Al Ain Water Resources Management

AGEDI LNRCC Final Project Symposium

15 March 2017

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Project Goal & Objectives

Goal: Examines the vulnerabilities of the water system of the Al Ain region of the UAE until 2060 due to risks arising from the anticipated demographic, and climate change.

- ✓ **Objective #1:** Research the interaction between surface and ground water to characterize the water resources system of the Al Ain region of the UAE
- ✓ **Objective #2:** Analyze vulnerabilities and strategies for coping with climate change impacts on the water resources in the Al Ain region of Abu Dhabi

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Data Collection – Water Resources

- The Al Ain Water Resource systems model was constructed to represent the water supply and demand of the region.
- Data disaggregation came from UAE-specific sources:
  - GTZ and GWRP groundwater exploration in the early 1990’s and 2000s
  - Population and per capita water demand data
  - Agricultural extent and use for several different crop types.
    - Date Palms, Fodder, Tomatoes (as vegetables) and Melon (as other crops)
  - Groundwater characteristics from EAD-USGS Groundwater Modeling Project
  - Information available from different National Water agencies

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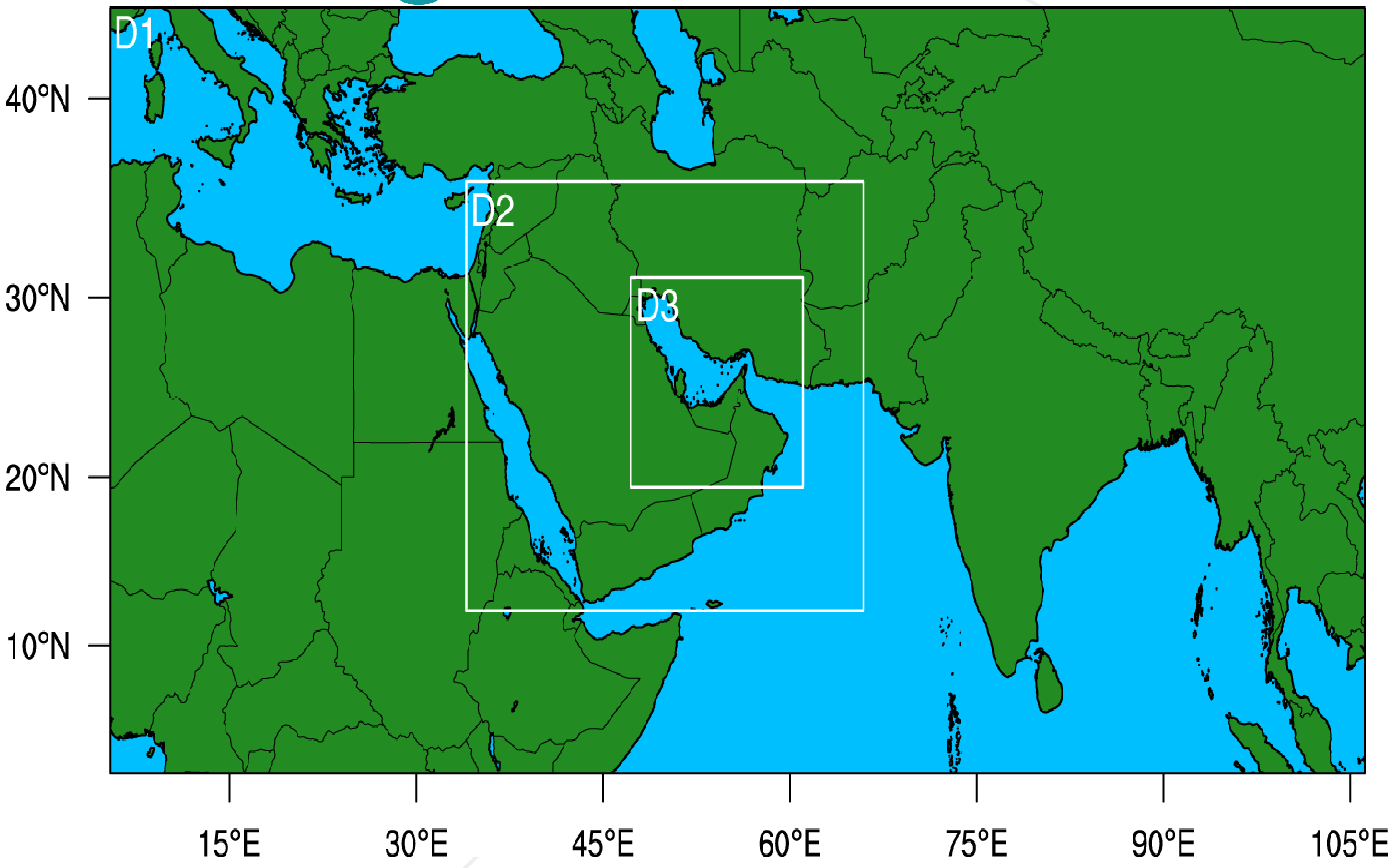
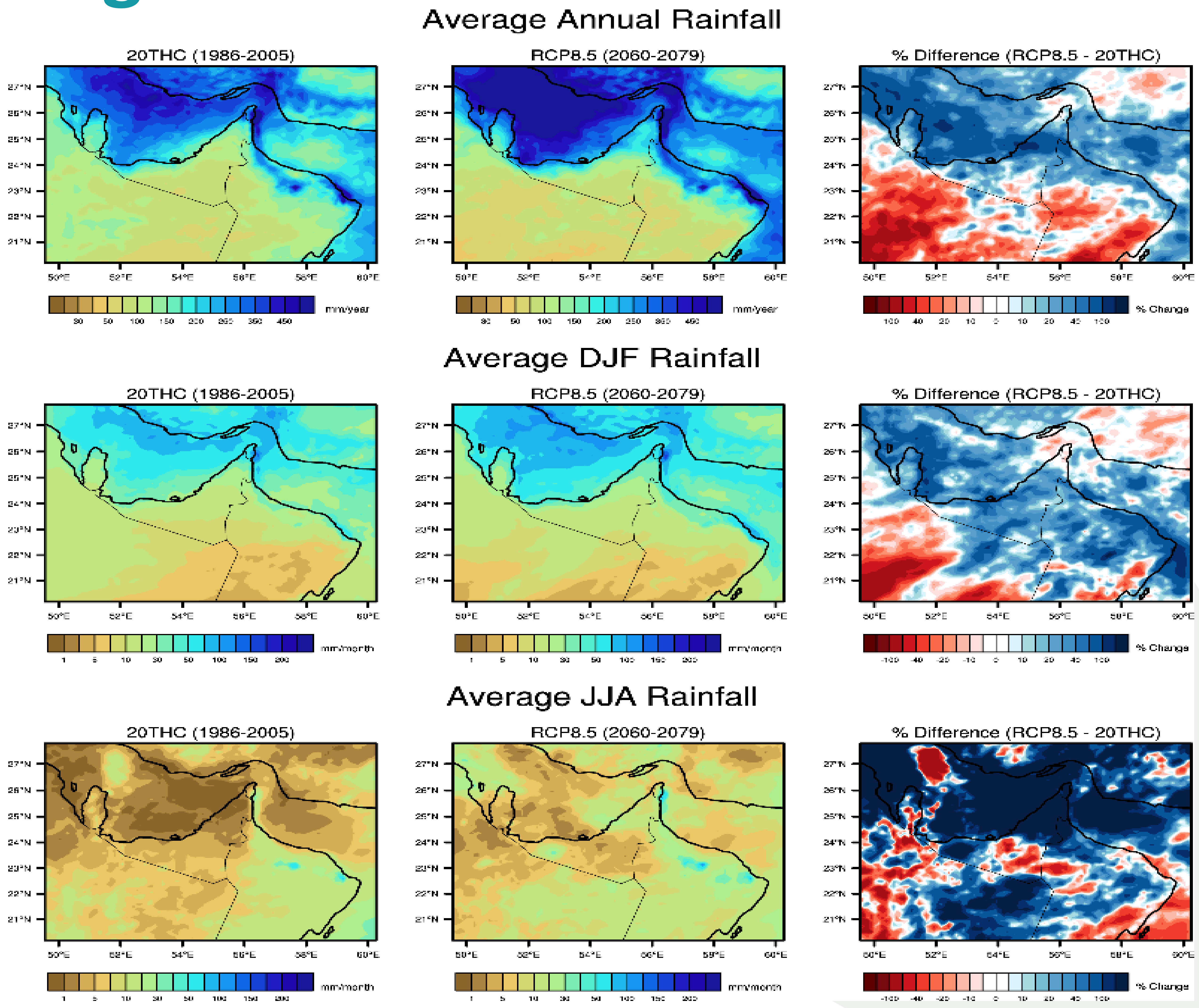
Modeling Methods: Climate Change



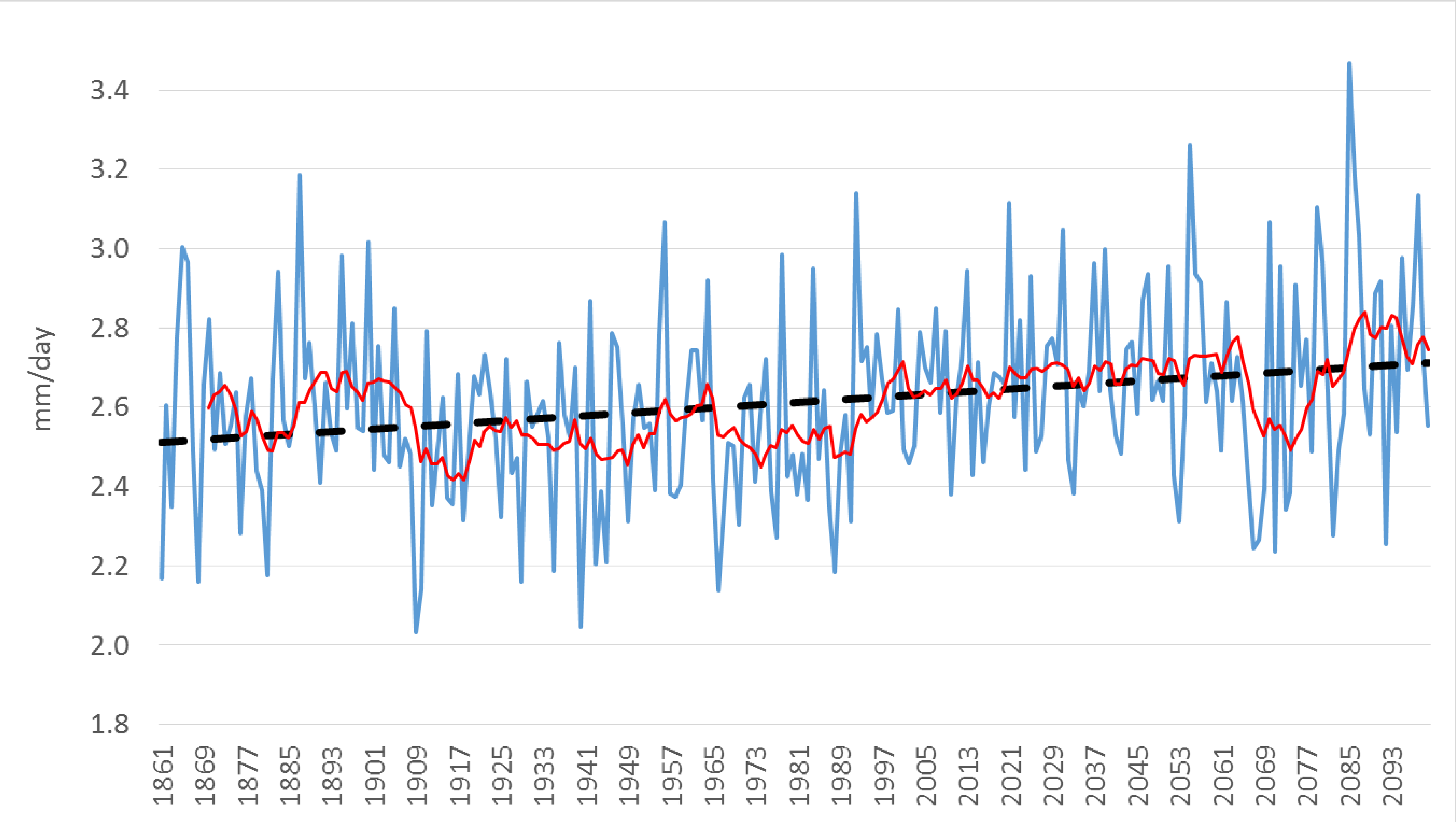


The climate change projection is based on outputs of LNRCCP sub-project: "Regional Atmospheric Modeling". Modeling involved a 20-year simulation of current (20thc) and future climate (RCP8.5). See excerpt of results (i.e., rainfall) at right >>>

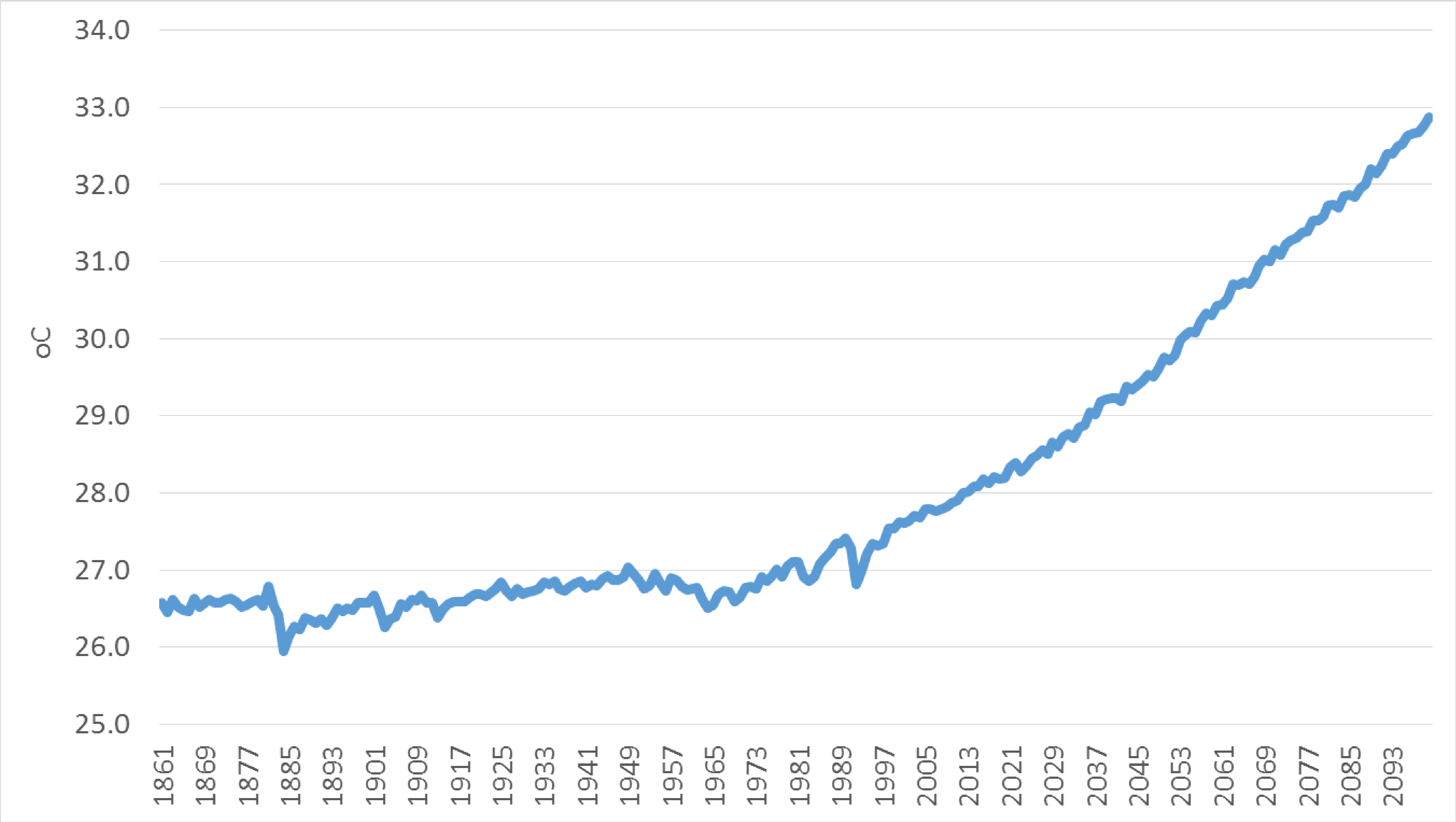
Background | WEAP | Scenarios | Results

Al Ain Region Ensemble Mean Climate Projections to 2100 (RCP 8.5)

Annual Avg Precipitation (mm/day)



Annual Avg Temp (°C)



Summary of Ensemble Mean: Precipitation is a Positive Trend and +5°C by end of Century

