Appendix O

Imperial Region Vulnerability to Climate Change and Evaluation of Greenhouse Gas Emissions

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Acronyms

AF	acre-feet
BCCA	Bias Correction Constructed Analogues
BCSD	Bias Correction Spatial Downscaling
CDD	cooling degree days
CDWR	California Department of Water Resources
CEC	California Energy Commission
CMIP3	Coupled Model Intercomparison Project
CVWD	Central Valley Water District
DP	Definite Plan
EDP	Equitable Distribution Plan
ET	Evapotranspiration
GCM	Global Climate Model
GRP	General Reporting Protocol GRP
HDD	heating degree days
IID	Imperial Irrigation District
IRWM	Integrated Regional Water Management Plan
LLNL	Lawrence Livermore National Laboratory
PUP	Power/ Utility Protocol
SCP	System Conservation Plan
SDI	Supply and Demand Imbalance
SRES	Special Report Emission Scenarios
TM	Technical Memorandum

USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
WELP	Water Energy Load Profiling
WF	Imperial Water Forum

Memo

To: Imperial Irrigation District

From: Kwabena Asante

Reviewed by:

Date: April 26, 2012

Subject: Technical Memorandum, Imperial Region Vulnerability to Climate Change and Method for Evaluating Greenhouse Gas Emissions

The Imperial Water Forum (Water Forum) is preparing the Imperial Integrated Regional Water Management Plan (IRWMP). The IRWMP will support adaption to climate change and help the region plan for and respond to uncertainty. The purpose of this Technical Memorandum (TM) is to assess climate vulnerabilities and impacts. The result of the study and review of this TM will be incorporated into the Imperial IRWMP.

CDWR IRWMP Standards for Climate Change

California Department of Water Resources (CDWR) IRWMP Proposition 84 & Proposition 1E Guidelines for the IRWM Grant Program (Guidelines; CDWR 2010) established the preliminary requirements for evaluating climate change and greenhouse gas emissions (GHG). The climate change analysis standards were intentionally written broadly in recognition of the vast variability in the degree and type of vulnerability to the effects of climate change among IRWM regions. CDWR and the U.S. Environmental Protection Agency (USEPA) subsequently published a handbook entitled "Climate Change Handbook for Regional Water Planning" (USEPA and CDWR) which provides a framework for considering climate change in water management. The Handbook is referenced in the CDWR for Climate Change Standard for Round 2 and 3 of the Prop 84 Implementation Grants which states that the IRWMP must:

- Include a climate change vulnerability assessment of the region that is at least equivalent to the qualitative check list assessment in the Handbook.
- Include a list of prioritized vulnerabilities based on the vulnerability assessment and the Regions IRWM's decision making process.
- Contain a plan, program, or methodology for further data gathering/analyzing of the prioritized vulnerabilities.

While the existing standards for including climate change in the Region's description and in the Project Review Process have not changed, the Handbook provides useful assistance on how to address climate change. Further, the Handbook in no way supersedes, replaces, or adds scope to the Climate Change Plan Standard contained in CDWR's 2010 IRWM Program Guidelines. The Handbook outlines a four-step process for completing a climate change adaptation analysis: (1) Assess Vulnerability, (2) Measure Impacts, (3) Develop and Evaluate Strategies, and (4) Implement Under Uncertainty.

O.1 PRIORITIZED VULNERABILITIES

The Water Forum adopted the IRWMP Mission, Goals and Objectives in September 2010. In March 2011, after an initial review of the resources management strategies, including the evaluation of how the strategies would help mitigate or adapt to the effects of climate change, the Water Forum prioritized the Imperial IRWMP goals and objectives. The Water Supply Goal was ranked the number 1 priority. This is in part due to the reliance on Colorado River supply. With the QSA/Transfer Agreements, demand management is also of significant importance. Climate change vulnerabilities that have the potential to affect the Colorado River supply or the Imperial Regions water demands, and which could be influenced by the IRWMP, are prioritized in this assessment.

O.2 SUMMARY OF IMPERIAL REGION VULNERABILITIES AND IMPACTS OF CLIMATE CHANGE

A broad understanding of potential effects and impacts of climate change, both within and outside Imperial region, will support definition of appropriate adaptive management strategies and responses. In evaluating the climate change vulnerability of the Imperial Region, the spatial scales of potential effects are important consideration. The spatial scales include the Imperial Region, Colorado River Basin, interregional and global climate change effects. This memorandum's focus is primarily on the climate change effects and vulnerabilities to the Imperial Region and Colorado River Basin. Interregional and global effects of climate change are noted but not extensively evaluated since the Imperial IRWMP has a limited ability to influence either of these scales. The more detailed evaluation for the vulnerabilities and impacts for the Imperial Region and Colorado River are presented in subsequent sections.

O.2.1 Imperial Region

Within the Imperial Region, climate change vulnerability would primarily be related to affects on water demands. Increases in the amount of evaporation associated with increased temperatures would increase crop water requirements. This could cause demand to outstrip supply, resulting in increased overruns and/or more frequent declarations of a Supply and Demand Imbalance (SDI) under the IID Equitable Distribution Plan (EDP). Increased evapotranspiration could also accelerate habitat loss in the marshes, and increase the rate of decline in Salton Sea elevation and salt concentration.

O.2.2 Colorado River Basin

The Imperial Region obtains its water supply from the Colorado River which flows from the upper basin states (Colorado, Wyoming, and Utah), through the lower basin states (Arizona, Nevada and California) before entering Mexico on its way to the Gulf of California. Under the Law of the River, Colorado River water supply imported by IID is quite secure and reliable because of the seniority of the IID water rights. As discussed in Attachment A, an array of studies have been carried out on the potential effects of climate change on the Colorado River, including recent work by the USBR (Technical Memorandum C -

Quantification of Water Demand Scenarios Appendix C10) as part of the Colorado River Basin Water Supply & Demand Study[1].

Water deficits must exceed the upper Colorado River Basin states' allocation before lower states' apportionment (and hence IID) are reduced. Also, the large volume of available reservoir storage on the Colorado River in Lake Mead and Powell buffer the potential climate change effects related to timing of flows that might occur if there were to be changes in the ratio of snow to rainfall. A reduction in the volume of water available is not envisaged even under the most extreme climate scenarios.

Finally, due to IID's historic water rights, reductions in Colorado River water supply would be absorbed by junior water rights holders prior to effecting IID's supply and the Imperial Region. Consequently, climate change poses a limited direct threat to the volume or timing of IID and Imperial Region water supply from the Colorado River.

