This cover page is intended for the Executive and Academic directors of the Master of Advanced Studies in Climate Science and Policy program at Scripps Institution of Oceanography to fulfill the Capstone project requirements.

**Project Description**

Water and energy are often incorrectly thought of as separate entities. So much so research, policy and regulation as well as distribution surrounding these resources are typically carried out distinctly of one another. However it has been identified that in order to build resilient cities and nations the water-energy nexus (WEN) must be taken thoroughly into consideration for future policy and decision makers. Moreover the consequences of climate change resulting from anthropogenic greenhouse gas emissions can radically alter the supply of these necessities to life and a prosperous economy. Additionally, specific water and energy sources can further exacerbate climate change.

Thus the goal of this report intends to provide a through understanding of the WEN for San Diego County and the associated perturbations that population growth and climate change will impose on these interwoven sectors. Furthermore, this report will help to prepare municipalities, agencies as well as businesses involved in developing these products and services to respond to these forthcoming changes. This project will additionally act as a stepping-stone or rather case-study for other cities, counties and the state as a whole concerned with the consequences of climate change to the WEN.

As previously mention these entities are often considered distinct from one another, especially by policy and decision makers. Therefore, my project fills a gap in the literature by providing my primary target audience, the California Energy Commission with a report to understand the relationship between water and energy, and further how climate change will shape these assets. The California Energy Commission’s (CEC) energy policy goals state the following,

- Make energy public policy recommendations based on relevant and objective information, forecasting and analyses to the Governor, Legislature and other federal, state and local decision makers that promote affordable energy supplies, improve energy reliability, and enhance health, economic well-being and environmental quality.

Therefore, this report has aimed to provide the CEC with relevant, objective and forecasted regional case-study that can be used as leverage to shape potential water-energy nexus policy for the state of California. Considering this report encompasses an extensive topic addressing both San Diego’s energy and water sources, usage, consumption as well as impacts to the regions resources due to greenhouse gases this report could be intended for a broad target audience. Therefore, physical copies of this report will be sent to my secondary target audience which includes mine as well as my Chair’s contacts at the San Diego County Water Authority (SDCWA), Water Quality Control Board (WQCB), as well as San Diego Gas and Electric (SDG&E).

**Resource Allocation**

Unforeseen cost arose when attending the California Annual Water Policy conference to meet Dr. Robert Wilkinson. The total cost of this conference came to $200 for registration fees. However, this project remained well under budget.

**Risk and Barriers**

Several risk and barriers were addressed during the completion of this research, primarily due to time and resource constraints. Considering Imperial County has a relativity small population compared to San Diego, receiving the adequate data was arduous and for that reason the project study area was attenuated to San Diego County alone. Furthermore, after seeking out expert advice regarding the project outline from Dr. Robert Wilkinson, the scope of the project was refined to focus on the energy-intensity of water resources for San Diego. One concern identified by my capstone committee was being able to properly link projected changes in temperature and precipitation to related changes in water and energy supplies, this is an on-going, critical research of interest within the field. Upon meeting with Bob Wilkinson, he advised the original project outline would be too expansive of a project to complete within this time frame. However this report further identifies the need for this type of research and this barrier to be completed in the future.

**Project Continuation**

The following report, including all of the figures and graphs produced was completed for the partial degree and Capstone project requirements for a Master of Advance Studies in Climate Science and Policy. However, regarding the long-term sustainability of this project, pertinent components and sections will be incorporated into a larger international study investigating the water-energy nexus for the California-Mexico border together with researchers Alan Sweedler and colleagues at San Diego State University and collaborators from El Colegio de la Frontera Norte (Colef) in Tijuana Mexico. Furthermore I have been asked by the Chair, Henry Abarbanel to present this material to the San Diego Regional Water Quality Control Board at their monthly meeting on June 22nd, 2017. Lastly, further research regarding the ability to directly connect changes in temperature, precipitation, snow pack and sea-level to water and energy resources for San Diego are vital to completely understand the implications of climate change on the water-energy nexus.
Climate scenario based assessment of the water-energy nexus for San Diego County, CA

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June 2017
Declaration of Authorship

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Furthermore, a thank you is extended to my connections at the California Energy Commission (CEC); Susan Wilhelm and the San Diego Country Water Authority (SDCWA); Toby Roy for their help in compiling and gathering relevant data to this research. Additionally, a thank you is extended to Dr. David Pierce at Scripps Institution of Oceanography and Dr. Nilmini Silva-Send at the University of San Diego School of Law. Additionally, a thank you to Dr. Henry Abarbanel of the University of California, San Diego/Scripps Institution of Oceanography for providing connections and networking opportunities within the field. Lastly, thank you to Dr. Robert Wilkinson Adjunct Professor at the Bren School of Environmental Science and Management at University of California, Santa Barbara for his expert opinion in scoping and framing this report and research. The completion of this report and the remainder of my Master’s work wouldn’t be possible without the continued support from each of these individuals, my family and friends.

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<td>Assessment Report</td>
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<td>BAU</td>
<td>Business as usual</td>
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<td>CCS</td>
<td>Carbon Capture and Storage</td>
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<td>IPCC</td>
<td>Intergovermental Panel on Climate Change</td>
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<td>IPR</td>
<td>Indirect potable reuse</td>
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<td>MWD</td>
<td>Metropolitan Water District</td>
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<td>Representative concentration pathway</td>
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Units

AF ............... Acre-feet (One acre-foot = enough water to cover an acre of land one foot deep)
GWh ............ Gigawatt-hour (Measure of energy, a gigawatt/hour = 1 billion watts used in an hour)
kWh ............. Kilowatt-hour (A measure of energy, a Kilowatt per hour = 1,000 watts used in an hour)
kWh/AF .......... Kilowatt-hour per acre-foot (A measure of the energy intensity of water supplies, a KWh/AF = the total energy in kilowatts it takes to produce one acre foot of water)
PPM ............. Parts/million or parts per million (A measure of concentration, a ppm = one part out of a million)
W/m² ............. Watt per meter squared (A measure of heat flux density or irradiance)
Executive Summary

San Diego County has a Mediterranean climate characterized by mild temperatures and low annual rainfall. This region is expected to experience a considerable population growth over the next 30 years, accompanied by economic expansion. The population of San Diego County is projected to grow to a total of 4.4 million residents by the year 2050, an additional million people compared to the current population of nearly 3.3 million. The San Diego County Water Authority is the region’s wholesale water agency responsible for providing the majority of the water supplies for the county. To meet the growing demand, the Authority has relied heavily on the Metropolitan Water District to transport imported water from both the Sacramento/San Joaquin Delta and Colorado River.

Climate change resulting from increasing greenhouse gas emissions imposes a threat to public health, infrastructure, biodiversity, economies, as well as public utilities (i.e. water and energy). Climate models project that San Diego will experience an increase in temperature, less predictable rainfall in an already arid region, and rise in sea levels. Regions from which San Diego imports water are also anticipated to see similar changes in temperature and precipitation, as well as decreased snow pack. This trend will have ramifications on San Diego’s already stressed water supply influenced by low-annual rainfall.

In addition to stressed water supplies, a substantial amount of energy is required to treat and transport water. The relationship between water and energy is referred to as the water-energy nexus, or WEN. Although both the energy and water sectors are fundamentally interconnected, policies related to these entities are often treated separately with little formal connection. This is the case regardless of the fact that energy used for water production, transportation, and treatment accounts for roughly 20% of California’s total electricity consumption. Conversely, 17.4% of California’s water withdrawals were used for thermoelectric power generation.

Adding to the complexity between the relationship of water and energy, climate change will influence both sectors. Included in this report, two climate scenarios are analyzed to evaluate the impacts on the WEN in San Diego County. Additionally included in this report is the embedded energy used for each water source currently available to San Diego County. Current and future sources of water and energy resources will both be negatively impacted by the consequences of climate change. San Diego will likely need to find alternative sources of water, as both local and imported supplies will be reduced due to temperature and precipitate changes. Concurrently, energy resources will be stretched, as average temperature and extreme heat days increase in the region.

By (1) maximizing the use of less water-intensive renewable energy, such as solar photovoltaic and wind; (2) expanding the water conservation programs currently in place; and (3) implementing less energy-intensive water sources, such as ground and recycled water; San Diego will be better prepared to meet the challenges posed by the expected climate changes.
1 | Background

1.1 Climate Change

Globally averaged land and ocean surface temperatures have already increased an average of 0.85°C since 1880. Since 1958, initiated by Charles D. Keeling, carbon dioxide (CO₂) concentrations in parts per million (ppm) have been measured at the Mauna Loa Observatory daily (Fig. 1.1). This curve depicts the exponentially rising concentration of CO₂, a greenhouse gas (GHG) as a result of anthropogenic emissions. Carbon dioxide currently resides at concentrations exceeding 400 ppm, a level anomalous in the last 800,000 years (Pachauri et al., 2015). Climate change, as a result of escalating anthropogenic GHG emissions, since the industrial revolution is driven by the combustion of fossil fuels.

Correlated with both economic and population growth, GHG emissions act as the driving force behind climate change. These changes to the climate, threaten a wide range of factors, and are anticipated to be expansive. Impacting public health, infrastructure, the environment, nation security and among others, resources (i.e. water and energy). As of 2014, the Intergovernmental Panel on Climate Change (IPCC) reported the warming of the Earth’s climate is "unequivocal". Averaged globally from 1880-2012, combined land and ocean surface temperatures have increased 0.85 (0.65 to 1.06)°C, as well as observed decreased snow and ice extent, and elevated sea levels (Pachauri et al., 2015).

