Quantifying the effects of climate variability on crop water use in Cyprus

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Water Scarcity:
water, water everywhere; nor any drop to drink*

Davos 2013: water scarcity is 'second most important world risk'

UN general secretary Ban Ki-moon tells Davos that we must appreciate water more as World Economic Forum recognises the scale of the problem – but what is being done?

Jo Confino in Davos
Guardian Professional, Thursday 24 January 2013 18.15 GMT

Davos 2013: tackling water stress is high on the agenda at this year's World Economic Forum. Photograph: Jim Lo Scalzo/EPA

World on course to run out of water, warns Ban Ki-moon

Freshwater supply and water quality under pressure, warns UN secretary general on International Day of Biological Diversity

John Parnell for RTCC, part of the Guardian Environment Network
guardian.co.uk, Wednesday 22 May 2013 12.20 BST

Woodland stream Snowdrop Valley, Exmoor. 'Although seemingly abundant, only a tiny amount of the water on our planet is easily available as freshwater,' said Ban Ki-moon. Photograph: Martin Fowler/Alamy

** The Rime of the Ancient Mariner*

by S. T. Coleridge (1772-1834)

Water Scarcity in Cyprus

- Limited water resources due to physical factors:
  - Inter-annual fluctuations in precipitation
  - Drought spells every 2-3 consecutive years
  - Intensified (magnitude and frequency) over time
- Demand > Available Supply
  - Highest Water Exploitation Index (45%) in the EU (EEA, 2011)
  - Irrigation-based agriculture (est. 65-70% of water availability)
    - High dependency on groundwater →saline intrusion in aquifers
  - Increasing demand in the domestic sector (including tourism)
  - Spatial distribution of water supply and demand

Water Policy

- No drop of water to the sea (1960-2000)
  - Dam construction → increased water storage capacity
  - Irrigation and conveyor schemes

- Independence from climatic conditions (since 2000)
  - Desalination plants → domestic supply
  - Water treatment plants → recycled water supply → agricultural water supply

Contents

- Quantifying agricultural (crop) water use (1995-2009)
  - year-to-year analysis to capture the impact of climate variability
  - distinguish the type crop water use (green vs. blue);
  - spatial and temporal variations on CWU & yield;
  - composition of crop water use;
  - quantify groundwater use and over-exploitation
- The water footprint of supply utilisation
  - virtual water exports
  - internal vs. external (import dependency vs. sufficiency)
  - supply utilisation
- Trends
- Conclusion / Recommendations

Introduction

- In arid and semi-arid regions, the greatest proportion of incoming precipitation returns to the atmosphere as evapotranspiration (80-90% in Cyprus).
- Blue water refers to the “usable” remainder of the incoming precipitation, which flows in streams and is stored in lakes, dams or aquifers.
- Green water originates from precipitation and refers to the water stored in the soil as soil moisture, which returns to the atmosphere as evapotranspiration.
- The water requirement of crops refers to the total amount of water that is needed to produce crops and is satisfied by green and/or blue water.
- Crop water requirements vary depending on the climate, type of crop, type of soil etc.

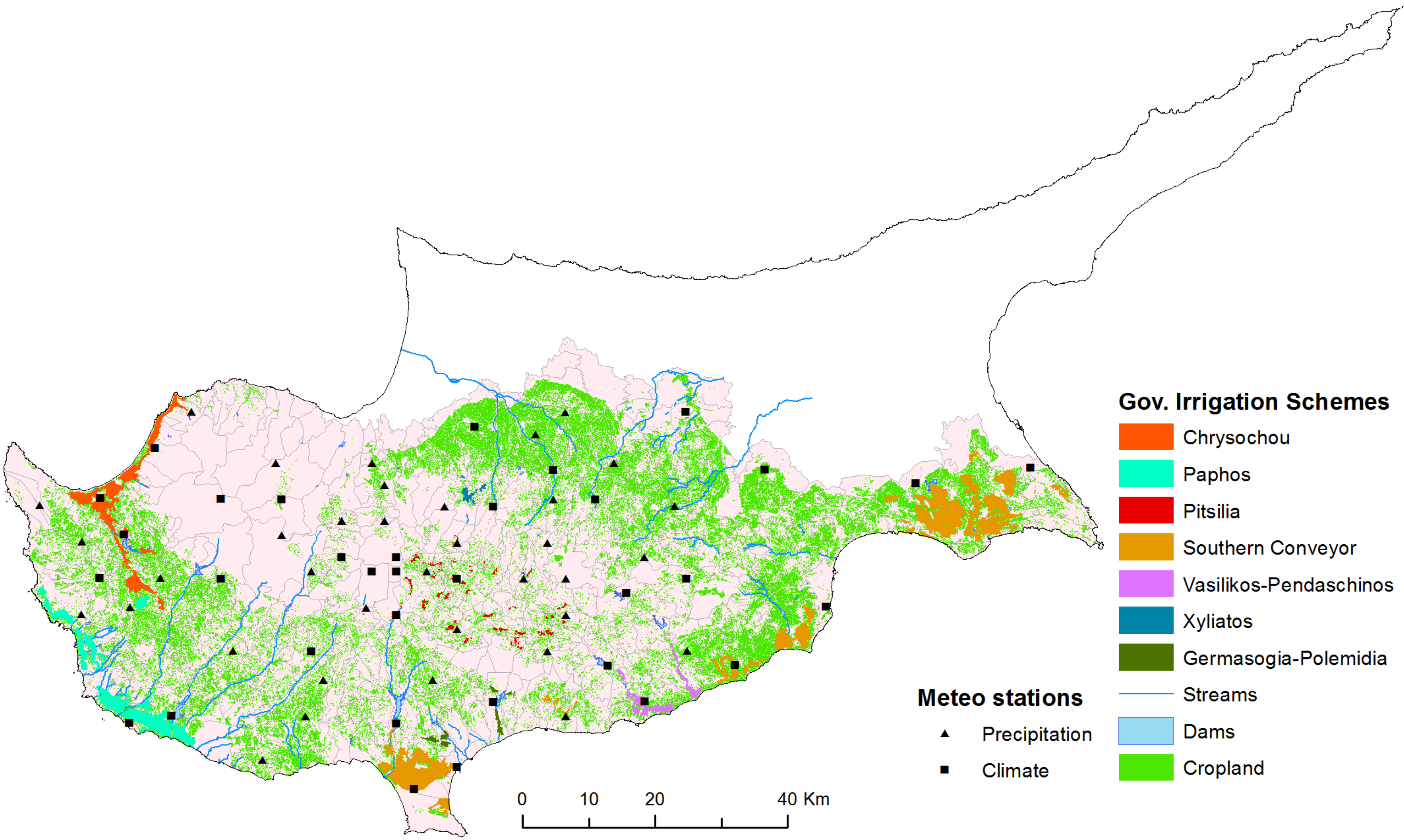
Methodology

- Total crop water use computed using the spatiotemporally explicit model developed by Bruggeman et al. (2011)
  - daily soil water balances which calculated the water use of all crop systems at community level in Cyprus (1980-2009)
  - adjusted for 1995-2009 (Zoumides et al. 2012, 2013)
- The model follows the FAO-56 dual crop coefficient approach for computing crop evapotranspiration (ET_c) and scheduling irrigation (Allen et al. 1998)
- The model distinguishes the crop's use of precipitation (green) and irrigation water (blue)
- Detail description of the procedure in Bruggeman et al. (2011) & Zoumides et al. (2012, 2013)

Model Input Data

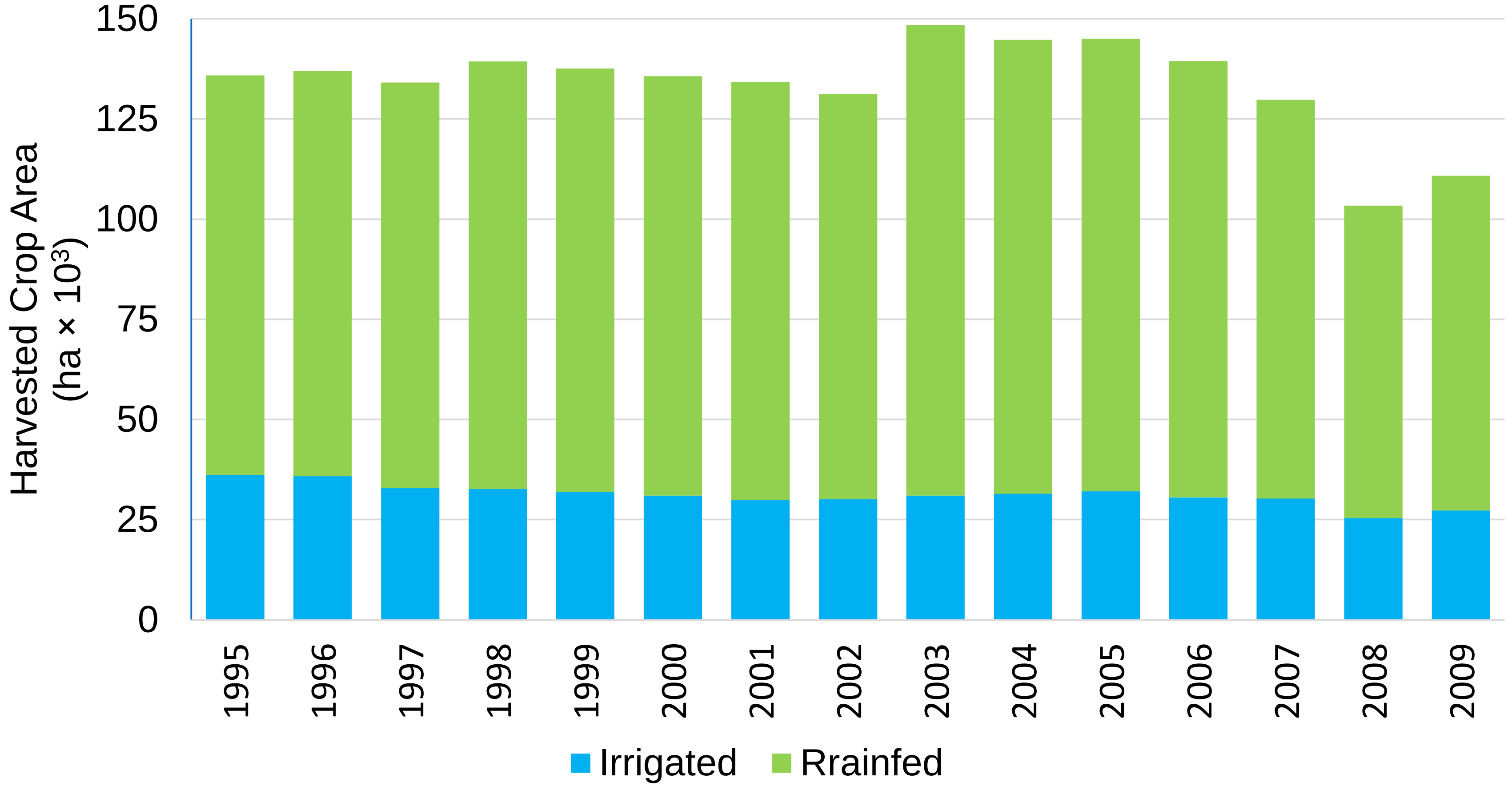
- **Climate variables**: daily data from 34 stations and 70 rain gauges (CMS)
- **Area & production**: annual data spatially adjusted to 431 communities based on 2003 agr. census (Cystat)
- **No. of Crop**: 83 crop production systems
- **Crop parameters**: Allen et al. (1998), adjusted to local conditions and irrigation practices (Markou & Papadavid , 2007)
- **Soil Properties**: Hadjiparaskevas (2005); FAO et al. (2009); ESBN (2005)

