WORKING PAPER

NOVEMBER 2012

WORKING PAPER 2012/1

Vulnerability to drought in a closed basin: the Guadalquivir case

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Language: English

Project denomination: CIRCLE-2

UNIVERSIDAD DE CÓRDOBA

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Working paper. Dpto Economia Agraria Universidad de Córdoba presented at CIRCLE-2 SHARE Workshop Responses to Extreme Water related Events (Madrid, Nov 2012)

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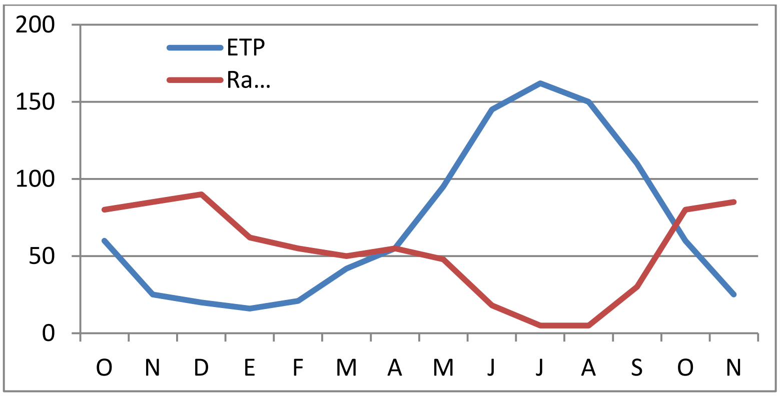
1. Introduction

Irrigation is considered by FAO as a key instrument to make possible the production of food to maintain planet population, World irrigated crops produce 40% of agricultural products in 227,0 million ha (18% of cultivated area), Spain with 3,5 million ha (17% of cultivated land) produces 60% of final agricultural product, and Andalucía 1 with 1 million ha (20% of cultivated land) produces 65% of final agricultural product, Guadalquivir with 850.00 ha of irrigated crops being the most important basin in Andalucía.

The need of irrigation in Mediterranean climates is a consequence of natural advantages and disadvantages of the climate. Figure 1 shows ETP and rain in Cordoba (located in the middle of Guadalquivir river basin).

Figure 1 shows ETP and rain in Cordoba



Source: Own elaboration

Irrigation is developed because of beneficial effects on economic systems:

- Irrigation to increase production and profit
  - New crops are available
  - Higher yields of crops irrigated versus rain fed

- Irrigation to reduce risk
    - More stable production (yields stabilized)
    - More crops available (risk diversification)

Irrigation makes possible these beneficial effects by moving water from:

- Winter to summer
- Wet to dry years
- Mountains to valleys
- Less to highly productive areas

Guadalquivir can be illustrated as an example of extreme events (especially droughts) adaptation and impact in a Mediterranean basin. Table 1 illustrates the differences in productivity in Guadalquivir rain fed and irrigated crops, and also a northern Spain river basin with much lower productivity.

Table 1: Economic functions of irrigation

Indicators	Duero			Guadalquivir		
€/ha-year	Rain fed	Irrigated	Irr/Rf	Rain fed	Irrigated	Irr/Rf
Gross margin	265,4	831,4	313%	627,2	2.653,6	323%
Subsidies	245,1	312,0	127%	308,3	969,9	215%
GDP	20,4	519,3	2.546%	118,9	1.683,7	1.317%

Source: Gomez-Limon et al (2007)