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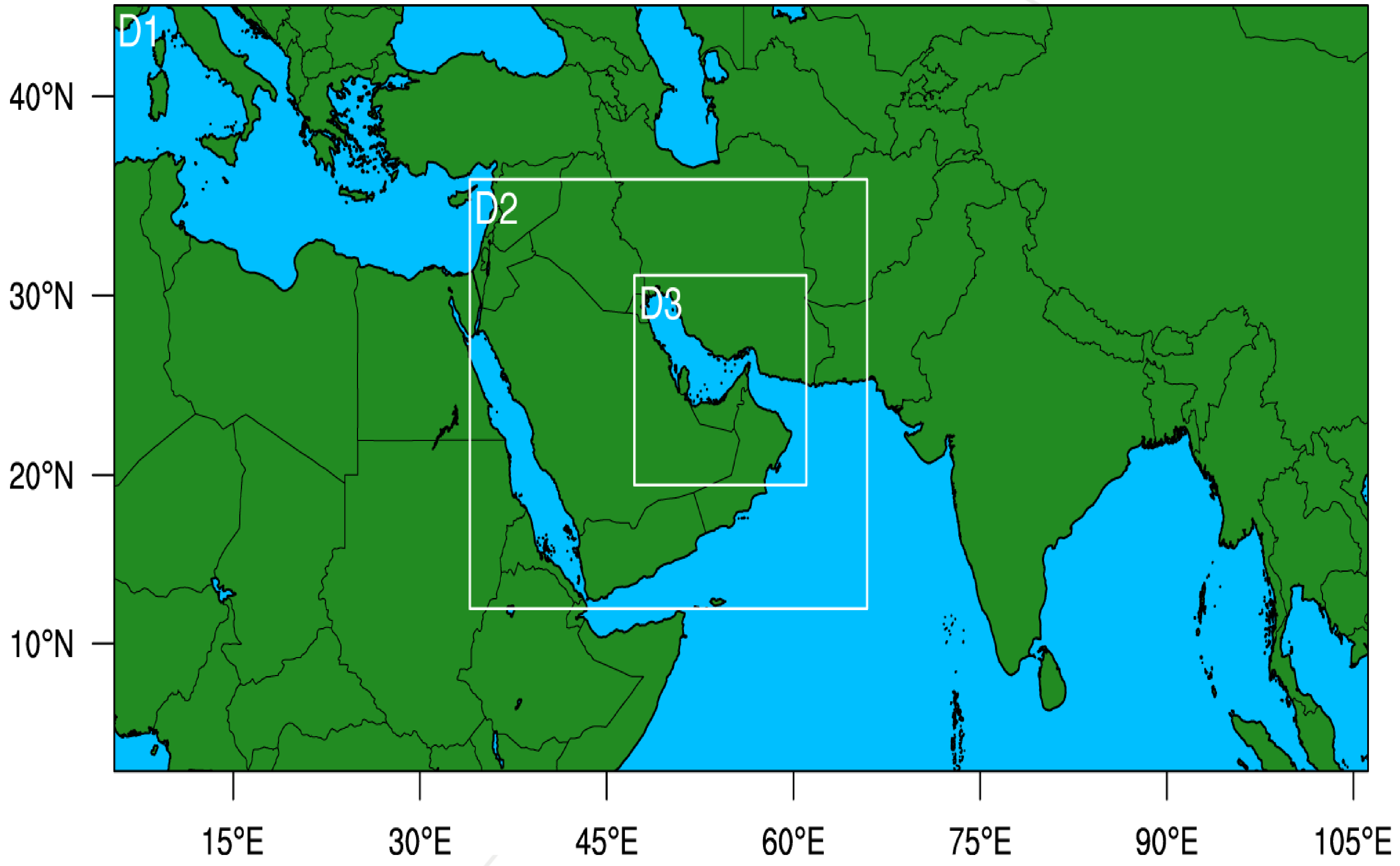
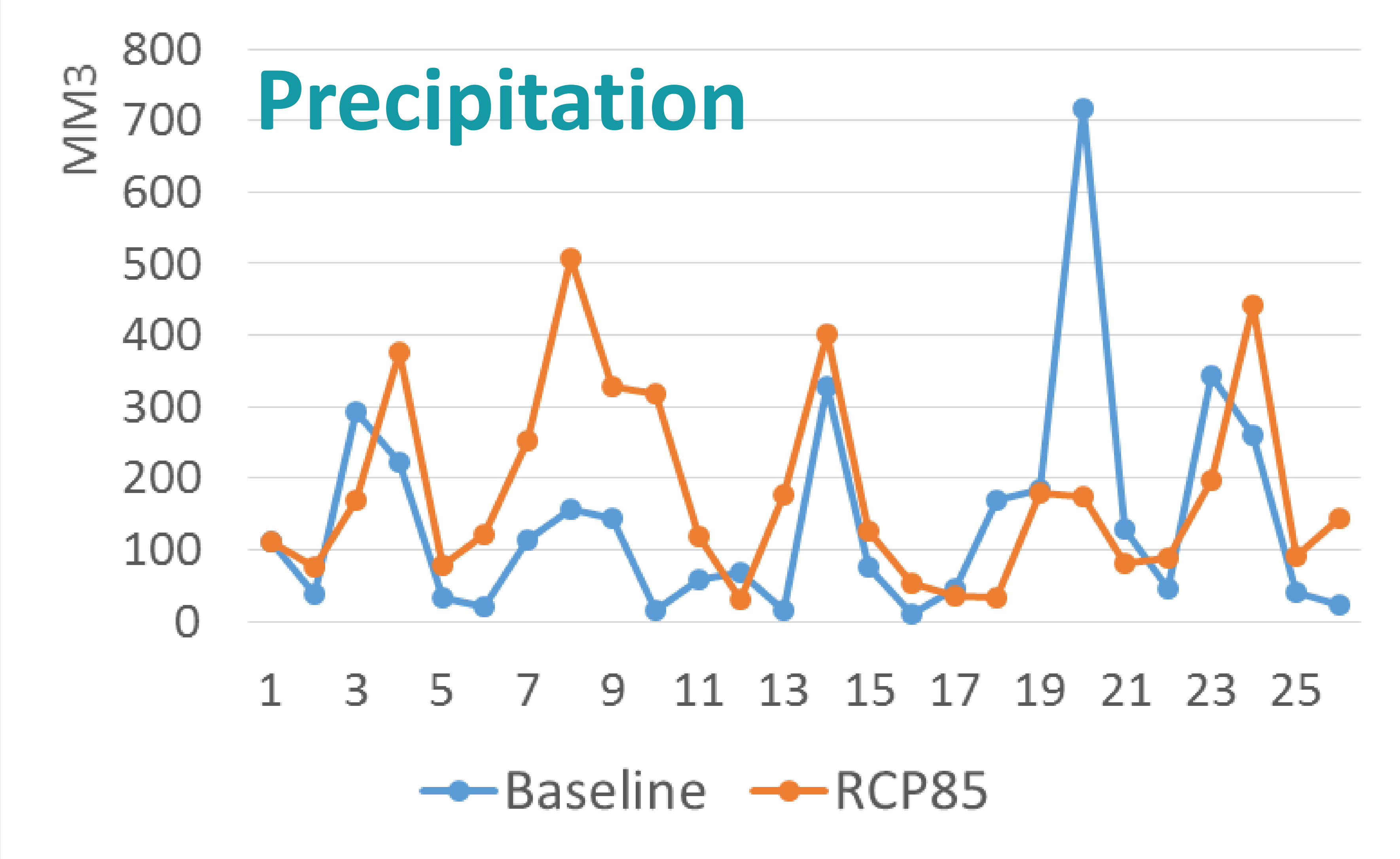
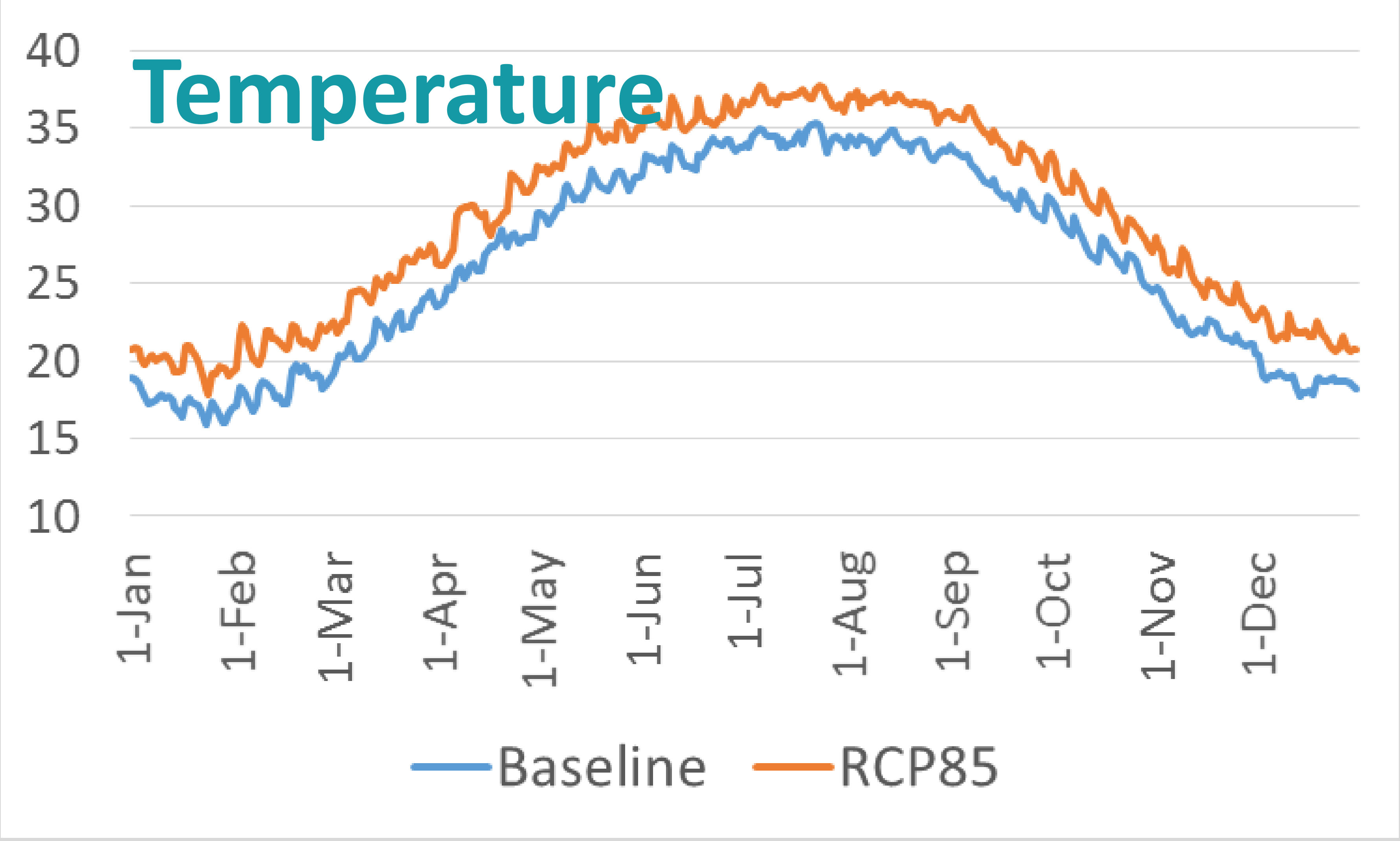
Climate Change Projections over the Al Ain Region





25% Increase in Avg Precip



2.25ºC warming By 2060

- Precipitation: Historic (20thc) vs future (RCP8.5) precipitation for the Al Ain region.
- Temperature: Change in daily mean temperature between historic (20thc) and future (RCP8.5).
- This projection falls well within the bounds of the ensemble mean from 39 climate models

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- WEAP is a decision support framework for water system planning and management
  - Water supply (ground and surface water); Water demand; Water Policy and Physically Imposed Constraints; Infrastructural conditions; Incorporates the impacts of climatic conditions and changes
- WEAP was the software tool used to build the Al Ain water system model

Al Ain water system model

- A Climatically Driven, Water Supply and Demand Model of the Al Ain Region of the Abu Dhabi Emirate
- Catchments represent the major wadis systems in the region (●), groundwater aquifers (■), and a desalination plant (◆)
- Agricultural demand (●) is driven by 4 crop types: Date Palms, Fodder, as Vegetables, and Other Crops (Fruits, melons, etc.)
- Municipal and Industrial Demand (●) based on population estimate and a per-capita use rate
- Validation of WEAP model was based on the water use trends in the region, including municipal, industrial, agricultural, forestry, and amenity water use
- Validation Includes the use of the USGS MODFLOW model whose information was used to estimate groundwater recharge to the alluvial aquifer near the Oman Mountains and Other local sources.

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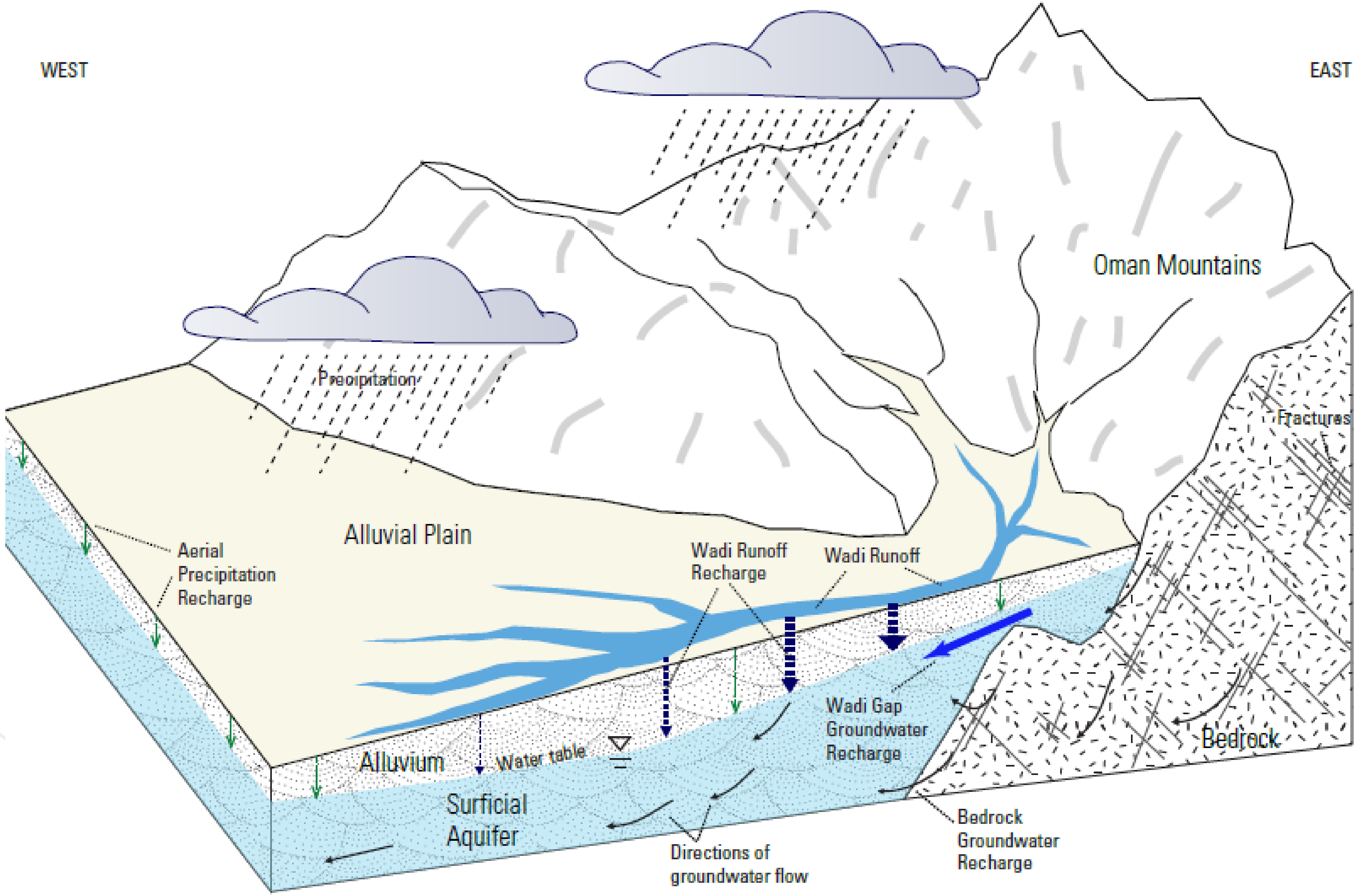
Modeled Components In the Al Ain water system model



A schematic representation of recharge mechanisms which occur throughout the Oman Mountain and the Al Ain Region of Abu Dhabi
(image courtesy, the US Geological Survey).

- WEAP represents the major flow pathways and recharge mechanisms of the near surface alluvial aquifers.
- The 15 Wadis provide flux via channel flux, Mountain Front Recharge, and Wadi Runoff Recharge.
- Study Domain includes about 17,000 km^2 which receives 900 MM3 on average. Natural recharge is less than 5% of annual precip. roughly 45 to 60 MM3 per year.
- Year-to-Year variability is large due to the erratic nature of rainfall in the region.

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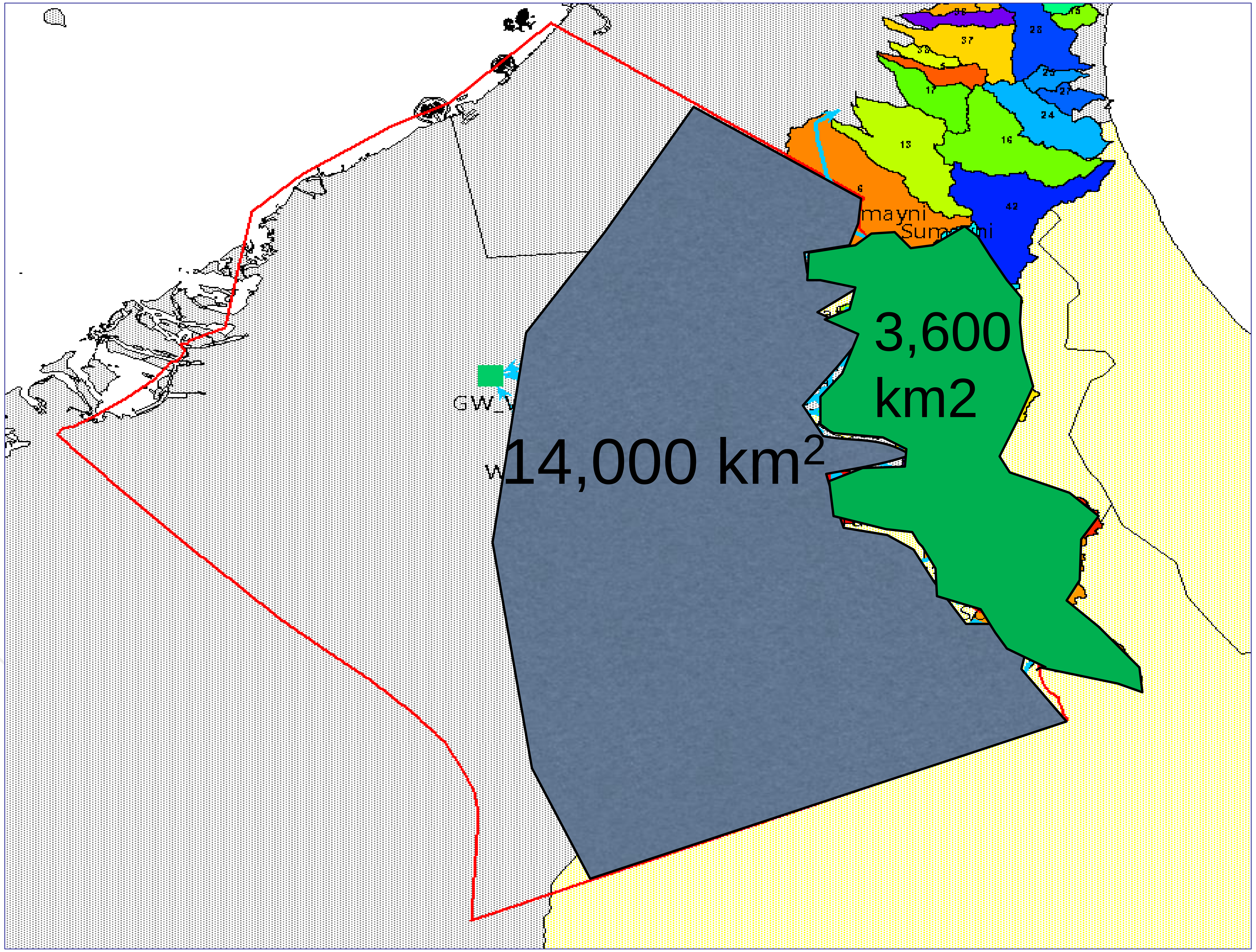
The Al Ain water system model schematic



- Water System Schematic of the system of the Al Ain region. The red boundary represents the modeling extent of the USGS MODFLOW model
- Al Ain Water Demand by Sector:
  - M&I Indoor and Outdoor
    - Amenity – Assumed 1% of study area.
    - Forest – from the GW Assessment,
    - Agriculture- Local sources
- 15 major wadis systems as catchments,
- 6 groundwater nodes, and a desalination supply.
- Desal Supply is estimated at nearly 200 MM3 in 2010, which is 4 times the estimated annual recharge