O.2.3 Interregional

Interregionally, climate change could affect the available supply to other IRWM regions in Southern California by influencing both demands and the available imported water supply from the Colorado River delivered via the California Aqueduct and the State Water Project, which delivers water from the San Joaquin/Sacramento Delta. Anything that reduces the reliability and amount of imported supplies to the Southern California Region would likely increase competition for the Colorado River, making the Imperial Region vulnerable to economic, legal and political pressure; however, MWD's aqueduct can only carry 1.25 MAFY.

O.2.4 Global

Global climate change has the potential to influence global agricultural production, food supplies and crop commodities markets. Reductions in global food supplies would increase crop prices and result in increased demand for Imperial Region agricultural products, which could in turn increase water demands.

O.3 IMPERIAL REGION VULNERABILITIES AND IMPACTS

O.3.1 Simulations of Future Climate

Climate change predictions for the Imperial IRWMP are derived from global climate model (GCM) simulations of past and future climate. For each GCM simulation, assumptions are made about the rate of change of carbon emissions from anthropogenic activities. The Intergovernmental Panel on Climate Change (IPCC) has developed a standard set of future emission scenarios that are used for climate prediction in all GCMs. The outcome of global climate policy negotiations and socio-economic

[1] http://www.usbr.gov/lc/region/programs/crbstudy.html

developments will determine which one of these emission scenarios eventually plays out. Since these factors are beyond the control of the Imperial IRWMP, predictions representing high (A1b), medium (A2) and low (B1) emission scenarios are used in this analysis, allowing a range of likely outcomes to be evaluated. Detailed descriptions of the emission scenarios are included in Attachment B of this IRWM report.

The U.S. Department of Energy has supported the development of the Coupled Model Intercomparison Project version 3 (CMIP3) archive of climate predictions for use in application sectors. The CMIP3 archive which is hosted by the Lawrence Livermore National Laboratory (LLNL) includes climate predictions from climate modeling groups around the world. The predictions are downscaled using one of two statistical downscaling approaches from their original coarse resolution (usually 2-degree cells) to finer (0.125-degree) cells to better incorporate local topographic and micro-climatic influences. The first downscaling approach is the Bias Correction Spatial Downscaling (BCSD) method which uses monthly GCM data but generates daily sequences based on reconstruction by randomly resampling historic data distributions. The second downscaling approach is the Bias Correction Constructed Analogues (BCCA) approach begins with daily GCM data and corrects bias to generate downscaled sequences. While BCCA is better able to reproduce strong gradients in daily variation, BCSD more accurately captures monthly aggregations. Climate predictions from monthly climate simulations downscaled using BCSD and daily climate simulations downscaled using BCCA are presented in this Imperial IRWMP report.

Predictions for the Imperial IRWMP region are processed from the CMIP3 archive for two US models, namely the National Center for Atmospheric Research's Parallel Climate Model (NCAR-PCM) and the Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM). Downscaled monthly predictions are extracted for both NCAR-PCM and GFDL-CM for the period 1971 to 2050. Downscaled daily predictions are extracted for GFDL-CM for a historical period (1981-2000) and the mid-century period (2046-2065). Downscaled daily predictions are not available for the intervening period or for the NCAR-PCM model. The extracted monthly and daily time series of climate simulations from the two models are processed to generate climate predictions as described below.

O.3.2 Assessment of Imperial Climate Change Predictions

Climate model simulation results provide sample weather distributions under predicted future climate conditions rather than an actual chronological time series of future weather. Hence, the sample weather distributions must be analyzed to estimate magnitudes of change in climate variables of interest to each application sector. Since agriculture is the primary economic activity of the Imperial region, particular attention is paid to the estimation of climatic changes that impact crop water use either directly by changing ET or indirectly through induced changes in cropping patterns. The scope of this analysis is also limited to variables which can be derived from data available in the LLNL CMIP3 climate prediction archive.

Monthly climate model simulations were extracted for maximum and minimum temperature, rainfall, potential evapotranspiration, and wind speed. Time series simulations from the grid cells that cover the Imperial IRWMP region were aggregated to obtain a single spatial average for each time step. The spatially-averaged time series was split into historical (1971-2010) and future (2011-2050) analysis sets. The four growing seasons for the analysis were defined as winter running from December to February, spring from March to May, summer from June to August and fall from September to November. Seasonal statistics were computed for each analysis set, and the percentage change between the historical and future analysis sets was computed. The results were summarized into predicted changes in seasonal maximum and minimum temperature, rainfall, potential evapotranspiration, and wind speed under climate change scenarios.

Climate predictions were also prepared for cumulative seasonal changes in number of heating degree days (HDD) and cooling degree days (CDD), using 65 F as the dividing threshold between heating and cooling. For the HDD and CDD analysis, the historical period is 1981 to 2000 while the future period is 2046 to 2065 since these are the analysis periods are for which daily data is available from the LLNL CMIP3 archive. Predicted changes in seasonal maximum and minimum temperature and rainfall are also prepared from the daily data. Mid-century changes provide a glimpse into the potential long-range effects of climate change.

O.3.3 Summary of Key Climate Change Predictions

The results of the monthly climate change analysis are presented for the high (A1b), medium (A2) and low (B1) emission scenarios in Table 1 with predicted increases greater than 3% and decreases less than -3% are highlighted.

Table O-1. Summary of key climate change predictions from monthly data analysis for Imperial IRWMP region with increases above 3% shown in green and decreases below -3% in orange.

Climate Variable	Emission Scenario	Climate Model	% Change in Mean			
			Winter	Spring	Summer	Fall
Evapotranspiration	High (A1b)	NCAR-PCM	0%	0%	1%	3%
		GFDL-GCM	2%	4%	2%	4%
	Medium (A2)	NCAR-PCM	0%	0%	1%	0%
		GFDL-GCM	0%	4%	1%	3%
	Low (B1)	NCAR-PCM	1%	-1%	1%	2%
		GFDL-GCM	-2%	3%	2%	2%
Rainfall	High (A1b)	NCAR-PCM	14%	58%	23%	15%
		GFDL-GCM	3%	-28%	-11%	-11%
	Medium (A2)	NCAR-PCM	8%	17%	24%	-3%
		GFDL-GCM	10%	-24%	-7%	17%
	Low (B1)	NCAR-PCM	19%	-15%	1%	-21%
		GFDL-GCM	-8%	-30%	-12%	28%
Maximum Temperature	High (A1b)	NCAR-PCM	3%	3%	1%	3%
		GFDL-GCM	4%	4%	5%	5%
	Medium (A2)	NCAR-PCM	3%	1%	1%	3%
		GFDL-GCM	3%	4%	4%	4%
	Low (B1)	NCAR-PCM	2%	1%	1%	2%
		GFDL-GCM	4%	4%	3%	4%
Minimum Temperature	High (A1b)	NCAR-PCM	9%	4%	3%	6%
		GFDL-GCM	14%	8%	8%	11%
	Medium (A2)	NCAR-PCM	3%	3%	2%	6%
		GFDL-GCM	5%	9%	7%	8%
	Low (B1)	NCAR-PCM	6%	1%	2%	4%
		GFDL-GCM	14%	8%	6%	6%
Wind Speed	High (A1b)	NCAR-PCM	0%	0%	1%	2%
		GFDL-GCM	2%	2%	-1%	1%
	Medium (A2)	NCAR-PCM	-1%	0%	0%	-3%
		GFDL-GCM	-1%	2%	-1%	1%
	Low (B1)	NCAR-PCM	1%	-1%	0%	2%
		GFDL-GCM	-3%	-2%	0%	0%

