

Hydrological 2D Modelling of Lithaios River Flows (Greece) Using GIS and Geostatistics for Environmental and Agricultural Water Resources Administration [†]

Agathos Filintas ^{1,2,*} , George Panoras ³ and George Stamatis ²¹ Department of Agricultural Technology, University of Thessaly—Campus Gaiopolis, 41500 Larisa, Greece² Institute of Mineralogy-Geology, Agricultural University of Athens, Iera Odos 75, 11855 Athens, Greece; stamatis@aua.gr³ Hellenic Agricultural Organization-Demeter, Water and Soil Resources Institute, 57400 Sindos, Greece; gpanoras@hotmail.com

* Correspondence: filintas@uth.gr

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

Abstract: The goal of our investigation is the hydrological 2D modelling of Lithaios River's (Central Greece) streamflow, using GIS and geostatistics for studying water velocity and discharge, stage elevation, and hydraulic features (streamflow depth, water flow area, wettable circumference, hydraulic radius and depth, n Manning's coefficient, Chow's composite n, Froude number, etc.). Moreover, compilations and validations of rating curves (RC) were performed from a series of stage $h(t)$ –discharge $Q(t)$ couples metrics, aiming to use these as a river toolkit to aid environmental and agriculture surface water resources management and help environmental flows calculation, streamflow tracking, and irrigation programming in the regional basin range. The statistical results showed that the Froude number during the study period was $Fr < 1$ showing that Lithaios River's streamflow is classified as subcritical. The models' validation outcomes by using various statistics and geostatistical alternative methods, model simulations and statistics errors criterions, were correlated with the retrieved power models' streamflow data matching for the RC curves and 2D GIS modelling and mapping of river velocity and discharge relationships and were highly satisfying since the stabilities of the deployed relationships were solid. The outcomes of the study results are recommended to provide a hydrological serving toolkit for environmental water resources administration and irrigation programming. This toolkit could assist water supply principalities to rapidly and precisely calculate streamflow volumes and features with a minimal cost rate and workload, and it could be engaged in water supply and agricultural watering administration, the calculation of environmental flows, flood protection, groundwater recharge, and other objectives.

Keywords: hydrological 2D streamflow modelling using GIS and geostatistics; flow velocity; discharge rate; n Manning's coefficient and Chow's composite n; hydraulic properties; rating curve



Citation: Filintas, A.; Panoras, G.; Stamatis, G. Hydrological 2D Modelling of Lithaios River Flows (Greece) Using GIS and Geostatistics for Environmental and Agricultural Water Resources Administration.

Environ. Sci. Proc. **2023**, *25*, 13.[https://doi.org/10.3390/](https://doi.org/10.3390/ECWS-7-14201)

ECWS-7-14201

Academic Editor: Lampros Vasiliades

Published: 14 March 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Streamflow velocity and discharge rate, water elevation, hydraulic deep, and flow form are the main themes in hydrology and are closely linked to water supply, quality and administration, flood protection, dewatering, irrigation, dam construction, and other related themes [1–3]. The streamflow velocity and discharge rate have a significant effect on water's retention period and quality [2,4,5]. Thus, these variables are typically needed for hydro-systems modelling. Unfortunately, the ongoing streamflow monitoring on a river's cross-section is commonly unfeasible or very costly [2–6]. Fast and accurate discharges calculation is of high importance for a great number of environmental engineering projects (real-time flood forecasting, water resources administration, etc.) [2,5–7]. The goal of our

research is hydrological 2D streamflow modelling of Lithaios River (Central Greece), using GIS, and geostatistics for studying water velocity and discharge, stage elevation, and hydraulic features (streamflow depth, water flow area, wettable circumference, hydraulic radius and depth, n Manning's coefficient, Chow's composite n, Froude number, etc.).

2. Materials and Methods

2.1. Lithaios River Measurements, Instruments Used, and Specifications

The study was conducted in Lithaios River (top width = 15 m) at Trikala monitoring station (M-S), in the region of Thessaly in Central Greece. A propeller current flow [7,8] meter (OTT) was employed together with a modern electronic metering system including a flow computer, data logger, and a real-time display monitor, all calibrated by the manufacturer. River flow data were computed by averaging over a 60 + 60 s measured couple. Vertical measurements of water depths and velocities were performed for temporal monitoring of the cross-section's velocity and discharge variation [8].