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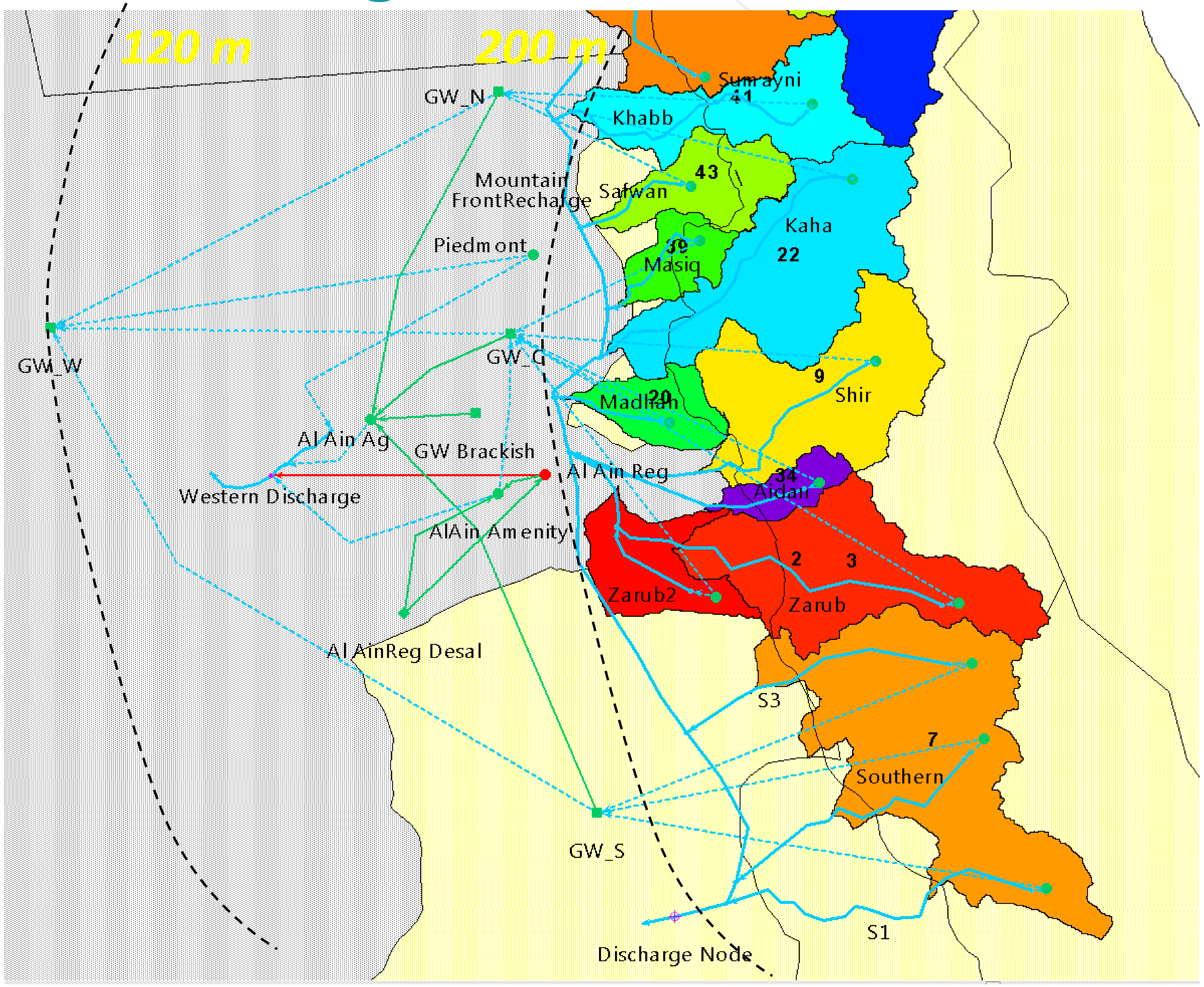
Al Ain Region in Abu Dhabi Emirate



- 15 Eastern wadis catchments recharge 3 fresh groundwater aquifers (North, Central and South). These groundwater aquifers gradually flux to the western groundwater.
- Darcy's Law is used to model this flux of groundwater from eastern Alluvial Aquifers (GW_N, GW_C, and GW_S to the western aquifer GW_W)
  - Q = k A dh/l; K = conductivity (m/day) 10 m /day; A = area of cross section 60 km w x 50 m deep. dh = change in depth across cross section - assume the downstream contour is constant (120m); L = length is about 75 kilometers from the 200 m contour to the 120 meter contour

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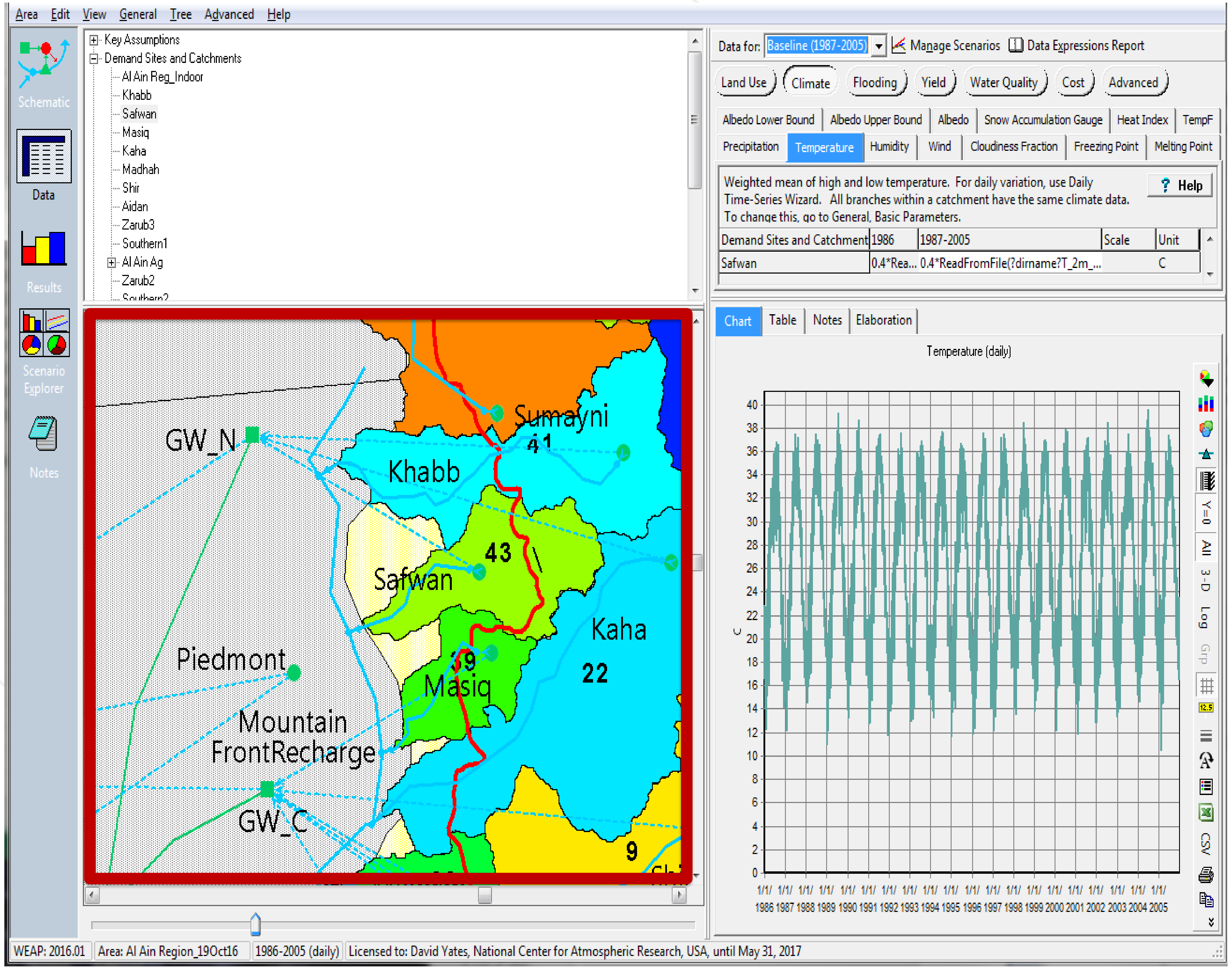
Al Ain Region in Abu Dhabi Emirate (continued)



- A zoom in over a select region in the norther portion of the study domain, showing wadis, their flow paths, their interaction with GW elements, and a temperature time series for a select wadi
- Fresh and fossil groundwater aquifers supplying Ag demand.
- Desalination supplies indoor, outdoor, and some amenity water demands
- Forest and Ag are from 1) Brackish and 2) Fresh Groundwater
- Amenity Water Supplied by 1) Reuse Water; 2) Desalinized Water @ 5%; and 3) from fresh groundwater @3%.

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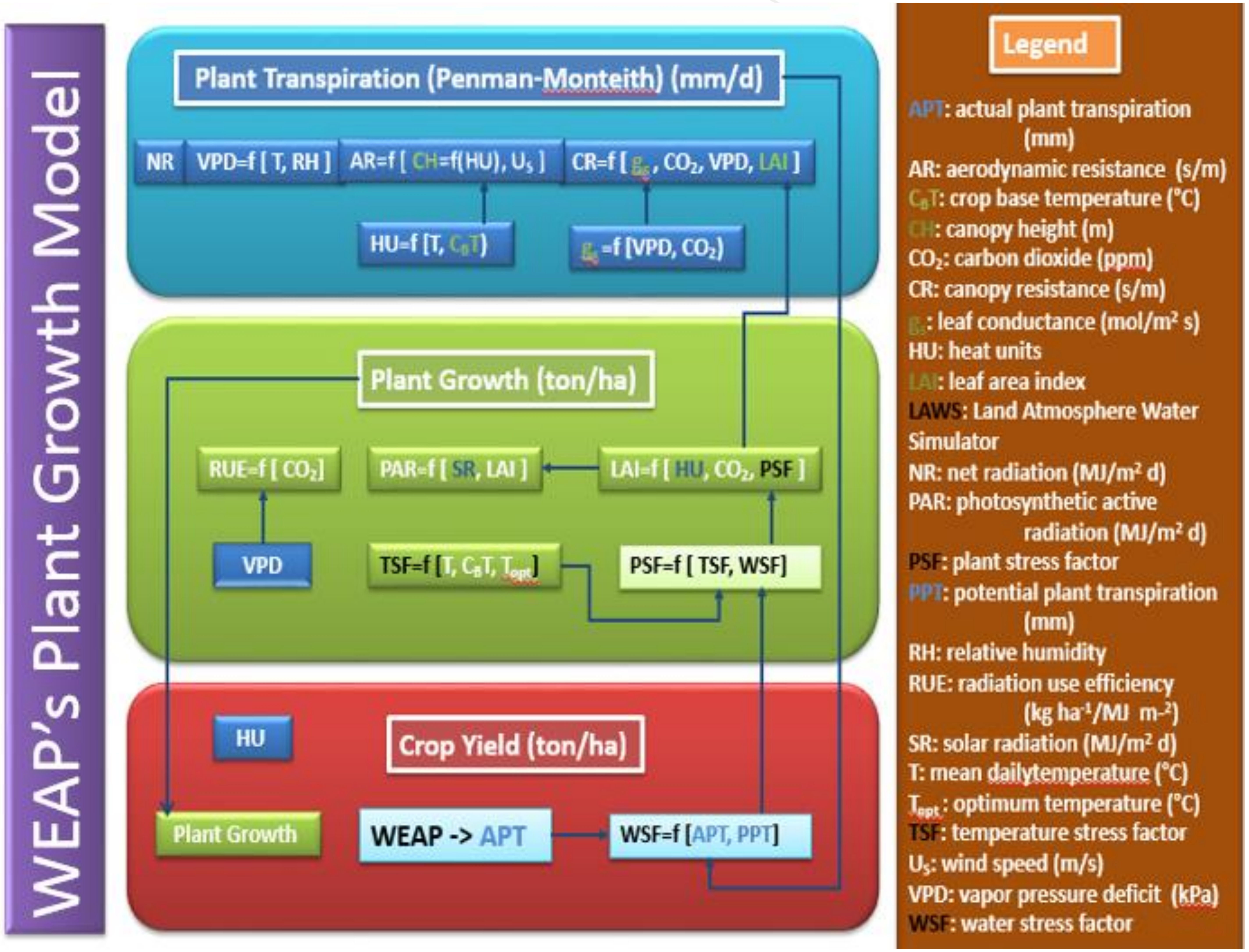
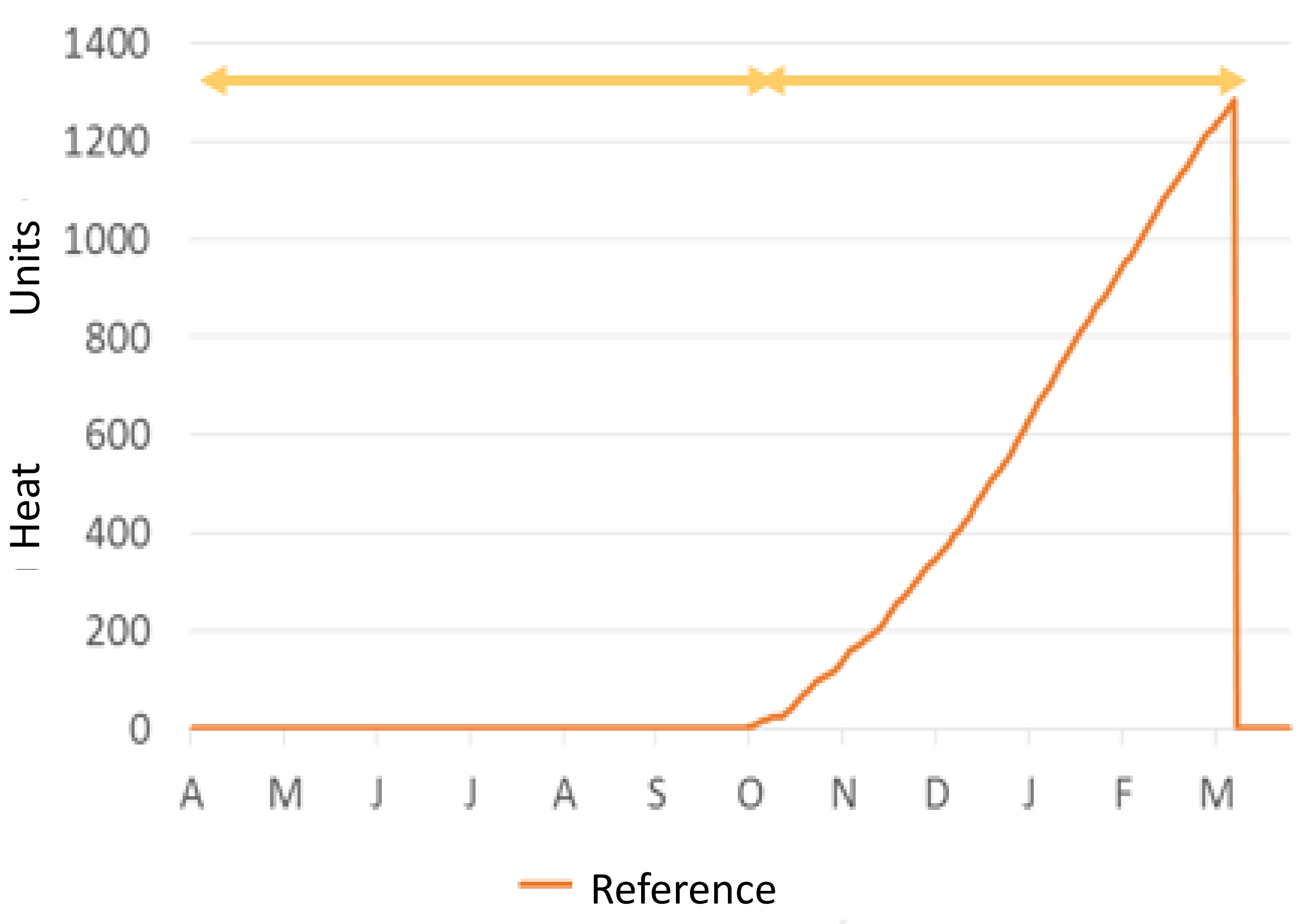
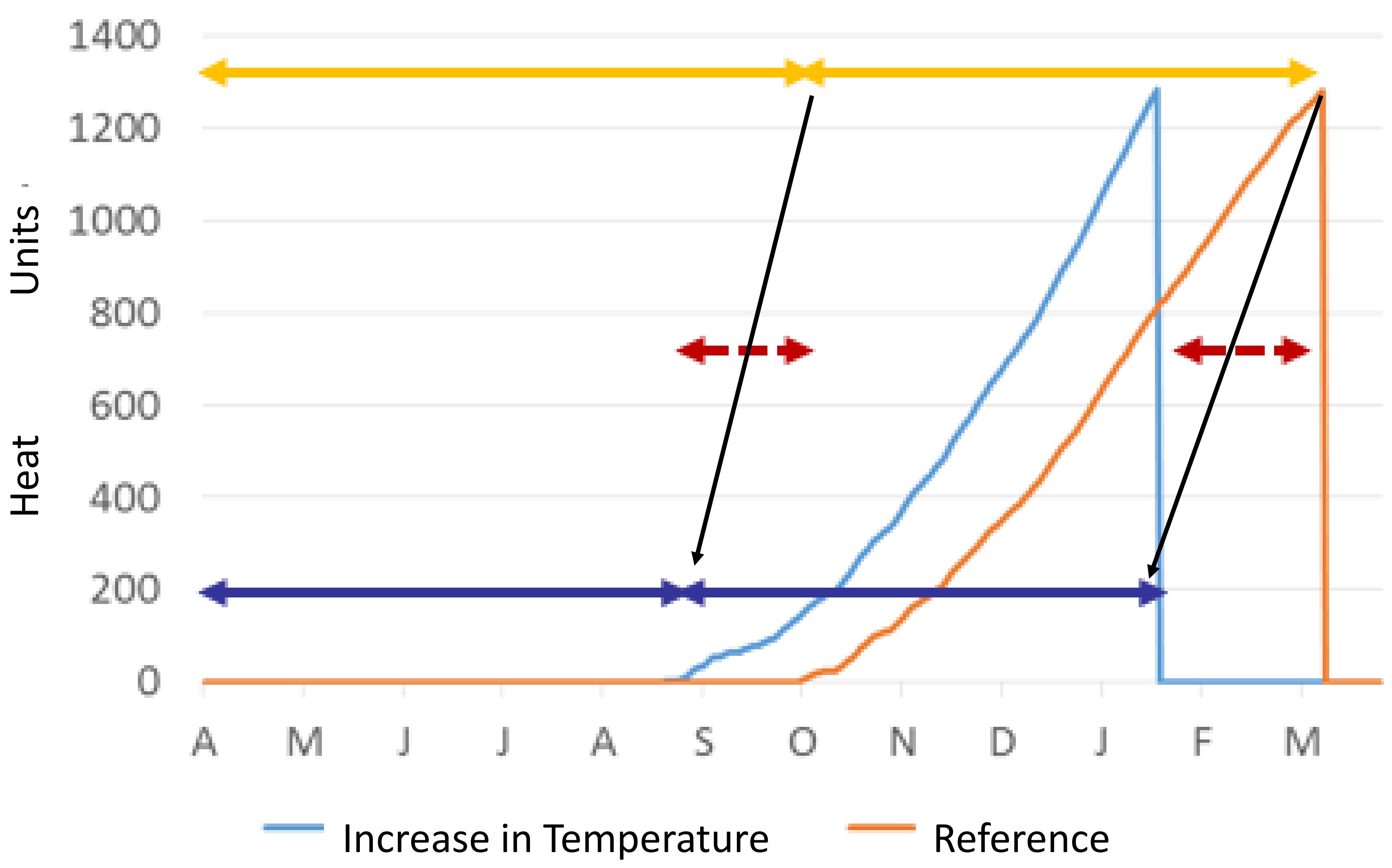
WEAP's Plant Growth Model



- Physically-based model of plant growth dynamics
- Daily simulation of transpiration, evaporation, irrigation requirements and scheduling, growth season, biomass production and crop yield
- Includes modules for estimating reference ET and soil water capacity
- Uses the Penman-Montieth equation
- Takes into consideration climate change and atmospheric CO2 effects on plant's evapotranspiration, biomass production and agricultural yield

Growing Season Length Responses to Temperature





Temperature effects on Growing Season Length

- Crop specific Basal temperature (Tb) required for onset of growing season
- Crop specific growing period based on Potential Heat Units (PHU)

