

Proceeding Paper

Ecosystem Services Evaluation from Sustainable Water Management in Agriculture: An Example from An Intensely Irrigated Area in Central Greece [†]

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Abstract: This study presents the provisional, regulating and cultural ecosystem services that can be delivered by the newly constructed multi-purpose reservoir of Lake Karla located in a water scarce agricultural area in central Greece. The present short paper takes advantage of literature data and outputs produced from a dynamic GIS hydrologic and management model of the study area with SWAT that simulated hydrology, reservoir operation, irrigation practices and crop production. The paper highlights the net provisional services that the local agricultural society can gain from the full operation of Karla and the additional benefits arising such as flood control, biodiversity maintenance, aesthetic improvement and touristic opportunities.

Keywords: ecosystem services; hydrologic modelling; irrigated agriculture; Karla reservoir; SWAT; water management

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1. Introduction

Irrigated agriculture is essential to crop production in the Mediterranean region, which faces water scarcity. Hence, its sustainability requires the efficient management of the available but limited regional water resources [1]. Investments for sustainable water management in the agricultural sector include a large variety of interventions from small ponds to large reservoirs that are able to collect, store and distribute water with the purpose to maximize the total farm income [2]. Especially in water scarce agricultural regions, reservoirs increase the availability of water for irrigated agriculture and at the same time they can preserve the integrity of the local ecosystem, while providing environmental benefits [3]. This study presents the newly created Karla reservoir, a large work constructed for the above purposes at the southeastern edge of the agricultural catchment of Pinios (~10,800 km²) in Central Greece. For decades the wider area has been a significant producer of agricultural crops, but water shortages during summers and over-abstractions of groundwater have caused significant losses of crop production [4], mainly cotton, which still drives the local agricultural economy [5].

Karla was a natural lake until 1962, when it was drained in favor of increasing agricultural land, but water scarcity and loss of wetland functions and values developed the need for its reconstruction [6], which was completed almost one decade ago. The new project is today a Natura and Ramsar aquatic ecosystem, and a functional reservoir [7] having as main water supply purpose the irrigation of crops. Its development was possible through natural winter runoffs from the surrounding areas and water diversions from Pinios river during the wet period of the year [8].

Irrigated crops are of high water demands as they need almost 5000 m³/ha per growing season, water that was abstracted mostly from groundwater sources in the past years. This has led to overexploitation of aquifers and to a significant increase of the energy cost of pumping [5,8]. The 38 km² re-constructed Lake Karla is designed to store water between the lower water depth of 2–2.5 m and the upper depth of 4.5–5 m. These depths correspond to ~100 × 10⁶ m³ and 180–200 × 10⁶ m³ of water, respectively. The depth of 2–2.5 m corresponds to the minimum water level of the reservoir, necessary to fulfill the ecological criteria of the wetland. So, the maximum allowable water volume is nearly 200 × 10⁶ m³, but only half is allowed for extraction. For security reasons, an artificial tunnel can remove excess water to the sea [8].

The purpose of this short paper is to briefly present and evaluate the significance of the expected delivered benefits from the construction of Karla both in terms of the available water for irrigation and respective crop productivity, and the environmental and socio-economic improvement of the surrounding area. To this end, we use literature information and already published environmental, hydrologic and crop growth modeling data [7–9].

2. Materials and Methods

A modeling system of Pinios basin with SWAT (Soil and Water Assessment Tool) model [10] has represented the hydrology, water management and crop productivity under two scenarios: (i) with irrigation water supply from Lake Karla and (ii) with the inexistence of the lake and irrigation water abstracted from groundwater [8]. Figure 1 shows the area of interest in GIS.

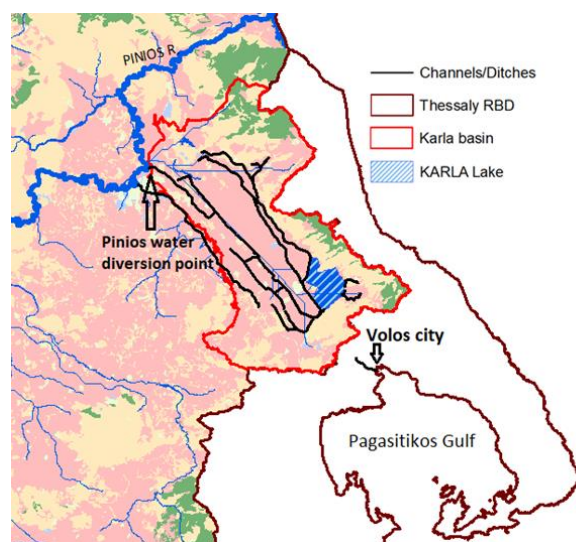


Figure 1. The Karla reservoir (lake) within the Karla basin of the Thessaly River Basin District (RBD) along with the channels/ditches diverting water from Pinios river and the surrounding areas into the lake.