Based on the monthly predictions in Table 1, likely climate changes for the Imperial IRWMP region include:

- Milder winters with an increase in the monthly minimum temperatures up to 14%.
- Warmer maximum temperatures are predicted for spring and fall with increases of 4% and 5%, respectively.
- Hotter summers with an increase in seasonal minimum temperatures up to 8%.
- The climate models displayed large discrepancies in predicted changes in monthly rainfall. The PCM models projected an overall increase in annual rainfall with seasonal increase of up to 59% , while the GFDL model projected a decrease in the amount of seasonal rainfall up to 30%.
- Minor increases of less than 3% are predicted for potential evapotranspiration but a few decreases are predicted under some scenarios.
- Minor changes in wind speed of less than 3% are not predicted with both increase and decrease predicted under different model scenarios.

The results of the daily analysis are summarized presented in Table 2 show the change in cooling, heating and growing degree days by season. Percentage changes in daily rainfall, minimum and maximum temperatures are presented for each season. Percentage changes in cumulative cooling, heating and growing degree days for each season are also computed from daily averages of maximum and minimum temperatures. Cooling degree days (CDD) are the sum of daily temperatures in excess of 65 F while heating degree days (HDD) accumulate temperatures below 65 F. HDD are an indicator of energy required for heating buildings while CDD is indicative of energy required for cooling in domestic and industrial applications. CDD is also an indicator of industrial water use for cooling in applications such as thermoelectric power generation plants. Growing degree days (GDD) are computed as the sum of mean daily temperatures above 46 F and below 90 F. Many crops must be exposed to a set range of growing degree days to reach various growth stages from flowering to harvest. Since plants have different water requirements at each growth stage, changes in seasonal patterns of increase in GDD will likely result in crop water use changes.

Table O-2. Summary of key climate change predictions from daily data analysis for Imperial IRWMP region with increases above 3% shown in green and decreases below -3% in orange.

Climate	Emission Scenario	Climate	Winter	Spring	Summer	Fall
Variable		Model				
Daily Rainfall	High (A1B)	GFDL	-5%	-22%	35%	37%
	Medium (A2)	GFDL	26%	-24%	13%	26%
	Low (B1)	GFDL	-11%	-20%	26%	-16%

Maximum Daily Temperature	High (A1B)	GFDL	8%	10%	8%	8%
	Medium (A2)	GFDL	5%	9%	8%	5%
	Low (B1)	GFDL	4%	7%	5%	5%
Minimum Daily Temperature	High (A1B)	GFDL	27%	19%	15%	17%
	Medium (A2)	GFDL	20%	16%	15%	13%
	Low (B1)	GFDL	12%	13%	9%	10%
Cooling Degree Days	High (A1B)	GFDL	373%	69%	25%	38%
	Medium (A2)	GFDL	174%	61%	25%	27%
	Low (B1)	GFDL	190%	49%	15%	23%
Heating Degree Days	High (A1B)	GFDL	-34%	-59%	0	-53%
	Medium (A2)	GFDL	-24%	-49%	0	-42%
	Low (B1)	GFDL	-17%	-42%	0	-43%
Growing Degree Days	High (A1B)	GFDL	19%	15%	9%	12%
	Medium (A2)	GFDL	11%	13%	9%	9%
	Low (B1)	GFDL	9%	10%	5%	7%

The daily climate change predictions presented in Table 2 are summarized as follows:

- During the winter, daily minimum temperatures are predicted to increase by about 26%.
- During the summer, daily maximum temperatures are predicted to increase by about 8%.
- During fall and spring, both minimum and maximum daily temperatures are predicted to rise substantially by between 6% and 17%.
- During the summer, daily rainfall intensity is predicted to increase by between 13% and 35%.
- During the spring, daily rainfall intensity is predicted to decrease by between -20% and -24%.
- Predictions of changes in daily rainfall intensity during fall and winter are inclusive with model scenario projections ranging between increases of 37% and decreases of -16%.
- Cooling degree days are projected to increase in all seasons with large projected increase in winter (174% to 373%) and spring (49% to 69%) and smaller increases in fall (23% to 38%) and summer (15% to 25%).
- Heating degree days are projected to decrease in all seasons except the summer (when heating is not required) with larger projected decreases in the spring and fall (-42% to -59%) than in the winter (-17% to -34%).
- Growing degree days are projected to increase in all the seasons with larger increases in winter and spring (9% to 19%) than in summer and fall (5% to 12%).

O.4 Impacts of Climate Change on Water Use

The likely impacts of the projected changes on water use in the Imperial IRWMP Region are presented in the table below. These impacts are based on literature review of weather related impacts.

Table O-3. Likely Impacts of Projected Climate Changes for Water Users

Season	Project Change	Positive Impacts	Negative Impacts
Winter	• Rainfall is predicted to increase by 3%-18% in 5 of 6 model runs. • Minimum temperature is predicted to increase by 3%-14% in all model runs. • Maximum temperature is predicted to increase by 2%-5% in all model runs. • Minor changes in wind speed with decreases of less than 3% in 4 of 6 model runs and similar increases 2 model runs. • Minor changes in evapotranspiration with 4 models showing minor increases of 2% or less while 2 models show minor decreases of less	• Increase in winter precipitation to help offset irrigation water demand. • Warmer winters could improve winter crop yields. • Reduced risk of damage to winter crops by cold spells. • Decrease in use of power for heating could result in lower industrial water use.	• Increased precipitation during harvest season could damage winter harvest crops such as Asparagus, Broccoli, Cabbage, Carrot, Celery, Cauliflower, Lettuce and Alfalfa. • These weather changes could lead to changes in cropping calendars and acreage planted which impact water use.