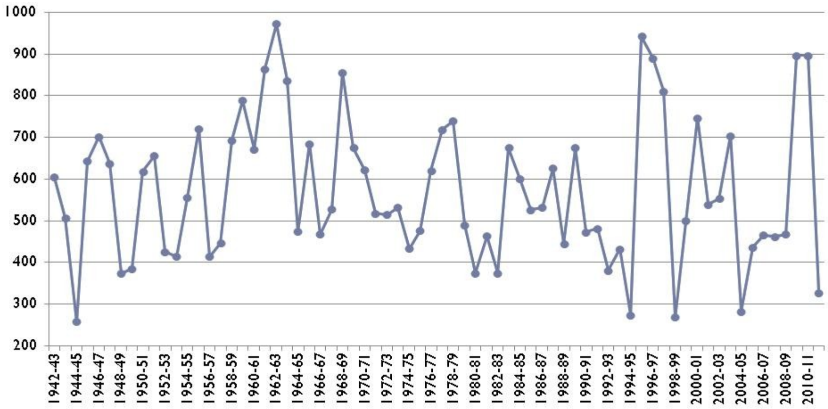
2. Case study

Guadalquivir River is the longest river in southern Spain with a length of around 650 km. Its basin covers an area of 57,527 km^2 and a population of 4.1 million. The basin has a Mediterranean climate with an heterogeneous precipitation distribution. The annual average temperature is 16.8 °C, and the annual precipitation averages at 573 mm, with a range between 260 mm and 983 mm (standard deviation of 161 mm). The average renewable resources in the basin amounts to 5,754 GL/year, ranging from a minimum of 372 GL/year to a maximum of 15,180 GL/year (Arguelles *et al.*, 2012). In a normal year a potential volume of around 8,500 GL can be stored through a complex and interconnected system of 65 dams. The main land uses in the basin are forestry (49.1%), agriculture (47.2%), urban areas (1.9%) and wetlands (1.8%) (Arguelles et al (2012).Water consumption from all sectors has increased since the last Hydrological Basin Plan (1998). For instance, urban consumption grew from 297 L/person per day in 1992, to 323 L/person per day in 2008 (CHG, 2012). However, although water demand from urban and industrial sectors increased, irrigated agriculture is still responsible for around 87% of total consumption.

The last dams, finished a few years ago, increased the regulation capacity of the basin from 7,145 GL to 8,562 GL per year (Arguelles *et al.*, 2012). Additionally, there is an important natural groundwater regulation capacity of 2,720 GL per year. The combined surface (reservoirs) and groundwater reserves amount to 140% of average renewable resources, but this is not sufficient if precipitation is scarce for more than two consecutive years. In that case, measures are activated according to the Special Drought Awareness and Mitigation Plan introduced provisionally in 2005 (because the existence of a drought) and approved finally in 2007 (CHG, 2007)

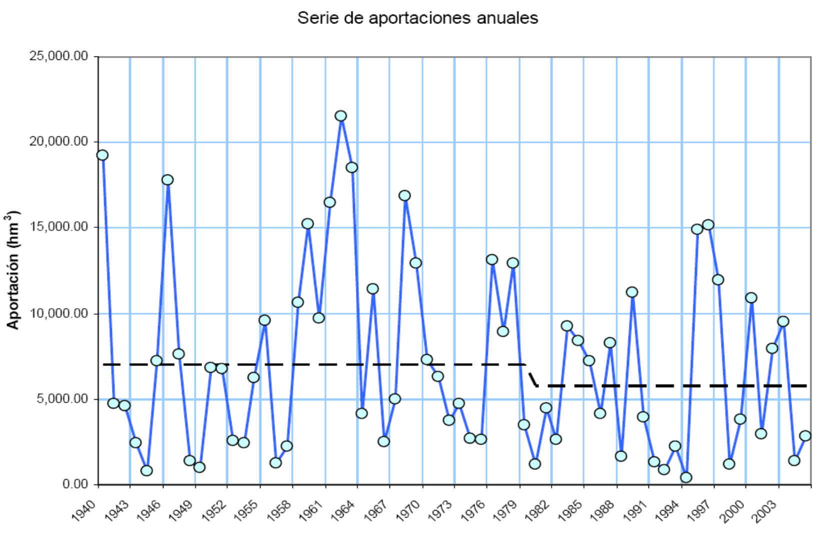
Figure 2 shows the average rain in the basin and figure 3 illustrates the annual renewable resources; table 2 illustrates the enlarged variability of resources compared to rain.

