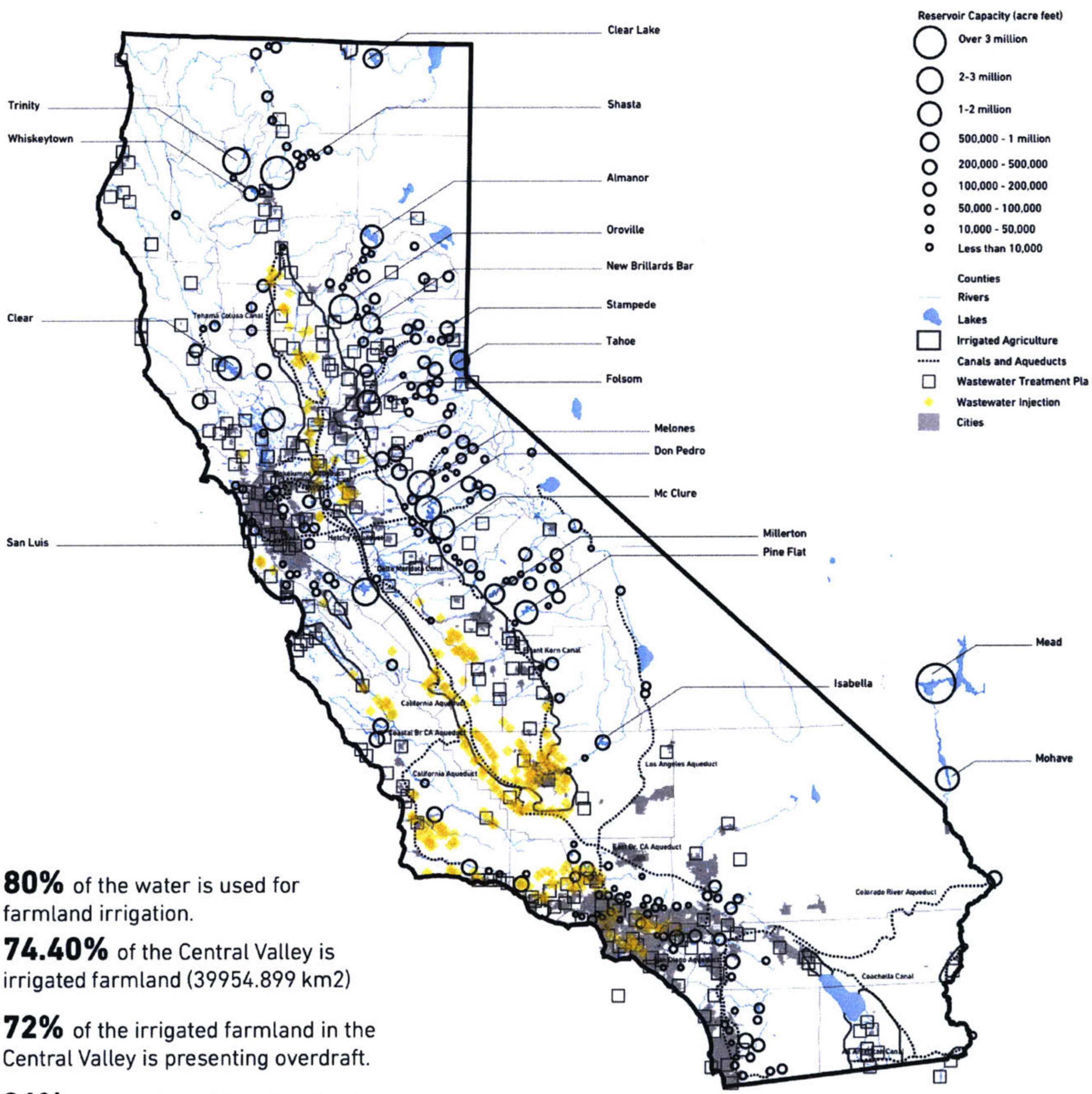
There are six main systems of aqueducts and infrastructure that transport and distribute water in California: the State Water Project, the Central Valley Project, the Colorado River delivery systems, the Los Angeles Aqueduct, the Tuolumne River/Hetch Hetchy system, and the Mokelumne Aqueduct.

These systems collect water both inside and outside the state to distribute it to water scarce areas in California. The supply system relies on 157 million acres of land spanning 8 states to collect, filter, and deliver water. (The Nature Conservancy of California, 2012).

From this mapping analysis, it was clear that most on the areas experiencing overextraction and subsidence are located within the sector irrigated by the CVP and SWP which can be interpreted as the result of a deficit the between the amount of water supplied by the system and the specific agricultural water needs of the area, leading farmers to groundwater pumping.

Central Valley Project (CVP)

State Water Project (SWP)



80% of the water is used for farmland irrigation.

74.40% of the Central Valley is irrigated farmland (39954.899 km2)

72% of the irrigated farmland in the Central Valley is presenting overdraft.

34% of the irrigated farmland in the Central Valley is presenting subsidence.

DATA SOURCE: ESRI, USGS, California Department of Water Resources

Central Valley Project

The Central Valley Project (CVP) is a federal water management project under the supervision of the United States Bureau of Reclamation. Devised in 1933 to provide irrigation and municipal water to California's Central Valley. The system regulates and stores water in reservoirs in the water-rich northern part of the state, and transports it to the water- poor San Joaquin Valley and surroundings by a series of canals, aqueducts and pumping plants.

Sacramento Valley

Sacramento River

The Shasta Division provides municipal water supply as well as irrigation of about 100,000 acres

Facility	Year	Notes
Shasta Dam	1945	Primary water storage and power generating facility of the CVP.
Keswick Dam	1950	
Red Bluff diversion dam	1964	
Tehama Colusa canal		Provides irrigation water to farmers growing a variety of permanent and annual crops.
Corning Canal	1945	150,000 agricultural acres.
Funks dam		

Trinity River

The Division's purpose is to divert water from the Trinity River into the Sacramento River drainage dowstream of Sahsta Dam to provide more flow and generate power in the process.

Facility	Year	Notes
Trinity Dam	1962	The second largest CVP water-storage reservoir, with just over half the capacity of Shasta
Clear creek tunnel		
Whiskeytown dam	1963	
Spring Creek Tunnel		
Keswick reservoir		Generates180 MW of electricity.
Spring creek debris dam	1963	Prevents acid mine drainage from the Iron Mountain Mine from continuing downstream and contaminating the river.

American River

The Division provides water supply for local settlements, and the rest of the system. The dams are also a flood control measure.The division is further divided into three units: the Folsom, Sly Park and Auburn-Folsom.

Facility	Year	Notes
Folsom Dam	1959	Primary water storage component. It stores 1,010,000 acre feet and generates 200 MW.
Nimbus Dam	1955	Generates 7.7 MW and includes a Fish Hatchery to compensate for the destruction of the river.
Sly park dam	1955	
Camino Conduit aqueduct		
Camp Creek Diversion Dam	1953	
Sugar Pine Dam	1979	
Folsom South Canal	1973	

San Joaquín Valley

Delta and canal system

Aqueducts and pumping plants that take water from the Sacramento-San Joaquin Delta to supply farms and cities

Facility	Year	Notes
Delta Cross channel	1951	intercepts Sacramento River and diverts it south
C.W. Bill Jones Pumping Plant	1951	Raises water into the Delta-Mendota Canal
Delta-Mendota Canal	1951	Travels 117 miles southwards to Mendota Pool
Contra Costa Canal	1948	Captures freshwater of the delta distributing water to the Clayton and Ygnacio Canals
Clayton canal		
Ygnacio canal		

San Joaquin River

The CVP also has several dams on the San Joaquin River in order to divert its water to southern Central Valley aqueducts.

Facility	Year	Notes
Friant Dam	1942	Millerton Lake provides water storage for San Joaquin Valley irrigators as well as a diversion point for canals.
Friant - Kern Canal	1951	sends water southwards to Bakersfield on the Kern River, supplying irrigation water to Tulare
Madera canal	1945	Takes water northwards to Madera County, emptying into the Chowchilla River

Stanislaus River

Facility	Year	Notes
New Melones Dam	1979	It can hold nearly 2,400,000 acre feet of water. It stores water during dry periods and releases it downstream to the northern San Joaquin Valley according to water demand.

Offstream storage and aqueducts

Storing and transporting water on the foothills of the California Coast Ranges.

Facility	Year	Notes
San Luis Dam (or B.F. Sisk Dam)	1968	Largest storage facility, holding 2,000,000 acre feet of water.
O'Neill Forebay	1967	
San Luis Canal	1968	Carries both CVP and SWP water. With a capacity of 13,100. It is one of the largest irrigation canals in the US
The Coalinga or Pleasant Valley Canal		
Los Baños Detenton Dam		Provides flood control in the Los Baños area.

DATA SOURCE: U.S. Bureau of Reclamation, California Department of Water Resources

State Water Project

The California State Water Project (SWP), is a water management project supervised by the California Department of Water Resources. The SWP provides drinking water for more than 23 million people and generates 6500 GWh of hydroelectric power every year. The SWP, however, is the largest consumer of power in the state, using an average of 5100 GWh. Since 1960, the SWP has built 21 dams and 700 miles of canals, pipelines and tunnels. It collects water from rivers in Northern California and redistributes it to the south. 70% of the water provided is used for urban areas and industry in Southern California and San Francisco Bay Area, and 30% is used for irrigation in the Central Valley. To reach Southern California, the water must be pumped 2.882 feet over the Tehachapi Mountains.

Feather River

The Feather River, a tributary of the Sacramento River, provides the primary watershed for the State Water Project.

Facility	Year	Notes
Antelope	1964	Has a maximum capacity of 58.548.000 m3, and a normal capacity of 27.835.000 m3
Frenchman	1961	Rock-fill and earthen dam 129 feet high, with a length of 720 feet at its crest. Normal water storage in the reservoir is 55.477 acre-feet
Davis	1966	Grizzly Valley Dam
Oroville Dam	1968	By volume, it is the largest dam in California and at 770 feet, it is the tallest dam in the United States. The Oroville-Thermalito Complex generates approximately 2.2 billion kilowatt hours per year, a third of the total power generated by SWP.

Sacramento–San Joaquin River Delta

Facility	Year	Notes
North Bay Aqueduct	1988	The aqueduct delivers water to clients in Napa and Solano counties.
Clifton Court Forebay	1969	Serves as the intake point of the California Aqueduct, and feeds the Delta-Mendota Canal to recharge San Joaquin Valley river systems.
Bethany Reservoir	1967	Serves as a forebay for South Bay Pumping Plant and a conveyance facility
South Bay Pumping Plant	1967	
South Bay Aqueduct	1962	Delivers water to Alameda County since 1962 and Santa Clara County since 1965. I tcarries a maximum of 188.000 acre-ft per year.
Lake Del Valle	1968	Serves as off-stream storage for the South Bay Aqueduct. The lake capacity is 77.000 acre feet

California Aqueduct

The over 400-mile aqueduct is the main feature of the California SWP. The aqueduct that runs through the San Joaquin Valley releases water to irrigate 750,000 acres of land on the west side of the valley.

Facility	Year	Notes
O'Neill Forebay	1967	Collects irregular water releases from the San Luis Dam and William R. Gianelli Powerplant
San Luis Reservoir	1967	Shared by the SWP and the federal Central Valley Project. Water can be switched between the California Aqueduct and Delta-Mendota Canal to cope with fluctuating demands.
A.D. Edmonston Pumping Plant	1974	Main feature of the SWP. It lifts water 1.926 feet (600 m) to cross the Tehachapi Mountains.

Coastal Branch

Built in 1994, it diverts about 48.000 acre-ft per year from the California Aqueduct to San Luis Obispo and Santa Barbara counties.

Facility	Year	Notes
Central Coast Water Authority extension	1997	
Lake Cachuma	1953	Maximum design capacity of 205.000 acre-ft (253.000.000 m3)

West Branch

Facility	Year	Notes
William E. Warne Powerplant	1982	
Pyramid Lake	1973	
Angeles Tunnel	1970	Final leg of the west branch of the California Aqueduct

East Branch

Provides water for cities and farms in the Inland Empire, Orange County, and other areas south of Los Angeles. Water deliveries from the East Branch averaged 995.000 acre-ft per year between 1995 and 2012.

Facility	Year	Notes
Devil Canyon Powerplant	1974	Largest "recovery plant", or aqueduct power plant, of the SWP system

4.4 HYDROLOGIC ELEMENTS

Average water use, statewide is approximately 50% environmental, 40% agricultural, and 10% urban. Agriculture relies heavily on surface-water diversions and groundwater, especially during droughts.(PPIC) A 25.58% and a 43.05% of the Central Valley present overdraft and critical overdraft respectively. This represents a 72% of the irrigated farmland in the Central Valley.

Approximately, a sixth of the country's irrigated land is in the Central Valley, and a fifth of the country's groundwater demand is supplied from its aquifers. This excesive extraction is causing problems beyond declining water levels. The compaction of aquifers caused by excessive groundwater pumping is the largest cause of subsidence in California. (USGS)

WIth almost half of the aquifer recharge areas (47.4%) devoted to agriculture it's important to consider that they aquifers in the Central Valley are not only facing overdraft but they are also being polluted by the seeping of fertilizers and pesticides. The combination of overextraction and percolation of pollutants leads to higher levels of contamination within the aquifer which could potentially be dangerous for communities relying on groundwater for water supply.

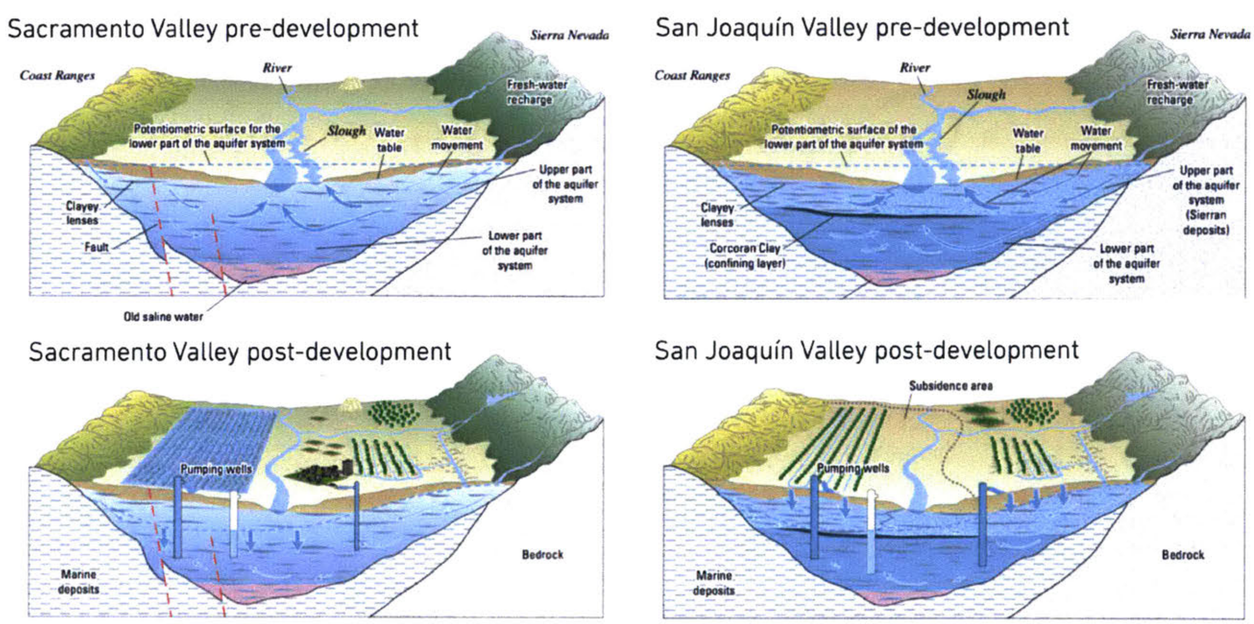
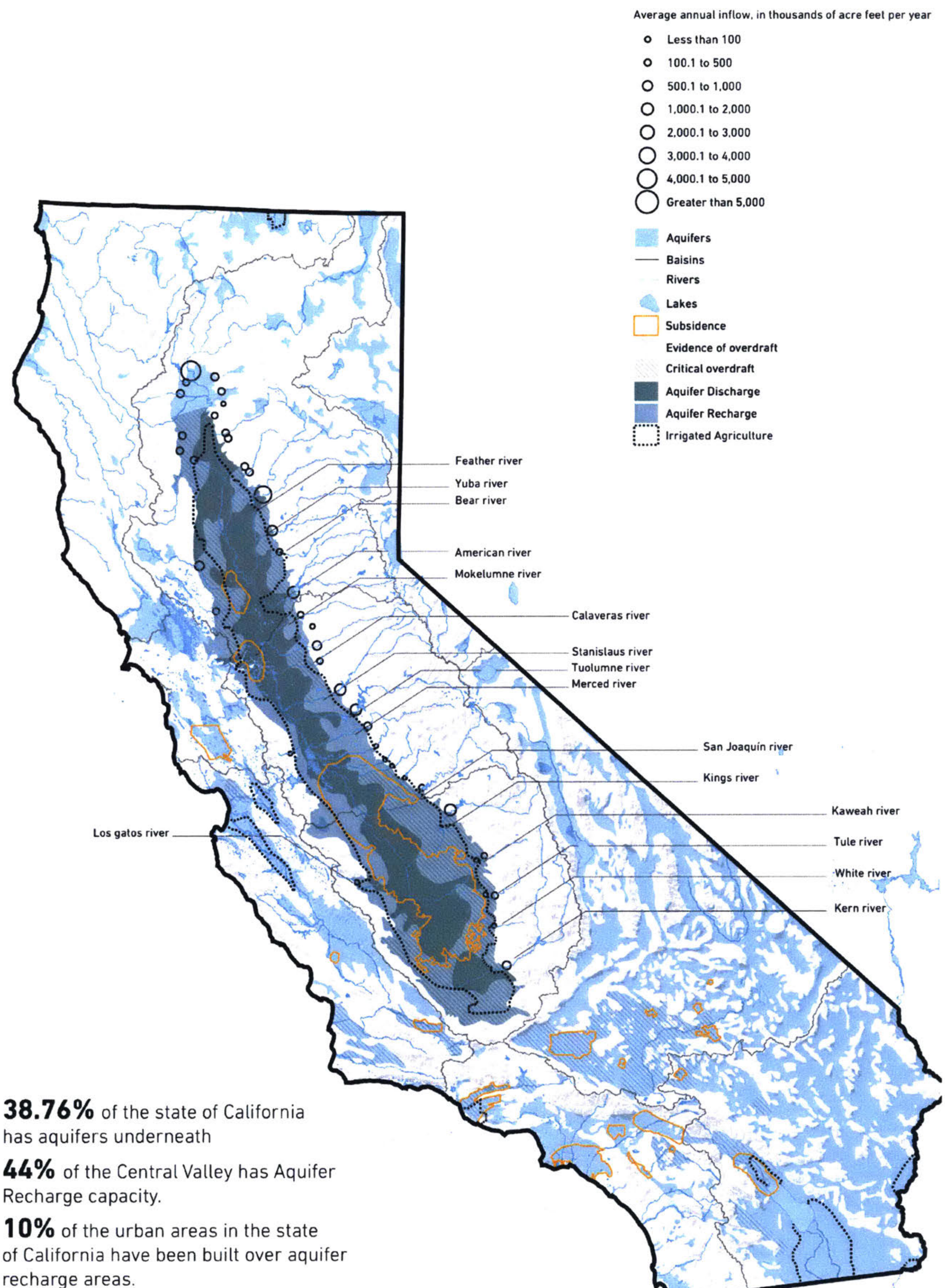


IMAGE SOURCE: Groundwater Availability of the Central Valley Aquifer, California USGS



38.76% of the state of California has aquifers underneath

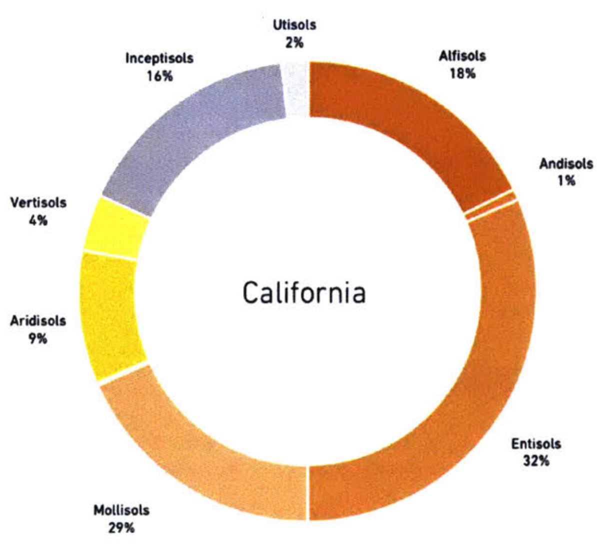
44% of the Central Valley has Aquifer Recharge capacity.

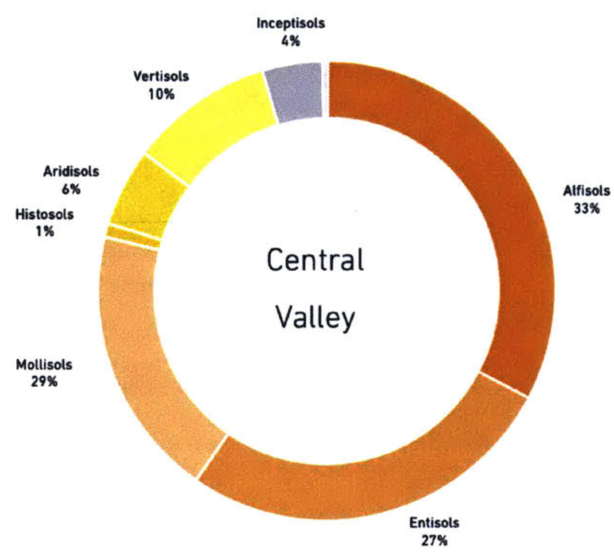
10% of the urban areas in the state of California have been built over aquifer recharge areas.

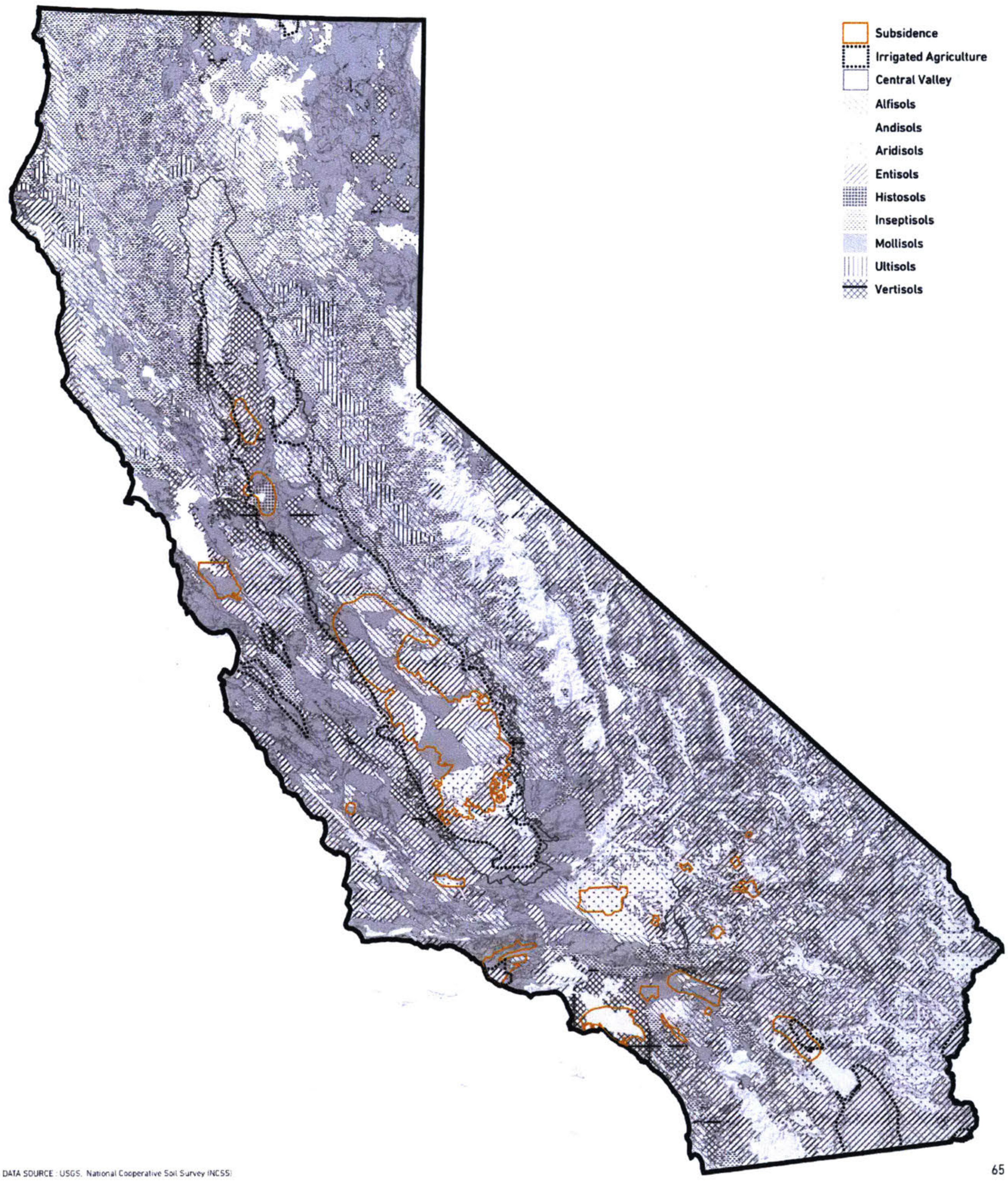
DATA SOURCE USGS California Department of Water Resources

4.5 SOIL

The central valley in California is the world's largest patch of Class 1 soil which refers to capability class or suitability for most kinds of field crops. (Bittman, 2012) Class 1 soils have slight limitations that restrict their use. The taxonomic analysis done by the National Cooperative Soil Survey also reveals that between Alfisols and Mollisols a 51.5% of the Central Valley has very high fertile and productive soils. In addition, Entisols, Aridisols, Histosols and Utisols, which make up for a 33.40% of the Central Valley, can be highly productive with proper drainage/ irrigation and use of fertilizers.