2.2. Hydrological Methodology

The river's streamflow velocity and the depths and widths of the defined segments were measured and engaged for the estimation of the cross-section's mean discharge of every segment [2–8]. The overall discharge [2–8] was estimated by the mid-section methodology [5–8]. The features of the cross-section, the water flow velocity of the defined segments and the overall mean flow velocity, were metered, computed, modeled, and depicted in diagrams and GIS maps, respectively, building up a hydrological toolkit for Lithaios River. Water stage elevation and flow measurements were taken monthly for a period of 1 year (January to December). In addition, more measurable variables (streamflow depth, the defined segments' width, overall river width, and water stage elevation) were measured, and more hydraulic features (streamflow depth, water flow area, wettable circumference, hydraulic radius and depth, n Manning's coefficient, Chow's composite n, Froude number, etc.) were computed and depicted in diagrams and saved in the hydrological toolkit. Equation (1) was applied in order to calculate the river flow velocities.

$$V_{i=1}^n = a + (b_{eq} \times N_{eq}) \quad (1)$$

where $V_{i=1}^n$ = stream flow velocity (m s^{-1}), n is the number of cross-section segments, a = the initial speed to overcome mechanical resistance, b_{eq} = the system's calibration constant, and N_{eq} = the equipment's rotations per second.

Equation (2) was used for the river's cross-section total discharge.

$$Q_T = \sum_{g=1}^n V_{i=1}^n A_{j=1}^n \quad (2)$$

where Q_T = total discharge ($\text{m}^3 \text{s}^{-1}$) of the river's cross-section, $g = 1 \dots n$ is the number of cross-section segments, $V_{i=1}^n$ = the mean flow velocity of each cross-section segment (m s^{-1}), and $A_{j=1}^n$ = the wet flow area of each cross-section segment (m^2).

Couples of stage water elevation $h(t)$ and discharge $Q(t)$ measurements were utilized to develop mathematical relationships between them. Lithaios River rating curves $(h(t) - Q(t))$ [2–8] and changes in the riverbed were computed on the basis of the measured variables using various model equations for regression, ANOVA statistical analysis, and the model's fit F test by utilizing the IBM SPSS v.26 statistics software [2,3,9–25].

2.3. Statistical and Geostatistical Data Analysis, Flow Velocity and Discharge Modelling, and 2D Mapping Methodology

The data were analyzed through the use of IBM SPSS v.26 [2,9,11,12] statistics software. The results are the observations' averages. ANOVA (analysis of variance) [2,3,9,11–25] was used to assess velocity ($V_{i=1}^n$), discharge (Q_T), and hydraulic depth effects. In the present study, we used geostatistics (the Kriging method with power model) [2,11–25] for

modelling and GIS (geographical information system) hydrological 2D mapping of Lithaios River's water velocity and discharge. Furthermore, the validation of Q_T and $V_{i=1}^n$ involves analysis of residual errors, which is the gap between predicted and observed data values and the bias forecast between over- and underestimates. For this purpose, we applied the statistical criteria described by other studies [2,11–16,18–20,22–28], such as the equations for residual sum squares (RSS), standard error (SE), and root mean square error (RMSE).

3. Results and Discussion

The streamflow velocity 2D modelling [2,27] results of the Lithaios River cross-section for the year's maximum (March) and minimum (August) water discharges and the univariate velocity model output statistics are depicted in Figure 1a–d. Lithaios River mean water flow velocity ($V_{i=1}^n$) of the cross-section segments for the year's maximum (March) and minimum (August) water discharge results show that $V_{i=1}^n(\text{max})$ ranged 0.199–0.329 (m s^{-1}) and $V_{i=1}^n(\text{min})$ ranged 0.098–0.177 ($\text{m}^3 \text{s}^{-1}$).