The model elaboration was based on recent land use, water management and climate data of the historic period 2001–2010. The second scenario represents a situation without the existence of the lake, thus without water diversions from the river of Pinios, with surface waters of the Karla basin routed naturally to the small nearby rivers, the area of the lake (Figure 1) being fallow and the limited groundwater storage being the only source of irrigation water for the 8000 ha of cropland around the lake's area. In the first scenario, the Karla reservoir was simulated in SWAT based on a water volume-surface area relationship and the calculation of its water balance on a monthly basis by considering precipitation, evaporation, inflows from Pinios diversions and natural runoff, abstractions in

the dry period for irrigating 8000 ha of crops, seepage and overflowing. SWAT incorporates a crop growth component, which simulates the potential growth and yield when crops do not meet temperature, water and nutrient stress [11]. The model was calibrated and validated based on reported hydrologic data and crop yields [8]. Regarding other data, necessary for discussing non-provisional services, we used the recent studies of Sid-iropoulos et al. [7] and Dodouras et al. [9], which describe and evaluate, based on real data, the entire new Lake Karla project.

3. Results and Discussion

The SWAT model was executed for a 10-y period with historic climate (2001–2010) for the two scenarios, including or not Lake Karla in the simulation, and provided monthly and annual outputs. The outputs of the calibrated model give estimates of provisional services, namely actual irrigation water applied to the 8000 ha crop area and the crop yield on a mean annual basis, while published studies give information about non-provisional services such as flood control, aesthetic improvement, enhancement of biodiversity and touristic opportunities. The whole information arising both from the simulation results and the reported data is summarized in Figure 1 and is associated to types of ecosystem services provided by the Lake [12].

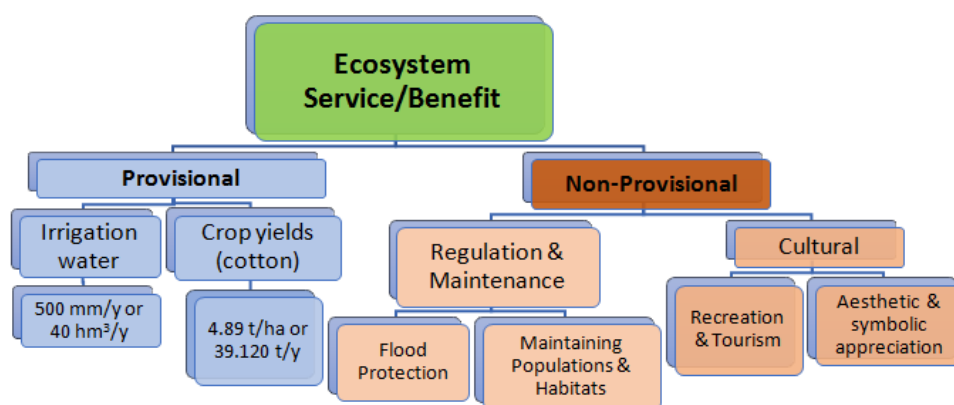


Figure 2. Ecosystem services relevant for Lake Karla (based on [12]).

With no Karla reservoir simulated, the model was forced to apply 500 mm (5000 m³/ha) of water from May to late September by abstracting groundwater. However, the availability of water in the aquifer could not fully cover the irrigation water doses. Hence, less than 50% of the optimum water was possible to be annually abstracted (215 mm or 2150 m³/ha). On the other hand, with Karla reservoir simulated, there was full availability of water for application to cotton fields thus, the model simulated optimum irrigation doses. This had very positive effects on crop production as the crop growth routine of SWAT simulated cotton yield as 4.89 t/ha/y for the 8000 of cotton land, almost double than without the Lake Karla in operation. This is attributed to the absence of water stress days in the accumulation of crop biomass development. Thus, with Lake Karla the irrigation requirements are fully met (100%), with the effectiveness of covering irrigation needs without Karla being only 43%. For the 8000 ha of irrigated land, total cotton production with Karla included is twice as much as without it; the annual production is 39,120 t and 21,520 t, respectively. The additional income rises up to 880 €/ha, which is equivalent to 7,040,000 € for the entire cropland area of the 8000 ha based on a guaranteed unit cotton price of 0.40 €/kg. For a typical individual land property of 4–5 ha the annual income increase for a single farmer is estimated as ~4000 €.