Climate variables



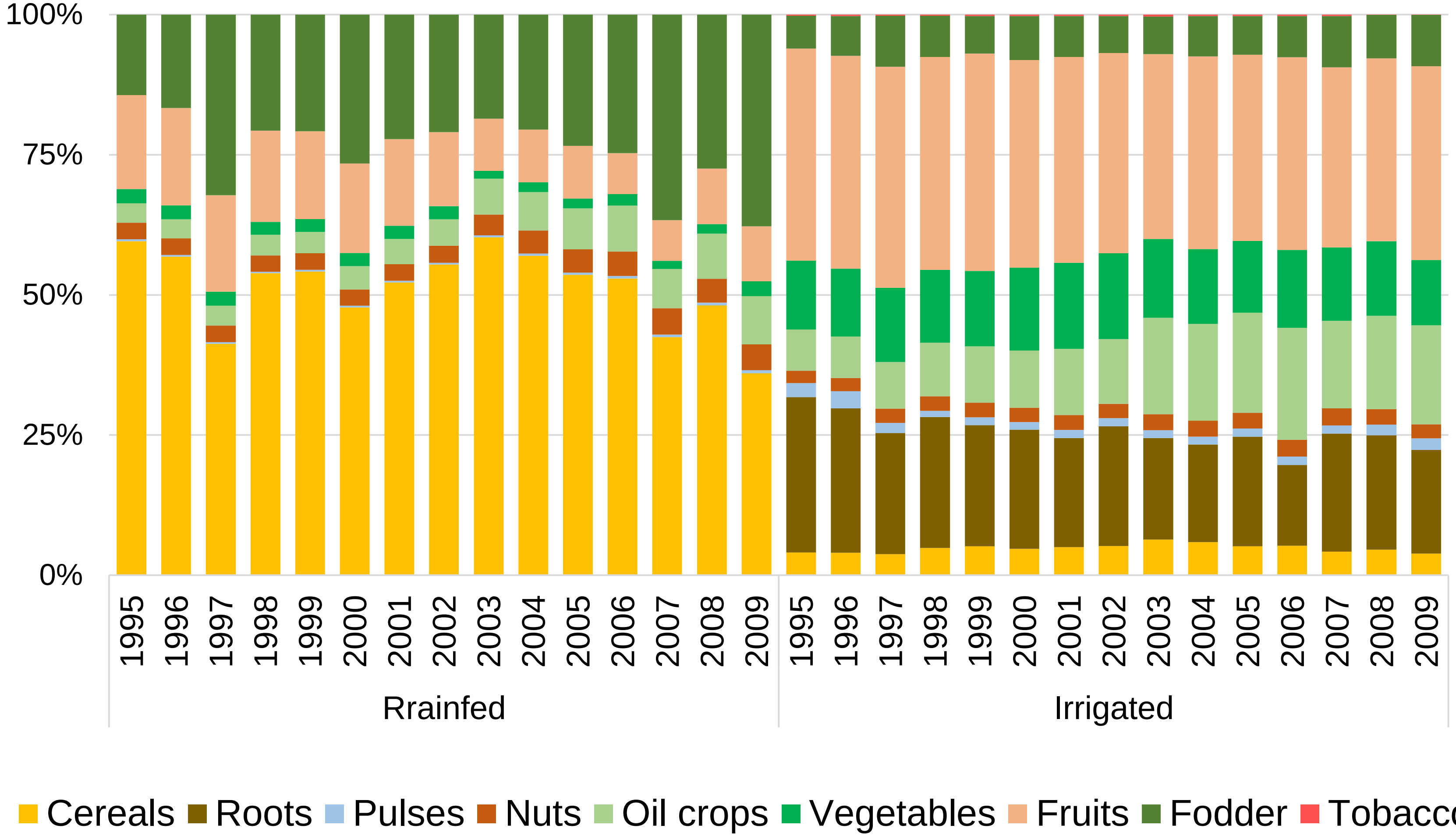
Source: Zoumides et al. (2012; 2013)

Irrigated vs. Rainfed cropland



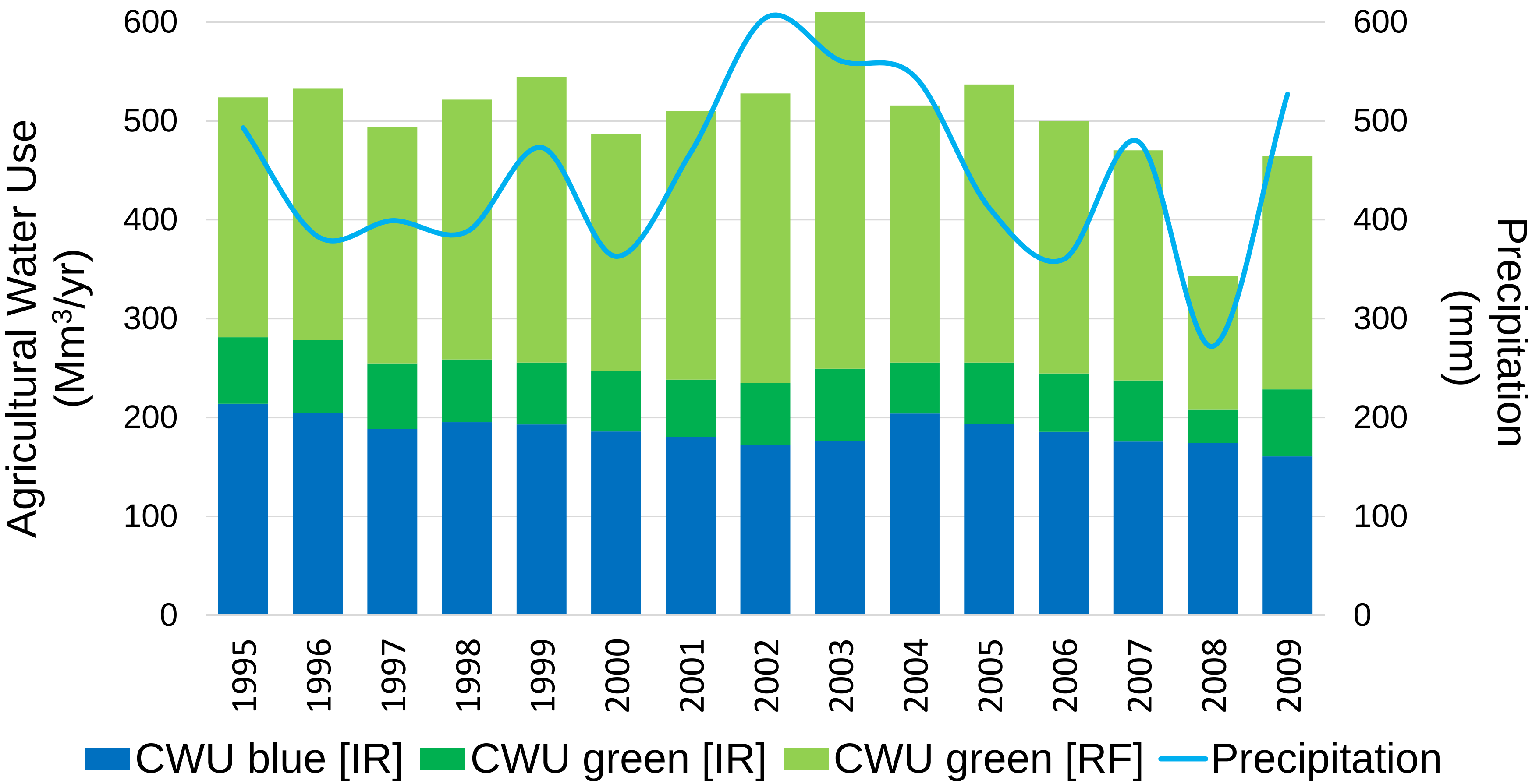
Source: Zoumides et al. (2012), based on Cystat (1997-2010)