Figure 2 Average rain in Guadalquivir basin



Source: own elaboration

Figure 3: Average renewable resources



Source: Basin Hydrological Plan (CHG, 2012)

Table 2: Annual average, maximum minimum rain and renewable resources

	Media	Max	Min	Des.tip	CV
Rain (mm)	536	849	280	158	0,29
	100%	*158%*	*52%*	*29%*	
Resources (hm^3)	5.754	15.180	372	4.532	0,79
	100%	*264%*	*6%*	*79%*	

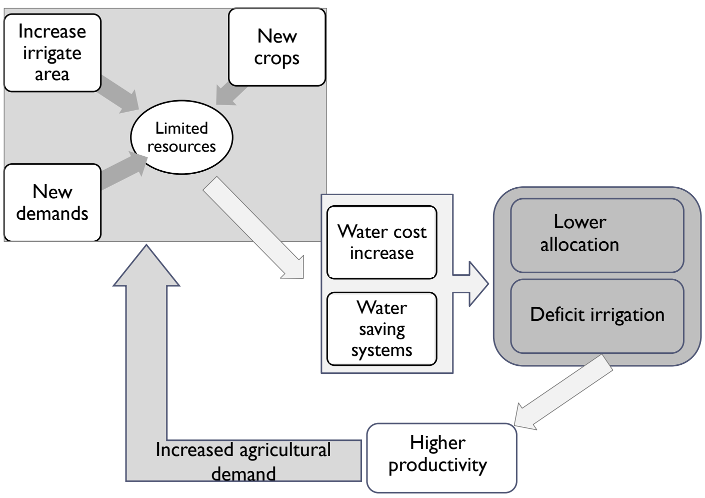
Source: Arguelles et al (2012)

3. Recent evolution of Guadalquivir river basin

The Guadalquivir River Basin has been managed through a centralized and hierarchical system for almost 80 years, which facilitated the evolution of a large and profitable agricultural sector that in turn has driven the basin towards closure.

Figure 4 taken from Berbel et al (2012) makes an scheme of basin development, these authors distinguish the following elements in the evolution towards closure: 1) Decreasing farm income; 2) Increase in irrigated area and factor intensification as a response to this; 3) Expansion of irrigation to formerly rain fed crops (i.e. olive groves); 4) New demand from other sectors; 5) Increase in environmental flow control; 6) Reduction in water allocation; 7) Increase in water costs; h) Introduction of water saving technologies; 8) Mainstream adoption of deficit irrigation; and 9) Administrative basin closure. The push towards water saving and efficiency increases is now leading to the emergence of two new driving forces: 10) Increase in water productivity and 11) More inelastic irrigation demand, which, paradoxically, could lead to higher vulnerability to extreme events as well as a further increase in water consumption.

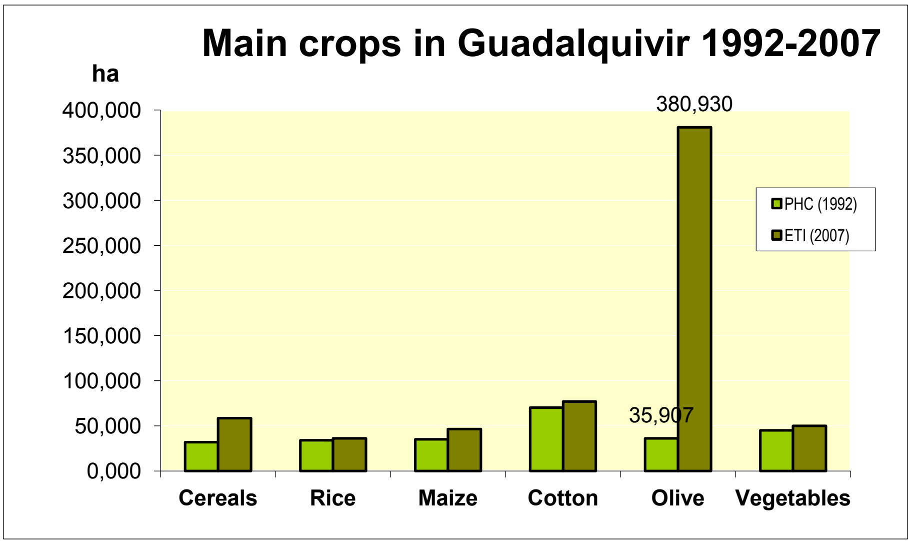
Figure 4: Schematic representation of basin evolution