HU = Tavg – Tb

- Growing season length has implications on plant transpiration and crop yields

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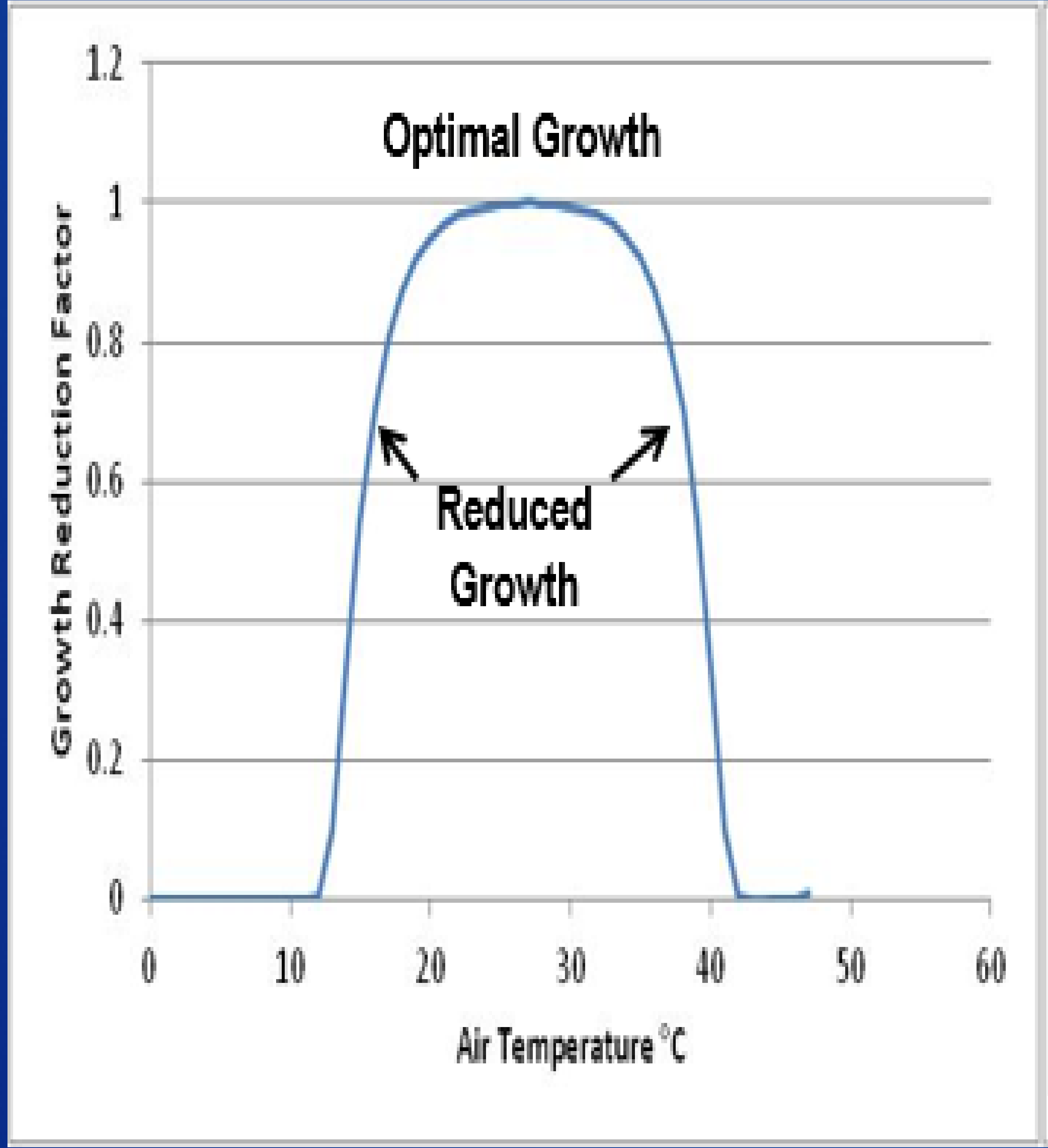
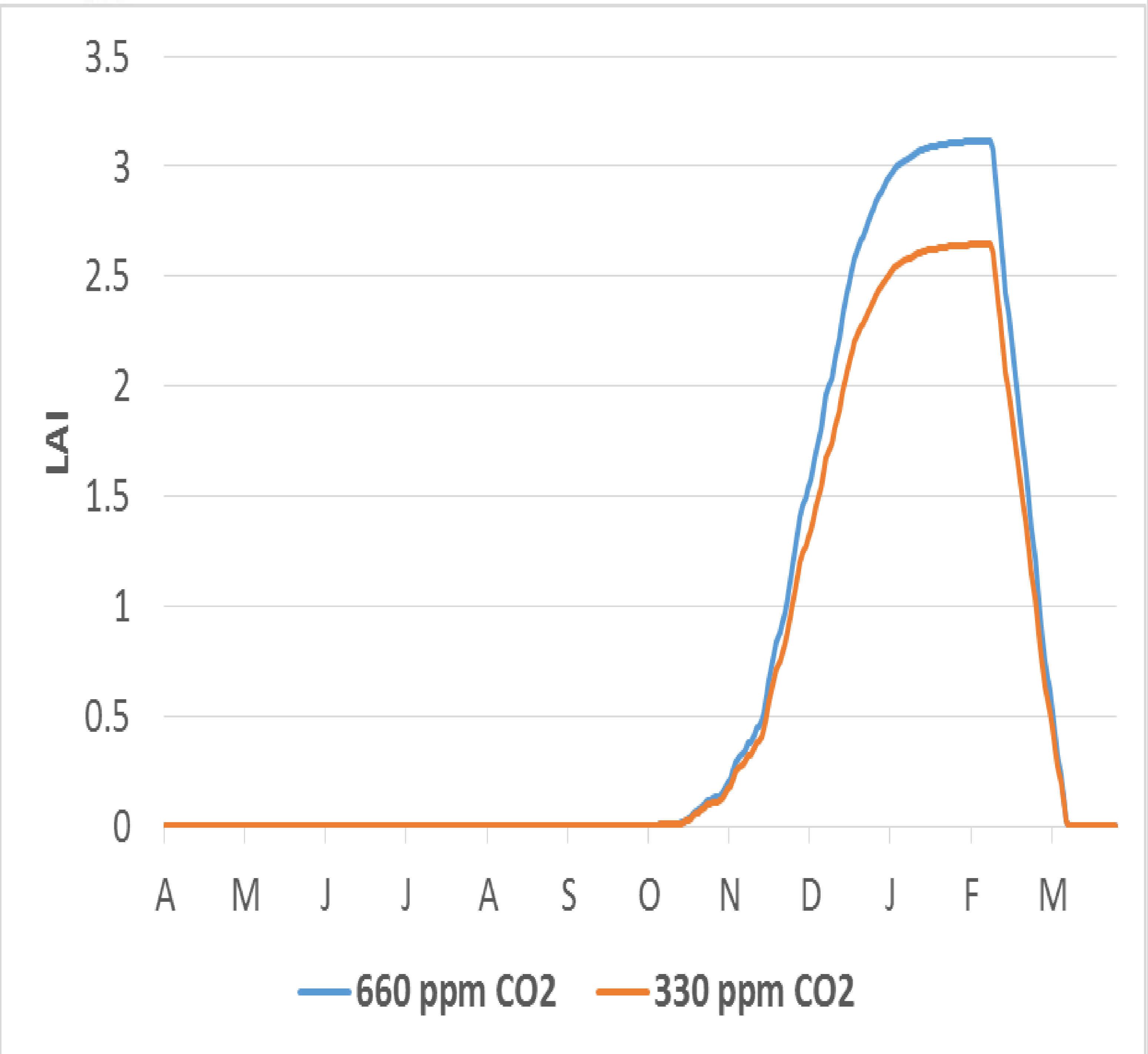
Plant Responses to Temperature and CO2 Changes



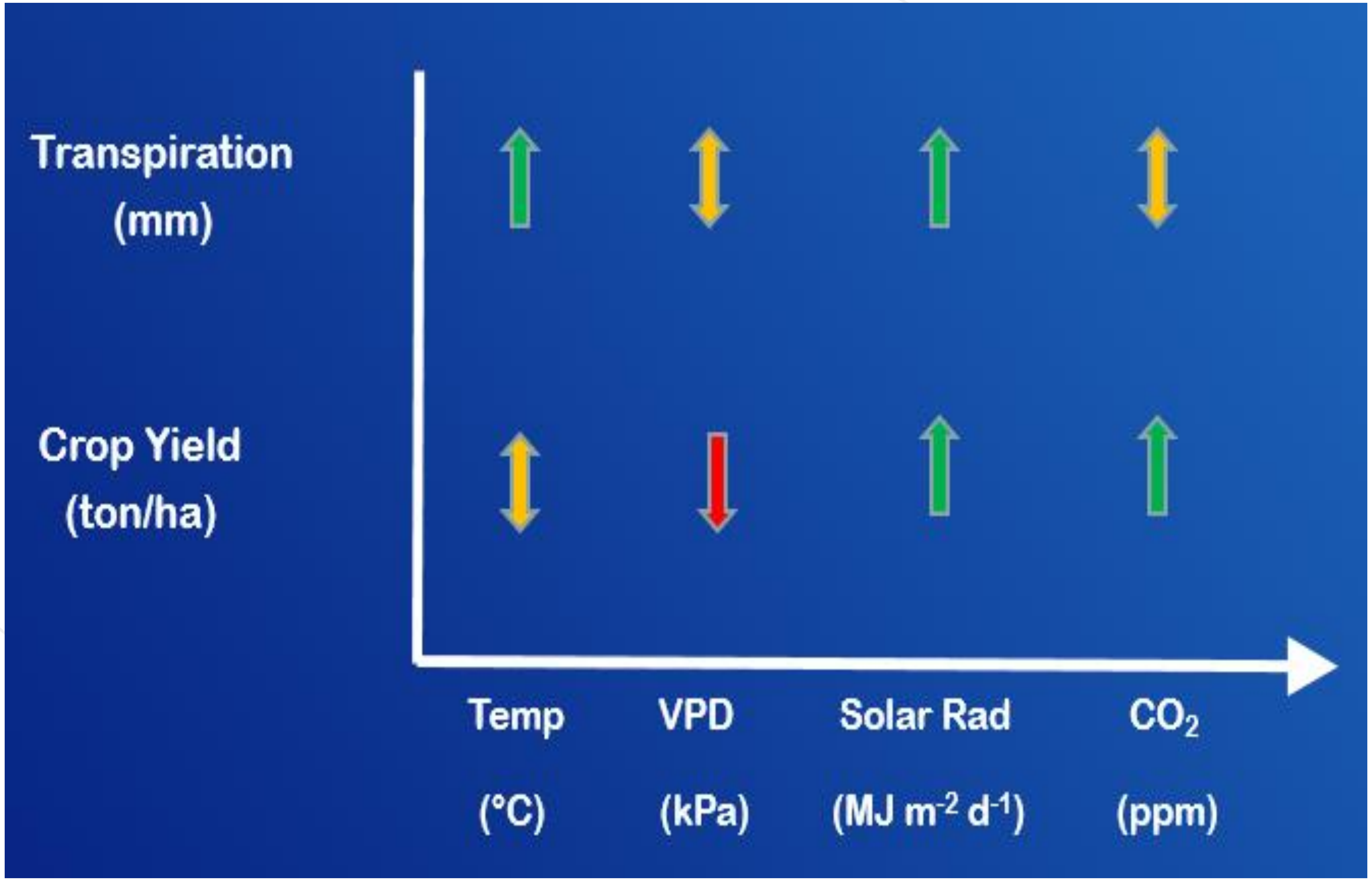
Temperature effects on Plant's Growth



CO2 effects on Plant's Transpiration

- Crop specific Optimal temperature growth range
- Canopy responses to atmospheric CO_2 concentrations
  - Increase in Left Area Index (LAI) increases plant transpiration
  - Increase in CO_2 concentrations decreases stomatal conductance
- Canopy development has effects on plant transpiration and crop yields

Plant Responses to Climate Factors



- Plant reposes to Climate factors are variable in magnitude and in direction (positive or negative)
- Increasing atmospheric carbon dioxide concentration affects plants in many ways. There are direct effects due to the elevated concentration of CO2 and there are expected indirect effects that will be caused by the changes in temperature expected with global warming.
- WEAP's PGM simulates all these effects together and their effects on plant water use and crop yield.

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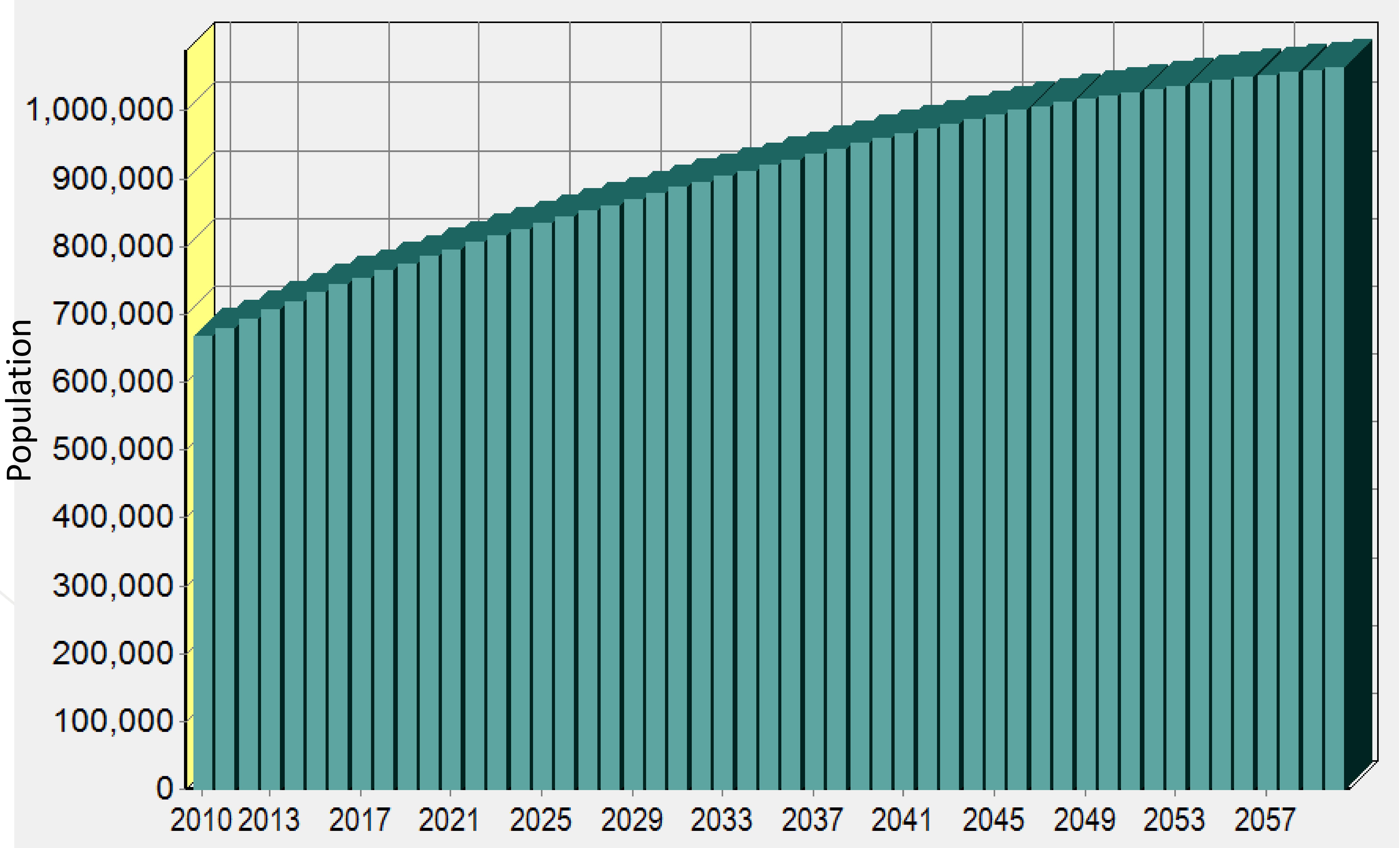
Data: Regional Population for Indoor Water Demand



- Population over time (shown in graph)
- WEAP models indoor water demand as a function of population
- Model has a 30% water consumption as a percentage of demand (water not consumed can be reused for outdoor use).
- Indoor Water use is assumed to be 200 Liters per capita per day (lpcpd).
- Outdoor water use is based on estimated area of 10,000 ha.
- Amenity Area is assumed to be 20,000 ha

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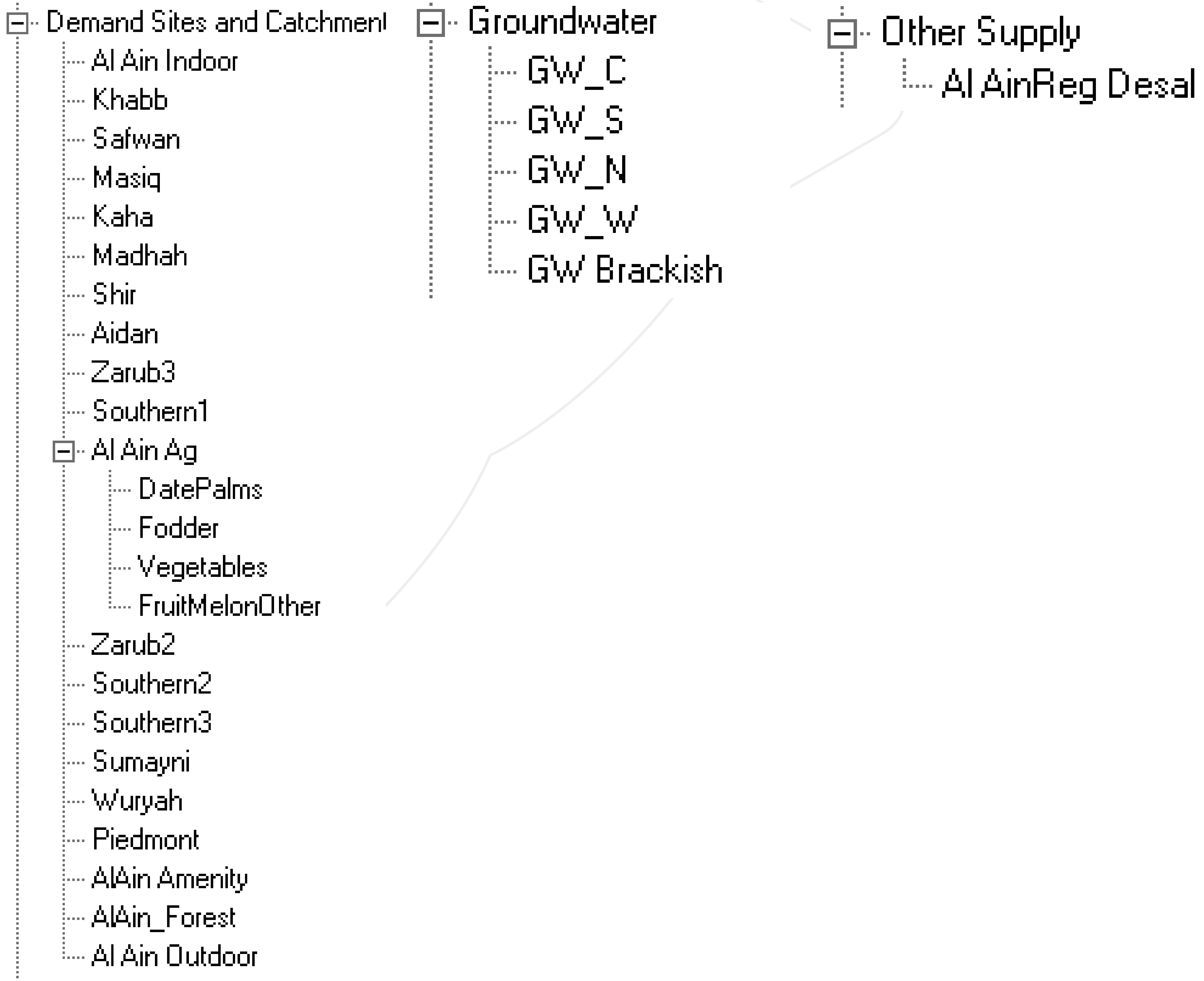
Water Demand and Supply Structure for the Al Ain water systems model



Water sources include:

- 15 wadis catchments
- 3 Fresh groundwater objects (GW_C, GW_S, and GW_N with an Initial Storage total storage of 5 BCM
- 1 Constant Head GW Boundary (GW_W)
- 1 Brackish groundwater (GW Brackish with 50 BCM of Initial Storage)
- Desalination (“Other Supply”) as a supply Al Ain region

Water Demands

Indoor; Outdoor; Amenity via reuse

Agricultural demand by 4 main crops.