Figure 1.1: A daily record of atmospheric greenhouse gas carbon dioxide (CO₂) concentrations measured in parts-per-million (ppm) at the Mauna Loa Observatory since 1958. Source: (The Keeling Curve, 2017).

Decreased snowpack, increased temperatures and alterations in precipitation patterns among others are all prevalent climate change driven modifications that will result in unfavorable consequences, particularly for water and energy supplies.

Among other consequences of climate change, fluctuations in temperature and precipitation have already been observed within the state of California. Increasing temperatures have resulted in a decreased expanse of snow pack within the western region of the United States, thus resulting in earlier snow melt for this region (Kassen & Williams, 2011). These continuous trends will intensify water scarcity, and fundamentally impinge the availability of water resources. In conjunction with a changing climate manipulated by GHG are increasing drought conditions. Accompanied by droughts, include a decrease in stream flow and increased water temperatures. These trends, will subsequently impact electricity supply concerning both water available for hydro-power generation and cooling-water for thermoelectric power generation (van Vliet et al., 2016). Warmer temperatures will further threaten electricity demands in the coming years.

1.2 Water and Energy

There is unanimity within the field that water and energy are intrinsically connected (Gleick, 1994; Wilkinson, 2011; Bauer et al., 2014). However, outside this discipline, water and energy are often considered two distinctive entities. These two resources are seldom taken jointly into consideration. While there is fundamentally a connection between the two, water and energy resources have previously been studied, regulated, and delivered to customers disjointly (Bauer, 2015). Nonetheless, water and energy have both been acknowledged as vital components to modern life and a prosperous economy (Hussey & Pittock, 2012). The water-energy nexus can be thought of primarily as two distinct components; (1) The water required for energy/electricity generation and (2) The energy required to distribute and produce potable water and again to treat wastewater.

Specifically, the water-energy nexus refers to the energy that is required to extract, convey, deliver, and treat water of adequate quality to end-users. Further, energy is also used to treat and recycle wastewater. Conversely, water is used for energy production and electricity generation. Specifically, within California, the energy required for the production, extraction, treatment of water and wastewater is 19.2% of the total electricity (250,494 GWh) and 30% of non-power plant natural gas consumption (Refining estimates of water-related energy use in California, 2006).

1.3 San Diego County

Geographical location and Climatology

This scenario analysis will focus solely on San Diego County, which is amongst two of the most southern counties within the state of California. San Diego County is nestled on the international border with Mexico. Relevant components of this report will be incorporated into a larger study investigating the impacts of climate change to the Baja region’s water-energy nexus.

San Diego has a mild climate, with low annual rainfall. Inclusive of coastlines, deserts as well as mountains, the
region has an eclectic landscape (Messner et al., 2009). According to the Köppen climate classifications, the County of San Diego has been defined as having a Mediterranean summer-dry climate. While conversely, to the East, Imperial County is classified as a dry desert climate (Fig. 1.2). Farther south, Baja Mexico has a similar climatology, but is considered a dry semiarid climate (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006; Rohli & Vega, 2012). San Diego’s geographical location and mild climate have fostered population, economic, as well as industrial growth in the region.

![Figure 1.2: California’s county climate map based on Köppen climate classifications, highlighting the study region for this report, San Diego County. Source: California Köppen Climate Classification map adapted by A. Rabe, 2017.](image)

**Population growth**

The population of San Diego County is expected to exceed over four million by the year 2050, a 29% increase from the current population of 3,317,749.

San Diego and Imperial County have drastically different populations. According to the most recent version of the United States Census Bureau data in 2016, the County of San Diego has a total population of roughly 3.3 million (3,317,749) individuals. While conversely, Imperial County has merely 180,883 individuals (San Diego County, California QuickFacts, 2016; Imperial County, California QuickFacts, 2016). For this reason, among others, Imperial County has been excluded in the analysis of the California side of the border.

The San Diego Association of Governments (SANDAG) has investigated and generated projections of population, housing units, employment, income, as well as land use growth within the region. According to the Series 13 Regional Forecast, by 2050 the county of San Diego is anticipated to grow in total population by 29%. (Fig. 1.3) (Series 13 Regional Growth Forecast, 2013). San Diego County is projected to see 460,000 additional jobs and 325,000 more housing units by the year 2050.

![Figure 1.3: The regions historic (2000-2010) and projected growth until the year 2050. Housing refers to total number of units in the county; single and multiple family as well as mobile mobile homes. Jobs refers to the total number of civilian non-military jobs for the county. Source: Data was compiled from SANDAG Series 13 Regional Forecast as well as the 2000 and 2010 Census data.](image)

The population within the county of San Diego itself is drastically different. Notably, a majority of the population within the county is located along the coast. As population is anticipated to grow, nearly 30% by the middle of the century, the density of population within San Diego will also be expected to grow. The regions population density is likely to move farther away from the coastline, and expanding eastward. As of 2015, SANDAG estimated that the binational region, of San Diego and Imperial County and Baja California, Mexico contains currently 6.4 million people.1 Moreover, this binational area is also expected to grow to nearly 10.6 million by 2040 (San Diego Forward The Regional Plan, 2015).

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1 Binational region encompassing two counties in California (i.e. San Diego and Imperial) and northern cities in Baja California, Mexico.
2 | Water-Energy Nexus

2.1 Introduction

According to the U.S. Department of Energy’s Water-Energy Tech Team (WETT), water and energy are interwoven. It has been identified that these two resources are connected as a result of the properties of water that make it a convenient mechanism for generating electricity. Conversely, energy is an essential aspect to treating water to potable standards, distributing said product to end members and lastly treating wastewater to discharge standards (Bauer et al., 2014). This relationship has thus been coined as the water-energy nexus.\(^1\)

Climate change, coupled with a growing population play a role in the WEN. Figure 2.1 explores the relationship between water, energy, an expanding population and the ever changing climate. Associated with an increasingly growing population comes an intensified demand for both water and energy resources. Further, population growth jeopardizes the state of the climate via land use changes and natural resource exploitation.

Energy choices have the ability to impact the climate, as well as water supplies. Traditional fossil-fuel energy sources and succeeding combustion; (i.e. coal, oil and natural gas) are the main contributors of GHG emissions. Further, some energy supplies; (i.e. hydroelectric, thermoelectric and nuclear) rely on water supplies in the process of electricity production.

Additionally, to produce potable water, energy is required in every step from accessing, transporting, treating to delivering this resource to users. Moreover, water usage has implications on the climate as exploiting this natural resources modifies the hydrological cycle, soil degradation and biodiversity. Finally, changes to the climate will continue to have implications on water resource availability. Worldwide, changes in temperature, precipitation, snowpack and increased drought conditions exacerbate already scarce water sources (Fig. 2.1).

Energy used for water production, transportation and treatment accounts for 20% of California’s total electricity consumption. Additionally, 17.4% of California’s water withdrawals were used for thermoelectric power generation.

2.2 History of the Water-Energy Nexus

First identified, by Peter Glieck, in 1994 at the Pacific Institute for Studies in Development, Environment and Security this is “intricately connected” relationship between water and energy was coined WEN,

“We use energy to help us clean and transport the fresh water we need, and we use water to help us produce the energy we need.” (Gleick, 1994)

This preliminary definition offers a simplified look at this intrinsically connected relationship. Delving farther, into both the complexities and quantifying the WEN, a diagram by the DOE WETT program was published in 2014 (Fig. Appendix 6).

This complex diagram demonstrates a breadth of knowledge, and information about the nexus. However, more importantly a few central players within the WEN. One of the key players in this diagram, representing more than 40% of total freshwater consumed, is the extensive amount of water required for cooling of thermoelectric power plants. The inefficiency associated with these plants is primarily due to electricity conversion which subsequently dissipates a great deal of the energy (Bauer et al., 2014). Other noteworthy players, include the energy required to treat effluent to discharge standards and transport potable water to households. This sector accounts for one of the largest consumptions of electricity for the state of California (Wilkinson, 2014).

\(^1\)Imperative to note, the water-energy nexus is often also referred to in the context of food resources, as the "water-energy-food nexus". Such that, food requires an extensive amount of both water and energy to produce, transport, deliver and finally prepare. To refine and attenuate the scope of research for this report, journals, articles and research pertaining to the "water-energy-food nexus" has been excluded, although its relevance and significance have been noted.

Figure 2.1: A simplified schematic of the interconnected relationship between water (blue), energy (orange), climate (green) and a growing population (grey). Credit: A. Rabe and J. Bailey
There are still some remaining missing links regarding the water-energy nexus that will be discussed in this report.

2.3 Related WEN Policies

National and state water policy have often not take into consideration the energy sector. Conversely, the same is true. Policy associated with energy typically does not involve water. Water and energy policies have remained distinct of one another regardless of this intrinsic connection.