Source: Adapted from Berbel et al (forthcoming)

Although most of the drivers, pressures and processes are common among other closed basins around the world, three factors make the Guadalquivir distinct: the cultivation of high-value irrigated Mediterranean crops, a predominance of deficit irrigation and a large investment in water saving technologies. Figure 5 shows the evolution of main crop irrigated area in Guadalquivir.

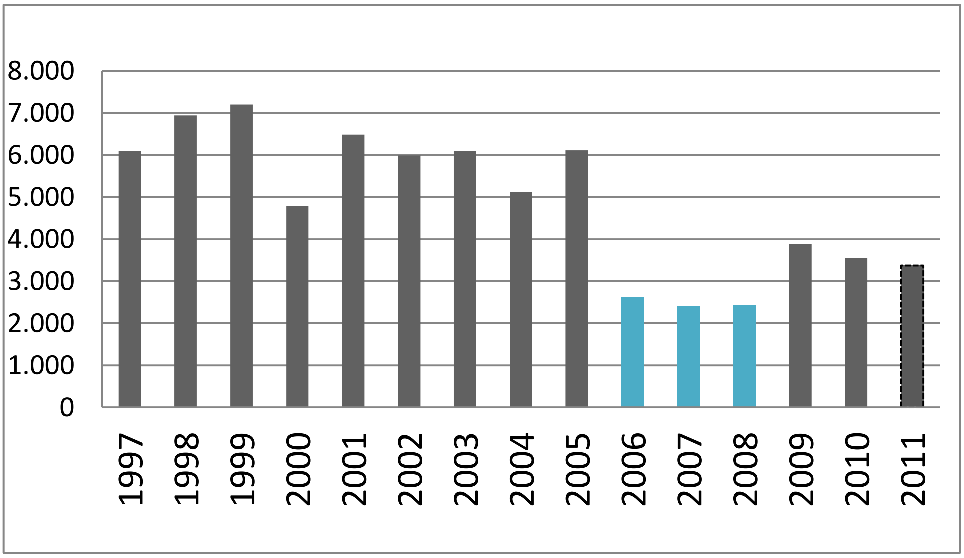
Figure 5: Crop evolution in Guadalquivir



Source: own elaboration from CHG (2012)

The consequence of this change in crop pattern and the need to adaptation to growing scarcity has driven the basin towards a generalized use of deficit irrigation. Berbel et al (2011) estimate average global RIS ratio in 0.72 for the whole basin in 2005. Figure 6 illustrates the average water use in the basin 1997-2011.

Figure 6: Average irrigation doses (m^3/ha)