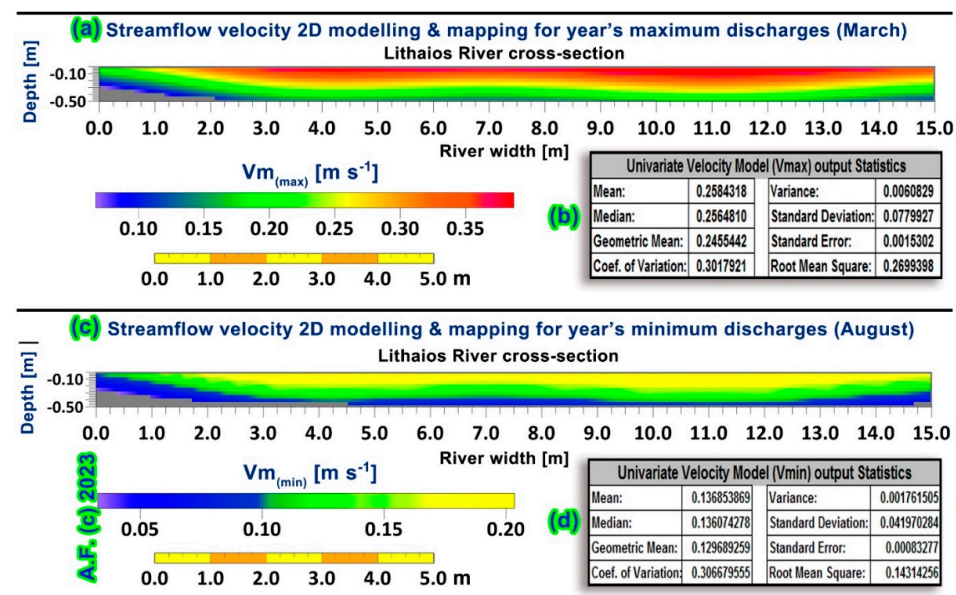


Figure 1. (a) Streamflow velocity 2D modelling results on a digital 2D $V_{i=1}^n$ map of the Lithaios River cross-section (Trikala M-S) for the year's maximum discharge (March), (b) univariate velocity model (Vmax) statistics, (c) streamflow velocity 2D modelling results on a digital 2D $V_{i=1}^n$ map of the Lithaios River cross-section (Trikala M-S) for the year's minimum discharges (August), and (d) univariate velocity model (Vmin) statistics.

The flow velocity ($V_{i=1}^n$) statistics [\bar{x} (mean), median, geometric mean, coefficient of variation (CV), s^2 (variance), and s (standard deviation)] for the year's maximum discharges (March) are presented in Figure 1b and the year's minimum discharges (August) are presented in Figure 1d. Velocity fluctuation of a river's cross-section can be specified by means of descriptive statistics [2,3,9,27–29], and of all the descriptive statistics, the coefficient of variation (CV) is the most important measure. [2,9]. The results for both CVs' of the cross-sections velocity variability for the year's maximum (March) ($\text{CV} = 0.302$) and minimum (August) ($\text{CV} = 0.307$) discharges were classified as moderate variability $V_{i=1}^n$. The resulting spatial distribution of water flow velocities obtained using river cross-section measurements was best fitted using the Kriging with power model, which resulted in minimum residual sum squares ($\text{RSS} = 0.0001694$), and the RSS used as one of the criteria to choose the greatest model. The other criteria used included the standard error (SE) and root mean square error (RMSE), as in other studies. [2,27]. The best SE for March's velocity modelling was the one using the Kriging with power model ($\text{SE} = 0.0002236$) and for August, it was also the same model ($\text{SE} = 0.0008328$). The RMSE using the Kriging with

power model for March's velocity modelling was found to be the best, RMSE = 0.0406329, and for August, it was found to be the best, RMSE = 0.1431426. These results are acceptable since the SE and RMSE scores should be close to zero for accurate prediction and they classified the Kriging with power model as the best model. The abovementioned outcomes, prove the validity and accuracy of the generated 2D digital velocity maps (Figure 1a,c). The relationships between the n Manning's coefficient [2,3,5,7], the Chow's composite n coefficient [5], and the river's water discharges modelling (power model) resulted in high coefficients of determination (R^2) [2,9,12,13,16] for the 12-month measurement study period (Figure 2a,b). The diagrams of the discharges power model (which resulted in being the best model), the Darcy–Weisbach f coefficient multinomial model, and the shear linear model for year's maximum (March) and minimum (August) water discharges are depicted in Figure 2c,d. The R-squared gives a measure of how accurately the observable outputs are reproduced by the model based on the percentage of the total variance that is explained by the model [2,9].

