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Water scarcity and food security : a global assessment of water potentiality in Tunisia

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References

- ***Besbes M., Chahed J., Hamdane A. (2007),*** Bilan intégral des ressources en eau de Tunisie, sécurité hydrique et sécurité alimentaire, Communication at Académie d'Agriculture. Paris, séance du 4-4-2007 (l'Avenir des Eaux Continentales)
- ***Chahed J., Hamdane A., Besbes M.,(2007),*** Bilan intégral des ressources en eau de Tunisie, sécurité hydrique et sécurité alimentaire, La Houille Blanche N°3,2007
- ***Chahed J., Hamdane A., Besbes M.,(2008),*** A Comprehensive Water Balance of Tunisia: Blue Water, Green Water, Virtual Water, Water International, 33:4, pp. 415-424

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Tunisian water resources

Pluvial water resources

36000 Mm^3 225 mm/year

Withdrawl water resources

4850 Mm^3 < 500 m3/cap/year

- **Surface water** : 2700 Mm^3
- **Ground water** : 2150 Mm3

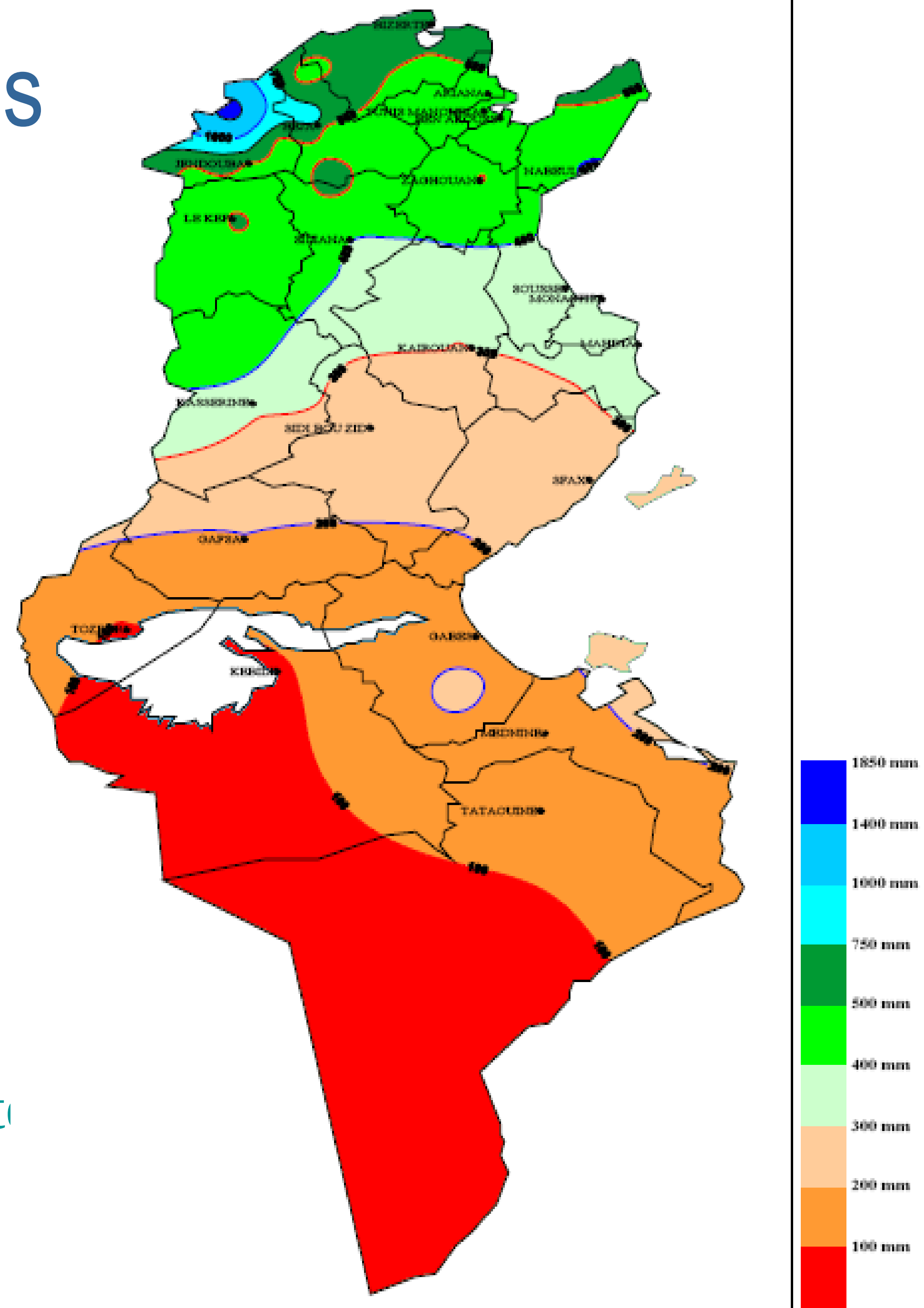
Withdrawal resources

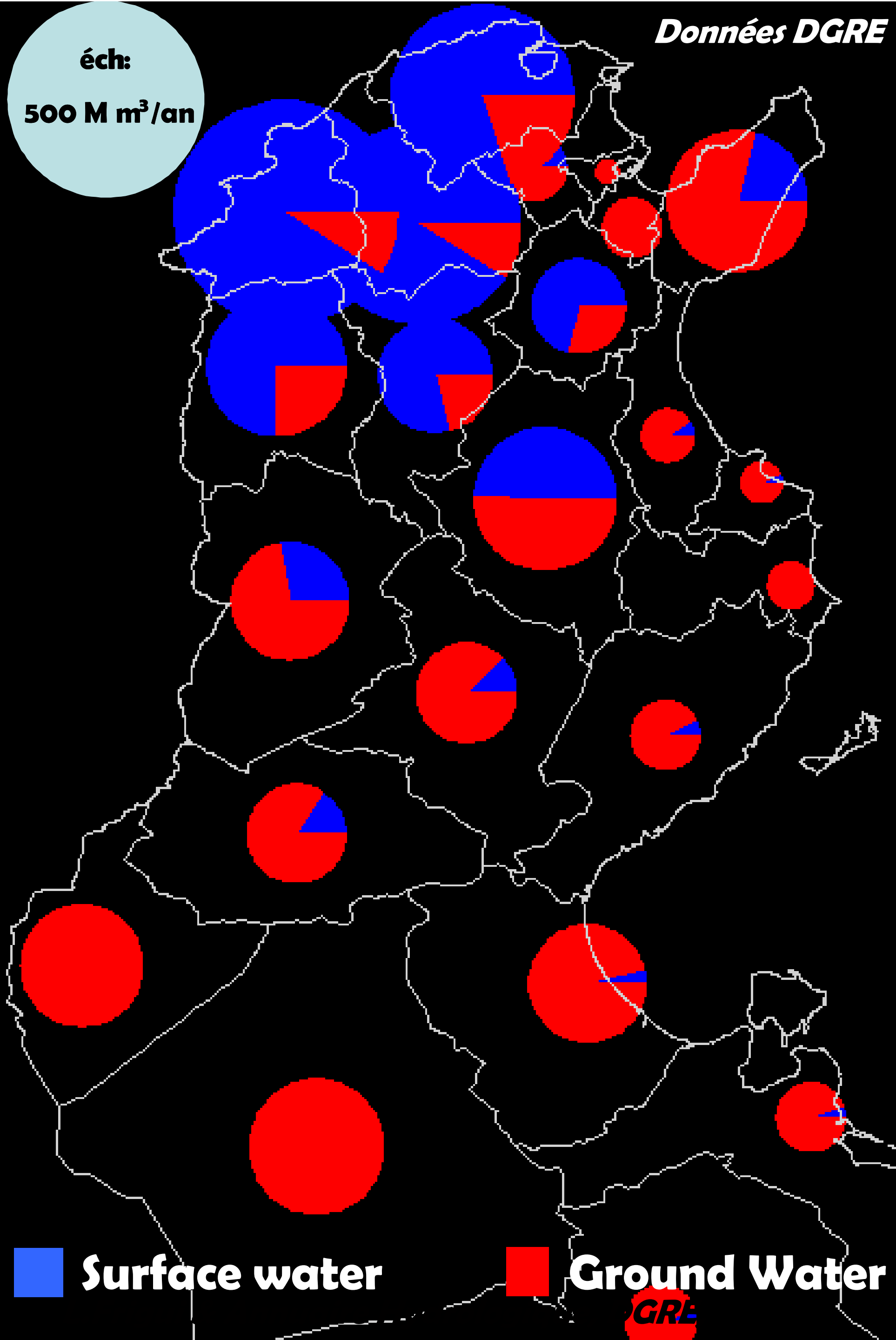
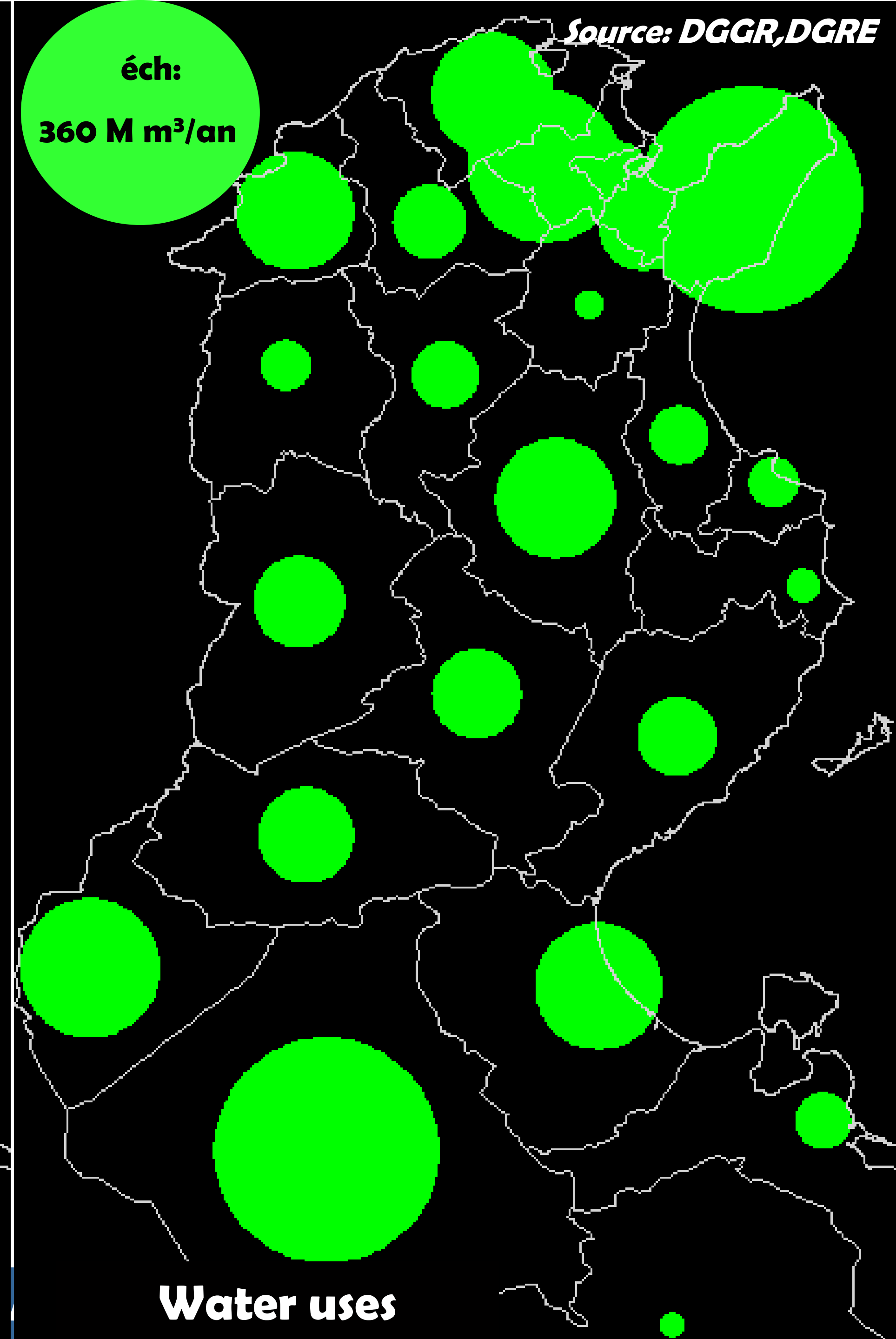
3150 Mm^3