This relationship, has now garnered a consensus that an intrinsic connection between water and energy exist. Further, the WEN has gained attention on local, state and federal levels. Including actors from the California Department of Water Resources (DWR), California Energy Commission (CEC), The United States Department of Energy (DOE) as well as others. However, insufficient policy has been sanctioned to foster the development of research surrounding the water-energy nexus. Various projects and related policies regarding water and energy are likely to impact these resources, and thus the nexus. With a potential risk of instability, the state of California has acknowledged that climate change via fluctuations in temperature, precipitation and increasing drought conditions, threaten future limitations to continuous inexpensive water and energy supplies (Ajami & Truelove, 2014).

2.4 Future of WEN

Regardless of the aforementioned connections, regulations and planning associated with water and energy have traditionally been carried out in isolation of one another (Hussey & Pittock, 2012). Furthermore, it has been recognized that in order to strengthen the resiliency of cities and nations, the frequently under assessed and often overlooked water-energy nexus must be taken thoroughly into consideration for future policy and decision makers ((Hussey & Pittock, 2012; Newell, Marsh, & Sharma, 2011). Moving forward there is a need for research and implementation of improved water and energy managements that can provide multiple benefits (Wilkinson, 2011). Frameworks that allow for feasible household and utility management of the WEN must be implemented in order to achieve these multi-benefits (Bauer, 2015). Pushing the historic infrastructure of the water-energy nexus out of mind, and decoupling water and energy resources will allow cities, counties, states and even nations to both mitigate and adapt to climate change.

2.5 Co-benefits to less energy-intensive water source

Given that energy is required in every step of the water process, the water sector is a large consumer of energy. Therefore, water conservation and efficiency measurements can also decrease consumption of electricity. Decoupling water and energy, can further lead to a reduction in GHG emissions, by either choosing: (1) water supplies that do not rely on GHG intensive energy sources and/or (2) less energy-intensive sources of water.

Not only can reducing energy consumption required for water supplies, potentially reduce greenhouse gas emissions, but also reduce the expense for water utilities. Thus, ultimately lowering the rate for water customers. Considering water and energy are interdependent, if the availability of water resources alters due to climate change, that will have a direct influence on energy demands. As available water resources are constantly being altered, more energy-intensive sources of water will be sought after. Thus, resulting in higher greenhouse gas emissions, the future climate must be assessed and projected.
3 | Climate Change Scenarios

3.1 Using climate model results to project future climate change

In order to assess how future projected emissions of GHGs will further impact the climate, it is necessary to compute the extent of climate change utilizing climate models. Climate models are essentially a series of mathematical equations, that represent how the Earth’s climate will respond to a variable. The variable used in this case, greenhouse gas emissions.

What is a Climate Scenario?

There are several inputs to generate greenhouse gas emission scenarios, which include the rate of population, economic as well as technological growth (Alcamo, 2008). Both socio-economic and emission scenarios are frequently used within climate research to provide a plausible description of how future GHG emissions will develop over time (Alcamo, 2008). The Intergovernmental Panel on Climate Change (IPCC) describes scenarios as,

“Images of the future, or alternative futures that are neither projections nor forecasts.” (Nazarenko et al., 2015)

Scenarios can be referred to as an “if-then” situation based on a range of driving force assumption (Alcamo, 2008). The scenarios or "driving force assumptions" used in this report are referred as Representative Concentration Pathways (RCPs) (See Section 3.4).

3.2 Introduction to Cal-Adapt

The impacts of climate change are anticipated to be expansive and inclusive, threatening both water as well as energy resources. In order to evaluate projected changes in temperature and precipitation for San Diego, an interactive climate data visualizations tool, Cal-Adapt was utilized for the extent of this report. Cal-Adapt compiles data from the scientific and research community within California intended to offer a visualization of how climate change will affect California at a regional scale. By utilizing some of the most applicable, well suited and credible climate models for this region, Cal-Adapt was developed to "encourage its use in a way that is beneficial for local decision-makers" (About Cal-Adapt, 2017; Lynn et al., 2015).

Developers

This tool was developed by the University of California, Berkeley’s Geospatial Innovation Facility (GIF). Cal-Adapt received funding from the CEC’s Public Interest Energy Research (PIER) Project, to build a tool that allows users to first hand examine changes in temperature, precipitation, snowpack and sea level rise on a local level via data from various scientific peer-reviewed communities. Cal-Adapt contributors of data include the following; Pacific Institute, Santa Clara University, Scripps Institution of Oceanography (SIO), UC Berkeley, UC Merced as well as the U.S. Geological Survey (USGS). (About Cal-Adapt, 2017). This collaborative tool compiles climate modeling data from various sources into one location, and has an immense potential to expand and shape future climate policy. Cal-Adapt can help communicate to policy and decision makers the impacts climate change will have, specifically to California in a visual and comprehensive manner.

3.3 Uncertainties and Strengths of Climate Models

Climate models are computer-based models derived from basic physical laws, such as conservation of mass, energy and momentum utilized to examine the physical impacts of climate change (Intergovernmental Panel on Climate Change et al., 2007). Climate models project how future emissions of greenhouse gases will perturb the climate, and result in a change in temperature, precipitation, snow pack and storm intensity among others. In order to do so, climate models rely on these projected rates of GHGs, also known as Representative Concentration Pathways (RCPs). General circulation or global climate models (GCMs) can have both an atmospheric and oceanic component, which are referred to as AGMCs and OGMCs, respectively. Climate models also do a fair job of incorporating well known feedbacks, such as the ice-albedo feedback. That is, as the global temperatures increase, additional land and sea-ice is lost. Subsequently lowering the Earth’s albedo and resulting in additional warming. However, different GCMs can model the same feedback or forcing in different ways resulting in various responses or results (Flato et al., 2013). This, as well as some of the lesser known feedbacks that aren’t currently included in GCMs, attribute to some of the uncertainty in climate models.

However, climate models can be used as an influential tool to inform policy and decision makers on the impacts of climate pollutants, we call greenhouse gases, on the future climate. Although, there are inherent uncertainties associated with forecasting the future. While it is impossible to predict exactly how future emissions will play out, climate scientist have worked to assess the reliability of these general circulation models. One of the ways to assess how well these climate models hold up, is to test their ability to reproduce both observed data of historic and current climate changes (Intergovernmental Panel on Climate Change et al., 2007). There are a total of 32 GCMs, the Cal-Adapt tool has ten possible climate model inputs available (Appendix 6). It has been identified and tested that these ten well-established and credible models represent the state of California with high accuracy at a down-scaled resolution (Lynn et al., 2015). While there are uncertainties associated with climate models, decades of research have provided a robust, quantitative evaluation of future climate change with the ability to shape and frame related policy.
3.4 Representative Concentration Pathways (RCPs)

It is insurmountable to foresee exactly what future emissions from fossil fuels will adhere to. These RCPs have provided a wide range of potential scenarios that take into account future economic, social, technological, and environmental conditions, that allow for further assessment of future climate change impacts.

Trends in projected greenhouse gas emissions are portrayed via representative concentration pathways (RCP). The IPCC left the development of scenario to the research community. In which, they provide information on possible development trajectories for greenhouse gases. Based on RCPs, further analyses to assess to the damages associated with anthropogenic perturbations can be conducted by Climate Models (CMs), such as this report, and in turn, Integrated Assessment Models (IAMs) (Alcamo, 2008; Van Vuuren et al., 2011).

Why RCP 4.5 and 8.5

Four various RCP scenarios exist, which include 2.6, 4.5, 6.0 and finally 8.5. The four RCPs values indicate a radiative forcing value in W/m² from 2.6 - 8.5 for the end of 2100.1. RCPs are considered trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use and have corresponding changes in temperature (Appendix 6).

RCP 2.5 is considered the lowest forcing level scenario, and both RCP 4.5 and 6.0 are considered median range scenarios. Conversely RCP 8.5 is considered the business as usual (BAU) scenario. Both RCP 4.5 and 8.5 were selected as the two various climate scenarios for this report. These two scenarios will act as both the low-range medium emissions (RCP 4.5) and high-range (RCP 8.5) global greenhouse gas emissions for this report. This report will assess the future of climate change to San Diego based on this low to high spectrum of greenhouse gas emissions. The Cal-Adapt tool utilized in this report only has RCP 4.5 and 8.5 available as inputs. However, there is validity and reasoning for why these scenarios were selected (Appendix 6).

Medium Emissions (RCP 4.5)

RCP 4.5 is characterized by stabilization, without an overshoot pathway of 4.5 W/m² (equivalent to 650 ppm of CO₂) by the year 2100. This pathway is associated with low to medium level greenhouse gas mitigation and medium air pollution (van Vuuren et al., 2011). Finally, this scenario is consistent with a future with relatively ambitious emissions reductions and stringent climate policies (Bjørnaes, 2013).

Business as Usual (RCP 8.5)

RCP 8.5 is characterized by a rising radiative forcing pathway leading to 8.5 W/m² (equivalent to 1370 ppm of CO₂) by the year 2100. This pathway is also associated with a high baseline for greenhouse gases, no further mitigation of climate pollutants and an associated medium to high level of air pollution (Van Vuuren et al., 2011). Additionally, this RCP is consistent with a future that has no policy changes to reduce emissions and a consistently heavy reliance on fossil fuels. Finally, RCP 8.5 represents a future consistent with three times today’s CO₂ emissions by 2100, a rapid increase in methane emissions and lastly a world population of 12 billion by the 2100 (Bjørnaes, 2013).