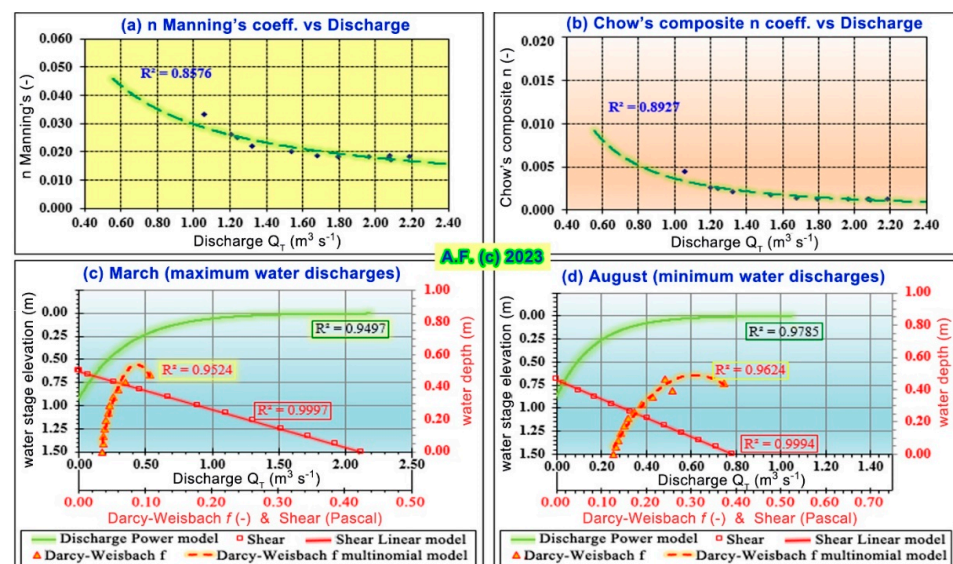


Figure 2. (a) Diagram of n Manning's coefficient vs. discharge, (b) diagram of Chow's composite n coefficient vs. discharge, (c) diagram of the discharge power model, the Darcy–Weisbach f coefficient multinomial model, and the shear linear model for year's maximum Q_T (March), and (d) the diagram of discharge power model, the Darcy–Weisbach f coefficient multinomial model, and the shear linear model for the year's minimum Q_T (August).

The R squared output results for the n Manning's coefficient vs. discharge showed a high $R^2 = 0.8576$ and the Chow's composite n coefficient vs. discharge also resulted in a high $R^2 = 0.8927$. The n Manning's coefficient and the Chow's composite n coefficient results show a high degree of correlation with the river's water discharges, with the Chow's composite n coefficient found to have a higher correlation. These results indicate that Chow's composite n [5]—which is built on the hypothesis that the overall force resisting the streamflow in the cross-section is equivalent to the summation of the resisting forces of streamflow in each of the defined segment's regions [2,5]—more accurately approximates the force resisting water flow in Lithaios River. Finally, the statistical results showed that the Froude number during the study period was $Fr < 1$, showing that the Lithaios streamflow is classified as subcritical [2,3,5].

4. Conclusions

The RSS and the prediction error (SE and RMSE) results of spatial and geostatistical 2-dimensional modelling, mapping, and validation of Lithaios River water flows confirmed the validity and accuracy of the generated 2D digital GIS velocity maps of the river's

cross-sections. These outcomes have proven that the Kriging with power model had good performance and that it is regarded as very appropriate for 2-D streamflow modelling and digital mapping, as well as being suitable for other hydraulic parameters (n Manning's coefficient, Chow's composite n coefficient, Froude number, shear, Darcy–Weisbach f coefficient, hydraulic radius, etc.). The outcomes of the study are recommended to provide a hydrological toolkit for environmental water resources administration and irrigation programming. This toolkit could assist water supply principalities to rapidly and precisely calculate streamflow volumes and the river's features with a minimal cost rate and workload, and it could be engaged in water supply and agricultural watering administration, the calculation of environmental flows, flood protection, groundwater recharge, and other objectives.

Author Contributions: Conceptualization, A.F.; methodology, A.F., G.S. and G.P.; software, A.F.; validation, A.F., G.S. and G.P.; formal analysis, A.F., G.S. and G.P.; investigation, A.F., G.S. and G.P.; resources, A.F. and G.P.; data curation, A.F., G.S. and G.P.; writing—original draft preparation, A.F.; writing—review and editing, A.F.; visualization, A.F.; supervision, A.F.; project administration, A.F.; funding acquisition, A.F., G.S. and G.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: All the data of the study are presented in the paper.