600 Mm^3 Reserve for drought

+120 Mm^3 EUT (Treated Waste Wat

Average rainfall




éch:
500 M m³/an
Données DGRE
Surface water
Ground Water

éch:
360 M m³/an
Source: DGGR,DGRE
Water uses

Tunisian water resources : Transfers and Water uses

Water resource

- is limited

~ 500 m³/Cap/year

- is non uniformly distributed

\- In space

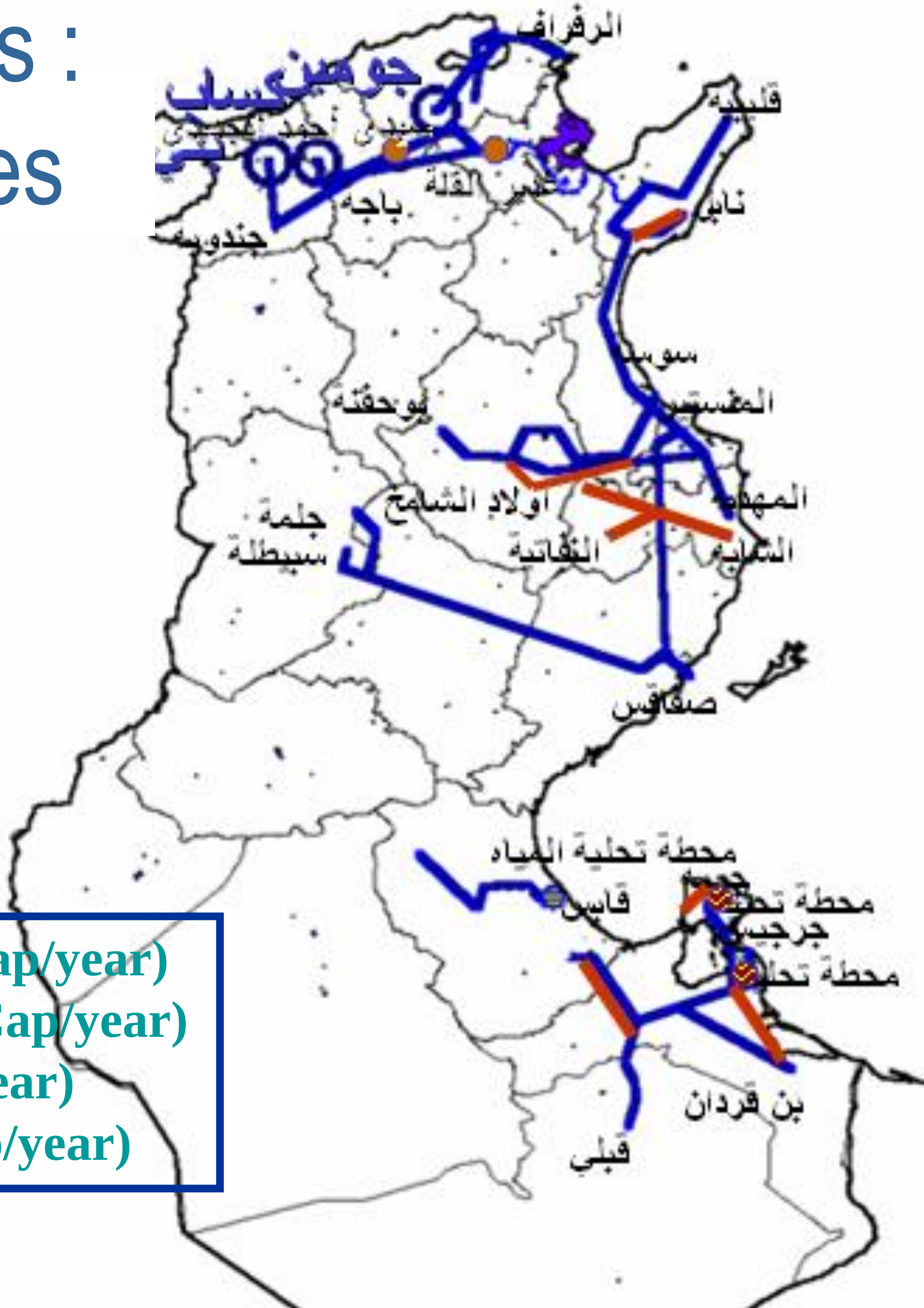
\- In time

- is largely exploited

(~ 80 %)

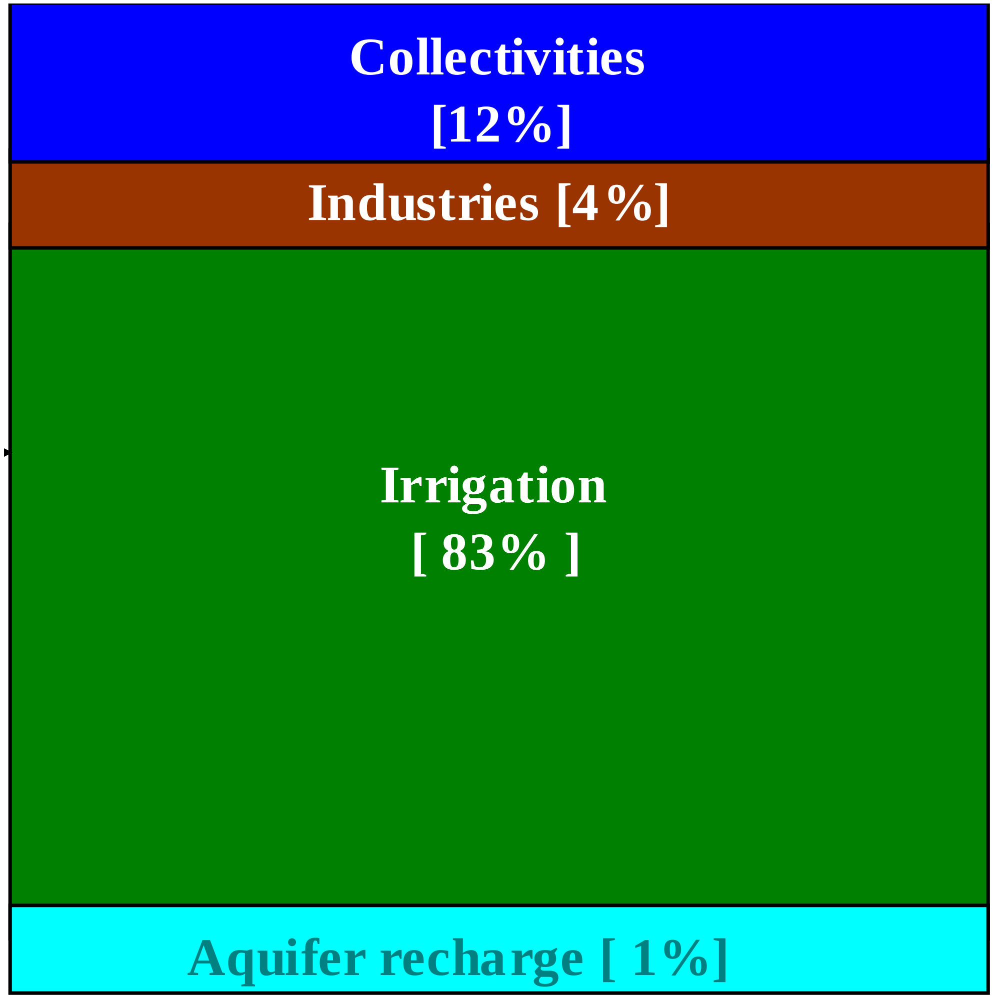
Water uses

Drinking Water: 300 Mm³ ≈ (30 m³/Cap/year)
Industrial Water: 100 Mm³ ≈ (10 m³/Cap/year)
Tourist Water : 20 Mm³ ≈ (2 m³/Cap/year)
Agriculture : 2100 Mm³ ≈ (210 m³/Cap/year)



Statement 1: Irrigation consumes a large part of water resources

- ***Direct water uses*** (collectivities, tourism, industry) represent less than 20 % of water uses.
- ***Agriculture water uses*** represent more than 80 % of water uses.
- **Irrigation** occupies less than 1/10 of cultivated areas and produces around 1/3 of food production



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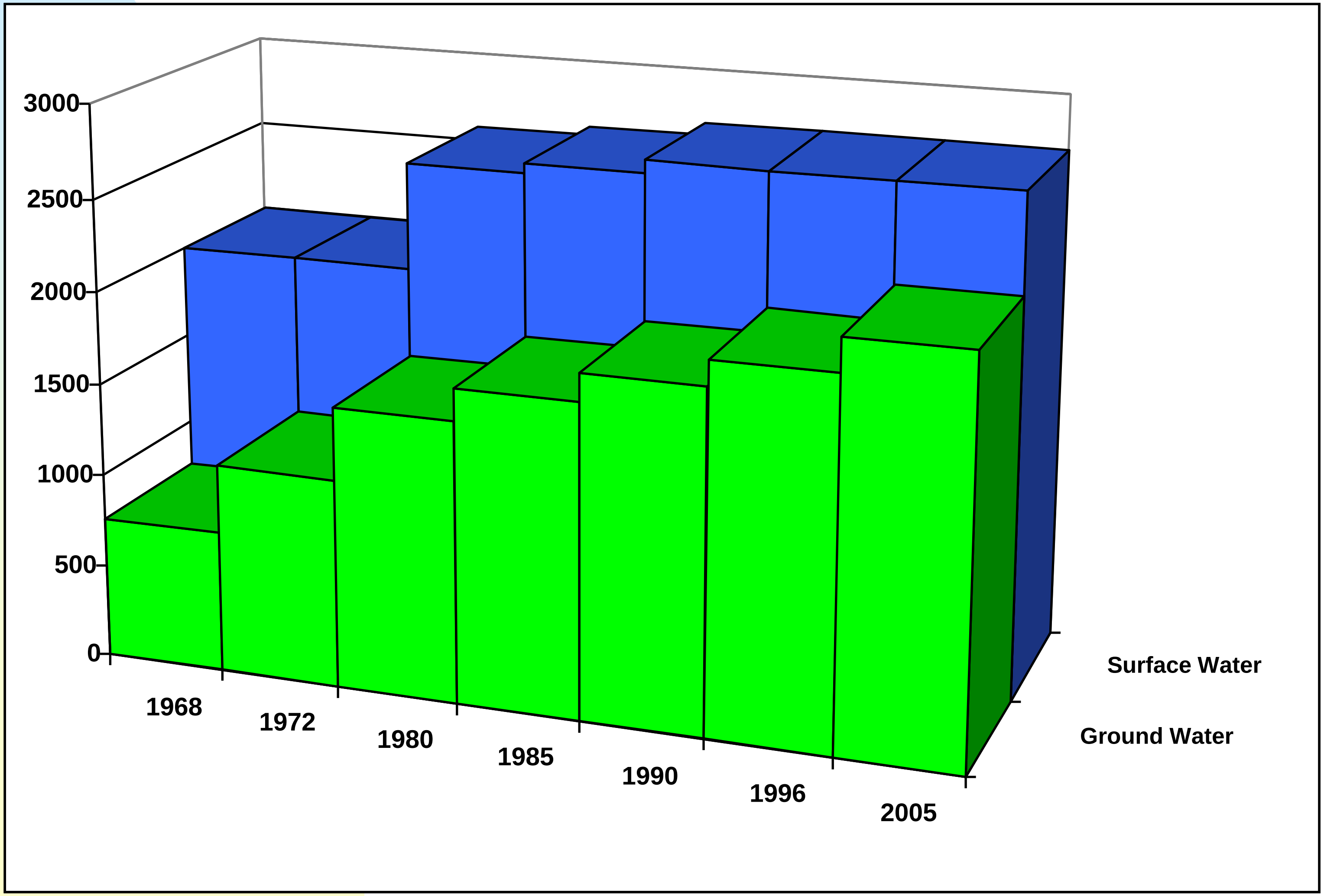
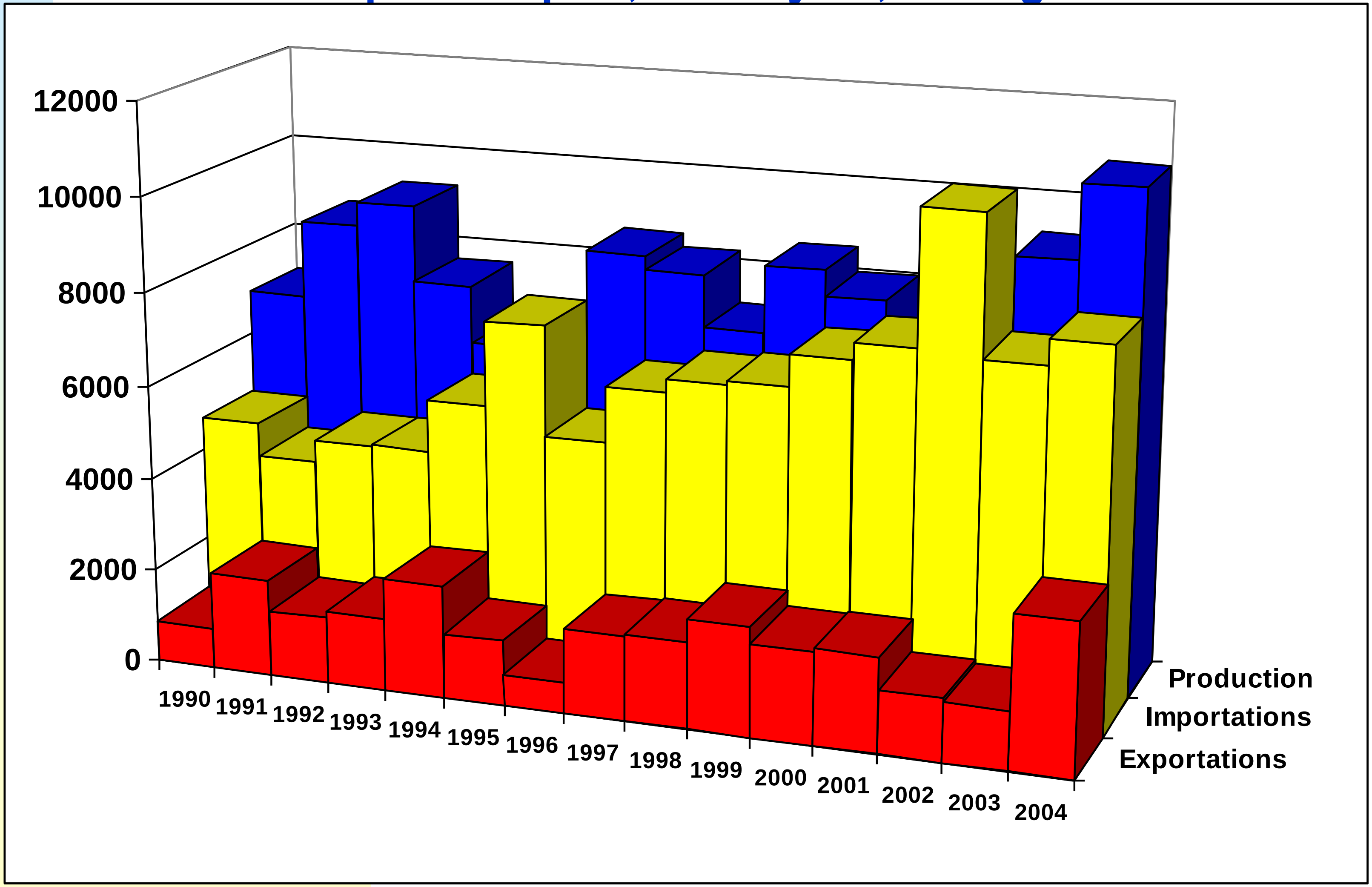
Statement 2: «Blue Water» supply is stabilized and agricultural water allocations will be reduced