3.5 Results

Temperature

By 2070-2099, the number of extreme heat days, exceeding 96.3°F, in San Diego County is anticipated to increase by from 4.3 to 28.7 days under the medium-emissions scenario and 53.7 days under the business as usual scenario per year.

In order to observe changes in temperature, the entire county of San Diego was selected in the Cal-Adapt tool for annual maximum and minimum temperature, as well as the annual number of extreme heat days. The results for each of these parameters are outlined within this section.

In order to remain within the planning and forecasting scope of water and energy utilities, projected changes in the climate’s natural systems were only observed from 2017-2050. Extending past that, however, to the end of the century, from 2070-2099 all the following impacts of climate change are expected to be exacerbated. More specifically, based on the same observed baseline time period from 1950-1999, San Diego’s annual maximum temperature is anticipated to increase 5.5°F under medium-emission scenario (RCP 4.5) and 8.4°F for business as usual emissions (RCP 8.5) by the end of the century. Furthermore, by 2070-2099, the average annual number of extreme heat days is anticipated to increase by 28.7 days under the medium-emissions scenario and 53.7 days under the business as usual scenario.

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1 Radiative forcing refers to the net change, often additional energy taken up by the Earth’s energy balance due to some imposed perturbation such as a climate change pollutant (Flato et al., 2013; Bjørnaes, 2013). Radiative forcing is determined by both positive forcing from greenhouse gases and negative forcing from aerosols. However, one of the prevailing factors influencing the radiative forcing is the presence and repercussions from CO₂ (Nazarenko et al., 2015)
Increased maximum temperature for San Diego

From 2017-2050, the average annual maximum temperature for San Diego is expected to increase from 3.2 - 3.7°F.

Maximum temperature refers to the average maximum temperature yearly for the county of San Diego. The observed, historic annual average maximum temperature, from the years 1950 to 1999 was reported as 74.8°F. If global GHG emissions take on the "low-range" (RCP 4.5) scenario within this study, San Diego’s annual maximum temperature for 2017-2050 is anticipated to increase by 3.1°F compared to the historic observed average. Conversely, if global greenhouse gas emissions continue on the current path with no mitigation, San Diego’s annual maximum temperature from 2017-2050 is anticipated to increase by 3.6°F (Fig. 3.1).

![Annual Average Maximum Temperature for San Diego County](image)

Figure 3.1: The annual average maximum temperature for the county of San Diego, CA. The three thermometers represent the observed historic average from 1950-1999, as well as the two projected scenario results, RCP 4.5 and 8.5 from left to right respectively averaged from 2017-2050. **Source:** The results depicted in this figure came from the Cal-Adapt modeling tool (Appendix 6).

Increased minimum temperature for San Diego

From 2017-2050, the average annual minimum temperature for San Diego is expected to increase from 2.8 - 3.4°F.

Similarly, minimum temperature refers to the average minimum temperature yearly for the county of San Diego. The historic (1950 to 1999) average minimum temperature for San Diego County was 47.7°F. Compared to the results, from each RCP selected for this report, 4.5 and 8.5 minimum temperature is expected to increase to 50.3°F and 51.2°F respectively (Fig. 3.2). If global emissions take on the lower-range within this study (RCP 4.5), San Diego’s annual average minimum temperature is anticipated to increase by 2.5°F by 2017-2050. Conversely, if global emissions continue on the current path, San Diego’s minimum temperature is anticipated to increase by 3.5°F by 2017-2050.

Increased frequency of extreme heat days

From 2017-2050, the average annual number of extreme heat days at or above 96.3°F for San Diego County is expected to increase to 19-22 days per year.

Extrem heat days refer to the annual number of days, when temperature in the county of San Diego reaches or exceeds the extreme heat threshold. The extreme heat threshold for San Diego County is 96.3°F. From 1950 to 1999, the average number of extreme heat days for San Diego County was observed as 4.3 days per year. If global emissions take on the the low-range scenario for this report, RCP 4.5, the number of extreme heat days in San Diego County is anticipated to increase by 14.7 days/yr. Resulting in a total of 19 days yearly exceeding 96.3°F averaged from 2017-2050. Conversely, for the alternative high-range scenario, RCP 8.5, the frequency of extreme heat days in San Diego is expected to increase further (Fig. 3.3). From 2017-2050, the number of extreme heat days will increase by 17.7 days/yr to a total of 22 days yearly at or exceeding 96.3°F in San Diego County.
Figure 3.2: The three thermometers represent the observed historic average from the period 1950-1999, as well as the two projected scenario results for RCP 4.5 and 8.5 from left to right respectively for the average minimum temperature over the period from 2017-2050. **Source:** The results depicted in this figure came from Cal-Adapt (Appendix 6).

Figure 3.3: The number of extreme heat days annually, where the daily high temperature is above the extreme heat threshold of 96.3 degrees Fahrenheit for the County of San Diego, CA. The three magnify-glasses with thermometers represent the observed historic average from 1950-1999, as well as the two projected scenario results, RCP 4.5 and 8.5 from left to right respectively. The magnify-glass represents the county of San Diego and each exploding thermometer, represents 4 days of extreme heat/yr. **Source:** Results from the Cal-Adapt (Appendix 6).

**Decreased precipitation for San Diego**

From 2017-2050, the average annual total precipitation for San Diego County is expected to decrease by 0.6 - 0.7 inches/year.

Changes in precipitation may be less prevalent than the projected fluctuations in temperature for this region (Fig. 3.4). However, variation in rainfall patterns and trends are anticipated to occur for the region. Averaged from 2017-2050, under the low-range emissions scenario, RCP 4.5, a slight decrease of 0.6 inches per year in rainfall for the region will occur. Further, an average decrease of 0.7 inches per year of rainfall under the high-emissions scenario will occur (RCP 8.5) from 2017-2050. This will result in a 4.05-4.73% decrease in annual rainfall for the already arid climate in San Diego.
Figure 3.4: The value inside each rain clouds represent the total average annual rainfall in inches for the county of San Diego, CA. The three rain clouds represent the observed historic average from 1950-1999, as well as the two projected scenario results for RCP 4.5 and 8.5 from left to right respectively. Source: The results depicted in this figure came from Cal-Adapt (Appendix 6).

Decrease snow pack for the Sierras

Considering more than 50% of San Diego’s water supplies are still imported from outside the area (Fig. 4.1), snow pack changes to the "Sierra" climate region were also examined using the Cal-Adapt tool (Appendix 6). Changes to snow pack, for the Sierra climate region, are anticipated to decrease substantially more with climate change. By 2017-2050, if global GHG emissions take on the RCP 4.5 pathway, snow pack for the Sierra climate region during the peak month of March is expected to decrease 16.8% from the historic mean (1950-1999) of 11.3 inches to 9.4 inches. If emissions continue, at the current rate with RCP 8.5, roughly a 20.4% reduction from 2017-2050 in snow pack for the Sierra climate region in the month of March will occur compared to the historic average (1950-1999). Decreases snow pack for the Sierra Climate region will result in more winter precipitation as rain and less as snow fall. Snow pack acts as a source of long-term water storage in the summer and fall for California. Unless, adequate reservoirs and storage are in place to capture this runoff earlier in the year, San Diego’s imported water supplies from MWD could face shortages. Further the annual sum of the Sierra climate regions snow pack from 2017-2050 is expected to decrease by 24.4% for RCP 4.5 and 27.9% for RCP 8.5 compared to the 1950-1999 historic observed sum of 51.7 inches. Imported water for San Diego comes from an array of sources, not exclusively the "Sierra" climate region. Additionally, imported water from The Colorado River via the All-American Aqueduct and Imperial Irrigation District are anticipated to have mean annual runoff decline of 7.4% (City of San Diego Urban Water Management Plan, 2016).

Figure 3.5: The annual monthly snow pack for the "Sierra climate" region. The three lines represent the observed historic average from 1950-1999 in blue, as well as the two projected scenario results for RCP 4.5 in orange and 8.5 in red Source: The results depicted in this figure came from Cal-Adapt (Appendix 6).
4 | The Water-Energy Nexus in San Diego County, California

4.1 Water Sources

San Diego has a Mediterranean dry-summer climate, characterized by a wet winter and dry summer seasonality of precipitation. Further, summer drought periods are a defining characteristic for this climate. For that reason the San Diego Country Water Authority (SDCWA), a public agency responsible for delivering a wholesale water supply to 24 retail water agencies has relied heavily on imported water from both the Colorado River and San Joaquin Valley/Sierra Nevada mountain range by means of the State Water Project (SWP) and Metropolitan Water District (MWD) in the past. Specifically, in 1991 the SDCWA was 95% reliant on imported from the Metropolitan Water District of Southern California (About Us, 2016).

As a result of climate change, increasing drought conditions and population growth for the region, the Water Authority has pursued diversifying local water supplies in efforts to become less vulnerable to water shortages from MDW (Water Supplies, 2016). San Diego now has an increasingly diverse array of water supplies particular to this low-rainfall region. The water sources for San Diego will be one of the primary focuses of this chapter in regards to the embedded energy or energy-intensity for each water source.

Water supplies and allocation have remained a management issue regarding several authorities and exist within the hands of multiple municipalities, states and nations. Simply put, there is not one single entity responsible for water resources. Water remains a public good, that not one particular body or individual has control over. Water travels via rivers, lakes, streams, precipitation and et cetera across various boundaries within counties, states, nations, or globally. Thus, making water an exceedingly challenging resource to regulate authority and allocation of. This section will shed light on both San Diego’s current and projected water sources up until the year 2050.

