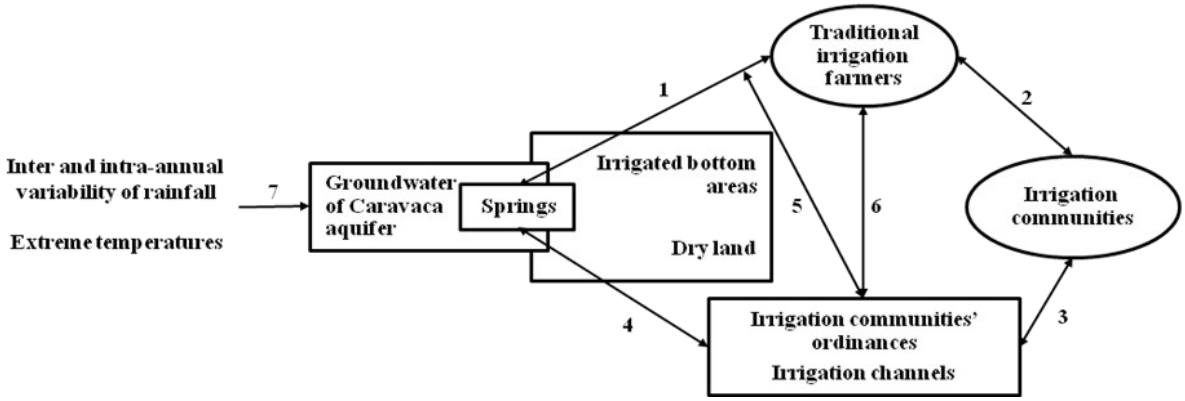
Structure of the traditional irrigation system (Figure 1)

Resource users are traditional irrigation farmers who use the groundwater that emerges as springs to irrigate land (**resource**). Crops are affected by water availability, which varies according to rainfall and by extremely low temperatures (spring frost) (**environmental external disturbances**). Farmers are organized in irrigation communities (IC) (**infrastructure providers**). The **physical infrastructures** are irrigation channels, used to distribute water among farmers. Irrigation channels are constructed by IC and are maintained by both IC and the individual farmers (**links 3 and 6**). Each IC has its own ordinances that constitute the **social capital**, and these ordinances have established the rules for both IC and farmers (IC functioning and structure, the boundaries of the system, the distribution of water among members, and monitoring and sanctioning). Only the farmers belonging to an IC can use water from the springs.

Figure 1. Conceptual model of the traditional irrigation system of the northwest Murcia Region (Spain) before the intrusion of new resource users (based on the conceptual social-ecological systems model of Anderies et al. 2004).



Vulnerabilities of the traditional irrigation system

This traditional irrigation system was robust in terms of its use of the water emerging from the springs to irrigate small patches of land. However, given this configuration and several external processes, this system has become very vulnerable to the intrusion of new resource users:

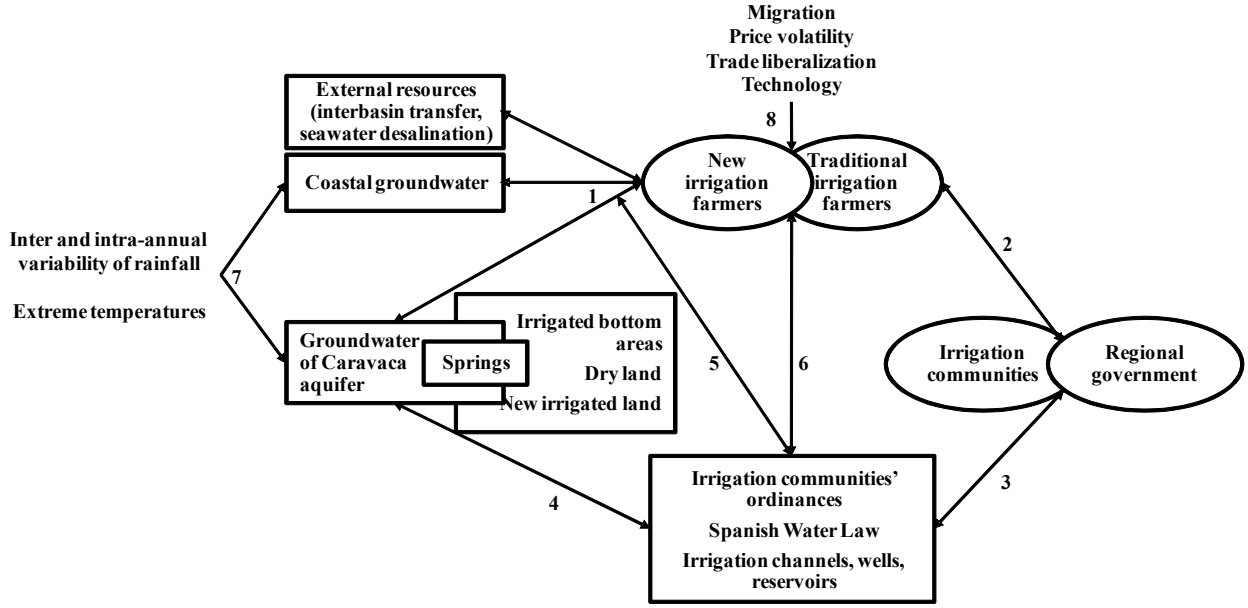
a) Public infrastructure providers and social capital: IC have the right to use and control the water emerging from the aquifer, but not the aquifer's groundwater itself, although any disturbance to the aquifer will affect the flow of the springs. The Spanish Government has difficulties in monitoring and controlling groundwater pumping.
b) Resource characteristics: groundwater is an important water reservoir in arid areas.
c) External forces on resource and infrastructure: The improvement of roads, and especially the construction of a new highway, connected this traditionally isolated area with the capital city and the markets. This situation increases the accessibility to new resource users to cultivate the land and transport products to markets.
   Innovative technologies have converted groundwater extraction by means of wells from which to pump this groundwater into a technical, economic and viable option.