Evolution of water resource estimation $10^6 m^3$



Statement 3: Equivalent-Water of foodstuffs imports is important

Foodstuffs imports-export, $10^6 m^3$/year, average 1990-2004



Statement 4: The amount of «Green Water» is considerable

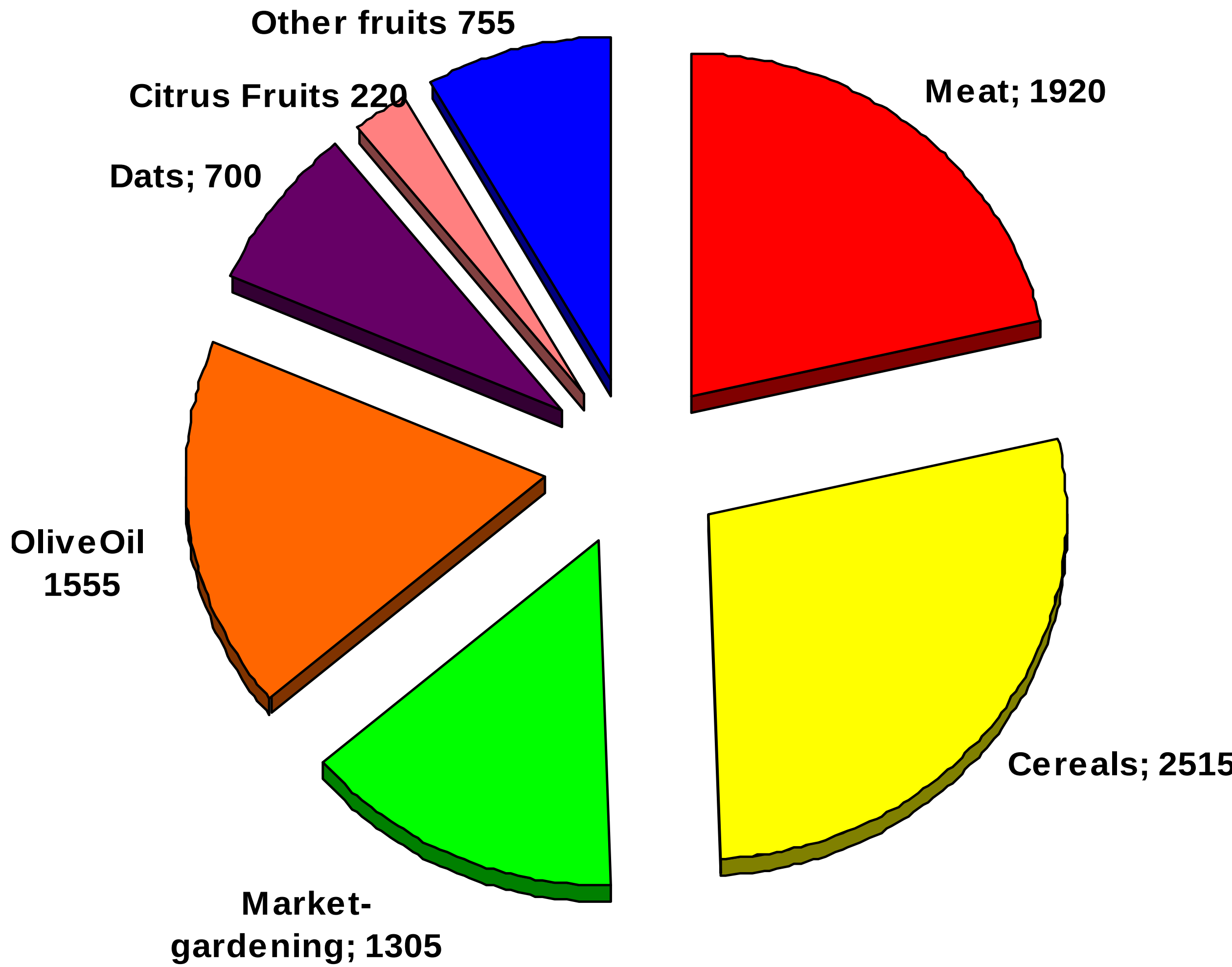
Equivalent Water of Food production, $10^6 m^3$/year, 1990-2004

Rainfed agriculture

- Cereals, Olive oil…

Irrigated agriculture

(Market gardening, Dats, Fruits…



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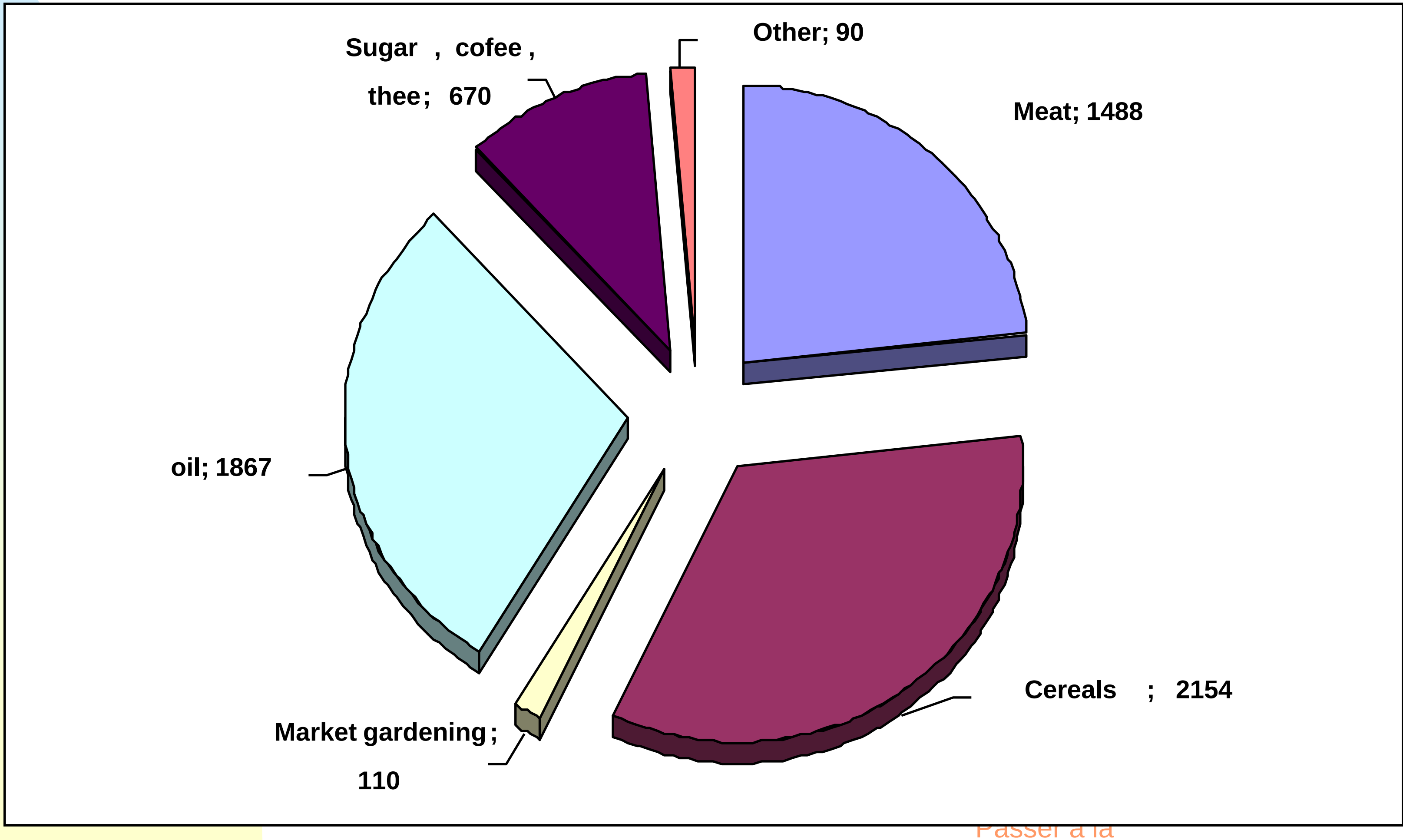
Statement 5: «Green Water» plays un important part in foodstuffs trade

Foodstuffs imports, Equivalent-Water [$10^6 m^3$/year], 1990-2004



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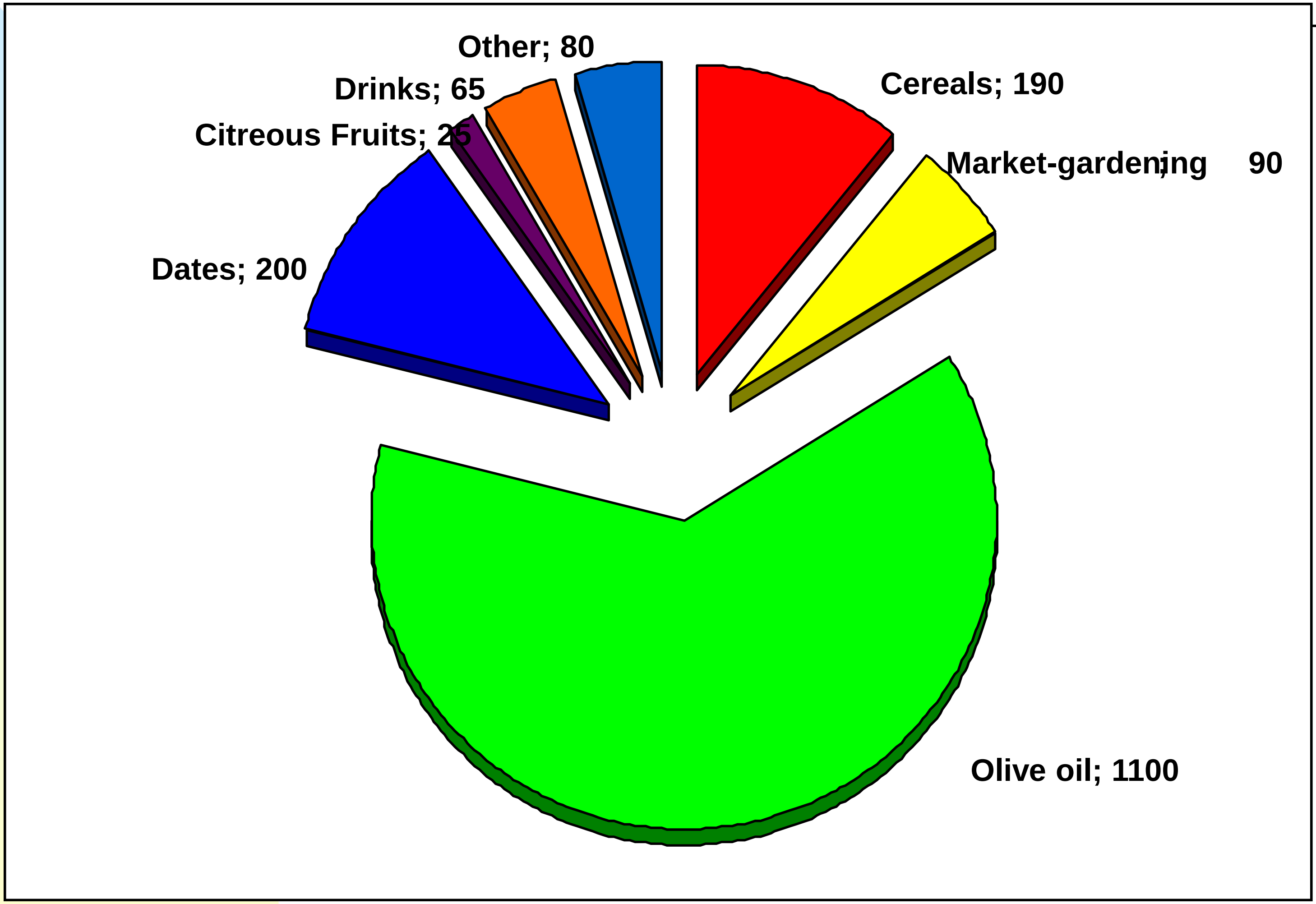
Foodstuffs exports, Equivalent-Water [$10^6 m^3$/year]



