environmental sciences proceedings

MDPI

*Proceeding Paper*

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

**Yiannis Panagopoulos *, Dimitrios Karpouzos, Pantazis Georgiou and Dimitrios Papamichail**

Department of Hydraulics, Soil Science and Agricultural Engineering, School of Agriculture, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece; dimkarp@agro.auth.gr (D.K.); pantaz@agro.auth.gr (P.G.); papamich@agro.auth.gr (D.P.)

* Correspondence: ypanag@agro.auth.gr; Tel.: +30-2310-998-708

† Presented at the 7th International Electronic Conference on Water Sciences, 15–30 March 2023; Available online: https://ecws-7.sciforum.net.

**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



**Citation:** Panagopoulos, Y.; Karpouzos, D.; Georgiou, P.; Papamichail, D. Ecosystem Services Evaluation from Sustainable Water Management in Agriculture: An Example from An Intensely Irrigated Area in Central Greece. *Environ. Sci. Proc.* **2023**, *25*, 4. https://doi.org/10.3390/ECWS-7-14250

Academic Editor: Athanasios Loukas

Published: 16 March 2023



## 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 of maximising the total farm income [2]. Particularly 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 km$^2$) 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 prompted 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 its 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 have high water demands as they need almost 5000 $m^3$/ha per growing season, water that had been abstracted mostly from groundwater sources in past years. This has led to the overexploitation of aquifers and to a significant increase in the energy cost of pumping [5,8]. The 38 $km^2$ reconstructed 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 ~$100 \times 10^6$ $m^3$ and $180–200 \times 10^6$ $m^3$ 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 $200 \times 10^6$ $m^3$, 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] 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.

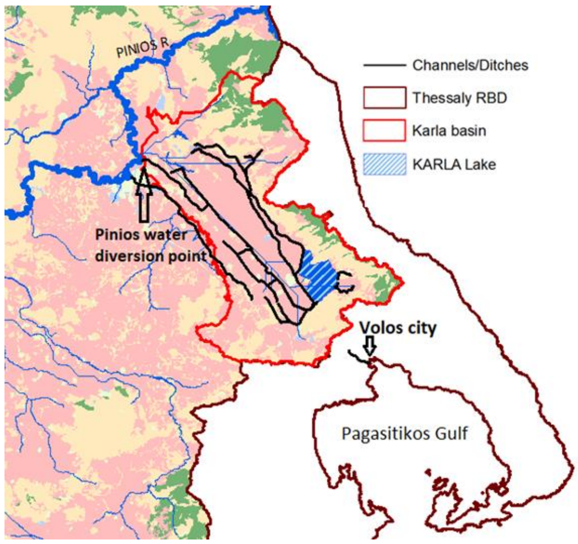


**Figure 1.** The Karla reservoir (lake) within the Karla basin of the Thessaly River Basin District (RBD) along with the channels/ditches diverting water from Pinios river and the surrounding areas into the lake.

The elaboration of the model 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 overflows. SWAT incorporates a crop growth component, which simulates the potential growth and yield when crops do not experience 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 Sidiropoulos 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) data 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. All information arising both from the simulation results and the reported data is summarized in Figure 1 and is associated with types of ecosystem services provided by the lake [12] (Figure 2).

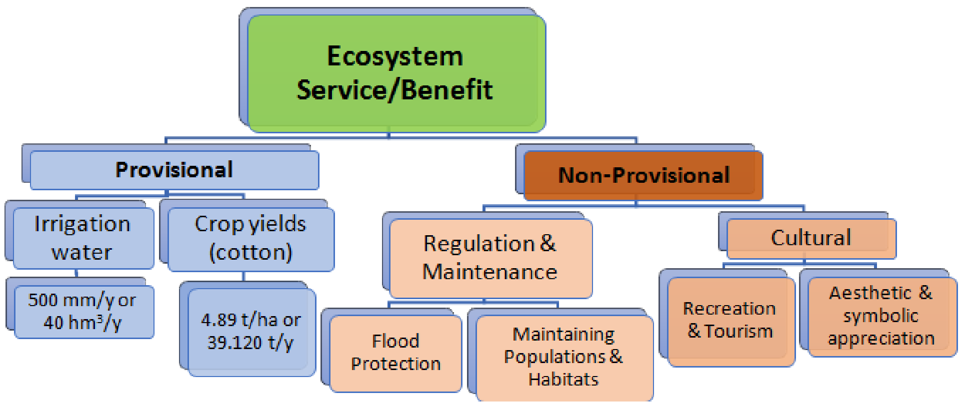


**Figure 2.** Ecosystem services relevant for Lake Karla (based on [12]).

With no Karla reservoir simulated, the model was forced to apply 500 mm (5000 $m^3$/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 could be annually abstracted (215 mm or 2150 $m^3$/ha). On the other hand, with the 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 that 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 EUR/ha, which is equivalent to 7,040,000 EUR for the entire cropland area of the 8000 ha based on a guaranteed unit cotton price of 0.40 EUR/kg. For a typical individual land property of 4–5 ha, the annual income increase for a single farmer is estimated as ~4000 EUR.

On the other hand, water saving in the aquifers is considerable as well. Lake Karla results in no pumping, thus saving 17.2 $hm^3$ annually in the aquifer (2150 $m^3$/ha for 8000 ha). With the 38 $km^2$ Karla Lake, continuous seepage (0.1 mm/h) from the lake's bottom can also result in an annual aquifer recharge of 33.2 $hm^3$/y, almost 30 $hm^3$/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 in 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 on the river. A minimum water level of 2.5 m and a volume of 100 $hm^3$ 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 $hm^3$ is always respected within the 10-year simulation period.