Irrigated vs. Rainfed cropland



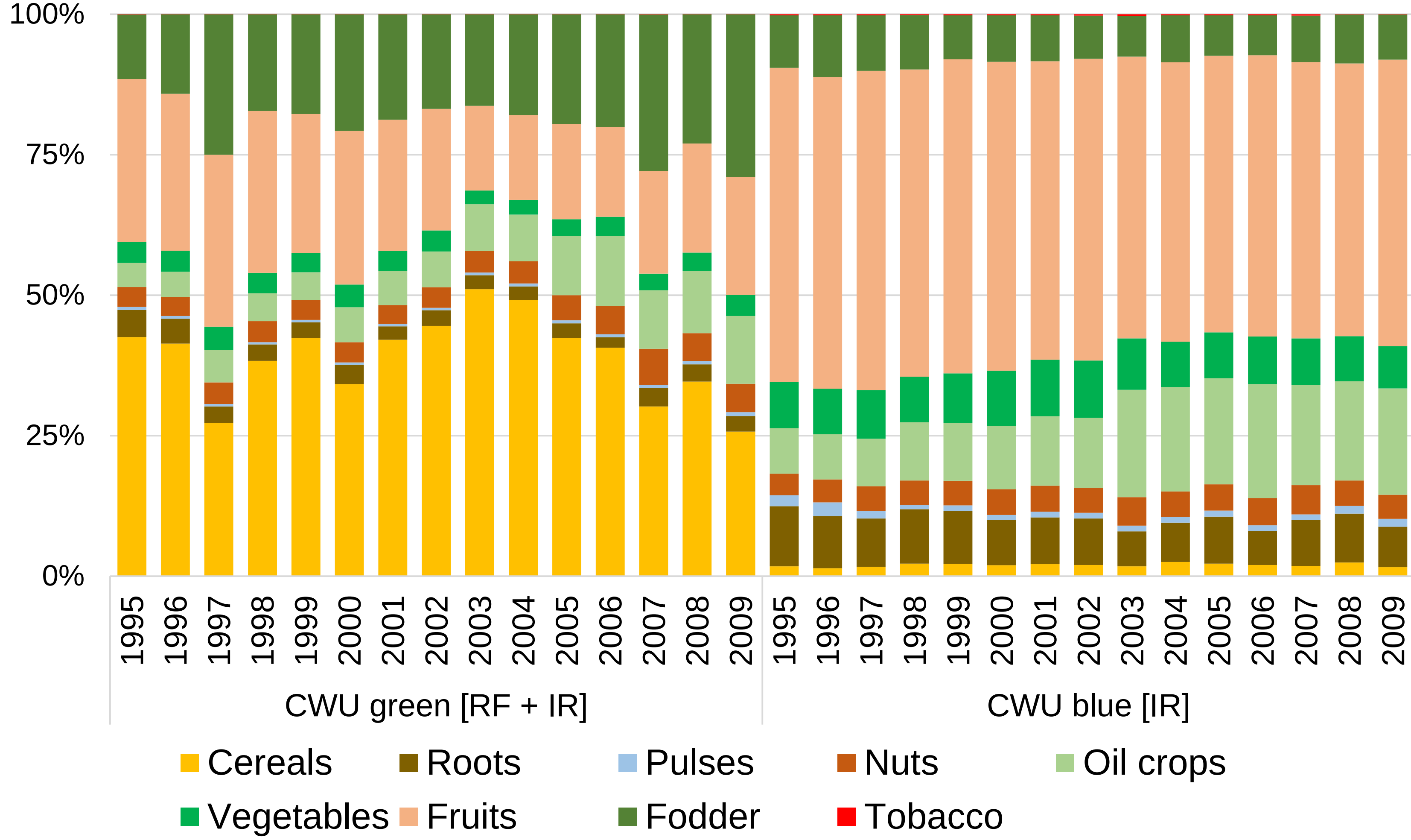
Source: Zoumides et al. (2012), based on Cystat (1997-2010)

Crop Water Use (1995-2009)



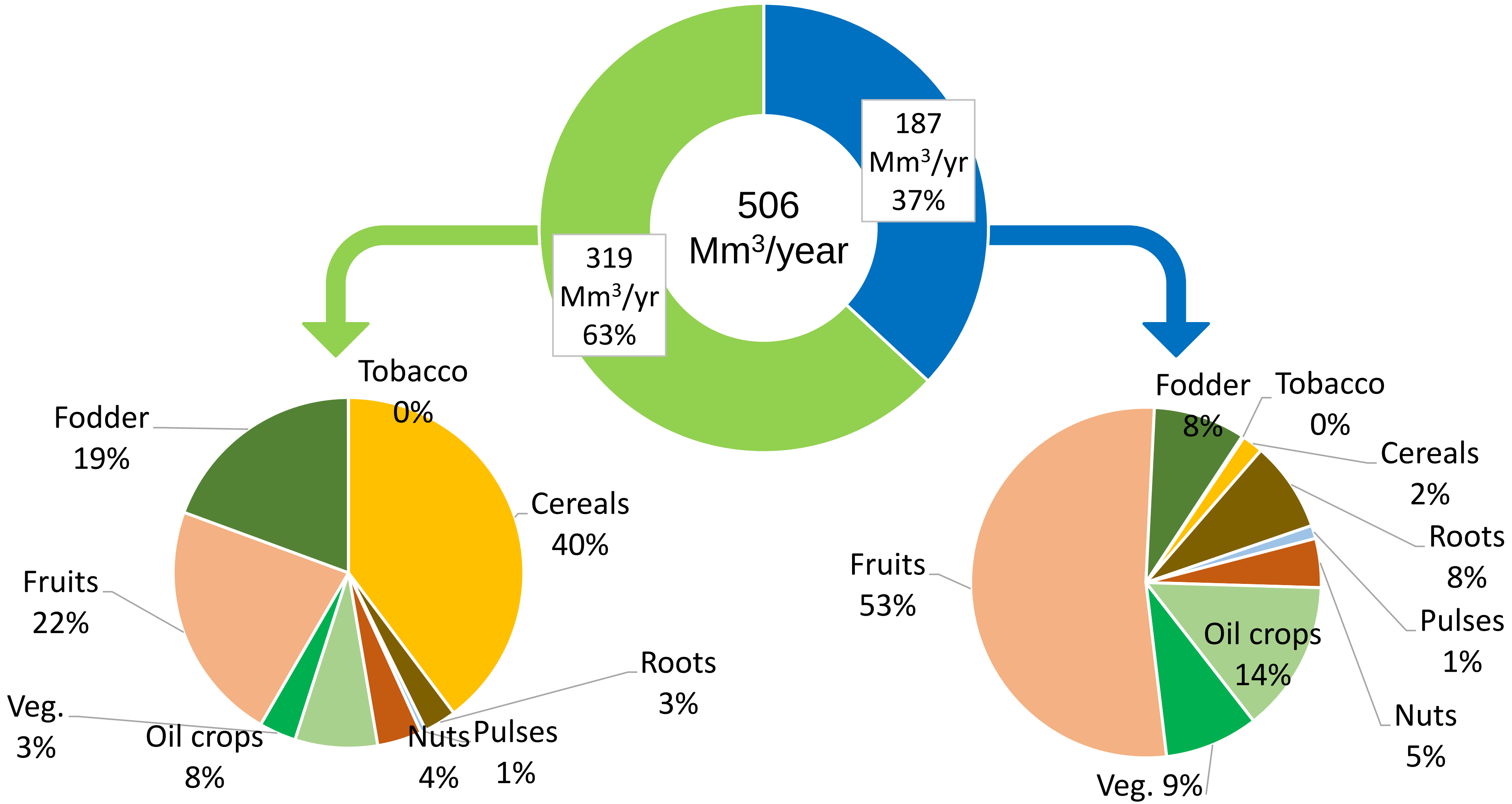
Source: Zoumides et al. (2012; 2013)

Composition of crop water use



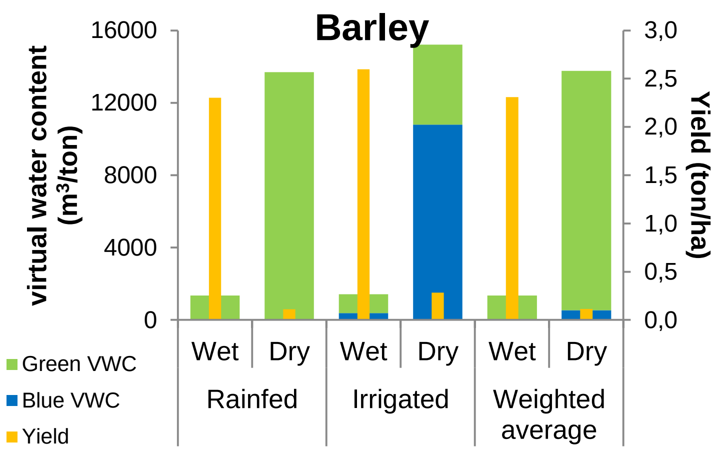
Source: Zoumides et al. (2012)

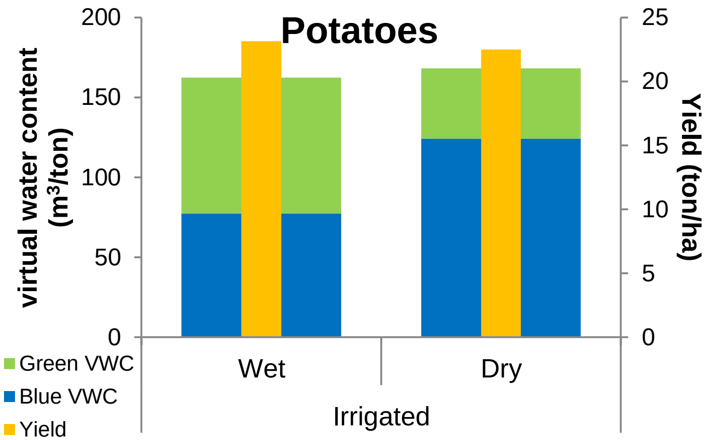
Average crop water use

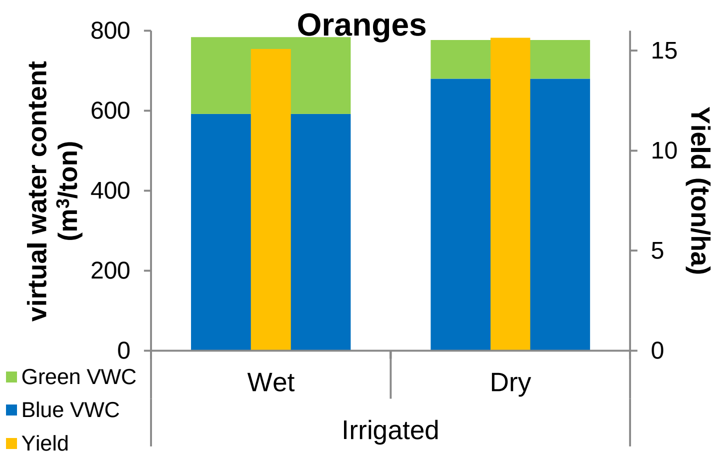


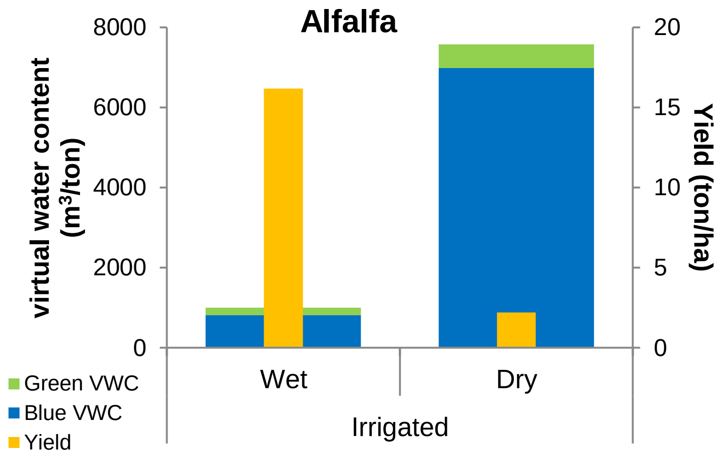
Source: Zoumides et al. (2012)