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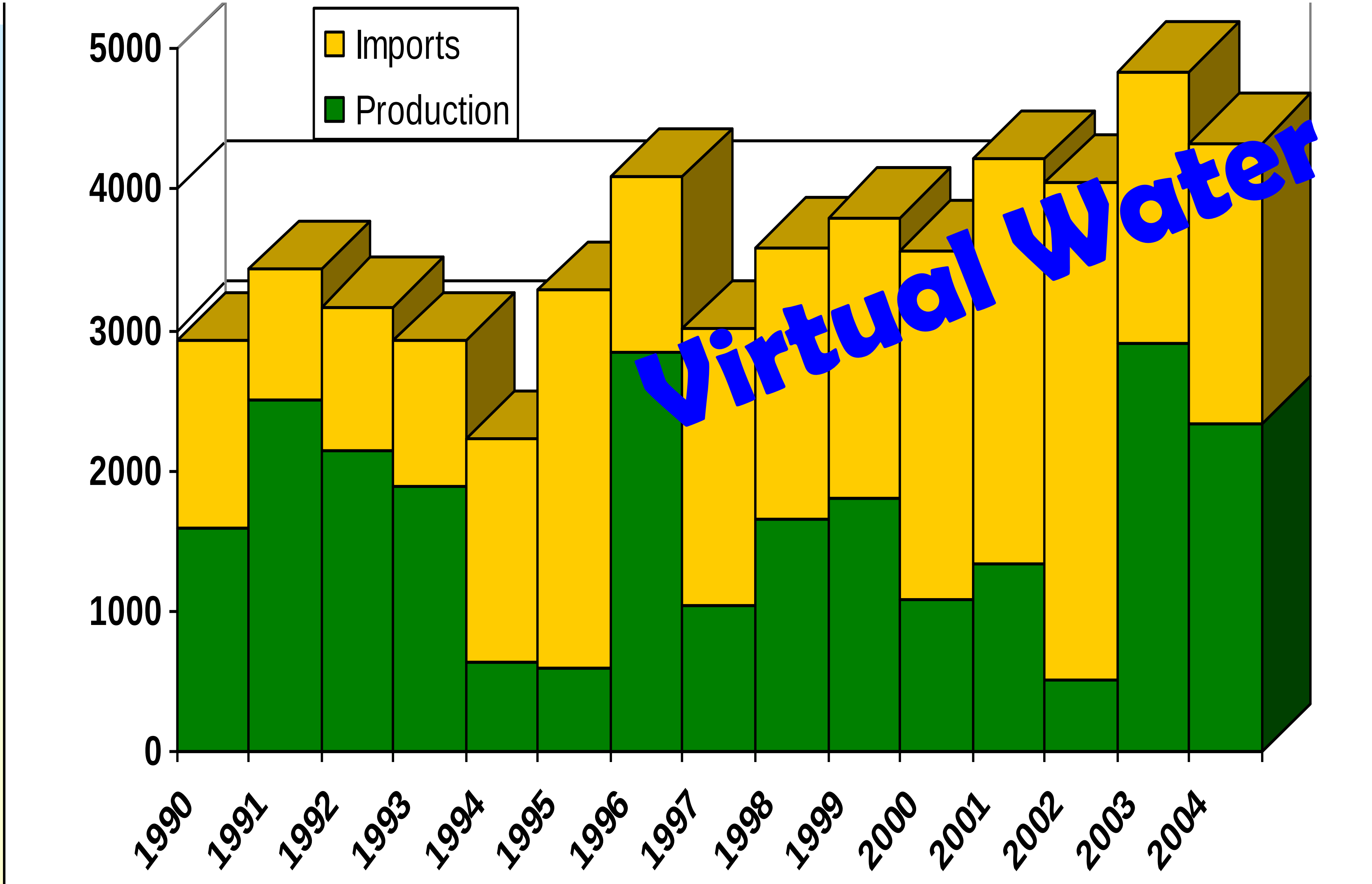
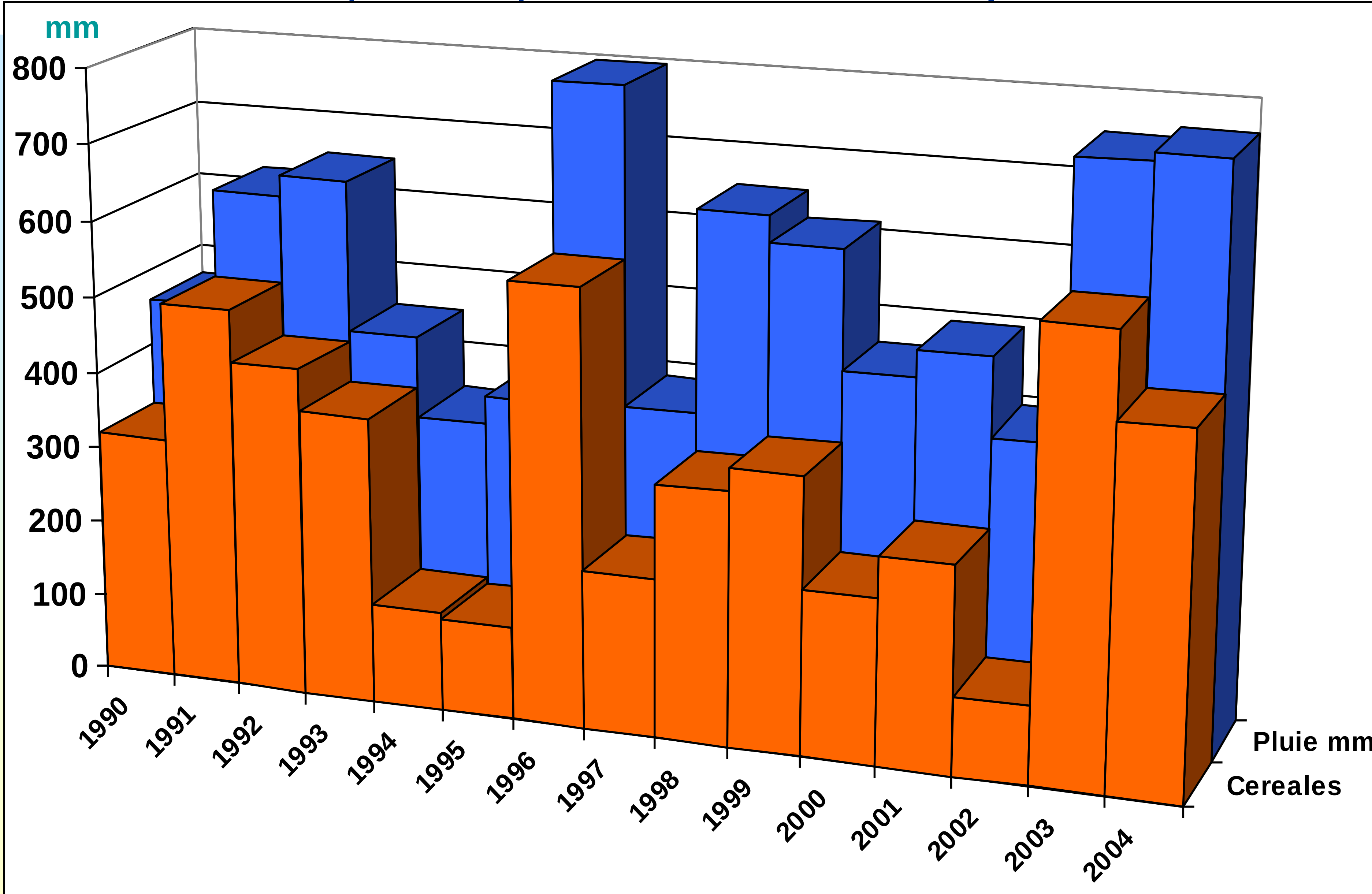
Cereals : Productions & Import (1000 tonnes)



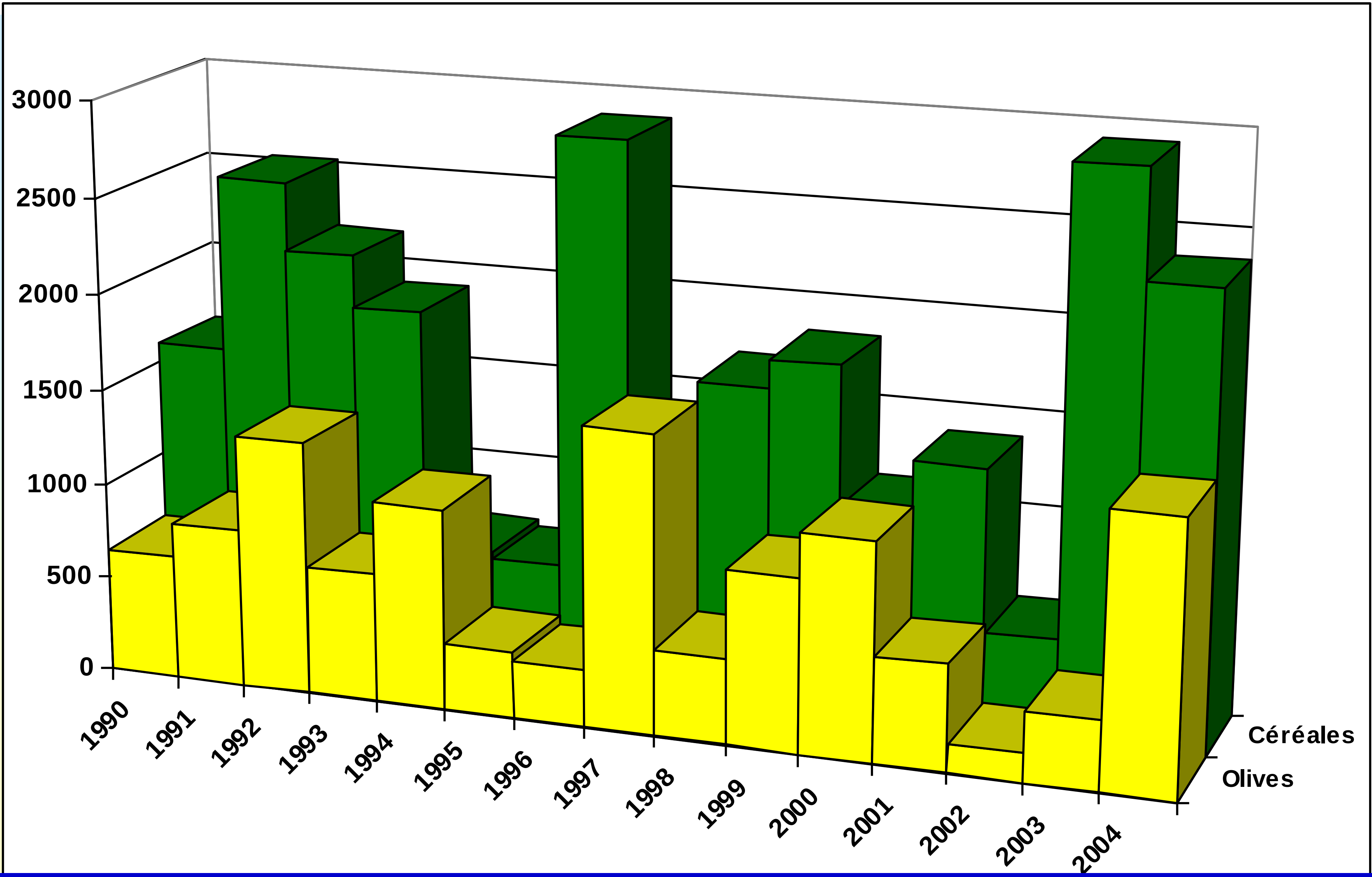
Source: Annuaire des statistiques agricoles , MARH.

Rainfall (North) versus cereals production



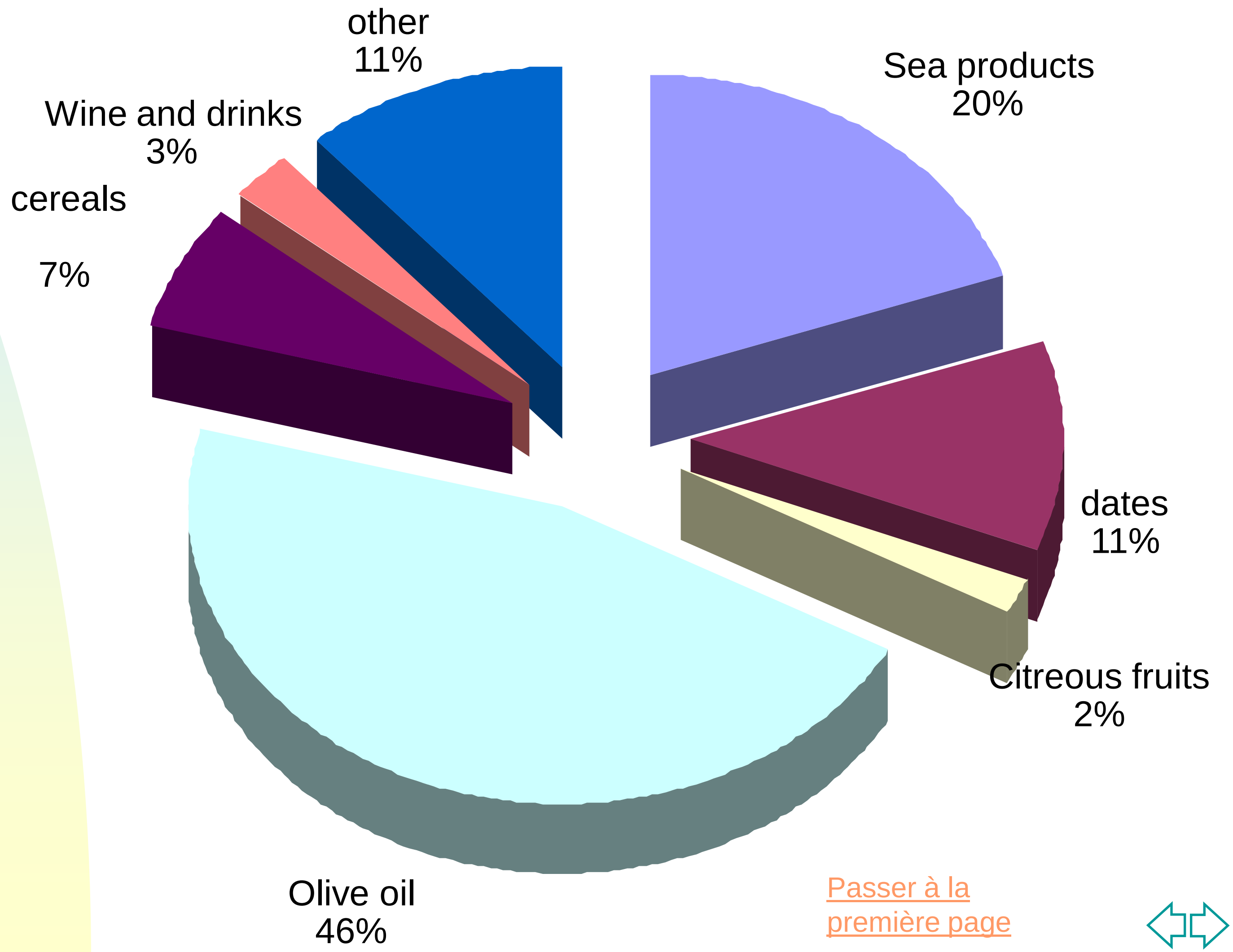
Source: Annuaires Pluviométriques , DGRE & Annuaire des statistiques agricoles , MARH.

