Ενεργειακές, Οικονομικές και Περιβαλλοντικές Αναλύσεις για την Αειφόρο Ανάπτυξη στην Ευρώπη και την Κύπρο (Βραβείο Έρευνας «Νίκος Συμεωνίδης» 2009)

Αρ. Πρωτοκόλλου: ΚΟΥΛΤΟΥΡΑ/ΒΕΝΣ/0609/02

Ανάπτυξη καινοτόμων αγρο-οικονομικών μεθόδων για τη διαχείριση των υδατικών πόρων της Κύπρου

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  - Department of Agriculture
  - Agricultural Payment Organization
  - Statistical Service
  - Geological Survey Department

Presentation Contents

- Agricultural Water Use in Cyprus (1995-2009)
  - Results from a spatio-temporal soil water balance model
  - Quantification of groundwater per year
- The Water Footprint of Crop Production and Supply Utilization of Cyprus
- Optimization model for sustainable (economic and environmental) use of land and water resources
- Conclusions – 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.

Objectives

- Estimate the year-to-year Agricultural Water Use in Cyprus for the period 1995-2009:
  - temporal and spatial variations;
  - type of crop water use (green vs. blue);
  - distinguish the source of blue crop water use (surface, groundwater & recycled)
    - estimate groundwater use and over-pumping per year

Methodology

- The spatiotemporally explicit model developed by Bruggeman et al. (2011), was used to compute the daily soil water balances and water uses of all crops grown in all communities in Cyprus
  - adjusted for the period 1995-2009 (Zoumides et al. 2012a)
- 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. (2012a)

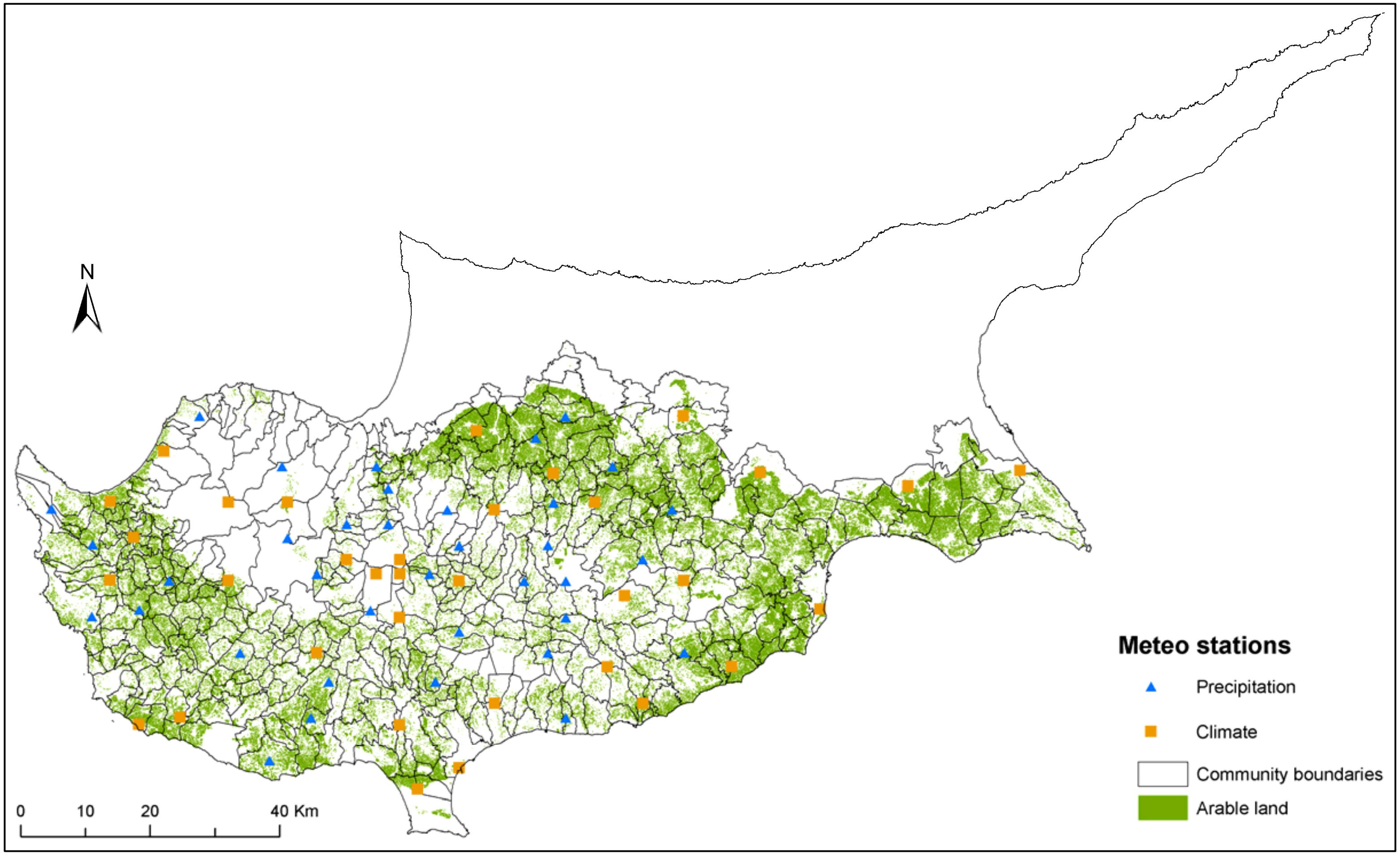
Model Input Data

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

What's New?

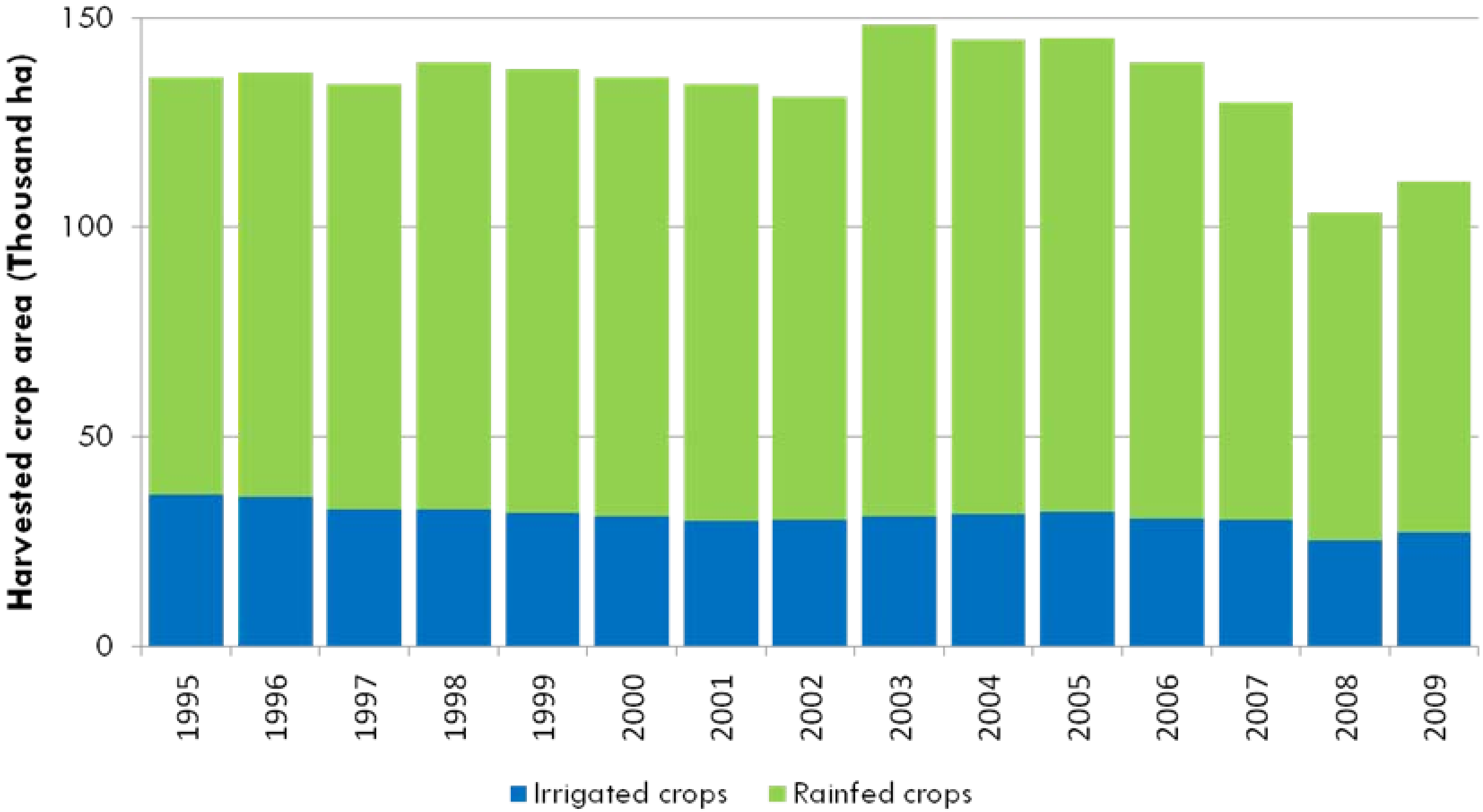
	WDD-FAO (2002)	WDD-Karavokyris & Associates (2011)	Zoumides et al. (2012a)
Period	2000	2011	1995-2009
Crop Areas	Crops-Growers Data Bank (only for irrigated crops)	CAPO (2008)	Cystat (1997-2010)
Spatial Resolution	Community level	Community level	Community level (adj. Census 2003), annual totals
No. Crops	10 categories	40 crops	83 crop systems
Soil Properties	No	No	Yes
Irrig. Eff. / Irrig. Fract.	Yes (irr. method) / No	Yes (irr. method) / No	Yes (irr. method) / Yes (on crop area)
Crop Water Req.	Dpt. Agriculture (Class A Pan ET)	Dept. Agri. & ARI	Daily soil water balance model
Blue/Green CWU	Yes/No	Yes/No	Yes/Yes

Climate variables



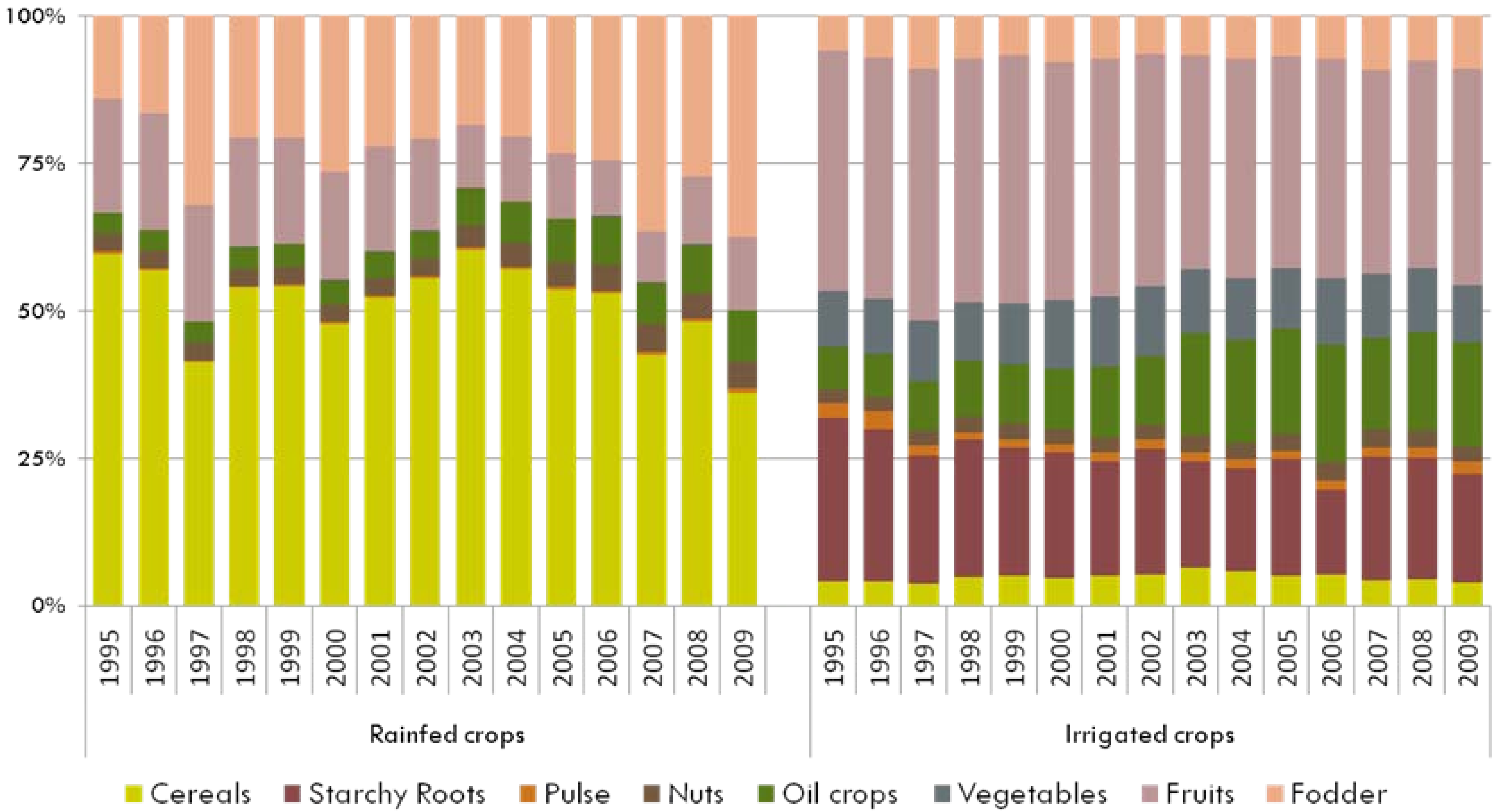
Source: Bruggeman et al. (2011); Zoumides et al. (2012a)