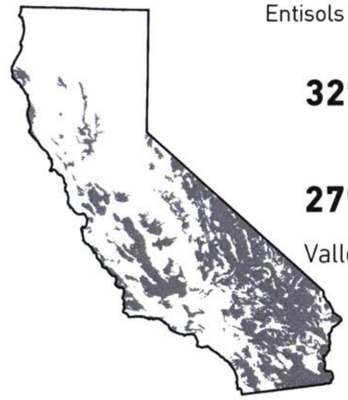






DATA SOURCE : USGS, National Cooperative Soil Survey (NCSS)

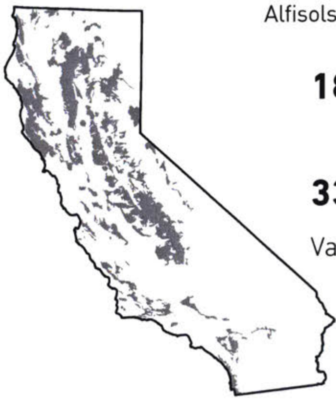
SOIL TAXONOMY ORDERS



Entisols

32% of state area

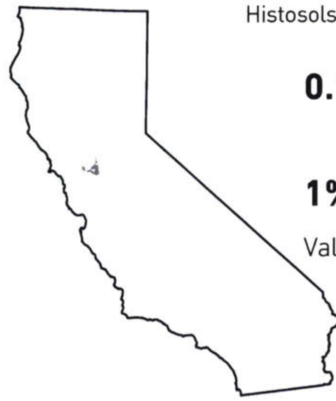
27% of the Central Valley area



Alfisols

18% of state area

33% of the Central Valley area



Histosols

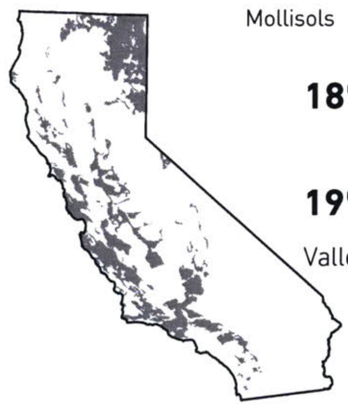
0.18% of state area

1% of the Central Valley area

Andisols

1% of state area

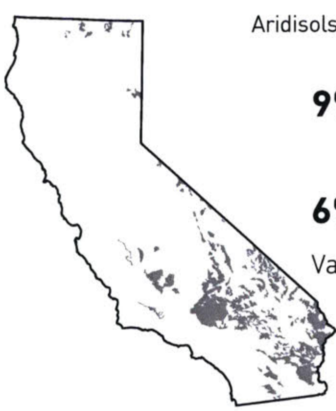
0% of the Central Valley area



Mollisols

18% of state area

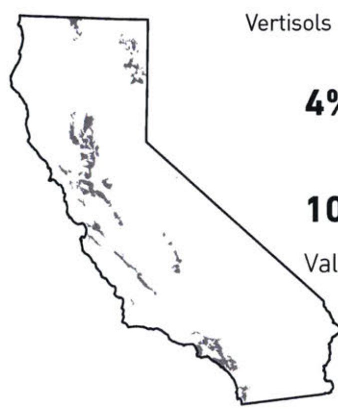
19% of the Central Valley area



Aridisols

9% of state area

6% of the Central Valley area



Vertisols

4% of state area

10% of the Central Valley area

Alfisols	Highly fertile and productive agricultural soils in which clays accumulate below the surface. Alfisols are found in humid and subhumid climates.
Andisols	Formed in volcanic materials, these are highly productive soils with high water- and nutrient- holding capabilities. Andisols are usuallly found in cool areas with moderate to high levels of precipitation.
Aridisols	Soils formed arid and semiarid environments where moisture is scarce and restricts weathering and leaching, resulting in the accumulation of salts and limited subsurface development. Typically light in color as there is little organic matter. The lack of moisture balance in these soils inhibits eluviation. Calcification and salinization are important soil forming processes acting in these soils. Soil horizons are weakly developed and sodium is often high in concentration making them alkaline. The coarse texture of these soils also makes it difficult to retain moisture. They can be quite fertile with proper irrigation. If improperly irrigated, a salt crust can form on the soil. Aridisols are commonly used for grazing.
Entisols	Commonly found in floodplains, mountains, and badland areas, where erosion or deposition rates outpace rates of soil development. When properly fertilized and irrigated, Entisols can be used in agriculture as rangeland and grazing land. Intensive use is restricted by depth, clay content, or water balance. Some Entisols can be intensively farmed, for example, river alluvium Entisols.
Histosols	Found on lake coastal areas, these are organic-rich soils where poor drainage creates conditions of slow decomposition and peat accumulates. Histosols can be highly productive farmland when drained; however, they can decompose rapidly and subside dramatically. They are also not stable for foundations or roadways.
Inceptisols	Soils with moderate weathering and development. Usually found on steep and young topography and over erosion- resistant bedrock.
Mollisols	Highly productive agricultural soils with a very fertile, organic- rich surface layer.
Ultisols	Soils with subsurface clay accumulations and low native fertility. Often red hued because of iron oxides. Ultisols are commonly found in humid tropical and subtropical climates. They can be productive with additions of fertilizer and lime.
Vertisols	Clayey soils with high shrink/swell capacity. During dry periods, these soils can shrink and develop wide cracks. During wet periods, they swell with moisture.

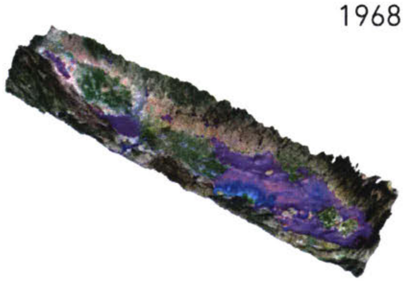
DATA SOURCE : Paleontological Research Institution

LAND SUBSIDENCE SIMULATION

25.45% of the Central Valley is experiencing subsidence as a result of groundwater overdraft. The 5,200 mi2 affected by subsidence in the San Joaquin Valley has been identified as the largest human alteration of the Earth's surface. (USGS)

1961

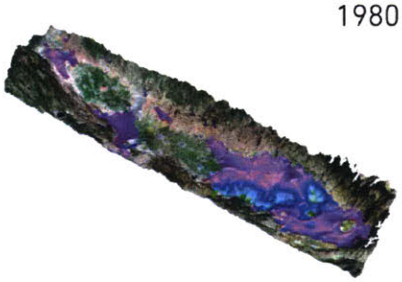
1968



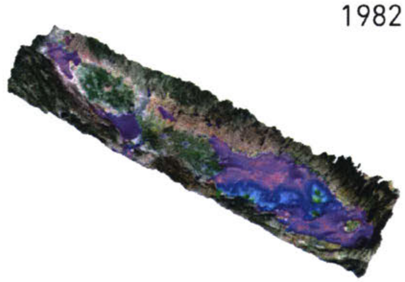
1970

1972

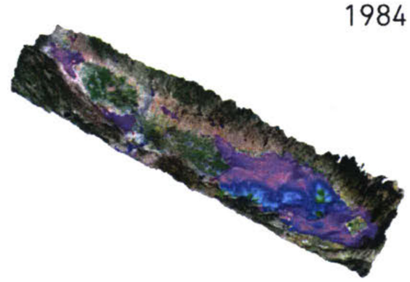
1980



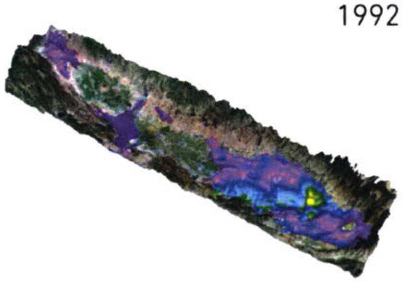
1982



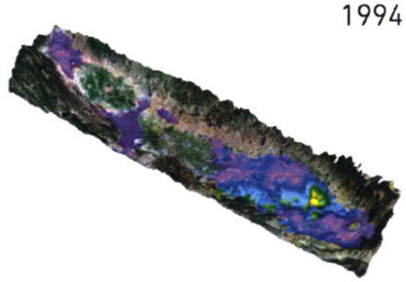
1984



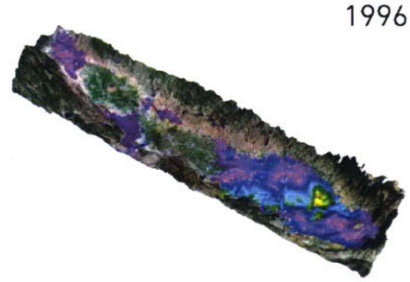
1992



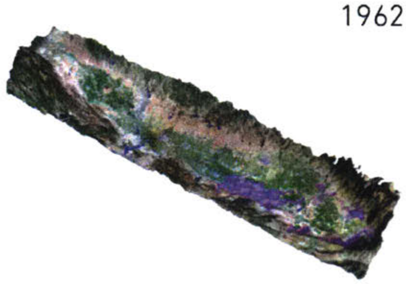
1994



1996



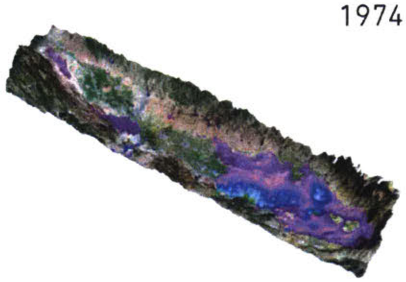
1962



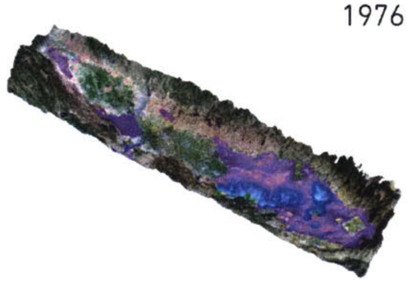
1964

1966

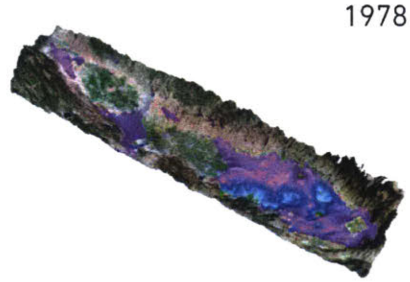
1974



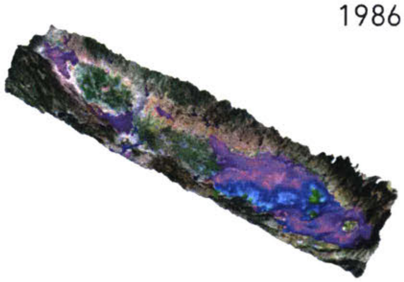
1976



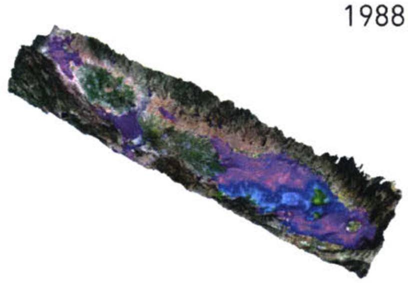
1978



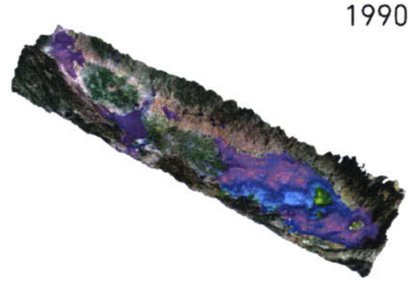
1986



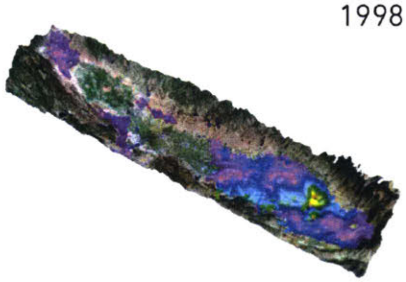
1988



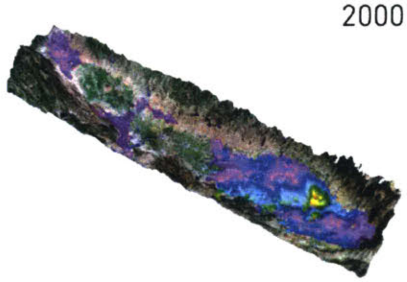
1990



1998



2000



2002

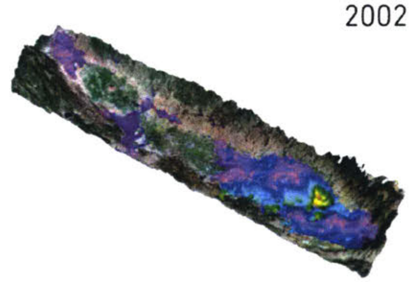


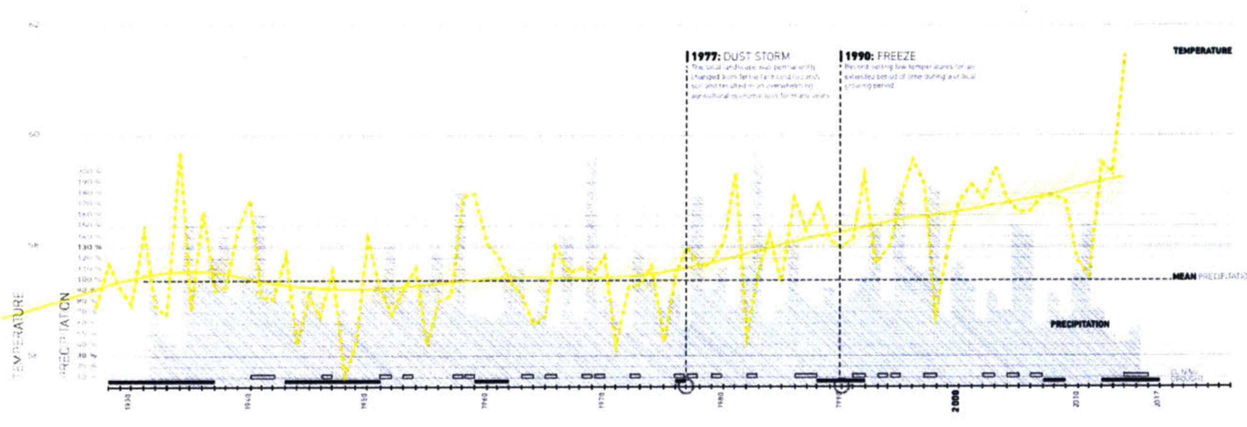
IMAGE SOURCE : U

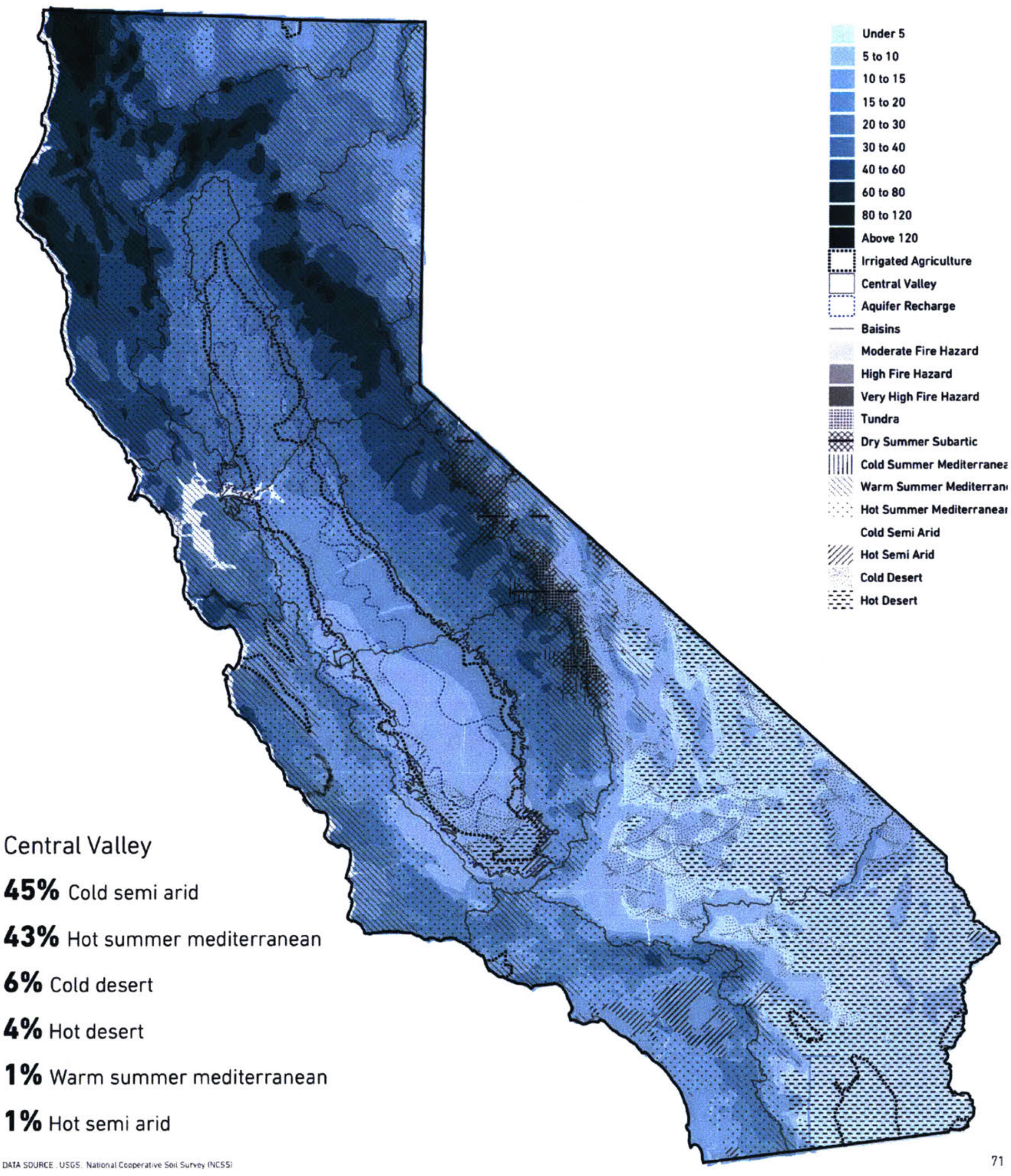
4.6 CLIMATE

On April 7th, 2017 California Govervor Jerry Brown declared an end to the state's drought emergency and lifted the emergency restrictions after powerful storms increased precipitation in the area to far above average. (USGS, 2017) But considering the true definition of drought, it is far from over. Even in a wet year California's water is not enough to cover all the state's demands, recharge overdrafted groundwater basins or overcome the massive deficits suffered by ecosystems. (Gleick, 2017)

Recent changes in rain patterns have been declared an anomaly by NOAA, which can be explained by ENSO (El Niño/Southern Oscillation, the whole El Niño & La Niña cycle). Even with the changes in precipitation, temperature continues to increase due to Climate Change and Global Warming. Temperature impacts, among other things, the demand for water by crops, vegetation, and people. It especially impacts the ratio of snow to rain that falls in the mountains playing a key role in worsening the scarcity of water and devastating the snowpack. (USGS, 2017)

Another important aspect to consider is that, historically, the highest levels of precipitation tend to happen outside of the Central Valley, far from most of the farmland and, most importantly, far from aquifer recharge areas. Without precipitation in this specific areas, aquifer recharge is very limited.





Central Valley

45% Cold semi arid

43% Hot summer mediterranean

6% Cold desert

4% Hot desert

1% Warm summer mediterranean

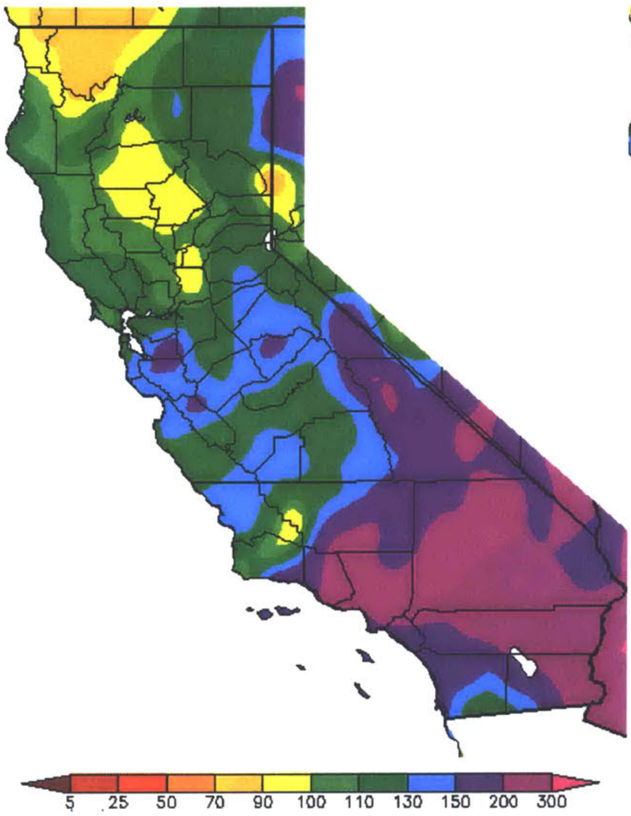
1% Hot semi arid

DATA SOURCE : USGS, National Cooperative Soil Survey (NCSS)

PRECIPITATION

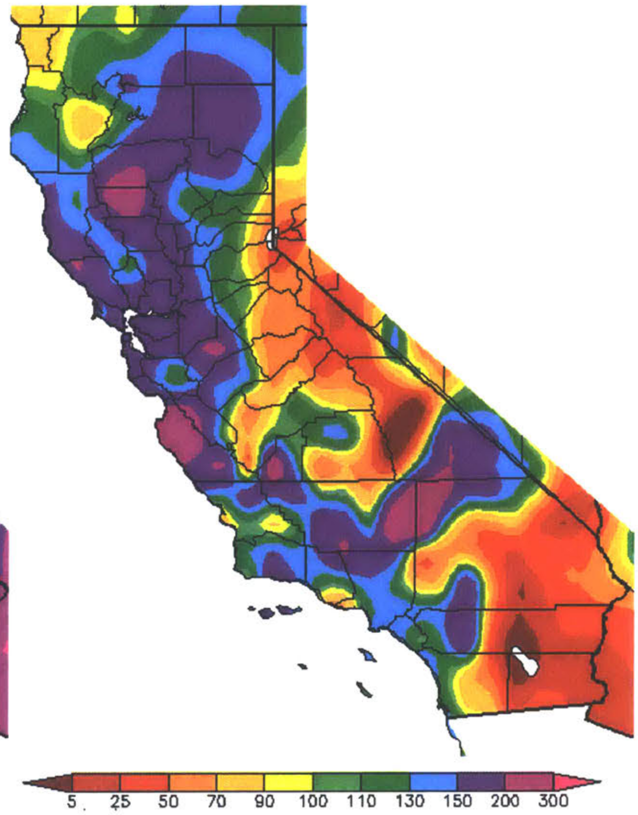
Percent of Average Precipitation (%)

1/1/2005 - 6/29/2005



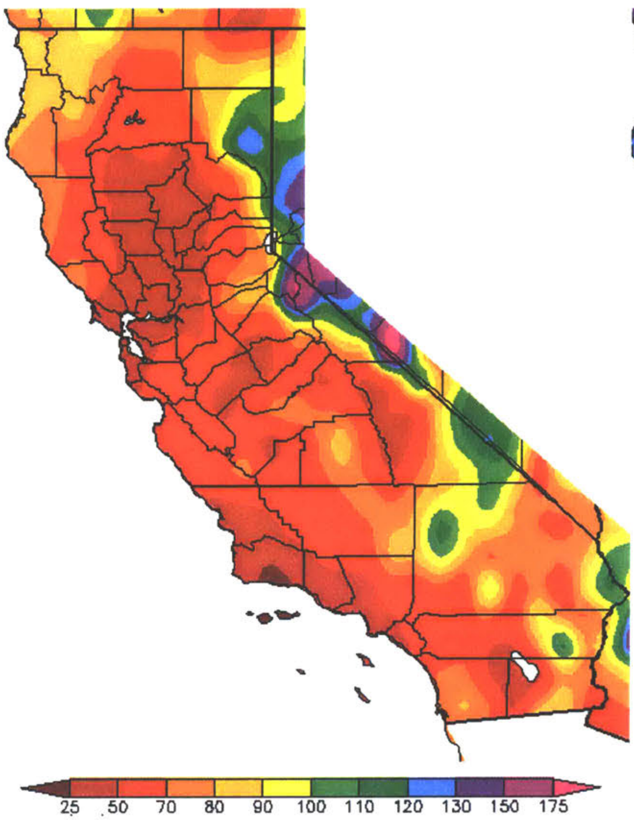
Percent of Average Precipitation (%)