Rainfed agriculture production (1000 tonnes)



Source: Annuaires des statistiques agricoles , MARH.

Foodstuffs exports in value [%]



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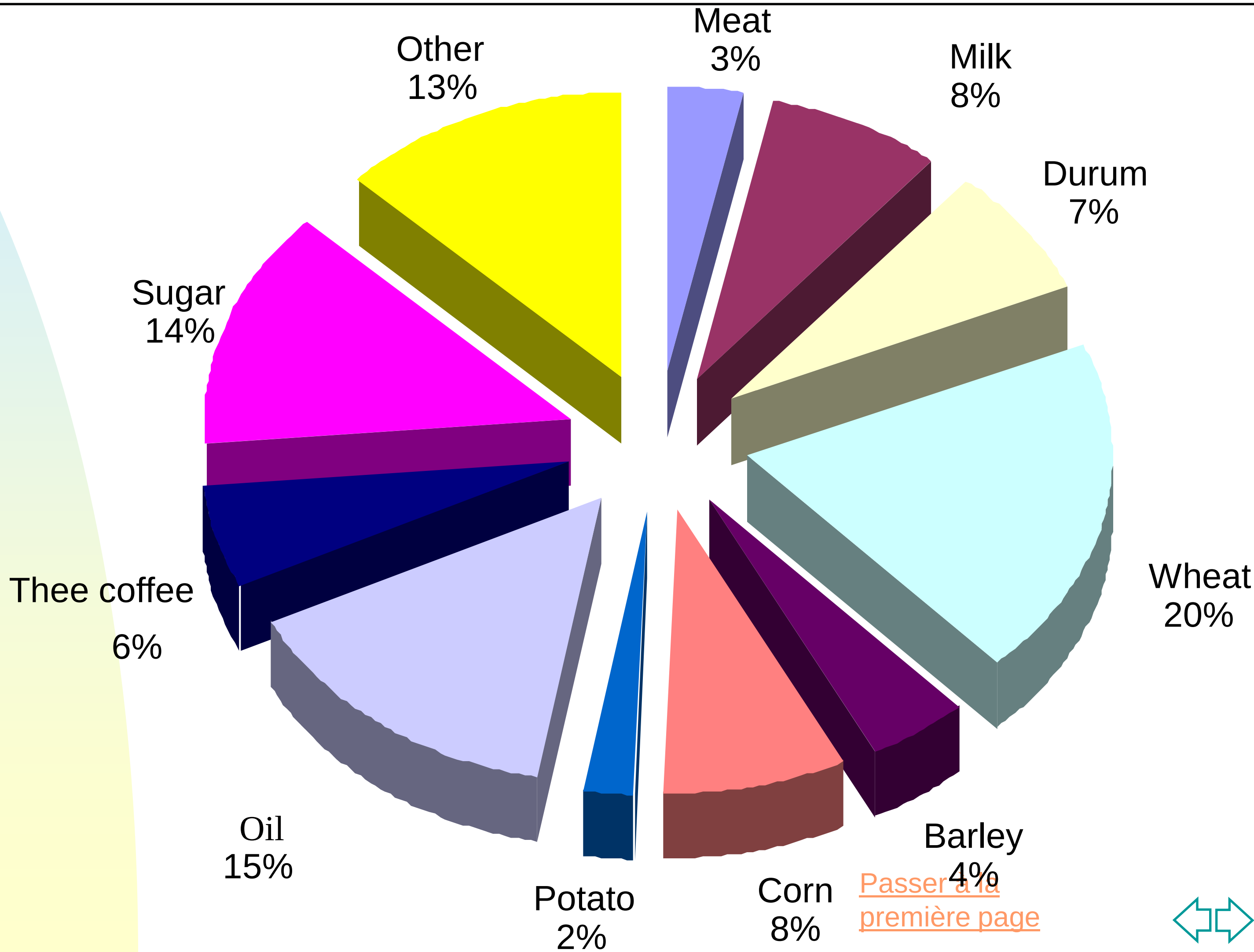
Foodstuffs imports in value [%]



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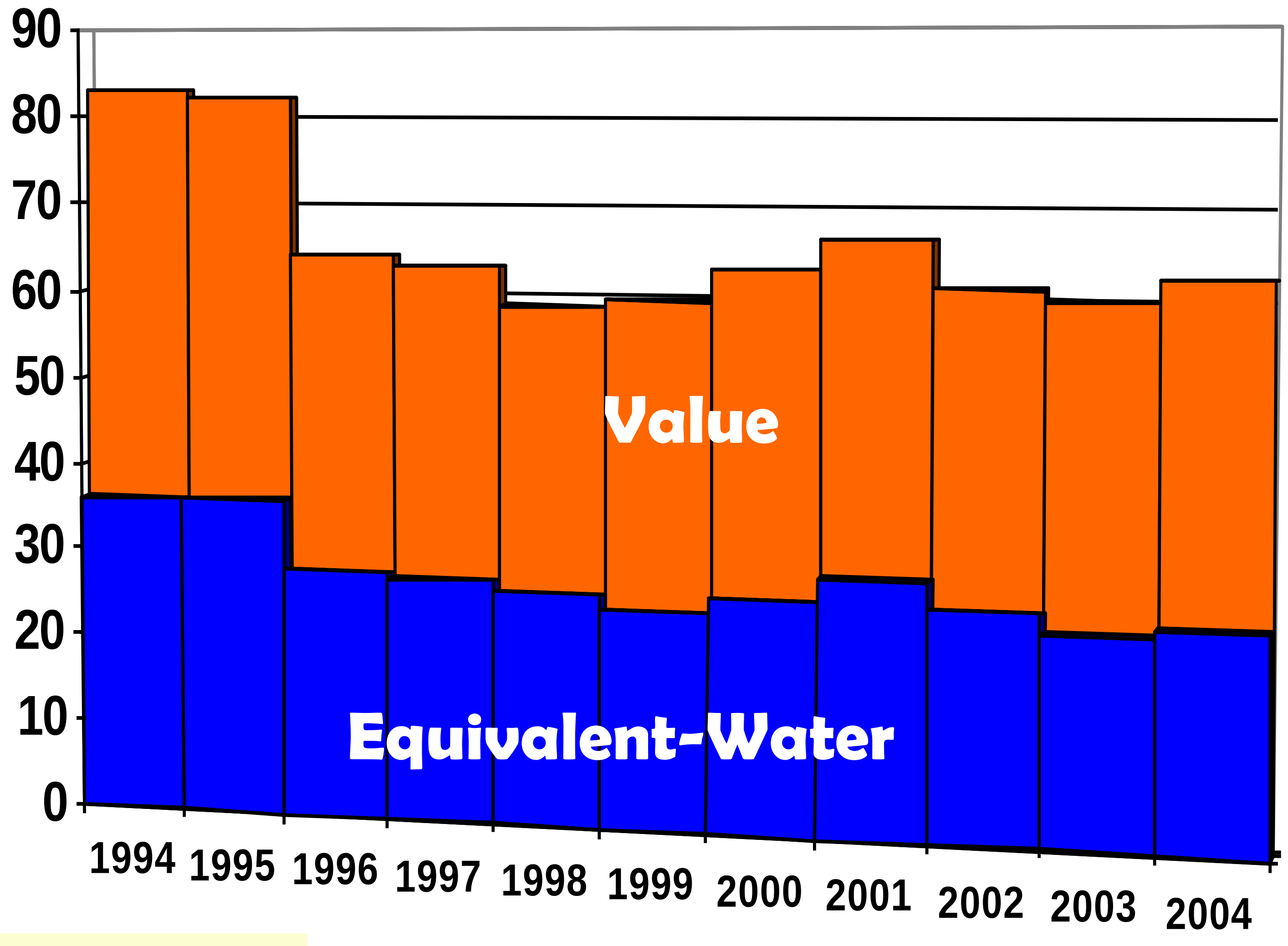
Coverage rate of foodstuffs trade balance [%]



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Global Water Demand in average year

Sector	Water demand 10^{9} m3/year
Irrigation	2,1
Rainfed agriculture [Green Water]	6
Deficit of food balance[Imported Vitual Water]	3,7
Urban [Cities, tourism]	0,4
Industry	0,1
Forests and Rangelands	5,5
Water Bank [Storage in dams for droughts]	0,6
Environment [conservation of humid areas]	0,1
Total Water Demand	18,5

Foodstuffs Demand (Equivalent-Water)

≈ 1/6 irrigated Agriculture (Bleu Water)

≈ 1/2 rainfed Agriculture (Green Water)

≈ 1/3 Foodstuffs import (Virtual Water)

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The established facts of water resource development and management in Tunisia

- **Water resources and food safety : An important part of withdrawal water «Blue Water» is used in agriculture (more than 80%)**
- **Mobilized «Blue Water» is stabilized and agricultural water allocations will be reduced**
- **Rainfed agriculture plays un important role in food security : the amount of equivalent water «Green Water» is considerable (~ 1/2 of foodstuffs water FP); its role in food trade balance is crucial : it contributes to 2/3 of the national agricultural production and 80% of the agricultural exports**
- **The foodstuffs balance indicates that the “Equivalent water” budget «Virtual Water» is important (~1/3 of foodstuffs water FP)**

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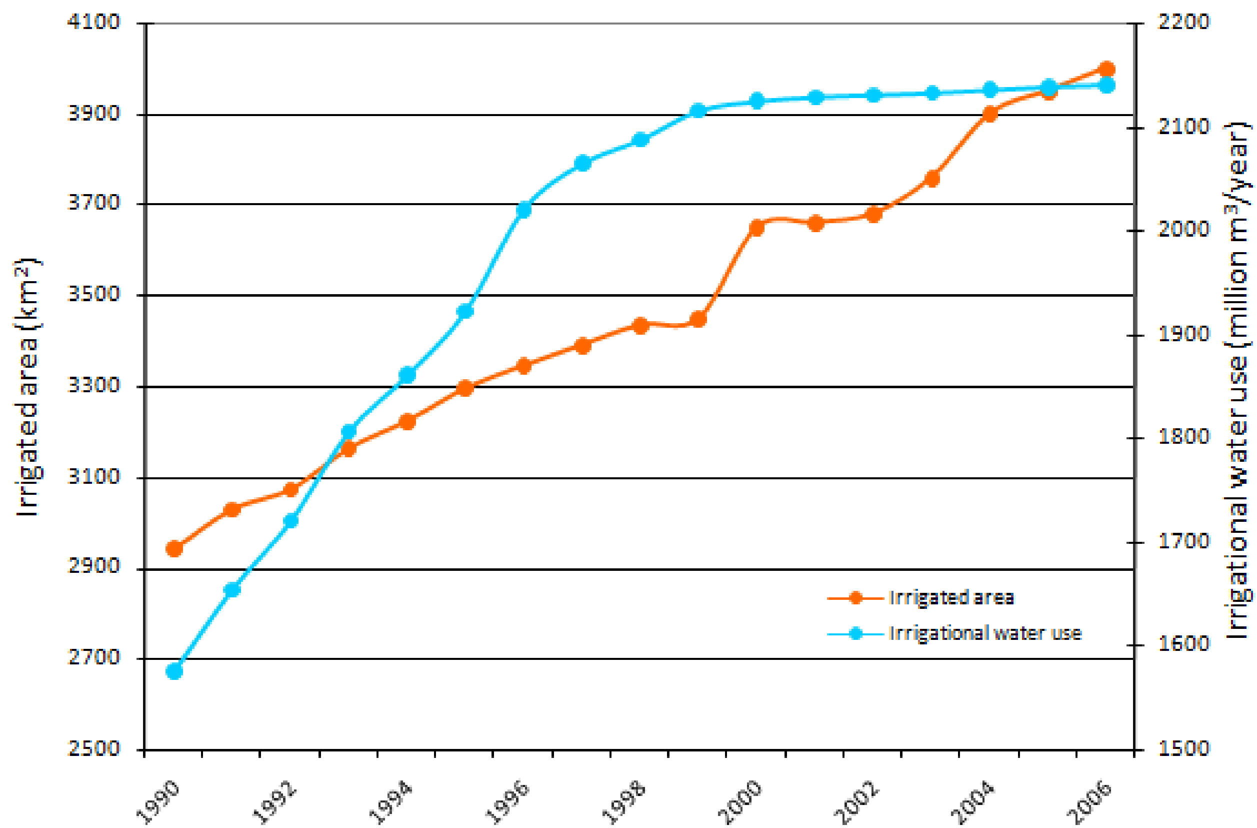
Trends in agricultural water use, 1990–2006