Irrigated vs. Rainfed cropland



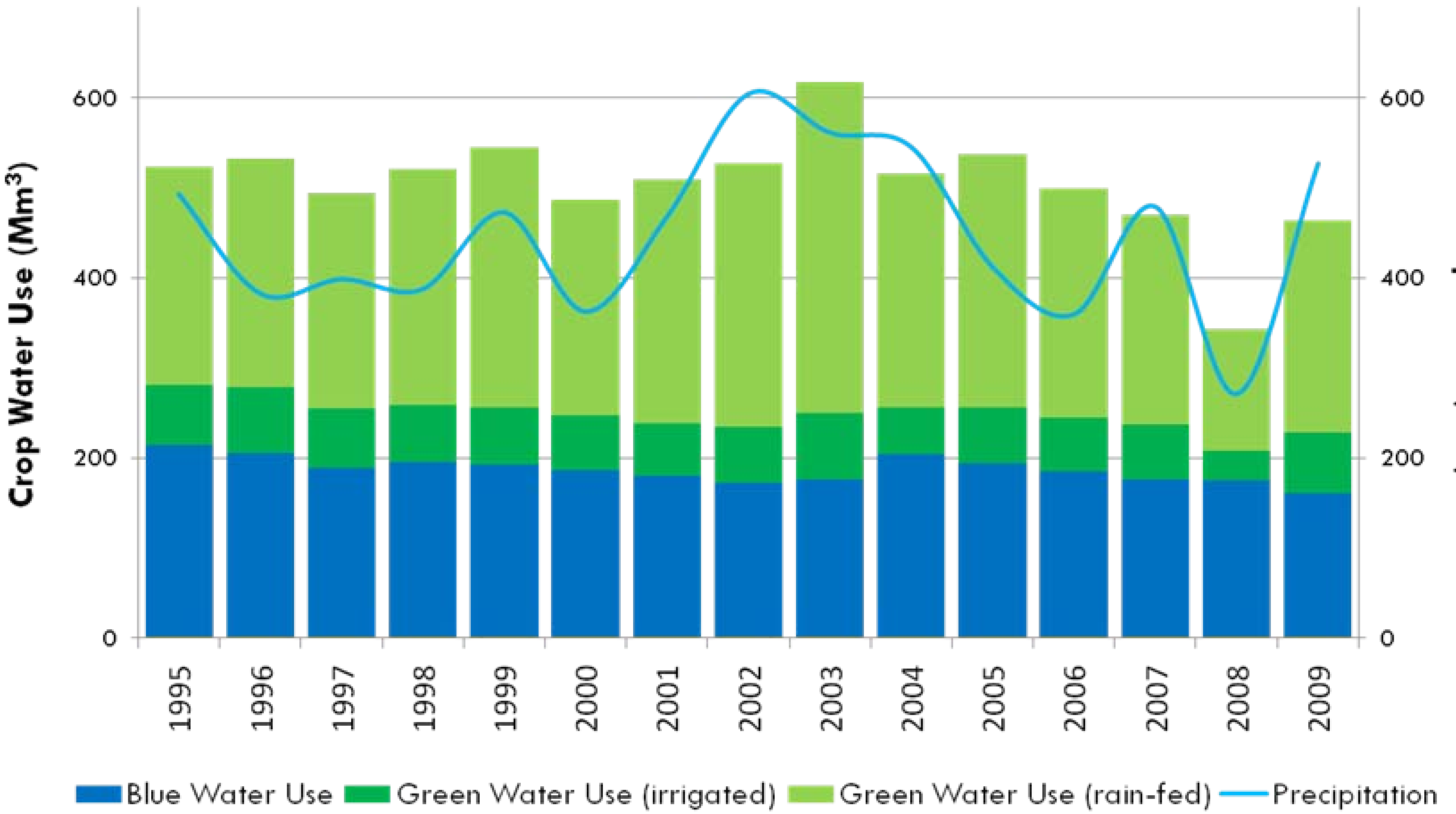
Source: Zoumides et al. (2012a), based on Cystat (1997-2010)

Land use composition



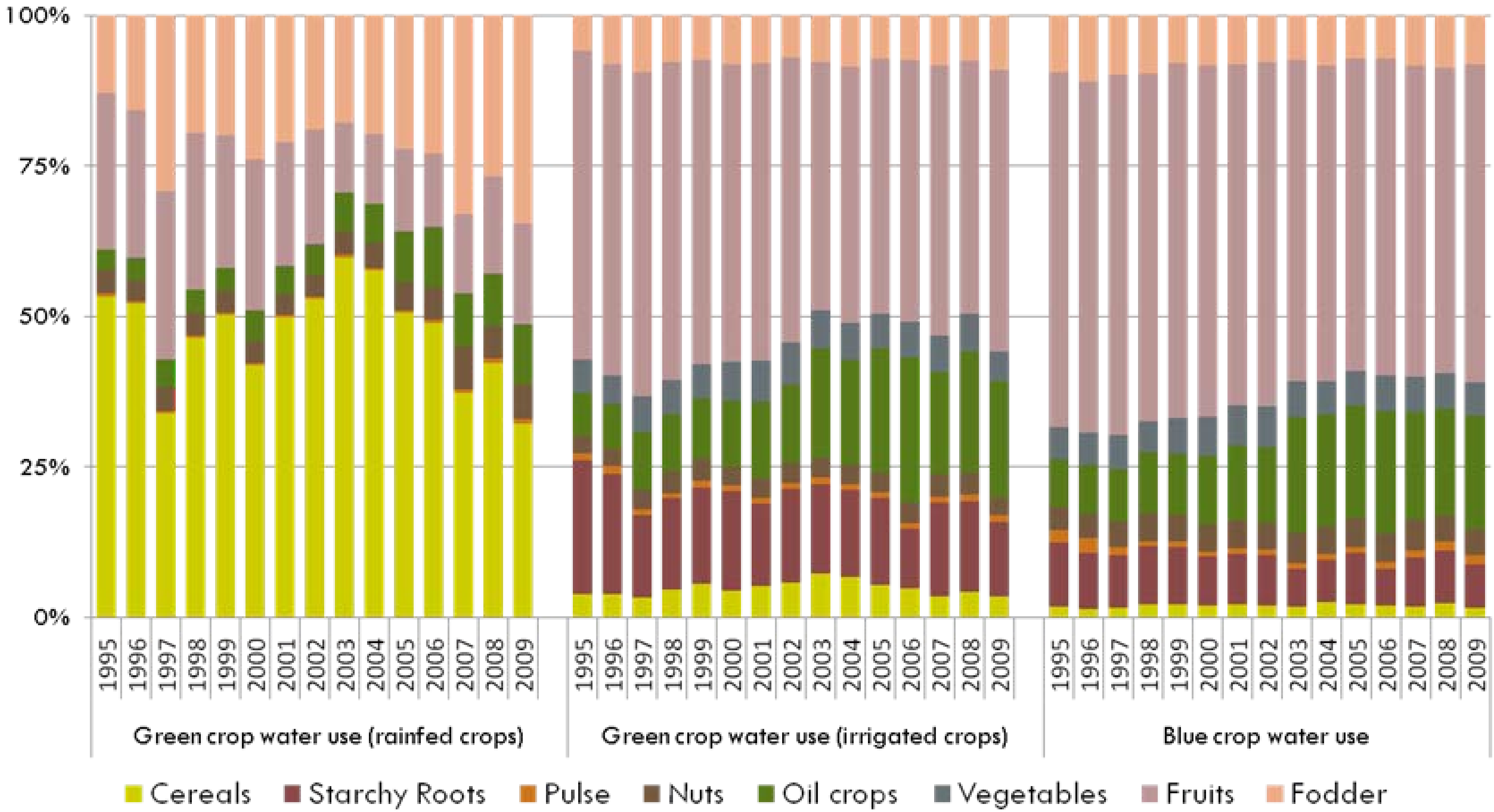
Source: Zoumides et al. (2012a), based on Cystat (1997-2010)

Agricultural Water Use



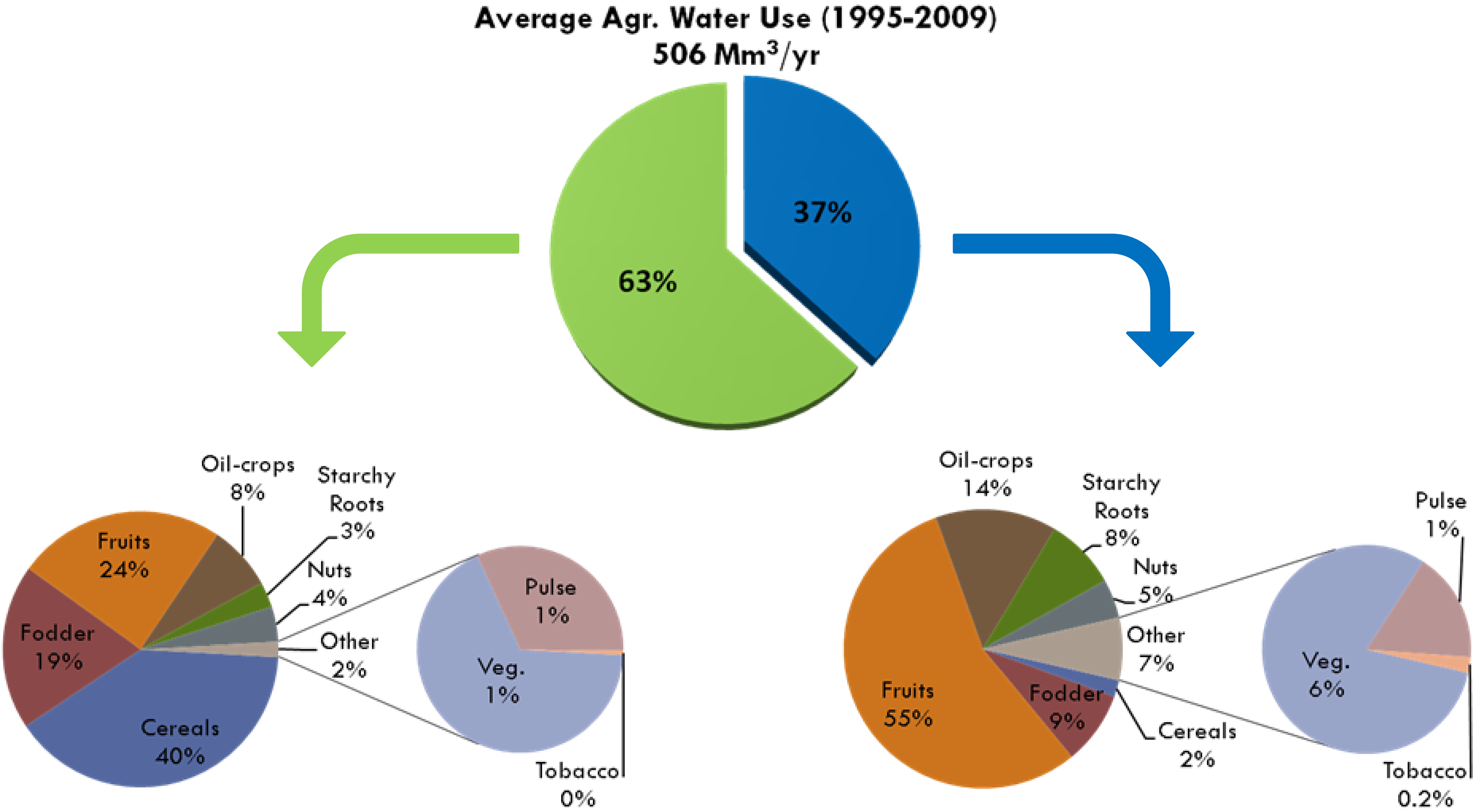
Source: Zoumides et al. (2012)

Composition of Agri. Water Use



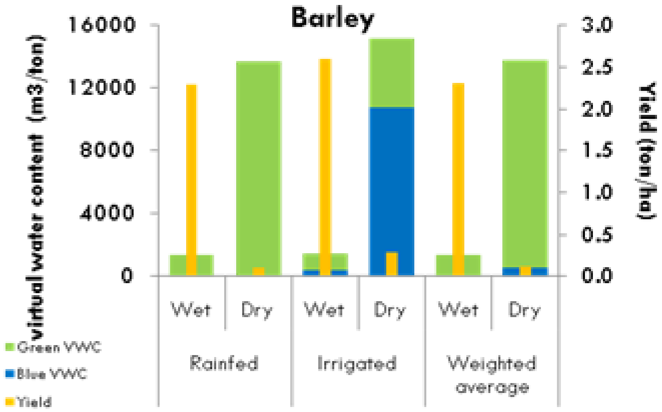
Source: Zoumides et al. (2012a)