d) External forces on social actors: Spain was progressively opened to global markets in 1986, when this country joined the European Union. This situation has attracted industrial agrarian companies to expand to new areas.
In 1985 a new water law considered the groundwater as public waters but, in order to recognizing the historical rights of private groundwater owners, the law gave them the right to register their groundwater use as private uses. Most of the owners of old wells in dry lands (traditionally used in punctual occasions during severe droughts or to give cattle water) registered them as private uses but they registered more water than they were traditionally using. The government was unable to verify this data due to the amount of registration.

Configuration of the irrigation system after the intrusion of new resource users (Figure 2)

As a consequence of the vulnerabilities mentioned above, in the early nineties industrial agrarian companies started to settle in this area and lead to a different configuration of the irrigation system:
The system is now composed by two types of **resource users**. While traditional farmers employ the water from springs to irrigate land, new farmers directly use groundwater as **resource** by pumping it from wells (**physical infrastructure**). New farmers come from more arid coastal areas where they use groundwater to irrigate land as well as other external water resources. In spring and summer when the high temperatures of the coastal areas do not permit the cultivation of certain horticultural crops, they irrigate the traditional dry lands of the study area.
Traditional farmers and IC have adapted to less abundant spring flows by constructing new **physical infrastructures**. This measure is also promoted by the Regional Government (new **infrastructure provider**) as a measure to prevent droughts and to efficiently improve the system by which the water is used. New public infrastructures include wells, reservoirs to store water in winter and to use it in summer, and modernized irrigation channels to prevent water evapotranspiration and infiltration.

Figure 2. Conceptual model of the traditional irrigation system of the northwest Murcia Region (Spain) after the intrusion of new resource users (based on the conceptual social-ecological systems model of Anderies et al. 2004).



Robustness of the irrigation system after the intrusion of new resource users

The next table summarizes the process and vulnerabilities in the entities and links (based on the conceptual social-ecological systems model of Anderies et al. 2004) of the traditional irrigation system due to the incursion of new resource users:

Entities/links	**Processes/Vulnerabilities**
Resource	Increase of uncertainty in the water flow Level decrease
Resource users	Collective action problems
Public infrastructure providers	Increase complexity
Public infrastructures	Increase infrastructures
Social capital	Ineffective boundaries rules Lack of robust govern system
Between resource and resource users *(link 1)*	Decrease of the volume flow Not enough water to continue with the traditional agriculture Increase of recovery periods
Between users and public infrastructure providers *(link 2)*	Increase economic investment to create and maintain infrastructures Collective action problems (e.g. infrastructure maintenance)
Between public infrastructure providers and public infrastructure *(link 3)*	Increase economic investment to create and maintain infrastructures Collective action problems (e.g. infrastructure creation and maintenance)
Between public infrastructure and resource *(link 4)*	Resource level decrease Decrease resilience of the resource Increase resource price
Between public infrastructure and resource dynamics *(link 5)*	Not enough water to continue with the traditional agriculture Decrease efficiency of infrastructures
Between resource users and public infrastructure *(link 6)*	Collective action problems (e.g. infrastructure maintenance) Increase of users´ debts Land abandonment
External forces on social actors *(link 8)*	Young people emigration
External forces on resource and infrastructure *(link 9)*	Decrease resilience of the resource