10/1/2014 - 12/13/2014



Percent of Average Precipitation (%)

1/1/2015 - 12/31/2015



Percent of Average Precipitation (%)

7/1/2016 - 1/22/2017

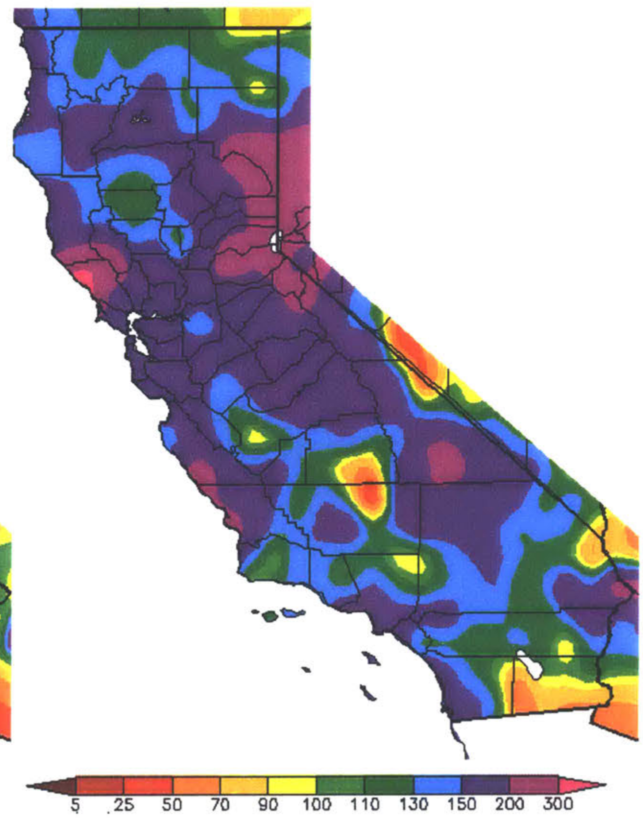
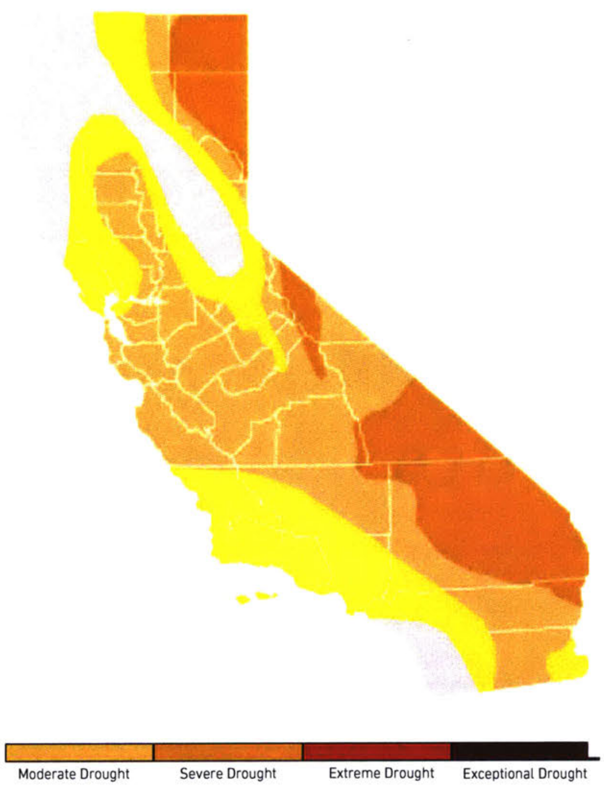


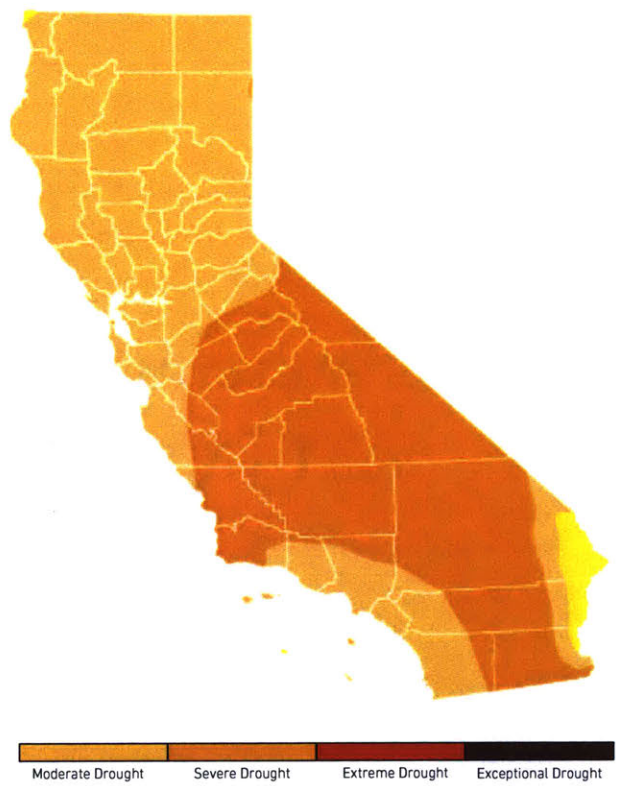
IMAGE SOURCE: NOAA REGIONAL CLIMATE CENTER

DROUGHT

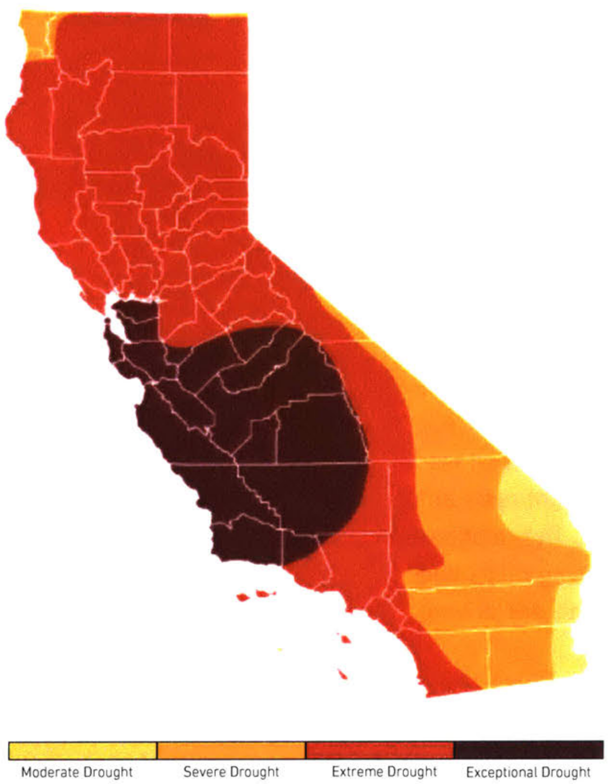
Drought Level at second week of May 2012



Drought Level at second week of May 2013



Drought Level at second week of May 2014



Drought Level at second week of May 2015

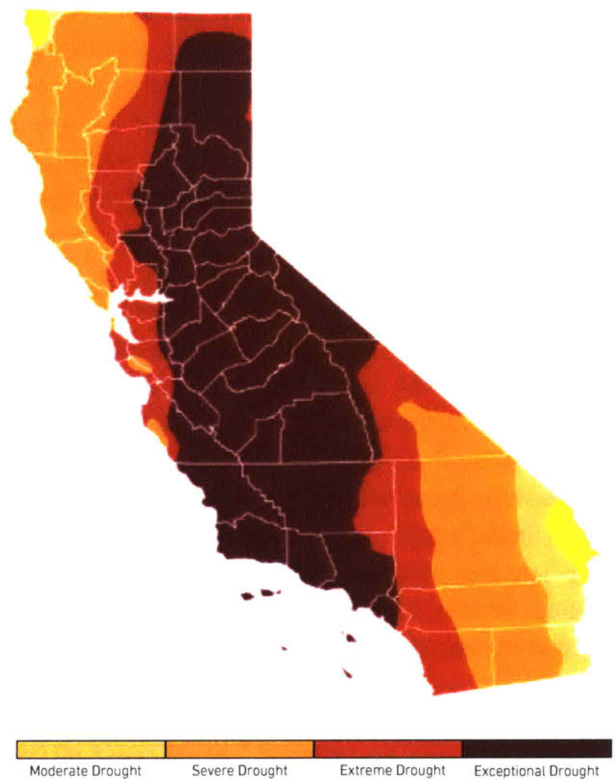


IMAGE SOURCE :US DROUGHT MONI

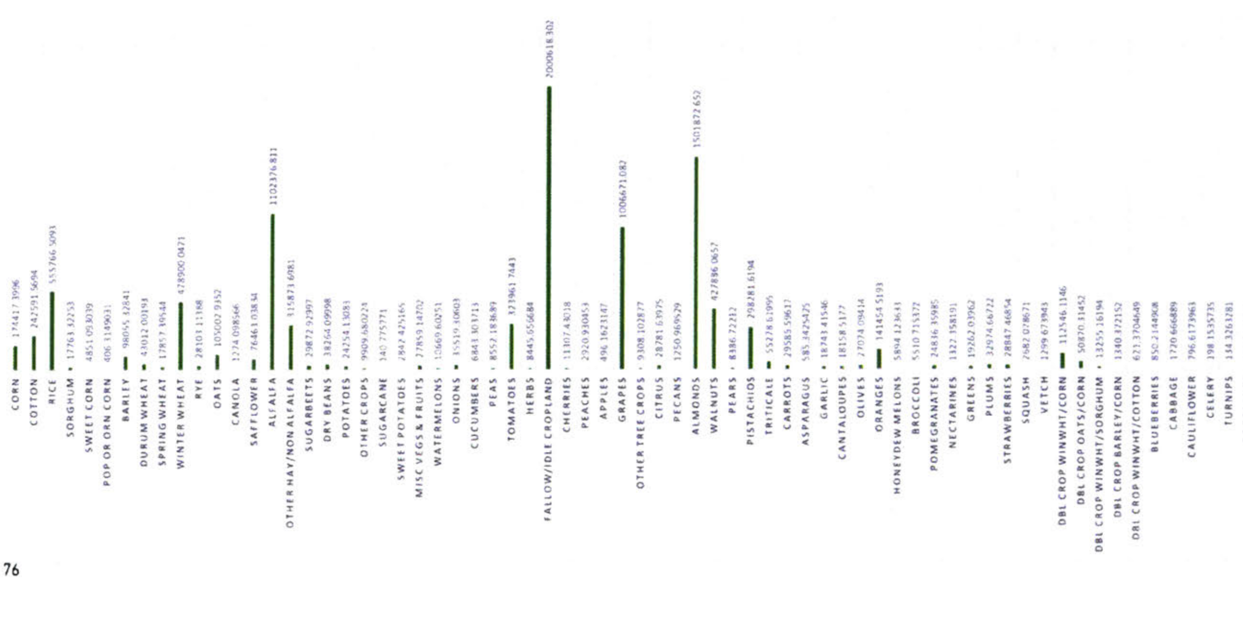
4.7 AGRICULTURE

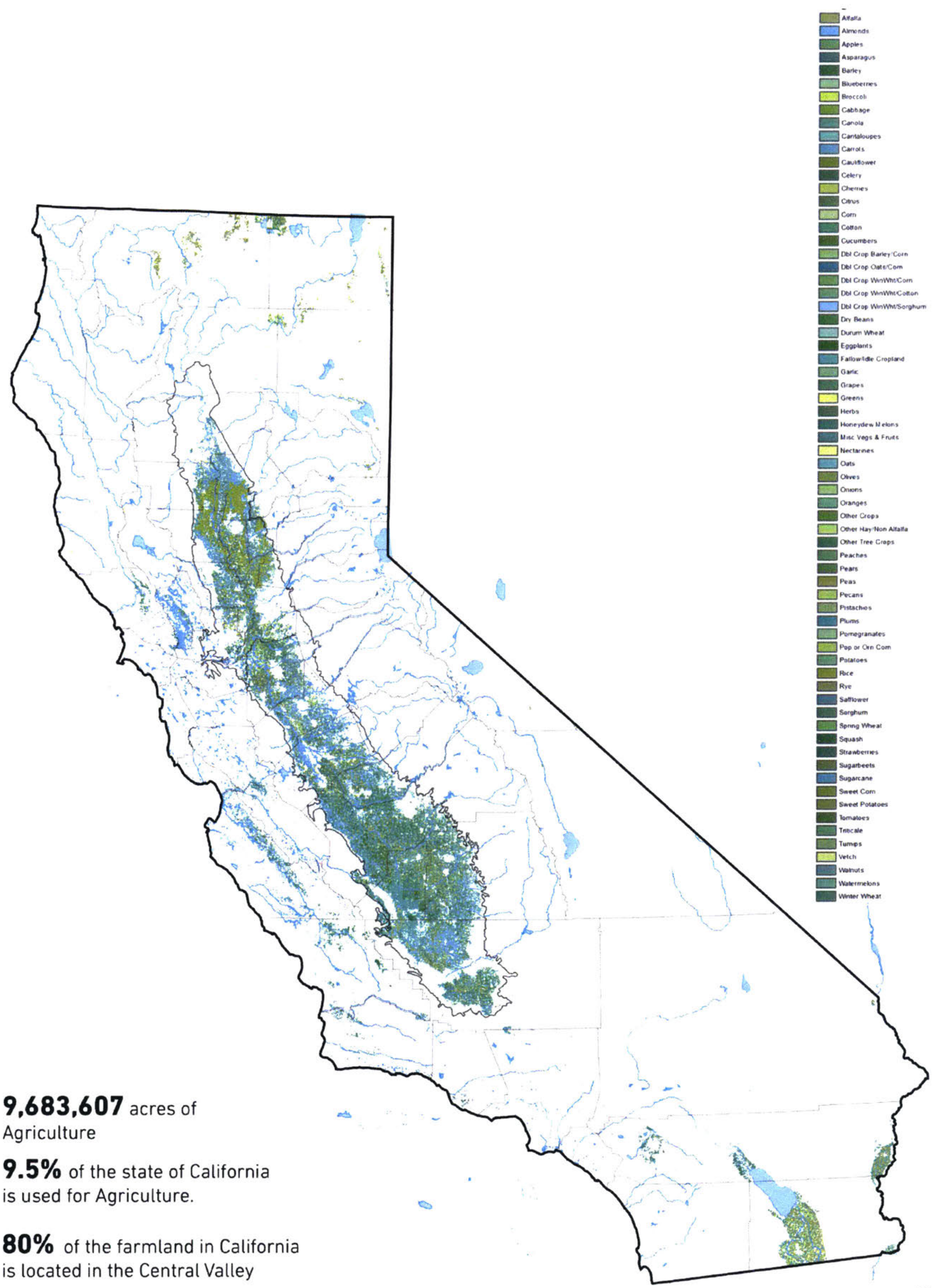
California, the country's largest agricultural producer and exporter, produces over a third of the country's vegetables and two-thirds of the country's fruits and nuts. Its agricultural output was $46.7 billion in 2013, with total U.S. output valued at $269.1 billion. Agriculture makes up just 2.2 percent of California's economy, but it is still the nation's green grocer, and farming is still the main economic activity of the state's arid center. (Norris, 2014).

The Central Valley, alone, is one of the most productive agricultural regions in the world with more than 250 different crops and an estimated value of $17 billion per year.(USGS) This irrigated agriculture relies heavily on surface-water diversions and groundwater pumpage. Water scarcity due to the recent drought has had a considerable impact on agricultural production. Farmers have been dealing with lower yields and higher costs for additional groundwater pumping which caused a higher percentage of cropland left for fallow.

A net water shortage of 1.6 million acre-feet was estimated to cause losses of $810 million in crop revenue with additional groundwater pumping costing up to $454 million. (Food Business News, 2014). As a result of the drought, farmers have also switched to cash crops such as nuts that unfortunately also have a large blue water footprint. However not all water intensive crops bring in a large revenue and not all drought resistant crops (lower water needs) have less potential for revenue. The relationship between those two remains unclear as seen in upcoming maps and figures. What is clear however is that demand and pricing are driving most of the decisions made in agricultural production.

AGRICULTURE IN CALIFORNIA





9,683,607 acres of Agriculture

9.5% of the state of California is used for Agriculture.

80% of the farmland in California is located in the Central Valley

DATA SOURCE USGS Cropscape from USDA NASS

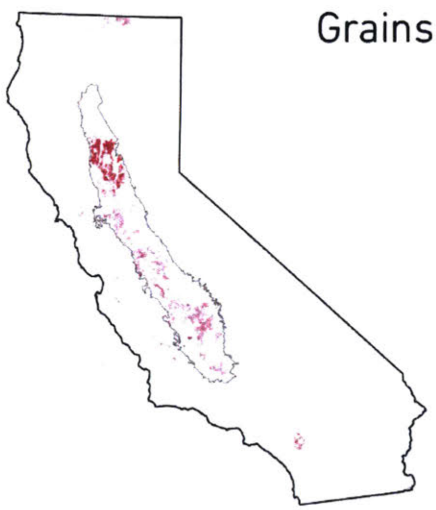
Canals
Irrigation
Over extraction
Subsidence
Alfalfa
Almonds
Apples
Asparagus
Barley
Blueberries
Broccoli
Cabbage
Canola
Cantaloupes
Carrots
Cauliflower
Celery
Cherries
Citrus
Corn
Cotton
Cucumbers
Dbl Crop Barley/Corn
Dbl Crop Oats/Corn
Dbl Crop WinWht/Corn
Dbl Crop WinWht/Cotton
Dbl Crop WinWht/Sorghum
Dry Beans
Durum Wheat
Eggplants
Fallow/Idle Cropland
Garlic
Grapes
Greens
Herbs
Honeydew Melons
Misc Vegs & Fruits
Nectarines
Oats
Olives
Onions
Oranges
Other Crops
Other Hay/Non Alfalfa
Other Tree Crops
Peaches
Pears
Peas
Pecans
Pistachios
Plums
Pomegranates
Pop or Orn Corn
Potatoes
Rice
Rye
Safflower
Sorghum
Spring Wheat
Squash
Strawberries
Sugarbeets

Fruits

1,656,842 Acres used for fruits

17.10% of the total farmland in California

60.76% Grapes
19.55% Tomatoes
8.54% Oranges
1.99% Plums
1.74% Strawberries
1.74% Citrus
1.50% Pomegranates
1.10% Cantaloupes
0.68% Cherries
0.64% Watermelons
0.56% Other Tree Crops
0.51% Pears
0.36% Honeydew Melons
0.18% Peaches
0.08% Nectarines
0.05% Blueberries
0.03% Apples

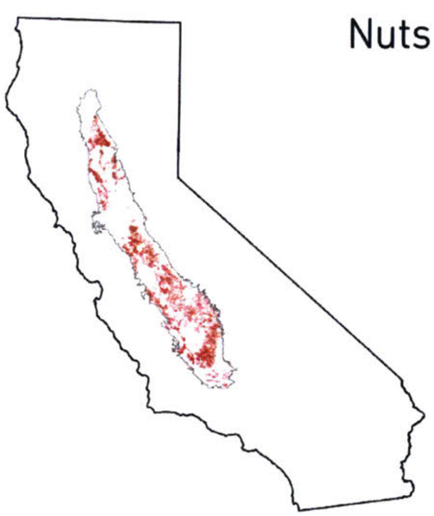


Grains

1,758,047 Acres used for grains

18.15% of the total farmland in California

31.61% Rice
27.24% Winter Wheat
9.92% Corn
6.40% Dbl Crop WinWht/Corn
5.97% Oats
5.58% Barley
3.14% Triticale
2.89% Dbl Crop Oats/Corn
2.45% Durum Wheat
1.60% Rye
1.02% Spring Wheat
1.01% Sorghum
0.75% Dbl Crop WinWht/Sorghum
0.28% Sweet Corn
0.08% Dbl Crop Barley/Corn
0.04% Dbl Crop WinWht/Cotton
0.02% Pop or Orn Corn



Nuts

2,229,559 Acres used for nuts

23.02% of the total farmland in California

67.36% Almonds
19.19% Walnuts
13.38% Pistachios
0.06% Pecans
0.01% Turnips
0.01% Eggplants

Sugar

30,014 Acres used for sugar

0.30% of the total farmland in California

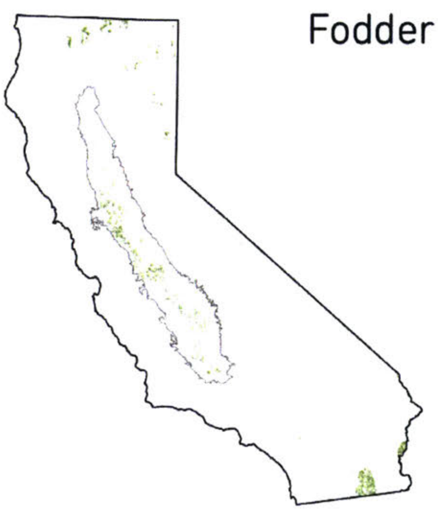
99.53% Sugarbeets
0.47% Sugarcane

Vegetables

148,521 Acres used for vegetables

1.53% of the total farmland in California

23.92%	Onions
19.92%	Carrots
18.23%	Olives
12.97%	Greens
12.62%	Garlic
4.61%	Cucumbers
3.71%	Broccoli
1.81%	Squash
1.16%	Cabbage
0.54%	Cauliflower
0.39%	Asparagus
0.13%	Celery



Fodder

1,419,550 Acres used for fodder

14.66% of the total farmland in California

77.66% Alfalfa
22.25% Other Hay
0.09% Vetch

Irrigated Farmland

74.5% of the Central Valley is irrigated
67.52% of area used for agriculture
80.85% of total farmland in California
>61 different crops

Aquifer Recharge

44% of the Central Valley is aquifer recharge.
47.40% of area used for agriculture
35.7% of total farmland in California
>57 different crops

19.40% Fallow/ Idle Cropland

17.21% Almonds

10.09% Alfalfa

9.87% Grapes

6.82% Rice

4.79% Winter Wheat

4.57% Walnuts

3.87% Tomatoes

3.34% Pistachios

2.96% Cotton

2.42% Hay

2.16% Corn

1.43% Oranges

0.96% Oats

23.12 % Almonds

18.65 % Fallow/ Idle Cropland

13.08 % Grapes

6.29 % Rice

6.16 % Walnuts

5.42 % Alfalfa

4.98 % Winter Wheat

4.10 % Pistachios

3.70 % Oranges

2.51 % Tomatoes

1.55 % Cotton

1.44% Hay

1.28 % Corn

0.88 % Oats

Aquifer Overdraft

68.6% of the Central Valley presents some level of aquifer overdraft.

72% of Irrigitated farmland in the Central Valley presents overdraft, which means that the water needs in these areas are greater than the water supplied.