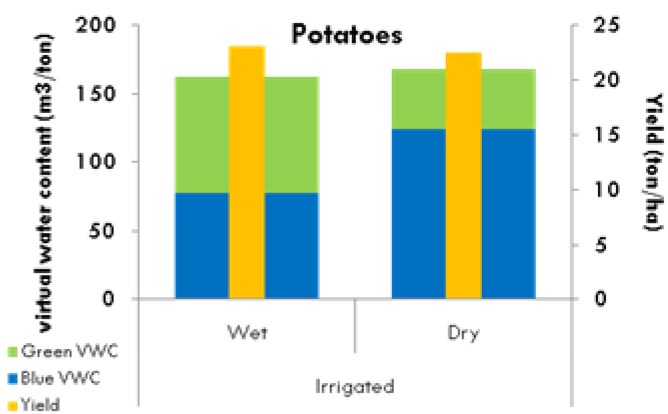
Agr. Water Use Composition

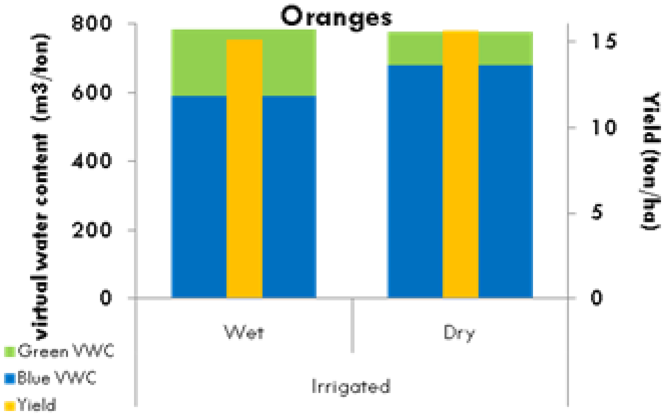


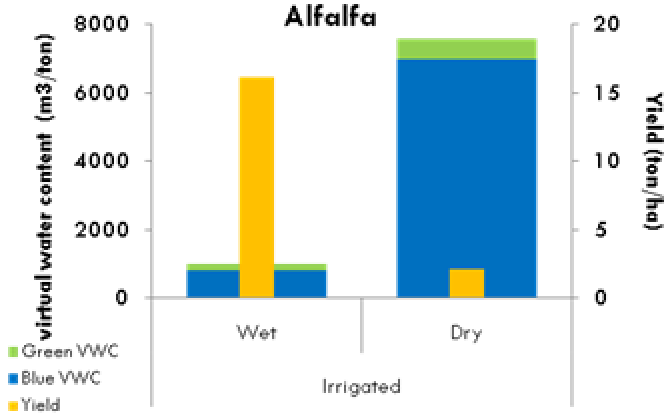
Source: Zoumides et al. (2012a)

Effects of climate variability



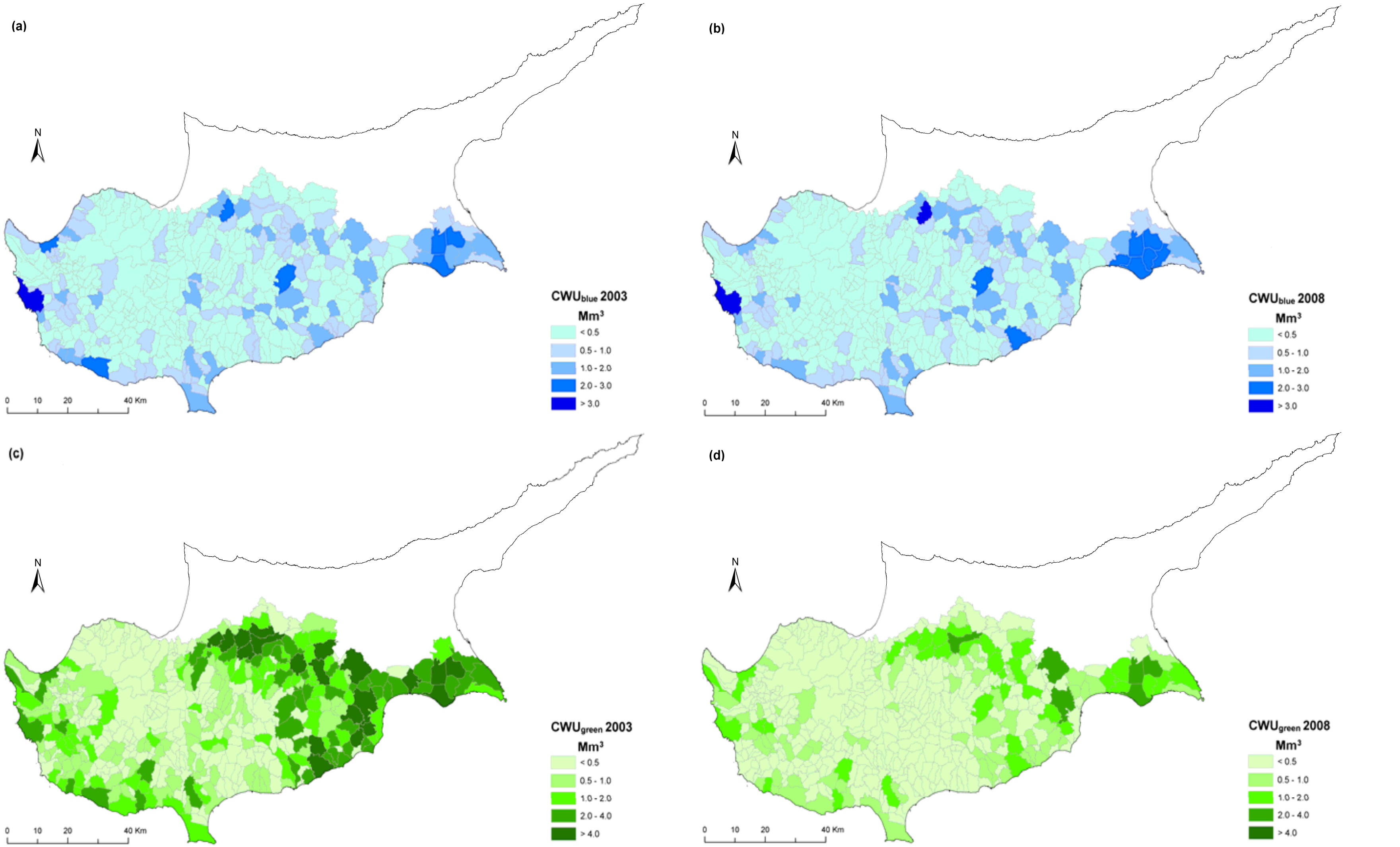






Source: Zoumides et al. (2012a)

Spatio-temporal CWU variations



Source: Zoumides et al. (2012a)

Groundwater Use Estimations

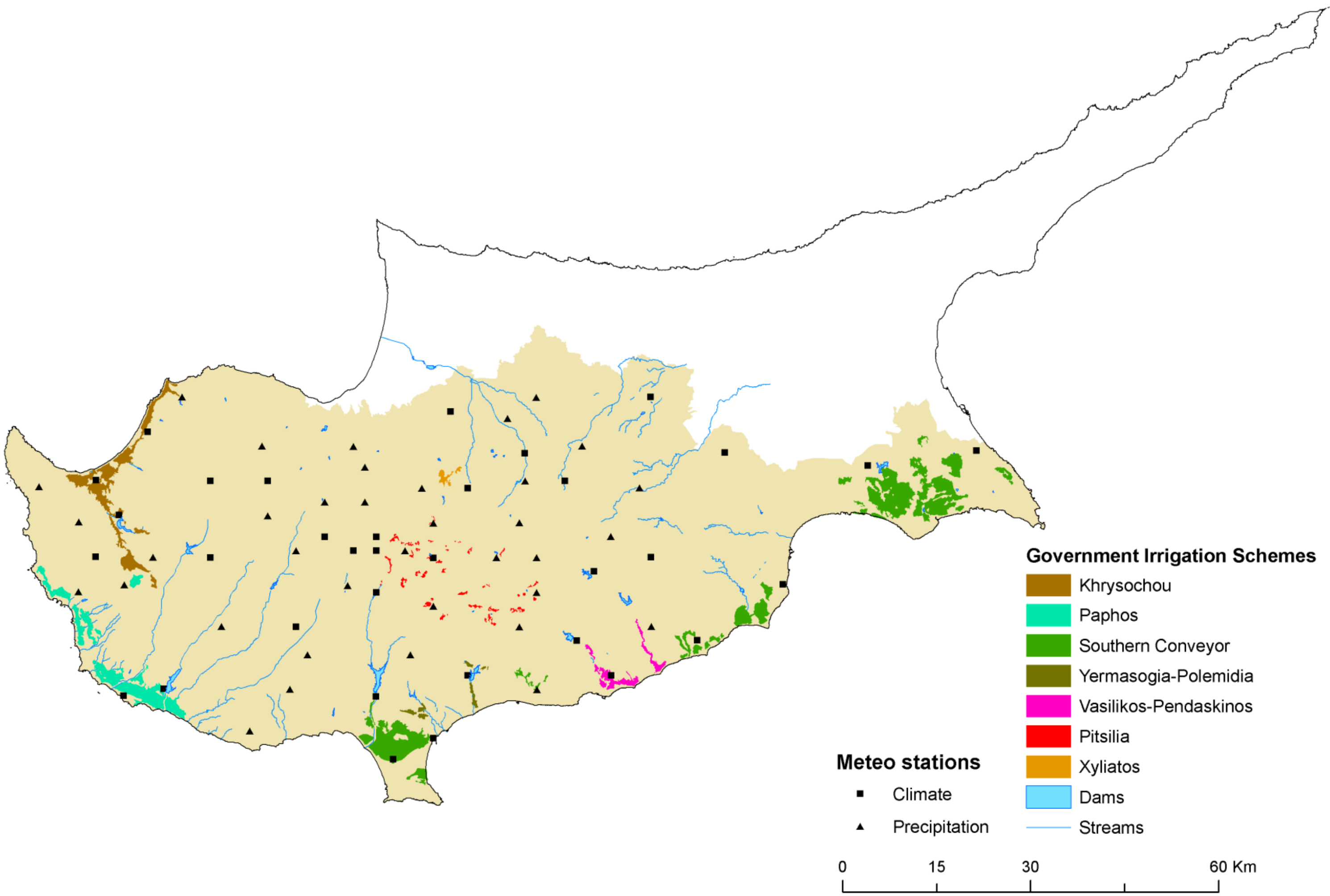
- For every community / year,
  - Blue Water is supplied by:
    - Government Irrigation Waterworks (surface (dams), recycled, groundwater)

and/or

    - Groundwater extracted by farmers (unknown)

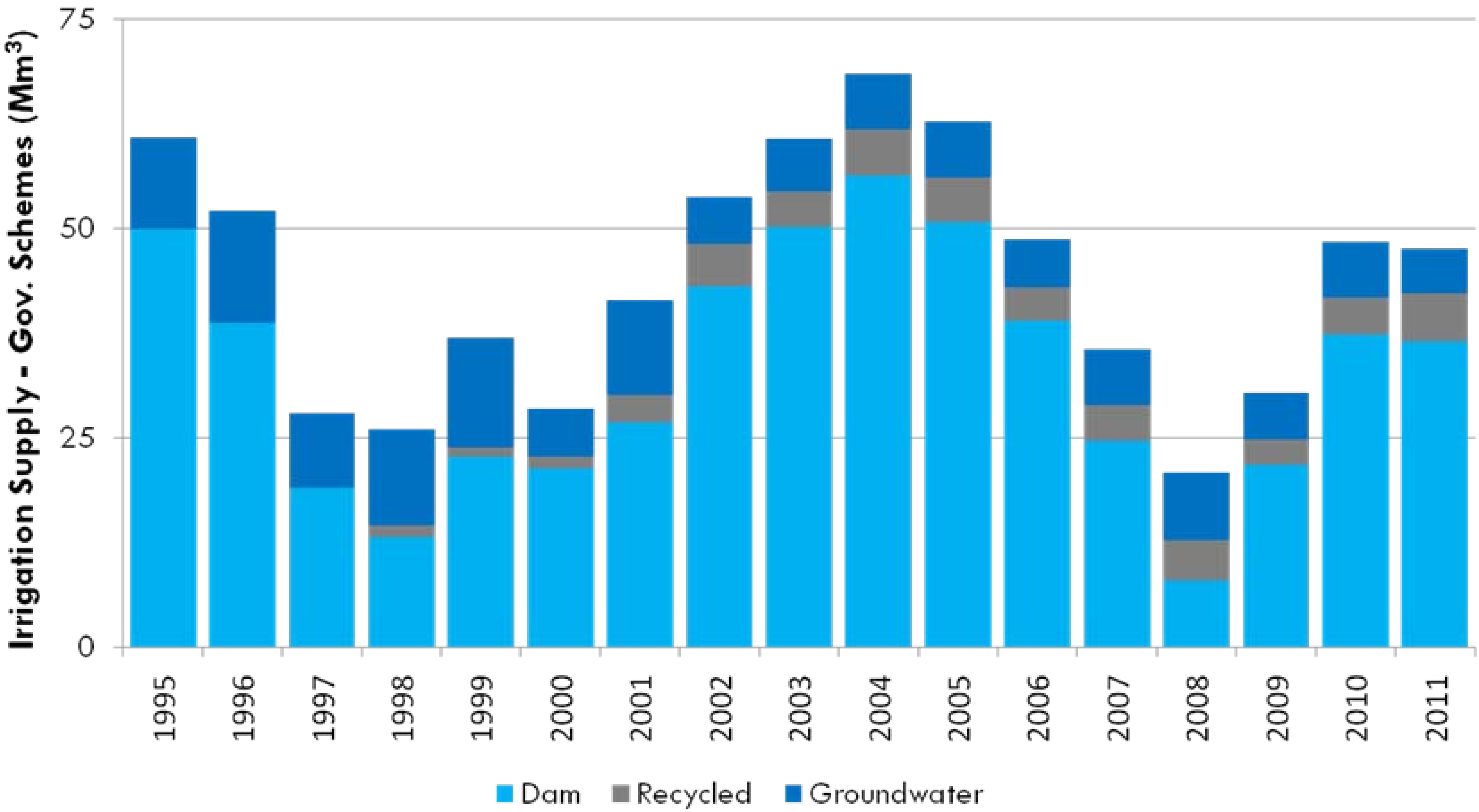
- Annual over-pumping is the volume of groundwater above the recommended level of 104.05Mm^3 (WDD,2011)