Estimated Water Uses in the Al Ain Region

All Demand Sectors			
Use Type	Activity	Annual Rate	Avg. Volume (MM3)*
Indoor	700,000 (cap)	73 m^3/cap	50
Outdoor	10,000 (ha)	5,000 /ha	66
Amenity	20,000 (ha)	3,000 /ha	27
Forest	10,000 (ha)	14,700 /ha	220
Agriculture	*35,000 (ha)*	*10,000/ha*	*446*
Total			**725**

Agriculture			
Crop	M3/ha	Area (ha)	Avg. Volume (MM3)*
Date Palm	15,000	10,500	155
Fodder	13,000	10,000	134
Vegetables	5,000	3,000	16
Fruits/ Other	10,000	14,700	149
Total	45,000	38,200	446

**Averaged over the period 2010 to 2014*

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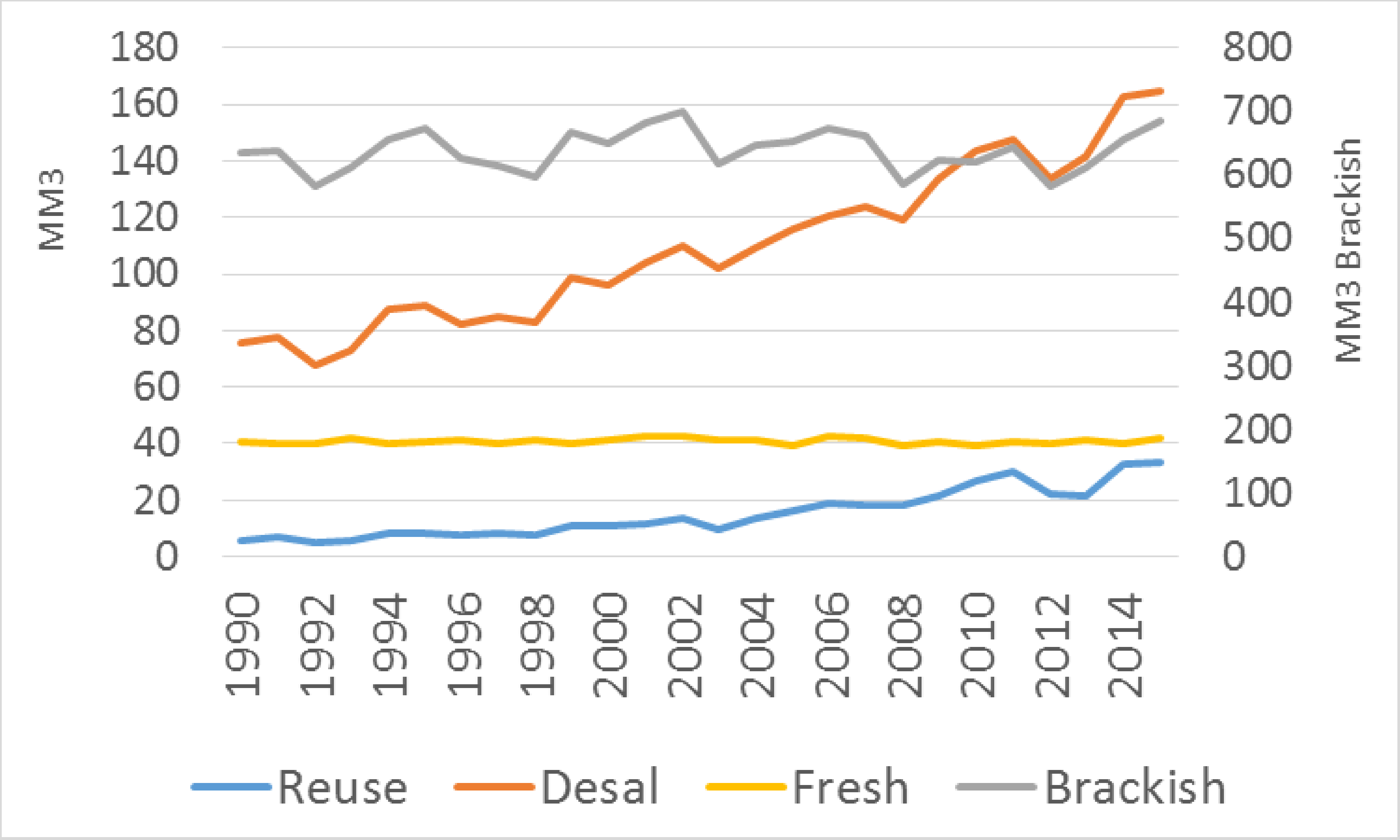
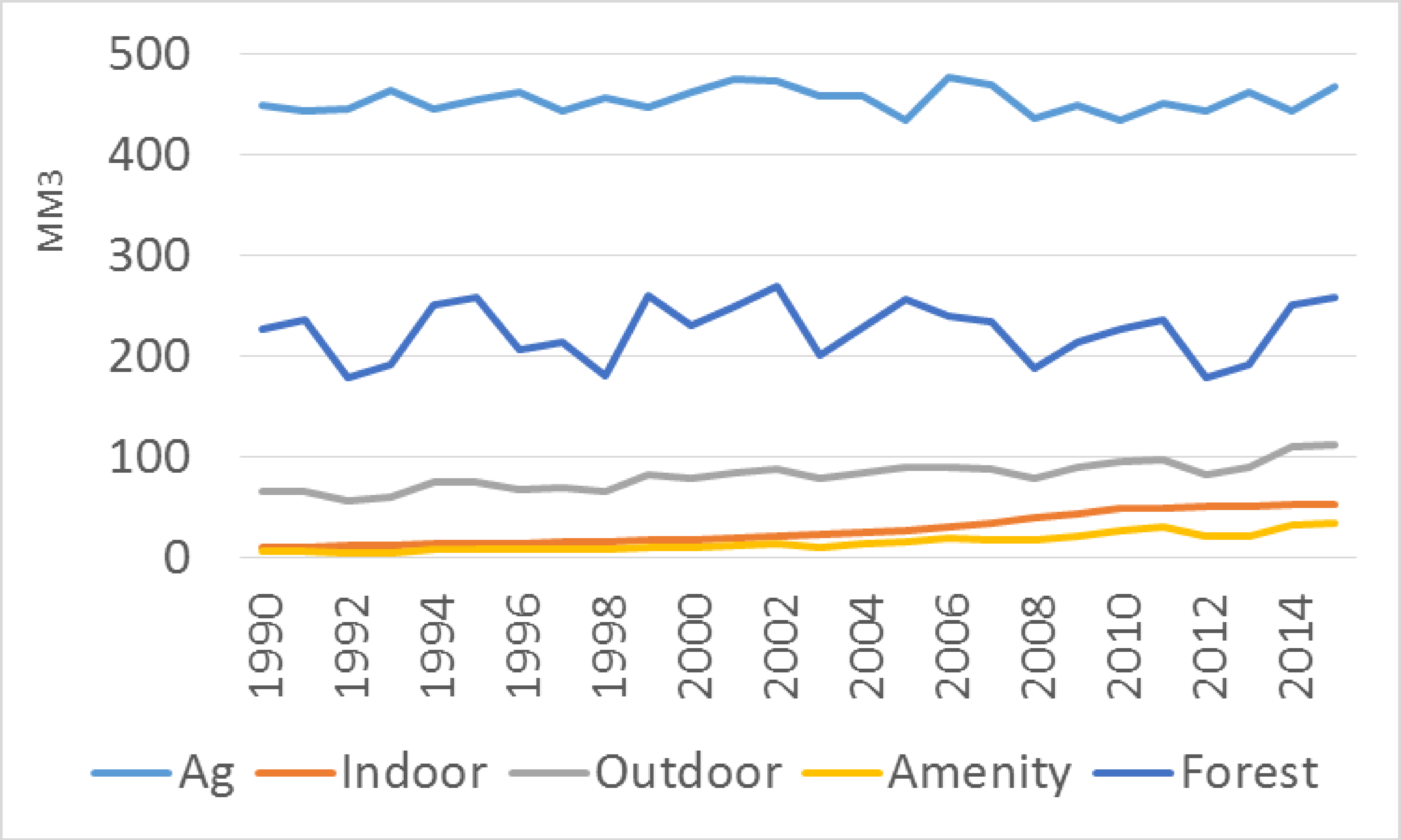
Estimated Water Balances in the Al Ain Region

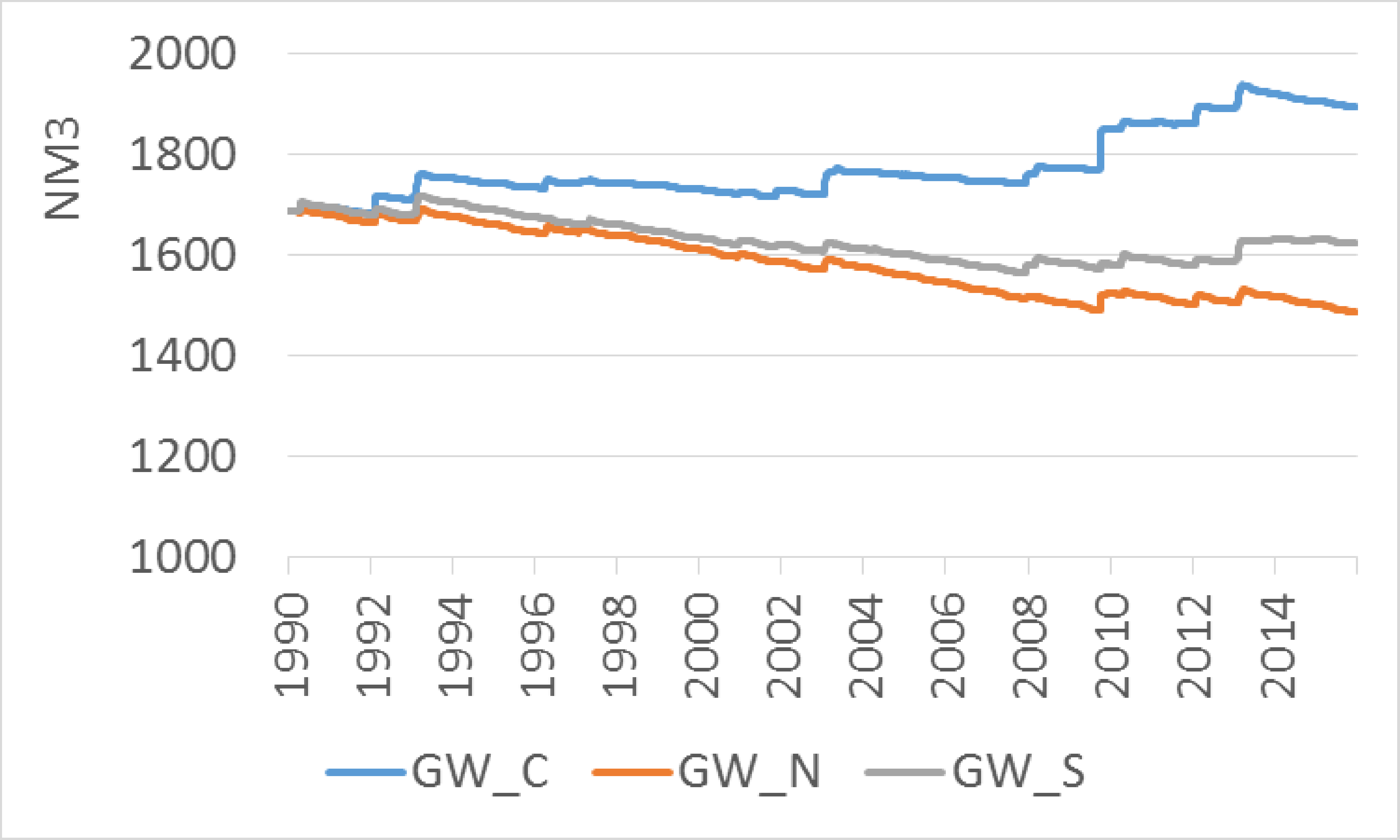
Water Supplied by Source



Water Use by Sector



Fresh Groundwater Storage for the 3 Alluvial GW Aquifers



- The importing of nearly 200 MM3 of desalinized water in the central region of Al Ain has actually resulted in elevated groundwater tables in some locations.
- Our Model captures this affect by showing total storage increasing by 200 MM3 in the Central Groundwater Zone (GW_C)
- Imported Water is about 4 times the natural recharge!

Drastic rise of groundwater table in Al Ain: Hydrogeologists have now been hired to solve the puzzle, after authorities ordered a probe into the drastic rise in groundwater table. (Gulf News, Nov. 2016)

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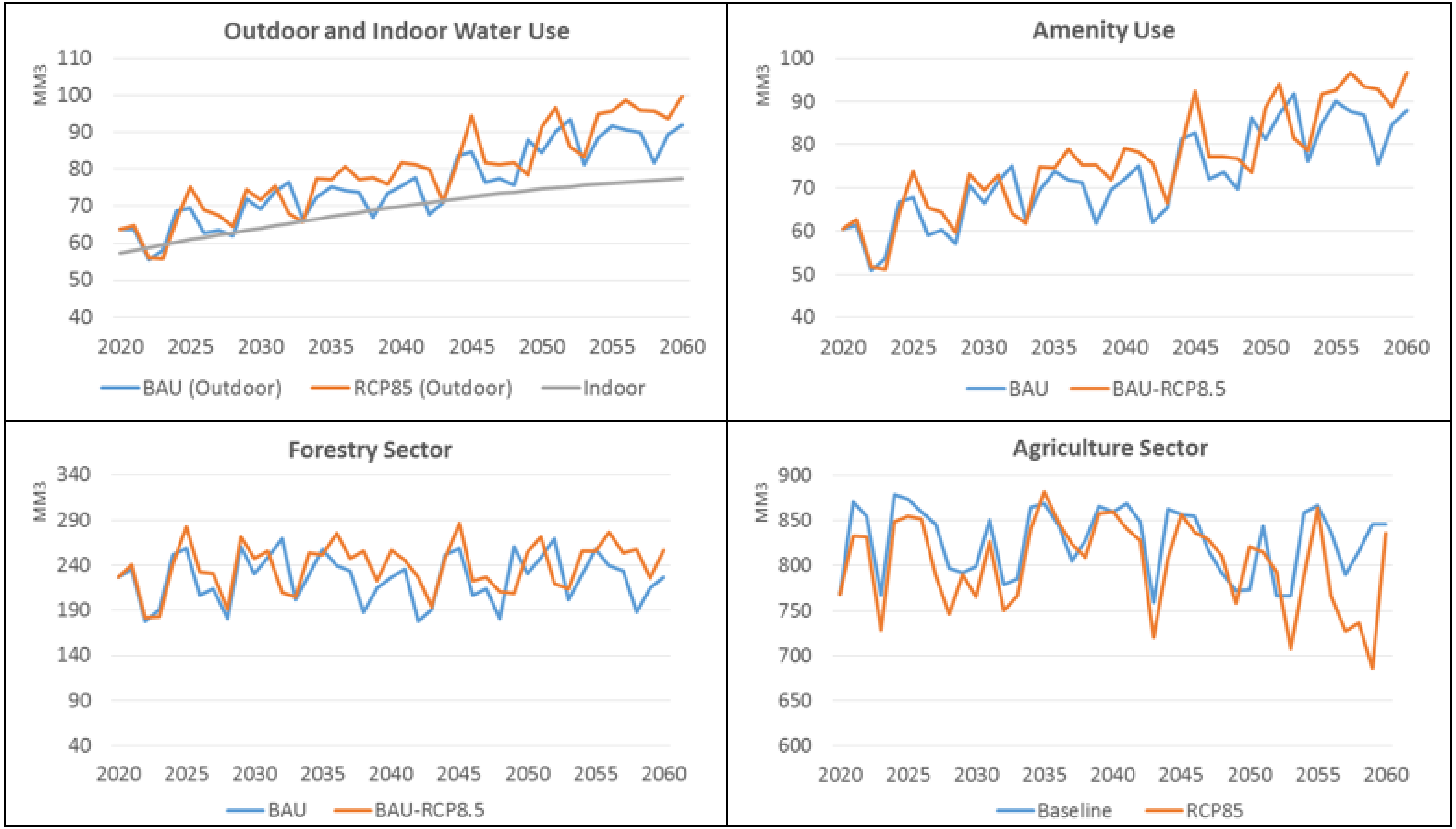
Scenarios: Business as Usual and Policy Interventions

Two Business-As-Usual Scenarios – Historic Climate (***BAU***) and Future Climate (***BAU-RCP8.5***).

FallowFF- A policy scenarios that explores what level of additional agricultural production could be possible if the Forest and Fodder sectors were gradually Fallowed. Principle of "Substitution-of-Service" applied. Focus on the brackish GW Supply.

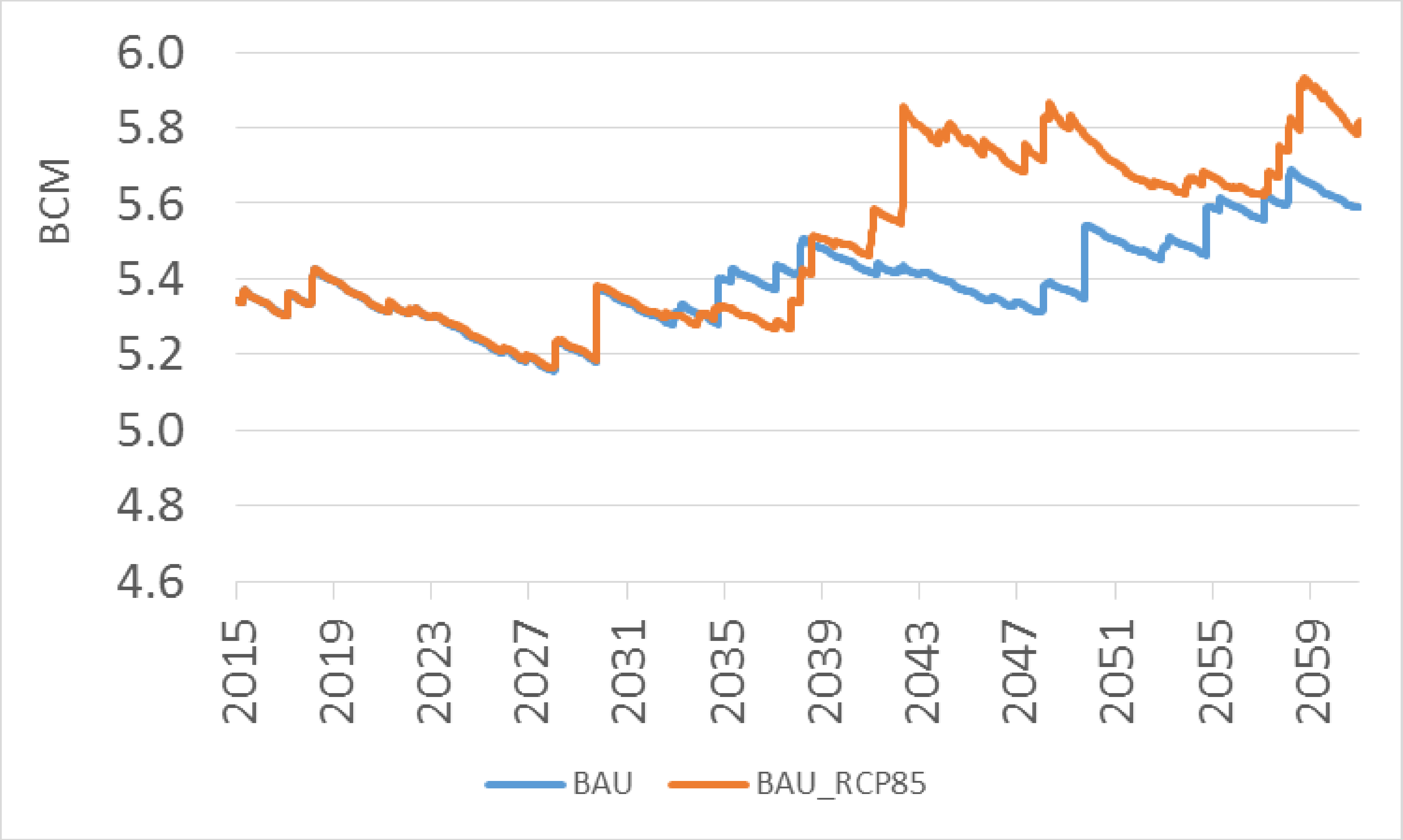
StablizeGW- This policy scenario focuses on the sustainability of the renewable GW supply of Al Ain regional aquifer under current and future climate. Exploring how local groundwater could be conjunctively used with imported desalinated water.