Effects of climate variability



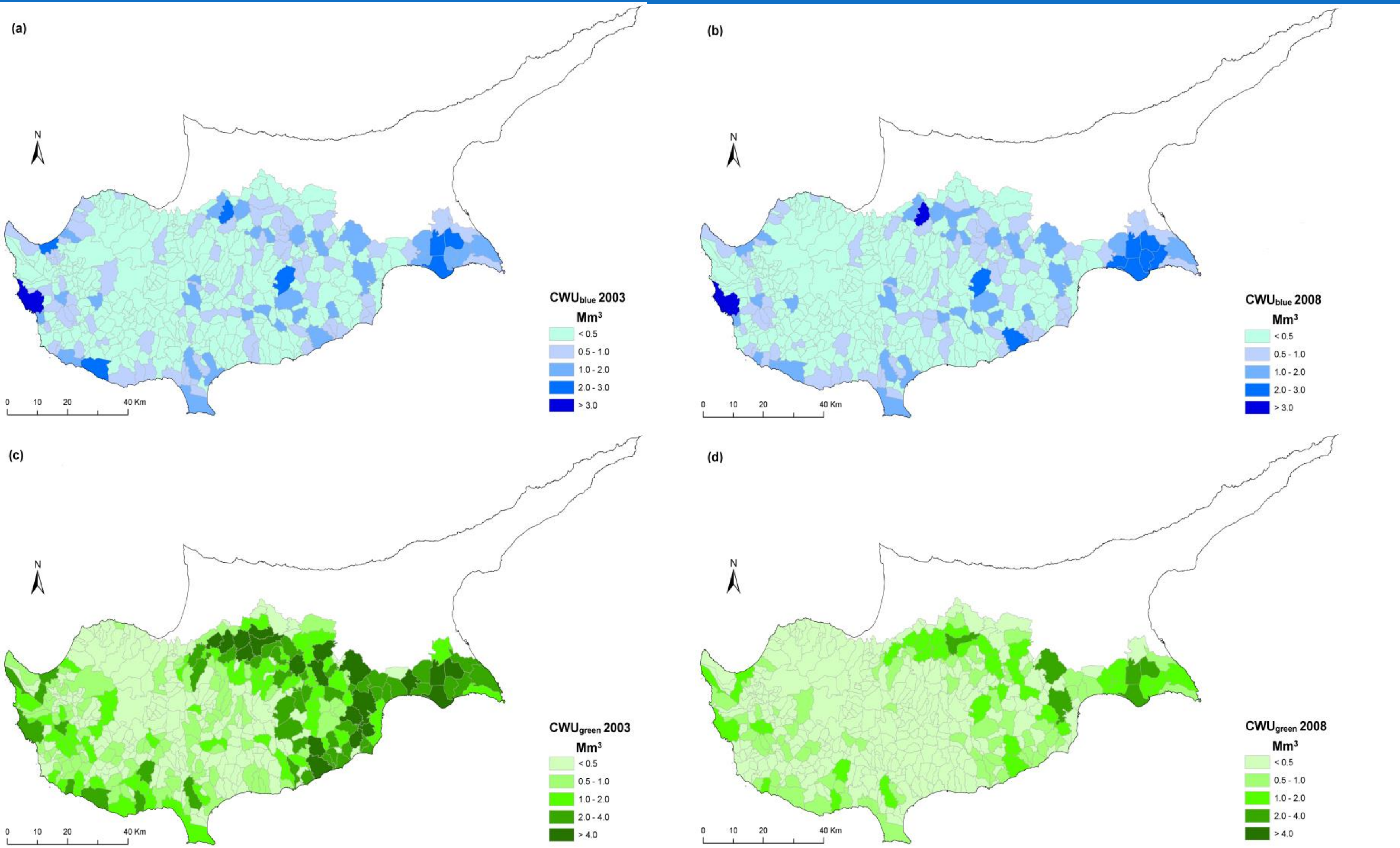






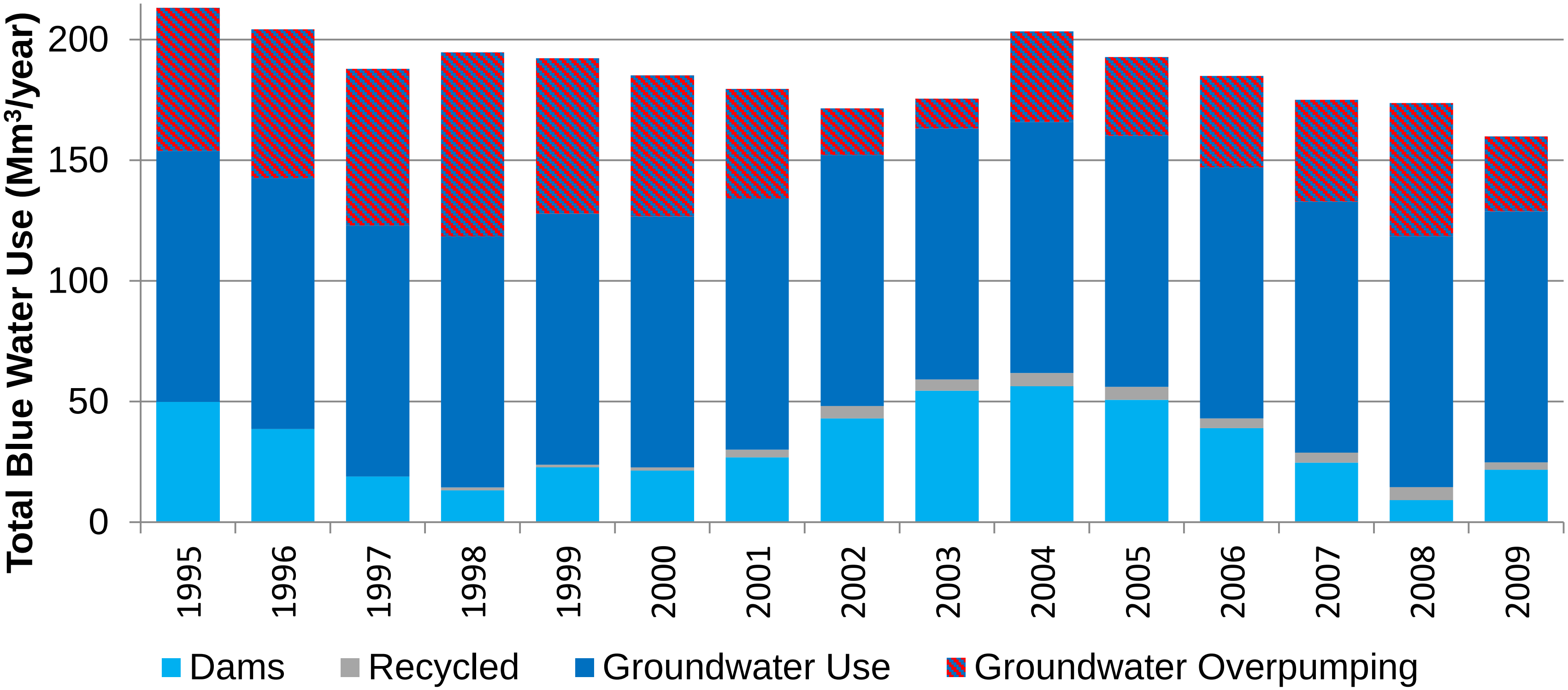
Source: Zoumides et al. (2012)

Spatiotemporal CWU variations



Source: Zoumides et al. (2013)