Areas under Gov. Irri. Schemes



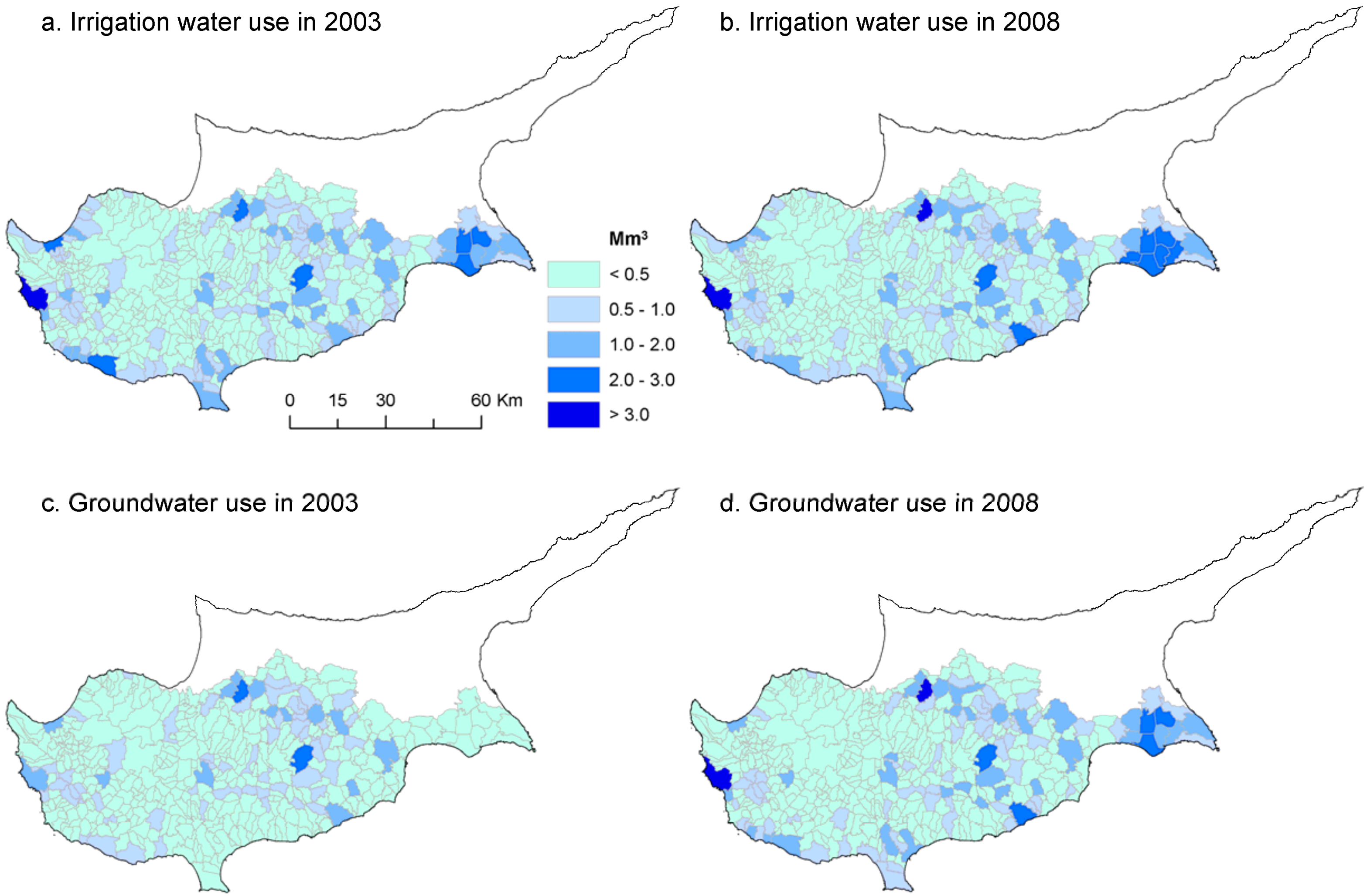
Source: Zoumides et al. (2012b)

Irrigation Supply – Gov. Schemes



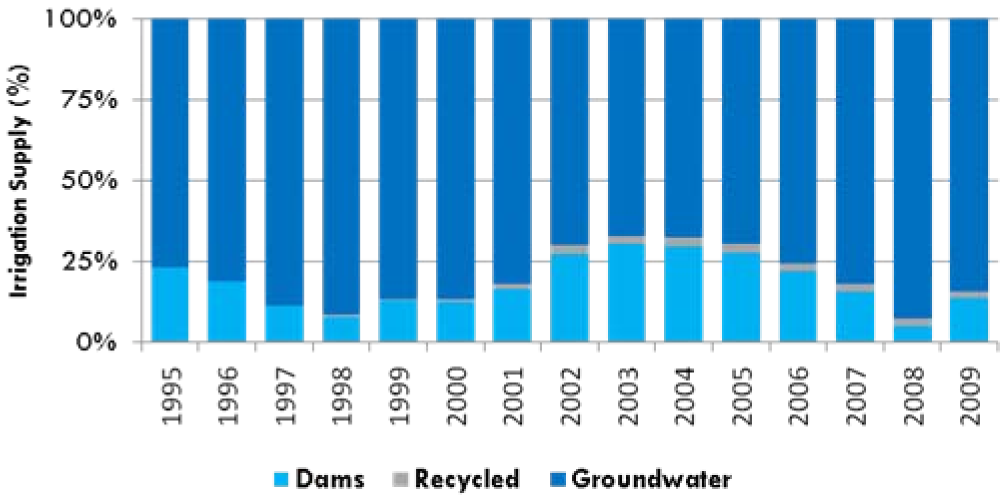
Source: WDD (2012)

Groundwater Use: Wet vs. Dry Years

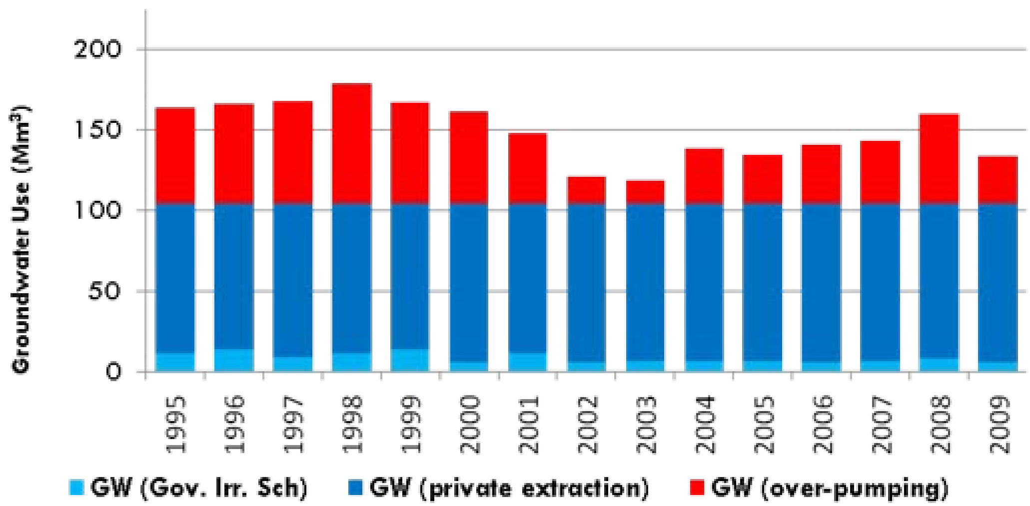


Source: Zoumides et al. (2012b)

Groundwater Use per Year



- GW contribution to blue water use:
  - Avg: 80% per year
  - Max: 92% (2008)
  - Min: 67% (2003)



- GW over-pumping:
  - Avg: 45 Mm^3/year
  - Max: 75 Mm^3 (1998)
  - Min: 14 Mm^3 (2003)

Source: Zoumides et al. (2012b)

Highlights

- Green water is the major contributor to agricultural water use in Cyprus (319 Mm^3/year - 63%)
  - highly variable due to precipitation; 441Mm^3 during the wet year 2003, to 169 Mm^3 during the dry year 2008
  - utilized by cereals (40%), fodder (19%) & grapes (15%)
- Blue water contributes on average 37% (187Mm^3/year)
  - relatively less variable; 214 Mm^3 (1995), to 161 Mm^3 in 2009
  - utilized by citrus (28%) and deciduous fruits (21%)
  - high dependence on groundwater resources; 80% on average
  - most pressure in costal areas → sea-water intrusion → resource depletion

Limitations

- The model relied on statistical data reported by Cystat (official data provider of the Republic of Cyprus).
  - Annual harvested area, production, yield, irrigation fractions per crop → Agricultural statistics
  - Spatial adjustments of annual crop distribution based on the latest (2003) Agricultural Census
- In general, the main scope of agricultural statistics is to accurately measure economic variables
- Water use estimations are therefore inherently subject to the quality and accuracy of the annually reported data

Objectives

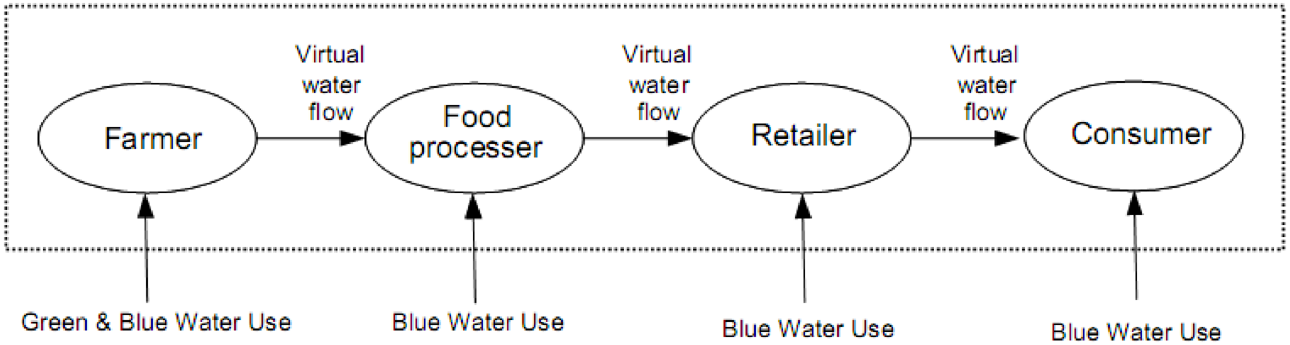
- Estimate the Water Footprint of Crop Production and Supply Utilization for the period 1995-2009
  - Virtual Water Trade Flows
  - Internal vs. External Water Footprint
    - Water Import Dependency vs. Sufficiency
  - Supply Utilization

What is the Water Footprint?

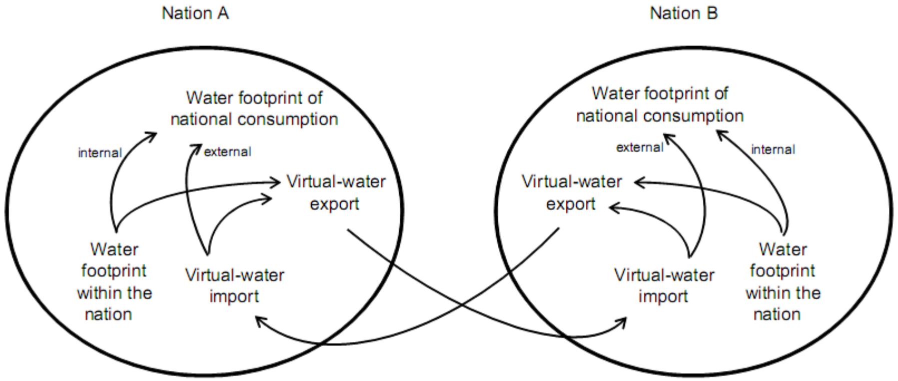
- A consumption-based indicator of water use (e.g. m^3/year) introduced by Hoekstra in 2002.
- What's new compared to traditional indicators:
  - direct *and* indirect use of water; in the case of crop production, it accounts for the use of blue and green water.
  - when *and* where; in the case of national WF, it accounts for the use of domestic *and* foreign water.

Virtual Water and Water Footprint

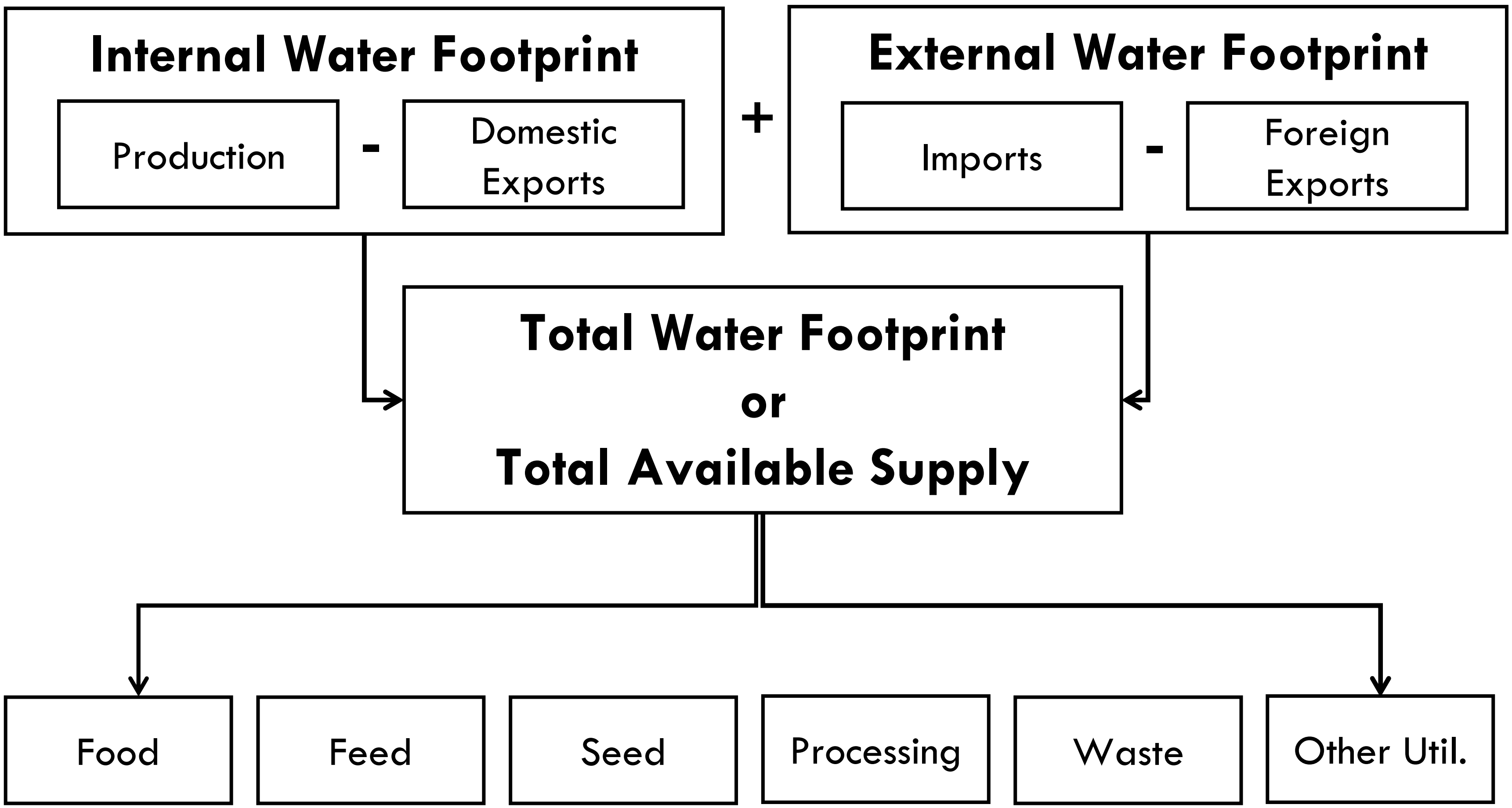
- Virtual water: the total volume of water required to produce a given good (e.g. m^3/ton), i.e. throughout the production chain