Current Water Sources

San Diego’s current water supply has shifted tremendously since being almost entirely (95%) imported water in 1991 to currently 53.3%. Shortages from imported suppliers required SDCWA to diversify supplies (Fig. 4.1).

The current sources of water supplies for the region of San Diego were assessed using the 2015 San Diego Country Water Authorities’ Urban Water Management Plan. Regardless of the Authorities efforts to diversify their water supply portfolio, more than half (53.3%) of the current water supplies in San Diego are still imported from outside the region. However, as of 2015, San Diego’s water supply is additionally bolstered by nearly 15% desalination, 22% local water (15% surface and about 7% groundwater) and finally roughly 9.5% recycled water (8.61% indirect potable and just under 1% potable reuse) (Fig. 4.1).

Projected Water Sources

Moving forward, San Diego’s water supply is projected to change even more. As climate change continues to threaten the regions supply, San Diego much like the rest of southern California will be forced to pursue local, climate change resilient sources of water like desalination and recycled wastewater. For a full distribution of San Diego’s future water supplies see Appendix 6.

4.2 Energy Sources

Current Energy Sources

SDG&E has made strides to increase their renewable portfolio. As of 2015, 35% of SDG&E energy were renewable. A 24% increase from just five years prior in 2010.

1The the San Diego Country Water Authority (SDCWA) will also be referred to as the Authority or the Water Authority through out the remainder of this report.
Projected Energy Sources

Unlike water, energy has become easier to regulate at various levels. For that reason, projected sources of energy are likely to be influenced by various policies surrounding greenhouse gas emissions. Projected energy sources will likely be based on regulations set at the state level such as AB 32, California’s Global Warming Solutions Act of 2006. AB 32 requires the state of California to reduce GHG emissions to 1990 levels by 2020. SDG&E was the first utility in California to commit to delivering 33% renewable energy by the year 2020. As of 2015, at least 35% of SDG&E’s Power Content Label was considered renewable (Fig. 4.2).

<table>
<thead>
<tr>
<th>Year</th>
<th>Renewable</th>
<th>Non-renewable</th>
<th>Unspecified</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>11%</td>
<td>80%</td>
<td>9%</td>
</tr>
<tr>
<td>2011</td>
<td>15.7%</td>
<td>65.9%</td>
<td>18.4%</td>
</tr>
<tr>
<td>2012</td>
<td>20%</td>
<td>39%</td>
<td>41%</td>
</tr>
<tr>
<td>2013</td>
<td>24.0%</td>
<td>70%</td>
<td>6%</td>
</tr>
<tr>
<td>2014</td>
<td>32.2%</td>
<td>47.8%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Table 4.1: SDG&E power mix of energy resources from 2010-2014.

Moving forward, SGG&E’s energy resource mix will continuously pursue renewable energy sources, in order to meet California’s stringent greenhouse gas and climate change mitigation initiatives (Table 4.1). For the year 2020 SDG&E has a contract to reach 45% renewable energy (California Renewables Portfolio Standard (RPS), 2017).

4.3 Water Consumption

SDCWA has seen an overall decreased consumption in both total and urban water consumption since 2007. Compared to the annual total water usage of 2007, consumption in 2016 decreased 34.8%. By far the largest consumer of water for San Diego County is residents, consuming over 62.6% of the total water usage (539,361 AF) in the year 2015.

San Diego counties’ water consumption data for the preceding ten years (2007-2016) was assessed from publicly available data (Fig. 4.3). This graph shows both total water usage (blue) and urban usage, which included municipal and industrial (orange) for San Diego County. The total water usage data excludes recycled, or rather “purple pipe water”.

The water consumption was then evaluated by sectors. By far and large the largest consumer of water for San Diego County is residents (blue), consuming an average of 361,383 AF of water annually between 2011 - 2015. Commercial, industrial, agricultural as well public and other combined still do not add up to the total amount of water used by residents in San Diego county (Fig. 4.4).

Conservation & Efficiency

When observing historic water consumption for San Diego, a decrease in consumption of water for both urban use, as well as total water use from the Water Authority was observed (Fig. 4.3). This decrease in water usage can be associated with a variety of factors which include; conservation, technological advancements and efficiency measurements. Historically, we have seen a political as well as technological emphasis placed on supply side management for both energy and water. However, within recent years technological innovation has led to the improvement of efficiency in water and energy resources (Wilkinson, 2011). Such efficiency

<35% Renewable comprised of (biomass, 2% , wind, 15% and solar 18%). This value does not include the 11% "unspecified energy" (See Miscellaneous Energy Section).
improvements include incentivizing the installation of high-efficiency wash-machines and similar technology via rebates.

Furthermore, according to the United States Drought Monitor, nearly a 100% of San Diego County experienced severe to extreme drought conditions from May 2013 to January 2017 (Appendix 6). The peak for the last drought in San Diego County, from July 2014 to December 2014, resulted in 90.12% of the county resided in "extreme drought" conditions. From the most recent report, on May 16th, 2017 San Diego County remains at 17.4% moderate and 100% abnormal drought conditions still. The decreased water consumption for SDCWA in the last ten years can largely be a response of the most recent drought conditions.

Figure 4.4: Water consumption measured in acre-feet by sector for 2011-2015. The top graph represents the largest consumer of water supplies for San Diego, residents. Followed by the bottom graph with commercial, industrial, agricultural and public/other users. Source: (SDCWA Finance Department, 2015)

4.4 Energy and Electricity Consumption

Commercial buildings and residents represent the largest consumers of electricity in San Diego, using 45.4% and 36.7% of total electricity respectively in the year 2015. Total electricity consumption in 2015 compared to 1990 has increased nearly 37% for SDG&E users.

This section will discuss the County of San Diego’s electricity as well as natural gas consumption for the past 25 years from 1990-2015 (Fig. 4.5). This data was taken for the California Energy Commissions and examines trends in total, non-residential and residential electricity consumption in (GWh). The large dip in electricity consumption for non-residential consumers in the late 1990’s can be explained by the California Energy Crisis (Fig. 4.5). Moreover, unlike the decreased consumption of water in the region, a steady increase in electricity consumption has occurred. The electricity consumption was broken up farther by utility (Fig. 4.6). By far the largest consumers for the County of San Diego are commercial buildings (orange) and residents (blue).

Figure 4.5: Historic electricity consumption (GWh) by sector San Diego Gas & Electric

Figure 4.6: The historic energy consumption for San Diego Gas & Electric by utility

Figure 4.7: The historic natural gas consumption for San Diego Gas & Electric by sector
4.5 Energy-intensity of Water Sources

Ancient civilizations relied on easily accessible sources of water, as well as gravity for transporting said resource via aqueducts, wells, and rainwater channels. Roughly, 71% of the Earth is covered by water. However, only a mere 2.5% is considered freshwater, most of which is trapped in glaciers and ice-caps (68.7%) or beneath the ground (30.1%) (The World’s Water, 2016). Seeking additional sources of water, in order to accommodate a growing demand will be required, potentially increasing energy demands and requirements. Calculating embedded-energy of water sources can be a difficult task, as the amount of energy required for various water sources vary based on the location of source and consumers, distance the resources has to travel, level of treatments and so forth. San Diego has a highly diverse water supply, which includes local water (i.e. ground and surface), imported water, recycled and finally desalination. This section will aim to provide an overall estimate of the energy-intensity of the various water supplies for the county of San Diego. Energy-intensity refers to the total amount of energy (kWh) required for the use, of a given amount of water, based on a specific location or type of source (AF). It is often also referred to as "embedded-energy" or energy-inputs of water supplies (Wilkinson, 2011).

Figure 4.8: Energy-intensity values for San Diego’s water supplies. From descending order, the most energy-intensive source of water is the Carlsbad Desalination Plant, imported water from the State Water Project, Imperial Irrigation District and the Colorado River, recycled water, groundwater, local surface water sources and finally conservation. Source: From left to right, the data sources include the following; desalination values provided by the SDCWA, State Water Project Delivery to MWD from (Water-energy nexus: State Water Project, 2016), and recycled (potable) values from (Water in the West, 2013), and remaining water sources from (Wolff et al., 2004).

San Diego’s total energy-intensity

The average annual energy-intensity for San Diego’s water supplies was assessed by multiplying the annual amount of each source (AF/yr), by the relative averaged energy-intensity (KWh/AF) for the corresponding source. The average relative energy-intensity for all of San Diego counties water supplies is 123 billion KWh per year (Table 4.2).