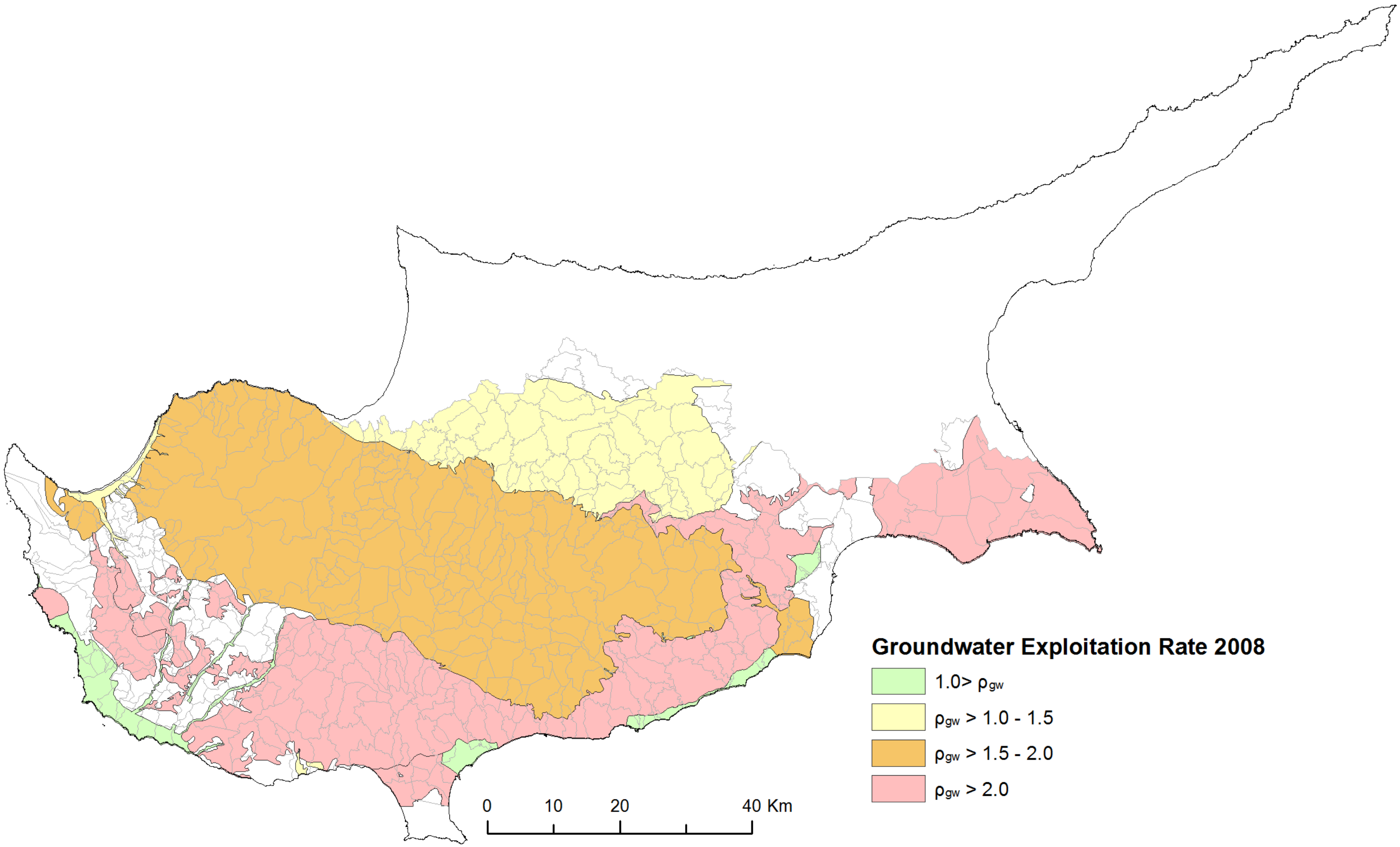
Annual Groundwater Use



- GW contribution to irrigation use
  - Avg: 81% per year (151 Mm^3/year)
  - Max: 91% in 2008 (159 Mm^3/year)
  - Min: 66% in 2003 (116 Mm^3/year)
- On average, groundwater overpumping was **30%** (47 Mm^3/year)

Source: Zoumides et al. (2013)

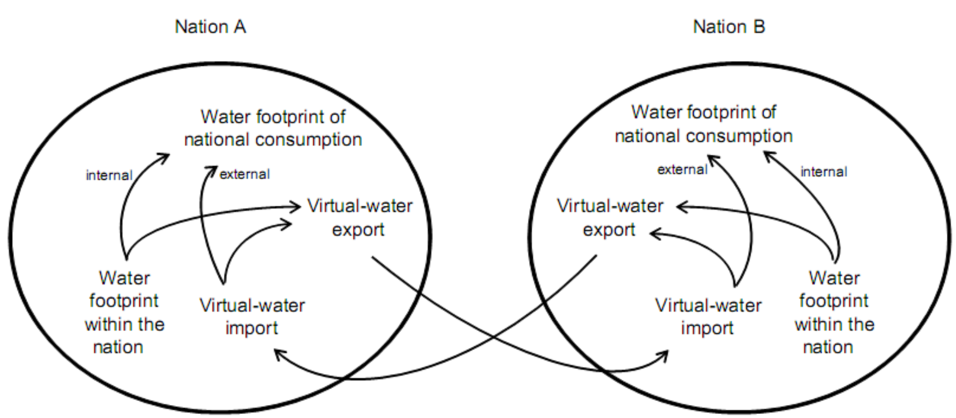
Groundwater Exploitation Rate



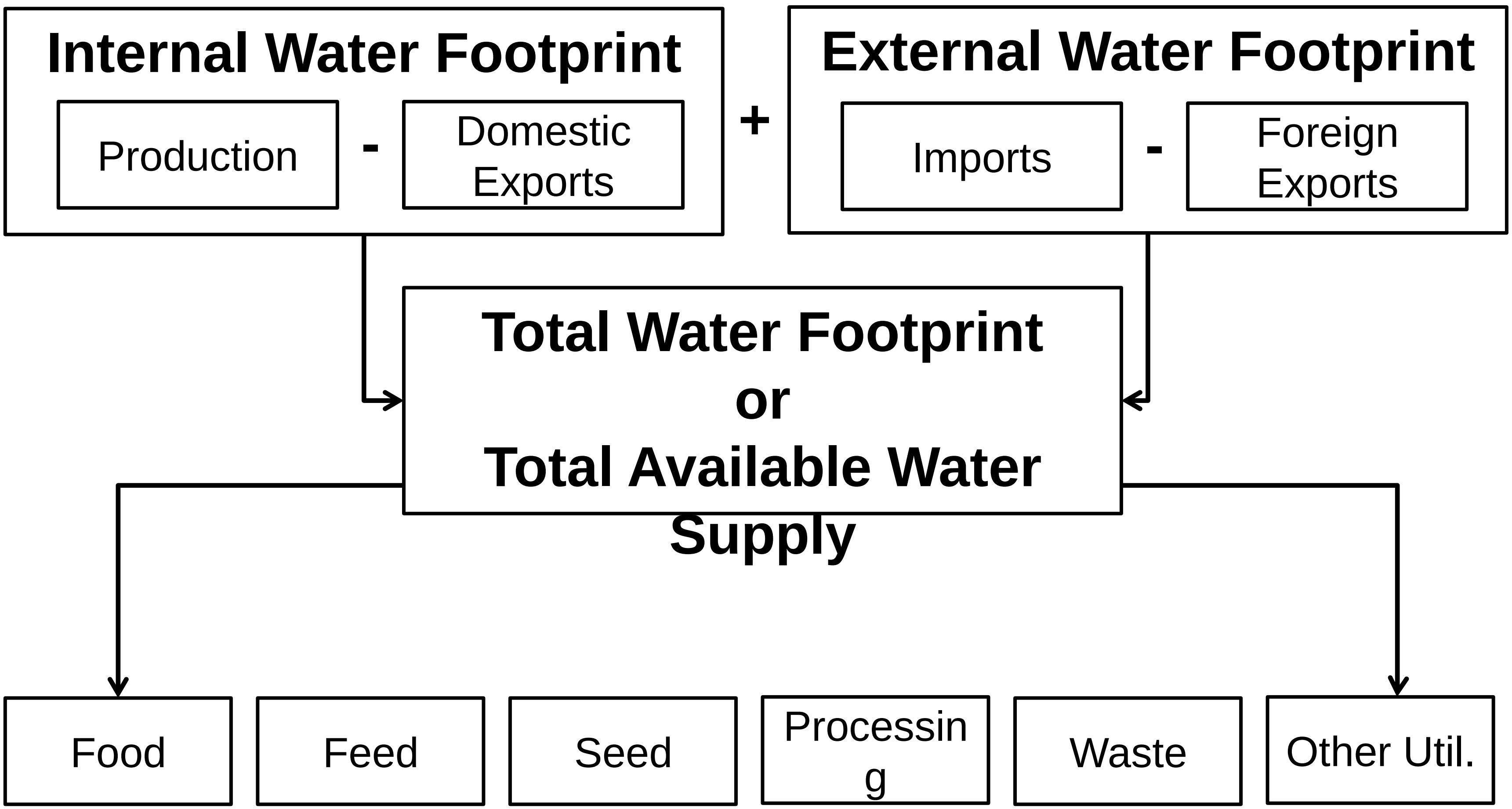
Source: Zoumides et al. (2013)

Water Footprint at National Level

- An indicator of water use (e.g. m^3/year) introduced by Hoekstra in 2002.
- What's new compare to traditional indicators:
  - direct *and* indirect use of water; in the case of crop production, it accounts for the use of irrigation and rain.
  - **when** *and* where; in the case of national WF, it accou foreign water.



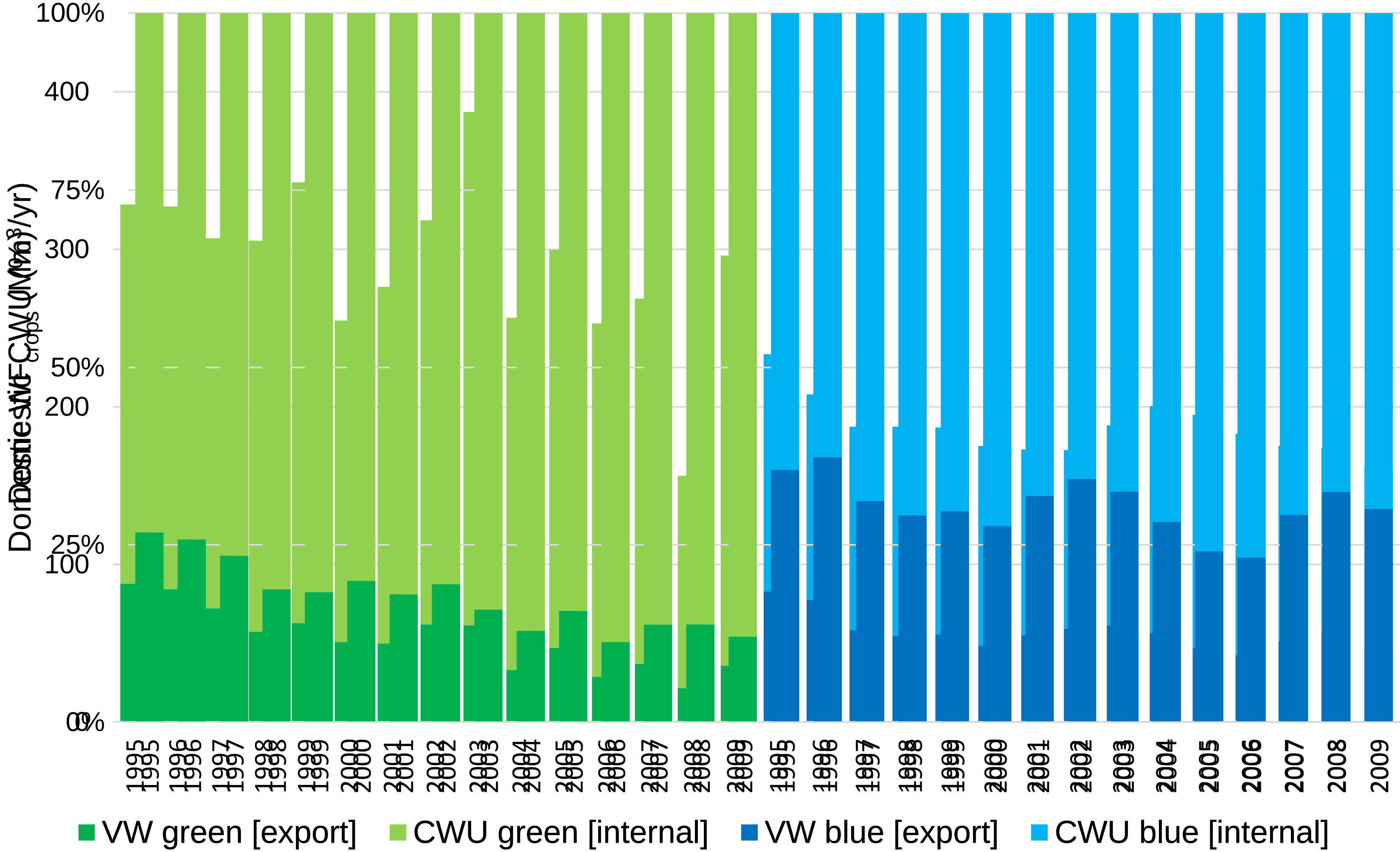
Water, Trade and Supply Utilization



Input Data

- **Trade data**: Combined Nomenclature (8-digit) (Cystat, 1997-2010) →1407 crop products
- **Conversion coefficients per country**: FAO (2003) and Eurostat (2008)
- **External WF**: Mekonnen and Hoekstra (2011)
- **Supply Utilisation Accounts**: FAOSTAT (2013) and Cystat (1997-2010)