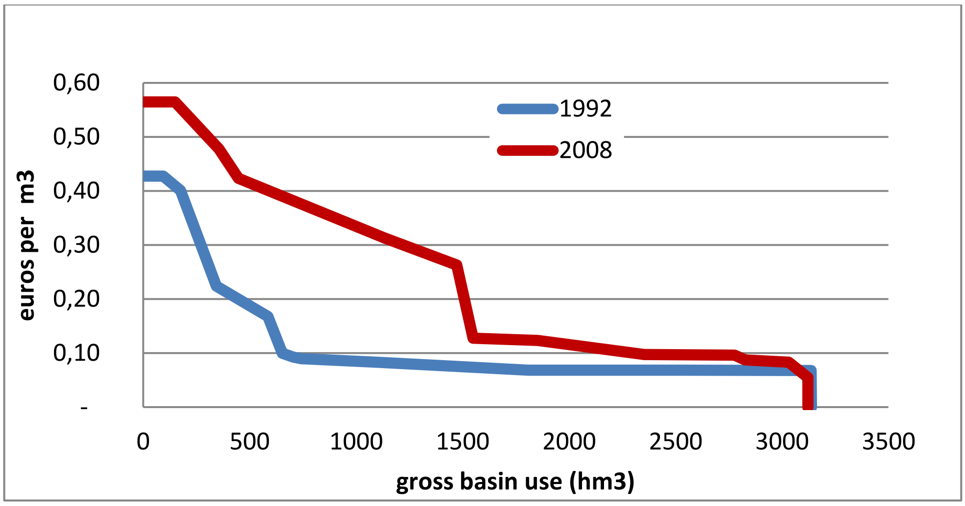


Source: own elaboration from CHG (2012)

The consequence of this change is an increase in water productivity. Carrasco et al (2010) estimate that between 1989 and 2005 Gross Added Value increased from 0.15 Euros/m^3 to 0.50 Euros/m^3, water use per hectare decreased by 40% and Global water use increased by 16%.

Figure 7 estimates crop distribution and average consumption for years 1992 and 2008, in both years according to the official data (Hydrological Plan 1998 and Draft Hydrological Plan 2012). Figure 8 graphically shows the cumulative distribution of net margin base 2008).