- National Water Footprint:



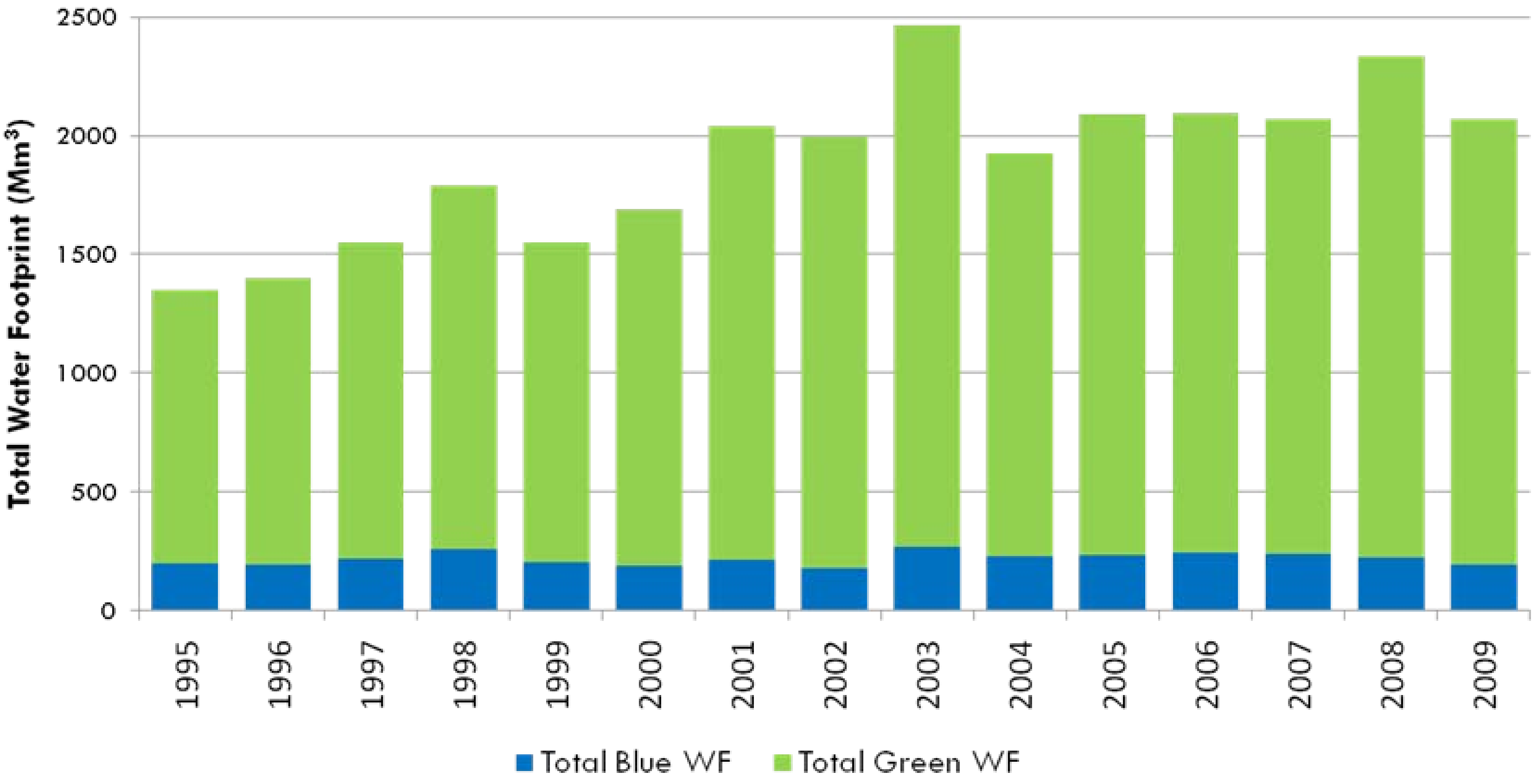
Water, Trade and Supply Utilization



Method & Data

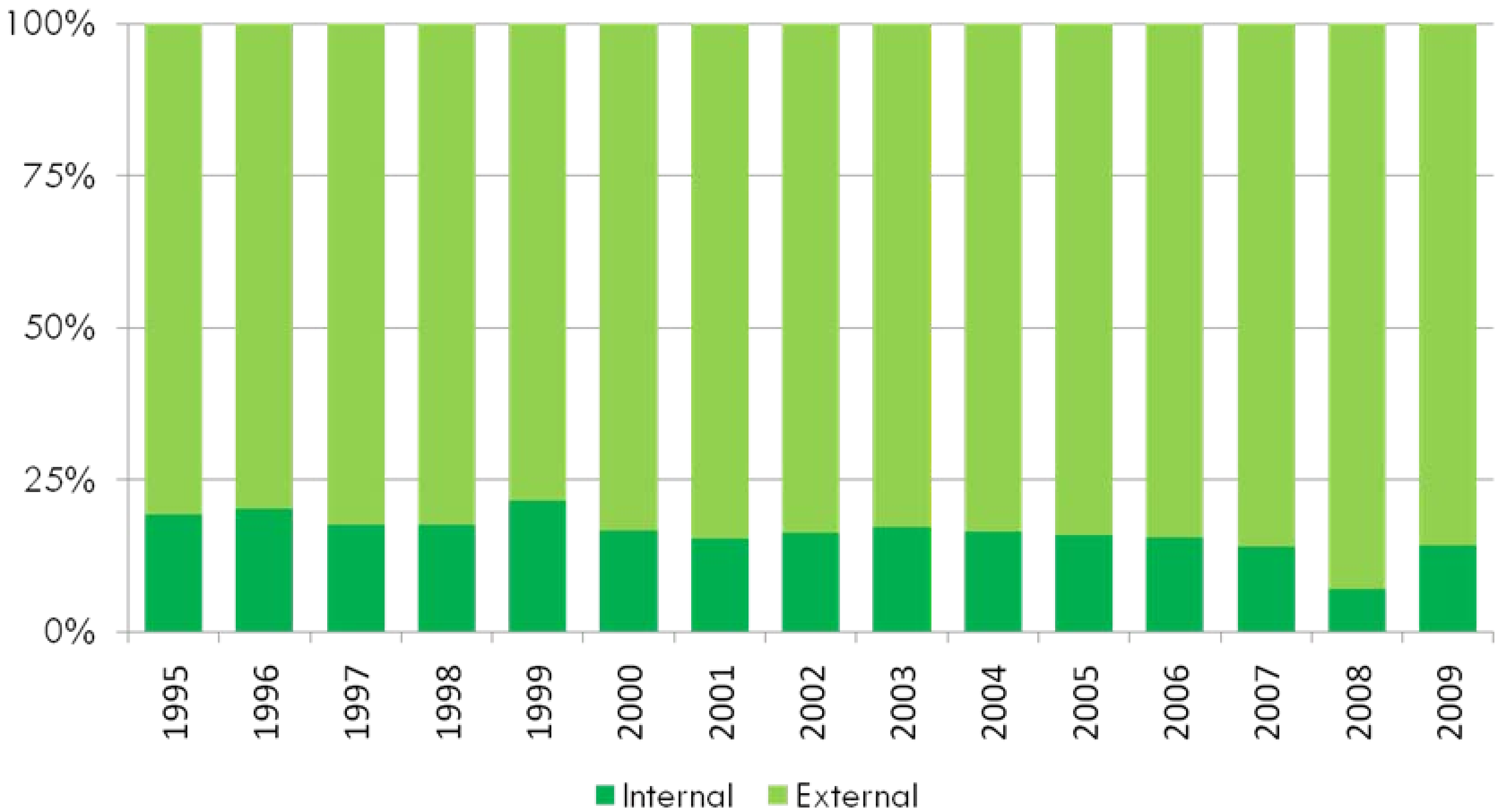
- Bottom-up approach (Hoekstra et al., 2011)
- **Trade data:** CN-8 digit (~1400 crop products)
- **Internal WF:** results from the soil-water balance model (Zoumides et al. 2012)
- **External WF:** results from global high-resolution water balance model Mekonnen and Hoekstra (2011)
- **Conversion coefficients:** FAO (2001) & Eurostat (2009)
- **Supply Utilization Accounts:** FAOSTAT (2012)

Total Water Footprint



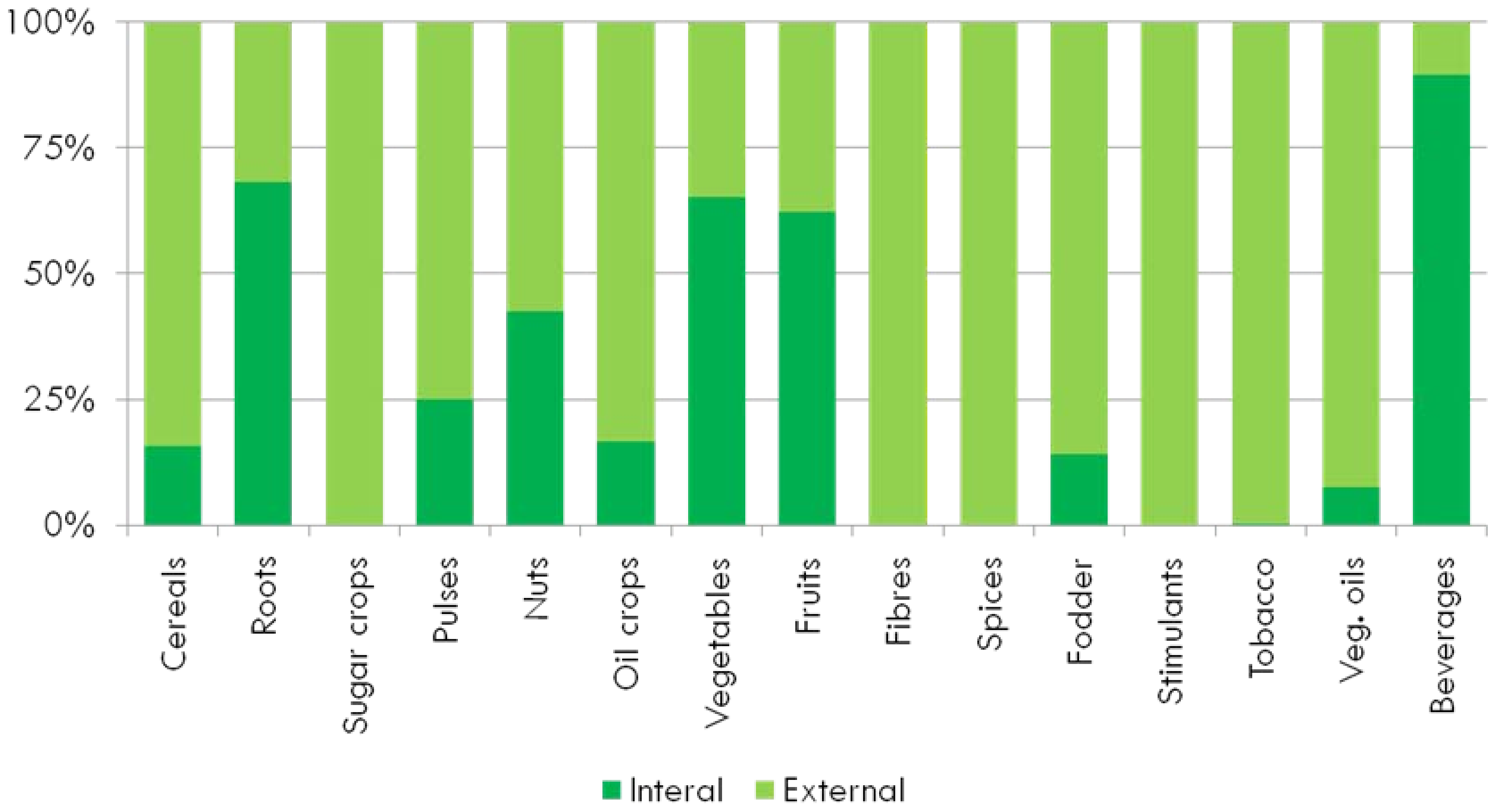
- Average Total WF: 1,894 Mm^3/year
  - Green WF = 88%
  - Blue WF = 12%