77% of area used for agriculture
62% of total farmland in California
>56 different crops

21 % Fallow / Idle Cropland

15.94 % Almonds

13 % Rice

8.6 % Grapes

21 % Almonds

7.19 % Walnuts

6.68 % Alfalfa

3.0% Tomatoes

2.94% Pistachios

2.0% Corn

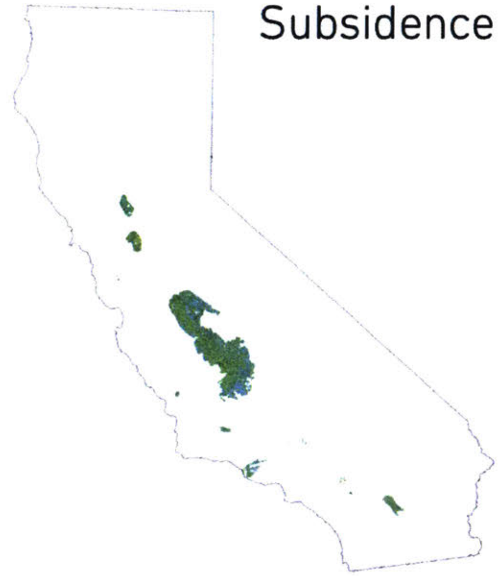
1.79% Cotton

1.76% Hay

1.67% Oranges

1.0 % Safflower

Subsidence



25.5% of the Central Valley presents land subsidence
63% of area used for agriculture
30% of total farmland in California
>59 different crops

20.5 % Fallow / Idle Cropland'

18.97 % Almonds

9.7 % Alfalfa

8.46 % Grapes

7.26% Winteer Wheat

63.5 % Cotton

5.3 % Pistachios

5.17 % Tomatoes

3.07 % Corn

2.0 % Walnuts

1.25 % Safflower

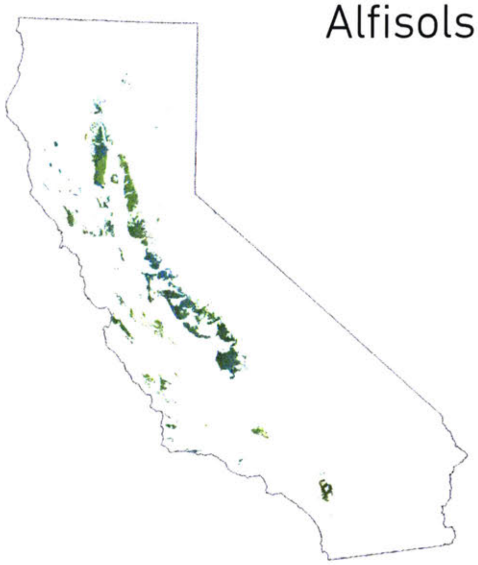
1.04 % Barley

0.92 % Oranges

0.91 % Triricale

DATA SOURCE : Cropscape from USDA NASS

Alfisols



13% of area used for agriculture
22.5% of total farmland in California
>54 different crops

Aridisols

6.6% of area used for agriculture
6.1% of total farmland in California
>54 different crops

Inceptisols

0.7% of area used for agriculture
1.12 % of total farmland in California
>43 different crops

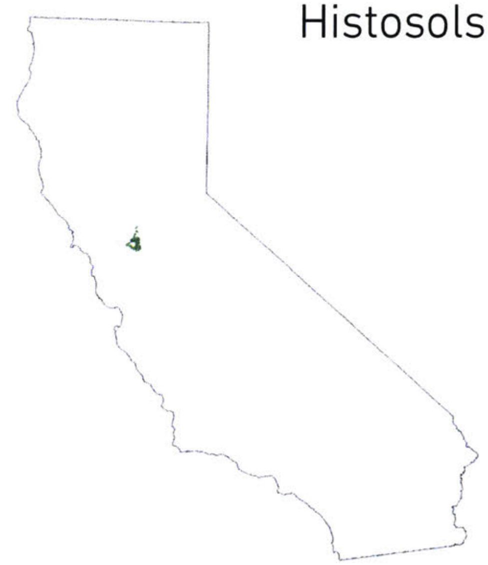
Mollisols

13% of area used for agriculture
23 % of total farmland in California
>56 different crops

Entisols

11.5% of area used for agriculture
35% of total farmland in California
>53 different crops

Histosols



50.8% of area used for agriculture
0.88% of total farmland in California
>38 different crops

Utisols

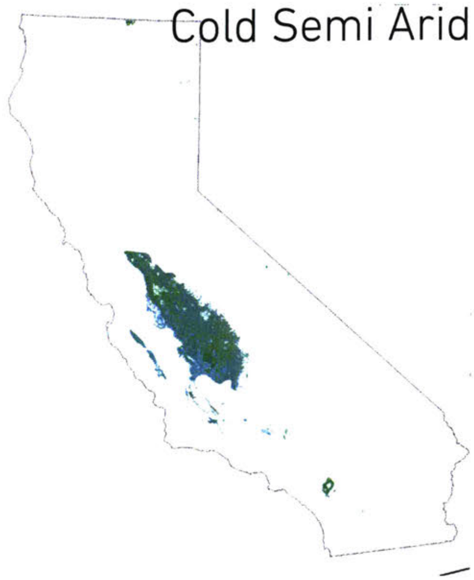
0.5% of area used for agriculture
0.1 % of total farmland in California
>55 different crops

Vertisols

25% of area used for agriculture
9.5 % of total farmland in California
>53 different crops

DATA SOURCE : Cropscape from, USDA, National Cooperative Soil Survey (NCSS)

Cold Semi Arid



27.9% of area used for agriculture
47 % of total farmland in California
>57 different crops

20.88% Almonds

19.57% Fallow / Idle Cropland

12.33% Grapes

8.64% Alfalfa

6.78% Winter Wheat

4.77% Pistachios

4.48% Cotton

4.17% Tomatoes

2.80% Walnuts

2.51% Oranges

1.38% Corn

1.25% Oats

1.11% Barley

0.95% Hay

Cold Desert

6.26% of area used for agriculture
4.5 % of total farmland in California
>47 different crops

33.50% Almonds

30.31% Fallow / Idle Cropland

10.76% Pistachios

6.55% Alfalfa

3.64% Winter Wheat

2.84% Cotton

2.55% Grapes

1.40% Tomatoes

1.13% Pomegranates

0.95% Corn

0.88% Potatoes

0.66% Barley

0.62% Walnuts

0.56% Oranges

Hot Desert

4.6% of area used for agriculture
10.5 % of total farmland in California
>7 different crops

26.26% Fallow / Idle Cropland

24.25% Alfalfa

6.79% Hay

5.06% Grapes

4.31% Almonds

3.33% Durum Wheat

2.88% Sugarbeets

2.27% Pistachios

2.20% Oranges

2.16% Citrus

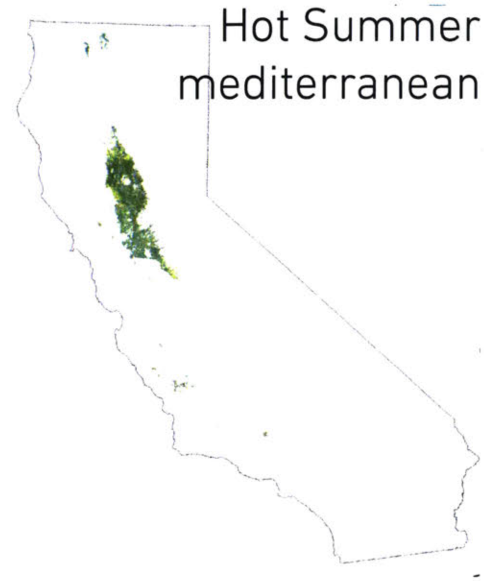
2.14% Cotton

1.93% Onions

1.86% Greens

1.83% Carrots

Hot Summer mediterranean



42% of area used for agriculture
31% of total farmland in California
>53 different crops