The BAU and BAU-RCP8.5 Showing the effects of Climate: 2020 to 2060.

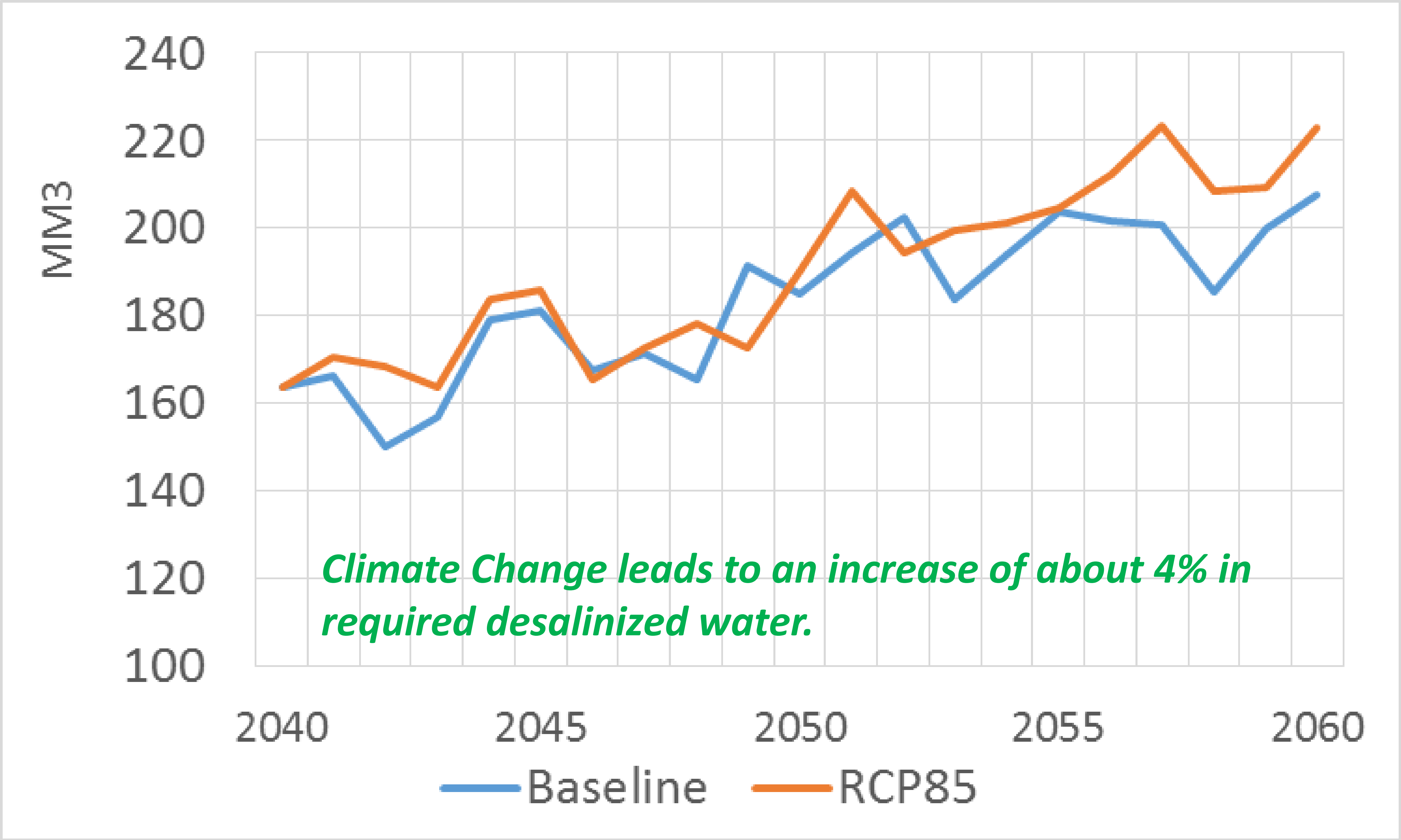


The Alluvial Groundwater Storage Increases rapidly. For the BAU scenario, the elevated storage is due to recharge alone.

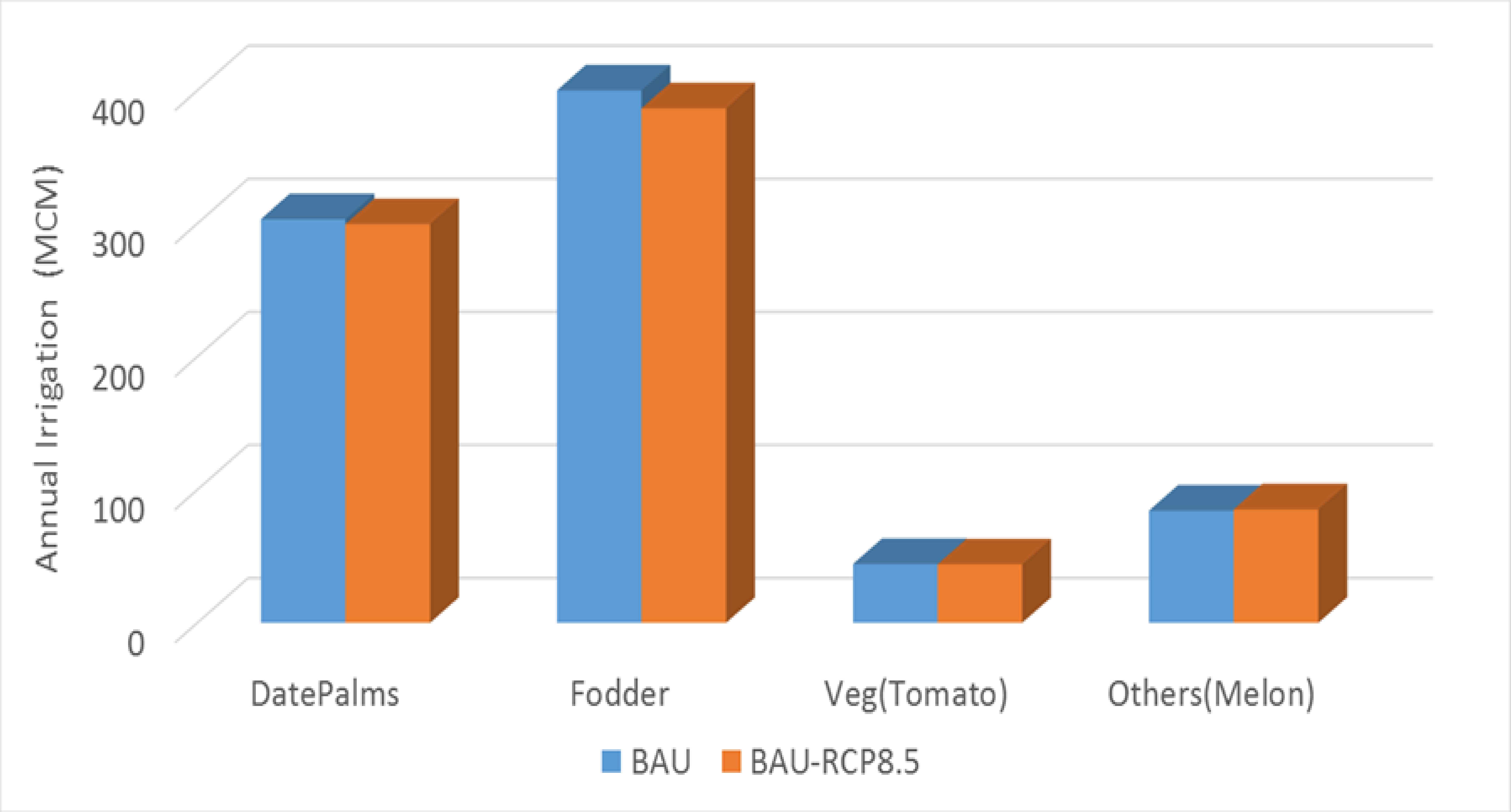
Alluvial Groundwater Storage



Desalinized Water Delivered



Average Crops' Total Irrigation



- Agricultural irrigation defined as:
  - Date Palms: daily irrigation (1.7 m of irrigation)
  - Fodder: 1.75 m of irrigation
  - Vegetables: irrigation as needed
  - Others: irrigation as needed.

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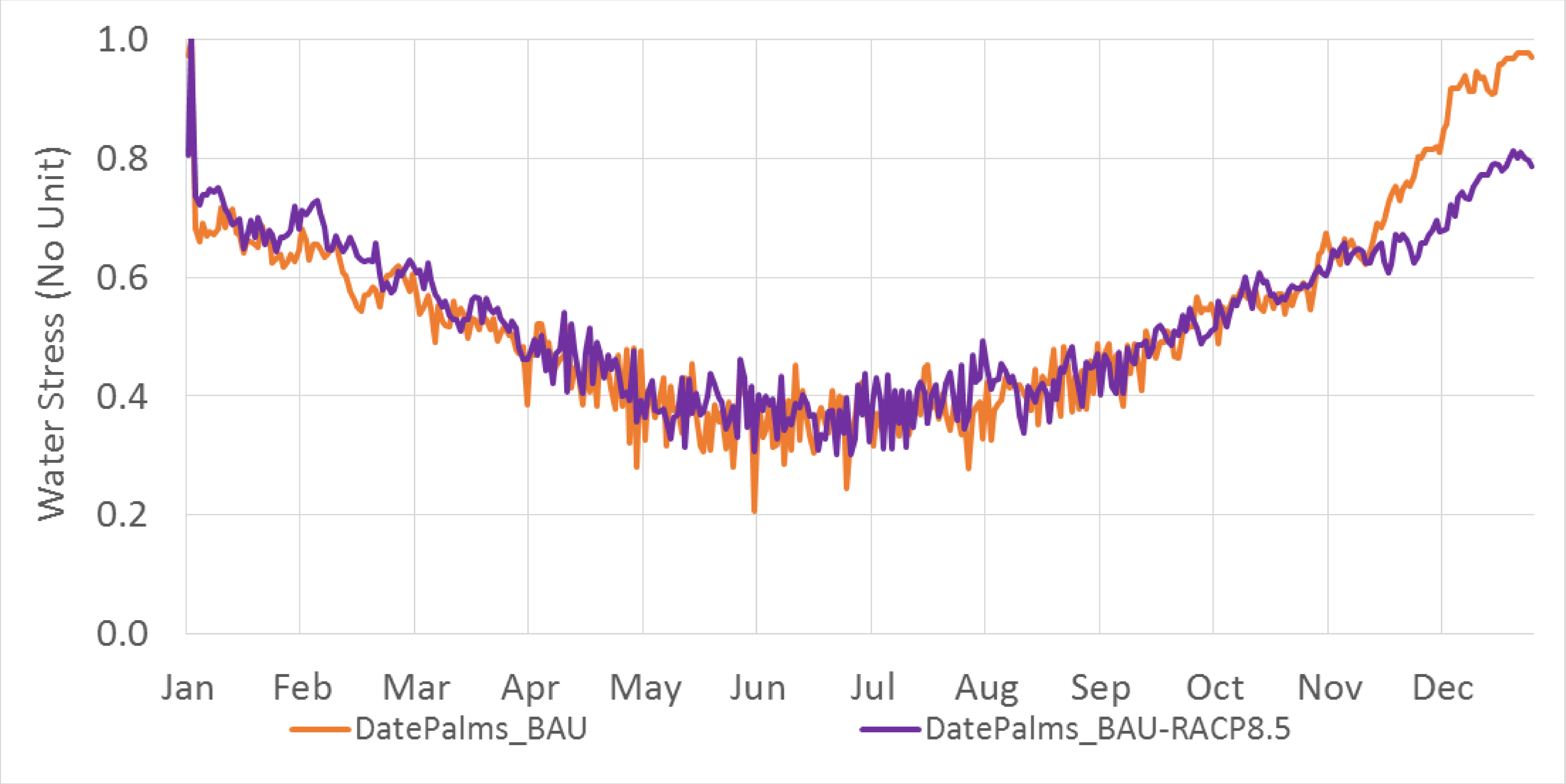
Date Palms' Water Stress



- ❑ Average daily Water Stress in Date Palms
- ❑ A value of 1 indicates no Water Stress at all
- ❑ A value of 0 indicates full Water Stress
- ❑ Water Stress depends on Potential ET and Actual ET
- ❑ Actual ET is in function of climate, irrigation, soil properties, and crop transpiration

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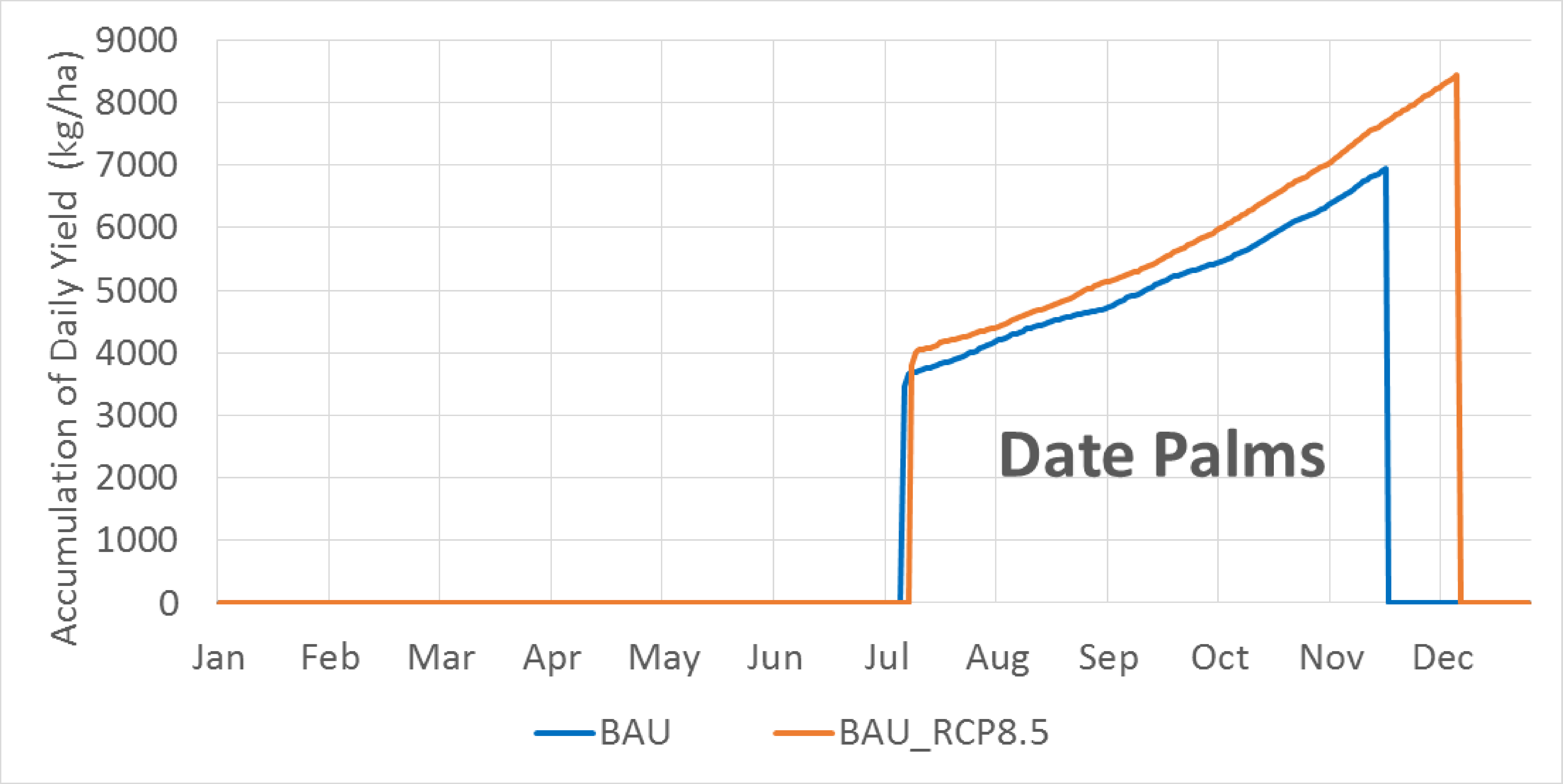
Accumulation of daily crop yields



- Date palms crop increase due to the difference in harvest season
- Crops under BAU-RCP8.5 scenario can accumulate more heat units due to warming conditions and have a longer growing season
- A longer growing season implies larger agricultural yields if conditions are favorable for crops

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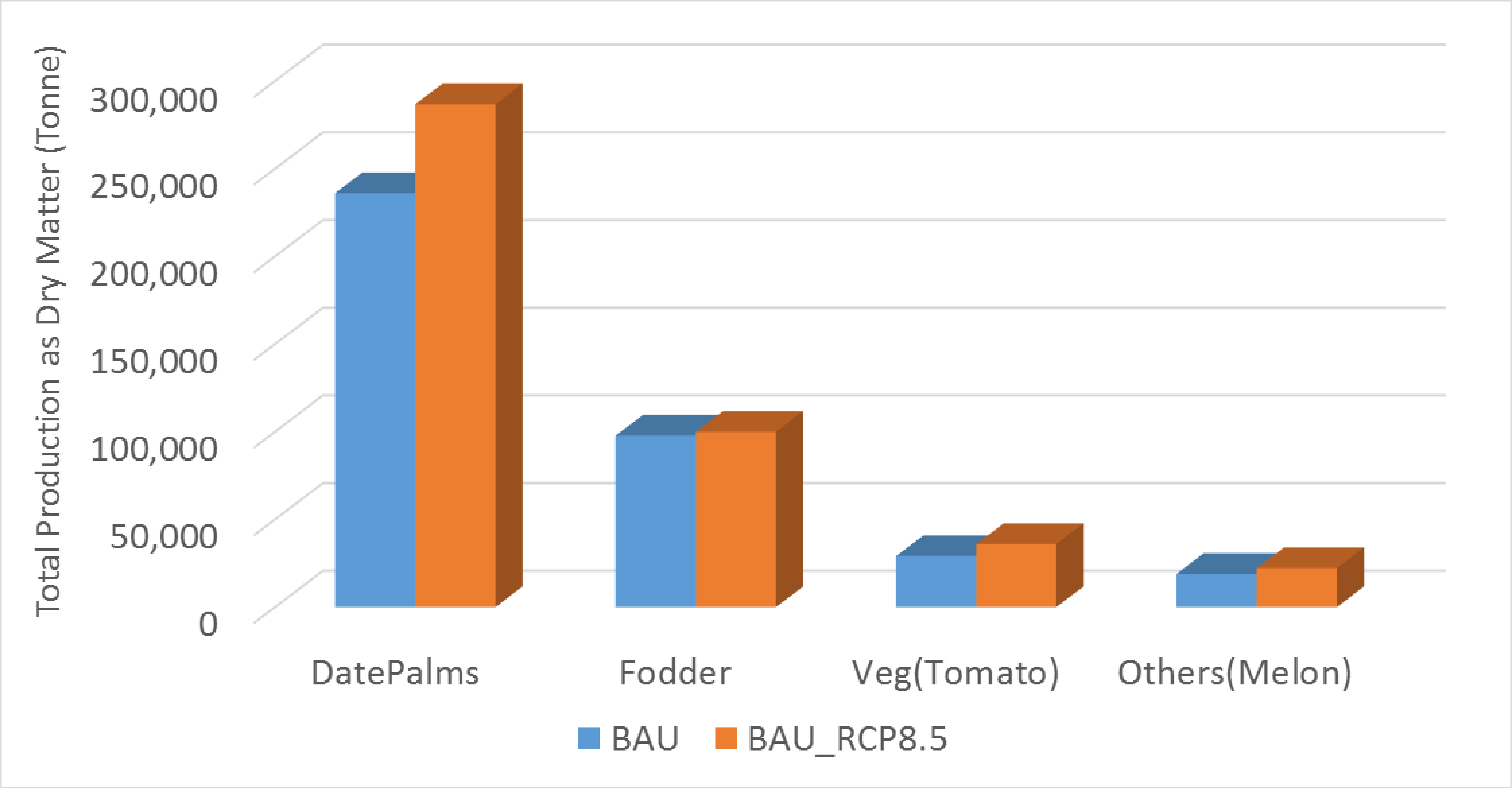
Total Commercial Crop Production