Figure 7: Water value (net margin) Guadalquivir 1992-2008



Source: Own elaboration

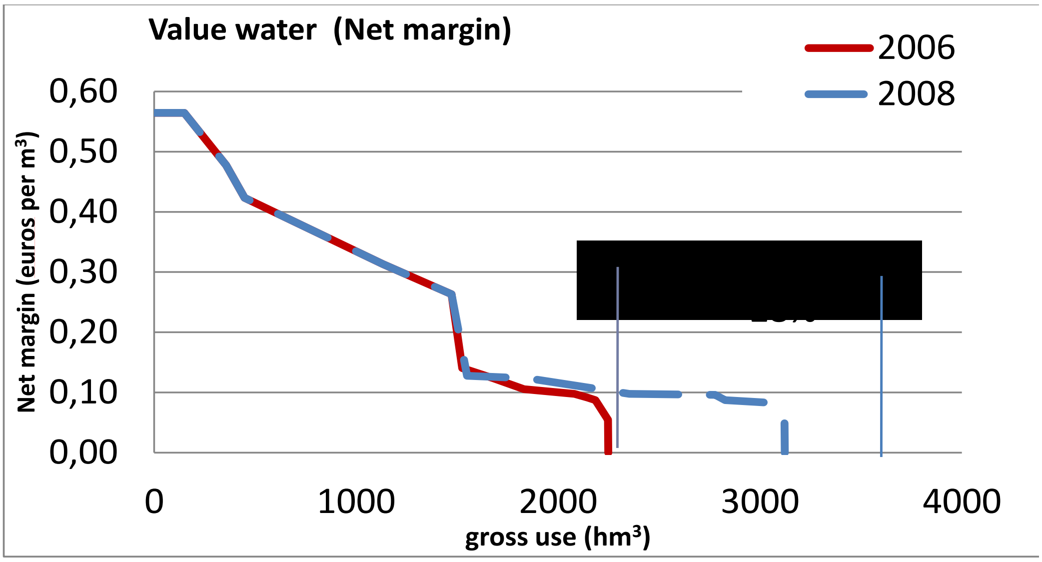
4. Impact of the drought 2005 2007

According the MIMAM (2000) the most dramatic drought in centuries XIX and XX are concentrated in the periods: Oct.1941 to Sept.1945, Oct.1979 to Sept.1983 and Oct.1990 to Sept.1995. The most recent long period of drought was during years 2005 to 2007 when most Spanish regions)suffered a drought when the strategy to develop awareness and management plan for drought was starting to be implemented, this is why some advanced measures were designed 'ad hoc' and later integrated in the management plans (CHG 2007). A report from the Ministry (MIMAM, 2008)) summarised main impacts of 2005-2007 drought concluding that there were not any relevant impacts either in urban supply or in environmental flows that belonged to the higher level of use hierarchy. Only agriculture suffered real reductions in the supply that amounted to 50% of average water rights during the campaigns ending in 2006, 2007 and 2008 in the case of Guadalquivir basin.

Figure 8 illustrates the impact of the drought. Global reduction in the basin amounted to 28% compared to average year (2008) as a result of the more severe restrictions in large irrigated areas (50% reduction) and there was a smaller reduction to crops that were irrigated with deficit or supplementary irrigation around 1500 m^3/ha and that were less affected.

The analysis of figure 8 shows that most of the economic damage affected crops with extensive use of water and low productivity, which are: maize, rice, etc. Meanwhile, crops with higher values (vegetables, fruits, olives) maintained the doses. Some crops changed to deficit irrigation (cotton, sugar beet) and others reduced the irrigated area (for example, rice was exactly 50% of average year).

Figure 8: Water value (net margin) Guadalquivir 2006 and 2008



Source: Own elaboration

The reduction in water supply implies a reduction in global net margin of 4% compared to an average year. This drought does not imply a dramatic fall in economic value of production compared with the previous one 1990-1995. Table 3 summarises some parameters in both cases.

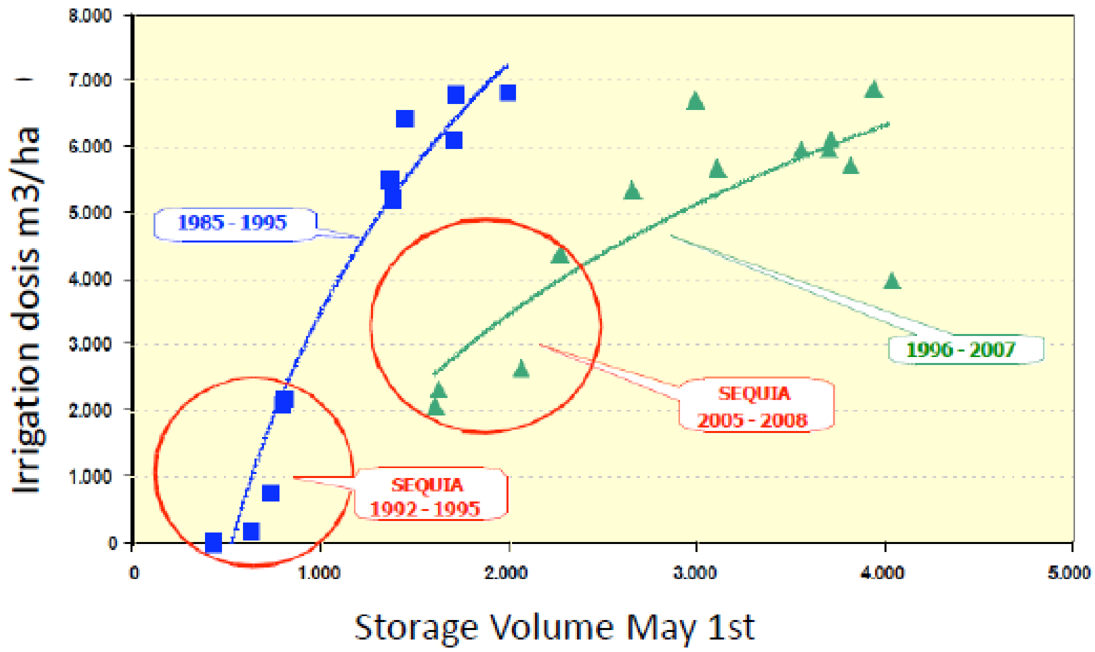
Table 3: Rain and irrigation doses in droughts 1990-95 and 2004-09