19.84% Fallow / Idle Cropland

18.41% Rice

11.89% Almonds

9.87% Walnuts

8.72% Alfalfa

8.16% Grapes

4.21% Hay

3.64% Tomatoes

3.38% Winter Wheat

3.22% Corn

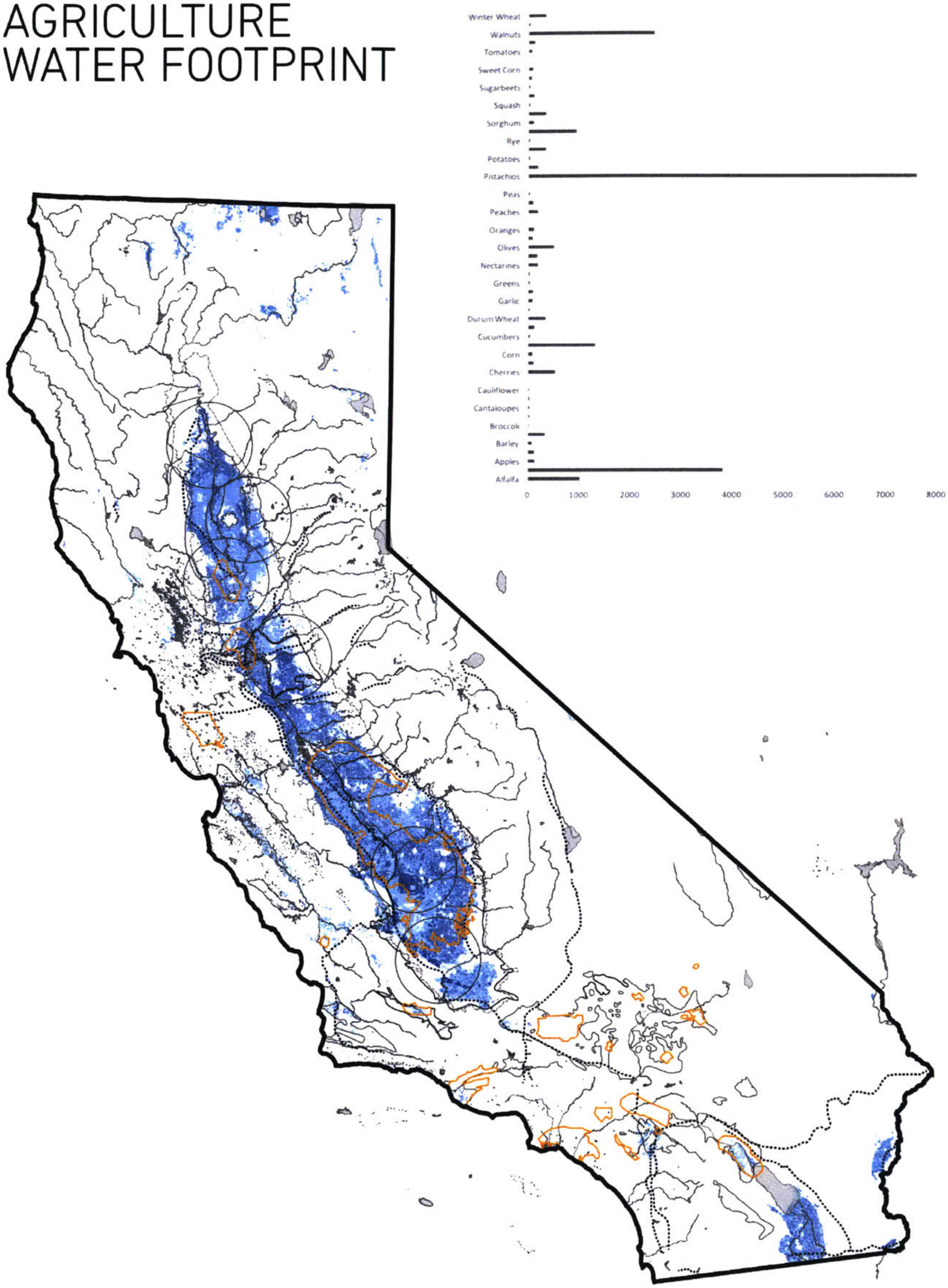
1.07% Safflower

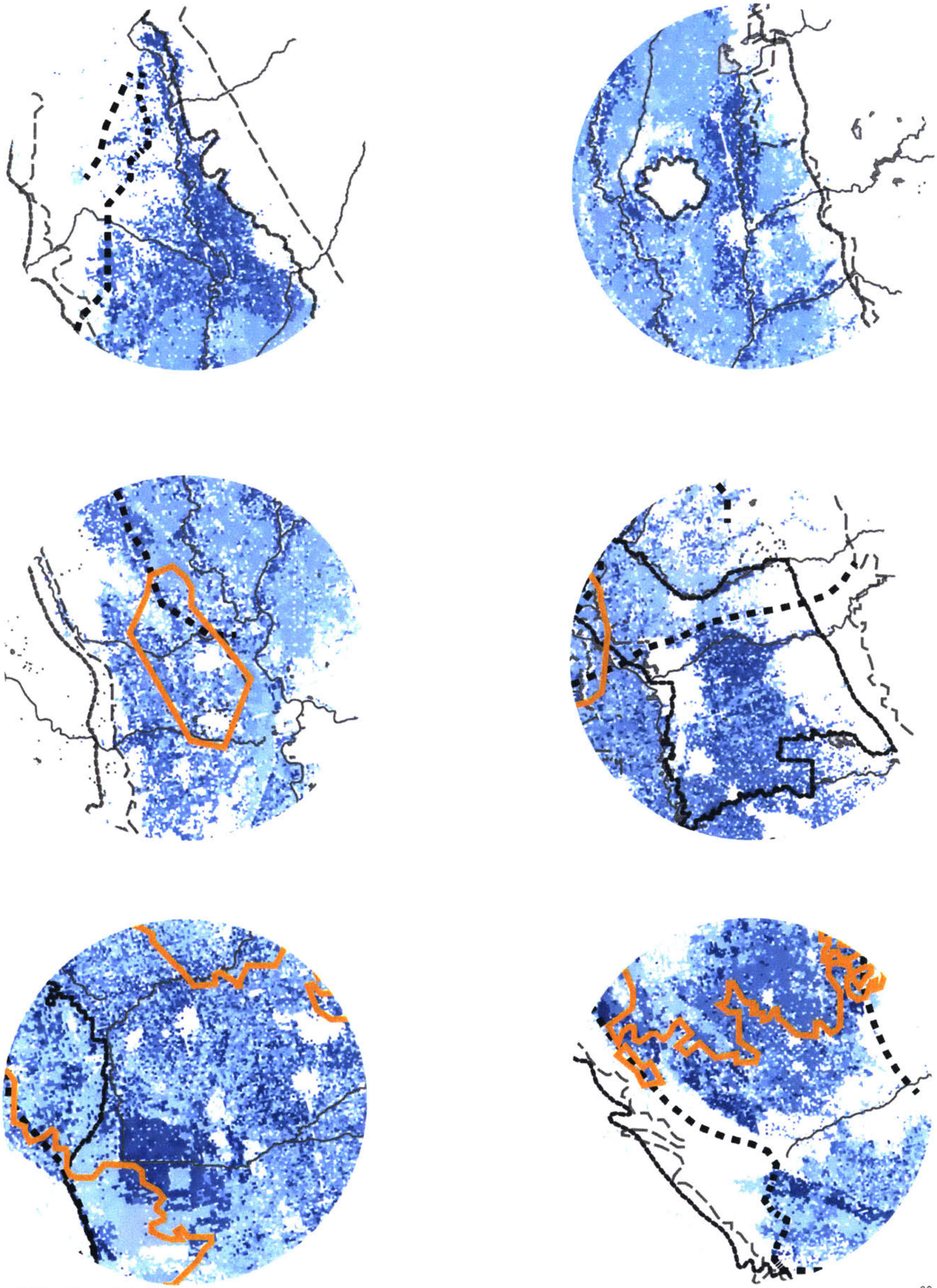
0.98% Plums

0.91% Oats

0.89% Barley

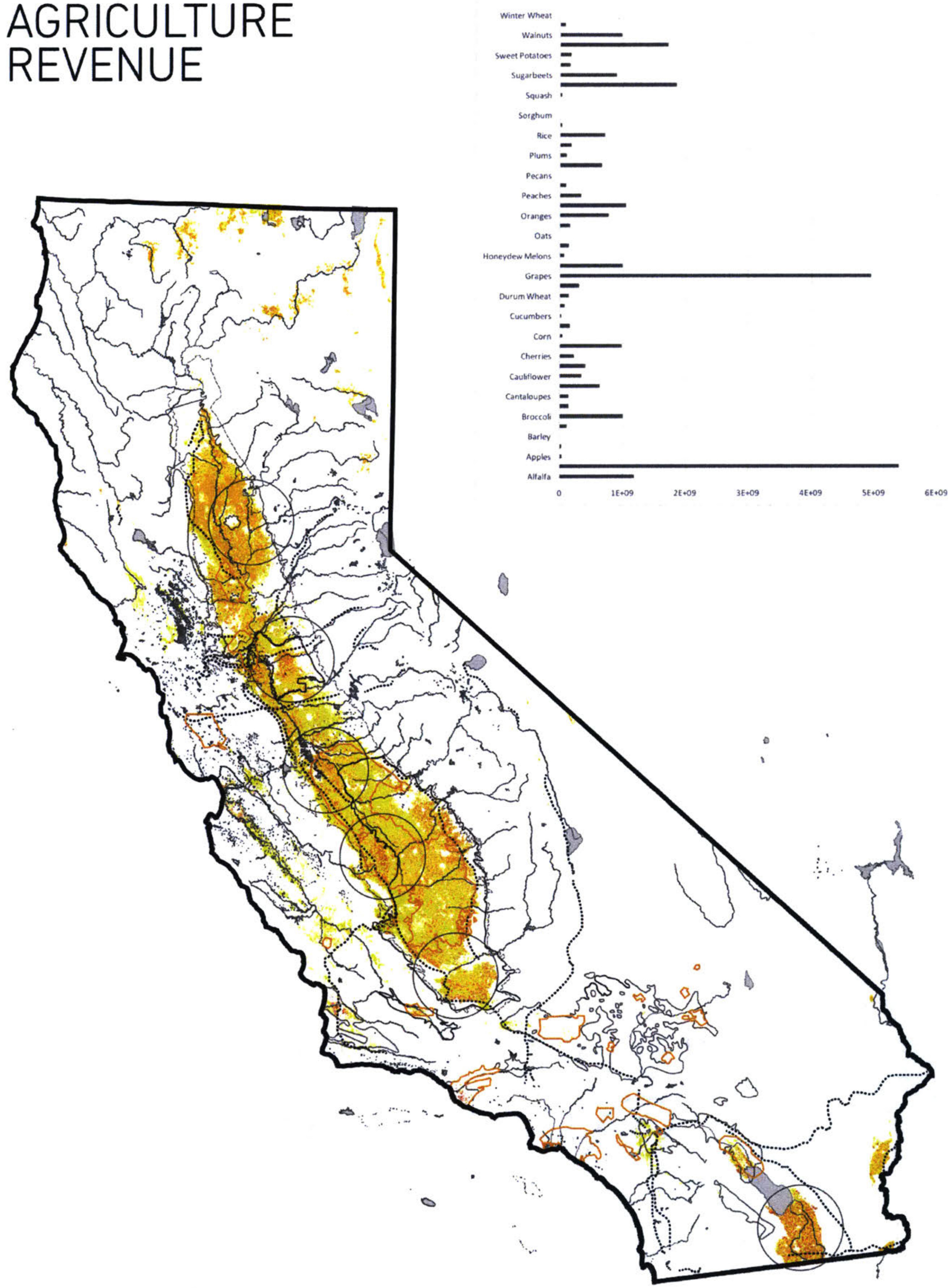
AGRICULTURE WATER FOOTPRINT

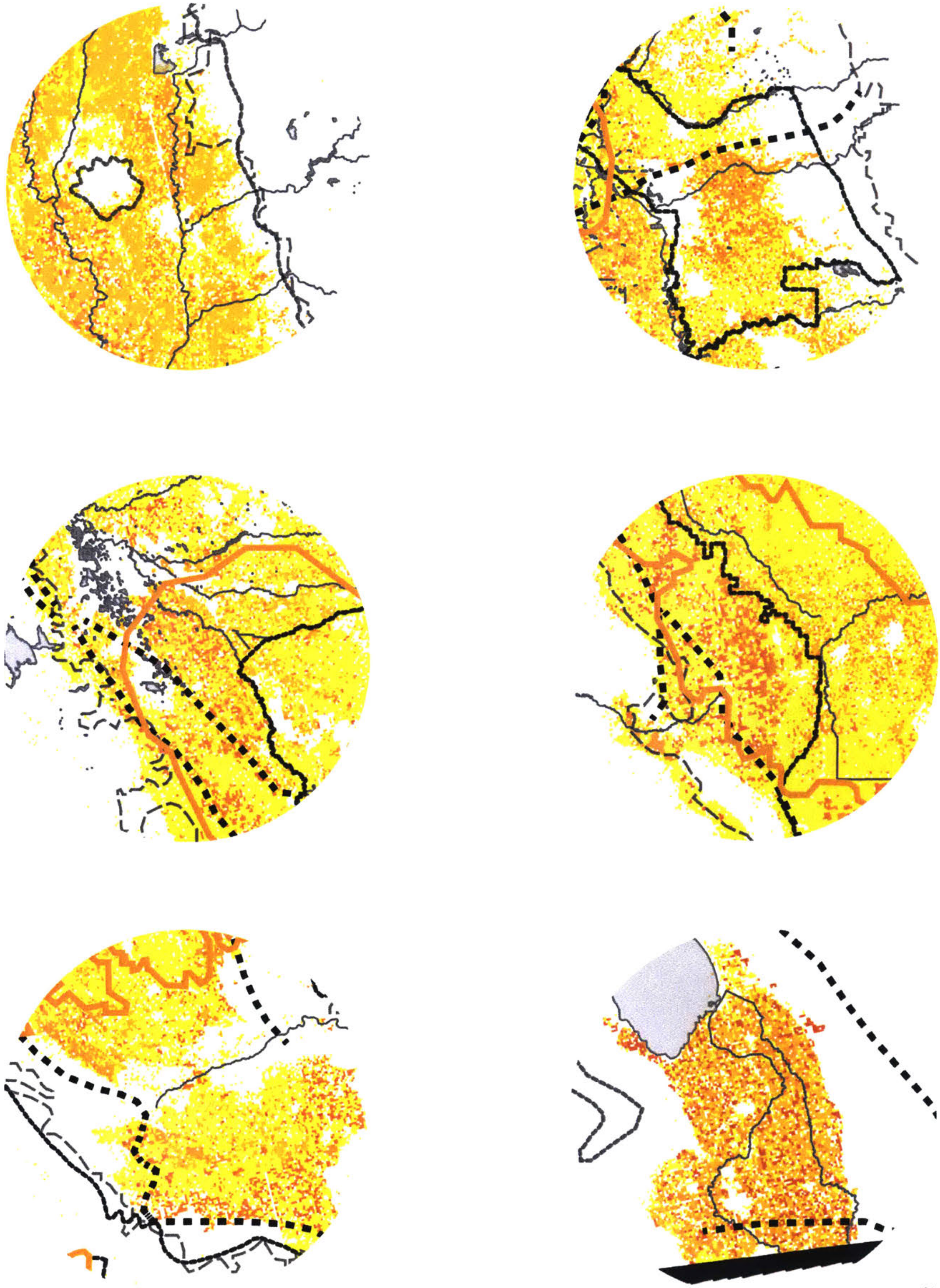




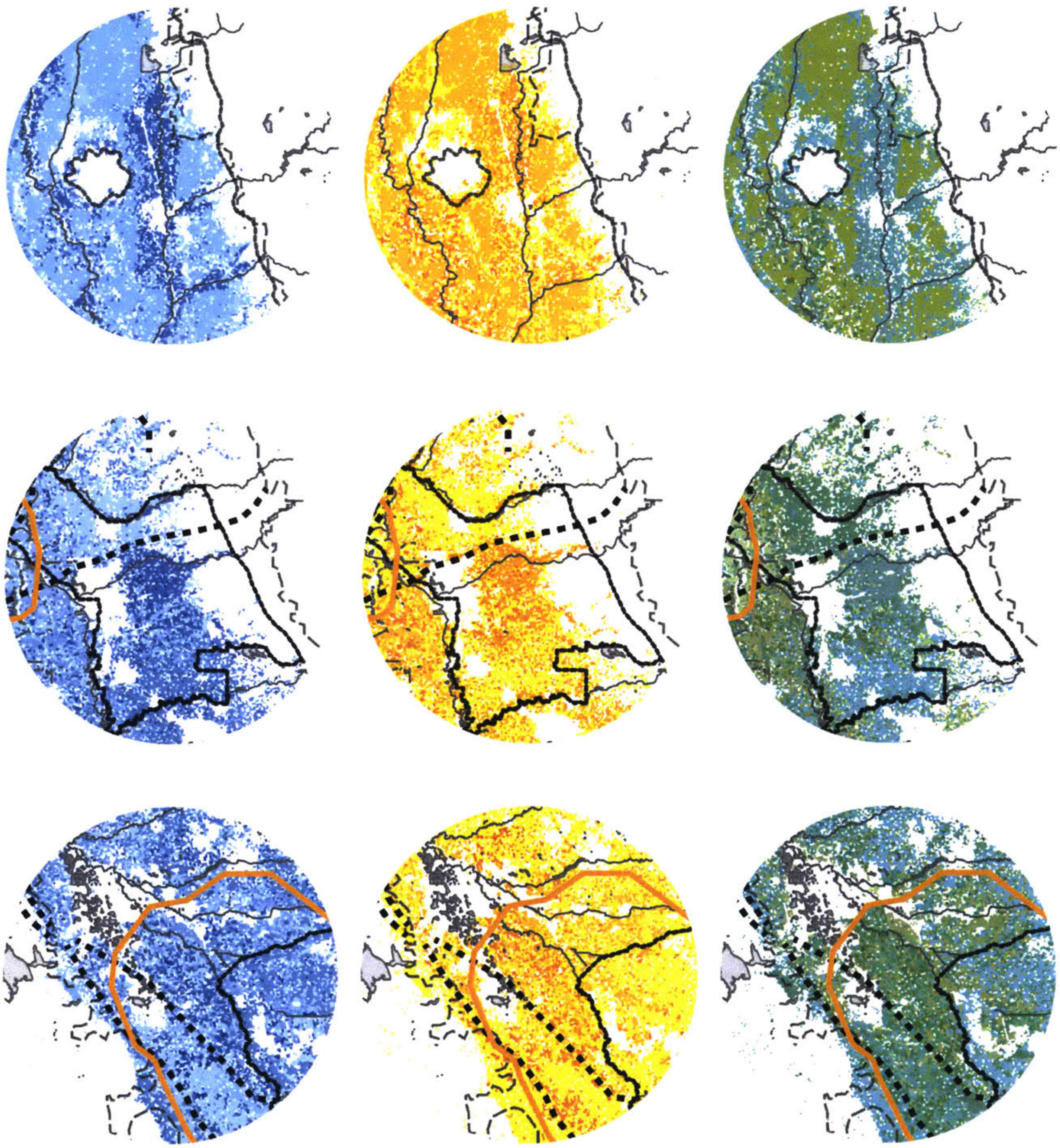
DATA SOURCE Cropscape from USDA NASS

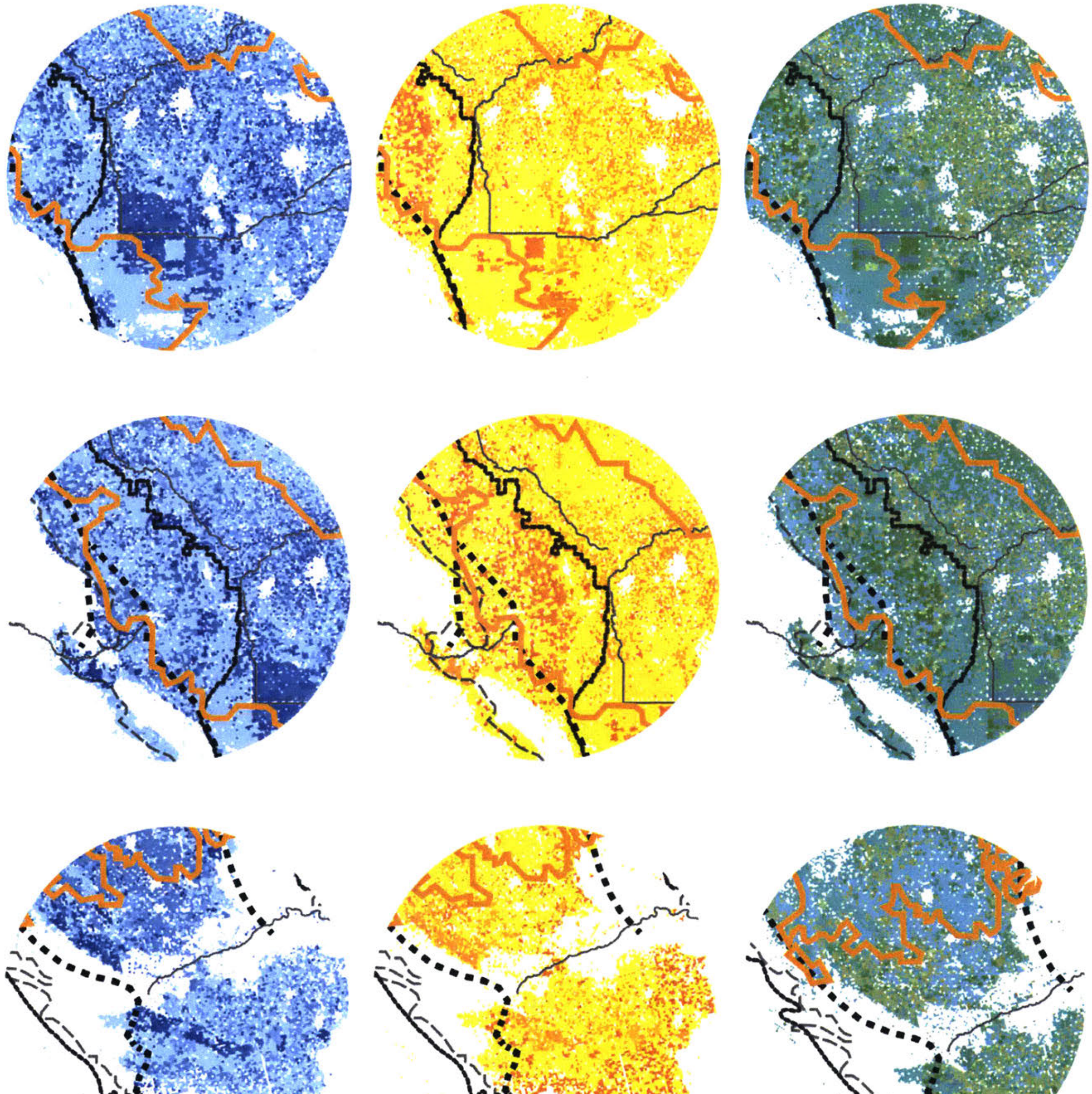
AGRICULTURE REVENUE





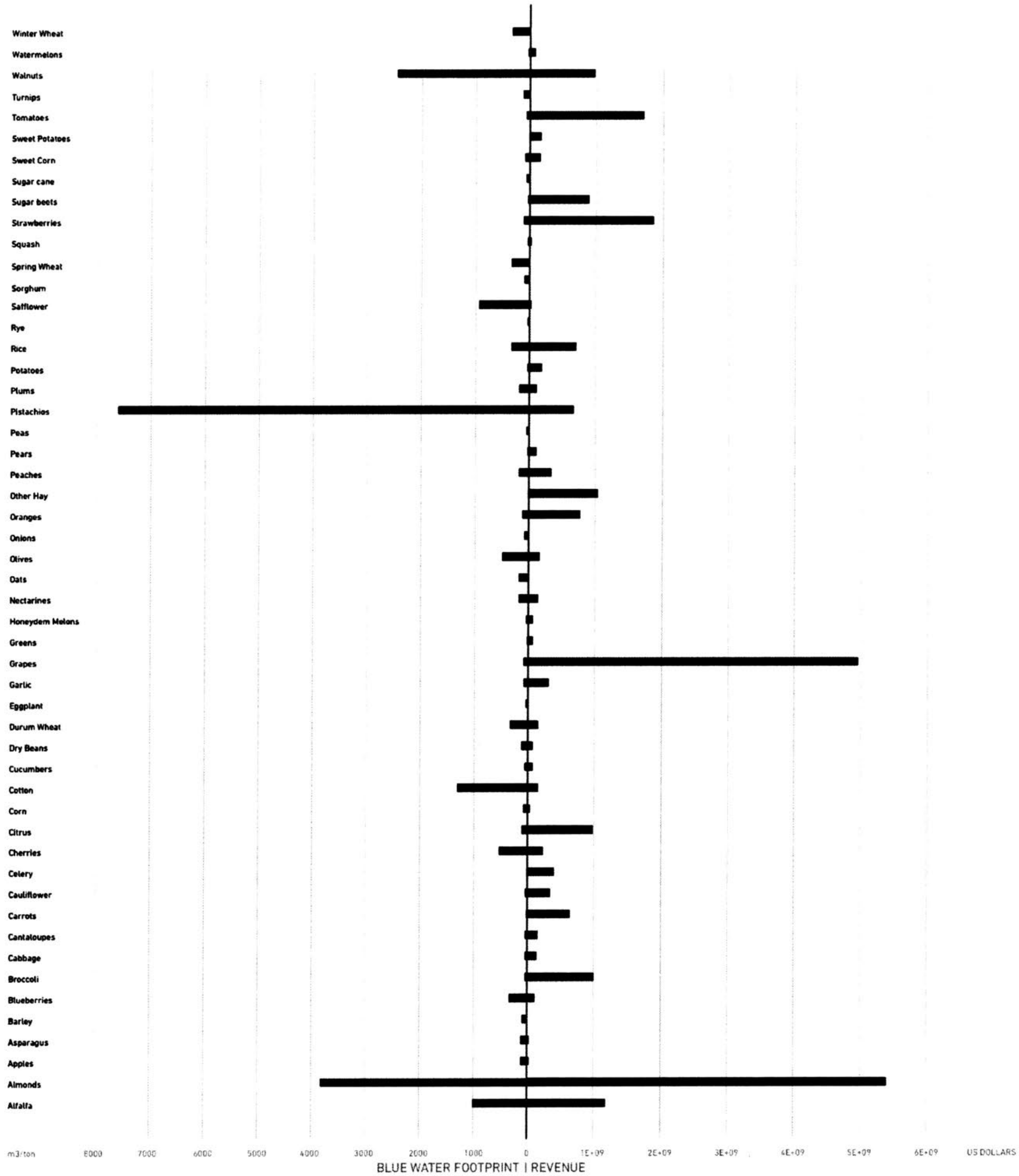
DATA SOURCE : Cropscape from USDA NASS





2015

CROP CATEGORY	CROP	WATER NEEDS	WATER FOOTPRINT BLUE WATER FOOTPRINT	YIELD	REVENUE PRICE	TOTAL REVENUE	TOTAL UTILIZED PRODUCTION
FIELD CROPS							
	Alfalfa	5.2 million acre-feet		6.9 tons/acre	$1,500 per harvested acre		5,451 (1,000 tons)
	Barley		79 m3/ton	1.197 tons/acre	$4.80 per bushel	7656000	1,595 (1,000 bushels)
	Beans, Dry Edible		125 m3/ton	1.155 tons / acre	$73.40 per cwt	75528600	1,029 (1,000 cwt)
	Corn, grain	2.2 million acre-feet	81 m3/ton	3.988 tons / acre	$4.50 per bushel	42390000	9,420 (1,000 bushels)
	Corn, sweet			10.64 tons / acre	$28 / cwt	159068000	5,681 (1,000 cwt)
	Cotton	0.9 million acre-feet	1306 m3/ton	1.608 tons / acre	$0.620 / pound	156537600	526 (1,000 bales)
	Cotton Lint		2955 m3/ton				
	Cottonseed		432 m3/ton		$284 / ton		199 tons
	Hay			5.79 tons / acre	$152 / ton	1047432000	6,891 (1,000 tons)
	Ladino Clover Seed						
	Oats		181 m3/ton	0.925 tons / acre	$3.20 per bushel	1920000	600 (1,000 bushels)
	Peppermint		63 m3/ton	0.0405 tons / acre	$24.80 per pound	4017600	162 (1,000 pounds)
	Potatoes	0.1 million acre-feet	33 m3/ton	22.008 tons / acre	$13.50 per cwt	186408000	13,808 (1,000 cwt)
	Potatoes, Sweet		5 m3/ton	19.04 tons / acre	$27.50 per cwt	172975000	6,290 (1,000 cwt)
	Rice	2.7 million acre-feet	341 m3/ton	7.9 tons / acre	$20.10 per cwt	708143100	35,231 (1,000 cwt)
	Rice, Sweet (short grain)			3.575 tons / acre			2,646 (1,000 cwt)
	Safflower	0.1 million acre-feet	938 m3/ton	1.05 tons / acre	$24.40 per cwt	27907500	128,100 (1,000 pounds)
	Sorghum		103 m3/ton				
	Sugar Beets	0.1 million acre-feet	26 m3/ton	44.7 tons / acre	$45.60 per cwt	898971428.4	1,104 (1,000 tons)
	Sunflower, non-oil		148 m3/ton	0.65 tons / acre	$34 per cwt	552500	1,820 (1,000 pounds)
	Sunflower, Oil		299 m3/ton	0.65 tons / acre	$25 per cwt	9575892.75	2,900 (1,000 pounds)
	Wheat		342 m3/ton	2.152 tons / acre	$7.90 per bushel	146900500	18,595 (1,000 bushels)
FRUIT AND NUT							
	Almond		3816 m3/ton	1.83 tons per acre	Price $2.84 / pound	5396000000	1,900,000 (1,000 pounds)
	Apples		133 m3/ton	5.2 tons per acre	Price $0.278 / pound	40310000	145,000,000 pounds
	Apricots		502 m3/ton	4.16 tons per acre	price $1,020 / ton	35190000	34,500 tons
	Avocados		283 m3/ton	3.77 tons per acre	price $1,400 / ton	274400000	196,000 tons
	Blackberries						
	Blueberries		334 m3/ton	5.45 tons / acre	Price $1.880 / pound	116842000	62,150 (1,000 pounds)
	Cherries, sweet		531 m3/ton	1.82 tons per acre	Price $3,900 / ton	232050000	59,500 tons
	Dates		1250 m3/ton	4.36 tons per acre	price $1,560 / ton	68016000	43,600 tons
	Figs		1595 m3/ton	4.44 tons per acre	price $724 / ton	21864800	30,200 tons
	Grapefruit		85 m3/ton	16 tons per acre	price $16.87 / box	64106000	3,800 boxes (1,000 boxes)
	Grapes / Vineyard	1.6 million acre-feet	97 m3/ton	8 tons per acre	price $724 / ton	4957228000	6,847,000 tons
	Grapes, Raisins		386 m3/ton	10.90 tons per acre	price $347 / ton	696429000	2,007,000 tons
	Grapes, Table			10.10 tons per acre	price $1,530 / ton	1736550000	1,135,000 tons
	Grapes, Wine		138 m3/ton	6.62 tons per acre	price $679 / ton	2515695000	3,705,000 tons
	Kiwifruit		168 m3/ton	5.93 tons per acre	price $1,340 / ton	30954000	23,100 tons
	Kumquat						
	Lemons		152 m3/ton	17.44 tons per acre	price $52.88 / box	1084040000	20,500 boxes (1,000 boxes)
	Limes		152 m3/ton				
	Mandarins		118 m3/ton				
	Nectarines		188 m3/ton	8.32 tons per acre	price $913 / ton	141515000	155,000 tons
	Olives		499 m3/ton	4.97 tons per acre	price $894 / ton	160026000	179,000 tons
	Oranges		110 m3/ton	13.8 tons per acre	price $14.31 / box	775602000	54,200 boxes (1,000 boxes)
	Peaches		188 m3/ton	14.10 tons per acre	price $562 / ton	339785200	604,600 tons
	Peaches, Clingstone			17.90 tons per acre	price $470 / ton	160082000	340,600 tons
	Peaches, Freestone			11.10 tons per acre	price $680 / ton	179520000	264,000 tons
	Pears		94 m3/ton	18.20 tons per acre	price $513 / ton	100035000	195,000 tons
	Pears, Bartlett			20.20 tons per acre	price $503 / ton	82995000	165,000 tons
	Pears, Other			11.50 tons per acre	price $567 / ton	17010000	30,000 tons
	Pecan				price $2.18 / pound	8632800	3,960 (1,000 pounds)
	Persimmons						
	Pistachios		7602 m3/ton	0.58 tons per acre	Price $2.48 / pound	669600000	270,000 (1,000 pounds)
	Plums		188 m3/ton	5.96 tons per acre	price $998 / ton	104790000	105,000 tons
	Pluots						
	Pomegranate						
	Prunes			6.79 tons per acre	price $693 / ton	221067000	319,000 tons
	Raspberries		53 m3/ton	9.9 tons per acre	Price $2.75 / pound	478225000	173,900 (1,000 pounds)
	Strawberries		109 m3/ton	38.64 tons per acre	Price $66.50 / cwt	1855948500	27,909 (1,000 cwt)
	Tangerines		118 m3/ton	15.24 tons per acre	price $45.20 / box	980840000	21,700 boxes (1,000 boxes)
	Walnuts		2451 m3/ton	2.01 tons per acre	price $1,620 / ton	976860000	603,000 tons
VEGETABLE, HERB, AND MELON							
	Artichokes		242 m3/ton	7.56 tons / acre	Price $87.80 / cwt	80600400	918 (1,000 cwt)
	Asparagus		119 m3/ton	1.456 tons / acre	Price $139 / cwt	32526000	234 (1,000 cwt)
	Bell peppers			25.48 tons / acre	Price $49 / cwt	367892000	7,508 (1,000 cwt)
	Broccoli		21 m3/ton	10.08 tons / acre	Price $48.20 / cwt	1006416000	20,880 (1,000 cwt)
	Brussels Sprout		21 m3/ton				
	Cabbage		26 m3/ton	23.8 tons / acre	Price $24.50 / cwt	143692500	5,865 (1,000 cwt)
	Carrots		28 m3/ton	17.808 tons / acre	Price $32.70 / cwt	638631000	19,530 (1,000 cwt)
	Cauliflower		21 m3/ton	10.08 tons / acre	Price $59.40 / cwt	345351600	5,814 (1,000 cwt)
	Celery			34.72 tons / acre	Price $25.10 / cwt	406118000	16,180 (1,000 cwt)
	Chile / Chili peppers		42 m3/ton	21.28 tons / acre	Price $31.50 / cwt	76356000	2,424 (1,000 cwt)
	Cilantro						
	Cucumber		42 m3/ton	11.48 tons / acre	Price $29.60 / cwt	21252800	718 (1,000 cwt)
	Daikon						
	Eggplant		33 m3/ton				
	Escarole / Endive						
	Garlic		81 m3/ton	9.24 tons / acre	Price $76.70 / cwt	305035900	3,977 (1,000 cwt)
	Kale						
	Lettuce, Head		28 m3/ton	21.28 tons / acre	Price $30.40 / cwt	999248000	32,870 (1,000 cwt)
	Lettuce, Leaf			14.56 tons / acre	Price $59.10 / cwt	703762800	11,908 (1,000 cwt)
	Lettuce, Romaine			16.8 tons / acre	Price $37.50 / cwt	714375000	19,050 (1,000 cwt)
	Melons, Cantaloupe			16.8 tons / acre	Price $17.40 / cwt	146160000	8,400 (1,000 cwt)
	Melons, Honeydew			15.12 tons / acre	Price $22.20 / cwt	64135800	2,889 (1,000 cwt)
	Melons, Watermelon		25 m3/ton	29.68 tons / acre	Price $14.50 / cwt	79924000	5,512 (1,000 cwt)
	Mushroom, Agaricus						
	Onions		88 m3/ton				18,765 (1,000 cwt)
	Onions, Green (Scallions)		44 m3/ton				
	Pumpkin		24 m3/ton	13.44 tons / acre	Price $17.80 / cwt	26059200	1,464 (1,000 cwt)
	Snap beans		54 m3/ton	6.72 tons / acre	Price $70.90 / cwt	37435200	528 (1,000 cwt)
	Spinach		14 m3/ton	7.28 tons / acre	Price $44.40 / cwt	189676800	4,272 (1,000 cwt)
	Squash		24 m3/ton	8.96 tons / acre	Price $34.50 / cwt	29808000	864 (1,000 cwt)
	Tomatoes	0.1 million acre-feet	63 m3/ton				14,362,491.29 tons
	Watercress						


Winter Wheat
Watermelons
Walnuts
Turnips
Tomatoes
Sweet Potatoes
Sweet Corn
Sugar cane
Sugar beets
Strawberries
Squash
Spring Wheat
Sorghum
Safflower
Rye
Rice
Potatoes
Plums
Pistachios
Peas
Pears
Peaches
Other Hay
Oranges
Onions
Olives
Oats
Nectarines
Honeydem Melons
Greens
Grapes
Garlic
Eggplant
Durum Wheat
Dry Beans
Cucumbers
Cotton
Corn
Citrus
Cherries
Celery
Cauliflower
Carrots
Cantaloupes
Cabbage
Broccoli
Blueberries
Barley
Asparagus
Apples
Almonds
Alfalfa
m3/ton
8000
7000
6000
5000
4000
3000
2000
1000
0
1E+09
2E+09
3E+09
4E+09
5E+09
6E+09
US DOLLARS
BLUE WATER FOOTPRINT | REVENUE


Credit John Chacon / California Department of Water Resources

PROPOSAL

REUSE WATER

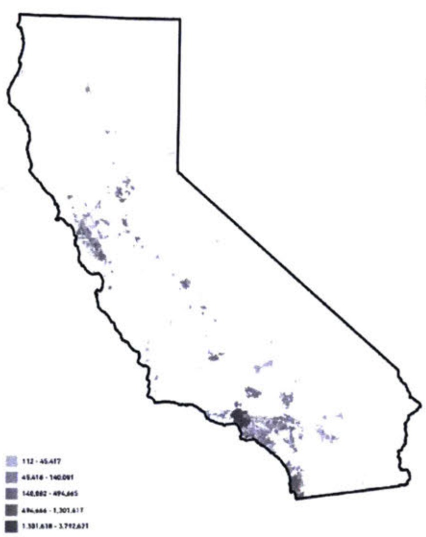
RESTORE SOIL MOISTURE

RELOCATE CROPS

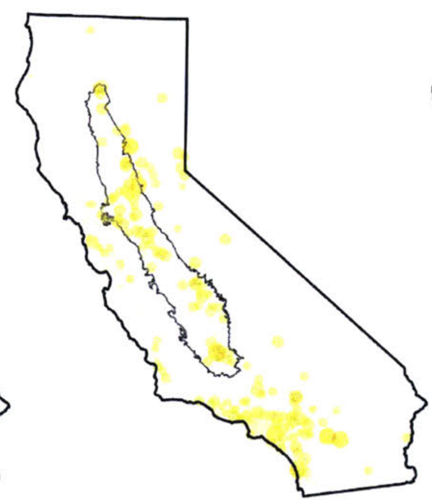
5.1 REUSE

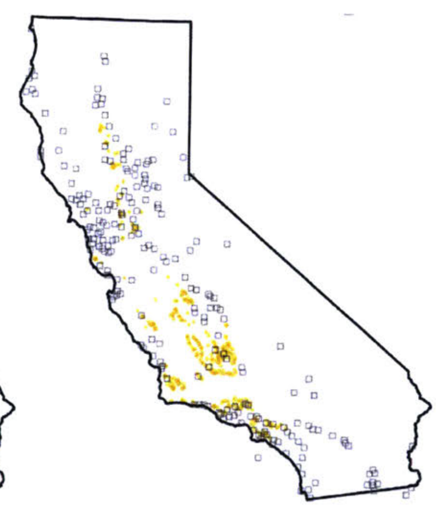
Guidelines

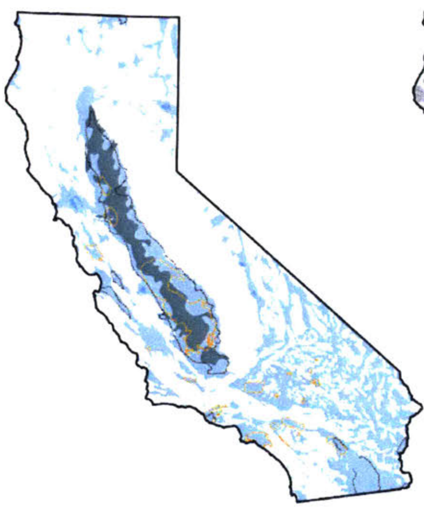
- Can be used both in and out of the irrigation area as long as there are no problems of overdraft or subsidence.
- Near urban centers with large residential water consumption and wastewater treatment.
- Must be over aquifers or discharge.
- Good soil
- Lower precipitation