- Date palms' production may increase in the future under future climate and atmospheric CO_2 concentrations
- Potential increase of almost 30,000 metric tonnes of date palms fruits

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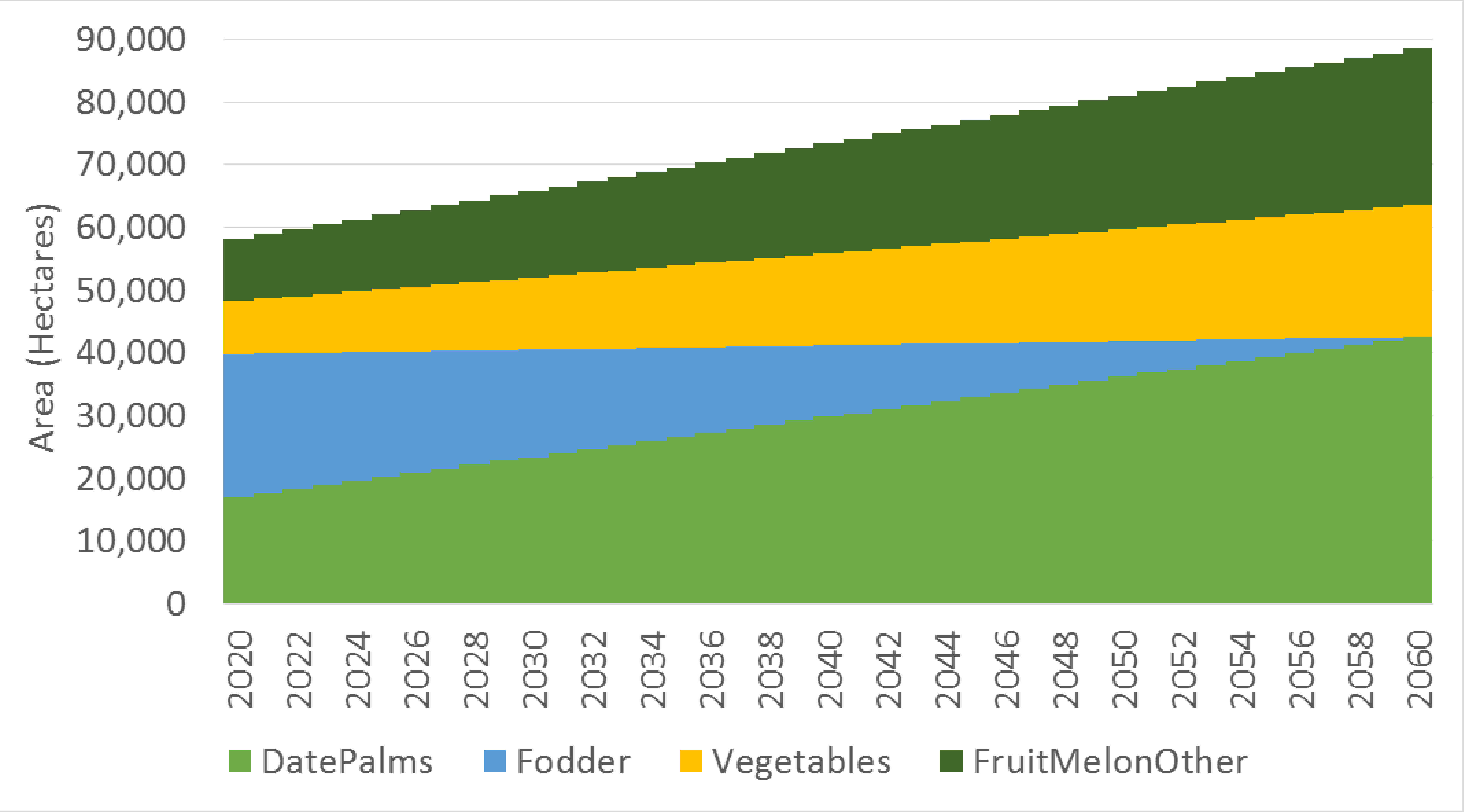
FallowFF Scenario: Agriculture Acreage Increased



- Fodder is gradually fallowed.
- Date Palms, Vegetables and Fruits planted acreage doubles.
- Increase in total area under production from 35,000 to 80,000 hectares.
- Forest sector is also gradually fallowed.
- 12 BCM are exchanged over the 40 year period.

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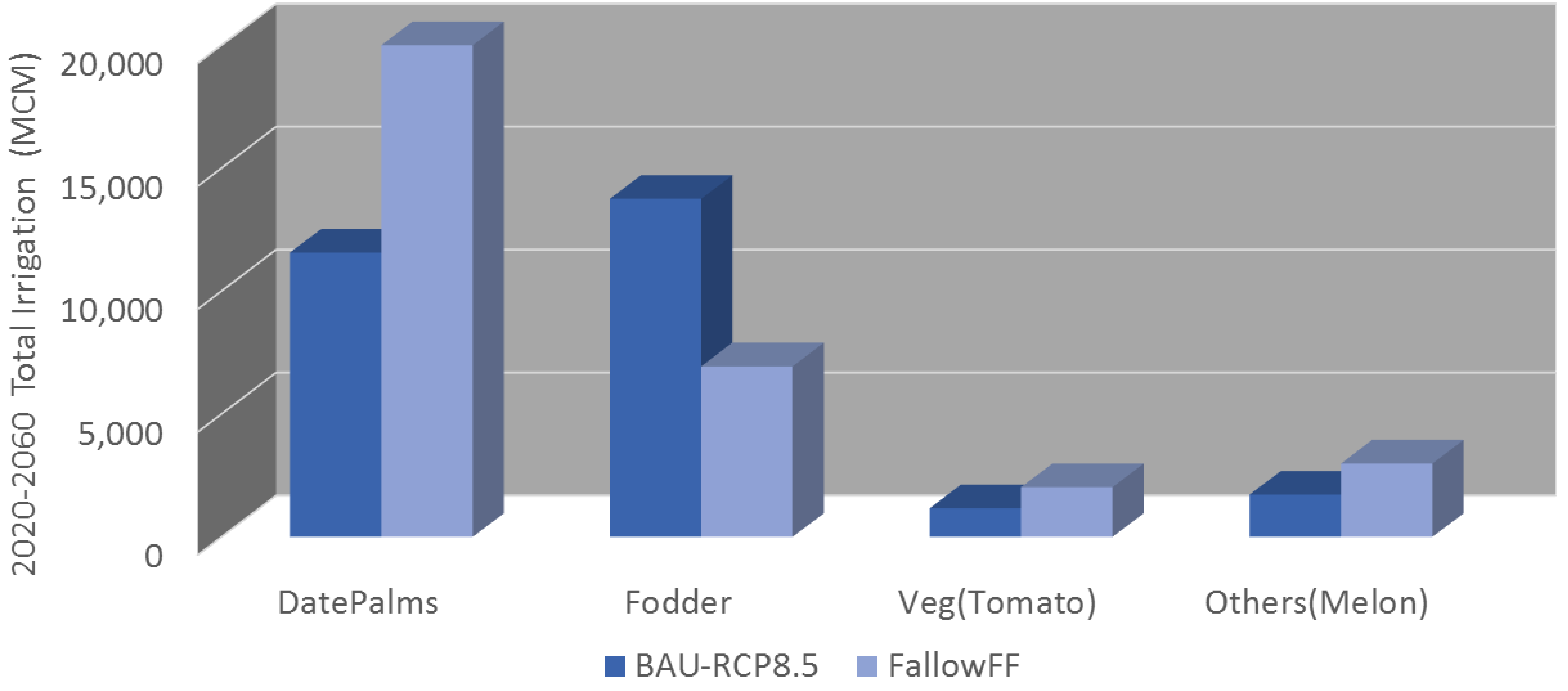
Water Delivered by Agricultural Activity from 2020-2060



Crop	DatePalms	Fodder	Veg(Tomato)	Others(Melon)
% Change	75	-50	73	73

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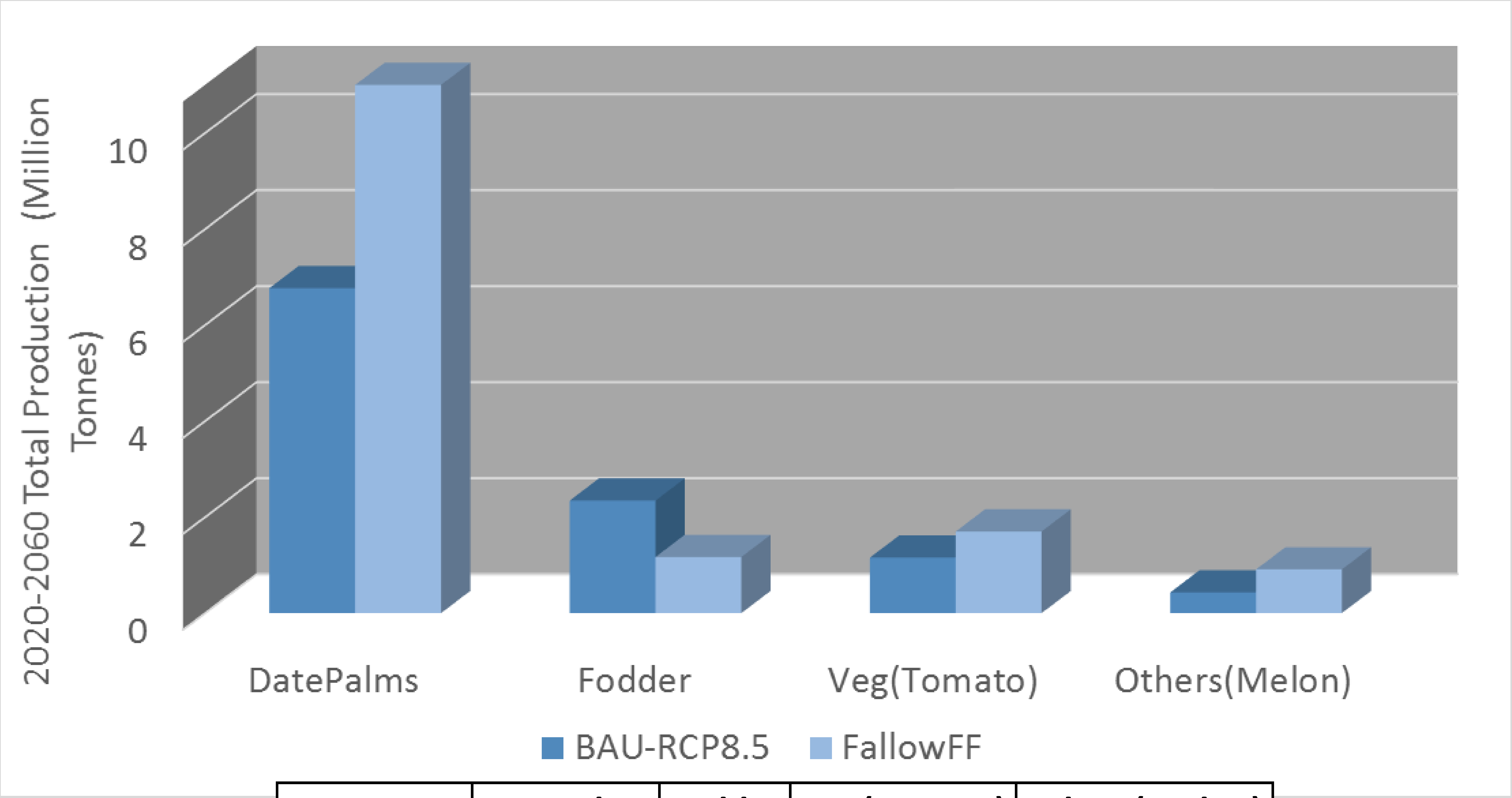
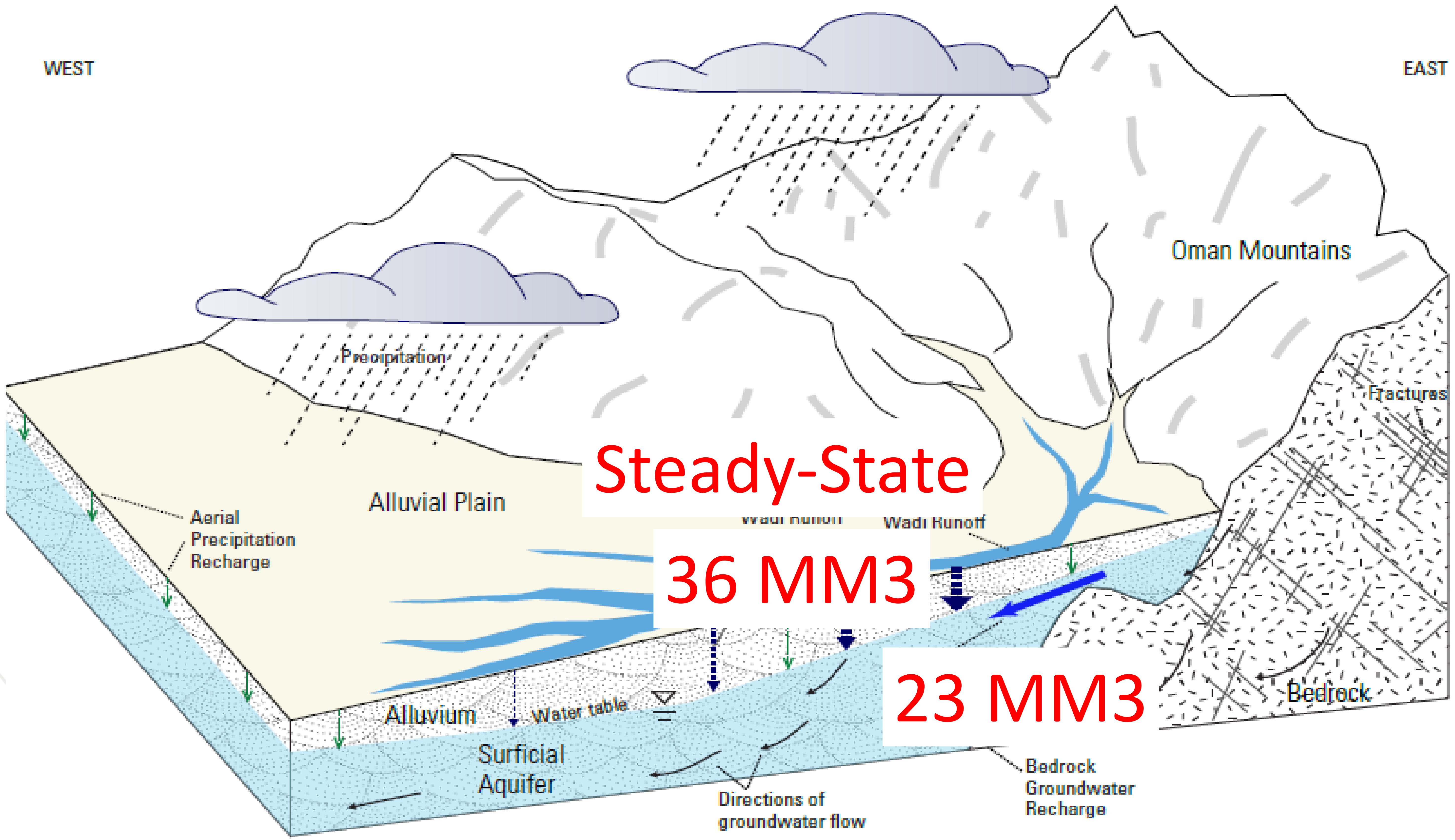
Total Agricultural Production from 2020-2060



Crop	DatePalms	Fodder	Veg(Tomato)	Others(Melon)
% Change	75	-50	47	111

StablizeGW: Conjunctive use of Alluvial Aquifer and Desal Water



- Steady-State Conditions-~ 59 MM3 annual natural recharge.
- Increase in total area under production from 35,000 to 80,000 hectares.
- Forest sector is also gradually fallowed.
- 12 BCM are exchanged over the 40 year period.

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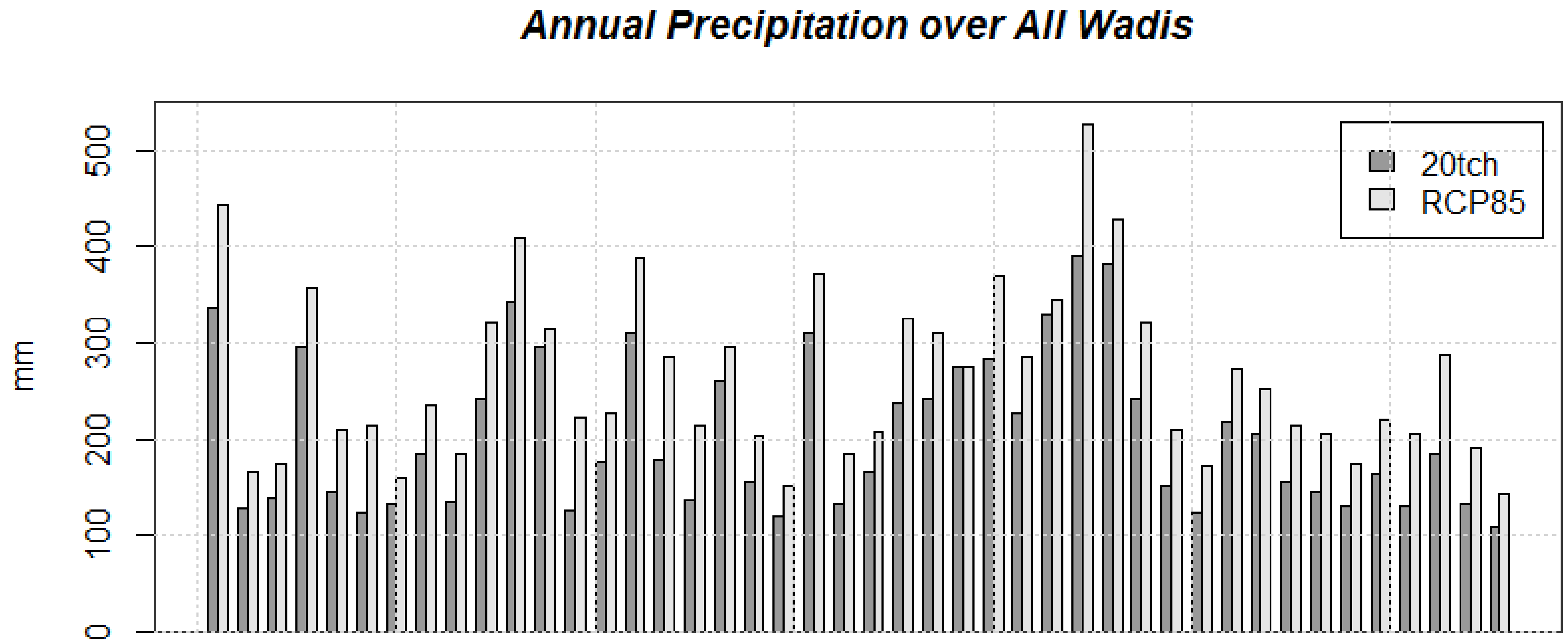
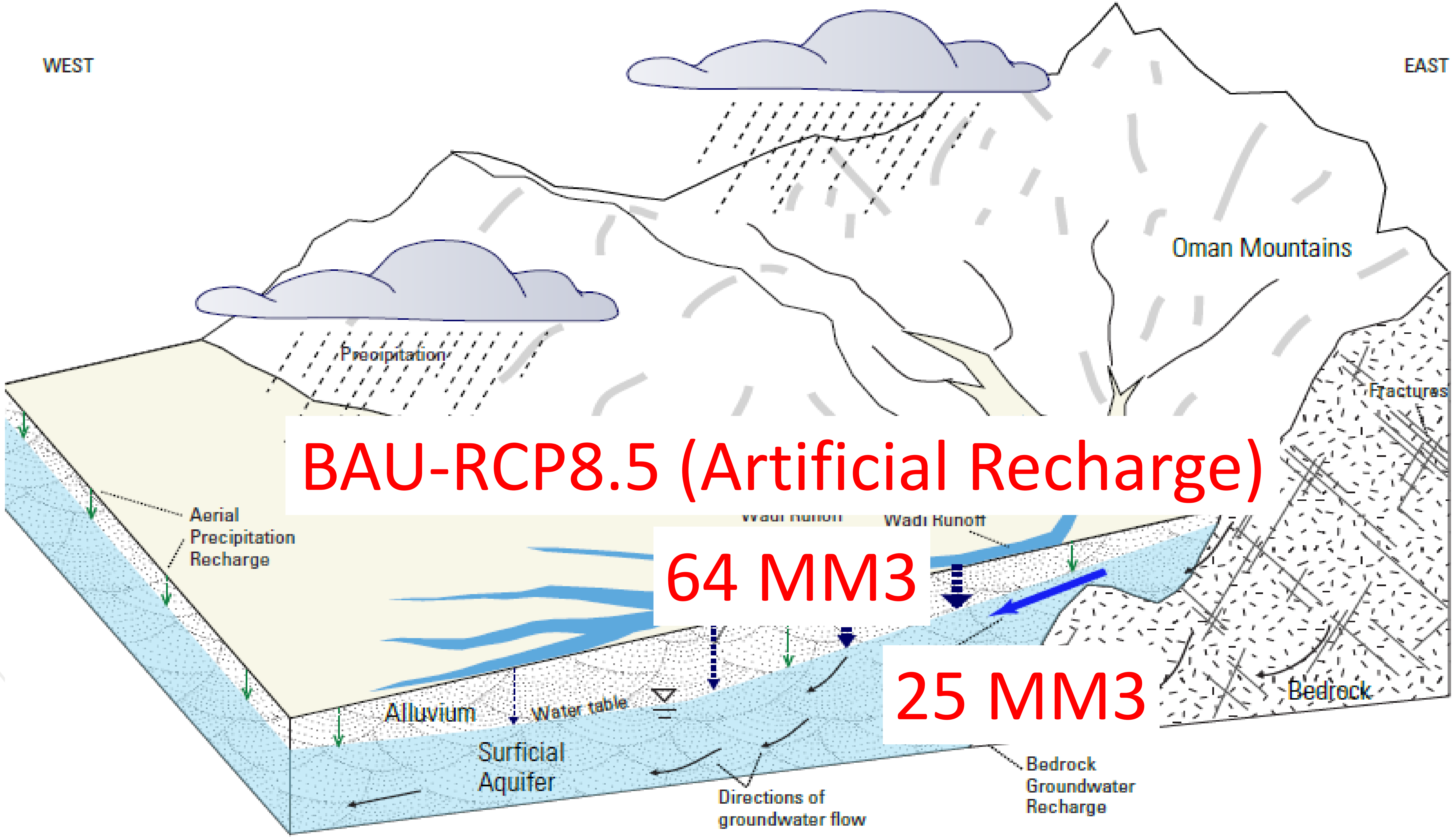
Current and Future Precipitation over the Oman Mountains