Season	Project Change	Positive Impacts	Negative Impacts
	than 2%.		
Spring	• Precipitation is predicted to decrease by 15%-30% in 4 of 6 models. • Minimum temperature is predicted to increase in all model runs with increases of 4%-9% in 4 of 6 model runs. • Maximum temperature is predicted to increase by up to 4% in all model runs. • Evapotranspiration is predicted to increase by up to 4% in 4 of 6 model runs with minor decreases of less than 1% in the other 2 model runs. • Wind speed is expected to remain unchanged with equal likelihood of minor increases or decreases.	• Less damage to harvest crops. • Wind pollination processes are not impacted.	• Increased water requirement for crops in their growth phase such as Wheat, Sweet Corn, Watermelons, Spring Tomatoes and Sudan Grass. • Decreased precipitation to offset water demand
Summer	• Minimum temperatures are predicted to rise by all models with increases of 5%-8% in 3 of 6 runs. • Maximum temperatures are predicted to rise by all models with increases of 3%-4% in 3 of 6 model runs. • Minor increases in evapotranspiration of 2% or less are predicted in all model runs. • Wind speed is expected to remain unchanged with equal likelihood of minor increases or decreases	• Aphid infestation will reduce due to high temperatures. • Wind pollination processes are not impacted. • Improved viability of renewable energy generation.	• Excessive summer heat could lead to seed germination problems, sunburn and lower yields. • Increased cooling water use per unit of power generation at existing thermoelectric power plants. • New water demands for industrial water, particularly for emerging geothermal and solar power plants. • Increased pressure to convert cropland to renewable energy generation driven by economic advantages
Fall	• Precipitation is predicted to increase by 15%-28% by 3 of 6	• Warmer weather is favorable for post	• Increased risk of infestations by warm

Season	Project Change	Positive Impacts	Negative Impacts
	model runs while 2 models predict similar decreases. One model predicts a minor decrease. • Minimum temperature is predicted to increase by 3%-11% in all model runs. • Maximum temperature is predicted to increase by 2%-5% in all model runs. • Evapotranspiration is predicted to increase by 2%- 4% in 5 of 6 model runs with the other model run predicts a minor decrease. • Changes in wind speed are relatively uncertain with 5 models predicting minor increases and one model predicting a minor decrease.	emergent weed control. • Increased fall precipitation would be beneficial for crops.	weather pests. • Change in yield could result in adaptive changes in cropping cycles and water use patterns. • Increasing air temperature causes a rise in the water temperature, increased evaporation and poorer water quality in water bodies. • Increased precipitation during harvest season, could damage crops harvested in fall such as Alfalfa, Bermuda grass, Kliengrass and Sudan grass.

O.5 Colorado River Supply Vulnerability and Impacts

The current body of knowledge on potential climate change effects on the Colorado River water resources is summarized under studies of historical changes in supply, studies of future changes in supply and studies of future changes in demand.

O.5.1 Studies of Historical Changes in Colorado River Water Supply

While historical temperature trends consistently show rising temperatures, a review of prior studies by the USBR Technical Work Group (USBR, 2007) found contradictory results on historical impacts of climate change on Colorado River water supplies. Early studies, which focused on changes in snow pack extent at the end of the accumulation period on April 1^{st}, noted a declining spatial extents (Mote, 2003; Hamlet et al, 2005; Regonda et al, 2005; Knowles et al, 2006; Mote, 2006; Kalra, 2007). Increases in snow water equivalent have been noted particularly in upper basins (Mote, 2005) as well as shift of precipitation from snow towards winter rainfall (Knowles et al., 2006). However, decreasing snow water equivalents have also been reported by other researchers (Regonda et. al., 2005; Kalra et al., 2007). From these results, it difficult to estimate the extent of historical precipitation change due to warming climate.

Historical changes in natural water supply in rivers are difficult to assess because observed streamflow at gauges already includes the effect of water withdrawals and usage. The US Geological Survey has identified a network of stations called the Hydro-Climatic Data Network that have minimal human impact (1992 U.S. Geological Survey Open-File Report 92-129). Studies performed using these stations have found no significant change in full, natural streamflow (Kalra et al., 2007). Unchanged historical streamflow has also been reported in other studies, including Lins and Slack (1999), Groisman et al. (2001), McCabe and Wolock (2002), Pagano and Garen (2005), and Stewart et al. (2005). It cannot be concluded from these results that streamflow will remain unchanged in the future as changes in the water cycle evolve more slowly and persist for much longer than changes in temperature and the energy cycle.

O.5.2 Studies of Future Changes in Colorado River Water Supply

Problems of long-term persistence are addressed by studies which integrate projections from global climate models with hydrologic models. Such long-term projection studies, including those reported by Milly et al. (2005) and Seager (2007), generally indicate reduced precipitation for the latitudes basins such the Colorado River basin. They also point towards increased variability of extreme droughts and floods. Simulations by Christensen and Lettenmaier (2007) report slightly decreasing summer precipitation coupled with similar increases in winter precipitation but little net change in annual precipitation. They report significant increases in evapotranspiration which could result in declining streamflow. However, these studies include a high level of uncertainty which makes it challenging for engineers, planners and decisions makers to prioritize and integrate resource management strategies or develop an adaptive management approach.

The USBR as the water master for the Colorado River evaluated operating policies in context of the Law of the River. Water supply scenarios were evaluated in the *Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead Final Environmental Impact Statement* (2007 Interim Guidelines Final EIS, Appendix N; USBR, 2007). These scenarios did not include consideration of climate change. To remedy this, the USBR conducted a water supply assessment as part of its Colorado River Basin Water Supply and Demand Study (Colorado River Basin Water Supply and Demand Study, Technical Report B – Water Supply Assessment, 2012). The characteristics of critical uncertainties, "changes in streamflow variability and trends," and "changes in climate variability and trends," were evaluated using downscaled global climate model (GCM) projections and simulated hydrology.

O.5.3 Colorado River Water Demand Studies

Several studies have focused on the sustainability of Colorado River supply under climate change. A study of hydropower generation by Payne et al. (2004) noted that effects of declining streamflow could be mitigated by modifying reservoir operations. Such mitigation is possible because reduced power demand during warmer winters permits greater carryover storage for use in summer. However, other water users could be impacted. Barnett and Pierce (2009) demonstrated that a 10% reduction in water supplies would result in scheduled deliveries being missed 58% of the time by mid-century. Similar results are reported by Rajagopalan et. al. (2009), show a 1000% increase in the annual probability of reservoir deficits beginning around 2026 under climate change. They also noted that there would be no discernable change in the annual probability of reservoir deficits in the absence of climate change, assuming population growth rates are sustained.