Population

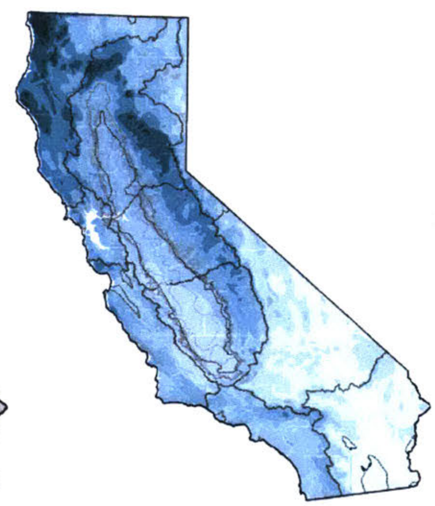

Residential water use


Wastewater treatment

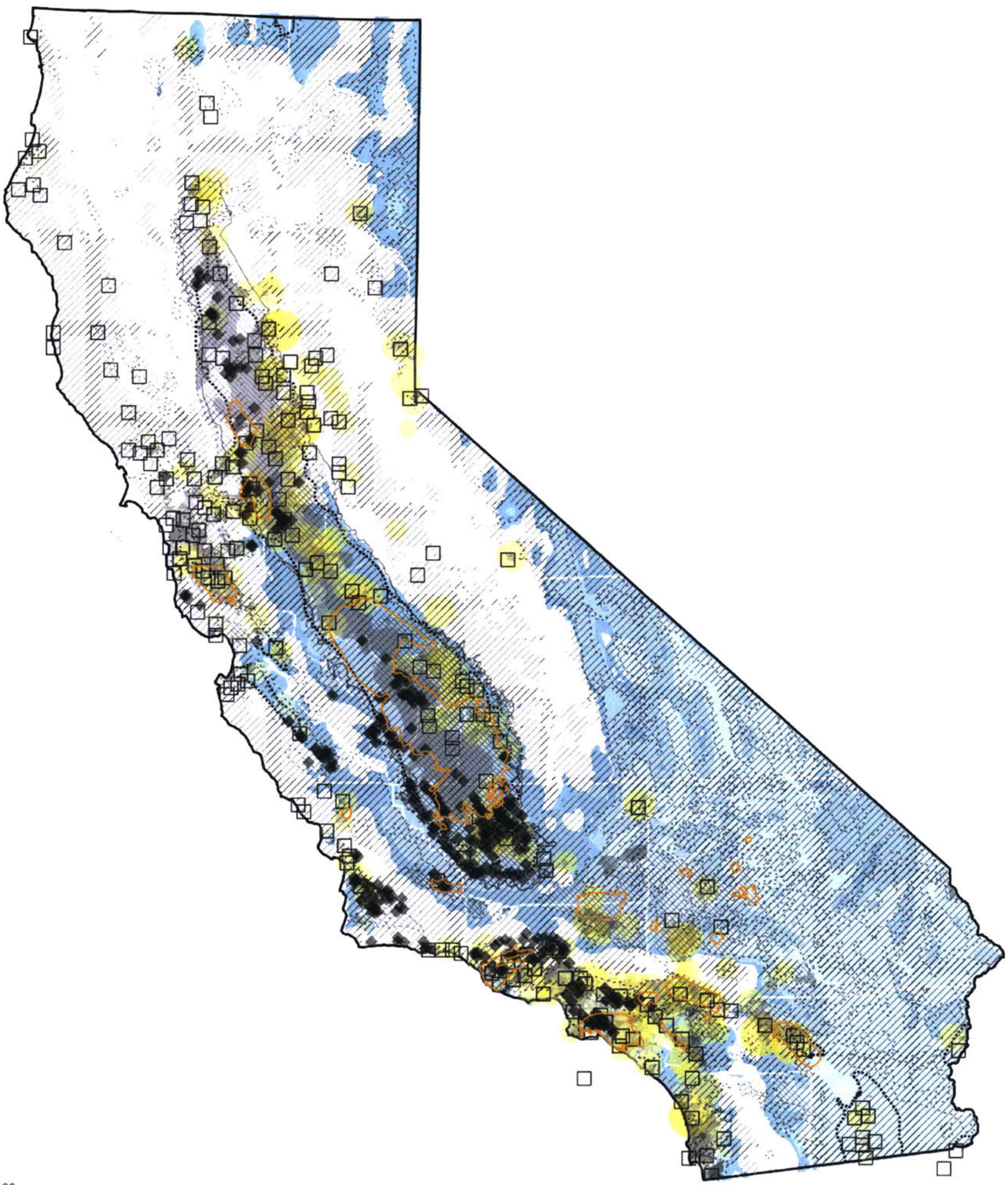


Aquifers

Soil



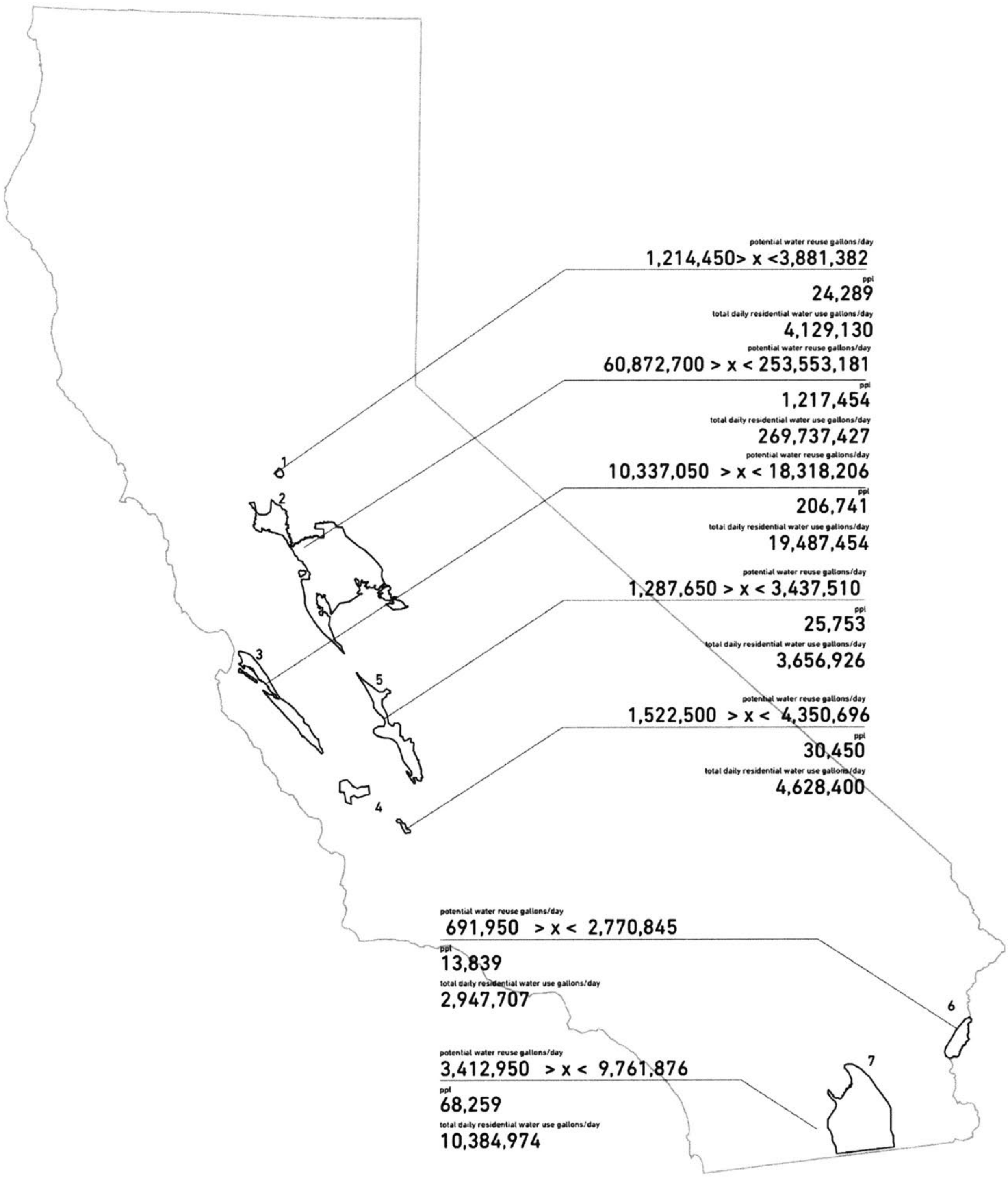
Precipitation

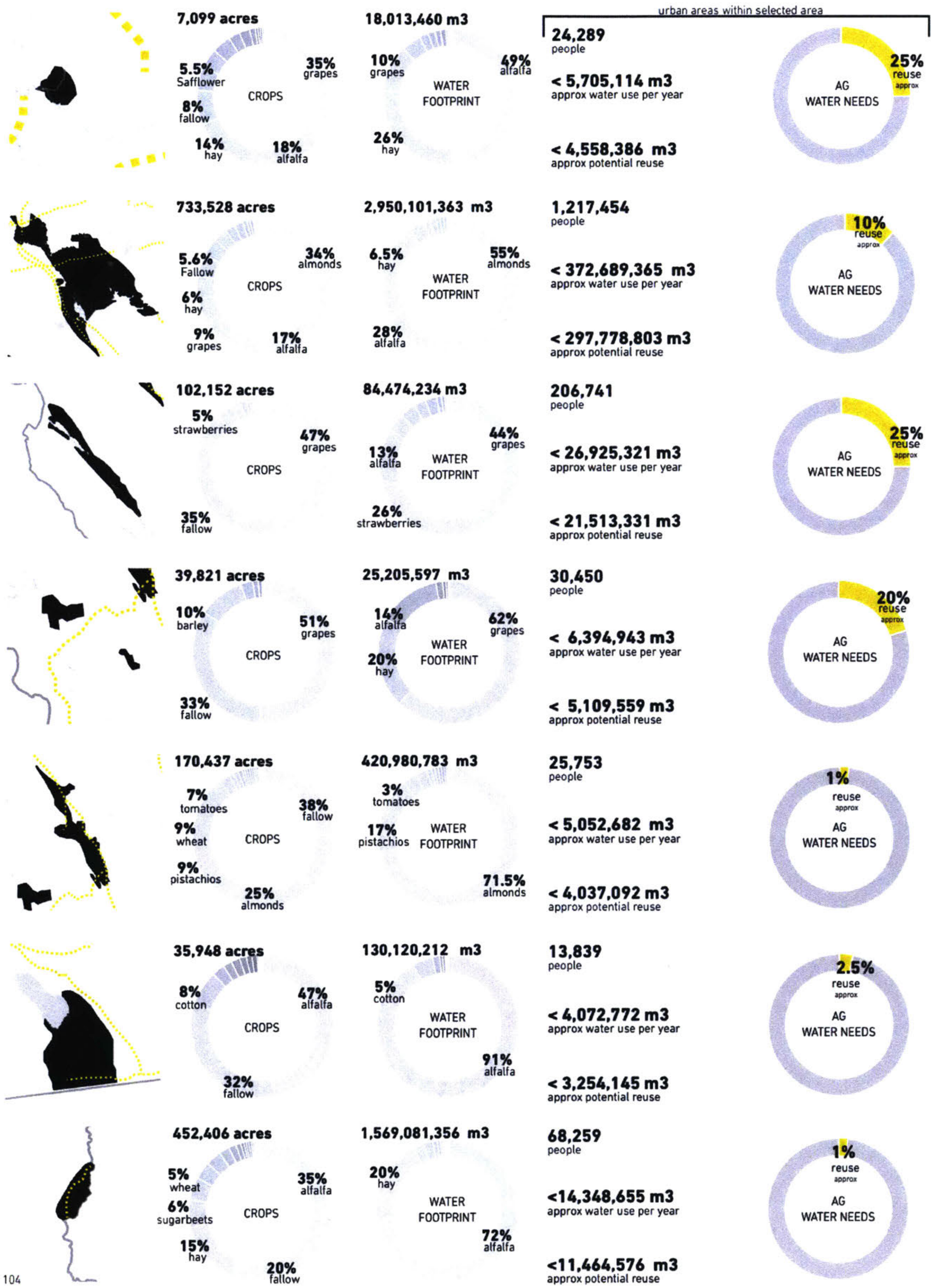


1,586,785 people

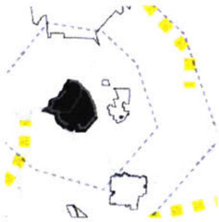
314,972,018 gallons daily residential water use

352,814 acre feet annually




urban areas within selected area
7,099 acres
5.5% Safflower
35% grapes
CROPS
8% fallow
14% hay
18% alfalfa
18,013,460 m3
10% grapes
49% alfalfa
WATER FOOTPRINT
26% hay
24,289 people
< 5,705,114 m3 approx water use per year
< 4,558,386 m3 approx potential reuse
AG WATER NEEDS
25% reuse approx
733,528 acres
5.6% Fallow
34% almonds
CROPS
6% hay
9% grapes
17% alfalfa
2,950,101,363 m3
6.5% hay
55% almonds
WATER FOOTPRINT
28% alfalfa
1,217,454 people
< 372,689,365 m3 approx water use per year
< 297,778,803 m3 approx potential reuse
10% reuse approx
AG WATER NEEDS
102,152 acres
5% strawberries
47% grapes
CROPS
35% fallow
84,474,234 m3
44% grapes
13% alfalfa
WATER FOOTPRINT
26% strawberries
206,741 people
< 26,925,321 m3 approx water use per year
< 21,513,331 m3 approx potential reuse
AG WATER NEEDS
25% reuse approx
39,821 acres
10% barley
51% grapes
CROPS
33% fallow
25,205,597 m3
14% alfalfa
62% grapes
WATER FOOTPRINT
20% hay
30,450 people
< 6,394,943 m3 approx water use per year
< 5,109,559 m3 approx potential reuse
20% reuse approx
AG WATER NEEDS
170,437 acres
7% tomatoes
38% fallow
9% wheat
CROPS
9% pistachios
25% almonds
420,980,783 m3
3% tomatoes
17% pistachios
WATER FOOTPRINT
71.5% almonds
25,753 people
< 5,052,682 m3 approx water use per year
< 4,037,092 m3 approx potential reuse
1% reuse approx
AG WATER NEEDS
35,948 acres
8% cotton
47% alfalfa
CROPS
32% fallow
130,120,212 m3
5% cotton
WATER FOOTPRINT
91% alfalfa
13,839 people
< 4,072,772 m3 approx water use per year
< 3,254,145 m3 approx potential reuse
2.5% reuse approx
AG WATER NEEDS
452,406 acres
5% wheat
35% alfalfa
6% sugarbeets
CROPS
15% hay
20% fallow
1,569,081,356 m3
20% hay
WATER FOOTPRINT
72% alfalfa
68,259 people
<14,348,655 m3 approx water use per year
<11,464,576 m3 approx potential reuse
1% reuse approx
AG WATER NEEDS

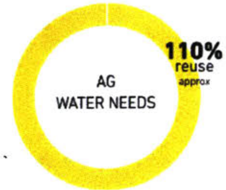
urban areas within a 30 km radius | urban areas within a 50 km radius

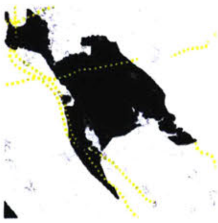


80,280
people

< 25,124,347 m3
approx water use per year

< 20,074,353 m3
approx potential reuse





1,308,149
people

< 410,428,858 m3
approx water use per year

< 327,932,657 m3
approx potential reuse

1,398,442
people

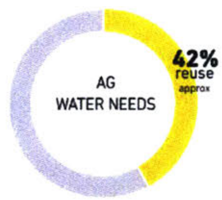
< 435,971,395 m3
approx water use per year

< 348,341,144 m3
approx potential reuse

333,064
people

< 45,219,209 m3
approx water use per year

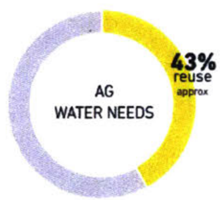
< 21,513,331 m3
approx potential reuse



60,459
people

< 13,485,060 m3
approx water use per year

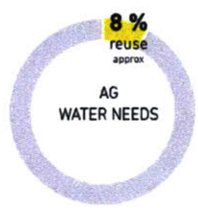
< 10,774,563 m3
approx potential reuse



142,805
people

< 41,499,629 m3
approx water use per year

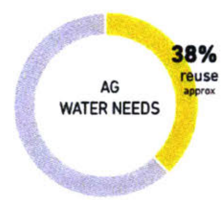
< 33,158,203 m3
approx potential reuse

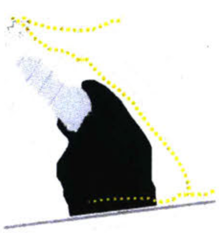


765,918
people

< 201,062,058 m3
approx water use per year

< 160,648,584 m3
approx potential reuse





California has been using recycled water for over 100 years now for different purposes including agriculture irrigation, landscape irrigation, aquifer recharge, industrial and environmental uses. In 2002, according to the California Department of Water Resources, 46% of the recycled water in the state was being used for agriculture.

Given the precedent, what this thesis proposes is to use the existing infrastructure for wastewater management to strategicallly implement a Soil Aquifer Treatment (SAT) system in areas with certain hydrological, geological and climatic conditions. Based on this study the ideal conditions for this system would be in areas with lower precipitation (under 15 inches of rain), and high yield capacity soils (alfisols, mollisols, entisols, histosols, aridisols and utisols). The area should also be located over an aquifer because of the nature of the SAT system and to minimize costs of building more infrastructure to carry water.

A critical factor for this proposal is that it can only be implemented in areas with certain proximity to urban centers (the constant providers of wastewater). Another important factor regarding hydrological resouces is that this system should not be encouraged in areas with overdraft or sudsidence. Areas presenting these problems should restore groundwater balance by using wastewater injection for an extended period of time before considering implementing an SAT system for irrigation.

To estimate potential reuse, each of these areas was analyzed individually considering the cities within the same area, a 30 km radius and a 50 km radius.

In order to keep infrastructure investment to a minimum only the cities which shared groundwater systems with the selected area were considered. This should allow wastewater to be seeped into the aquifer in one location and extracted a few kilometers away, instead of building pipelines to transport it. Using the existing injections wells for this would bring costs to a bare minimum, however, infiltration basins such as the ones used in Shafdan are strongly recommended since the percolation process will give the water one additional stage of treatment.

The specific population and residential water consumption of each city was used to estimate total water consumption in each area. The data used corresponds to the summer of 2014, a drought year. This shows the potential for water reuse in a difficult scenario and where agriculture is demanding the most water. This data was used to estimate the amount of wastewater produced by each city. According to the EPA (2006) between a 94% and 98% of the watewater used for residential purposes is discharged as wastewater. This thesis works on the assumption that it is a 94% and that all this wastewater is being captured a treated. After this, the potential for reuse was estimated using as a reference the statistics from Shafdan which indicate that 85% of the wastewater treated can be reused. Using previously generated data on water footprint per crop, the specific agricultural water needs for each area were determined and compared to the reuse potential. As seen on the previous graphs. The results indicate that reuse is a viable option for some areas, some others would need to extend to the second or third radius and some would need to find water sources other than reuse.

As for implementation, the system was originally envisioned as top to bottom approach as it would require the creation of new reuse policies, especifically targeted to agricultural reuse , and the creation of an enforcing entity potentially within the existing California Department of Water resources partnering with with the individual water agencies currently managing each of the Water Districts included in the selected areas.

Control of water use and enforcement of water restrictions has long been a challenge for the state of California. Therefore this part of the implementation process would be considered the most critical and perhaps the main reason why a system like this hasn't been implemented yet.

As previously mentioned, when it comes to new infrastructure the main elements would be the recommended infiltration basins which have to be built near the existing wastewater treatment plants. It is important to point out that the system would still work by using the existing injection wells instead of building the basins. The level of depuration, however, would not be the same.

As for making the argument in favor of reusing residential wastewater instead of turning to other potential water sources such as desalination; reusing wastewater is less likely to lead to salinization of the soil which is extremely difficult and expensive to reverse.

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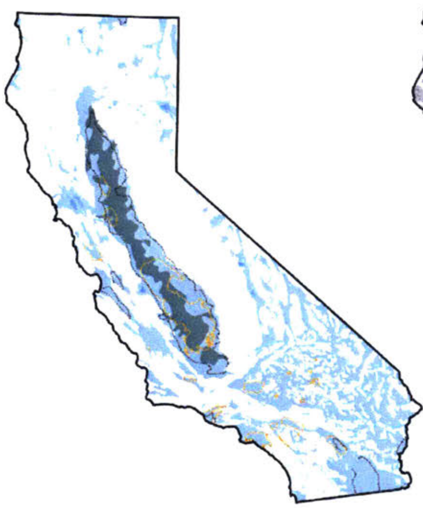
5.2 KEYLINE

Guidelines

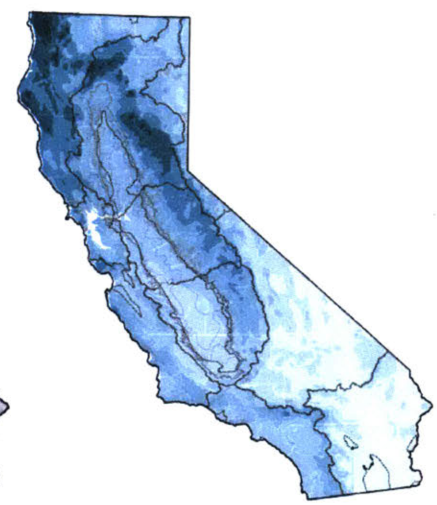
- Outside of irrigation area or within irrigation in areas presenting overdraft and/or subsidence.
- Can be used both with and without aquifers underneath or discharge.
- Good soil
- +/- precipitation

Topography

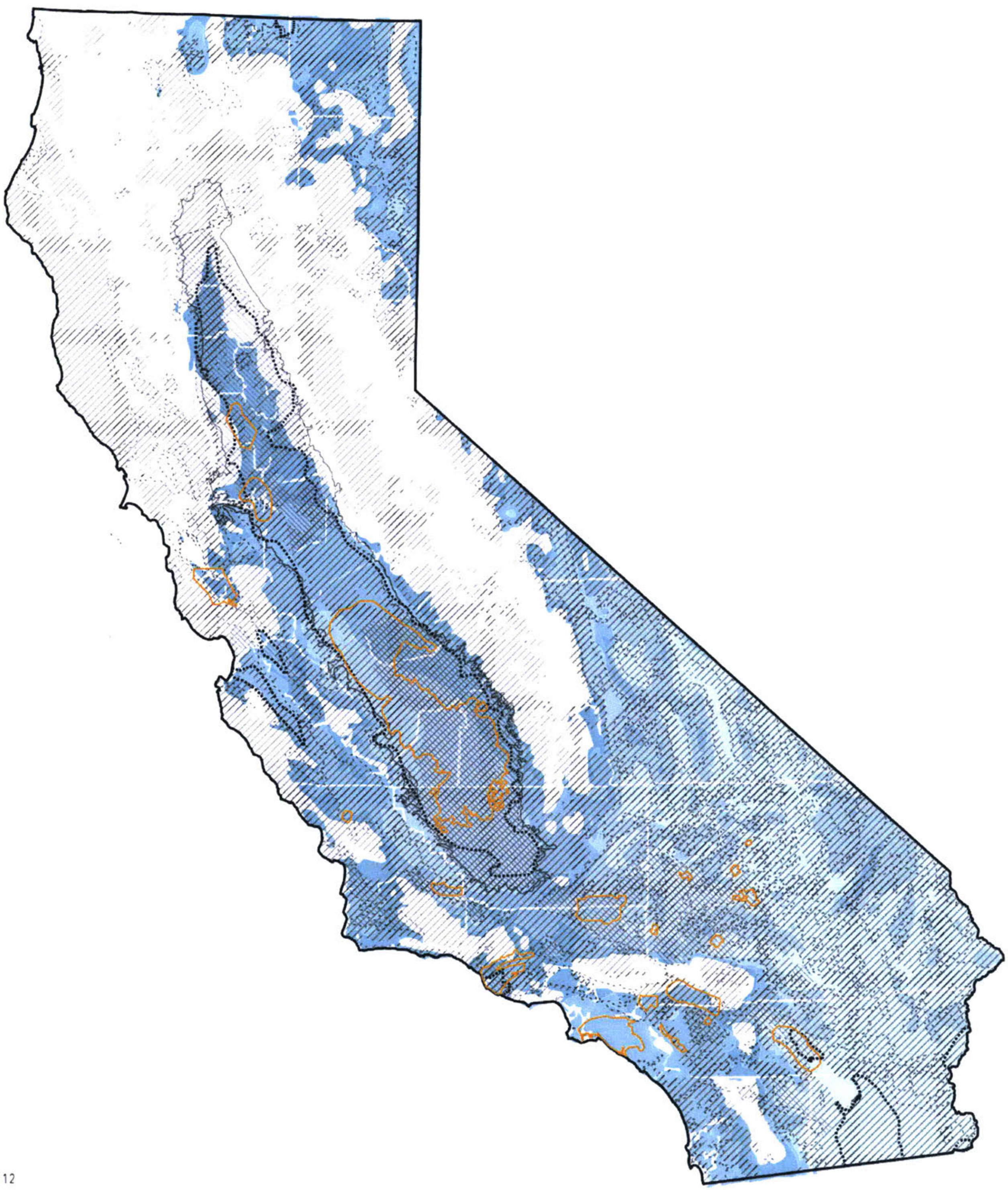


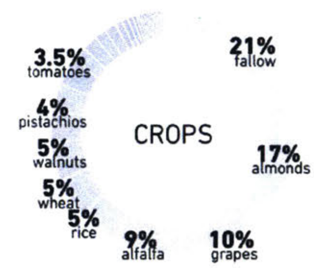
Aquifers

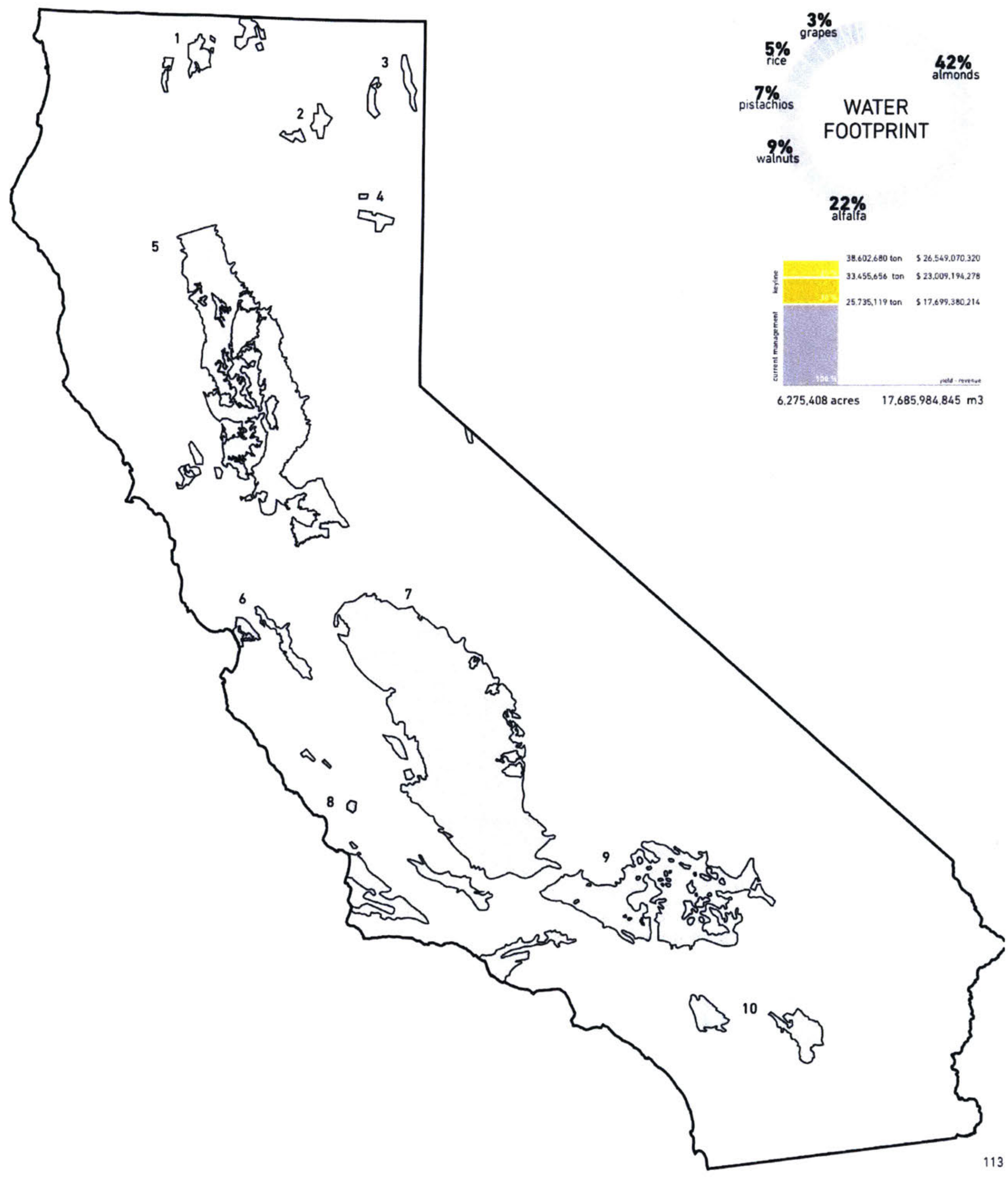
Soil



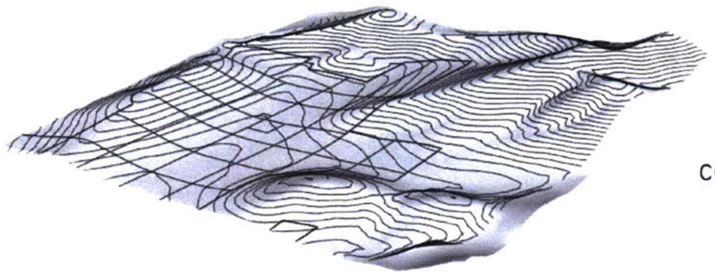
Precipitation



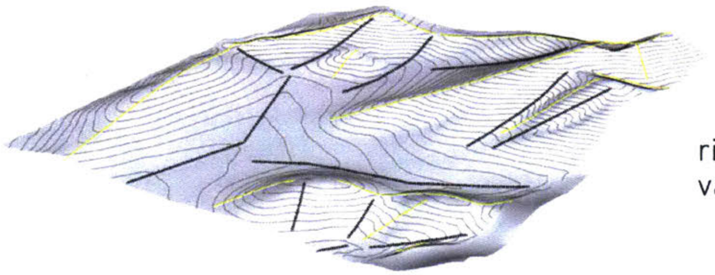

CROPS
21% fallow
17% almonds
10% grapes
9% alfalfa
5% rice
5% wheat
5% walnuts
4% pistachios
3.5% tomatoes