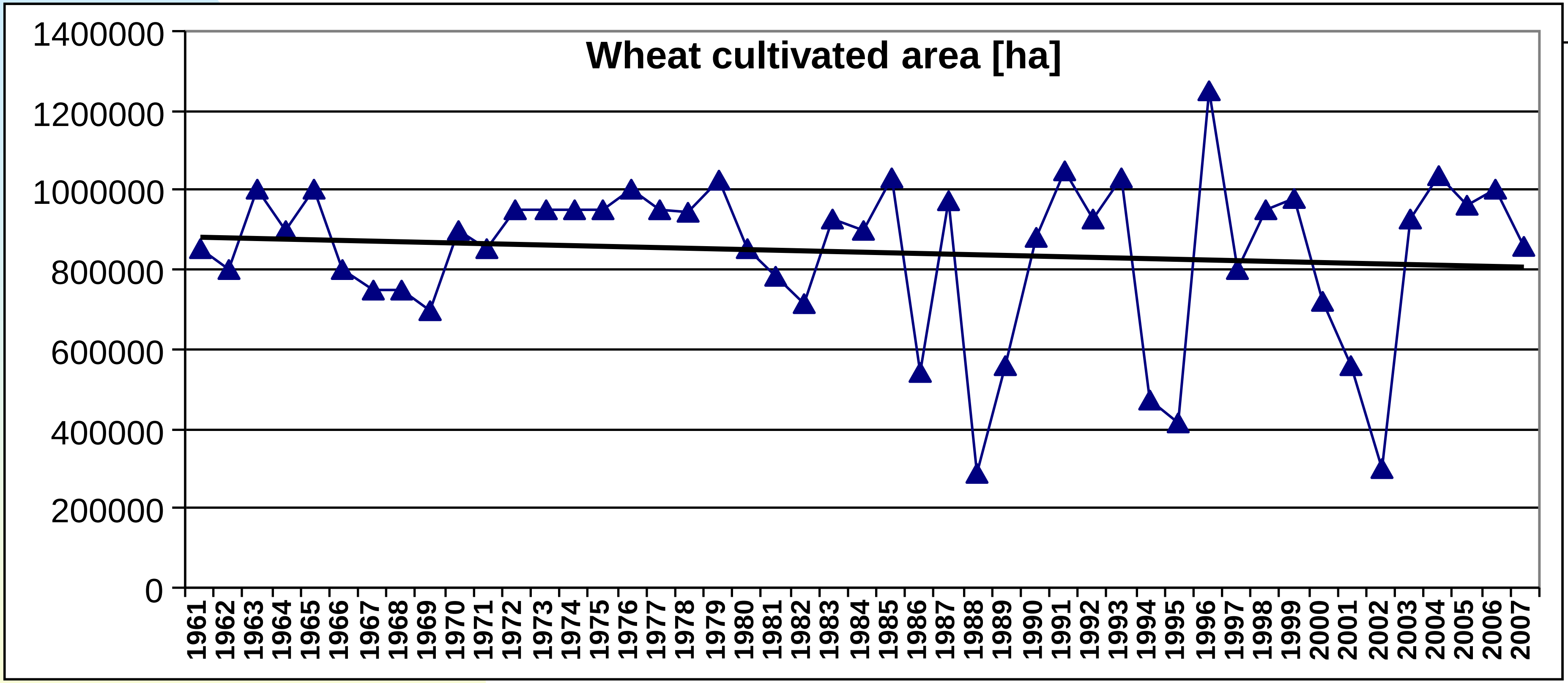


Eau 21 Projection

"Eau 21, Long term water strategy in Tunisia, 2030", Min. Agr., 1998

Year	1996	2000	2005	2010	2015	2020	2025	2030
Water use allocation m³/ha	6320	6020	5666	5323	5058	4809	4575	4355
Irrigated area ha	334700	353282	377968	402200	417285	433145	449825	467370

Rainfed agricultural evolution, 1960–2007



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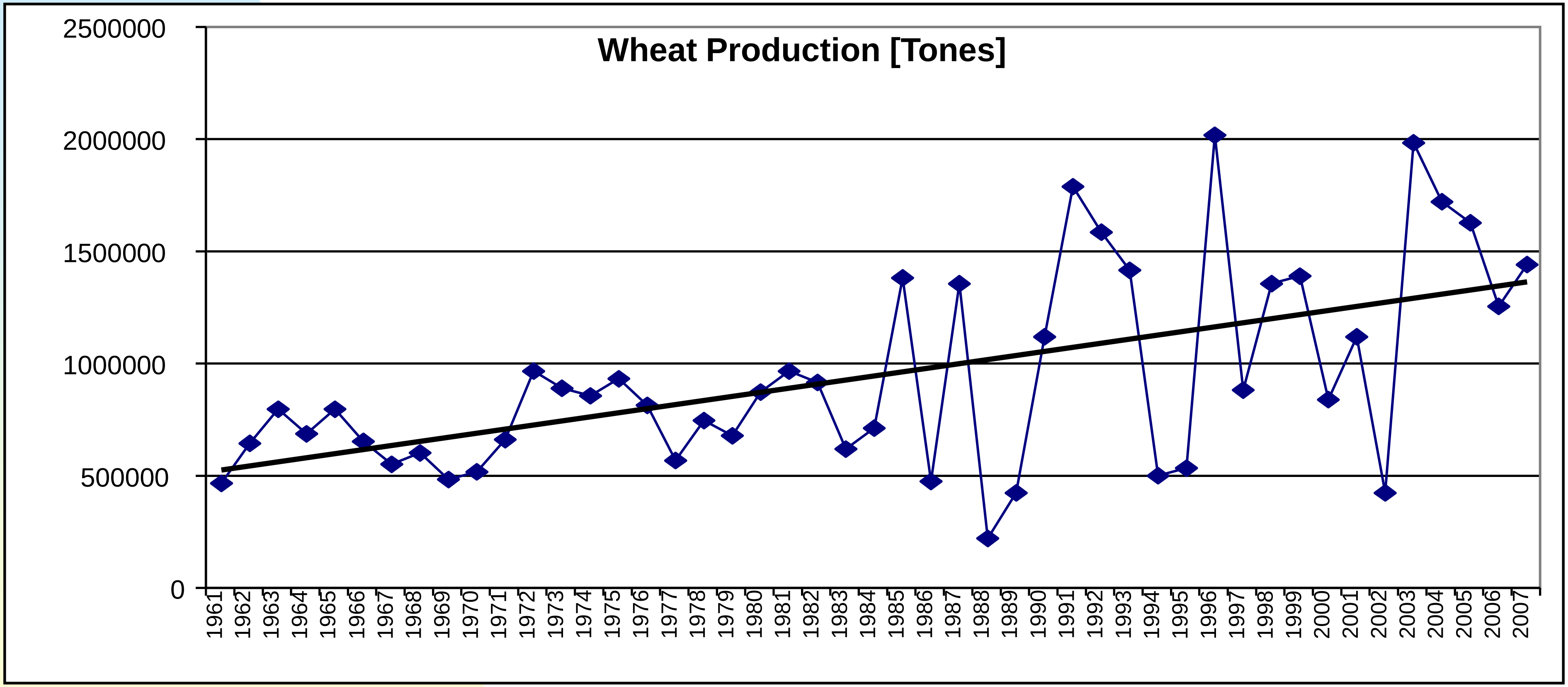
Rainfed agricultural evolution, 1960–2007



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Modeling long term water demand and resources

Trend Scenarios (horizons 2025 -2050)

Based on classic management of **«Blue Water»**

- Simulation 1 : optimistic

- drastic control of all water uses

- low increase water demand for direct uses

- low increase of the equivalent water of food demand

- Simulation 2 : realistic

- drastic control of all water uses

- reasonably increase of water demand

- improve in the equivalent water related to food demand

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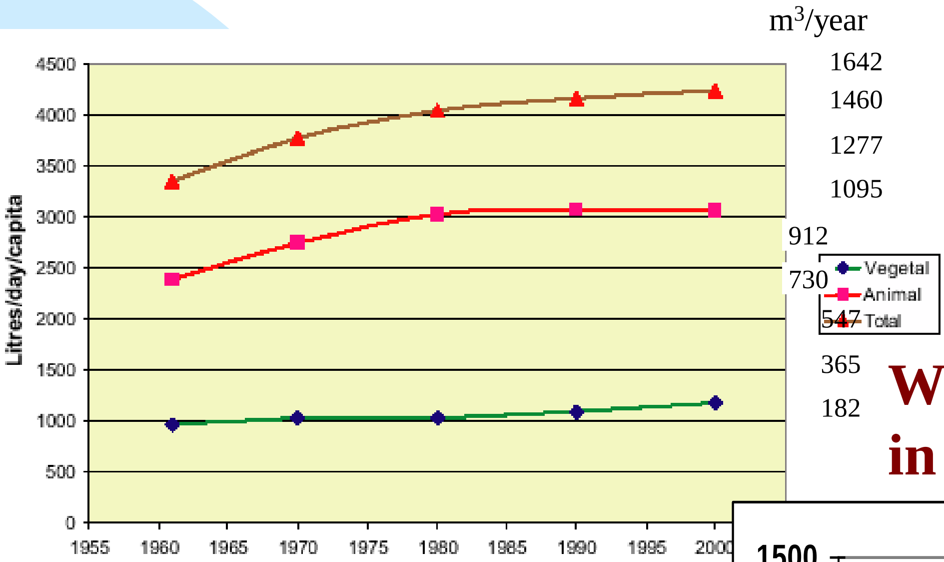
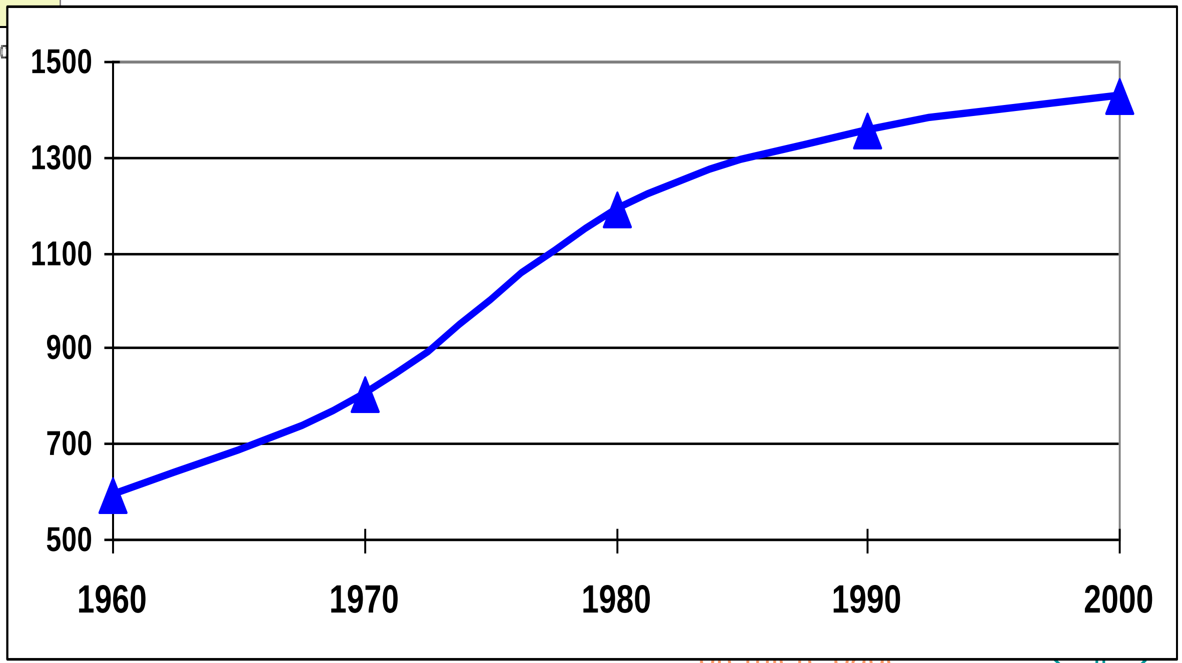
Water requirements for food production in Europe per Capita per year