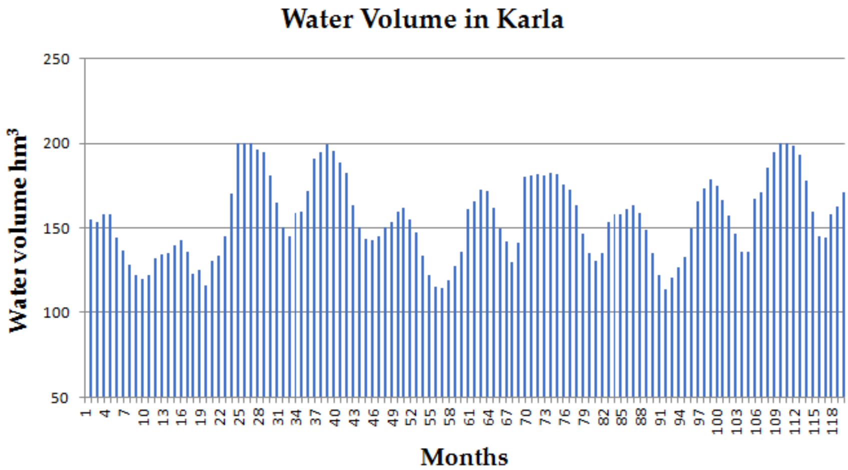


**Figure 3.** Water stored in Karla reservoir on each month within a 10-year (120 months) simulated historic period starting in 2001 (1 = first month of the simulation).

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 favor 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].

(**a**) (**b**) (**c**)

**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 in 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 with biodiversity enhancement can also offer great cultural services. Info kiosks, 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, 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 overexploitation 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 further develop 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 can act as an important biodiversity site and healthy ecosystem.

**Author Contributions:** Conceptualization, Y.P.; methodology, Y.P.; D.K.; P.G. and D.P.; software, Y.P.; validation, Y.P.; formal analysis, Y.P.; D.K.; P.G. and D.P.; investigation, Y.P.; D.K.; P.G. and D.P.; resources, Y.P.; data curation, Y.P.; D.K.; P.G. and D.P.; writing—original draft preparation, Y.P. and D.K.; writing—review and editing, Y.P.; D.K.; P.G. and D.P.; supervision, D.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to their large size and the fact that they are modelled data.

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

## References

1. Mademli, V.; Karpouzos, D.; Georgiou, P.; Pantelakis, D. Development of a scalable computational tool for irrigation scheduling. *Eur. Water* **2020**, *71*, 15–26.
2. Georgiou, P.E.; Papamichail, D.M. Optimization model of an irrigation reservoir for water allocation and crop planning under various weather conditions. *Irrig. Sci.* **2008**, *26*, 487–504. [CrossRef]
3. Pistocchi, A. *Nature-Based Solutions for Agricultural Water Management*; EUR 31351 EN; Publications Office of the European Union: Luxembourg, 2022; ISBN 978-92-76-60487-7. [CrossRef]
4. Loukas, A.; Vasiliades, L. Probabilistic analysis of drought spatiotemporal characteristics in Thessaly region, Greece. *Nat. Hazards Earth Syst. Sci.* **2004**, *4*, 719–731. [CrossRef]
5. Panagopoulos, Y.; Makropoulos, C.; Kossida, M.; Mimikou, M. Optimal implementation of irrigation practices: Cost-effective desertification action plan for the Pinios basin. *J. Water Resour. Plan. Manag.* **2013**, *140*, 1943–5452. [CrossRef]
6. Zalidis, G.; Takavakoglou, V.; Panoras, A.; Bilas, G.; Katsavouni, S. Reestablishing a sustainable wetland at former Lake Karla, Greece, using Ramsar restoration guidelines. *Environ. Manag.* **2004**, *34*, 875–876. [CrossRef] [PubMed]

7. Sidiropoulos, P.; Chamoglou, M.; Kagalou, I. Combining conflicting, economic, and environmental pressures: Evaluation of the restored Lake Karla (Thessaly-Greece). *Ecohydrol. Hydrobiol.* **2017**, *17*, 177–189. [CrossRef]
8. Panagopoulos, Y.; Dimitriou, E. A Large-Scale Nature-Based Solution in Agriculture for Sustainable Water Management: The Lake Karla Case. *Sustainability* **2020**, *12*, 6761. [CrossRef]
9. Dodouras, S.; Lyratzaki, I.; Papayannis, T. *Lake Karla Walking Guide*; Mediterranean Institute for Nature and Anthropos (med-INA): Athens, Greece, 2014; 228p.
10. Gassman, P.W.; Sadeghi, A.M.; Srinivasan, R. Applications of the SWAT Model Special Section: Overview and Insights. *J. Environ. Qual.* **2014**, *43*, 1–8. [CrossRef] [PubMed]
11. Neitsch, S.L.; Arnold, J.G.; Kiniry, J.R.; Williams, J.R. *Soil and Water Assessment Tool—Theoretical Documentation Version 2009*; Texas Water Resources Institute Technical Report 406; Texas A&M University System College Station: College Station, TX, USA, 2011; Available online: http://swat.tamu.edu/media/99192/swat2009-theory.pdf (accessed on 10 January 2023).
12. Grizzetti, B.; Lanzanova, D.; Liquete, C.; Reynaud, A. *Cook-Book for Water Ecosystem Service Assessment and Valuation*; EUR 27141; Publications Office of the European Union: Luxembourg, 2015. [CrossRef]
13. Management Authority of Lake Karla. Available online: http://www.fdkarlas.gr/Default.aspx (accessed on 10 January 2023).