1
2
3
4
5
6
7
8
9
10
WATER FOOTPRINT
42% almonds
22% alfalfa
9% walnuts
7% pistachios
5% rice
3% grapes
keyline
current management
38.602.680 ton
$ 26.549.070.320
33.455,656 ton
$ 23.009.194,278
25.735,119 ton
$ 17.699.380.214
yield - revenue
6,275,408 acres
17,685,984,845 m3

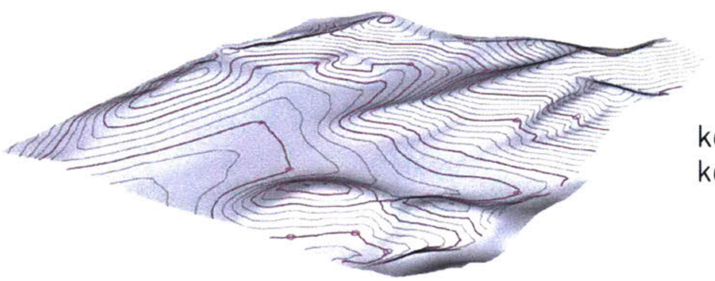
current state



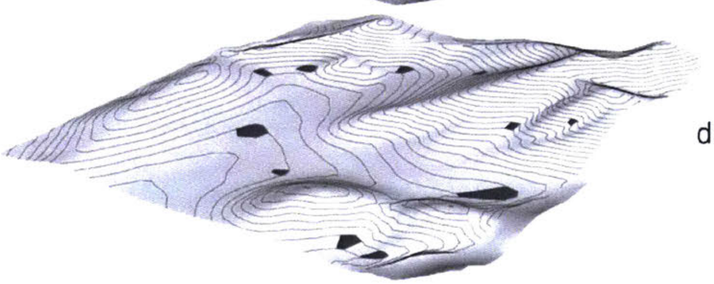
contours



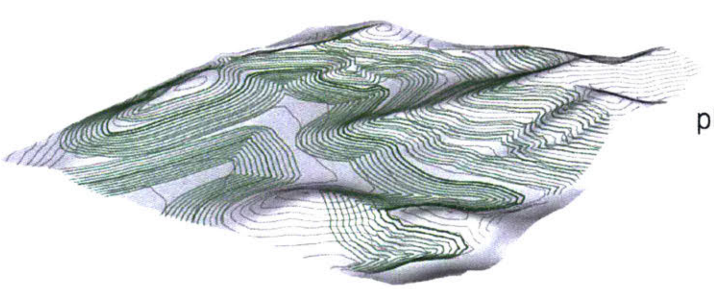
ridges and valleys



keylines and keypoints



dams



plowing

Crop : Almonds
Area: 365.31 acres

Current State
Usual yield: 1.83 ton/acre
Estimated yield: 668.51 tons
Estimated revenue: $2,214,832

Implementing Keyline
Estimated yield: 851.73 - 982.76 tons
Estimated revenue: $ 2,821,834 - $ 3,255,962

From the analysis, several areas were identified where making a better use of precipitation should be considered the main option to increase water availability. Some of this areas are presenting overdraft or subsidence problems, some do not have direct access to water infrastructure for irrigation, and others do not have direct access to aquifers for groundwater extraction.
From the case studies, this thesis suggests that a system like Keyline design be implemented. The landscape based patterning allows to capture and maintain in the soil as much water from rainfall as possible. Excess water is collected in large ponds and used later on for irrigation. Plowing for an off contour cultivation reverses the natural flow and concentration of water into valleys, and drifts it to adjacent ridges making water availability in the soil more consistent through the farm. Having more water in the soil, in scenarios of scarcity, will increase overall yields. Keyline has been deemed responsible for incrementing yields between 30% and 50% in some Farms in Australia. Using this data an alternative scenario was created for an almond farm just outside of Porterville, California. Using the Keyline system it was estimated that even while loosing some area for the creation of the dams and keeping the almond orchard within the same boundary, yield and revenue would be higher than the current state.

For farms where changing plowing patterns is not financially feasible, the recommendation would be to implement other rainwater harvesting strategies such as check dams which are commonly used in arid and semi arid regions such as Rajasthan, India.

As for implementation, this proposal can work both ways. As a bottom up system, each farmer could implement Keyline in their property simply by changing the plowing pattern and building the retention ponds. It would require further analysis for each individual case to determine if it is viable as a private investment.

This proposal could also be implemented with a top-down approach. Since plowing costs are the main restriction for implementing this system, creating a subsidy for farmers to apply it would be the most effective implementation strategy. Subsidies have a long history of nudging agricultural production in certain directions and therefore it is safe to assume that it would have a similar effect on this case.

Applying precipitation retention strategies is in everyone's best interest. Not only will higher levels of moisture in the soil lead to higher yields, but it can also help as an aquifer recharge strategy and reduce the posibility of fires.

Keyline and check dams are both highly reccommended for the entire state of California but especially the areas selected in this proposal.

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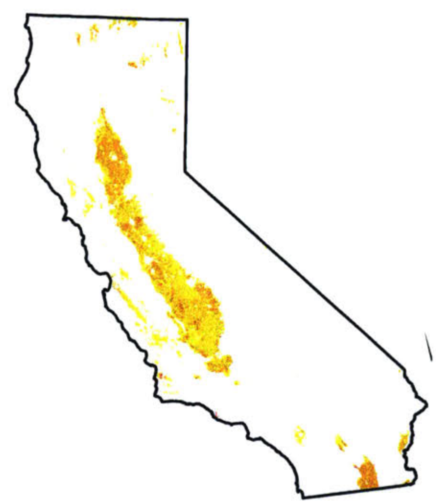
5.3 RELOCATING

Guidelines

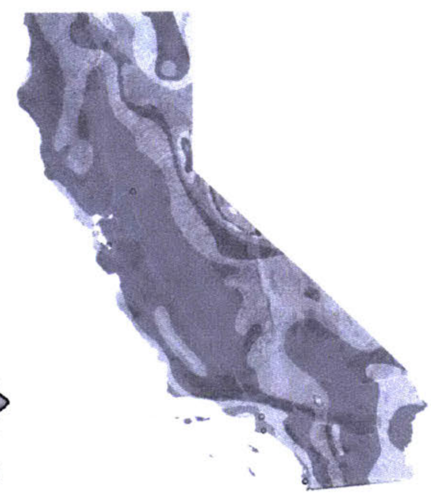
- Considering soil taxonomy
- Considering plant hardiness
- Considering water needs
- Considering revenue



Revenue

Water needs

Soil



Plant Hardiness

SOIL

The ideal soil - crop pairings where identified for most of the crops analysed on this thesis.

The soil type classification system based on texture was chosen for this proposal because it was the only one that established a clear relationship between a specific soil type and a specific crop. Picking the right crop for a specific soil involves a more thorough analysis including nutrient availability, this should be considered one of the limitiations for this specific thesis.

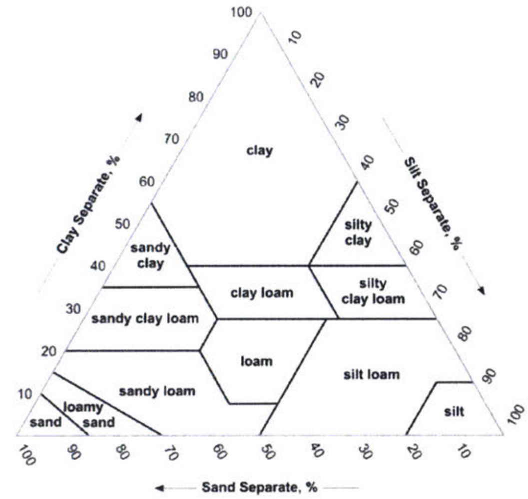


Image source: USDA

PLANT HARDINESS

Is a standard by which farmers can determine what crops are more likely to thrive in a specific location. The plant hardiness zones are based on temperature, indicating the average minimum for each area. The USDA recently made this data available for all states including California.

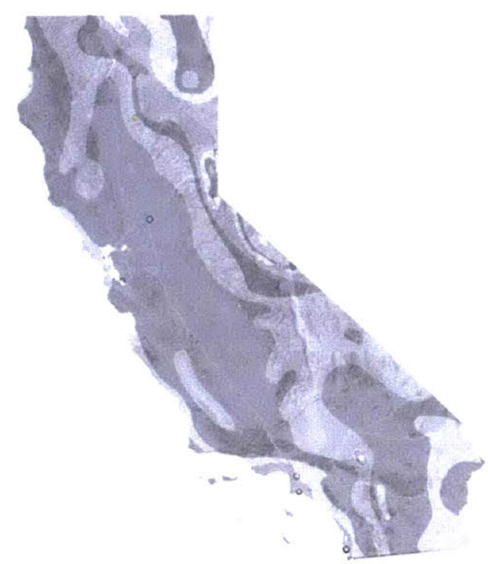


Image source: USDA

WATER FOOTPRINT

Given that water availability on a specific location depends on a combination of precipitation, amount of water carried by the CVP or SWP, groundwater, water rights and overall water costs, this was considered another limitation for this research. Instead, this thesis works on the assumption that each farmer is aware of the amount of water they have available and therefore this system focuses on providing information on the water needed for each crop so farmers can create water budgets to determine if a crop is viable or not.

Water footprint scale (m3/acre/year)

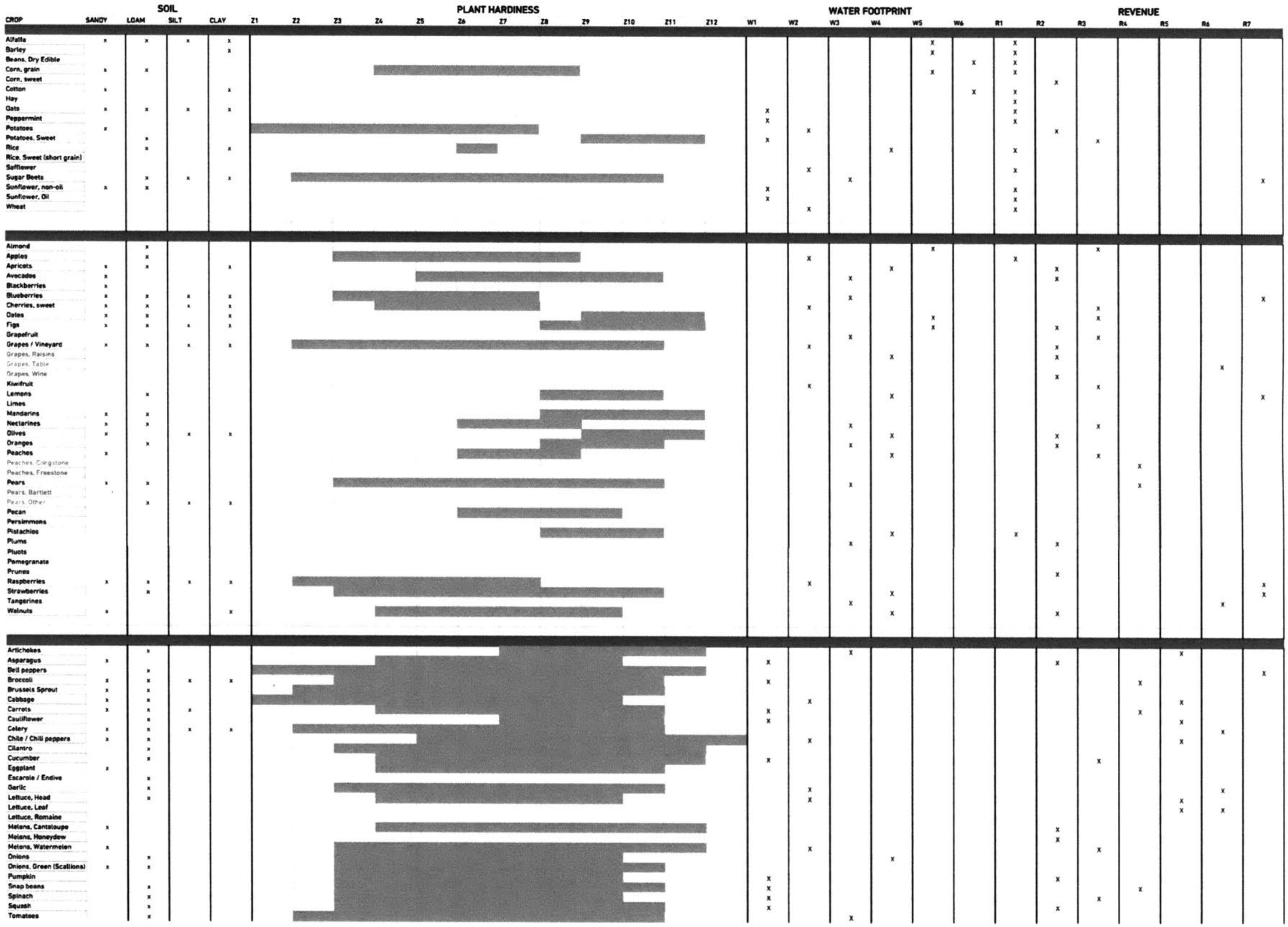
W1 0 - 500
W2 501 - 1,000
W3 1,001 - 2,000
W4 2,001 - 4,000
W5 4,001 - 5,000
W6 5,001 - 32,000
W7 32,001 - 2,005,000

REVENUE

The revenue classification system works very similarly to the water footprint system. It is based on the collected data for revenue of each crop for the year of 2015, sorted from smallest to largest and divided into categories. The units were changed $/acre to match the footprint and to facilitate a quick calculation based on the area avaible and the desired crop what is the potential revenue. Revenue was left as the last step in the system on purpose as the the other three variables should be considered more relevant when choosing crops. Maximizing revenue is still a posibility but within a set of more suitable crops.

Revenue scale ($/acre/year)

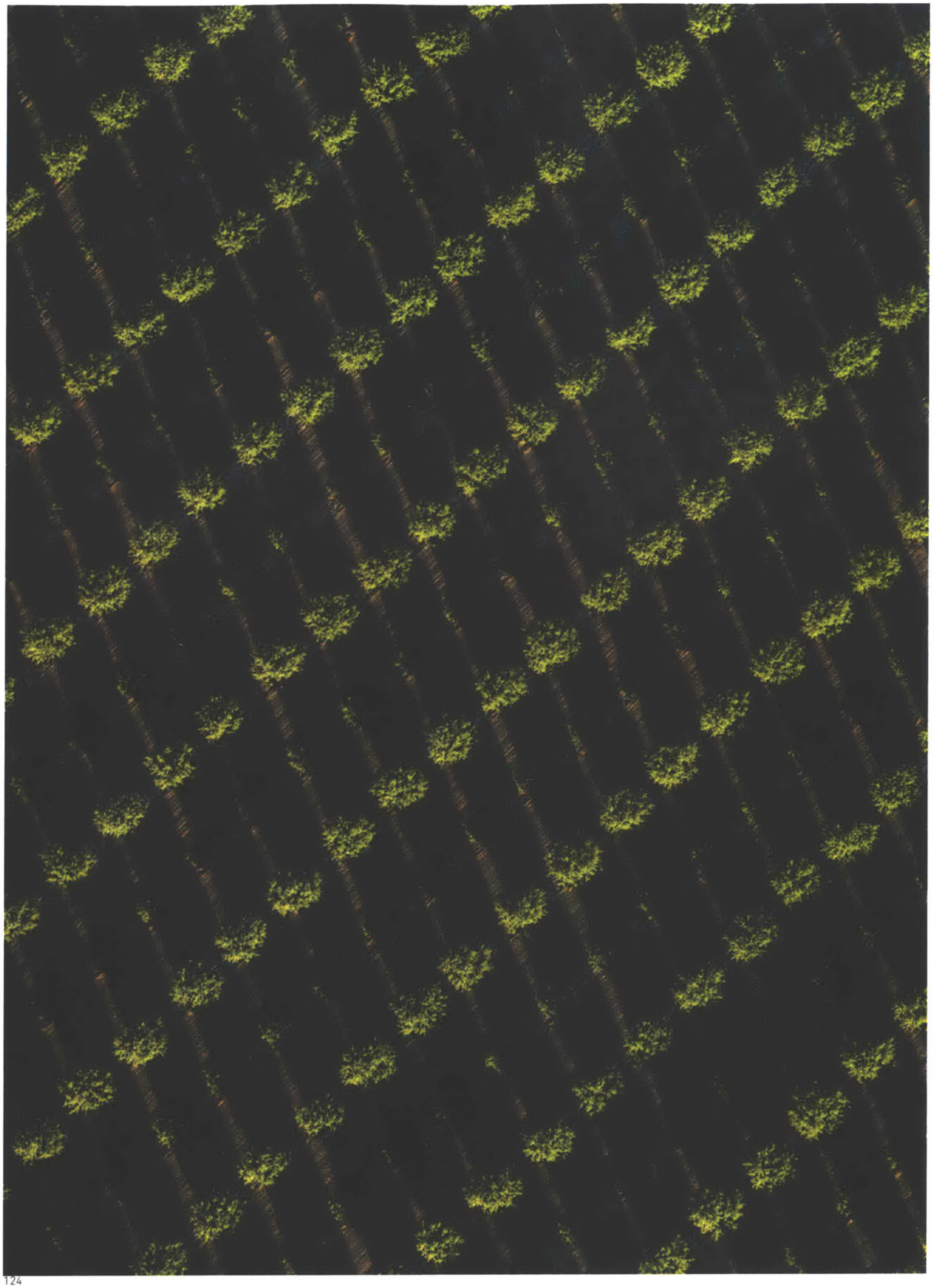
R1 0 - 3,000
R2 3,001 - 6,000
R3 6,001 - 8,000
R4 8,001 - 10,000
R5 10,001 - 12,000
R6 12,001 - 20,000
R7 20,001 - 55,000

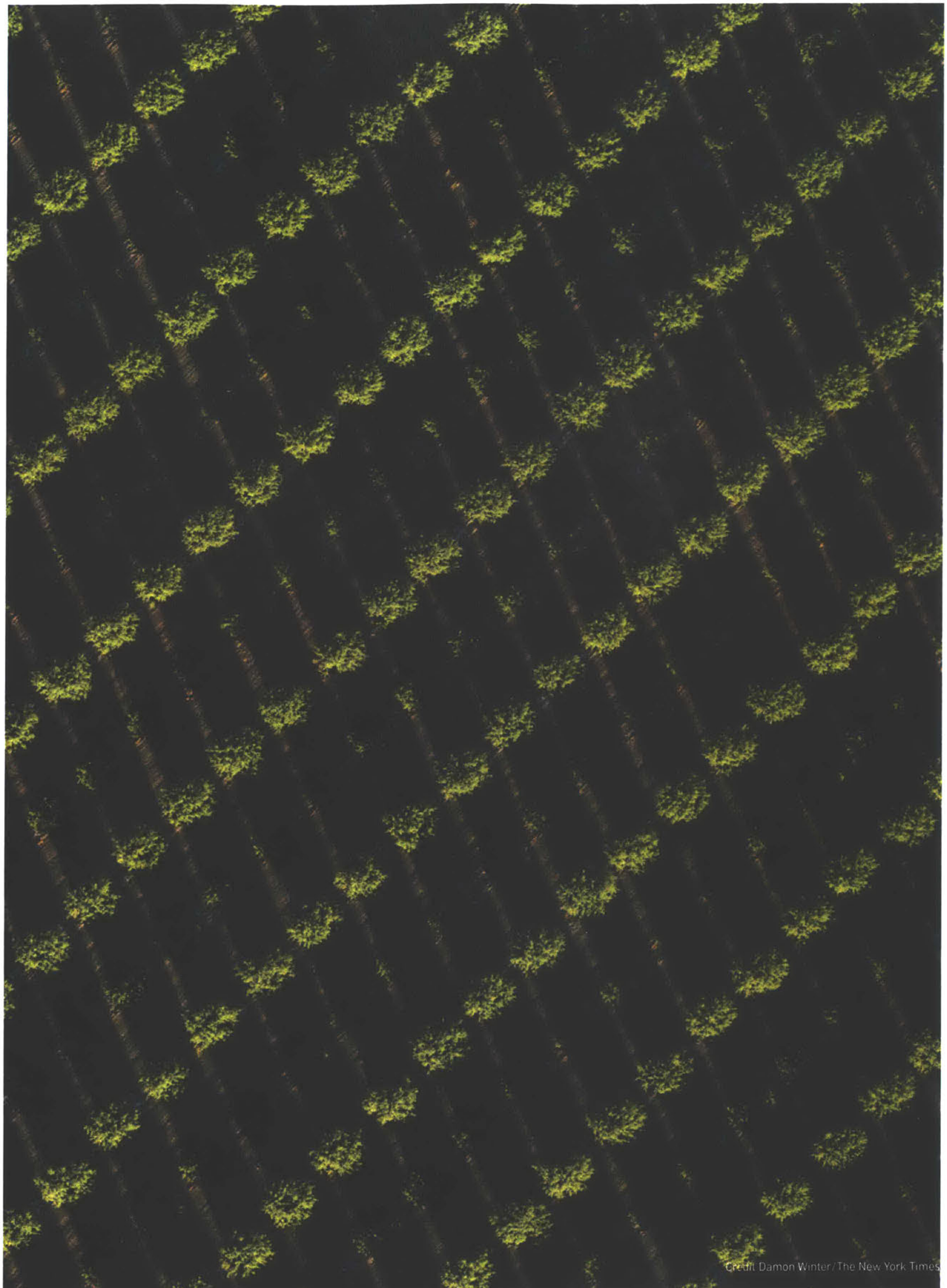

SOIL
PLANT HARDINESS
WATER FOOTPRINT
REVENUE
CROP
SANDY
LOAM
SILT
CLAY
Z1
Z2
Z3
Z4
Z5
Z6
Z7
Z8
Z9
Z10
Z11
Z12
W1
W2
W3
W4
W5
W6
R1
R2
R3
R4
R5
R6
R7
Alfalfa
Barley
Beans, Dry Edible
Corn, grain
Corn, sweet
Cotton
Hay
Oats
Peppermint
Potatoes
Potatoes, Sweet
Rice
Rice, Sweet (short grain)
Safflower
Sugar Beets
Sunflower, non-oil
Sunflower, Oil
Wheat
Almond
Apples
Apricots
Avocados
Blackberries
Blueberries
Cherries, sweet
Dates
Figs
Grapefruit
Grapes / Vineyard
Grapes, Raisins
Grapes, Table
Grapes, Wine
Kiwifruit
Lemons
Limes
Mandarins
Nectarines
Olives
Oranges
Peaches
Peaches, Clingstone
Peaches, Freestone
Pears
Pears, Bartlett
Pears, Other
Pecan
Persimmons
Pistachios
Plums
Pluots
Pomegranate
Prunes
Raspberries
Strawberries
Tangerines
Walnuts
Artichokes
Asparagus
Bell peppers
Broccoli
Brussels Sprout
Cabbage
Carrots
Cauliflower
Celery
Chile / Chili peppers
Cilantro
Cucumber
Eggplant
Escarole / Endive
Garlic
Lettuce, Head
Lettuce, Leaf
Lettuce, Romaine
Melons, Cantaloupe
Melons, Honeydew
Melons, Watermelon
Onions
Onions, Green (Scallions)
Pumpkin
Snap beans
Spinach
Squash
Tomatoes

As for implementation, this proposal can work both ways. As a bottom up system, used by individual farmers who want to make better informed decisions and as top - bottom by planners how might want to restructure agriculture production by nudging farmers into more suitable crops for their location and water availability.