Domestic WF: Internal WF & WF$_{export}$



Source: Zoumides et al. (forthcoming)

Green VW exports per crop group

Crop Group	VW green, export (Mm³/year)			% of CWU green, domestic		
	Min	Max	AVG	Min	Max	AVG
Cereals	1.2	6.3	0.5	1%	10%	2%
Starchy Roots	3.8	11.8	9.7	45%	79%	66%
Sugar crops	-	-	-	-	-	-
Pulses	0.0	0.4	0.2	1%	26%	12%
Nuts	0.0	0.3	0.1	0%	2%	1%
Oil crops	0.0	0.1	0.1	0%	1%	1%
Vegetables	2.3	8.6	3.1	35%	74%	51%
Fruits	5.9	21.3	39.1	26%	50%	36%
Fibres	-	-	-	-	-	-
Spices	-	-	-	-	-	-
Fodder crops	0.0	0.3	0.3	0%	1%	0%
Stimulants	-	-	-	-	-	-
Tobacco, rubber, etc.	0.0	0.1	0.2	0%	100%	47%
Vegetable oils	0.0	14.8	1.7	0%	90%	13%
Beverages	3.5	50.5	2.1	17%	97%	63%
Total	**21.5**	**87.9**	**57.0**	**9%**	**28%**	**17%**

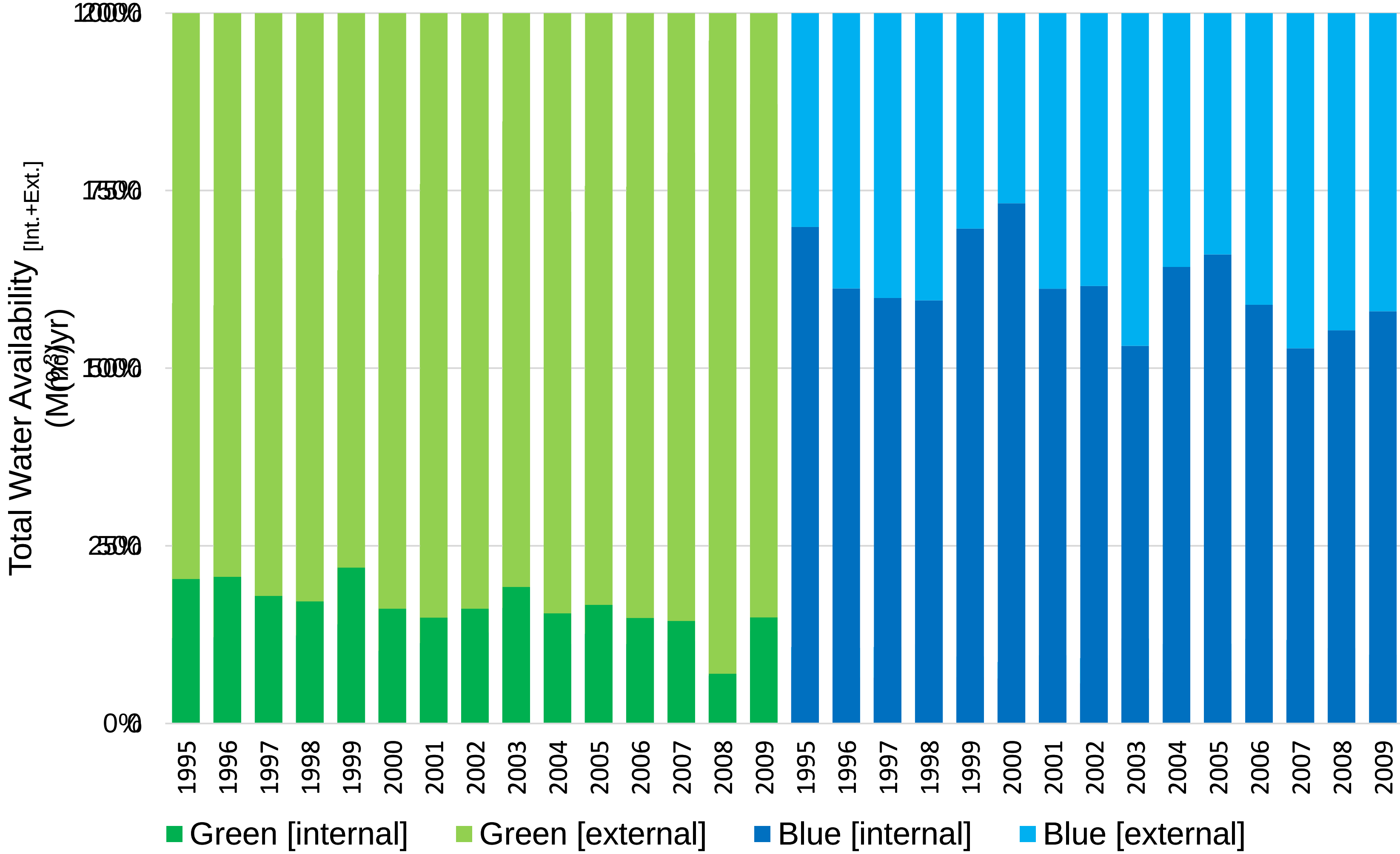
Source: Zoumides et al. (forthcoming)

Blue VW exports per crop group

Crop Group	VW blue, export (Mm^3/year)			% of CWU blue, domestic		
	Min	Max	AVG	Min	Max	AVG
Cereals	0.1	1.5	0.5	3%	36%	12%
Starchy Roots	6.4	17.4	9.7	43%	76%	62%
Sugar crops	-	-	-	-	-	-
Pulses	0.1	0.3	0.2	2%	17%	7%
Nuts	0.0	0.5	0.1	0%	6%	2%
Oil crops	0.0	0.1	0.1	0%	2%	1%
Vegetables	1.9	5.3	3.1	13%	35%	20%
Fruits	28.2	57.1	39.1	32%	53%	43%
Fibres	-	-	-	-	-	-
Spices	-	-	-	-	-	-
Fodder crops	0.0	1.4	0.3	0%	8%	2%
Stimulants	-	-	-	-	-	-
Tobacco, rubber, etc.	0.0	0.4	0.2	0%	100%	47%
Vegetable oils	0.0	12.8	1.7	0%	91%	12%
Beverages	0.4	4.4	2.1	6%	43%	27%
Total	**42.4**	**83.0**	**57.0**	**23%**	**39%**	**31%**

Source: Zoumides et al. (forthcoming)

Total Water Availability: Int. vs. Ext.



Source: Zoumides et al. (forthcoming)

Green Water Import Dependency

Crop Group	Internal (Mm³/year)			External (Mm³/year)			Green Water Import Dependency (%)		
	Min	Max	AVG	Min	Max	AVG	Min	Max	AVG
Cereals	37.8	148.3	97.7	320.6	713.7	516.7	77%	95%	84%
Starchy Roots	1.2	5.1	3.2	0.8	2.3	1.5	21%	66%	32%
Sugar crops	-	-	-	6.2	18.9	15.1	100%	100%	100%
Pulses	1.1	2.5	1.6	3.6	7.4	4.7	64%	82%	75%
Nuts	8.2	18.6	13.0	9.9	24.2	17.6	43%	75%	57%
Oil crops	3.6	25.8	10.3	29.0	105.0	51.2	55%	96%	83%
Vegetables	3.1	8.3	5.2	1.3	4.1	2.8	16%	57%	35%
Fruits	12.7	32.7	21.8	5.9	21.4	13.2	21%	62%	38%
Fibres	-	-	-	0.5	3.3	2.1	100%	100%	100%
Spices	-	-	-	1.0	2.6	1.7	100%	100%	100%
Fodder crops	35.0	87.5	61.5	138.4	640.3	372.1	67%	94%	86%
Stimulants	-	-	-	63.7	170.3	100.2	100%	100%	100%
Tobacco, rubber, etc.	0.0	0.1	0.0	2.6	14.8	5.9	99%	100%	100%
Vegetable oils	5.8	16.8	11.0	72.8	246.2	131.4	88%	96%	92%
Beverages	5.1	27.3	13.8	2.0	8.5	4.1	12%	41%	23%
Total	**134.7**	**325.8**	**239.1**	**934.5**	**1787.9**	**1240.4**	**78%**	**93%**	**84%**