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

References

1. Filintas, A. Land Use Systems with Emphasis on Agricultural Machinery, Irrigation and Nitrates Pollution, with the Use of Satellite Remote Sensing, Geographic Information Systems and Models, in Watershed Level in Central Greece. Master's Thesis, Department of Environment, University of Aegean, Mitilini, Greece, 2005.
2. Filintas, A. Land Use Evaluation and Environmental Management of Biowastes, for Irrigation with Processed Wastewaters and Application of Bio-Sludge with Agricultural Machinery, for Improvement-Fertilization of Soils and Cultures, with the Use of GIS-Remote Sensing, Precision Agriculture and Multicriteria Analysis. Ph.D. Thesis, Department of Environment, University of the Aegean, Mitilini, Greece, 2011.
3. Hatzigiannakis, E.; Filintas, A.; Ilias, A.; Panagopoulos, A.; Arampatzis, G.; Hatzispiroglou, I. Hydrological and rating curve modelling of Pinios River water flows in Central Greece, for environmental and agricultural water resources management. *Desalination Water Treat.* **2016**, *57*, 11639–11659. [[CrossRef](#)]
4. Schulze, K.; Hunger, M.; Doll, P. Simulating river flow velocity on global scale. *Adv. Geosci.* **2005**, *5*, 133–136. [[CrossRef](#)]
5. Chow, V.T. *Open-Channel Hydraulics*; McGraw-Hill, Inc.: New York, NY, USA, 1959.
6. Munson, B.R.; Young, D.F.; Okiishi, T.H. *Fundamentals of Fluid Mechanics*, 4th ed.; John Wiley and Sons, Inc.: New York, NY, USA, 2002.
7. Herschy, R.W. *Hydrometry: Principles and Practice*, 2nd ed.; John Wiley and Sons: New York, NY, USA, 1999.
8. ISO 748:2007; Hydrometry-Measurements of Liquid Flow in Open Channels Using Current-Meters or Floats. International Standard, Fourth Edition 2007-10-15. ISO (International Standards Organizations): Geneva, Switzerland, 2007.
9. Norusis, M.J. *IBM SPSS Statistics 19 Advanced Statistical Procedures Companion*; Pearson: London, UK, 2011.
10. Corato, G.; Moramarco, T.; Tucciarelli, T. Discharge estimation combining flow routing and occasional measurements of velocity. *Hydrol. Earth Syst. Sci.* **2011**, *15*, 2979–2994. [[CrossRef](#)]
11. Filintas, A.; Nteskou, A.; Kourgialas, N.; Gougoulas, N.; Hatzichristou, E. A Comparison between Variable Deficit Irrigation and Farmers' Irrigation Practices under Three Fertilization Levels in Cotton Yield (*Gossypium hirsutum* L.) Using Precision Agriculture, Remote Sensing, Soil Analyses, and Crop Growth Modeling. *Water* **2022**, *14*, 2654. [[CrossRef](#)]
12. Stamatis, G.; Parpodis, K.; Filintas, A.; Zagana, E. Groundwater quality, nitrate pollution and irrigation environmental management in the Neogene sediments of an agricultural region in central Thessaly (Greece). *Environ. Earth Sci.* **2011**, *64*, 1081–1105. [[CrossRef](#)]
13. Dioudis, P.; Filintas, A.; Koutseris, E. GPS and GIS based N-mapping of agricultural fields' spatial variability as a tool for non-polluting fertilization by drip irrigation. *Int. J. Sus. Dev. Plan.* **2009**, *4*, 210–225. [[CrossRef](#)]
14. Filintas, A.; Wogiatzi, E.; Gougoulas, N. Rainfed cultivation with supplemental irrigation modelling on seed yield and oil of *Coriandrum sativum* L. using Precision Agriculture and GIS moisture mapping. *Water Supply* **2021**, *21*, 2569–2582. [[CrossRef](#)]