Green WF: Internal vs. External

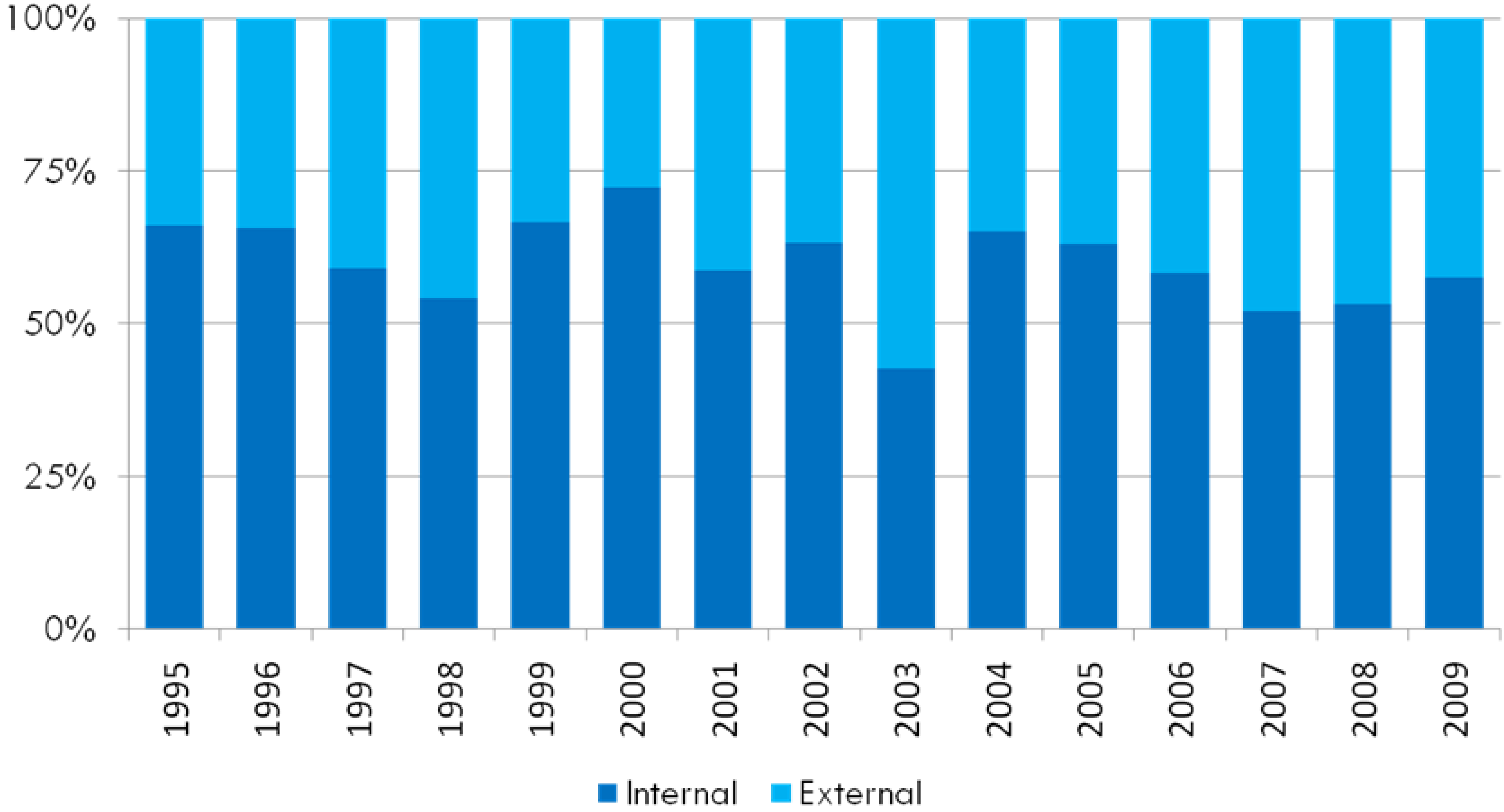


- On average: 16% Internal and 84% External

Average Green WF Composition: Import Dependency vs. Self Sufficiency

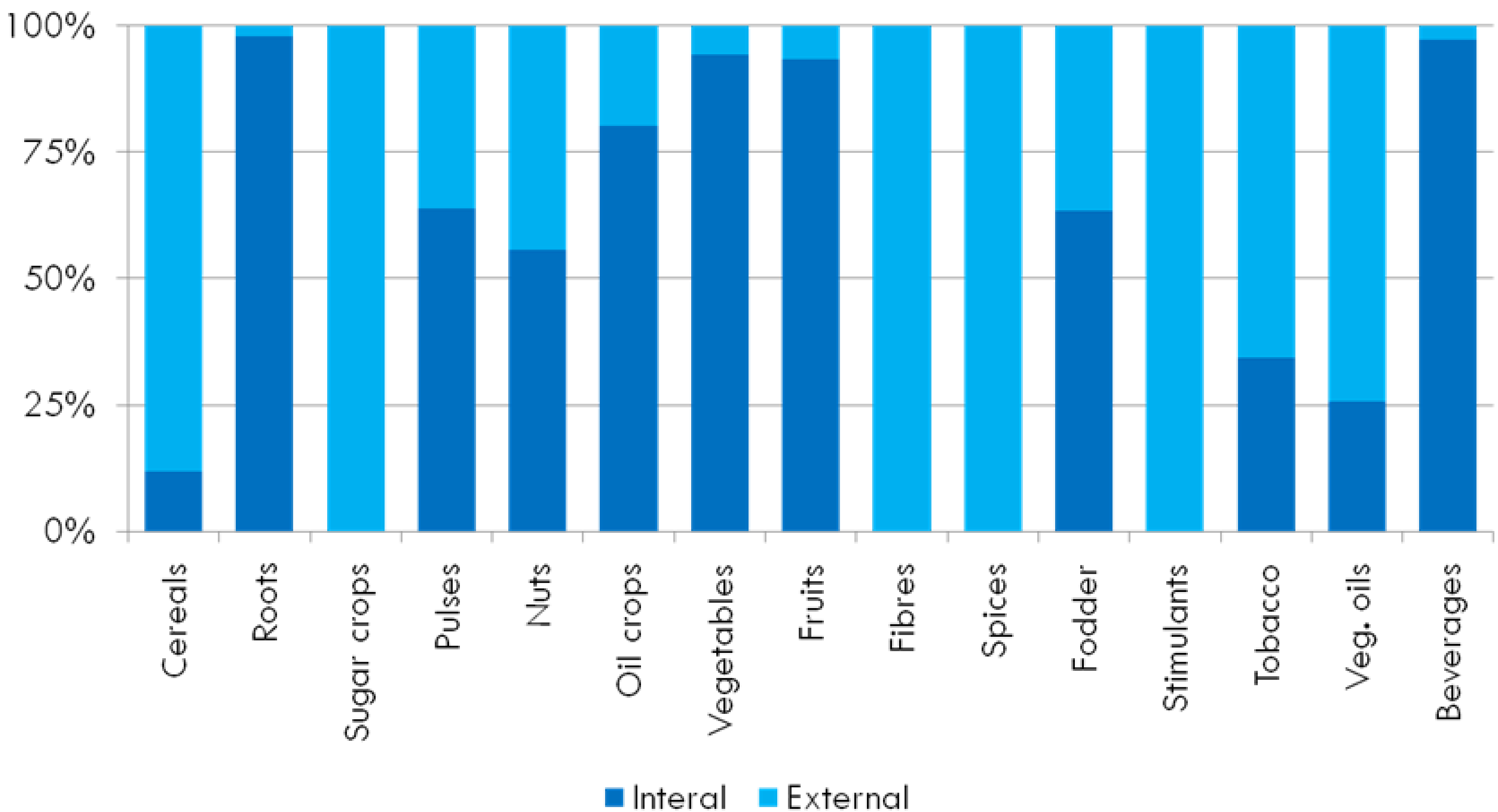


Blue WF: Internal vs. External

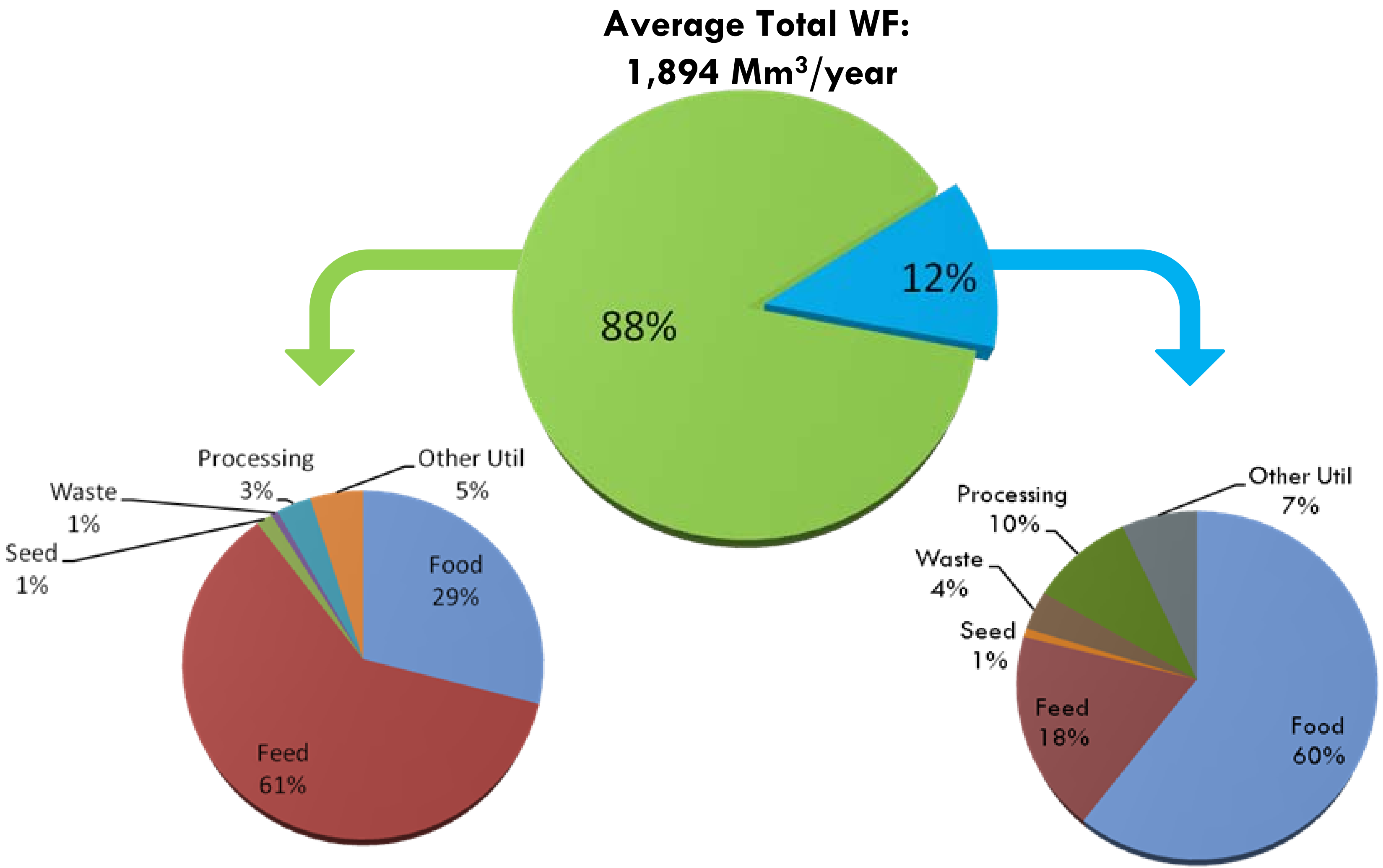


- On average: 59% Internal and 41% External

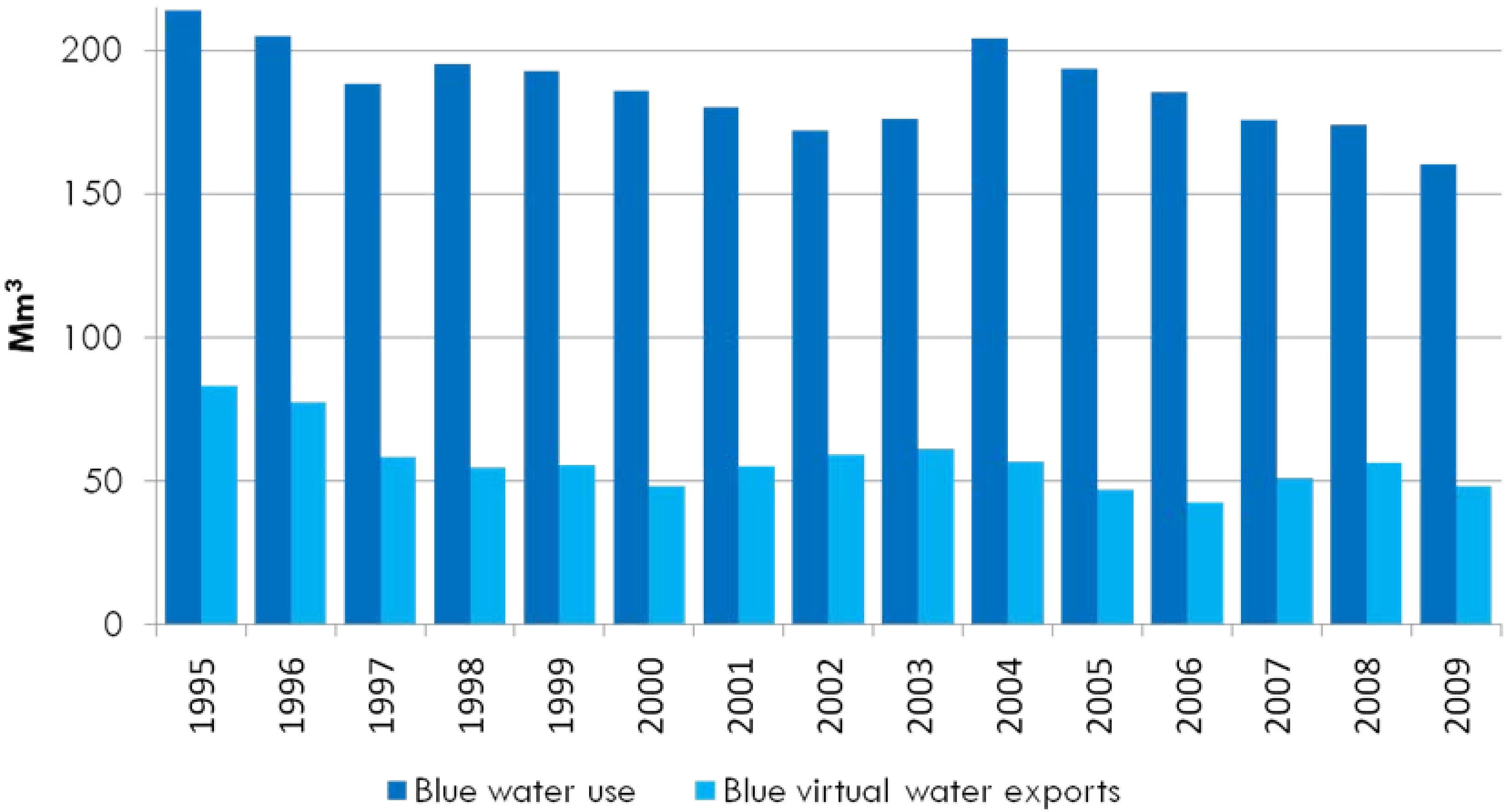
Average Blue WF Composition: Import Dependency vs. Self Sufficiency