<table>
<thead>
<tr>
<th>Source</th>
<th>Supply (AF/yr)</th>
<th>Energy-intensity (KWh/AF)</th>
<th>Total (KWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imported</td>
<td>180,200</td>
<td>2,451</td>
<td>441,730,267</td>
</tr>
<tr>
<td>Desalination</td>
<td>50,000</td>
<td>5,239</td>
<td>261,927,540</td>
</tr>
<tr>
<td>Groundwater</td>
<td>23,773</td>
<td>487.5</td>
<td>11,589,338</td>
</tr>
<tr>
<td>Surface</td>
<td>51,680</td>
<td>80</td>
<td>4,134,400</td>
</tr>
<tr>
<td>Recycled (non-potable)</td>
<td>29,095</td>
<td>400</td>
<td>11,638,000</td>
</tr>
<tr>
<td>Recycled (potable)</td>
<td>3,300</td>
<td>1,130</td>
<td>3,729,000</td>
</tr>
<tr>
<td>San Diego’s average energy-intensity</td>
<td>1,631.2 (KWh/AF)</td>
<td>122,458,091 (KWh/yr)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2: Total average relative energy-intensity of San Diego Counties water sources.
Each of the water supplies are broken up as follows;

**Desalination**

Desalination is the process of converting seawater to potable water via the process of pretreatment filtration, microfiltration, reverse osmosis (RO), and post-treatment disinfection. For more information on the overall process and infrastructure of the Carlsbad Desalination plant refer to the how it works webpage.

As a result of increasing drought conditions, via climate change, numerous large-scale seawater desalination facilities have already been either proposed or built. Within San Diego County specifically, the Carlsbad’s "Poseidon", a private investor-owned (PIO) desalination plant was completed in the winter of 2015. This plant currently produces 50,000 AF annually of potable water to the SDCWA and will continue to do so until the year 2040 (Fig. 4.1). However, this plant has the potential to increase the annual average production capacity to 61,600 AF, if necessary as an adaptive resource management strategy. Desalination, in this arid region and in similar climates around the world act to diversify local water supplies in a climate-change and drought proof alternative to traditional imported supplies (Final 2015 Urban Water Management Plan, 2016). Desalination, could act as a fall back option for water-stressed coastal regions, as saline water is considered an abundant source of water.

However, there are several disadvantages associated with the use of desalination technology, such as, the up front cost and environmental concerns. More notably, for the purpose of this report desalination is considered an exceedingly energy-intensive process to producing potable water. Regardless of new technology and infrastructure, desalination still remains to be the most energy intensive source of water within San Diego, Ca (Fig. 4.8). The proposed or estimated energy-intensity of desalination was expected to be roughly 4,400 kWh/AF (Wilkinson, 2011). However, the associated energy-intensity of the Carlsbad Poseidon plant was reported to have an average energy consumption of 3,651 kWh/AF without PW pumps and total energy consumption of 5,239 kWh/AF.

**Groundwater**

Groundwater, refers to a source of water supply that resides beneath the surface in aquifers or basins, and requires the process of pumping or extraction to obtain. Groundwater aquifers can be a major supply of water for various parts of Southern California. However, San Diego’s has relatively limited groundwater assets (Local Rainfall and Reservoirs, 2017). While groundwater opportunities for this region are limited, this source of water does currently bolster supplies for the county. This report will not discuss privately owned and operated wells, but rather brackish groundwater and wells that pump groundwater that do not require desalination. The Authority has identified, as of the year 2015, nearly 7% (18,944 AF) of the region’s annual water supply originates from groundwater sources (Fig. 4.1).

There are several factors that can influence the availability, quality and effort required to obtain groundwater. This includes, the amount of rainfall, groundwater recharge and water degradation (Final 2015 Urban Water Management Plan, 2016). Urbanization largely influences this source of water, as the increased amount of impervious surfaces (i.e. asphalt, concrete and pavement) decreases the amount of groundwater recharge. Historically, engineers have advocated the concept of “conveyance”, a permanent waterway, intended to divert storm water runoff away from cities. Storm water runoff has been perceived as a threat to building foundations and urban infrastructure. Thus, many urban cities were constructed with a vast array of impervious surfaces, intended to quickly and efficiently transport water away from buildings and streets through gutters and canals to the ocean (Ruby & Gillespie, 2006).

**Surface Water**

Surface water, refers to water that resides in rivers, lakes, streams, creeks and reservoirs. Surface water is a critically important source of water, used for a variety of purposes (i.e. potable water, irrigation, agriculture and thermoelectric-power generation for the cooling of electricity-generating equipment). Surface water is considered runoff, from local rainfall that flows into reservoirs. Local reservoirs can also act as a place of storage for imported water or indirect potable water. This source currently represents a vital, but relativity small portion of San Diego County’s water supply needs, due to the arid climate and low rainfall. At this point most of the surface water resources that are available have already been used, allocated and accounted for. However, there is the potential to increase surface water by optimizing rainfall capture.

There are a total of 24 reservoirs amongst the Authority and its member agencies. As of 2015, the San Diego County Water Authority’s water supply was comprised of 15.3% (51,680 AF) surface water (Fig. 4.1). Compared to other sources of water for this region, surface water is a relatively energy efficient sources of water. Surface water has an associated energy intensity of roughly, 80 KWh/AF.

**Imported Water**

San Diego is considered an arid region, characterized by low annual rainfall. For this reason, the SD-CWA has historically relied on imported water from the Sierra Nevada mountains as well as the Colorado River purchased from the Metropolitan Water District (MWD). Imported water for San Diego is transported by means of the Imperial Irrigation...
District, the All-American Canal as well as the Coachella Canal. In 1959, California established the State Water Project (SWP) via the California Department of Water Resources (DWR), which sanctioned the transfer of roughly five billion cubic meters (4,053,572 AF), of water every year from the more wet region of northern California, downward to dry parts of the state such as Los Angeles and San Diego (Gleick, 1994). The SWP project is recognized by the Department of Water Resources as “the nations’ largest state-built water and power development and conveyance system” (California Renewables Portfolio Standard (RPS), 2017).

Imported water has remained an important and heavily relied on source of water for San Diego in the past. However, MWD has been historically subject to cut water deliveries to San Diego in the past. For example, during the 1991 drought period MWD cut San Diego’s water supply by nearly 30%, as the drought reduced MDW’s total available water availability. As such, MDW is not a reliable source of water for the region, and has forced the Water Authority to seek out alternative sources. In fact, the ratio of imported water from MWD has decreased from 95% in 1991 to 53.3% in 2015. However, the energy-intensity of imported water remains high considering the transportation cost. As of 2015, more than half (53.3%; 180,200 AF) of SDCWA’s supply originated from imported water (Fig. 4.1). The range of energy-intensity for imported water in San Diego is roughly 2,000 - 3,300 kWh per acre foot. Part of this, is a result of the SWP, a system that produces on average 7 million MWh/yr, and conversely consumes over 12.4 million MWh/yr, ultimately resulting in a large net consumption of energy (Gleick, 1994).

**Recycled**

Another water supply with room for immense growth in local supply, similar to desalination is the utilization of recycled water. Recycled water is also considered a drought and climate change resilient water source, that decreases San Diego’s dependency on imported water from MDW. Recycled water has the potential to grow, as currently 175 million gallons of wastewater per day from the the Point Loma Wastewater Treatment Plant, for the most part is currently discharged into the Pacific ocean (Point Loma Wastewater Treatment Plant, 2017). However, in 2014, the City of San Diego implemented a potable water reuse plan, also refereed to as Pure Water San Diego. This plan, proposed using up to 83 million gallons of Point Loma wastewater ocean discharge per day, to be diverted to an advanced water treatment facility. The facility would then send the highly purified water to augment local drinking water reservoirs or other reuse projects (Mogharabi & Gibson, 2016).

Reclaimed water is considered the process of treating and disinfecting treated wastewater for reuse. Similar to desalination, this is an energy-intensive source of water, using from 400-1130 KW/H/AF (Fig. 4.8). There are different types of recycled water, which includes both potable and non-potable, as well as indirect and direct reuse.

Wastewater for reuse involves the use of a municipality’s wastewater as an alternative source to supplement a region’s water supply. Two forms of planned potable reuse exist: both direct potable reuse (DPR) and indirect potable reuse (IPR) (Tchobanoglous et al., 2015). DPR is purposed when highly treated wastewater is introduced into an existing drinking water supply system. Conversely the latter, IPR occurs when treated wastewater is introduced into an environmental buffer such as a groundwater aquifer or lake, before the blended water is later introduced into a water supply system (Tchobanoglous et al., 2015). The purple pipe system is currently used within San Diego County for both irrigation purposes and industrial process. This includes replenishing lakes, fountains, irrigating parks and recreational field. Recycled water is also used for cooling towers and certain toilets. As of 2015, 9.596% (32,395 AF) San Diego’s annual water supply was supplemented by recycled water (Fig. 4.1).

There are also a few disadvantages associated with reclaimed water as well. For instance, one large hurdle to overcome is the public acceptance or rather lack thereof for recycled water. Since infamously being coined "toilet-to-tap" in the 1990’s, which originates from a lack of understanding regarding the water recycling treatment process. Further concerns stem from the financial and economic as well as the regulatory issues with reclaimed wastewater. For more information on the process, constrains and benefits to using recycled water refer to the DWR’s quick Water Recycling Facts Sheet or the full, white paper funded by American Water Works Association and Water Environment Federation on Framework for Direct Potable Reuse.

### 4.6 Water-intensity of Energy Sources

**Solar**

Various sources of solar energy exist, which include photovoltaic (PV), solar thermal energy as well as concentrated solar power (CSP). PV cells produce electricity directly from sunlight. The water used in order to produce PV cells is often considered negligible, as they are frequently produced in water-rich regions and shipped to more arid regions. Solar PV electricity is considered among one of the least water intensive energy sources. Conversely, solar thermal energy is the process of utilizing the sun’s energy to heat and vaporize water or another fluid to produce electricity, which is considerably more energy intensive than PV cells. Solar farms can also further require a considerable amount of water for washing and cleaning of mirrors (Glassman et al., 2011).