O.5.4 National and Statewide Climate Change Studies

A long range historical analysis from 400-year reconstructed rainfall of California (Haston and Michelson, 2000) concluded that the twentieth century was unusually wet relative to other periods in the data. It also found spatial shifts in the location of anomalies including periods of north-south dipole reversal when northern parts of the State were drier than the south. These results are further reinforced by a more recent 1400-year paleoclimatology reconstruction (Woodhouse, 2010) which indicates that while temperature and precipitation do not always change together, the longest period of sustained drought coincided with a period of elevated temperature. Also, a national assessment by the US Global Climate Change Program (2008) provides insights on projected impacts of climate change in the Southwest. Key regional impacts identified include reduced precipitation, increased frequency of flooding, and degradation of unique ecosystems, affecting species, resorts and parks which support tourism and recreation. Taken together, these results indicate the likelihood of a zone of reduced precipitation over parts of the Southwest.

O.6 Baseline Greenhouse Gas (GHG) Emissions

Baseline emissions GHG Emissions contributed by water-related activities are estimated to establish a basis for comparing the emissions impact of implementing alternative plans to generate new water through the IRWMP. Since GHG is emitted in most thermoelectric electricity generation, each unit of electricity used in a water-related activity contributes to GHG emission. The standard measure of emissions for electrical power is pounds of carbon dioxide equivalent emissions per megawatt hour (lbs of CO_2e/MWh). IID delivers most of the electricity used within the Imperial IRWMP region. Emission factors reported by IID are therefore applied to electricity use for water-related activities in the region to estimate the emissions contribution. Emissions factors are also reported for some major non-water use activities to provide a basis for comparison.

As a major energy generating utility, IID is required to report the emissions associated with its energy generation and purchased power for delivery within its service area. The California' Climate Action Registry's General Reporting Protocol (GRP) provides guidelines for the reporting standard known as the Power Utility Protocol (PUP). The most recent GRP PUP report of annual emissions that is publicly available for IID is 2008. Net power from all generation and purchases less exports is reported by IID as 3709.65 GWh with a GHG contribution of 2,138,500 metric tons of CO_2e emissions. The resulting emissions factor of 1270.9 lbs CO_2e/MWh is applied to subsequent computations of emissions from electricity use in this IRWMP analysis.

As a Load-Serving Entity (LSE), IID is required to report its energy generation to California Energy Commission, and prepare future electricity resource plans to meets projected demand. Data for actual energy generation from 2010 are available in IID's Public Electricity Resource Planning Form (S-2) – Energy Balance Accounting Table. For 2010, IID reported a firm requirement of 3565 GWh which translates to a global warming potential of approximately 2.02 million metric tons of CO_2e.

California EPA's Air Resources Board provides an online tool CEPAM-2009 ALMANAC- Population and Vehicle trends tool. Data for vehicle fuel use categorized by type of fuel used was obtained using this tool. Data for vehicle miles travelled disaggregated according to size and fuel types of vehicles used was also obtained from this source. Emission rates for carbon dioxide emissions for use of per unit fuel according to type of fuel are available along with emission rates of methane and nitrous oxide per unit mile for each size and fuel type of vehicle at USDOE Information Administration's Voluntary Reporting of Greenhouse Gases Program. Conversion factors given in USEPA's Climate Leadership Resource report are used to determine the Carbon dioxide equivalent for nitrous oxide (0.31) and methane (0.021). These equivalent emissions amount to 0.002% of the total emissions. The total emissions from on-road mobile sources for the Imperial County computed using the above the data account for 1.37 million Metric Tons of CO_2e.

O.6.1 Computing Greenhouse Gas (GHG) Emissions from Water Use

Data available from various sources for the year 2010 are used for computations of the baseline GHG emissions for water-related activities. These emissions result from energy use in treatment and distribution of drinking water, treatment of wastewater, recycling of wastewater, desalination, pumping groundwater, conveyance and pumping of water. The energy intensities of water-related activities are assessed in kilowatt hours per million gallons of water. Potential future emissions from proposed changes in water use within the Imperial Region are computed by applying the energy intensities to the carbon emission factor previously computed and the proposed volume of water alteration.

To compute this inventory, total energy consumed for treatment of drinking water, wastewater, desalination of water, pumping groundwater and agricultural activities is estimated. Energy consumed by each activity is converted to the associated emissions using an emissions factor which describes the equivalent carbon dioxide emissions occurring per unit of electricity consumed. A variety of water-energy use values are available from studies undertaken during the past decade. Energy intensity factors used in the analysis are chosen by prioritizing regional and recent estimates over national values. It is also assumed that changes in the magnitude of energy intensity factors during the past decade are small enough to be neglected.

O.6.2 Baseline Emissions for Water Delivery

Water flows by gravity, without pumping, from Imperial Dam on the Colorado River through the All American Canal to the Imperial Region. The water travels 82 miles and drops through 175 ft of elevation to reach the Imperial region. Five hydropower plants have been set up for electricity generation along the All American Canal. Most of Mexico's share of Colorado River water also flows through the All American Canal and is returned to the Colorado River near Yuma where a sixth hydropower plant, called the Pilot Knob Power plant, generates additional electricity. The generation of renewable energy translates the energy intensity for water delivery to a negative factor. In 2011, the power plants generated 32 MW of energy. Water deliveries through the All American Canal at Mesa Lateral 5 are reported as 2,871,993 acre-ft for 2011 in IID's Provisional Internal Water Balance from IID's Water Information System (WIS 2012). The resulting energy intensity for water delivery to the Imperial IRWMP region is -304 kWh/MG. For 2010, WIS reported 2,580,286 acre-ft water delivered by the All American Canal. The emissions reductions that can be attributed to this delivery amount to -147,300 metric tons of CO_2e.

O.6.3 Baseline Emissions for Water Treatment and Distribution

The California Energy Commission (California's Water Energy Relationship 2005, "Energy Intensity in Northern and Southern California". Table 1-3, 11) water-energy report estimates statewide water-energy intensity for water treatment operations at 100 KWh/MG. The report estimates a further 700 kWh/MG for distribution of treated water. The statewide estimate for water treatment was used as no local or regional estimates could be found. Appendix D, Table 16 estimates 37,543 acre-ft of water delivered for domestic, commercial, and industrial use in 2010. The emissions associated with treating and distributing this volume of water are 5,642 Metric Tons CO_2e.

O.6.4 Baseline Emissions for Wastewater Collection and Treatment

Two applicable energy intensity estimates were found for wastewater treatment operations. The California Energy Commission's water-energy report (California's Water Energy Relationship 2005, "Energy Intensity in Northern and Southern California". Table 1-3, 11) estimates statewide wastewater-energy intensity at 2500 kWh/MG. The Table 7-3 presented in Chapter 7 of this 2012 IRWMP report provides a wastewater-energy intensity estimate of 3067 kWh/MG for the Imperial region. This regional estimate is adopted for wastewater computations instead of the statewide estimate.