Water requirements for food production in Tunisia per Capita per year



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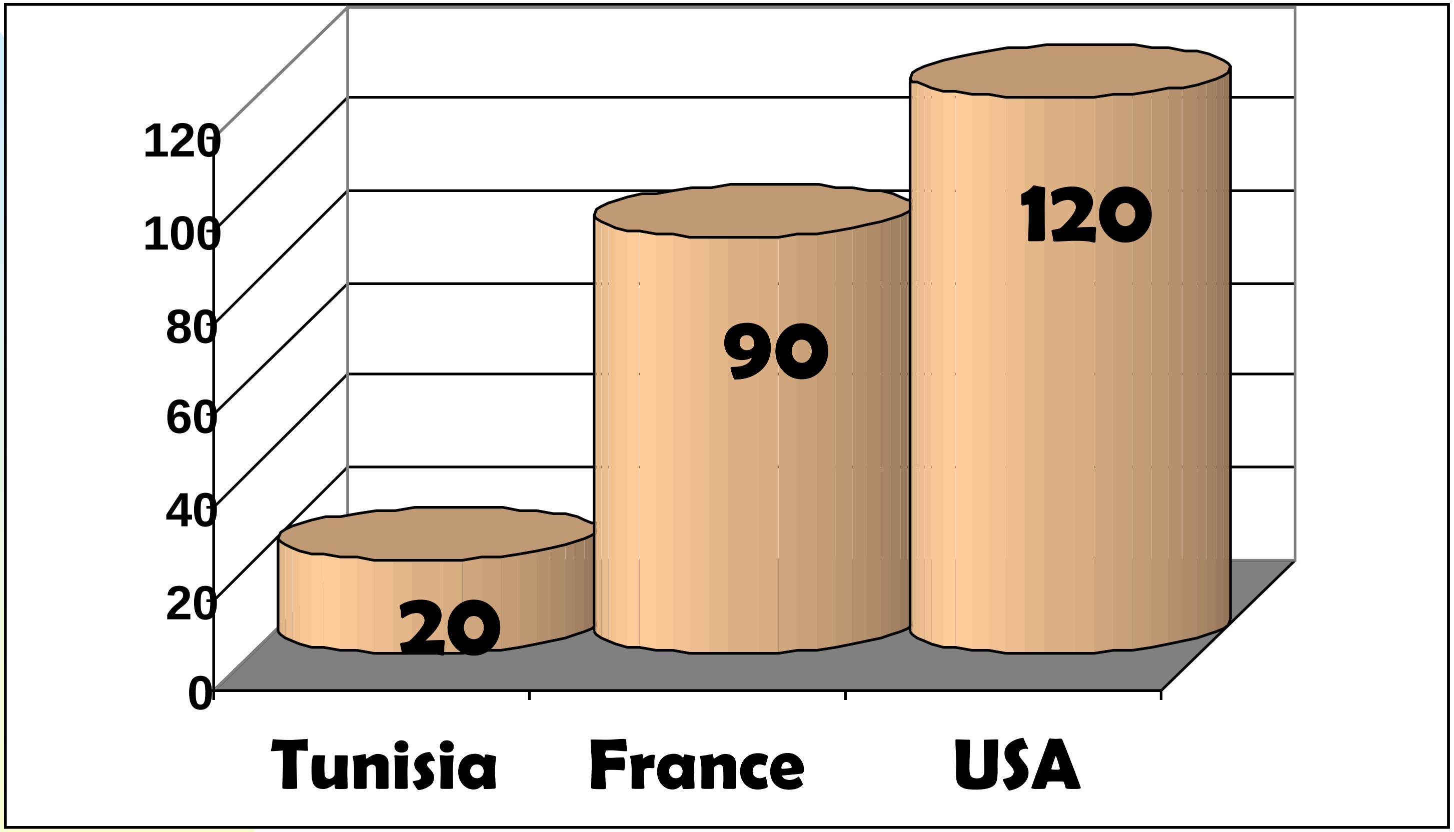
data : FAO www.fao.org/countryprofiles & INS Tunisie

Meet consumption kg/capita/year : (except fish an sea products), 2000



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Modeling long term water demand and resources

Sustainable Scenario (horizons 2025 -2050)

Based on a global water vision including (**Blue Water**, **Green Water**, **Virtual Water**).

- Hypothesis as in Simulation 2 : realistic

- drastic control of all water uses

- reasonably increase of water demand

- improve in the equivalent water related to food demand

- Concrete development of rainfed agriculture (Green Water)

-

λ

Modeling Food Demand Water Footprint

Irrigation Water Volume at constant flux

The direct demand (drinking water, industry) is incompressible and increases with the population.
Consequently, irrigation allowance is adjusted to the quantity of *blue water* available when the direct water demand has been satisfied :

$$IW = EWR - (1 - RI)DD - ENV$$

IW : Irrigation Water Volume
EWR : Exploitable Water Resources (EWR) **« Blue Water »**
DD : Direct Water Demand (collectivities, tourism, industry) ;
RI : Rate of Water Recycling
ENV : Environmental Water demand

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λ

Modeling Food Demand Water Footprint

$$VW = FD - GW - \lambda\underbrace{(EWR + (1 - RI)DD - ENV)}$$

Virtual Water

Green Water

Blue Water

FD : Equivalent Water Demand for Food

GW : Equivalent-Water of rainfed agricultural production « **Green Water** »

EWR : Exploitable Water Resources (EWR) **« Blue Water »**

DD : Direct Water Demand (collectivities, tourism, industry) ;

RI : Rate of Water Recycling

λ : Global Irrigation Factor

VW : Equivalent-Water deficit **« Virtual Water »**

ENV : Environmental Water demand

Dependency Rate of Food Demand (Equivalent-Water)

$$\rho = \frac{VW}{FD}$$

$$VW = FD / \rho$$

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Model validation 1996-2004

$$FD = GW + \lambda(EWR - (1 - RI)DD - ENV) + VW$$

Green Water — Blue Water — Virtual Water

	1996	2004
Population [10^6 habitants]	9,1	9.93
Exploitable Resource (EWR) [$10^6 m^3$/year]	2880	2500
Food demand, Eq. water [m^3/year/Capita]	1350	1450
Total food demand (FD) water[$10^6 m^3$/year]	12280	14399
Direct water demand [m^3/year/Capita]	45	55
Total direct water demand (DD)[$10^6 m^3$/year]	410	546
Reuse rate, RI	0.08	0.1
Total irrigation allocation (IW) [$10^6 m^3$/year]	2008	2008
Rainfed agriculture (GW) [$10^6 m^3$/year]	6500	8000
Conversion factor, λ	0,9	0.9
Deficit of food balance (VW) [$10^6 m^3$/year]	3982	4591
Total water demand	12695	14945
Rate of dependency	31%	31%

Modeling long term water demand and resources

Trend scenarios (horizon 2025)

$FD = GW + \lambda\underbrace{(EWR - (1-RI)DD - ENV)} + VW$	Model Adjustment 2004	Simulation 1	Simulation 2
Population [10^6 habitants]	9.93	12,15	12,15
Exploitable Resource (EWR) [$10^6 m^3$/year]	2500	2700	2700
Food demand, Eq. water [m^3/year/Capita]	1450	1600	1700
Total food demand (FD) water[$10^6 m^3$/year]	14399	19440	20655
Direct water demand [m^3/year/Capita]	55	60	70
Total direct water demand (DD)[$10^6 m^3$/year]	546	729	851
Reuse rate, RI	0.1	0,5	0,5
Total irrigation allocation (IW) [$10^6 m^3$/year]	2008	2336	2275
Rainfed agriculture (GW) [$10^6 m^3$/year]	8000	8000	8000
Conversion factor, λ	0.9	0,9	0,9
Deficit of food balance (VW) [$10^6 m^3$/year]	4591	9338	10608
Total water demand	14945	20169	21506
Rate of dependency	31%	46%	49%

Modeling long term water demand and resources

Trend scenarios (horizon 2050)

$FD = GW + \lambda\underbrace{(EWR - (1 - RI)DD - ENV)}{} + VW$	Model Adjustment 2004	Simulation 1	Simulation 2
Population [10^6 habitants]	9.93	13	13
Exploitable Resource (EWR) [$10^6 m^3$/year]	2500	2700	2700
Food demand, Eq. water [m^3/year/Capita]	1450	1700	1800
Total food demand (FD) water[$10^6 m^3$/year]	14399	22100	23400
Direct water demand [m^3/year/Capita]	55	70	80
Total direct water demand (DD)[$10^6 m^3$/year]	546	910	1040
Reuse rate, RI	0.1	0,5	0,5
Total irrigation allocation (IW) [$10^6 m^3$/year]	2008	2245	2180
Rainfed agriculture (GW) [$10^6 m^3$/year]	8000	8000	8000
Conversion factor, k	0.9	0,9	0,9
Deficit of food balance (VW) [$10^6 m^3$/year]	4591	12080	13438
Total water demand	14945	23010	24440
Rate of dependency	31%	52%	55%

Modeling long term water demand and resources

Sustainable scenario (horizons 2025 -2050)

$FD = GW + \lambda\underbrace{(EWR - (1-RI)DD - ENV)} + VW$	Model Adjustment 2004	Sustainable Scenario	
		2025	2050
Population [10^6 habitants]	9.93	12,15	13
Exploitable Resource (EWR) [$10^6 m^3$/year]	2500	2700	2700
Food demand, Eq. water [m^3/year/Capita]	1450	1700	1800
Total food demand (FD) water[$10^6 m^3$/year]	14399	20655	23400
Direct water demand [m^3/year/Capita]	55	70	80
Total direct water demand (DD)[$10^6 m^3$/year]	546	851	1040
Reuse rate, RI	0.1	0,5	0,5
Total irrigation allocation (IW) [$10^6 m^3$/year]	2008	2275	2180
Rainfed agriculture (GW) [$10^6 m^3$/year]	8000	10000	12000
Conversion factor, λ	0.9	0,9	0,9
Deficit of food balance (VW) [$10^6 m^3$/year]	4591	8608	9438
Total water demand	14945	21506	24440
Rate of dependency	31%	40%	39%

Prospects for the improvement of the global water balance

- **Enlargement** of the **Water Resource** notion to all kind of the contributions to the **Global Water Balance** : «**Blue Water**», «**Green Water**», «**Virtual Water**», «**Non-conventional Water**».
- **Enlargement** of the **Demand Management** notion to all kind of water uses including the water requirements for food demand
- **Optimization** of all water uses including the water involved in the rainfed agriculture production «**Green Water**», and in the international trade exchange «**Virtual Water**»,

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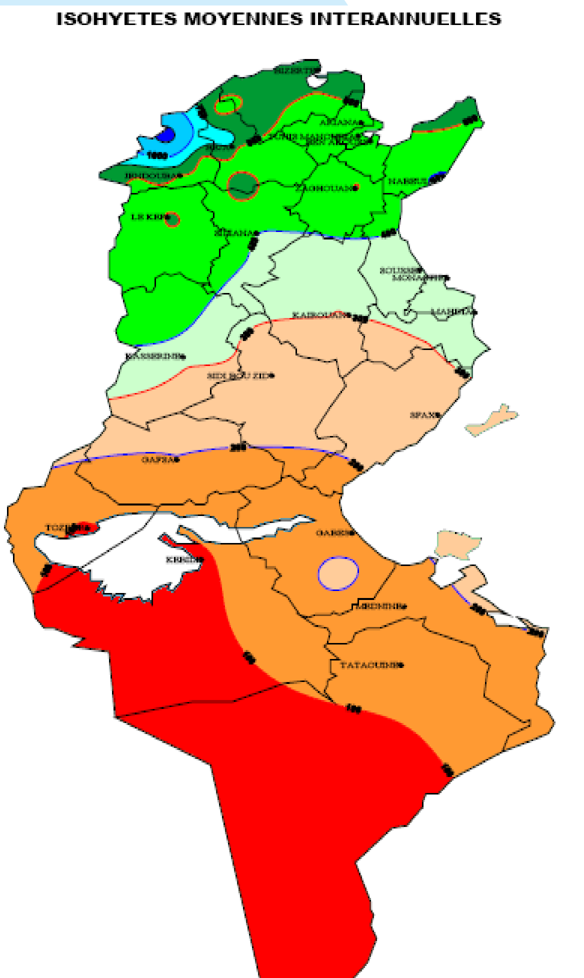
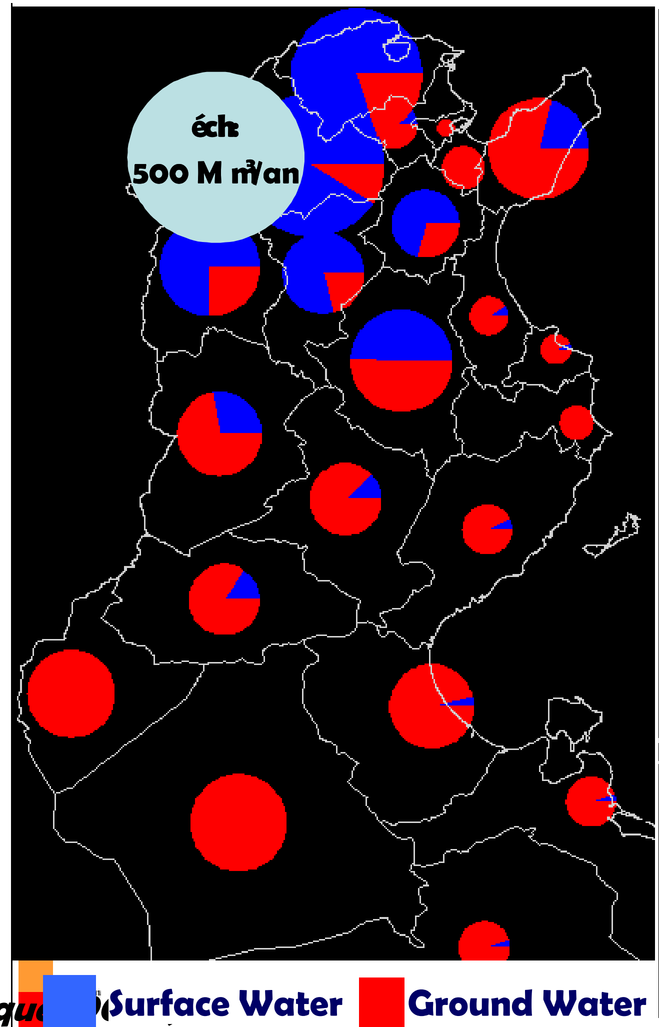
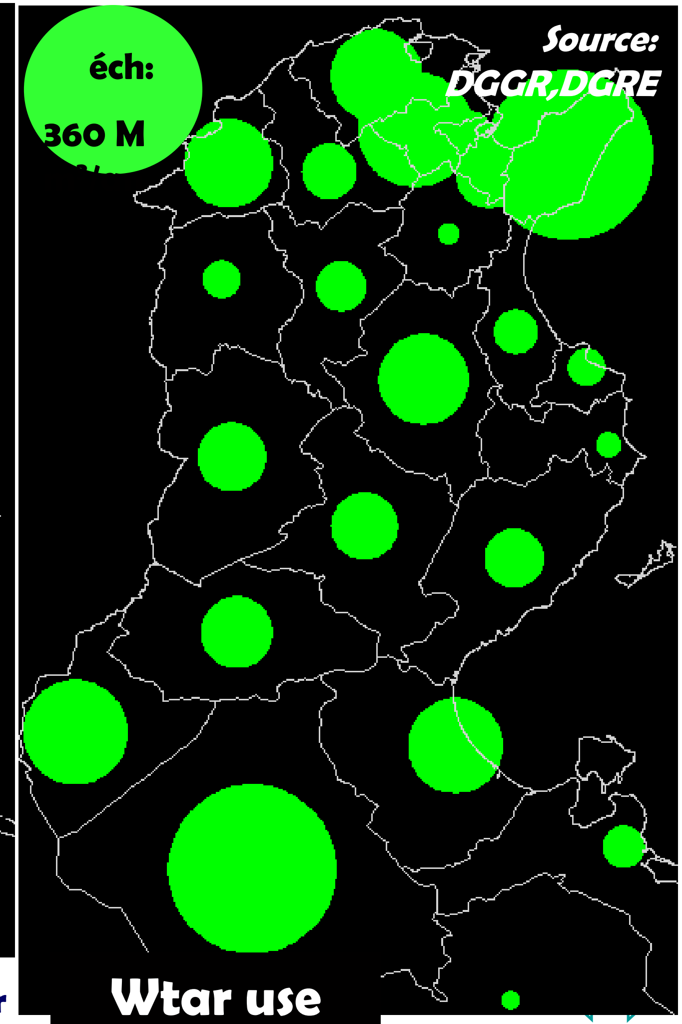
Some progresses in the global water vision, may be achieved by taking into account:

- the disparities between the regions of the country
- the inter-annual variability of water resources
- Water quality constrains : salinity, reuse of treated water, over exploitation…

Disparities between the regions

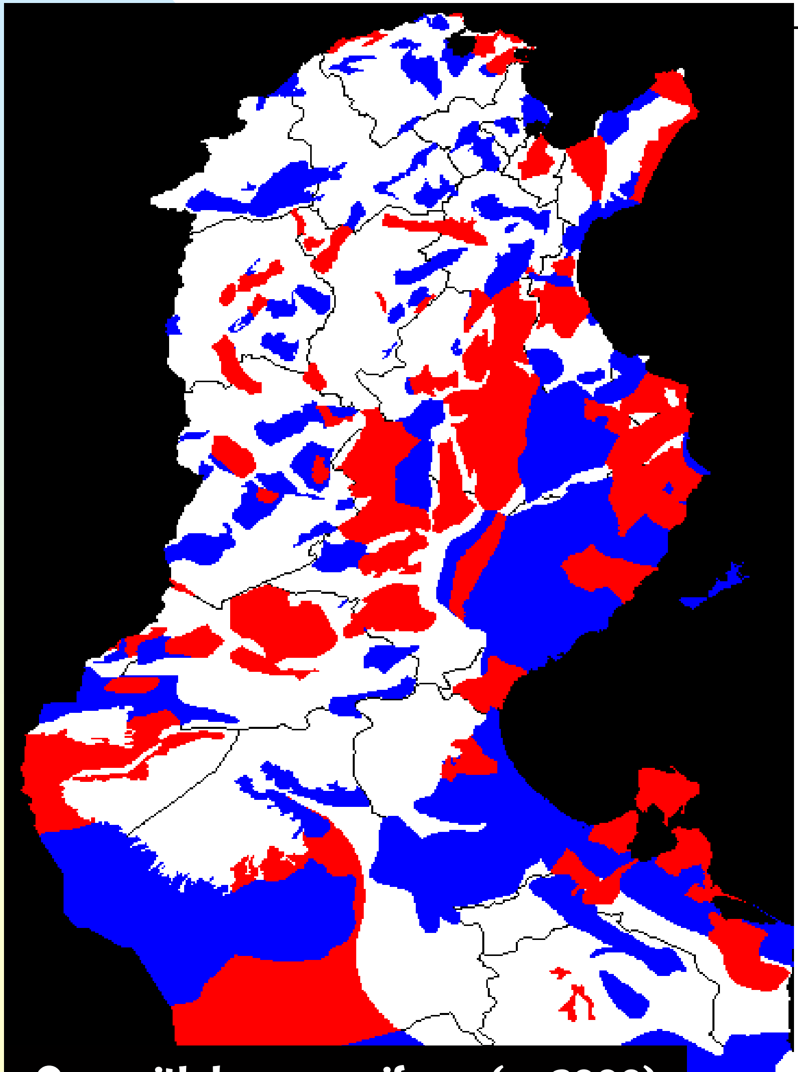




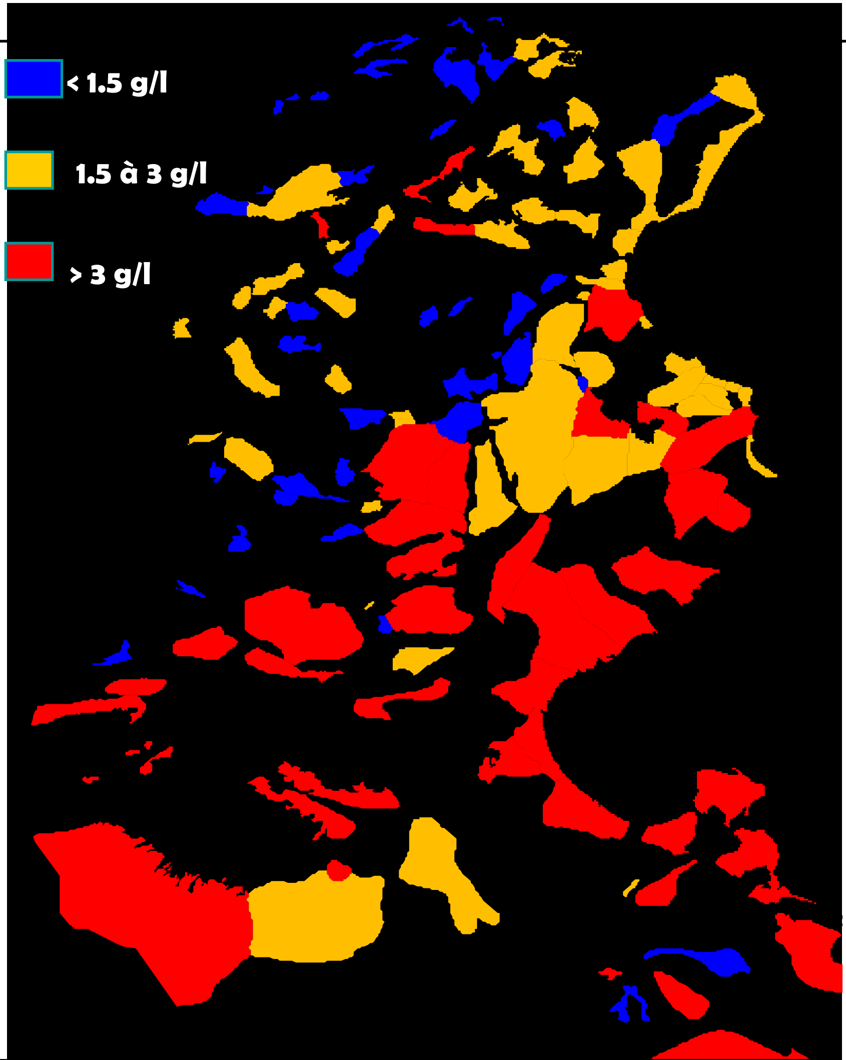


L.Frigui & Annuaire Hydrologique

Water quality constrains



Over withdrawn aquifers (en 2000)



Salinity of water table aquifers

Ongoing research: Global Water balance regionalization *[Region (i) ; Water quality (k)]*

Equivalent-water of foodstuffs production

$$FD = \sum_i \left[GW_i + \sum_k \left[\lambda_{ki} \left[EWR_{ki} + \sum_j [I_{kij}] - DD_{ki} - ENV_{ki} \right] + \lambda_{EU\,ki}(1 - IR_{ki})DD_{ki} \right]\right] + VW$$

Green Water **Blue Water** **Virtual Water**

FD : Equivalent Water Demand for Food

GW_i : Equivalent-Water of rainfed agricultural production « **Green Water** »

EWR_{ki} : Exploitable Water Resources (EWR) « **Blue Water** »

DD_{ki} : Direct Water Demand (collectivities, tourism, industry) ;

RI_{ki} : Rate of Water Recycling

: λ_{ki} λ_{EUki} Irrigation Factors for fresh and recycled agriculture water use

VW : Equivalent-Water deficit « **Virtual Water** »

ENV_{ki} : Environmental Water demand

I_{ij} is the volume transferred from region (j) to region (i) that verifies :

$I_{ij} = -I_{ji}$ et $I_{ii} = 0$ so that: $\sum_i \sum_j I_{ij} = 0$

Conclusions

The Tunisian case study illustrates how:

- “blue water”, “green water”, and “virtual water” are interlinked and constitute the entirety of the water cycle at a national scale
- this general analysis acquires a particular and timely relevance in countries that have limited water resources and that have mobilized a large share of their resources.

This aspect of the issue should

- call into question certain established concepts, such as the definition of water resources, water stress, water policies, integrated water resource management, and demand management,
- require more investigations in order to precise the different elements of the global water resource balance particularly the accurate assessment of green water potential

Ongoing research : Green Water assessment

Rainfall variablity – climate change impacts ?

Equivalent-water of foodstuffs production

$$FD = \sum_i \left[GW_i + \sum_k \left[\lambda_{ki} \left[EWR_{ki} + \sum_j \left[I_{kij} \right] - DD_{ki} - ENV_{ki} \right] + \lambda_{EU\,ki} (1 - IR_{ki}) DD_{ki} \right] \right] + VW$$

Green Water **Blue Water** **Virtual Water**

GW_i : Equivalent-Water of rainfed agriculture « **Green Water** »

To be evaluated according the cultivated aeras and rainfall in region (i)

$$GW_i = k_{ev\,i} P_i S_i$$

For olive trees in the region of Sfax

$$k_{ev} \approx 0{,}64$$

But the transformation of rainfall-green Water is not necessary linear ?

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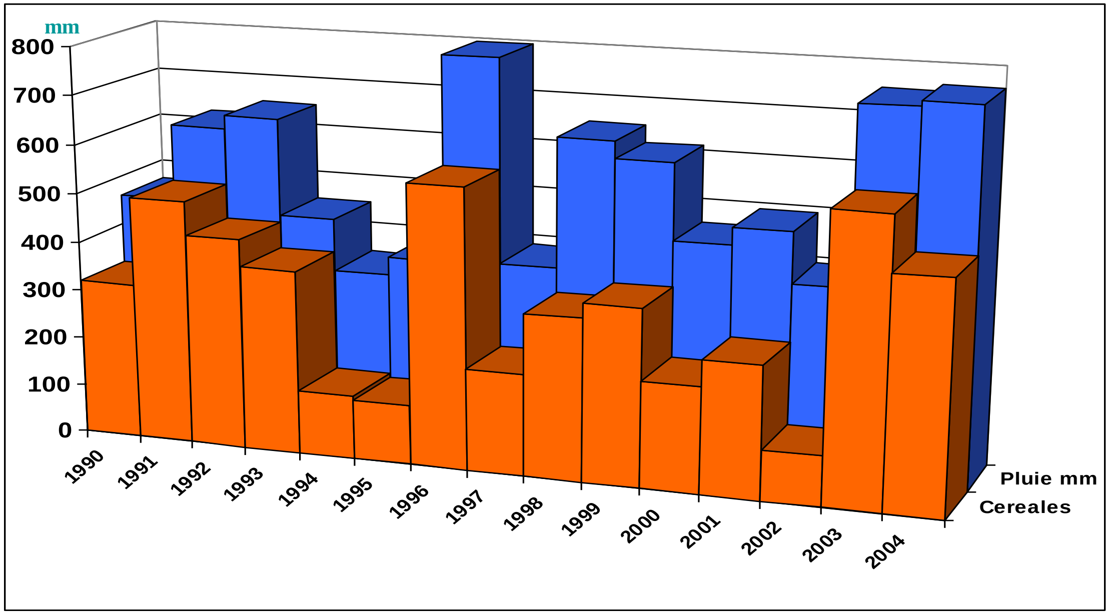
Ongoing research : Green Water assessment

Rainfall variablity – climate change impacts ?

But the transformation of rainfall-green Water is not necessary linear ?



For a given hydrologic condition (h)

$$GW(h) = k_{EV}(h)P(h)S \ ?$$

$$\overline{GW} = \int k_{EV}(h)P(h)Sf(h)dh$$

where f(h) is the pdf of the hydrologic condition (h)

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