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3Recycled water and reclaimed water are synonymous and will be used interchangeably throughout this report.
Wind energy facilities require no water for the production of electricity and almost none for the construction of the wind turbines. As with photovoltaic cells, wind turbines can be fabricated anywhere and set up in regions with energy demand and sufficient wind resources. Along with PV cells, wind energy is considered to be one of the least water intensive sources of energy (Glassman et al., 2011).

Bioenergy

Biomass, or often referred as "biofuels", is the process of growing and producing crops to be converted into liquid fuels. Biofuels represent an expanding renewable source of energy within the United States (Pate, 2011). Energy produced from biomass can provide the opportunity to displace imported fossil fuel dependency and subsequently reduce greenhouse gas (GHG) emissions (Pate, 2011). However, it is imperative to note that biomass energy has the potential to have disadvantageous implications to the water-energy nexus. For example, irrigated first-generation soy and corn-based biofuels can require up to thousands of times more water than traditional oil drilling, primarily through irrigation of crops (Glassman et al., 2011). The WEN relation to bioenergy will depend significantly area crops are grown and irrigation practices under which it is implemented. Specifically, for arid regions, like San Diego, with a water-sparse climatology, it is anticipated to have far greater implications on local water resources compared to biomass grown in areas with a greater amounts of precipitation (Kenney & Wilkinson, 2011).

Natural Gas

Natural gas, primarily comprised of methane, also contains hydrocarbons gas liquids and nonhydrocarbon gases. Similar to coal and petroleum, natural gas is considered the remains of decayed organic material that has been pressurized into its current form. Natural gas production has increased as a result of prices in recent years dropping. Natural gas has also reduced reliance of imported fossil-fuels.

In order to identify the areas beneath the earth’s crust where natural gas is likely to reside, geologist have gone to extensive lengths. In pursuance of natural gas, which often resides inside rock formations, water, chemicals and sand are forced to "fracture" the rock and release the gas. Natural gas, when burned, releases fewer emissions of CO₂ per unit of heat produced than coal or refined petroleum products according to the EIA (Natural Gas Explained, 2016). However, natural gas is primarily methane and leaks from natural gas wells can occur. Methane is considered a long-lived climate pollutant that can that can have a global warming potential 28-36 times greater than CO₂, and subsequently remain in the atmosphere for about a decade on average (Understanding Global Warming Potentials, n.d.).

Water is a big component in the process of both extracting natural gas, as well as transforming this fuel’s chemical energy into a usable form of electricity. A study in 2016 researched the amount of water used for natural gas production via hydraulic fracturing in the US. The report found that within 14 states, the annual average water used per well ranged from 100 cubic meters (m³) to 30,000 (m³). It was identified within the study that, the application of hydraulic fracturing requires high volumes of water and therefore has the potential to promote a high demand for freshwater, induce groundwater contamination, and require significant expenses in wastewater disposal (Chen & Carter, 2016).

Miscellaneous Energy

The power content labels (PCLs) were instituted by AB 162 and SB 1305, in which all electricity suppliers were required to disclose the energy sources used to generate electricity to the state’s consumers. Part of the includes a "Unspecified Sources of Power" section.

This refers to electricity that is not traceable to a specific generating facility, such as electricity traded through open market transaction. Unspecified sources of power are typically a mix of a resource types, and may include renewables according to the California Energy Commission where all PCLs can be found.
Climate change is expected to impact different parts of the world in various ways. A global increase in temperature of 0.85°C has already been observed (Pachauri et al., 2015). As evident by the Cal-Adapt results, San Diego County is also projected to see an increase in temperature by just the middle of the century (Fig. 3.1, 3.2, 3.3). Beyond 2050, average temperature for San Diego is anticipated to increase even more. This chapter will provide a brief overview of how the projected changes in temperature, number of extreme heat days as well as precipitation and snow pack will likely impact water and energy supplies for this region.

5.1 Water Supplies

Water and energy resources are expected to be impacted by climate change. Changes in temperature, precipitation as well as snow pack extent threaten water resources throughout California, a state already vulnerable to water shortages. Increasing temperatures could severely reduce spring snowpack and result in increasing water shortages. This is especially true for arid regions of the state, such as southern California that rely heavily on imported water from wetter regions like northern California. Climate change is expected to cause more precipitation in the form of rain and less in the form of snow. Further, when snow is anticipated to fall later in the year, it is expected to melt earlier, further reducing Sierra Nevada snowpack upward of 70-90%.

As a warmer climate for California means a decreased supply and early melt of snowpack, this will result in the inability to provide the entire state with potable water during the dry, peak demand months. Another consequence of climate change, not evaluated in this report that threatens water supplies is sea-level rise. Estimates suggest that global mean sea level will rise between 8 inches (0.2 meter) and 6.6 feet (2.0 meters) by 2100 (Lindsey, 2016). Sea-level rise puts at risk coastal communities like San Diego that rely on groundwater to the danger of saltwater intrusion for freshwater or brackish aquifers. For the state of California and San Diego specifically, dealing with climate change could mean severe changes to water resources management and allocations.

5.2 Energy Supplies

Energy supplies will also likely to be impacted by climate change unless serious greenhouse gas mitigation occurs. Increasing temperatures and extreme heat days associated with climate change will result in an increasing use of air-conditioners and subsequent demand for electricity. Electricity demand in the region is expected to increase due to higher temperatures and increased number of extreme heat days (Fig. 3.1, 3.2, 3.3). Additionally, as population expands eastward away from the coast this will further increase electricity demands as this is the hottest region of the county. A larger population will also mean more energy demands to deliver water a farther distance than currently. Distribution of water resources remains as one of the most energy-intensive process of providing water to the region of San Diego (City of San Diego Urban Water Management Plan, 2016).

Decreased snowpack and fluctuating, less predictable precipitation cycles will result in a decrease supply of energy from hydroelectricity. Saltwater intrusion of groundwater aquifers from associated sea-level rise will require further energy requirements and electricity demands to treat and convert this water source into a potable supply. Changes in temperature and precipitation will ultimately influence the availability of water resources for potable consumption as well as energy production. Associated drought conditions, such as low streamflow and increased water temperatures have impacts on both hydroelectric and thermoelectric power capacity. As a result of drought conditions, an observed reduction of 5.2% and 3.8% in hydropower and thermoelectric power respectively, relative to the long-term average utilization rates for 1981-2010 was observed (van Vliet et al., 2016). This study revealed that anticipated fluctuations in water resources would also further influence energy supplies for regions where drought condition are typical.
The findings of this climate scenario assessment are outlined below:

- San Diego County’s population is expected to increase 29% by the year 2050.
  - An overall increasing population for the county will expand population density within the inland region, away from the coast.
  - Regions farther away from the coast are anticipated to see the greatest increase in temperature. A sprawling population will require additional energy resources to transport water farther distances away from current potable water infrastructure.

- Climate change will continue to alter San Diego’s cherished mild climate.
  - San Diego County is expected to see an increase in the annual maximum temperature of 3.2-3.7°F for 2017-2050.
  - Additionally, the annual average minimum temperature for San Diego County is expected to increase 2.8-3.4°F for 2015-2050.
  - The number of annual extreme heat days at or above 96.3°F for San Diego County is expected to increase from 4.3 to 19-22 days of the year.
  - Annual rainfall patterns from 2017-2050 for the county of San Diego are expected to decrease by 0.6-0.7 inches in a year.
  - San Diego has historically relied on imported water, such that more than half, 53.3% of SDCWA’s 2015 supply was imported from regions outside the county. Imported supplies are transported from both the San Joaquin delta and Colorado River.

- Snow pack changes to the Sierra Nevada mountains and Colorado mountains and resulting runoff could have implications for nearly half of San Diego’s water supply.

- These observed changes in temperature, precipitation, and snow pack as a result of anthropogenic climate change will have explicit repercussions on the region’s WEN.
  - Increased temperatures for the region will have a direct effect on electricity demand. As temperatures and the frequency of extreme heat days increase throughout the year, San Diego residents air-conditioning usage will escalate, creating an even larger demand for future electricity.
  - Electricity consumption will increase by at least 60% by the year 2050, with higher temperatures causing approximately 7% of the increase (Kuni, Kelly, & Young, n.d.).

- A decreased supply of local water from changes in precipitation patterns will have ramifications for the regions water supply.
  - Rising temperatures will result in an increased evaporation of local surface water supplies.
  - Prolonged and more frequent drought conditions for the region will diminish local water supplies.

- Sea-level rise and associated salt water intrusion will have adverse effects on San Diego’s groundwater availability.

Climate change will threaten both local and imported water resources as well as increase energy demands. As a result of these consequences San Diego County Water Authority will be forced to seek out alternative sources of water. SDCWA’s plan to diversify their water portfolio includes desalination and recycled water. Desalination is the most energy-intensive water source for the SDCWA. From an energy perspective, it has been identified that recycled water and available groundwater sources, despite the required advanced treatment are the most cost-effective (Wilkinson, 2011).