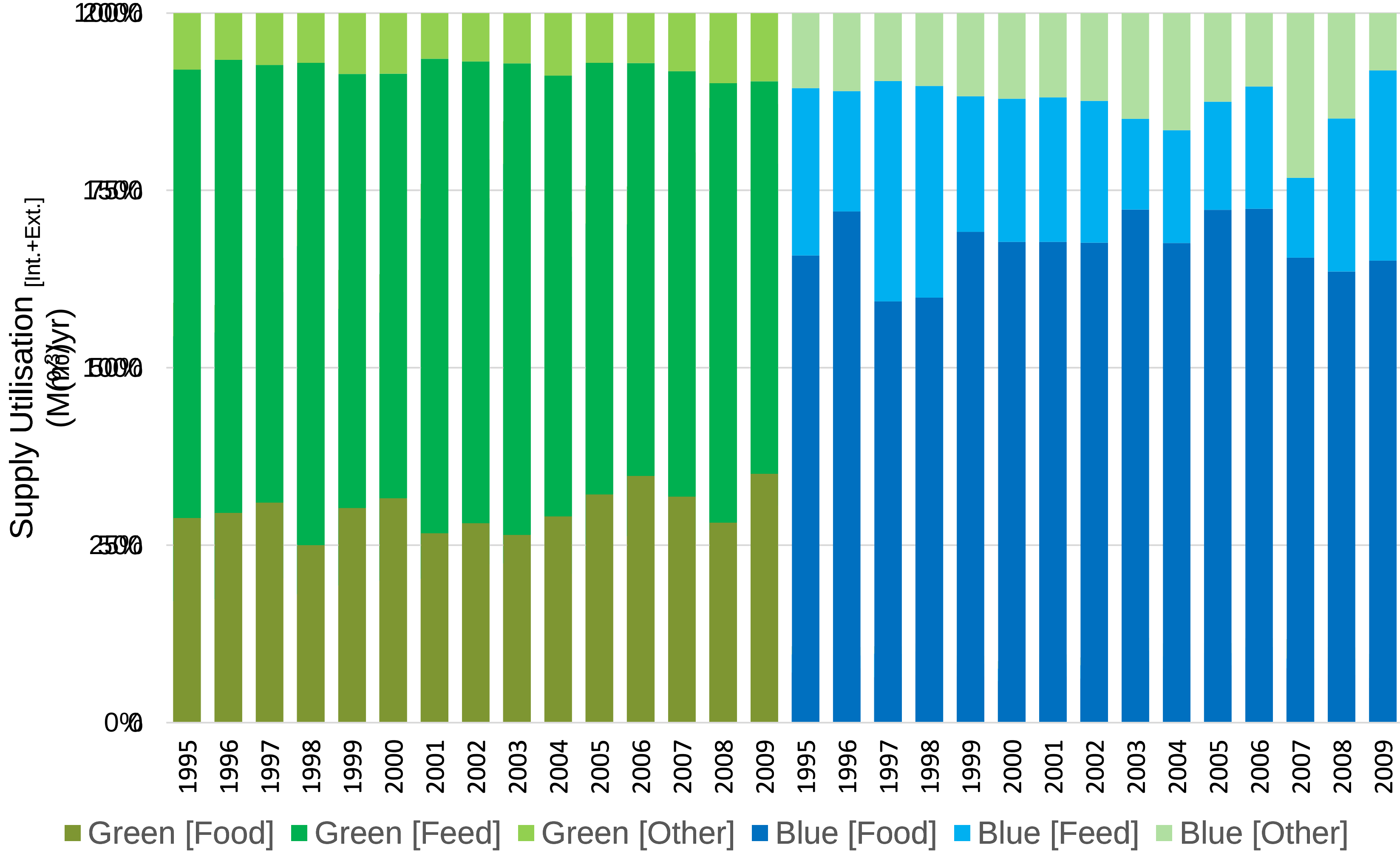
Source: Zoumides et al. (forthcoming)

Blue Water Import Dependency

Crop Group	Internal (Mm^3/year)			External (Mm^3/year)			Blue Water Import Dependency (%)		
	Min	Max	AVG	Min	Max	AVG	Min	Max	AVG
Cereals	1.6	3.8	2.5	11.9	33.0	21.0	83%	95%	89%
Starchy Roots	3.9	9.3	5.9	0.0	0.2	0.1	1%	5%	2%
Sugar crops	-	-	-	0.6	4.1	2.2	100%	100%	100%
Pulses	1.2	4.8	2.1	0.7	2.1	1.2	15%	53%	36%
Nuts	6.5	9.0	8.3	2.9	11.1	6.6	25%	55%	44%
Oil crops	5.4	25.2	12.0	0.8	16.8	3.0	4%	74%	20%
Vegetables	7.6	14.6	12.3	0.3	1.3	0.8	2%	12%	6%
Fruits	43.9	62.6	52.3	1.1	8.8	3.7	2%	17%	7%
Fibres	-	-	-	0.3	2.9	1.1	100%	100%	100%
Spices	-	-	-	0.7	1.5	1.0	100%	100%	100%
Fodder crops	12.2	21.1	15.5	1.5	22.7	9.0	6%	58%	37%
Stimulants	-	-	-	0.5	1.3	0.8	100%	100%	100%
Tobacco, rubber, etc.	0.0	0.4	0.2	0.1	0.8	0.3	30%	100%	66%
Vegetable oils	6.8	16.9	11.1	4.1	67.5	30.8	32%	86%	74%
Beverages	2.6	28.2	7.5	0.0	0.6	0.2	0%	17%	2%
Total	**112.2**	**150.5**	**129.7**	**46.3**	**111.9**	**81.7**	**27%**	**47%**	**39%**

Source: Zoumides et al. (forthcoming)

Supply Utilisation



Source: Zoumides et al. (forthcoming)

Green Water Supply Utilisation

Crop Group	Food (% Total Available)			Feed (% Total Available)			Other (% Total Available)		
	Min	Max	AVG	Min	Max	AVG	Min	Max	AVG
Cereals	11%	28%	18%	61%	84%	75%	5%	11%	7%
Starchy Roots	39%	65%	54%	7%	11%	9%	28%	52%	37%
Sugar crops	85%	96%	93%	0%	12%	3%	3%	6%	4%
Pulses	79%	96%	91%	0%	1%	1%	4%	20%	8%
Nuts	100%	100%	100%	-	-	-	-	-	-
Oil crops	18%	91%	55%	0%	79%	37%	2%	16%	8%
Vegetables	83%	86%	85%	0%	5%	2%	11%	16%	13%
Fruits	71%	93%	87%	-	-	-	7%	29%	13%
Fibres	-	-	-	-	-	-	100%	100%	100%
Spices	100%	100%	100%	-	-	-	-	-	-
Fodder crops	-	-	-	100%	100%	100%	-	-	-
Stimulants	100%	100%	100%	-	-	-	-	-	-
Tobacco, rubber, etc.	-	-	-	-	-	-	100%	100%	100%
Vegetable oils	48%	76%	62%	-	-	-	24%	52%	38%
Beverages	94%	100%	98%	-	-	-	0%	6%	2%
Total	25%	35%	30%	55%	68%	62%	6%	10%	8%

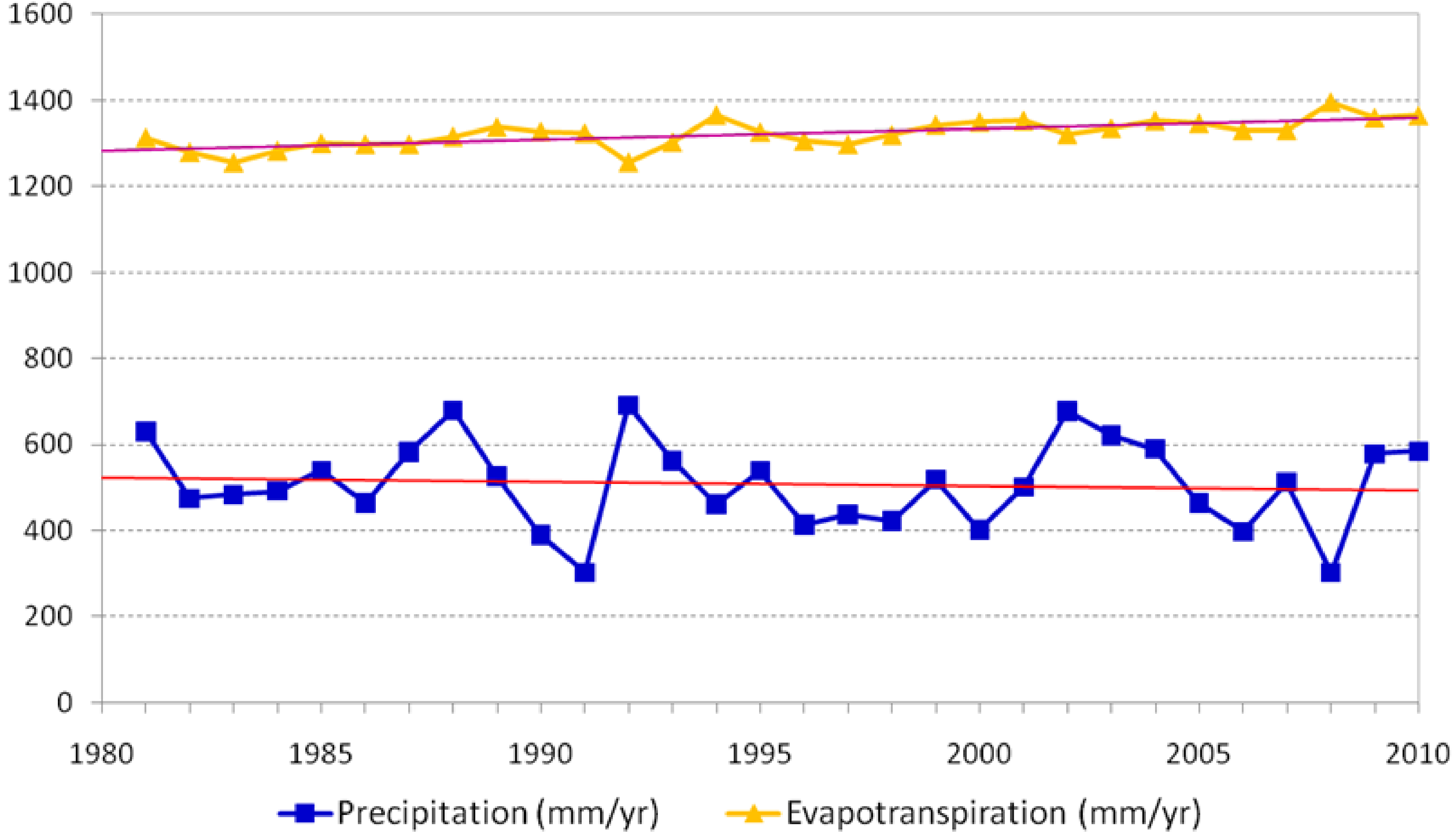
Source: Zoumides et al. (forthcoming)