For this last approach, offering financial incentives for switching to better suited crops could prove succesful.

Another variable that should be added to this system is current and projected relevance to the American diet, as a way to shift into a more inward perspective to agricultural production and trade and create greater resilience when it comes to food security issues. Focusing on satisfying the national demand first could potentially reduce prices for final consumers by reducing transportation costs.




Credit Damon Winter / The New York Times

CONCLUSIONS AND RECOMMENDATIONS

As previously mentioned on this thesis, Climate Change and Global Warming will continue to challenge agricultural production all over the world. Water will be more scarce, regardless of precipitation because of a continous increase in temperature which intensifies evapotranspiration and reduces soil moisture. As a result of this and many other factors, yields are expected to be much lower making food more expensive. Current and future food security needs to become a priority for planners and government officials.

Looking at the current agriculture paradigm the problem is that we have forgotten that it is intrinsically natural. It depends on the interaction of multiple natural systems. For hundreds of years it has been forced to function under conditions less than ideal, forcing us to develop infrastructure to compensate for the things missing in order to meet demand and maximize profit. What we have been left with is a system that is not only over exploiting water but is also highly vulnerable.

Agricultural production needs to be re-thought of based on the specific natural systems, carrying capacity of the area and future demand.


Credit Lucy Nichol[illegible]

APPENDIX

PROPOSAL 1 / ESTIMATING POTENTIAL REUSE

URBAN CENTERS WITHIN SELECTED AREA

WASTEWATER

fixed wastewater

		Population	daily Water Use per capita gallons	daily water use city (gallons)	annual water use city (gallons)	conversion to m3	50	85% over 50 could be reused per day per city (gallons)	85% over 50 per year (gallons)	70	85% over 70 could be reused per day per city (gallons)	85% over 70 per year (gallons)
1	Galt	24289	170	4129130	1507132450	5705114	1,214,450	1032282.5	376,783,113	1,700,230	1445195.5	527,496,358
						0		0	-		0	-
2	Antioch	106455	144	15329520	5595274800	21180409	5,322,750	4524337.5	1,651,383,188	7,451,850	6334072.5	2,311,936,463
	Brentwood	54741	193	10565013	3856229745	14597411	2,737,050	2326492.5	849,169,763	3,831,870	3257089.5	1,188,837,668
	Tracy	85146	148	12601608	4599586920	17411322	4,257,300	3618705	1,320,827,325	5,960,220	5066187	1,849,158,255
	Patterson	20922	168	3514896	1282937040	4856443	1,046,100	889185	324,552,525	1,464,540	1244859	454,373,535
	Turlock	71181	216	15375096	5611910040	21243380	3,559,050	3025192.5	1,104,195,263	4,982,670	4235269.5	1,545,873,368
	Livingston	14894	220	3276680	1195988200	4527306	744,700	632995	231,043,175	1,042,580	886193	323,460,445
	Los Baños	37168	273	10146864	3703605360	14019665	1,858,400	1579640	576,568,600	2,601,760	2211496	807,196,040
	Newman	10668	138	1472184	537347160	2034079	533,400	453390	165,487,350	746,760	634746	231,682,290
	Riverbank	23298	191	4449918	1624220070	6148339	1,164,900	990165	361,410,225	1,630,860	1386231	505,974,315
	Ceres	46463	183	8502729	3103496085	11748005	2,323,150	1974677.5	720,757,288	3,252,410	2764548.5	1,009,060,203
	Oakdale	21442	234	5017428	1831361220	6932453	1,072,100	911285	332,619,025	1,500,940	1275799	465,666,635
	Manteca	74334	253	18806502	6864373230	25984467	3,716,700	3159195	1,153,106,175	5,203,380	4422873	1,614,348,645
	Ripon	14915	341	5086015	1856395475	7027218	745,750	633887.5	231,368,938	1,044,050	887442.5	323,916,513
	Modesto	217269	316	68657004	25059806460	94861642	10,863,450	9233932.5	3,370,385,363	15,208,830	12927505.5	4,718,539,508
	Atwater	29500	344	10148000	3704020000	14021234	1,475,000	1253750	457,618,750	2,065,000	1755250	640,666,250
	Merced	83400	316	26354400	9619356000	36413206	4,170,000	3544500	1,293,742,500	5,838,000	4962300	1,811,239,500
	Stockton	305658	165	50433570	18408253050	69682785	15,282,900	12990465	4,741,519,725	21,396,060	18186651	6,638,127,615
						0		0	-		0	-
3	Salinas	157380	93	14636340	5342264100	20222660	7,869,000	6688650	2,441,357,250	11,016,600	9364110	3,417,900,150
	Soledad	16729	126	2107854	769366710	2912368	836,450	710982.5	259,508,613	1,171,030	995375.5	363,312,058
	Greenfield	17898	94	1682412	614080380	2324546	894,900	760665	277,642,725	1,252,860	1064931	388,699,815
	King	14734	72	1060848	387209520	1465747	736,700	626195	228,561,175	1,031,380	876673	319,985,645
						0		0	-		0	-
4	Paso Robles	30,450	152	4628400	1689366000	6394943	1,522,500	1294125	472,355,625	2,131,500	1811775	661,297,875
						0		0	-		0	-
5	Coalinga	13380	142	1899960	693485400	2625127	669,000	568650	207,557,250	936,600	796110	290,580,150
	Avenal	12373	142	1756966	641292590	2427555	618,650	525852.5	191,936,163	866,110	736193.5	268,710,628
						0		0	-		0	-
6	Blythe	13839	213	2947707	1075913055	4072772	691,950	588157.5	214,677,488	968,730	823420.5	300,548,483
						0		0	-		0	-
7	Brawley	27743	202	5604086	2045491390	7743024	1,387,150	1179077.5	430,363,288	1,942,010	1650708.5	602,508,603
	Calexico	40516	118	4780888	1745024120	6605632	2,025,800	1721930	628,504,450	2,836,120	2410702	879,906,230
		1,586,785	5367	314,972,018	1.14965E+11							

percent (over daily consumption per city) gallons

		94	85% over 94 could be reused per day per city (gallons)	85% over 94 could be reused per year per city (gallons)	98	85% over 98 could be reused per day per city (gallons)	85% over 98 could be reused per year per city (gallons)	AG area acres	water needed m3
1	Galt	3,881,382	3299174.87	1,204,198,828	4,046,547	3439565.29	1,255,441,331	7099.057484	18,013,460
			0	-		0	-		
2	Antioch	14,409,749	12248286.48	4,470,624,565	15,022,930	12769490.16	4,660,863,908		
	Brentwood	9,931,112	8441445.387	3,081,127,566	10,353,713	8800655.829	3,212,239,378		
	Tracy	11,845,512	10068684.79	3,675,069,949	12,349,576	10497139.46	3,831,455,904		
	Patterson	3,304,002	2808401.904	1,025,066,695	3,444,598	2927908.368	1,068,686,554		
	Turlock	14,452,590	12284701.7	4,483,916,122	15,067,594	12807454.97	4,674,721,063		
	Livingston	3,080,079	2618067.32	955,594,572	3,211,146	2729474.44	996,258,171		
	Los Baños	9,538,052	8107344.336	2,959,180,683	9,943,927	8452337.712	3,085,103,265		
	Newman	1,383,853	1176275.016	429,340,381	1,442,740	1226329.272	447,610,184		
	Riverbank	4,182,923	3555484.482	1,297,751,836	4,360,920	3706781.694	1,352,975,318		
	Ceres	7,992,565	6793680.471	2,479,693,372	8,332,674	7082773.257	2,585,212,239		
	Oakdale	4,716,382	4008924.972	1,463,257,615	4,917,079	4179517.524	1,525,523,896		
	Manteca	17,678,112	15026395.1	5,484,634,211	18,430,372	15665816.17	5,718,022,901		
	Ripon	4,780,854	4063725.985	1,483,259,985	4,984,295	4236650.495	1,546,377,431		
	Modesto	64,537,584	54856946.2	20,022,785,362	67,283,864	57191284.33	20,874,818,781		
	Atwater	9,539,120	8108252	2,959,511,980	9,945,040	8453284	3,085,448,660		
	Merced	24,773,136	21057165.6	7,685,865,444	25,827,312	21953215.2	8,012,923,548		
	Stockton	47,407,556	40296422.43	14,708,194,187	49,424,899	42011163.81	15,334,074,791	733528.2786	2,950,101,363
			0	-		0	-		
3	Salinas	13,758,160	11694435.66	4,268,469,016	14,343,613	12192071.22	4,450,105,995		
	Soledad	1,981,383	1684175.346	614,724,001	2,065,697	1755842.382	640,882,469		
	Greenfield	1,581,467	1344247.188	490,650,224	1,648,764	1401449.196	511,528,957		
	King	997,197	847617.552	309,380,406	1,039,631	883686.384	322,545,530	102152.5038	84,474,234
			0	-		0	-		
4	Paso Robles	4,350,696	3698091.6	1,349,803,434	4,535,832	3855457.2	1,407,241,878	39821.08445	25,205,597
			0	-		0	-		
5	Coalinga	1,785,962	1518068.04	554,094,835	1,861,961	1582666.68	577,673,338		
	Avenal	1,651,548	1403815.834	512,392,779	1,721,827	1463552.678	534,196,727	170437.2038	420,980,783
			0	-		0	-		
6	Blythe	2,770,845	2355217.893	859,654,531	2,888,753	2455439.931	896,235,575	35948.30519	130,120,212
			0	-		0	-		
7	Brawley	5,267,841	4477664.714	1,634,347,621	5,492,004	4668203.638	1,703,894,328		
	Calexico	4,494,035	3819929.512	1,394,274,272	4,685,270	3982479.704	1,453,605,092	452406.4029	1,569,081,356
								1,541,393	5,197,977,005

URBAN CENTERS WITHIN 30 KM RADIUS

WASTEWATER

fixed wastewater | percent (over daily consumption per city) gallons

		Population	daily Water Use per capita gallons	daily water use city (gallons)	annual water use city (gallons)	conversion to m3	50	85% over 50 could be reused per day per city (gallons)	85% over 50 per year (gallons)	70	85% over 70 could be reused per day per city (gallons)	85% over 70 per year (gallons)	94	85% over 94 could be reused per day per city (gallons)	85% over 94 could be reused per year per city (gallons)	98	85% over 98 could be reused per day per city (gallons)	85% over 98 could be reused per year per city (gallons)
1	Fruitridge	21,441	272	5,831,952	2,128,662,480	8,057,860	1,072,050	911,243	332,603,512.50	1,500,870	1,275,740	465,644,918	5,482,035	4,659,730	1,700,801,322	5,715,313	4,858,016	1,773,175,846
	ELk Grove	34,550	238	8,222,900	3,001,358,500	11,361,372	1,727,500	1,468,375	535,956,875.00	2,418,500	2,055,725	750,339,625	7,729,526	6,570,097	2,398,085,442	8,058,442	6,849,676	2,500,131,631
					-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Rio Vista	8,324	301	2,505,524	914,516,260	3,461,819	416,200	353,770	129,126,050.00	582,680	495,278	180,776,470	2,355,193	2,001,914	730,698,492	2,455,414	2,087,101	761,792,045
	Lodi	63,651	348	22,150,548	8,084,950,020	30,604,851	3,182,550	2,705,168	987,386,137.50	4,455,570	3,787,235	1,382,340,593	20,821,515	17,698,288	6,459,875,066	21,707,537	18,451,406	6,734,763,367
	Chowila	18,720	142	2,658,240	970,257,600	3,672,823	936,000	795,600	290,394,000.00	1,310,400	1,113,840	406,551,600	2,498,746	2,123,934	775,235,822	2,605,075	2,214,314	808,224,581
					-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	watsonville	65,739	106	6,968,334	2,543,441,910	9,627,970	3,286,950	2,793,908	1,019,776,237.50	4,601,730	3,911,471	1,427,686,733	6,550,234	5,567,699	2,032,210,086	6,828,967	5,804,622	2,118,687,111
	Marina	31,405	78	2,449,590	894,100,350	3,384,536	1,570,250	1,334,713	487,170,062.50	2,198,350	1,868,598	682,038,088	2,302,615	1,957,222	714,386,180	2,400,598	2,040,508	744,785,592
	Alco	29,179	131	3,822,449	1,395,193,885	5,281,381	1,458,950	1,240,108	452,639,237.50	2,042,530	1,736,151	633,694,933	3,593,102	3,054,137	1,114,759,914	3,746,000	3,184,100	1,162,196,506
					-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Atascadero	30,009	171	5,131,539	1,873,011,735	7,090,117	1,500,450	1,275,383	465,514,612.50	2,100,630	1,785,536	651,720,458	4,823,647	4,100,100	1,496,536,376	5,028,908	4,274,572	1,560,218,775
					-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Kerman	13,551	245	3,319,995	1,211,798,175	4,587,153	677,550	575,918	210,209,887.50	948,570	806,285	294,293,843	3,120,795	2,652,676	968,226,742	3,253,595	2,765,556	1,009,427,880
	Hanford	57,050	208	11,866,400	4,331,236,000	16,395,504	2,852,500	2,424,625	884,988,125.00	3,993,500	3,394,475	1,238,983,375	11,154,416	9,481,254	3,460,657,564	11,629,072	9,884,711	3,607,919,588
	Lemoore	25,281	225	5,688,225	2,076,202,125	7,859,276	1,264,050	1,074,443	392,171,512.50	1,769,670	1,504,220	549,040,118	5,346,932	4,544,892	1,658,885,498	5,574,461	4,738,291	1,729,476,370
	Wasco	21,170	260	5,504,200	2,009,033,000	7,605,014	1,058,500	899,725	328,399,625.00	1,481,900	1,259,615	459,759,475	5,173,948	4,397,856	1,605,217,367	5,394,116	4,584,999	1,673,524,489

URBAN CENTERS WITHIN 50 KM RADIUS

WASTEWATER

fixed wastewater | percent (over daily consumption per city) gallons

		Population	daily Water Use per capita gallons	daily water use city (gallons)	annual water use city (gallons)	conversion to m3	50	85% over 50 could be reused per day per city (gallons)	85% over 50 per year (gallons)	70	85% over 70 could be reused per day per city (gallons)	85% over 70 per year (gallons)	94	85% over 94 could be reused per day per city (gallons)	85% over 94 could be reused per year per city (gallons)	98	85% over 98 could be reused per day per city (gallons)	85% over 98 could be reused per year per city (gallons)
1	Rio Linda	10,936	325	3,554,200	1,297,283,000	4,910,748.04	546,800	464,780	169,644,700	765,520	650,692	237,502,580	3,340,948	2,839,806	1,036,529,117	3,483,116	2,960,649	1,080,636,739
	Davis	65,783	157	10,327,931	3,769,694,815	14,269,840.45	3,289,150	2,795,778	1,020,458,788	4,604,810	3,914,089	1,428,642,303	9,708,255	8,252,017	3,011,986,157	10,121,372	8,603,167	3,140,155,781
	west sacramento	50,836	291	14,793,276	5,399,545,740	20,439,494.44	2,541,800	2,160,530	788,593,450	3,558,520	3,024,742	1,104,030,830	13,905,679	11,819,828	4,314,237,046	14,497,410	12,322,799	4,497,821,601
	Sacramento	163,226	212	34,603,912	12,630,427,880	47,811,348.00	8,161,300	6,937,105	2,532,043,325	11,425,820	9,711,947	3,544,860,655	32,527,677	27,648,526	10,091,711,876	33,911,834	28,825,059	10,521,146,424
	San Juan	38,943	562	21,885,966	7,988,377,590	30,239,284.41	1,947,150	1,655,078	604,103,288	2,726,010	2,317,109	845,744,603	20,572,808	17,486,887	6,382,713,694	21,448,247	18,231,010	6,654,318,532
				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Vacaville	86,893	207	17,986,851	6,565,200,615	24,851,976.06	4,344,650	3,692,953	1,347,927,663	6,082,510	5,170,134	1,887,098,728	16,907,640	14,371,494	5,245,595,291	17,627,114	14,983,047	5,468,812,112
	Groveland	3,400	147	499,800	182,427,000	690,560.99	170,000	144,500	52,742,500	238,000	202,300	73,839,500	469,812	399,340	145,759,173	489,804	416,333	151,961,691
				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Bakman	13,960	315	4,397,400	1,605,051,000	6,075,776.11	698,000	593,300	216,554,500	977,200	830,620	303,176,300	4,133,556	3,513,523	1,282,435,749	4,309,452	3,663,034	1,337,007,483
	Clovis	106,076	241	25,564,316	9,330,975,340	35,321,567.36	5,303,800	4,508,230	1,645,503,950	7,425,320	6,311,522	2,303,705,530	24,030,457	20,425,888	7,455,449,297	25,053,030	21,295,075	7,772,702,458
	Fresno	503,077	170	85,523,090	31,215,927,850	118,165,085.44	25,153,850	21,380,773	7,803,981,963	35,215,390	29,933,082	10,925,574,748	80,391,705	68,332,949	24,941,526,352	83,812,628	71,240,734	26,002,867,899

PROPOSAL 3 / ORGANIZING DATA FOR RELOCATING CROPS

CROP	WATER FOOTPRINT (M3/TON)	YIELD (TON/ACRE)	TOTAL REVENUE	TOTAL AREA (ACRES)	TOTAL PRODUCTION (TON)	TOTAL WATER FOOTPRINT (M3)	WATER / ACRE (M3)	REVENUE /ACRE ($)
Alfalfa	1,018	7	1,580,790,000	790,000	5,451,000	5,549,118,000	7,024	2001
Barley	79	1	7,656,000	80,000	9,164,232	723,974,328	9,050	95.7
Beans, Dry Edible	125	1	75,528,600	45,000	87,235,533	10,904,441,625	242,321	1678.413333
Corn, grain	81	4	42,390,000	440,000	169,051,320	13,693,156,920	31,121	96.34090909
Corn, sweet		11	159,068,000	30,000	1,692,483,520	-	-	5302.266667
Cotton	1,306	2	156,537,600	164,000	251,712,461	328,736,473,805	2,004,491	954.497561
Hay		6	1,047,432,000	1,190,000	6,890,100	-		880.194958
Oats	181	1	1,920,000	120,000	111,000	20,091,000	167	16
Peppermint	63	0	4,017,600	2,000	81	5,103	3	2008.8
Potatoes	33	22	186,408,000	35,400	779,083	25,709,746	726	5265.762712
Potatoes, Sweet	5	19	172,975,000	18,500	352,240	1,761,200	95	9350
Rice	341	8	708,143,100	392,000	3,096,800	1,056,008,800	2,694	1806.4875
Rice, Sweet (short grain)		4		37,000	132,275	-	-	
Safflower	938	1	27,907,500	61,000	64,050	60,078,900	985	457.5
Sugar Beets	26	45	898,971,428	24,700	1,104,090	28,706,340	1,162	36395.60439
Sunflower, non-oil	148	1	552,500	1,400	910	134,680	96	394.6428571
Sunflower, Oil	299	1	9,575,893	33,000	21,450	6,413,550	194	290.1785682
Wheat	342	2	146,900,500	520,000	1,119,040	382,711,680	736	282.5009615
Almond	3,816	2	5,396,000,000	890,000	1,628,700	6,215,119,200	6,983	6062.921348
Apples	133	5	40,310,000	14,000	72,800	9,682,400	692	2879.285714
Apricots	502	4	35,190,000	8,300	34,528	17,333,056	2,088	4239.759036
Avocados	283	4	274,400,000	52,000	196,040	55,479,320	1,067	5276.923077
Blueberries	334	5	116,842,000	5,700	31,065	10,375,710	1,820	20498.59649
Cherries, sweet	531	2	232,050,000	33,000	60,060	31,891,860	966	7031.818182
Dates	1,250	4	68,016,000	10,000	43,600	54,500,000	5,450	6801.6
Figs	1,595	4	21,864,800	6,800	30,192	48,156,240	7,082	3215.411765
Grapefruit	85	16	64,106,000	9,500	152,000	12,920,000	1,360	6748
Grapes / Vineyard	97	8	4,957,228,000	856,000	6,848,000	664,256,000	776	5791.154206
Grapes, Raisins	386	11	696,429,000	184,000	2,005,600	774,161,600	4,207	3784.940217
Grapes, Table		10	1,736,550,000	112,000	1,131,200	-	-	15504.91071
Grapes, Wine	138	7	2,515,695,000	560,000	3,707,200	511,593,600	914	4492.3125
Kiwifruit	168	6	30,954,000	4,000	23,720	3,984,960	996	7738.5
Lemons	152	17	1,084,040,000	47,000	819,680	124,591,360	2,651	23064.68085
Nectarines	188	8	141,515,000	19,000	158,080	29,719,040	1,564	7448.157895
Olives	499	5	160,026,000	36,000	178,920	89,281,080	2,480	4445.166667
Oranges	110	14	775,602,000	157,000	2,166,600	238,326,000	1,518	4940.140127
Peaches	188	14	339,785,200	43,000	606,300	113,984,400	2,651	7901.981395
Peaches, Clingstone		18	160,082,000	19,000	340,100	-	-	8425.368421
Peaches, Freestone		11	179,520,000	24,000	266,400	-	-	7480
Pears	94	18	100,035,000	11,100	202,020	18,989,880	1,711	9012.162162
Pears, Bartlett		20	82,995,000	8,500	171,700	-	-	9764.117647
Pears, Other		12	17,010,000	2,600	29,900	-	-	6542.307692
Pistachios	7,602	1	669,600,000	233,000	135,140	1,027,334,280	4,409	2873.819742
Plums	188	6	104,790,000	17,800	106,088	19,944,544	1,120	5887.078652
Prunes		7	221,067,000	47,000	319,130	-	-	4703.553191
Raspberries	53	10	478,225,000	8,770	86,823	4,601,619	525	54529.64652
Strawberries	109	39	1,855,948,500	40,500	1,564,920	170,576,280	4,212	45825.88889
Tangerines	118	15	980,840,000	57,000	868,680	102,504,240	1,798	17207.7193
Walnuts	2,451	2	976,860,000	300,000	603,000	1,477,953,000	4,927	3256.2
Artichokes	242	8	80,600,400	6,800	51,408	12,440,736	1,830	11853
Asparagus	119	1	32,526,000	9,500	13,832	1,646,008	173	3423.789474
Bell peppers		25	367,892,000	16,600	422,968	-	-	22162.16867
Broccoli	21	10	1,006,416,000	118,000	1,189,440	24,978,240	212	8528.949153
Cabbage	26	24	143,692,500	13,800	328,440	8,539,440	619	10412.5
Carrots	28	18	638,631,000	67,000	1,193,136	33,407,808	499	9531.80597
Cauliflower	21	10	345,351,600	32,600	328,608	6,900,768	212	10593.60736
Celery		35	406,118,000	26,400	916,608	-	-	15383.25758
Chile / Chili peppers	42	21	76,356,000	6,500	138,320	5,809,440	894	11747.07692
Cucumber	42	11	21,252,800	3,500	40,180	1,687,560	482	6072.228571
Garlic	81	9	305,035,900	24,300	224,532	18,187,092	748	12552.9177
Lettuce, Head	28	21	999,248,000	87,000	1,851,360	51,838,080	596	11485.6092
Lettuce, Leaf		15	703,762,800	47,000	684,320	-	-	14973.6766
Lettuce, Romaine		17	714,375,000	64,000	1,075,200	-	-	11162.10938
Melons, Cantaloupe		17	146,160,000	28,500	478,800	-	-	5128.421053
Melons, Honeydew		15	64,135,800	11,500	173,880	-	-	5577.026087
Melons, Watermelon	25	30	79,924,000	11,700	347,256	8,681,400	742	6831.111111
Onions	88	25		45,800	1,154,160	101,566,080	2,218	
Pumpkin	24	13	26,059,200	6,200	83,328	1,999,872	323	4203.096774
Snap beans	54	7	37,435,200	4,500	30,240	1,632,960	363	8318.933333
Spinach	14	7	189,676,800	27,000	196,560	2,751,840	102	7025.066667
Squash	24	9	29,808,000	5,600	50,176	1,204,224	215	5322.857143
Tomatoes	63	17		327,600	5,687,136	358,289,568	1,094	

Credit Justin Sullivan / Getty Images

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