The Urban Water Management Plans (UWMP, 2011) for the cities of Brawley, Calexico, El Centro and Imperial, provided estimates of water delivered and wastewater treated in respective cities. The average of wastewater treated to water delivered in these cities is assumed to be applicable to the region. Using this average, the wastewater collected is estimated to be 47% of domestic water delivered. Applying this percentage, total wastewater treated in 2010 is computed at 17,637 acre-ft. The emissions from treating the wastewater are computed as 10,160 metric tons of CO_2e.

O.6.5 Baseline Emissions for Groundwater Pumping

Groundwater pumping in the imperial region is not significant. However, the Coachella Valley Water District (CVWD) and East Mesa are being considered as potential sites for groundwater banking of IID's under-runs. Energy intensity from the CVWD is used for evaluating emissions for pumping groundwater in the region. The Water Energy Load Profiling (WELP) Tool developed by GEI (Embedded Energy in Water Studies 2010, "Appendix B", 43, Table 3) for the study of embedded energy in water estimates the groundwater energy intensity for the CVWD at 2410 kWh/MG. Baseline groundwater-related emissions from the region are zero as groundwater use is negligible.

O.6.6 Baseline Emissions for Water Desalination

Desalination is being considered as a planning project alternative. Three relevant estimates for the energy intensity of water desalination were found. GEI (Embedded Energy in Water Studies 2010, "Appendix B", 131, Table 8) estimates embedded energy intensity for the Inland Empire Utilities Agency (IEUA) to be between 3819 kWh/MG and 3945 kWh/MG. The California Energy Commission's study (California's Water Energy Relationship 2005, "Water and Wastewater Treatment and Distribution",33) reports a statewide estimate of 3900 kWh/MG. Table 6-3 in Chapter 7 of this 2012 Imperial IRWMP report estimates an intensity factor of 2840 kWh/MG. The local estimate of 2840 kWh/MG is used in this inventory. Baseline emissions from desalination are zero as there are no desalination plants operating in the Imperial region.

O.6.7 Baseline Emissions for Water Recycling

Two applicable estimates of energy intensity were found for recycling water. The embedded energy study (Embedded Energy in Water Studies 2010, "Appendix B", 131, Table 8) estimates water-energy intensity of recycling operations for IEUA in the range 752 – 1262 kWh/MG. The CEC (California's Water Energy Relationship 2005, "The Energy Intensity of Water Supplies". Figure 2-2, 23) report on California energy use also provides an estimate of 1228 kWh/MG for IEUA. CEC intensity is used as it is consistent with the range from the embedded energy study. There are no water recycling operations in the region and hence baseline emissions are zero.

O.6.8 Baseline Emissions for Agricultural Operations

California Energy Commission (California's Agricultural Water Electricity Energy Requirements 2003) estimates both water use and electrical energy requirements for agricultural operations for an average year in different zones within California. The CEC estimate includes only energy consumed for pumping water onto the farm. Thus, the computed emissions are exclusive of emissions from energy consumed in operation of farm equipment and fertilizer application. No other applicable water-energy intensity estimates were found for agricultural sector. Imperial county and parts of Riverside make up Zone 18 in the CEC report. Total annual energy use for agricultural operations in Zone 18 are reported as 429,388 MWh/yr while annual water use is reported as 4,190,200 AFY. Taken together, the CEC estimates imply a water-energy intensity for agricultural operations of 314 kWh/MG which is used for the Imperial region analysis. Based on an ad hoc report generated from IID's Water Information System in May 2012, total water delivered for agricultural purposes to be 2,141,945 acre-feet. Estimated emissions from the on-farm agriculture are 126,500 metric tons of CO_2e.

O.6.9 2047 Emission Projections for Water Use

The analysis of future emissions is limited to 2047 since the initial 45-year term of water sharing under the QSA ends in 2047. It is assumed that the energy intensity of water-related activities (Table 4) and the emission factors associated with power generation do not change in the future. This assumption allows present day emission factors to be conservatively applied for future emission computations.

Table O-4. Water-Energy Intensities used for Imperial Region Water Operations

Water Operation	Energy Intensity (kWh/MG)
Water Delivery	-304
Drinking Water Treatment	800
Wastewater Treatment	3,067
Groundwater Pumping	2,410
Water Desalination	2,840
Agriculture Operations	314
Water Recycling	1,228

O.6.10 Climate Mitigation under Project Alternatives

The Imperial IRWMP intends to implement projects to generate up to 100 KAFY of new water. The 2047 emissions analysis is undertaken to compute the change in emissions that would result from implementing any of the project alternatives for achieving the conservation. Without the conservation of 100KAFY water, the changes in emissions for 2047 presented here are attributable to changes in water delivered. Exhibit B of Quantification and Transfers of the Colorado River Water Delivery Agreement estimates IID's Net Consumptive Use to be 2607.8 KAFY by 2047. Table 5 summarizes the volumes of water used for computations of baseline emissions.

Table O-5. Baseline Water Use

Consumption	Baseline Volume (AFY)	Baseline Volume in Million Gallons (MG)
IID Water Delivered	2,580,286	840,915
Drinking Water Treatment	37,543	12,235
Waste Water	17,638	5,748
Irrigated Agriculture Operations	2,141,945	698,060
Miscellaneous use	400,798	130,620

Increased volume of water estimated to be delivered in 2047 leads to increase hydropower generation with an overall decrease in emissions of -148,835 Metric Tons CO_2e or -1.067%.

Alternative 1: 100 KAFY of Water through Groundwater Banking

In this alternative, 100 KAFY water is assumed to be withdrawn from groundwater banks which would be recharged by water from deep percolation of tailwater. This project alternative would cause about 45,280 Metric Tons CO_2e increase in water-related emissions.

Alternative 2: 100 KAFY of Water from Recycling Wastewater

In this project alternative, wastewater from domestic uses is recycled through tertiary treatment for reuse. The energy intensity of recycling depends on the quality of waste water. This project alternative would cause about 23,070 Metric Tons CO_2e increase in water-related emissions.

Alternative 3: 100 KAFY of Water by Retiring Agricultural Land

Retirement of agricultural land would eliminate the emissions due to energy required to apply water to farm land. This project alternative would result in an overall emissions reduction of about 5,907 Metric Tons CO_2e. The agricultural intensity factors used in the analysis do not include indirect emissions from transportation fuel from operating farm equipments and the product live-cycle emissions from insecticides and fertilizers. Thus, the overall emissions reduction due to agricultural land retirement could be higher than the computed water-related emissions.