Blue Water Supply Utilisation

Crop Group	Food (% Total Available)			Feed (% Total Available)			Other (% Total Available)		
	Min	Max	AVG	Min	Max	AVG	Min	Max	AVG
Cereals	19%	54%	32%	37%	76%	62%	4%	9%	5%
Starchy Roots	45%	66%	56%	8%	11%	9%	26%	45%	35%
Sugar crops	61%	96%	85%	0%	37%	11%	2%	6%	4%
Pulses	90%	95%	93%	0%	1%	0%	5%	9%	6%
Nuts	100%	100%	100%	-	-	-	-	-	-
Oil crops	25%	92%	77%	0%	72%	13%	4%	18%	9%
Vegetables	84%	87%	86%	0%	4%	1%	10%	15%	12%
Fruits	84%	91%	87%	-	-	-	9%	16%	13%
Fibres	-	-	-	-	-	-	100%	100%	100%
Spices	100%	100%	100%	-	-	-	-	-	-
Fodder crops	-	-	-	100%	100%	100%	-	-	-
Stimulants	100%	100%	100%	-	-	-	-	-	-
Tobacco, rubber, etc.	0%	0%	0%	-	-	-	100%	100%	100%
Vegetable oils	52%	87%	73%	-	-	-	13%	48%	27%
Beverages	99%	100%	100%	-	-	-	0%	1%	0%
Total	59%	72%	67%	11%	31%	20%	8%	23%	13%

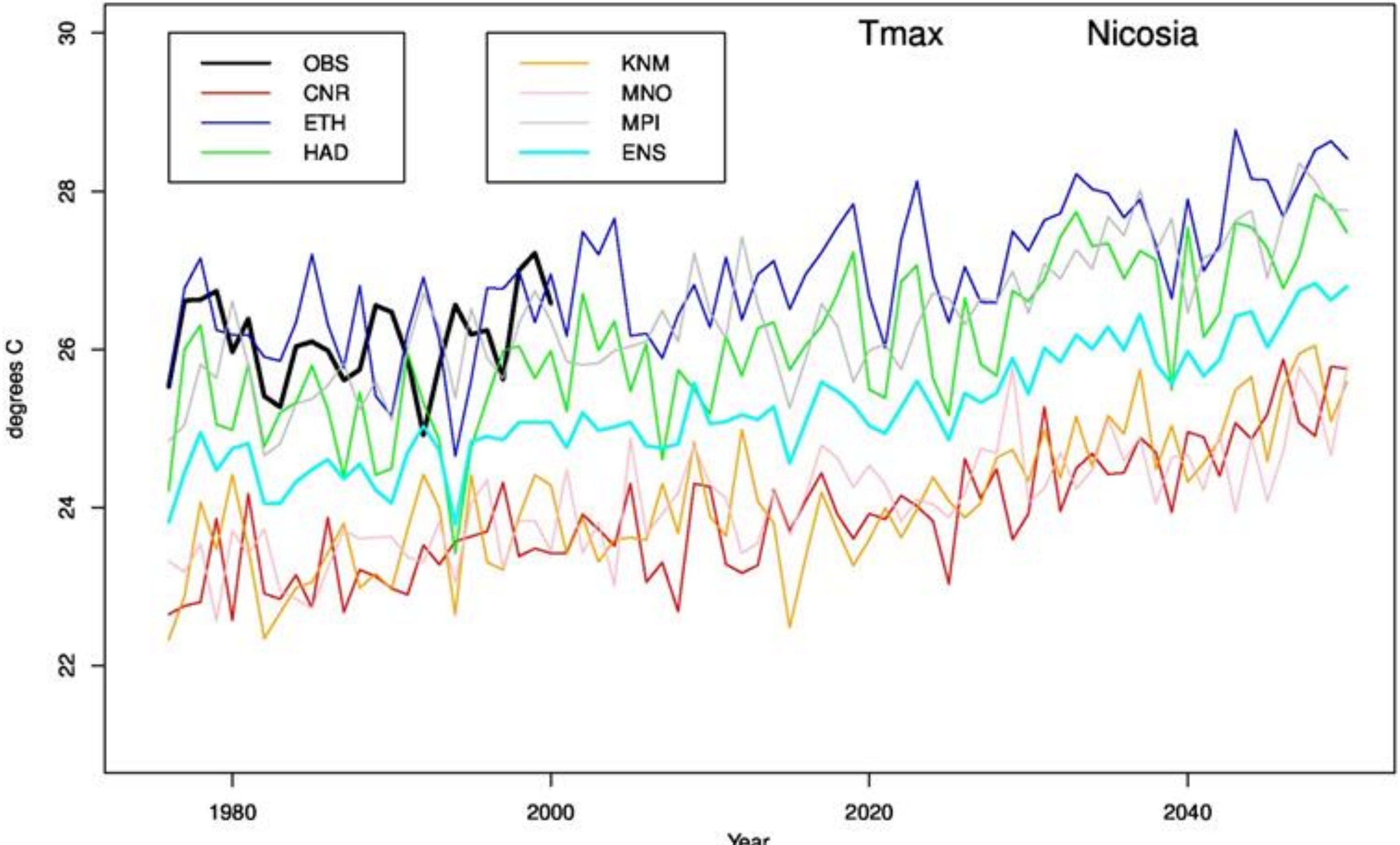
Source: Zoumides et al. (forthcoming)

Precipitation and Evapotranspiration: Observed trends (1980-2010)



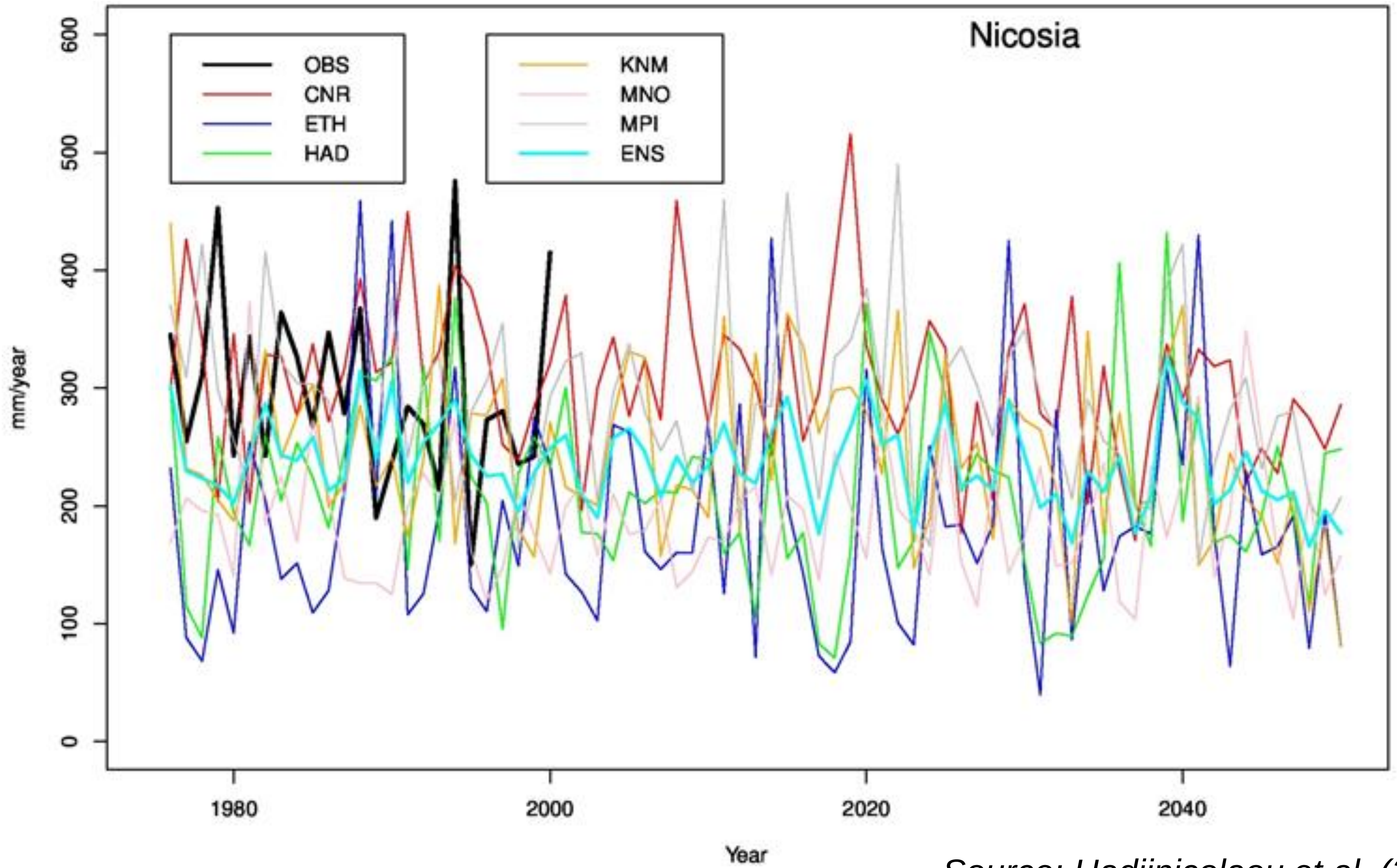
Source: Bruggeman et al. (2011)

Regional climate models: Temperature projections (1976-2050)



Source: Hadjinicolaou et al. (2011)

Regional climate models: Precipitation projections(1976-2050)



Source: Hadjinicolaou et al. (2011)

WF & climate change adaptation

- *“Water footprint is highly valuable as an awareness-raising, educational and advocacy tool that leads to better understanding of water impacts and can demonstrate the case for better water management.*
- *As part of a framework of climate impact assessment it can help […] to assess the ability of hydrological systems to meet the demands being placed upon them.*
- *Water footprint assessments should be recognized as the basis upon which water adaptation policies can be formulated:*
  - *changing crop varieties;*
  - *providing incentives for production and consumption with lower water demands;*
  - *developing robust IWRM plans that manage the competing demands on water resources within environmental constraints.*
- *All countries should conduct sectoral water footprints studies”*

Global Public Policy Network on Water Management (2009:11)

Conclusions / Recommendations

- On average, crop production relies on 63% green & 37% blue water
- Highly variable precipitation
  - significant impact on crop water use and yield
  - determines the availability of blue water (surface) resources
  - with the existing crop matrix → groundwater overpumping
- Virtual Water Trade
  - net losses on blue water → fruit and potato exports
  - net gains on green water → mainly for feed → high meat and dairy consumption
- Climate change adaptation requires identifying and adjusting production (and consumption) patterns based on available water resources
  - Policy options for crop production systems under climate change
    - @ National Level → **AGWATER** (2012-2014)
    - @ EU level → COST Action ES1106 **EURO-AGRIWAT** (2012-2016)

Reference

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Thank You

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