StablizeGW: Conjunctive use of Alluvial Aquifer and Desal Water



- Steady-State Conditions-~ The BAU-RCP8.5 scenario implies an increase in total discharge.
- Still, total recharge is a relatively small fraction of total use.

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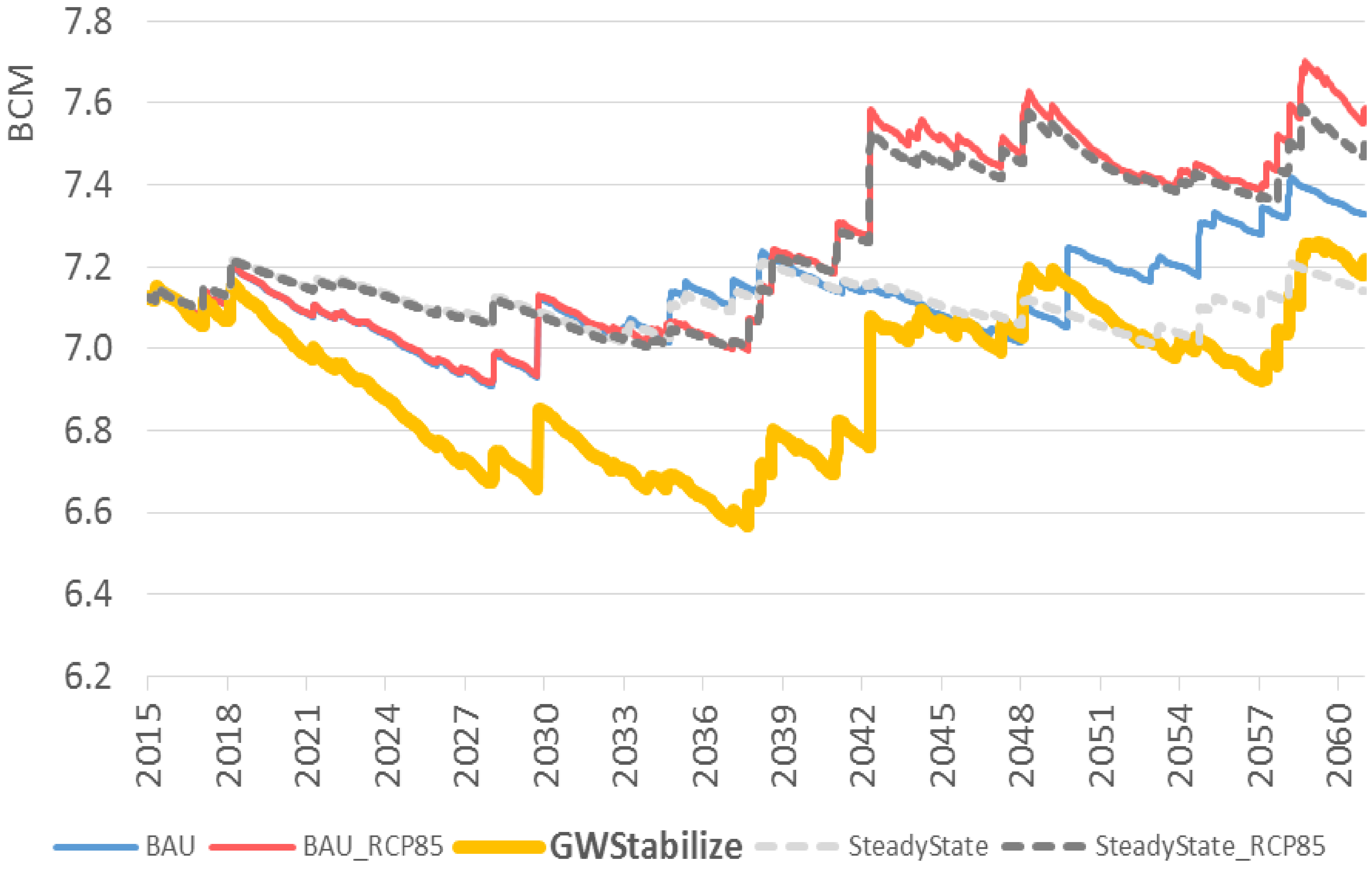
StablizeGW: Conjunctive use of Alluvial Aquifer and Desal Water



- ❑ Steady-State Conditions-~ 59 MM3 annual natural recharge.
- ❑ Show all scenarios (note steady-state conditioin).
- ❑ We have estimated the level of pumping needed to maintain a “relatively” stead-state condition

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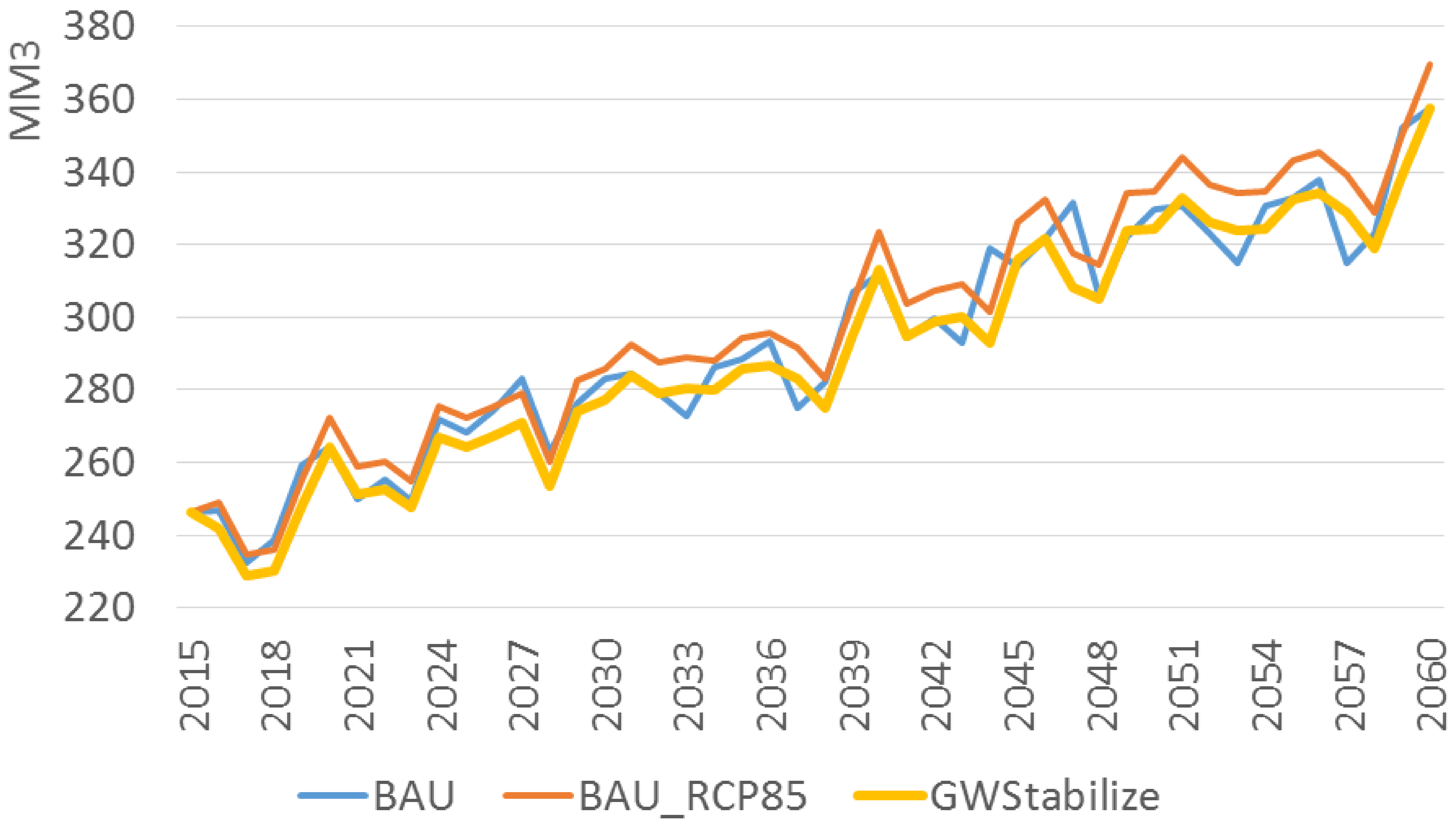
StablizeGW: Supply Delivered by Desalinization



- Steady Growth in Desalinization water, driven mostly by population growth.
- Total savings of desalinated water over the 45 year study horizon is about 400 MM3 (or about 2 years at current rates of use).

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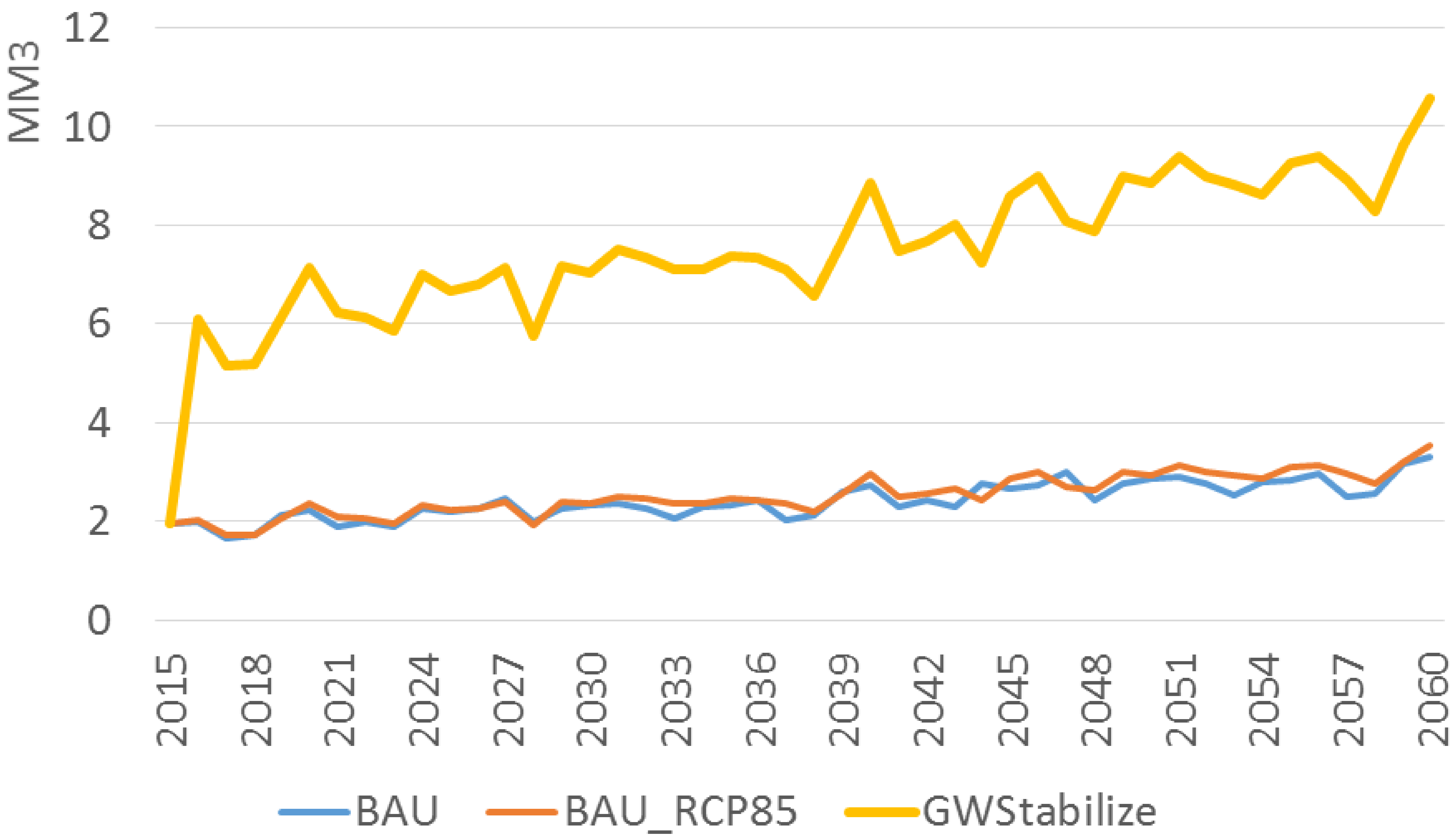
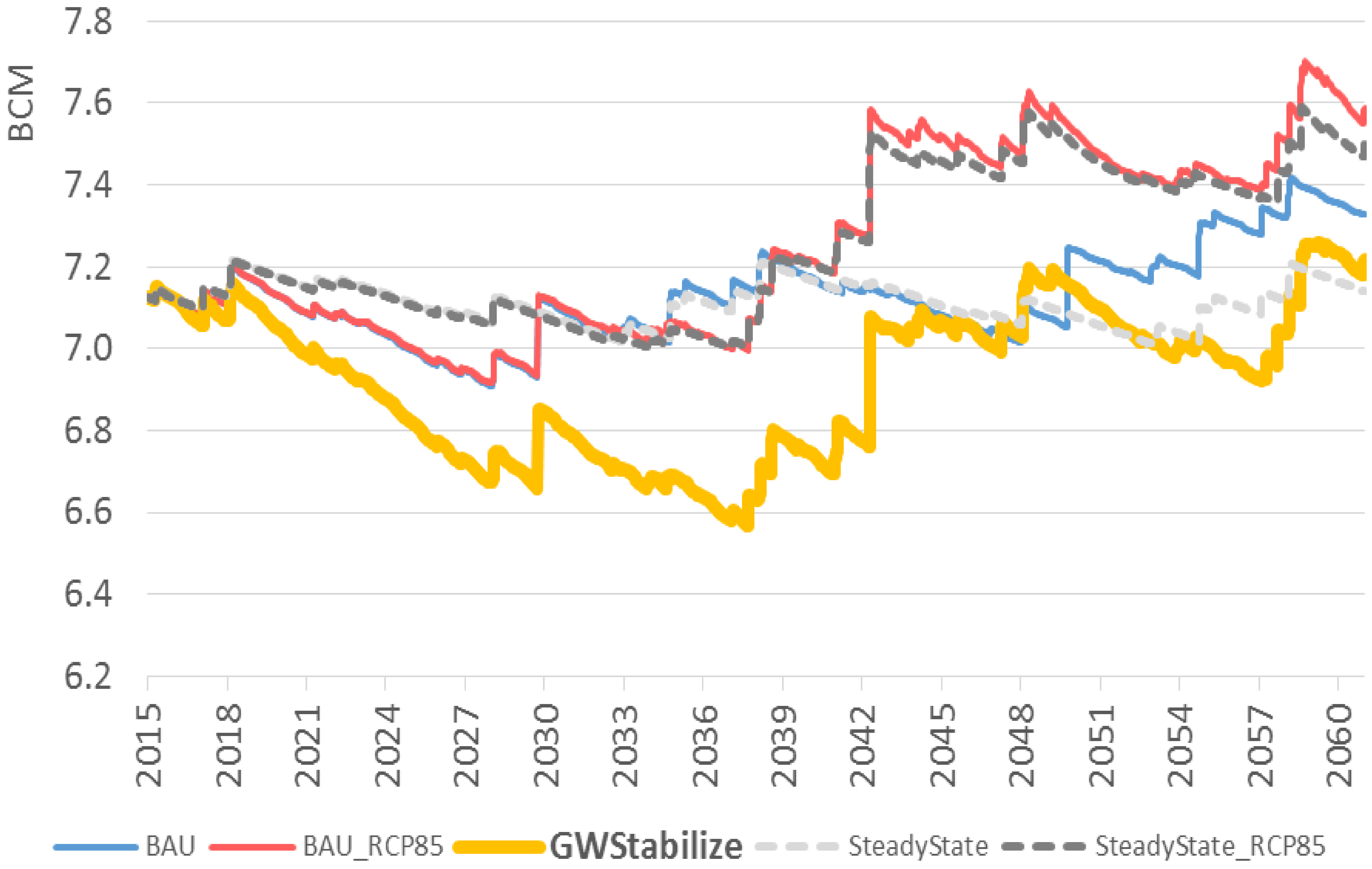
StablizeGW: Supply Delivered from Alluvial Aquifers



- Steady Increase in Water Withdrawn from Alluvial Aquifers.
- Still a relatively small portion of total supply.
- This is the level of use that leads to the steady state condition shown previously.

StablizeGW: Conjunctive use of Alluvial Aquifer and Desal Water



- Steady-State Conditions-~ 59 MM3 annual natural recharge.
- Show all scenarios (note steady-state conditioin).
- We have estimated the level of pumping needed to maintain a “relatively” stead-state condition

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