Years	Rain (mm)	Irriga. (m^3/ha)	Year	Rain (mm)	Irriga. (m^3/ha)
90-91	472,2	7.000	04-05	281,8	5.561
91-92	481,3	2.100	05-06	436,4	2.628
92-93	380,2	180	06-07	465,3	2.403
93-94	432,3	760	07-08	462,1	2.500
94-95	273,9	0	08-09	467,3	3.900
Media	*408,0*			*422,6*	

Source: Own elaboration, CHG (1998), CHG (2007) and CHG (2012)

Yearly rain is similar in both period but the conversion from rain to natural resources available in aquifers and reservoirs has not a direct relation and the first period has the lowest value of resources as figure 9 shows. Nevertheless, the difference in the management of water resources is related to both supply management and demand management. Figure 9 illustrates the supply management before and after the implementation of Drought Awareness Plan (CHG, 2007).

Figure 9: Supply management and storage level



Source: Adapted from Corominas (2010)

Regarding the demand management, Corominas (2010) hypothesized that both a new supply management (see figure 9) and a new demand management with a majority of area under drip irrigation (over 70%) are responsible for the smaller impact of the 2005-2007 drought compared with the catastrophic consequences of 1990-1995.

5. Evolution of vulnerability

We have seen in the previous section the co-evolution of supply and demand. The analysis has detected the moderate increase in storage capacity in the period 1992-2012, from 7500 hm^3 to 8562 hm^3 (14%); this value contrasts with the increase in irrigated area from 443,000 ha to 849,243 (91%). The question is if the improvement in water demand through the implementation of water saving systems has compensated the increase in irrigated area in order to improve or deteriorate vulnerability.

A previous question is the supply reliability guarantee. The definition in Guadalquivir basin regarding surface regulated water is that irrigation should have a 10% average fail in the most limiting decade (1990-2000 for Guadalquivir). With this definition, the irrigation users that depend on surface regulated water improve the guarantee from an average failure from 40% to 26% after the implementation of the Programme of Measures associated to Basin Hydrological Plan (CHG 2012) including last reservoirs that have recently entered into operation.

Nevertheless an average failure of 26% does not imply that in a specific series of dry years the water supply fails might be over this value. The Basin Hydrological Plan uses the concept of 'gap' in the basin. Gap is defined for regulated water as the excess over the rule of 10% fails; i.e. as the regulated surface water has defined water rights of 2,160 hm^3, a final gap of circa 350 hm^3 implies that average fail in the most restrictive decade (1990-2000) would be 26% below the water rights. We should remember that 1990-1995 has been considered the worst drought in 200 years of meteorological data in the basin.

A previous question is the definition of vulnerability. There are numerous definitions of this concept and the indicators to make it operational. Plummer et al (2012) identify and synthesise 710 indicators proposed in the literature. For many researchers, social vulnerability is analyzed in terms of individuals, families or social groups and is more related to subsistence levels (shortage of drinking water; lack of sanitation, etc,). Our interest is the socioeconomic vulnerability of the irrigated agriculture in a developed country, member of the European Union, where the most basic needs are guaranteed. Nevertheless, in Guadalquivir basin these factors should be considered:

- Small farms (below 5 ha) are 72% of holdings in basin.
- High value crops are associated to financial leverage and marketing channels that imply long term impacts in the case of drought.
- Investment in value chain (processing plants) needs high reliability on water supply.

Regarding this, the socioeconomic vulnerability in a preliminary assessment will be related to lack of irrigation water from vulnerable crops. Table 4 summarises scenario 1992 and 2008.