Alternative 4: 100 KAFY of Water from Salton Sea Desalination

Water desalination is a high energy consuming process, and the energy intensity depends on the source of water. This alternative assumes retrieving 100 KAFY of water from groundwater banking. The desalination would lead to about 53,360 Metric Tons CO_2e increase in overall emissions.

A summary of the net change in emissions which would result from retrieving all 100 KAFY from a single project alternative are presented in Table 6. A combined configuration of more than one of these alternatives may be required to achieve the 100 KAFY target

Table O-6. Baseline and Future Emissions due to IRWMP Project Alternatives

	Total Emissions (MT CO2e)
Total Baseline Emissions (including hydropower generation)	-4,926
Alternative 1 – Groundwater Banking	45,280
Alternative 2 – Wastewater Recycling	23,070
Alternative 3 – Retiring Farm Land	-5,907
Alternative 4 – Desalination	53,360

O.7 FUTURE EMISSIONS FROM WATER USE FOR GEOTHERMAL OPERATIONS

Geothermal power generation is an emerging water use in the Imperial region. Emissions factors are required for assessing the potential GHG impacts of water use in geothermal projects. The guidance manual for renewable energy management by Renewable Energy action team (REAT Best management Practices and Guidance Manual, 2010) reported water consumption as 90 -113 AF/MWh of Geothermal Energy produced at the Ormesa Geothermal Complex located in the Imperial Region. In the most recent publicly available 2007 GRP PUP report, Calpine reported an emissions factor of 77 lbs CO_2e/MWh for geothermal electricity generation. Using these estimates, the emission per acre-foot of water consumed for geothermal energy is computed as 0.68 - 0.85 lbs CO_2e/AF. Using 100 KAFY of water in geothermal power plants would increase emissions by 30 - 38 Metric Tons CO_2e.

O.8 NEXT STEPS

We recommend dissemination of the results of this assessment of climate change impacts and the emissions impacts of Imperial IRWMP resource management strategies. The report could initially be disseminated to IRWMP member agencies for technical review and refinement. The public should also be informed of the choices to be made, and input from stakeholders should be solicited on priorities in implementing tradeoffs among the resource management strategies. While climate change and emissions analysis presented in Appendix O provides a template for evaluating project choices, the final composition of project alternatives should be adapted to stakeholder responses and water demands.

References

Barnett, Tim and Pierce, David. "Sustainable water deliveries from the Colorado River in a changing climate". PNAS, 106(18), 7334-7338. 2009.

California Air Resources Board (CARB). "ALMANAC-Population and Vehicle trends tool". CEPAM. 2009. 07 Mar 2012. < http://www.arb.ca.gov/app/emsinv/trends/ems_trends.php >.

California Air Resources Board (CARB). "Power Generation/Electric Utility Reporting Protocol: Annual Emissions Report". Imperial Irrigation District. 2008. 09 Mar 2012. < www.climateregistry.org >.

California Energy Commission (CEC), IID's "Energy Balance Accounting Table". Form S-2. 2011.

Carleton, Tamara and Cockayne, William. "The power of prototypes in foresight engineering". Proceedings from the 17th International Conference of Engineering Design (ICED), Stanford, Calif. 2009.

Carleton, Tamara, Cockayne, William and Leifer, Larry. "An exploratory study about the role of ambiguity during complex problem solving". Proceedings for the 2008 Association for the Advancement of Artificial Intelligence (AAAI) Spring Symposium. Stanford, Calif. 2008.

Christensen, N. S. and Lettenmaier, D. P. "A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin". Hydrology and Earth System Science. 11:1417–1434. 2007

Colorado River Basin Water Supply and Demand Study Team. "Colorado River Basin Water Supply and Demand Study, Technical Report B – Water Supply Assessment". U. S. Bureau of Reclamation (USBR). February 2012 Update. 2012a. <http://www.usbr.gov/lc/region/programs/crbstudy/Report1/Updates/TechRptB.pdf>

Coupled Model Intercomparison Project (CMIP3). " Bias Corrected and Downscaled WRCP CMIP3 Climate Projections". World Climate Research Programme (WCRP). 12 Apr 2012. <http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/>

Dynamic Consulting Engineers Inc. "2010 Urban Water Management Plan". City of Brawley. 2011.

Dynamic Consulting Engineers Inc. "2010 Urban Water Management Plan". City of Calexico. 2011.

Dynamic Consulting Engineers Inc. "2010 Urban Water Management Plan". City of El Centro. 2011.

Dynamic Consulting Engineers Inc. "2010 Urban Water Management Plan". City of Imperial. 2011.

eGRID. "GHG Annual Output Emission Rates. Version 1.1 Year 2007". 2010.

Final Staff Report. “California’s Water Energy Relationship”. California Energy Commission (CEC). CEC-700-2005-011-SF. 2005.

GEI Consultants Inc. “Embedded Energy in Water Studies”. California Public Utilities Commission (CPUC), 2010.

GEI Consultants Inc. “Historical and Future Municipal, Commercial, and Industrial Water Demands”. Imperial Water Forum. 2011.

IID Energy Department. “Net Electricity Load”. 2011.

IID Water Department. “Flows at Hydropower Plants”. 2012.

IID Water Department. “Monthly Crop Acreage Report”. May 14, 2012.

IID Water Information System. “Imperial Irrigation District Provisional Internal Water Balance”. 2012.

Imperial Irrigation District. “IID Annual Report 2009”. 2009.

Irrigation Training and Research Center (ITRC). “California’s Agricultural Water Electricity Energy Requirements”. California Energy Commission (CEC). 2003.

Lempert, Robert. “A new decision sciences for complex systems”. PNAS, 99(3), 3 7309-7313. 2002.

Maurer, E. P., H. G. Hidalgo, T. Das, M. D. Hettinger, and D.R. Cayan. “The utility of daily large-scale climate data in the assessment of climate change impacts on daily streamflow in California”. Hydrology and Earth System Sciences. 14, 1125-1138, doi: 10.5194/hess-14-1125-2010. 2010.

McCabe, Gregory and Wolock, David. “Warming may create substantial water supply shortages in the Colorado River basin”. Geophys Res Lett, 10.1029/2007GL031764. 2007.

Milly, P., Dunne, K. and Vecchia, A., “Global pattern of trends in streamflow and water availability in a changing climate”. Nature. 438:347–350. 2005.

Mote, Philip, Hamlet, Alan, Clark, Martyn and Lettenmaier, Dennis. “Declining mountain snowpack in western North America”. Bull Am Meteorol Soc. 86:39–49. 2005.

Payne, Jeffrey, Wood, Andrew, Hamlet, Alan, Palmer, Richard and Lettenmaier, Dennis. “Migtigating the effects of climate change on the water resources of the Columbia River Basin”. Climatic Change 62, 233–256. 2004.