Average Water Supply Utilization

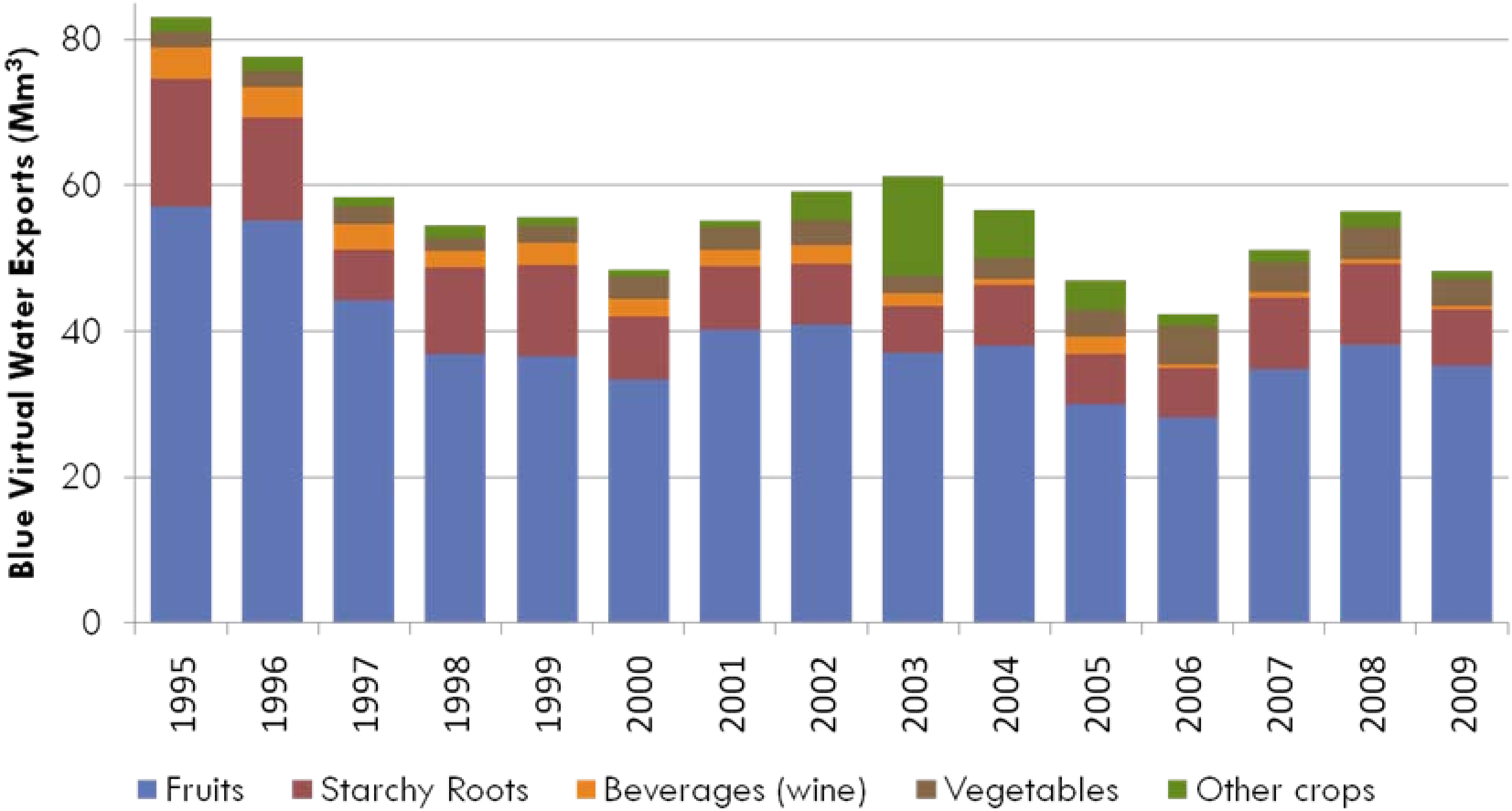


How much blue water is exported?



- On average: 57 Mm^3/year → 31% of Blue CWU

Where is this water embedded?



Highlights

- 88% of total water footprint relies on green water
  - 84% import dependency on rainfed crops that are mainly utilized in the livestock sector → high demand for meat and dairy products
    - Cypriots consume on average 102kg of meat/cap/year; W. Europe: 89kg, World Average 37kg (FAOSTAT, 2012)
- Cyprus exports 57 Mm^3/year of blue water, on average, or 31% of average annual blue crop water use
    - Reminder: average groundwater over-pumping is 45Mm^3/year
    - In 2008, Cyprus imported 8Mm^3 real water with tankers for domestic supply

Limitations

- Internal WF: the data limitations of the soil-water balance model also apply here
- External WF: relies on global soil-water balance model
  - Uncertainty? → Global vs Local estimates (Zoumides et al. 2012a)
- Supply Utilization: relies on many derived statistics
  - Trade
  - Conversion coefficients

Objective

- **The problem:**
  - high agricultural (blue) water demand compared to supply
  - variable supply from Gov. Irrigation Schemes (particularly dams) → yield depends on precipitation
  - groundwater overexploitation and depletion
- The objective of the model is to obtain different land use scenarios that maximize net return, given
  - the available land and water resources;
  - different growing conditions (wet, dry and average);
  - current irrigation prices

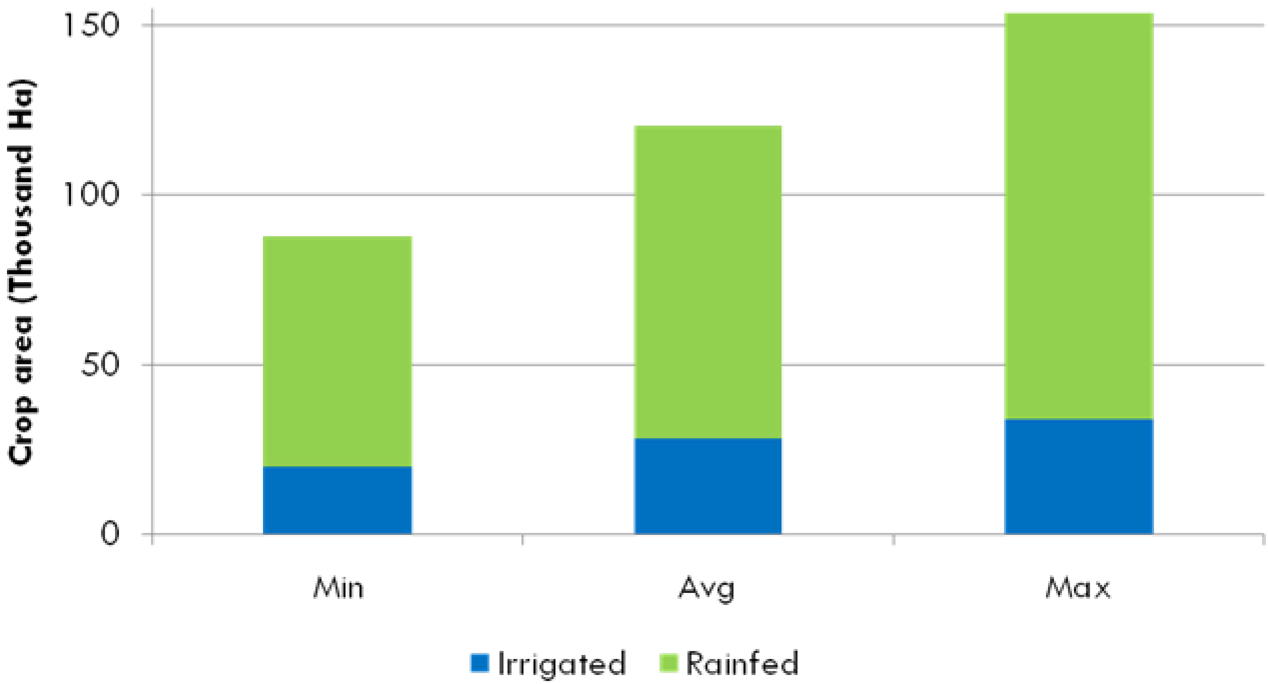
Optimization Model

- $Max: Z = \sum A_{c,t} \times \left[\left[(Y_{c,t} \times P_c) + S_c\right] - PC_c - IC_c\right.$
  - Max: Z = maximum net return (€)
  - A: crop area (ha)
  - c = a specific crop
  - t = growing condition index (avg., wet or dry year)
  - Y = yield (ton/ha)
  - P = Producer Price (€/ton)
  - S = subsidy (€)
  - PC = fixed and variable production cost, other than irrigation (€/ha)
  - IC = irrigation cost(€/ha)

Land use scenario (I)

- Baseline scenario: average land use for the period 2006-2009 (Cystat)
  - max & min range for the same period
- Land constraints:
  - The area of any given crop should be at least equal to the minimum and less or equal to the maximum
    - $A_{c\,min} \leq A_c \leq A_{c\,max}$
  - The sum of all crop areas should be less or equal to the total available cropland
    - $\sum A_c \leq TA_c$

Land use scenario (II)



- **Land deductions:** for citrus fruit and potato, the minimum area was reduced by the equivalent half of exported volume
- **Exclusions:** Bitter orange, tobacco, and sesame seed were excluded from the land use scenarios → no production and price data

Irrigation Cost (WDD & Private)

- Irrigation cost per source per hectare (€/ha)
  - [Blue water req. (m^3/ha) x Vol. price (€/m^3)] + Fixed (€/ha)
- Private pumping cost: average 2006-2009 extraction cost (fuel, electricity, repairs) divided by average groundwater extraction volume
  - Extraction cost obtained from Cystat

Source	Fixed (current)	Volumetric (current)	Fixed (future)	Volumetric (future)
SW & GW (Gov. Irr.)	17.10 €/ha	0.17 €/m3	66.10 €/ha	0.24 €/m3
Recycled (Gov. Irr.)	-	0.07 €/m3	49.60 €/ha	0.18 €/m3
GW (private)	0	0.18 €/m3	0	+ 0.11€/m3

Water availability / Env. constraint

- We know the supply volume from Gov. Irri. Sch., but we do not know the irrigated area and crops
  - area allocated to each source (dif. price) assuming that:
    - any crop can be irrigated from SW & GW from Gov.
    - any crop can be irrigated from private GW
    - only fodder and tree crops can be irrigated from Recycled

Source (Vol. in Mm^3)	Avg. (2002-2011)	Wet (2004)	Dry (2008)
SW & GW	43.13	63.10	16.10
Recycled	4.62	5.50	4.70
Available GW	97.72	97.35	95.95
Total	**145.47**	**165.95**	**116.75**

Growing conditions - Assumptions

- Growing conditions determined by crop water requirements
  - e.g. dry conditions = high blue water requirements
- Fixed yields for irrigated crops for any growing condition
  - No yield reduction assuming that irrigated crops grow under no water stress
- Variable yields for rainfed crops, depending on growing conditions