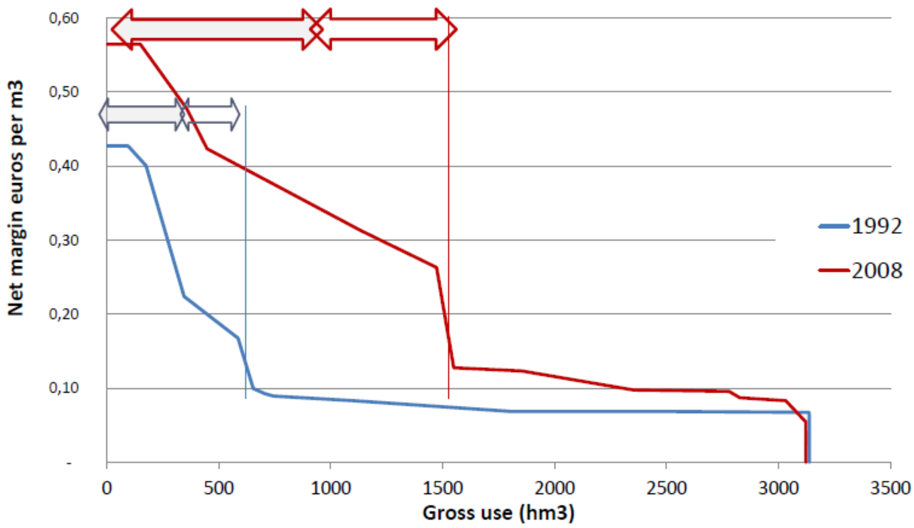
Table 4: Socioeconomic vulnerability in Guadalquivir irrigated agriculture

Vulnerable crops	**High (hm^3)**	**Medium (hm^3)**
1992	216	95
2008	812	506
Crops	fruit, citrus, vegetables	irrigated olive

Source: Own elaboration, various sources

Figure 10 illustrates the point, as it can be seen, that the water value estimated as net margin, that is an indicator of farmer income, is now more dependent on water reliability. The new management rules derived from the Drought Awareness Plan, the increased capacity and the reduced demand have increased de reliability on supply and the water guaranteed, but the consequences of a catastrophic event such as 1990-1995 will have more dramatic consequences. In scenario of crop area and irrigation dosis existing in the hydrological plan 1992, the critical crops water supply is estimated in 216 hm^3 plus a certain strategic need of 95 hm^3 for irrigated olives; in this case, olive can support a certain water stress but the financial leverage that usually is linked to irrigation investment makes irrigated olives a crop socioeconomically vulnerable. These values increase to 812 hm^3 and 506 hm^3 respectively.

Figure 10: Socioeconomic vulnerability to drought



Source: Own elaboration, various sources

6. Concluding remarks

The evolution of irrigation in a Mediterranean basin is generally defined by a trajectory towards closure. Nirvana concepts, which underpin overarching frameworks of analysis and models of policies or development interventions (see Molle, 2008), suppose that water saving measures is the solution to problems of over-extraction and lack of guarantee in water supply once the possibility of supply augment is abandoned as a consequence of basin development.

The implementation of water saving technologies increases water productivity and differential profitability of irrigated versus rain fed crops and thus induces additional pressure on resources.

Regarding vulnerability to drought events, we conclude the following: on the one hand, the implementation of water saving technologies will increase the water supply guarantee, and the basin will be more protected to moderate and medium level drought if there is not rebound effect (see Pfeiffer and Lin2010, Fernandez et al 2012), but, on the other hand, there will be probably more vulnerability to severe drought as the crops cultivated will be more dependant on water supply both for agronomic reasons (fruit, citrus,..) and socioeconomic aspects (need to maintain marketing channels and value added infrastructures.

The present document is a preliminary assessment of the impact of changes in Guadalquivir irrigated system in the profitability, sustainability and vulnerability of the system. A complete view should also integrate rain fed agriculture as the links and barriers between irrigated and rain fed are somewhat arbitrary and diffuse frontiers.

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