Rajagopalan, Balaji, Nowak, Kenneth, Prairie, James, Hoerling, Martin, Harding, Benjamin, Barsugli, Joseph, Ray, Andrea and Udall, Bradley. "Water supply risk on the Colorado River: Can management mitigate?". Water Resources Research. W08201, doi:10.1029/2008WR007652. 2009.

Renewable Energy Action Team Manual (REAT), "Best Management Practices and Guidance Manual". Desert Renewable Energy Projects. 2010.

Sarma, V. V. S. "Decision making in complex systems". Systemic Practice and Action Research. 7(4), 399-407. 1994.

Schrader, Stephan, Riggs, William and Smith, Robert. "Choice over Uncertainty and Ambiguity in Technical Problem Solving". Journal of Engineering and Technology Management. 10(1-2), 73-99. 1993.

Slack, J., and J. Landwehr. "Hydro-Climatic Data Network (HCDN): A U.S. Geological Survey

streamflow data set for the United States for the study of climate variations, 1874-1988". U.S. Geol.

Surv. Open-File Rep. 92-129, 193 pp. 1992.

United States Bureau of Reclamation (USBR). "Technical Memorandum C - Quantification of Water Demand Scenarios." Colorado River Basin Water Supply and Demand Study, Appendix C 10. 2012.

United States Bureau of Reclamation (USBR). "West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections". Technical Memorandum No. 88-68210-2011-01. Prepared by - The U.S. Department of Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 138pp. 2011.

United States Bureau of Reclamation (USBR). Final Environmental Impact Statement. "Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead." 2007. <www.usbr.gov/lc/region/programs/strategies/FEIS/index.html>

United States Environmental Protection Agency (USEPA) and California Department of Water Resources (CDWR), "Climate Change Handbook for Regional Water Planning". 2011.

United States Environmental Protection Agency (USEPA). "Optional Emissions from Commuting, Business Travel and Product Transport. Climate leaders GHG inventory protocol core module guidance". 2008. 08 Mar 2012.
<http://epa.gov/climateleadership/documents/resources/commute_travel_product.pdf>

United States Global Change Research Program (USGCRP). "Scientific assessment of the effects of global change on the United States". 2008.

US Department of Interior. “Colorado River Water Delivery Agreement: Federal Quantification Settlement Agreement. Exhibit B: Quantification and Transfers”. 10 Oct 2003. <http://www.iid.com/Modules/ShowDocument.aspx?documentid=825>

Voluntary Reporting of Greenhouse Gases Program. “Instructions to Form EIA-1605: Appendix H: Fuel Emission Factors”. Energy Information Administration (EIA). 2011.

Western Electricity Coordinating Council (WECC). “California Region- Actual Water use and Water-Electricity Intensity”.

Woodhouse, Connie, Meko, David, MacDonald, Glen, Stahle, Dave and Cook, Edward. “A 1,200-year perspective of 21st century drought in southwestern North America”. PNAS. 107(50), 21283-21288. 2010.

Attachment A: Studies of Climate Change Impacts on Colorado River Streamflow

Study	Climate Variable Source	Runoff Generation Technique	Results				
			Temperature Change	**Precipitation Change**	**Runoff Change**	**Annual Runoff (MAF)**	**Notes**
Stockton and Boggess, 1979	Scenario - 4 different scenarios on +/-2C temp change and +/-10% change in precipitation	Empirical, Langbein (1949) historical runoff-temperature-precipitation relationships	+2C	-10%	-33%	10	
			+2C	+10%	-33%	10	
			-2C	+10%	+50%	23	
			-2C	-10%	0%	15	
Revelle and Waggoner, 1983	Scenario, any combination of temperature and precipitation changes can be accommodated in the regression equation	Statistical Regression on Upper Basin historical temp and precip based on period 1931-1976	+2C	-10%	-40%	9	Regression explains 73% of variance gage flow record
			+2C	0%	-29%	11	
			0	-10%	-11%	13	
Nash and Gleick, 1991, 1993	10 Scenarios / GCM Simulations from 3 models	National Weather Service River Forecasting System (NWS-RFS) Hydrology Model	+2C	-10%	-20%	12	(52 results, range 33% to +19%)
			+2C	0%	4-12%	14	
Christensen et al., 2004	GCM simulations from PCM for 3 time periods, "Business as Usual" future emissions and a control run (no additional emissions)	Variable Infiltration Capacity (VIC) Hydrology Model	+0.5C	-1%	-10%	14	(Control)
			+1.0C	-3%	-14%	13	(2010-2039)
			+1.7C	-6%	-18%	12	(2040-2069)
			+2.4C	-3%	-17%	12	(2070-2098)
Hoerling and Eischeid, 2008	GCM results from IPCC Fourth Assessment Report, "Business as Usual" emissions	Statistical regression on Palmer Drought Severity Index (PDSI) using data from 1895-1989	+1.4C	0%	-33%	10	(2006-2030)
			+2.8C	0%	-45%	8	(2035-2060)
Christensen and	GCM results from IPCC Fourth Assessment Report,	Variable Infiltration Capacity (VIC) Hydrology	+1.2C	-1%	0%	15	(A2, 2010-2039)

Lettenmaier, 2008	emission scenarios A2 (high) and B1 (low), for 3 time periods	Model	+2.6C	-2%	-6%	14	(A2, 2040-2069)
			+4.4C	-2%	-11%	13	(A2, 2070-2099)
			+1.3C	+1%	0%	15	(B1, 2010-2039)
			+2.1C	-1%	-7%	14	(B1, 2040-2069)
			+2.7C	-1%	-8%	14	(B1, 2070-2099)

(Source: Udall, 2007. Reproduced from USBR, 2007)

Attachment B: Special Report Emission Scenarios (SRES) scenarios

A1 – Scenario envisions a globalized world with focus on rapid economic development and spread of ideas and technologies. A usage of fuels is uncertain here, so sub-scenarios assume different usage. A1F assumes widespread usage of fossil fuels. A1T envisions renewable intensive economies. A1B assumes a balance between use of fossil fuels and renewable energy.

B1 – Scenario assumes a globalized world with a focus on rapid development of clean technologies and economies driven by investing in environment friendly solutions.

A2 – Scenario is of a disjointed regionalized world with less transfer of ideas and technology; economically driven scenario with the highest projected population among all scenarios.

B2 – Scenario is of a regionalized, self reliant and environmentally sustainable world with a variation in the extent of development and sustainability regionally. Simulations for this scenario are not performed because downscaled predictions are not available.

IMPERIAL IRWMP

INTEGRATED REGIONAL WATER MANAGEMENT PLAN

GEI Consultants