15. Dioudis, P.; Filintas, A.; Papadopoulos, A. Corn yield response to irrigation interval and the resultant savings in water and other overheads. *Irrig. Drain.* **2009**, *58*, 96–104. [\[CrossRef\]](#)
16. Filintas, A.; Dioudis, P.; Prochaska, C. GIS modeling of the impact of drip irrigation, of water quality and of soil's available water capacity on Zea mays L, biomass yield and its biofuel potential. *Desalination Water Treat.* **2010**, *13*, 303–319. [\[CrossRef\]](#)
17. Koutseris, E.; Filintas, A.; Dioudis, P. Antiflooding prevention, protection, strategic environmental planning of aquatic resources and water purification: The case of Thessalian basin, in Greece. *Desalination* **2010**, *250*, 318–322. [\[CrossRef\]](#)
18. Filintas, A. Soil Moisture Depletion Modelling Using a TDR Multi-Sensor System, GIS, Soil Analyzes, Precision Agriculture and Remote Sensing on Maize for Improved Irrigation-Fertilization Decisions. *Eng. Proc.* **2021**, *9*, 36. [\[CrossRef\]](#)
19. Kalavrouziotis, I.K.; Filintas, A.T.; Koukoulakis, P.H.; Hatzopoulos, J.N. Application of multicriteria analysis in the Management and Planning of Treated Municipal Wastewater and Sludge reuse in Agriculture and Land Development: The case of Sparti's Wastewater Treatment Plant, Greece. *Fresenius Environ. Bull.* **2011**, *20*, 287–295.
20. Filintas, A.; Nteskou, A.; Katsoulidi, P.; Paraskebioti, A.; Parasidou, M. Rainfed and Supplemental Irrigation Modelling 2D GIS Moisture Rootzone Mapping on Yield and Seed Oil of Cotton (*Gossypium hirsutum*) Using Precision Agriculture and Remote Sensing. *Eng. Proc.* **2021**, *9*, 37. [\[CrossRef\]](#)
21. Dioudis, P.; Filintas, A.; Papadopoulos, A.; Sakellariou-Makrantonaki, M. The influence of different drip irrigation layout designs on sugar beet yield and their contribution to environmental sustainability. *Fresenius Environ. Bull.* **2010**, *19*, 818–831.
22. Filintas, A.; Gougoulas, N.; Salonikioti, A.; Prapa, E. Study of soil erodibility by water on tillage and no tillage treatments of a *Helianthus Tuberosus* crop using field measurements, soil laboratory analyses, GIS and deterministic models. *Ann. Univ. Craiova Ser. Biol. Hortic. Food Prod. Process. Technol. Environ. Eng.* **2019**, *29*, 529–536.
23. Koutseris, E.; Filintas, A.; Dioudis, P. Environmental control of torrents environment: One valorisation for prevention of water flood disasters. *WIT Trans. Ecol. Environ.* **2007**, *104*, 249–259. [\[CrossRef\]](#)
24. Filintas, A.; Gougoulas, N.; Papachatzis, A. Soil organic matter modelling and digital mapping of a Triticum turgidum cropfield using as auxiliary variables the plant available water, texture, field measurements, soil laboratory analyses, GIS and geostatistical models. *Ann. Univ. Craiova Ser. Biol. Hortic. Food Prod. Process. Technol. Environ. Eng.* **2019**, *24*, 537–544.
25. Loague, K.; Green, R.E. Statistical and graphical methods for evaluating solute transport models: Overview and application. *J. Contam. Hydrol.* **1991**, *7*, 51–73. [\[CrossRef\]](#)
26. Lu, G.Y.; Wong, D.W. An adaptive inverse-distance weighting spatial interpolation technique. *Comput. Geosci.* **2008**, *34*, 1044–1055. [\[CrossRef\]](#)
27. Filintas, A.; Hatzigiannakis, E.; Arampatzis, G.; Ilias, A.; Panagopoulos, A.; Hatzispiroglou, I. Hydrometry's classical and innovative methods and tools comparison for Stara river flows at Agios Germanos monitoring station in north-west Greece. In Proceedings of the International Conference EGU European Geosciences Union General Assembly 2015, Vienna, Austria, 12–17 April 2015; Volume 17. EGU2015-13601.
28. Filintas, A.; Hatzigiannakis, E.; Panagopoulos, A.; Arampatzis, G.; Ilias, A.; Hatzispiroglou, I. Hydrological modelling of Pinios River (Greece) water flows as assisting tool for environmental and agricultural water resources management using River Analysis Models. In Proceedings of the Fifth International Conference on Environmental Management, Engineering, Planning & Economics (C.E.M.E.P.E. 2015) and SECOTOX, Mykonos Island, Greece, 14–18 June 2015; ISBN 978-960-6865-86-2.
29. Hatzigiannakis, E.; Filintas, A.; Sassalou, M.; Panoras, G.; Zavra, A. Hydro-measurements and water quality sampling monitoring for agricultural use of Pinios River water in Central Greece. In Proceedings of the 13th International Conference on "Protection and Restoration of the Environment", Water Resources Management and Contamination Control, Mykonos Island, Greece, 3–8 July 2016.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.