On the other hand, water saving in the aquifers is considerable as well. Lake Karla results in no pumping, thus saving 17.2 hm³ annually in the aquifer (2150 m³/ha for 8000 ha). With the 38 km² Karla Lake, continuous seepage (0.1 mm/h) from the lake’s bottom

can also result to an annual aquifer recharge of 33.2 hm³/y, almost 30 hm³/y more than the precipitation that could become net groundwater recharge through percolation on an annual basis from the same area. In combination, increased percolation and zero groundwater abstractions result to significant benefits for the aquifer and the soil stability.

Water availability within Lake Karla relies mainly on Pinios diversions during the wet period of the year with abstracted water quantities that never cause hydrologic pressures to the river. A minimum water level of 2.5 m and a volume of 100 hm³ in the lake has to be maintained to support biodiversity. SWAT simulated the actual monthly water storage as shown in Figure 3 where the minimum of 100 hm³ is always respected within the 10-y simulation period.

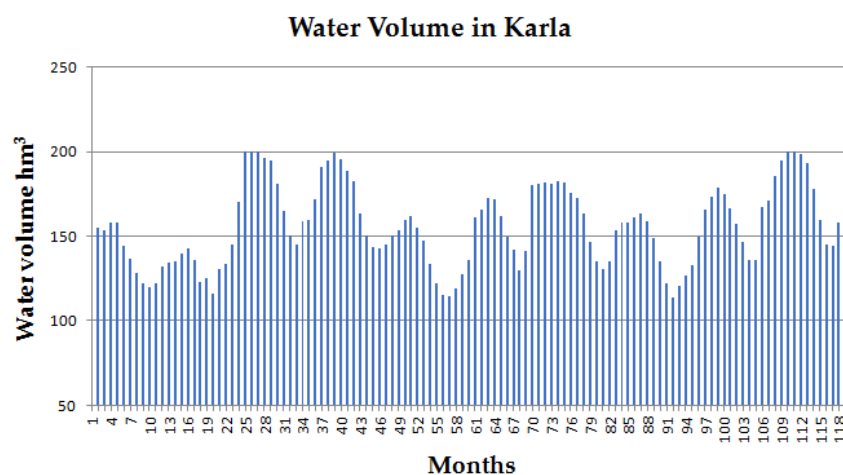


Figure 3. Water stored in Karla reservoir on each month within a 10-y (120 months) simulated historic period starting in 2001 (1 = first month of the simulation).

Thus, apart from the provisioning services of irrigation water and crop productivity (Figure 4a), several other benefits can be obtained through ecosystem services from the restored Lake Karla. The lake offers shelter and food for many species of migratory birds, being a biodiversity hot-spot. Birds favour nesting in the marshes and artificial islands (Figure 4b). The fish community of Lake Karla is composed of six families and thirteen species with the family of Cyprinidae being the most dominant in terms of abundance and biomass [7].



Figure 4. Ecosystem services provided by Lake Karla: (a) crop areas irrigated by the lake’s water, (b) part of the lake with bird nesting areas, (c) the museum, a touristic attraction. Photos taken by the first author of the manuscript on October 2019.

The agricultural floodplain in the perimeter of Karla will be highly protected from inundation, even during seasons with high precipitation and runoff depths. The Karla

reservoir will have the capability to trap flooded waters through the operation of the already constructed works. As a result, it will be possible to prevent farmland inundation, enhance groundwater restoration over the years and mitigate desertification. Increased groundwater availability may also support other water uses.

The ecological benefits associated to biodiversity enhancement can also offer great cultural services. Info-kiosks and bird watching sites, the tourist information center and the local museum of natural history (Figure 4c) already exist [13] The area can offer activities such as visiting environmental education sites, hiking and cycling, while encouraging the development of additional services/facilities such as accommodation and water sports.

4. Conclusions

This short study summarized the main provisional and non-provisional ecosystem services delivered by the new Lake Karla reservoir located in the southeastern part of Pinios river basin, Thessaly region, central Greece. Based on a previous modelling study and literature information, water supply in irrigated agriculture and the respective crop production and farmers' income in the surrounding cropland areas of Lake Karla can be maximized with the presence of the reservoir, and at the same time, water scarcity and over-exploitation of groundwater resources can be mitigated. Maintaining a minimum water level in the reservoir can also support biodiversity and other ecosystem functions uninterruptedly. Cultural (aesthetic and recreational) services also have a great potential to be further developed.

However, for the project's successful operation in the long term, there is a need to raise awareness among all of the stakeholders, not only for the benefits but also for the maintenance and to develop further the actions required. Of high priority is the construction of the remaining parts of the collective irrigation network around the reservoir. For the economic viability of the project, a volumetric pricing of irrigation water that is counterbalanced by crop productivity should be established. Finally, it has to be ensured that the minimum water level in the reservoir is always maintained so that the lake acts as an important biodiversity site and healthy ecosystem.

Conflicts of Interest: The authors declare no conflict of interest.

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