Moving forward it is essential for agencies to not only plan for the consequences of climate change, but also the influences to the WEN. Future research to directly correlate changes in temperature, precipitation, snow pack and sea-level rise to water and energy resources for San Diego are required. Decoupling these resources by choosing less water-intensive renewable energy sources and less energy-intensive local water sources allow for both local regions and the nation to alleviate the effects and rate of climate change and build resilient and secure societies. Warming temperatures, increased number of extreme heat days, sea-level rise, and more frequent wildfires and droughts resulting from climate change threaten San Diego’s public health, biodiversity, economy, infrastructure and unless properly planned, the management of water and energy resources. Water and energy have historically been studied, regulated and distributed by separate agencies despite the intrinsically linked connection between the two resources. By moving away from this compartmentalized approach, there are numerous opportunities and co-benefits associated with integrating water and energy sector planning. Simultaneously, by choosing less energy-intensive water sources and less water-intensive energy sources can mitigate climate change, and build resilient cities that are less reliant on imported sources of energy and water (Wilkinson, 2011).
References


Intergovernmental Panel on Climate Change, Solomon, S., Qin, D., & Manning, M. (Eds.). (2007). Climate change 2007: the physical science basis: contribution of Working Group I to the Fourth Assessment Report


A. Additional Resources

Additional Resources on Climate Change

NASA: Climate Change and Global Warming
National Oceanic and Atmospheric Administration
NOAA’s National Centers for Environmental Information
Scripps Institution of Oceanography Center for Climate Change Impacts and Adaptation

Additional Resources on the Water-Energy Nexus

US Department of Energy’s Water-Energy Nexus Report
US Department of Energy’s Water Energy Tech Team
Internation Energy Agency World Energy Outlook
Pacific Institute; Water-Energy Nexus
National Conference of State Legislatures
California Energy Commission; Water-Energy Nexus

Additional Resources on Climate Models and Scenarios

National Oceanic and Atmospheric Administration; Climate Models
University Corporation for Atmospheric Research Center for Science Education; Climate Modeling
Intergovernmental Panel on Climate Change; Scenario Process for AR5
B. DOE Sankey Nexus Diagram

Energy and water flows are depicted by the green and blue colors respectively. The sources of both these sectors, energy and water, are represented on the left-hand side of the graph while conversely, the alternative side of the diagram depicts the sinks, exports or uses in both sectors. The magnitude of energy and water being either produced or consumed is exemplified by the thicknesses of each line in units of quad/yr and billion gallons/day respectively (DOE, 2014).

Figure 1: A Sankey diagram from the U.S. Department of Energy estimating and quantifying the relationship and movement between water and energy within the U.S. based on 2011 data. Energy is reported in units of Quads/year and conversely water is reported in units of Billion Gallons/day. Source: (Bauer et al., 2014)
C. Representative Concentration Pathways (RCPs)

As mentioned, CO\textsubscript{2} is considered the most dominant radiative forcing agent for each of the RCPs. Referring to Figure 1.1, the current concentration of atmospheric CO\textsubscript{2} is over 410 ppm. In order to reach RCP 2.6, incredibly ambitious greenhouse gas emissions reductions would be required over time (Bjørnæs). In order to reach this RCP, extensive technology of carbon-capture and sequestration (CCS) would already need to be implemented. Considering this, RCP 4.5 was chosen as the "low-range" emission scenario for this report. Alternatively, RCP 8.5 or "business as usual" scenario was picked for the "upper-end range" emission scenario. This scenario is consistent with a future where no policy changes are implemented to reduce emissions.

![Figure 2: The associated concentration of atmospheric carbon dioxide CO\textsubscript{2} (ppm) for each RCP, the dominant radiative forcing factor across the scenarios. Source: (Nazarenko et al., 2015)](image1)

Additionally, each RCP is associated with a corresponding change in temperature (°C) based on the radiative forcing of each pathway. The representative concentration pathways 4.5 and 8.5 chosen for this report correlate with roughly a 2.0°C and 3.5°C warming respectively by the end of the century.

![Figure 3: The corresponding change in temperature (°C) for each pathway. Source: (Nazarenko et al., 2015)](image2)
D. Cal-Adapt

A: Climate Change Projections Cal-Adapt has various tools built using LOCA downscaled CMIP5 climate change projections. These include annual average (maximum, minimum, precipitation), extreme heat, sea level rise, snowpack as well as wildfires and long drought scenarios to become available soon.

B: Region Various locations and regions can be selected to observe changes in the aforementioned climate change projections. Boundaries can be changed and selected based on census, environmental or planning boundaries. More specifically, 6x6km grids, counties, census tracts, congressional districts, watersheds, climate zones, electricity utilities and et cetera. For the purpose of this report snowpack changes were observed based on the "Sierra climate" zone and changes in temperature and precipitation were observed for San Diego County.

C: Historic Observed Data An annual mean year or range, from observed data may be selected to use as a historic reference. The value displayed is the annual mean maximum temperature in San Diego County for 1950-1999. For consistency purposes, 1950-1999 was selected for every climate scenario within this report.

D: Projected Range An annual mean, for a projected range or year may be selected. The value displayed below represents the change in temperature for the region selected based on the climate scenario input (E), climate model input (F). Again, for consistency within this report, 2017-2050 was as the projected range for each climate change projection.

E: Climate Scenarios Two inputs for climate scenarios, RCP 4.5 and 8.5 (Appendix 2 & Section 3.3).

F: Climate Models The ten out of 32 global climate models (GCM) inputs available for all climate change projections. The models with * text to the names are the four standard climate models for Cal-Adapt. Within this report, all ten available climate models were selected for each climate change projection (Appendix 4).

G & H: Graph The results of the climate models based on the climate scenario inputs are displayed here. Each colored line represents the corresponding climate models predicted value. The single gray line represents the historic observed data. The shaded gray regions is the results of all 32 global climate models. For this climate change projection, the y-axis is maximum temperature in degrees Fahrenheit and the x-axis is both historic and projected years.

Figure 4: A screen shot taken May, 2017 of the Cal-Adapt website, displaying the interface for maximum temperature climate change projection for San Diego County. The letters A-H were added and explained in this appendix.
E. Climate Models used in Cal-Adapt

Climate models are the principle mechanism for evaluating how the climate is projected to change based on various forcings, such as trajectory of greenhouse gas emissions. This section provides a brief explanation for each of the ten climate models used in Cal-Adapt. The name, in the corresponding color is the official Coupled Model Intercomparison Project (CMIP5) model names. The institution refers to the institution/organization(s) that sponsors each model. The reference refers to the main reference The models with ∗ are the Cal-Adapt’s four default priority climate models. For a detailed description on each of the models used, the development as well as all the various model components (atmosphere, aerosol, atmosphere chemistry, land surface, ocean, ocean biogeochemistry and finally sea ice) see the IPCC’s Working Group 1 AR 5. Additionally, for more information on the reliability of climate models refer to NOAA’s FAQs on Climate Models

**HadGEM2-ES**

Institution(s): UK Met Office Hadley Centre
Year Published: 2009

**CNRM-CM5**

Institution(s): Centre National de Recherches Meteorologiques and Centre Europeen de Recherche et Formation Avancées en Calcul Scientifique.
Year Published: 2010

**CanESM2**

Institution(s): Canadian Center for Climate Modelling and Analysis
Year Published: 2010

**MIROC5**

Institution(s): University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
Year Published: 2010

**ACCESS1-0**

Institution(s): Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia
Year Published: 2011

**CCSM4**

Institution(s): US National Centre for Atmospheric Research
Year Published: 2010

**CESM1-BGC**

Institution(s): NSF-DOE-NCAR
Year Published: 2010

**CMCC-CMS**

Institution(s): Centro Euro-Mediterraneo per & Cambiamenti Climatici
Year Published: 2009

**GFDL-CM3**

Institution(s): NOAA Geophysical Fluid Dynamics Laboratory
Year Published: 2011

**HadGEM2-CC**

Institution(s): UK Met Office Hadley Centre
Year Published: 2010
F. "Sierra" Climate Region

In order to assess changes to California’s snow pack, the "Sierra" climate region was selected in Cal-Adapt. This area is represented by the purple shaded area (Fig. 5).

Figure 5: The "Sierra" climate region (purple) used to observe changes in snow pack to California and part of San Diego’s imported water supplies. Source: Screen grab from Cal-Adapt.
G. San Diego Drought Monitor

The U.S. Drought Monitor produces a weekly map of drought conditions for the entire United States constructed by the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture, and the National Drought Mitigation Center (NDMC). The results are based on measurements of climatic, hydrological and soil conditions around the country. The following graph depicts drought conditions for San Diego County based on the US Drought Monitor from December 2006 to May 2017, which displays two major drought periods for the region. The peak of the drought for San Diego occurred when 90.12% of the county resided in extreme drought conditions from July 2014 to December 2014. Additionally, a drought map of entire state of California was produced during this peak drought time for San Diego County and the most recent map published for reference was included (Fig. 7).

Figure 6: The drought conditions of San Diego County as reported by the U.S Drought Monitor from December 2006 to May 2017. Source: US Drought Monitor

Figure 7: The drought conditions of San Diego County as reported by the U.S Drought Monitor from December 2006 to May 2017. Source: US Drought Monitor
H. San Diego County Water Authorities Future Supplies

In efforts to become less reliant on imported water the San Diego County Water Authority has projected to diversify their portfolio tremendously by the year 2035.

Figure 8: The projected future water supplies for San Diego County until the year 2035. Source: SDCWA

Enhancing Water Supply Reliability