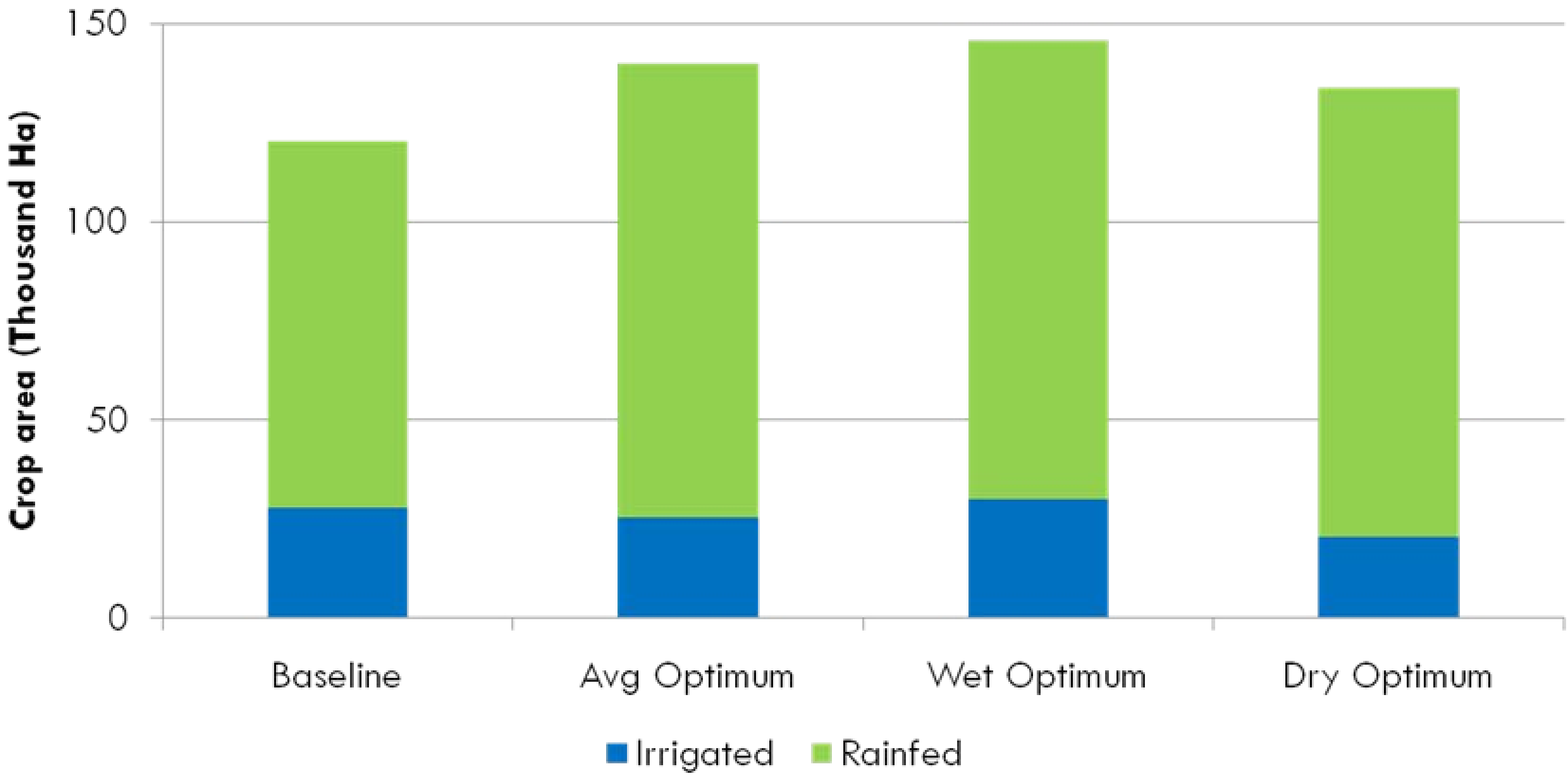
Production cost - Assumptions

- Production cost per crop (e.g. fertilizers, wages, machinery etc.) obtained from Dept. of Agriculture (2012) and Markou & Papadavid (2012)
  - Note: these production costs assume best growing conditions, management practices and maximum yield
- The minimum land use constraint implies that a portion of land will be chosen by the model in the crop mix, even though net return is negative (production cost > gross revenue), provided that the water constraint is satisfied.

Producer Prices and Subsidies

- Average Producer Prices per crop, for the period 2008-2010 (Cystat)
- Subsidies per crop: 2010 prices obtained from CAPO, and include the following components:
  - Single Area Payment Scheme (SAPS – 100% EU funds)
  - Complementary National Payment Scheme (CNDP – 100% National funds)
  - State Aid Scheme (SAIDS – 100% National funds)
  - we assumed that all farmers receive an additional subsidy for growing in less favorable areas (measure 2.1)

Optimum Land Use

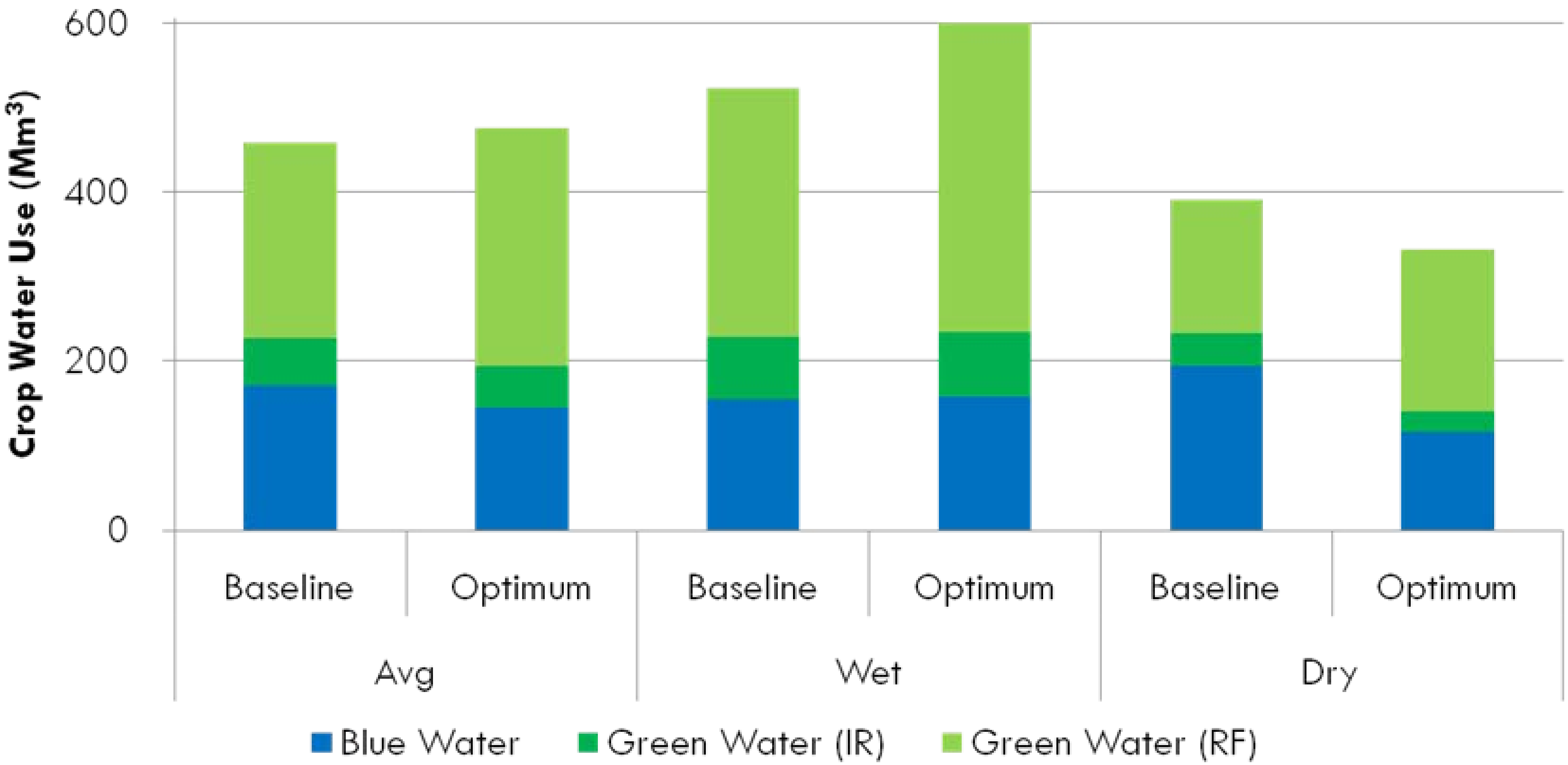


- Changes in Land Use:
  - Irrigated: Avg: -9%; Wet: +8%; Dry: -27%
  - Rainfed: Avg: +24%; Wet: +25%; Dry: +23%

Optimum Crop Mix

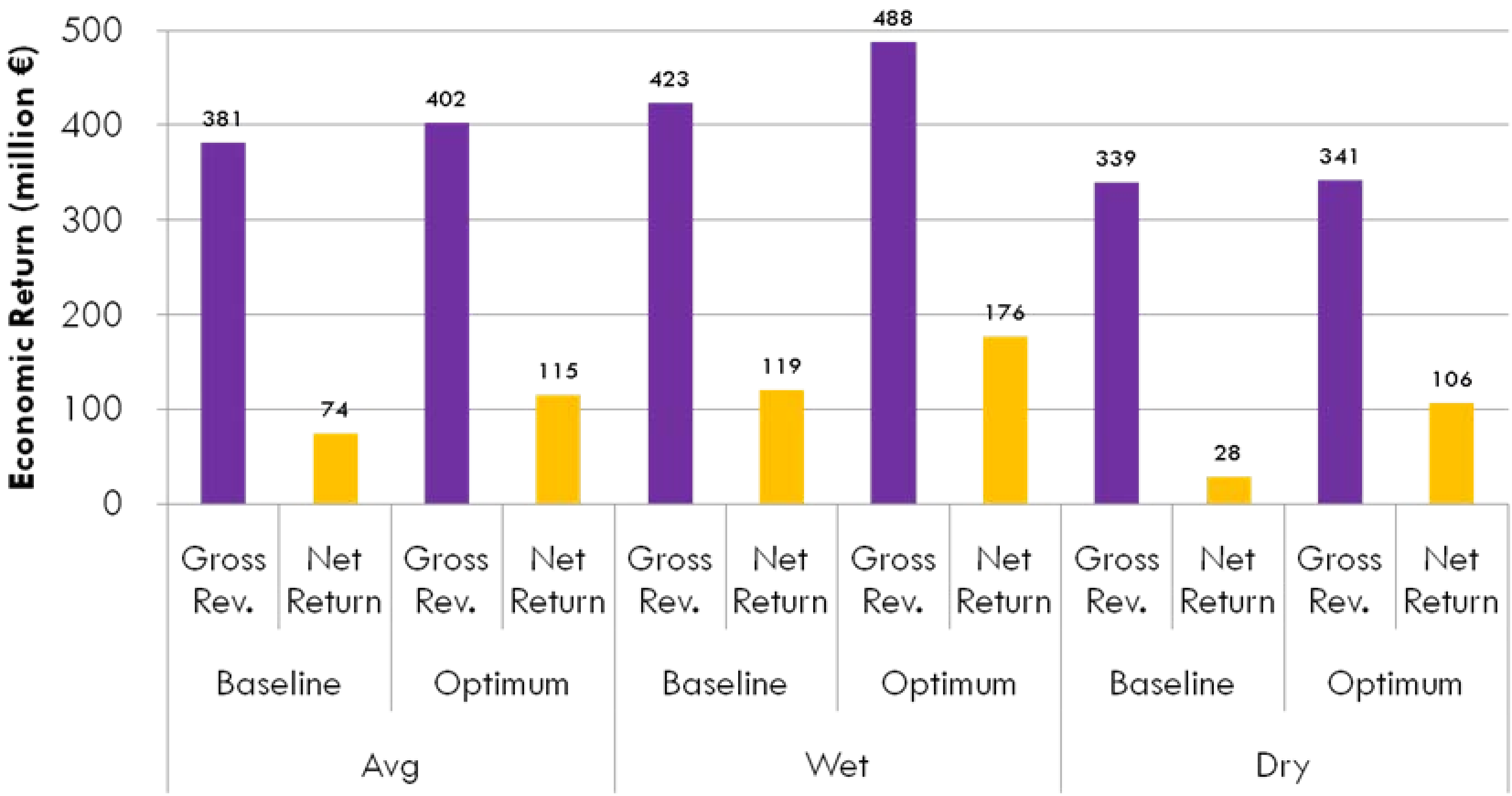
Crop Group	Baseline (thousand ha)	Optimum		
		Avg	Wet	Avg
	Irrigated			
Cereals	1.3	-25%	29%	-55%
Fodder	2.3	-23%	19%	-15%
Fruits	9.5	-21%	2%	-38%
Nuts	0.8	-23%	-10%	-51%
Oil crops	5.0	-14%	-14%	-85%
Pulses	0.5	-13%	9%	-24%
Starchy Roots	5.3	18%	22%	22%
Vegetables	3.3	10%	22%	19%
	Rainfed			
Cereals	41.9	38%	38%	38%
Fodder	28.9	28%	28%	28%
Nuts	4.1	-20%	-20%	-20%
Oil crops	7.4	-14%	-14%	-14%
Pulses	0.6	16%	16%	16%
Vegetables	9.6	-1%	10%	-11%

Optimum Water Use



- Changes in blue water:
  - Avg: -15%; Wet: +1%; Dry: -40%

Gross vs. Net Returns



- Net Return Increase:
  - Avg: 155%; Wet: 148%; Dry: 379%

Highlights

- Based on the input data, and given the land and water constraints, the optimal solution that maximizes net returns was to:
  - increase rainfed areas under any growing conditions
    - cereals and fodder
  - decrease irrigated area, except during wet years
    - all crops, except vegetables and roots.
- The model can be easily adjusted to assess the effects of policy change, e.g.:
  - Irrigation prices (implementation of the WFD)
- Extensions of this work → AGWATER project

Limitations

- Derived area per crop for Gov. Irrigation Schemes
  - the available WDD data refers only to claimed irrigated area and is classified in broad crop categories
- Production cost data per crop determines, to a large extent, the net return
  - the costs assume maximum yield and perfect growing conditions
- Data available in Cystat is only for the total production cost and not per crop
  - any adjustments would have been very arbitrary

Conclusions

- The three inter-related models presented improve our understanding about agricultural water use in Cyprus
  - Spatiotemporal water balance model:
    - Effects of climate variability on blue and green CWU
    - Groundwater use and over-pumping
  - Water Footprint:
    - Internal vs External
    - Supply utilization
    - Virtual blue water exports
  - Optimization Model:
    - Sustainable (economic and environmental) use of land and water resources
- These tools provide additional information that can be particularly useful to policy makers

Recommendations

- Establish a database with a common, detailed and consistent classification system for the agricultural sector in Cyprus
  - Crop area (merge CAPO & Cystat databases)
    - consistently register if fields are irrigated
  - Production (link with crop area)
  - Farming cost (extent FADN to smaller farmers)
  - Crop processing (Industrial statistics →PRODCOM)
  - Agricultural Trade (Combined Nomenclature)
  - Common farmer registration number (WDD, CAPO, Cystat)
    - Such information can be useful to WDD to check registered irrigation water requests by irrigation project and by community
    - Control and monitoring of groundwater use (requires registration and licensing of boreholes)
- Better Data → Better Predictions → Better Management
- It is feasible if we take advantage of the small size of Cyprus

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- Note: References not included here, can be found in Bruggeman et al. (2011) and Zoumides et al. (2012a, b)

Thank You

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